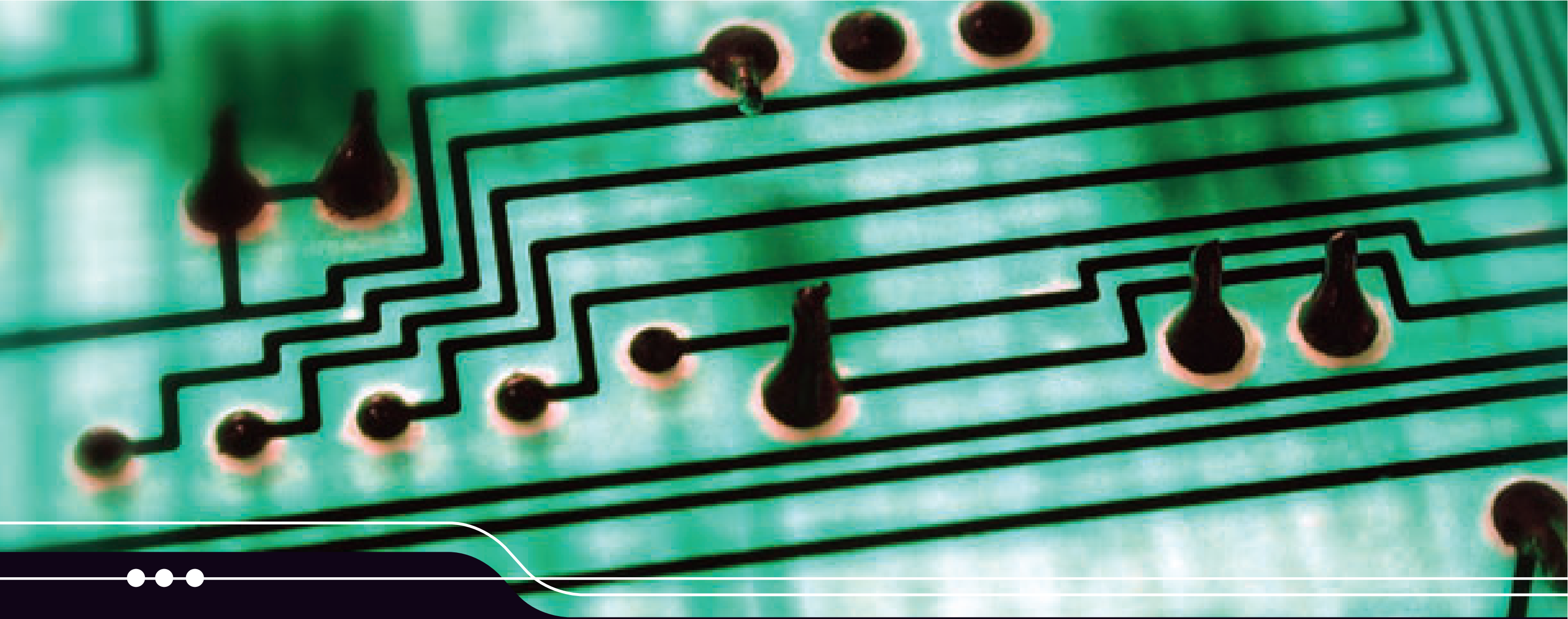

Science Aspects 4

An outcomes approach

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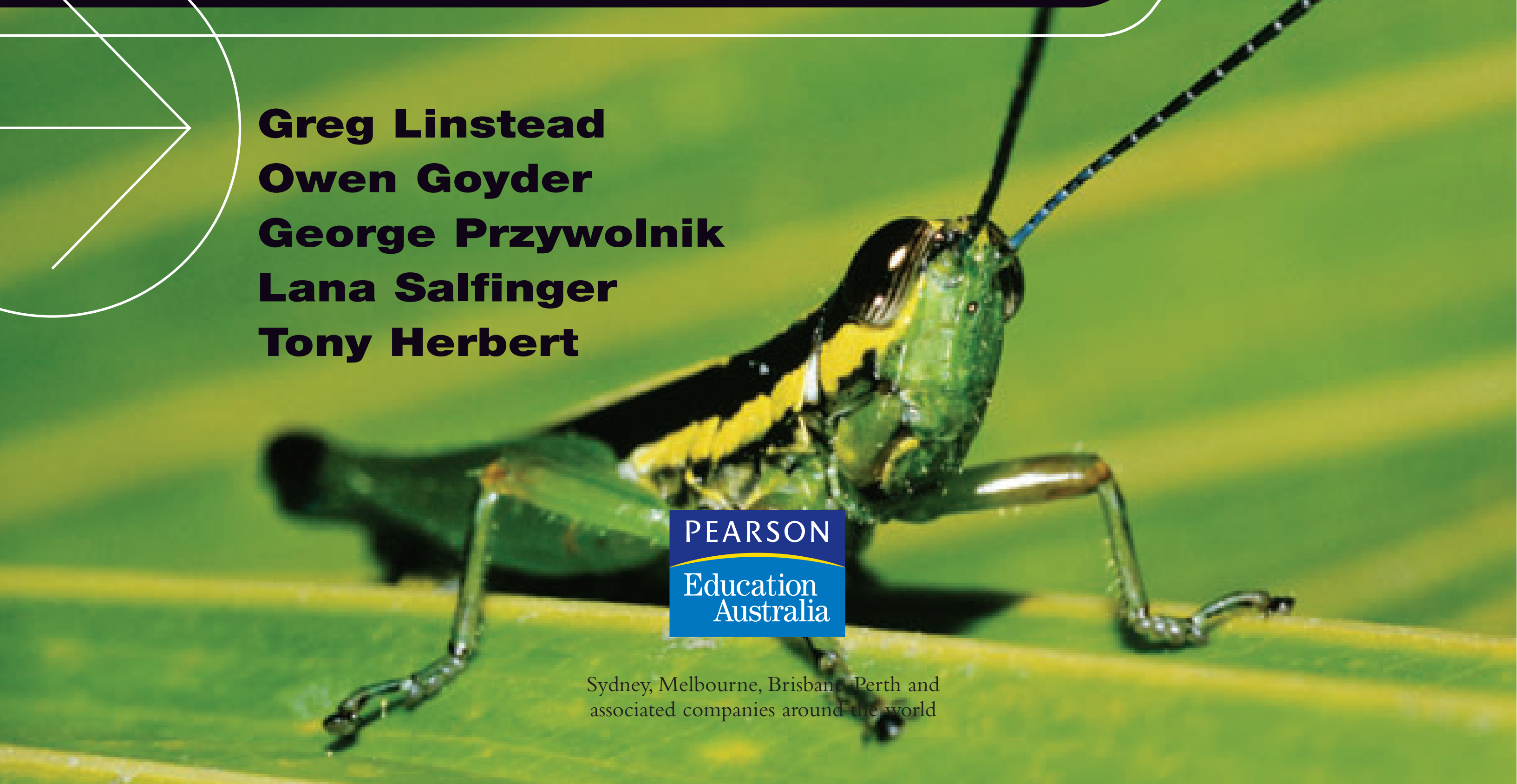

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Contents

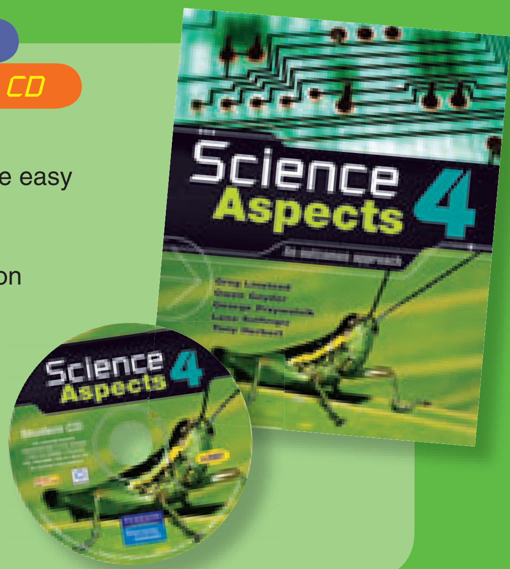
Science Aspects 4
An Outcomes Approach

The complete science package!

Science Aspects 4: ***An Outcomes Approach*** has been designed to meet the requirements of the latest curriculum initiatives in Western Australia. It integrates an outcomes approach, drawing on the:

- Curriculum Framework
- Curriculum Framework Curriculum Guide
- Progress Maps.

Science Aspects 4: *An Outcomes Approach*
Coursebook *Includes Student CD*



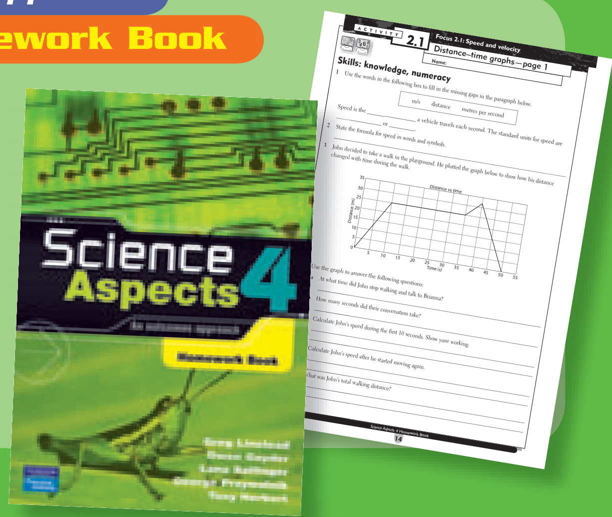
The **coursebook** consists of chapters with the following features:

- the most up-to-date science content presented in foci (units) that are easy to read and follow
- graded Review Questions to allow all students to achieve success
- investigating questions to encourage further research and exploration
- section reviews to consolidate and apply learning
- practical activities.

Each **coursebook** includes an interactive Student CD containing:

- an electronic version of the coursebook
- the Companion Website on CD
- a link to the live Companion Website.

Science Aspects 4: *An Outcomes Approach*
Homework Book



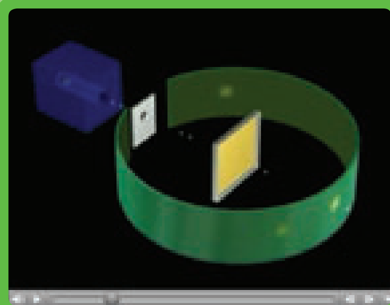
The **homework book** provides a structured homework program to complement the coursebook. These homework activities:

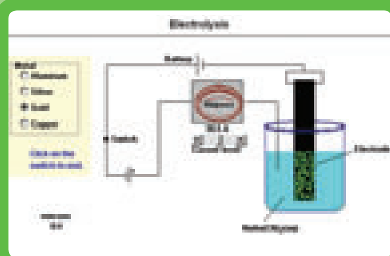
- cover various skills required in science
- offer consolidation and interesting extension activities
- provide revision activities, including the construction of a glossary
- cater for multiple intelligences through varied activity types.

Science Aspects 4: *An Outcomes Approach*

Companion Website

www.pearsoned.com.au/schools/secondary





The **Companion Website** is available live, and on the Student CD. It contains a wealth of support material for students and teachers, written to enhance teaching and learning:

- **Review Questions**: auto-correcting multiple-choice, labelling, matching and fill-in-the-blanks questions
- **Web Destinations**: a list of reviewed websites that support research and exploration
- **Interactive Animations** to engage students in exploring ideas
- **Drag and Drop Interactives** to revise key terms and key diagrams
- **QuickTime Videos** to explore chemical concepts in a visually stimulating way
- **Interactive Crosswords** to revise basic concepts and key terms for each section
- **3D molecules gallery** for viewing and manipulating molecular structures
- **Teacher's Resource Centre**: password-protected part of the site.

  All documents are available as editable MS Word documents, enabling teachers to modify and adapt any resources to meet their needs.

  The Teacher's Resource provides a wealth of teacher support material including:
  - coursebook answers
  - homework book answers
  - teacher assessments and levelling guides
  - levelling guides for section review questions of the coursebook
  - laboratory notes for practical activities.

For more information on the *Science Aspects: An Outcomes Approach* series, visit **www.pearsoned.com.au/schools/secondary**

How to use this book

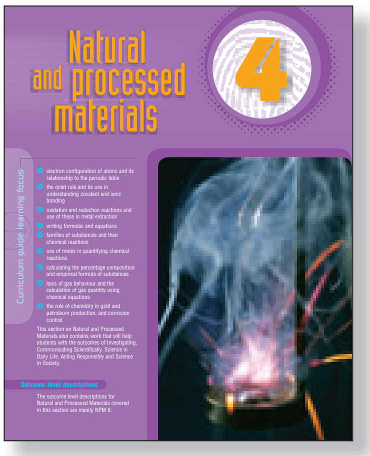
Science Aspects 4: *An Outcomes Approach* has been designed to meet the requirements of the latest curriculum initiatives in Western Australia. It integrates an Outcomes approach with the latest science content to intrigue and motivate students. The content is presented through varied contexts to engage students in seeing the relationship between science and their everyday lives.

The structure of the coursebook draws on information in the following documents to produce a cohesive resource that will allow teachers to meet the demands of teaching, learning and assessment using an Outcomes-based approach:

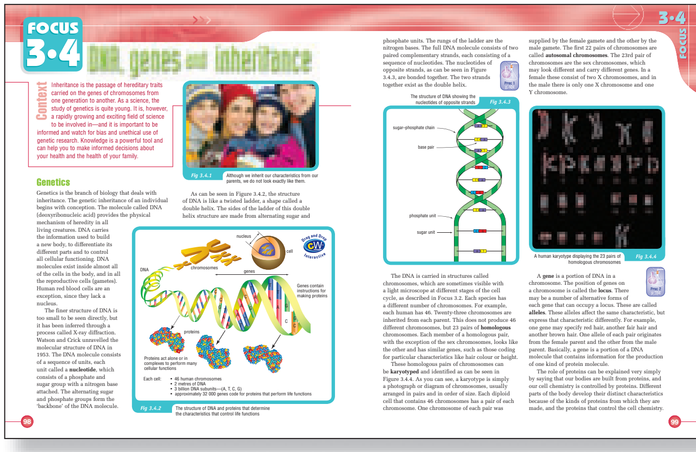
- Curriculum Framework
- Curriculum Framework Curriculum Guide
- Progress Maps.

Each coursebook consists of sections with the following features:

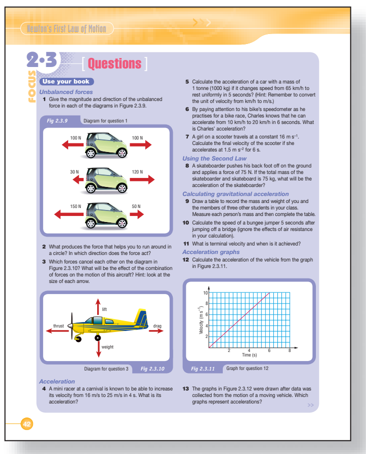
- **section opening pages**, which include:
  - Curriculum Guide Learning Focus relevant to the section content
  - Outcome Level Descriptions
  - photograph to stimulate interest.



- **foci** (units) that open with a 'context' to encourage students to make meaning of science in terms of their everyday experiences. The foci also reinforce contextual learning by presenting theory, photos, illustrations and 'science snippet' boxes in a format that is easy to read and follow.

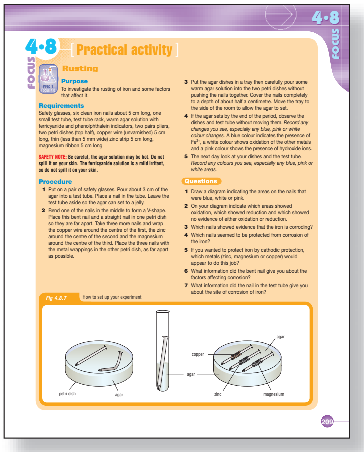


- **focus review sections**, divided into straightforward 'use your book' questions that build confidence and allow all students to achieve success, followed by 'use your head' questions requiring application and higher level problem-solving. There are also 'investigating questions' for further research and exploration, and to reinforce skills. These also include 'design your own' investigations.



- **practical activities**, which are placed at the end of each focus to allow teachers to choose when and how to best incorporate the practical work. Icons for practical activities are included in the focus theory to signal suggested points for practical work.

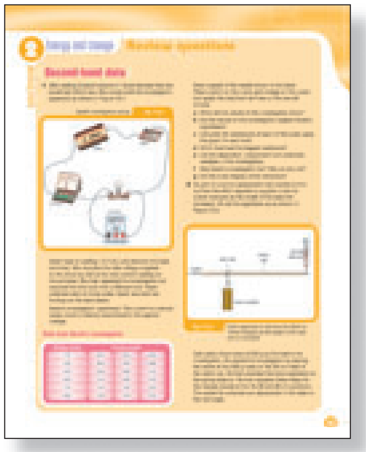
Prac 3
p. 67

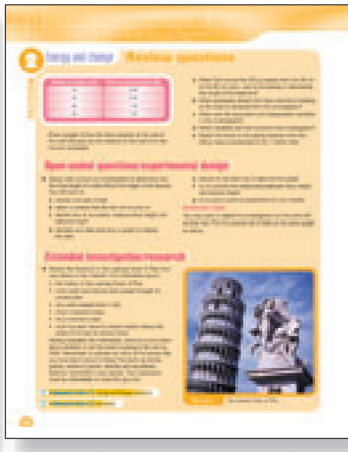


- **skills**, which are integrated throughout the coursebook. Each section and each focus has activities that will develop students' science skills, allowing progressive development in this area.
- **section review activities**, following the last focus in each section. These activities are divided into three types:
  - second-hand data
  - open-ended question/experimental design
  - extended investigation/research.

These activities integrate outcomes from all foci for each section of the coursebook, and provide opportunities for all students to consolidate new knowledge and skills. These activities are structured tasks that can be used as levelling assessment tasks. Levelling grids for these activities are supplied in the Teacher's Resource.

They can also be used as practice assessment tasks before an assessment activity from the *Science Aspects 4: An Outcomes Approach Teacher's Resource* is used.





Other icons used in the *Science Aspects 4: An Outcomes Approach* coursebook are listed below:

Homework book 2.11 Sci-words

The Homework Book icon indicates an activity that is available in the *Science Aspects 4: An Outcomes Approach Homework Book*.

The DYO icon indicates where a 'design your own' investigation is suggested.

DYO

The CW icon indicates when an activity is available for students on the *Science Aspects 4: An Outcomes Approach* Companion Website. The text written around the icon indicates the type of activity that is available. In the electronic version of the coursebook on CD these icons are directly linked to the actual activity for convenience.

Interactive CW Animation

Science Aspects 4: *An Outcomes Approach* package

Do not forget the other ***Science Aspects 4: An Outcomes Approach*** components that will help engage and excite students in science:

- *Science Aspects 4: Homework Book*
- *Science Aspects 4: Companion Website*
- *Science Aspects 4: Teacher's Resource (available through the Companion Website).*

Science Aspects 4: *An Outcomes Approach*

Curriculum correlation

Science Aspects 4: An Outcomes Approach is designed using the **Curriculum Framework,** the **Curriculum Framework Curriculum Guide** and **Progress Maps**. The following grid outlines how each focus of the coursebook matches the contents of these documents to produce a cohesive resource, allowing teachers to meet the demands of teaching, learning and assessment using an outcomes-based approach.

The **Investigating** learning area outcome is integrated into all sections to ensure that it is covered progressively throughout the course.

	Progress Maps Aspect/Organiser	Curriculum Guide— scope and sequence Learning focus/Content
SECTION 1 Earth and beyond		
1.1 Birth, life and death of stars	EB 5, 6 Relationship between Earth, the Solar System and the Universe	Formation of the Universe, star life cycle, novas and supernovas, pulsars, white dwarfs, red dwarfs, gravity effects in formation of stars and planets, H–R diagrams
1.2 Investigating deep space	EB 5, 6 Relationship between Earth, the Solar System and the Universe	Measuring the distances to stars and galaxies (parallax, brightness, variable stars, red shift and the expanding Universe), the microwave background, size of the Universe
1.3 Finding Earth resources	EB 5, 6 Sustainability of life and wise resource use	Remote mapping methods (seismic, aeromagnetics, gravity, landsat, infrared), onsite methods (drilling, downhole logging)
1.4 Future shocks	EB 5, 6 Relationship between Earth, the Solar System and the Universe Sustainability of life and wise resource use	Future of the Universe and Solar System, implications for life on Earth

	Progress Maps Aspect/Organiser	Curriculum Guide—scope and sequence Learning focus/Content
SECTION 2 Energy and change		
2.1 Speed and velocity	EC 5, 6 Transfer and transformation Energy sources, patterns and uses	Difference between speed and velocity, calculating and graphing motion
2.2 Newton's First Law of Motion	EC 5, 6 Transfer and transformation Energy sources, patterns and uses	Force and motion, Newton's First Law of Motion, vehicle crashes, inertia
2.3 Newton's Second Law of Motion	EC 5, 6 Transfer and transformation Energy sources, patterns and uses	Effects of unbalanced forces, Newton's Second Law of Motion, acceleration due to gravity, calculating and graphing acceleration, weight as a force
2.4 Newton's Third Law of Motion	EC 5, 6 Transfer and transformation Energy sources, patterns and uses	Action and reaction, Newton's Third Law of Motion, collisions, rocket and jet engines, thrust and drag, weight and lift
2.5 Stability and equilibrium	EC 5, 6 Transfer and transformation Energy sources, patterns and uses	Equilibrium and centre of gravity, calculations on moments, vehicle stability and design, body stability in standing and walking
2.6 Transferring mechanical energy	EC 5, 6 Transfer and transformation Energy sources, patterns and uses	Kinetic and potential energy and total mechanical energy, calculating work done from Law of Conservation of Energy, quantitative relationship between power, energy and work
2.7 Electric power	EC 5, 6 Transfer and transformation Energy sources, patterns and uses	Ohm's law, electric power, energy efficiency rating, power rating, calculating voltage, current, resistance, power and efficiency
2.8 Waves	EC 6, 7 Transfer and transformation Energy sources, patterns and uses	Waves and wave properties, wave properties in transverse waves, wave aspects of magnetism plus electricity

	Progress Maps Aspect/Organiser	Curriculum Guide—scope and sequence Learning focus/Content
SECTION 3 Life and living		
3.1 Gas exchange	LL 5, 6 Structure and function	Changes at a cellular level in carbon dioxide and oxygen exchange, diffusion, transport of oxygen and carbon dioxide, nervous control of breathing and carbon dioxide levels
3.2 Cellular reproduction	LL 5, 6 Reproduction and change	Mitosis and meiosis, advantages of sexual and asexual reproduction, importance of meiosis, errors in meiosis
3.3 Reproduction and pregnancy	LL 5, 6 Reproduction and change Structure and function	Human reproductive structure, dependence of reproductive system on other systems, prenatal development, role of placenta, birth, reproductive problems, hormonal controls
3.4 DNA, genes and inheritance	LL 5, 6 Reproduction and change	Structure of DNA, genes, genotype, phenotype, dominance, recessiveness, monohybrid crosses, calculating probabilities, pedigrees
3.5 Complex inheritance	LL 5, 6 Reproduction and change	Sex-linkage—pedigrees and probabilities, polygenic inheritance, interaction of genotype and environment, mutation, sustainability, diversity and evolution
3.6 Diversity	LL 5, 6 Interdependence Structure and function Reproduction and change	Identifying diversity, classification and evolutionary relationships, classification and keys, classifying flowering plants, diversity and survival, natural selection, sustainability and diversity
3.7 Studying ecosystems	LL 5, 6 Interdependence	Sampling methods in field investigations—capture–recapture, quadrats, transects, pyramids of biomass and energy
3.8 Genetics and health	LL 5, 6 Reproduction and change	Manipulation of DNA and human health—IVF, stem cells, cloning, gene splicing, gene therapy, germline genetic engineering, ethics
3.9 Genetics and industry	LL 5, 6 Reproduction and change Interdependence	Manipulation of DNA for industry—selective breeding, GM foods, forensics, conservation genetics

	Progress Maps Aspect/Organiser	Curriculum Guide—scope and sequence Learning focus/Content
SECTION 4 Natural and processed materials		
4.1 Electron configuration	NPM 6 Structures, properties and uses Interactions and changes	Electron shells, electron configuration, valence shells, octets, periodicity of properties, periodic table and valence
4.2 Covalent and ionic bonding	NPM 6 Structures, properties and uses Interactions and changes	Octet rule and bonding, covalent bonding, ionisation and ionic bonding, naming ionic compounds, writing chemical formulas
4.3 Redox	NPM 6 Structures, properties and uses Interactions and changes	Oxidation and reduction definitions, half equations, metal displacement reactions and activity series of metals, carbon reduction, electrolytic extraction, iron and aluminium extraction
4.4 Chemical equations	NPM 5, 6 Structures, properties and uses Interactions and changes	Balancing equations, molecular and ionic equations, types of reactions—such as acid–carbonate and acid–metal, precipitation, metal displacement, etc.
4.5 Moles	NPM 6 Interactions and changes	Definition of the mole, calculations using $n = m/M$, using equations to find moles and mass
4.6 Empirical formulas	NPM 6 Interactions and changes	Percentage composition, empirical formula
4.7 Gases in chemical equations	NPM 5, 6 Structures, properties and uses Interactions and changes	Gases and the kinetic theory, pressure and moles, pressure and volume relationship, volume and temperature relationship, using equations to determine moles, volume and mass
4.8 Chemistry in industry	NPM 5, 6 Structures, properties and uses Interactions and changes	Gold extraction, petroleum production, corrosion control

Acknowledgements

We would like to thank the following for permission to reproduce photographs, texts and illustrations. The following abbreviations are used in this list: t = top, b = bottom, l = left, r = right, c = centre.

Association of Reproductive Health Professionals (ARHP): pp. 125b, 126t, 127b, 127t.

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Department of Industry and Resources, *Australian Gas Reserves* map, revised edition February 2007: p. 205b.

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Pearson Education Australia: *Foundations of Chemistry* by P.J. Garnett & J. D. Anderton, pp. 203, 204; *Fundamentals of Science 4* by John Anderton, Volker Hopfmueller, Edward King, John Leahy, Greg Linstead, Brian Lindberg, Richard Rennie, David Wood, pp. 70b, 112r, 126b, 163r, 176; Michelle Jellett: p. 155 (drain cleaner); *Science Focus 4* by Kerry Whalley, Carol Neville, Peter Robertson, Greg Rickard, pp. 44cl, 47br, 49, 98b, 99l, 102l; *Science Outcomes 3* by John Anderton, Volker Hopfmueller, Edward King, John Leahy, Greg Linstead, Brian Lindberg, Richard Rennie, David Wood, pp. 118, 120t, 120b.

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Princeton University Press: *Niche Construction* by F. John Odling-Smee, Kevin N. Laland and Marcus W. Feldman, p. 114.

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Science Aspects 4

Earth and beyond

1

Curriculum guide learning focus

- formation of the Universe and the Solar System
- the life cycle of stars
- methods of determining distances in the Universe
- technologies for exploration and mining
- the properties and structure of materials making up the Earth
- future of the Universe and the Solar System

This section on Earth and Beyond also contains work that will help students with the outcomes of Investigating, Communicating Scientifically, Science in Daily Life, Acting Responsibly and Science in Society.

Outcome level descriptions

The outcome level descriptions for Earth and Beyond covered in this section are mainly EB 5 and EB 6.

FOCUS 1·1 Birth, life and death of stars

Context

Stars have been going through their life cycles for billions of years, and will continue to do so long after we are gone. Some stars are dwarfs while others are giants, and their life spans seem to depend strongly on how massive they are. Is our own Sun liable to explode soon? Or will it fade slowly into obscurity?

The Big Bang

The evidence from astronomical measurements shows that the Universe is expanding. If we trace the expansion back through time, we find that the Universe contracts, occupying less volume as we go back in time. About 13 billion years ago, the entire Universe fitted into a volume the size of an atom. We have no idea whether anything existed before the instant that the Universe began to expand. This starting moment is called the **Big Bang**.

Originally, the term 'Big Bang' was coined to ridicule those scientists who supported the idea. The term is no longer derogatory, and is used by both supporters and opponents of the theory. While much evidence, from the expansion of the Universe to the amount of hydrogen in stars, supports the Big Bang theory, much remains to be worked out in detail.

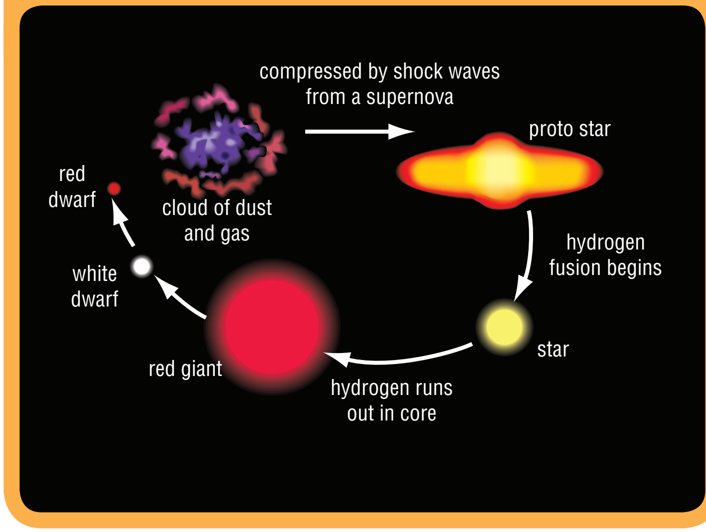
One interesting part of the Big Bang theory is that a huge amount of energy was released at the moment of the Big Bang. This energy is still detectable, billions of years on, in radio telescopes such as that shown in Figure 1.1.1. Amazingly, you can also pick it up with a television set. The random pattern of flickering black and white blobs that you see as you turn to a vacant channel is a dim echo of the Big Bang.

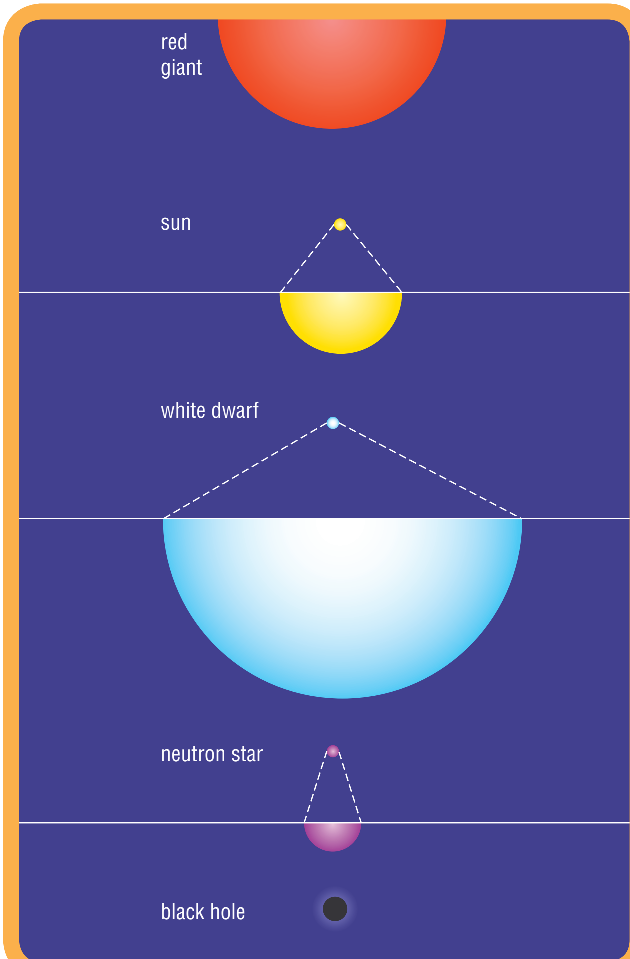
Star life cycles

For most of human history, people believed that the stars were perfect, unchanging heavenly bodies. We now know that stars are created, evolve over time and eventually die. Of course, we don't mean death as in the death of a living thing. Stars are not 'alive' in that sense. Different stars have different life cycles—it all depends on the star's mass. The greater a star's mass, the shorter its life, and the more violent its end. Thus, low-mass stars have long lives, measured in billions of years. Really massive stars may last only a few million years from birth to death.

Fig 1.1.1 These instruments can detect the electronic echoes of the Big Bang.

Fig 1.1.2 This diagram shows the pattern of a typical star's existence from its birth to its end.





Stars range in size from a few kilometres across (black holes and neutron stars) to hundreds of millions of kilometres across (red giants). Fig 1.1.3

A star's colour tells us its surface temperature. Red means relatively cool, yellow is hotter, blue is very hot. Stars of different masses and at different stages in their life cycles may be almost any combination of size and colour, such as red dwarf, red giant, white dwarf and so on. Our own Sun is a relatively small, not-very-hot star called a 'yellow dwarf'.

Stars begin as clouds of dust and gas. Some event triggers gravitational collapse in a part of the cloud. The triggering event may be a shock wave from a nearby exploding star, or supernova. Once the cloud starts to contract, gravity pulls more and more material into its centre. The extra mass increases the gravitational attraction and even more material is pulled in. The temperature and the pressure in the gas cloud increase. When the centre becomes sufficiently hot and dense, some of its hydrogen atoms begin to stick together as they collide. This process of **nuclear fusion** liberates energy each time that hydrogen nuclei combine. The raw material for such fusion is hydrogen, and the product is helium.

The energy released by fusion tends to push the outer layers away from the star's core. This balances the inward pull of gravity. In most stars there is a balance between the inward gravity force and the expansion from fusion. Often this balance is dynamic, like a swinging seesaw. These stars are intrinsic variables, whose brightness varies periodically. This may be a result of rhythmic expansion and contraction in the star's outer layers, like a huge, slow-beating heart.

The Orion Nebula is a 'stellar nursery', where new stars form. Fig 1.1.4

The rate of fusion depends on the mass of the star. This is because stars of greater mass have higher temperatures and pressures at their cores. Whatever the size of the star, eventually the hydrogen in the core runs out, and fusion stops. With nothing pushing the outer layers away from the core, gravitational collapse begins again. What happens next depends, again, on the star's mass.

Science Snippet

Making elements

The Big Bang resulted in a Universe consisting of hydrogen mixed with a small fraction of helium. We know of about 90 naturally occurring elements. Where did they all come from? Our best model for element formation is that elements up to atomic number 6 (carbon) are created in the cores of ordinary stars such as the Sun. Elements up to atomic number 28 (iron) are created in the cores of supermassive stars. Heavier elements, with atomic number greater than 28, are created during supernova events. The energy from the supernova blows away the outer regions of the star, spreading these heavy atoms into space. So almost every element in your body was made in a star somewhere long ago.

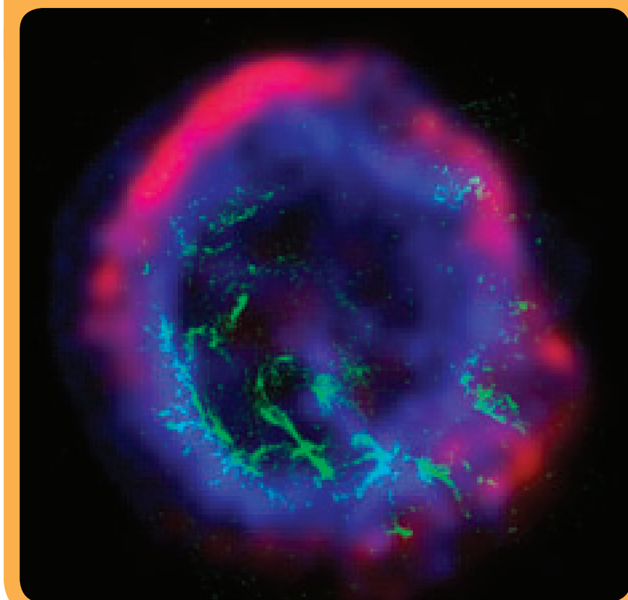
Supernovas

Gravitational collapse increases the pressure inside the star, raising the temperature so much that helium starts to fuse, forming carbon. The star suddenly shines brightly again, and it puffs out to considerably larger than its original size. The outer layer of gas keeps on expanding. While the star's core is much hotter than it was, its surface is now far from the core, and much cooler. The star has become a red giant. Red giants are unstable, and slowly lose their outer layers. The escaping gas forms an expanding gas cloud called a planetary nebula, while the core remains as a small, white-hot sphere—a white dwarf.

Fig 1.1.5 Three rings of glowing ejected gas surround the remnant of supernova 1987A.

If the star is very massive, its initial gravitational collapse does not lead to the formation of a red giant. As gravity collapses it, its helium begins to fuse, forming carbon. But the process does not end there—the carbon fuses, forming even bigger atoms. Eventually, the core of such a massive star is layered with different elements. The biggest atoms (up to iron, atomic number 28) are in the middle, grading to hydrogen on the outside. At some point, fusion stops and the star collapses. This time, the collapse creates an enormous blast of energy from the core. The star shines, briefly, more brightly than the galaxy it is in. The blast of energy also causes the outer layers to blow away completely in an event called a **supernova**.

Fig 1.1.6 The colours in this image of a supernova shock wave represent X-ray emission from very hot regions (blue), visible light from cooler regions (green) and radio waves from the edge of the shock wave (red).

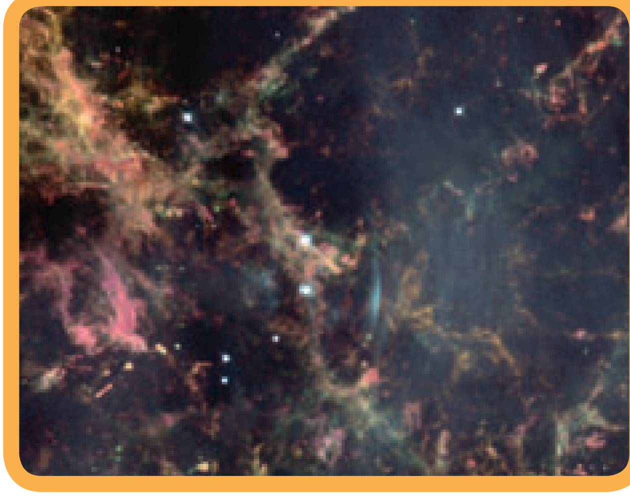


Pulsars

The extreme explosive energy released by a supernova blows off the outer layers of the star, but it also compresses the core. As much matter as is in the Sun, a star about 1.4 million kilometres in diameter, is compressed into a sphere perhaps 10 kilometres in diameter. The left-over core becomes a form of 'degenerate matter', consisting only of neutrons. In effect, the remnant is one huge atomic nucleus. Its density is unimaginable—one cubic centimetre would have a mass of about 10 million tonnes. The resulting object is called a **neutron star**, or a **pulsar**.

The pulsar at the centre of the Crab Nebula is the brighter of the two white stars to the left of the centre of the photograph. It is surrounded by strands of ejected material.

Fig 1.1.7



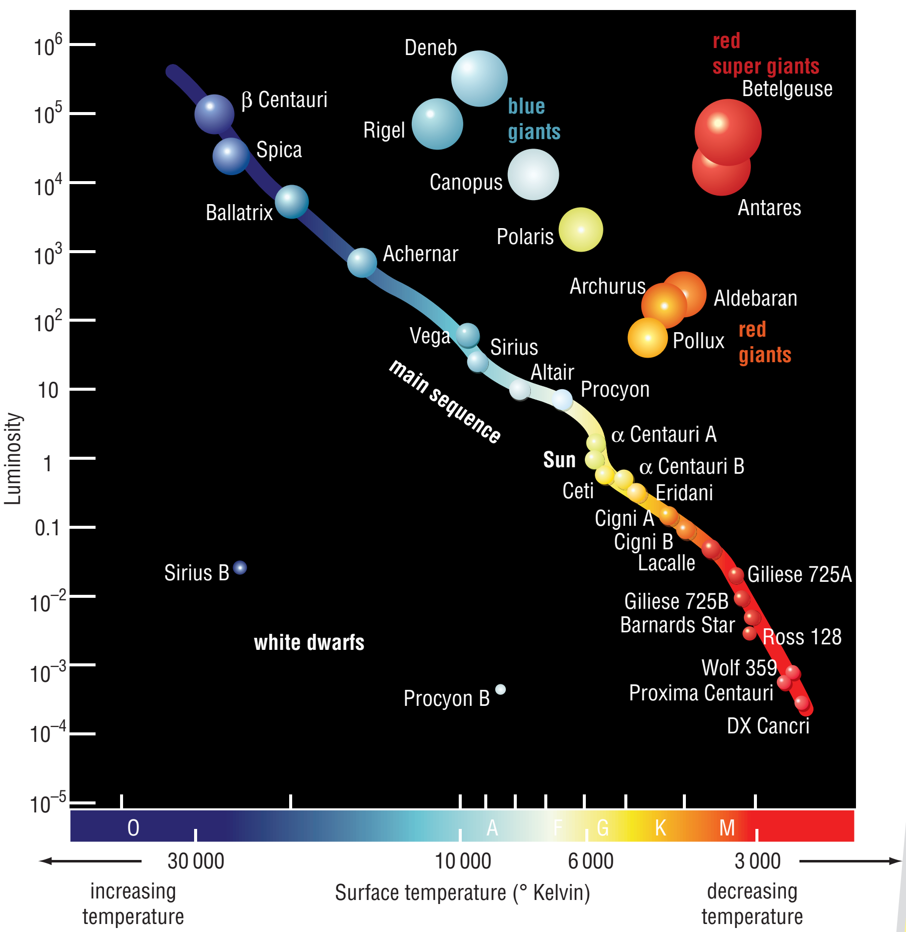
Astronomers observing pulsars see the light from them blinking on and off. The reason seems to be that pulsars emit light in a narrow beam from particular places on the surface. The pulsar spins rapidly on its axis, and the beam can flick past an observer like the beam from a lighthouse. The beam is only visible if the observer is in its path, so there are probably many pulsars out there that cannot be observed.

Dwarf stars

The compressed core of a star in which fusion has ceased glows white-hot. This is a white dwarf. A white dwarf produces no energy. Over time, it cools down by radiation, and its colour changes from white to red. Thus, a red dwarf is a white dwarf that has cooled down. Such dwarf stars are difficult to study, because their small size and low energy output makes them appear dim, even if they are relatively close to us.

Further cooling results in the red glow dying away, and the remains of the star fades into invisibility. It will eventually become a black dwarf—a cold lump of mostly carbon. Theory predicts that the Universe is not yet old enough for black dwarfs to have formed.

Fig 1.1.8 A Hertzsprung–Russell diagram



Science Snippet

The Hertzsprung–Russell diagram

About a hundred years ago, astronomers Ejnar Hertzsprung and Henry Norris Russell summarised their knowledge of stars in a diagram that would make their names live on. The H–R diagram shows how the mass and brightness of a star are related. The majority of observable stars occupy the 'main sequence', a curving line that sweeps from upper left to lower right. The stars on the main sequence are mostly dwarf stars (that is, not giants) about the size of the Sun. Above the main sequence are the giant stars. The clump of stars at bottom left consists of white dwarfs. Our own Sun at this point in its life cycle is roughly in the middle of the diagram.

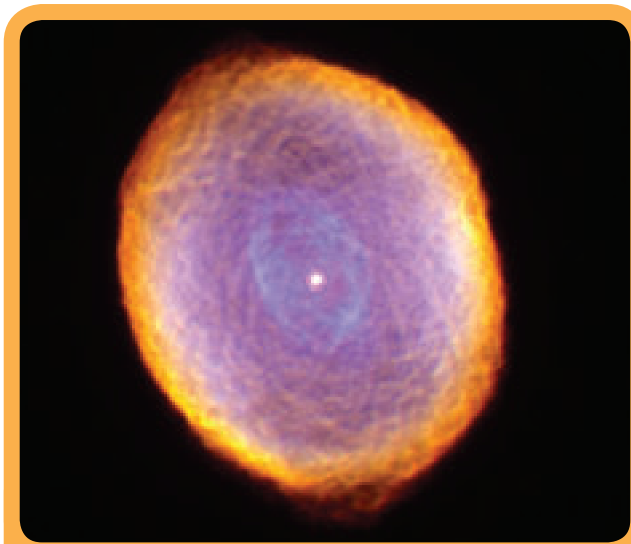


Fig 1.1.9 The white dot at the centre of this planetary nebula is a white dwarf.

One of the strangest categories of dwarf star is the brown dwarf. These objects range in size between planets and stars. Small brown dwarfs are too small to sustain fusion and are probably very large planets. Large brown dwarfs are big enough to have fusion going on, slowly, in their cores. There is some debate among astronomers about exactly where 'planets' end and 'stars' begin.

Technically, our Sun is a yellow dwarf. This does not mean that the Sun is a cooling white dwarf. Yellow dwarf stars are ordinary stars whose mass puts them into a group sized between brown dwarfs and giant stars.

Homework book 1.1 The H–R diagram

Novas

Bright stars, suddenly appearing where no bright star was before, have surprised astronomers throughout history. The word *nova* means 'new' in Latin.

For centuries, such 'guest stars' were believed to be omens, signs or messages from the gods. It is only very recently that we have started to understand why some stars 'go nova' and why some manage to do it repeatedly.

Many stars are binaries—two stars orbiting a common centre of mass. If one of the two is a white dwarf and its companion is very close, the white dwarf can attract gas from the companion's outer layers. When enough hydrogen has accumulated on the surface of the white dwarf, a wave of fusion can occur, lighting up the tiny star so it is thousands of times brighter than the Sun. The reaction also blows material into space, forming an expanding cloud of gas. Novas fade back into obscurity as the reaction on the surface ends, but further outbursts are possible if more matter accumulates on the surface.

Drag and Drop CW Interactive

Prac 1 p. 8

Light from the latest nova event can be seen reflecting off rings of ejected material from previous outbursts. *Fig 1.1.10*

1·1 FOCUS [Questions]

Use your book

The Big Bang

1 Describe briefly two pieces of evidence that support the Big Bang theory.

2 Suggest how astronomers might have worked out that the Universe is about 13 billion years old.

Star life cycles

3 Scientists believe that the Sun is a bit less than 5 billion years old.

a Was the Sun created in the Big Bang?

b What evidence is there for your answer?

c Describe briefly how the Sun may have formed.

>>

4 Consider the planetary nebula shown in Figure 1.1.8.
   a What type of star created this nebula?
   b Why is there a developing white dwarf at the centre of this nebula?

Supernovas

5 Will the Sun ever become a supernova? Why, or why not?

6 There is evidence that supernovas are associated with the formation of new stars. What is the connection?

Pulsars

7 Pulsars were given that name because they appear to 'pulse' or blink rapidly on and off. Why do pulsars pulse?

8 How do pulsars form?

Dwarf stars

9 White dwarfs and red dwarfs are a part of the life cycle of some stars. How are white and red dwarfs connected?

10 White dwarfs and yellow dwarfs are also connected through a life cycle. Explain.

11 Brown dwarfs are not connected to white, red or yellow dwarfs. Explain.

Novas

12 Astronomers once thought that novas were simply small supernovas. Novas are now believed to be surface events while supernovas are core events. Explain.

Use your head

13 Many stars are intrinsic variables. Is this why stars twinkle? Explain your answer.

14 Is a recurring nova an intrinsic variable? Explain.

Investigating questions

15 The short story 'Nightfall' was written by Isaac Asimov. It describes a rare event in a solar system very different from ours. Find the story, read it and write a brief description of the ways in which the fictitious solar system is different from our own.

16 Why are elements with atomic number greater than 26 only formed in supernova events?

FOCUS 1·1

[Practical activity]

Prac 1
Focus 1.1

Life cycles of dwarfs and giants

Purpose

To summarise the life cycles of various types of stars.

Requirements

Copy of a Hertzsprung–Russell diagram, coloured pens or pencils.

Procedure

1 Research the characteristics (mass, luminosity, age etc) of the Sun, Deneb (alpha Cygni) and eta Carinae.

2 Use different coloured pens or pencils to mark on the diagram:
   a the stages in a life cycle of a low-mass star (such as our Sun)
   b the stages in a life cycle of a high-mass star (a white giant such as Deneb)
   c the stages in a life cycle of a very high-mass star (a blue hypergiant such as eta Carinae).

Questions

1 Do all three stars end up in the same location at the ends of their life cycles? Explain.

2 Why does the H–R diagram not show black holes?

3 Which of the three types of star could contribute to the creation of new stars? How?

FOCUS 1.2 Investigating deep space

Context

For thousands of years, humans looked into the night sky and speculated about the distances to the stars. Only in the last hundred years or so have astronomers begun to understand the scale of the Universe and what the phrase 'astronomical distance' really means.

Measuring the distances to stars

The stars appear in the same relative positions from night to night. There is no easily observable evidence that they are able to move around. The simplest hypothesis is that the stars are fixed in place, all at the same distance from us. This was the accepted view for thousands of years. In the 16th century, the development of the telescope brought about some changes in astronomers' ideas. It revealed that there are many more faint stars than anyone had expected. Better telescopes showed ever more faint stars. And many star-like objects were actually fuzzy objects that became known as 'nebulas', a Greek word meaning 'clouds'.

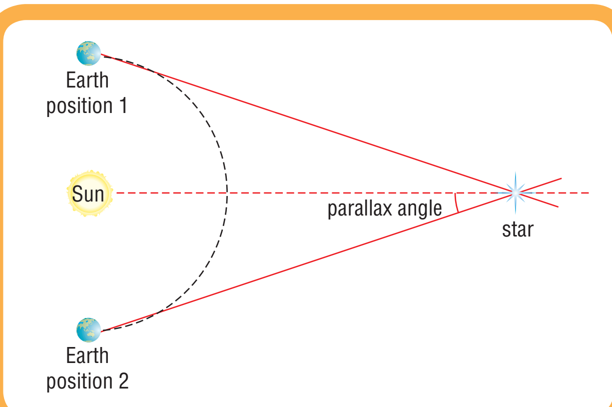


Fig 1.2.1 If the two measuring points are far apart, you can measure how far away a star is.

The first attempts to measure the distance to the 'fixed stars' involved **parallax**. You can get the idea of parallax easily by holding one finger upright in front of your face. Look at your finger with one eye, and move your head sideways without moving your hand. Your finger seems to move across the more distant background, although of course it is your head that has moved. You can see similar effects if you look out of a moving vehicle—close objects whiz past more distant ones, while distant objects seem to move much more slowly.

The Earth moves around the Sun at a distance of 150 million kilometres. Thus if you look at the stars now, then again six months later, your viewpoint will have moved 300 million kilometres. Even with such a huge change in your viewing position, only the nearest stars appear to change their relative positions. Measurements taken using this technique showed astronomers that even the nearest stars are very far away. The remainder must be incredibly distant.

Prac 1
p. 13

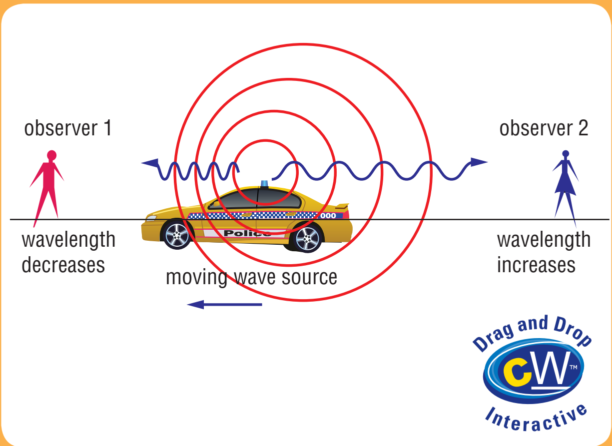
Once astronomers had values for the distance to the nearest stars, they began to work out ways to measure the distance to the rest of the stars. One early method involved brightness. If you know how bright a star is, its brightness or dimness is a good guide to its distance. The problem of course is in knowing the intrinsic brightness—how luminous it is—rather than its observed brightness, which is changed by its distance from the observer. Even so, many early estimates using this method gave good, if not accurate, results. As more information came in, astronomers realised that the colour of a star shows its surface temperature, which is a reasonable guide to its intrinsic brightness.

Red shift and the expanding Universe

You have probably heard the intriguing sound that a passing vehicle can make—the sound of its engine or siren increases in pitch as it gets closer. The change in pitch happens because the wavelength decreases. The pitch then decreases after the vehicle has passed. This is the Doppler effect, and it is not just true for sound waves. Light also exhibits a Doppler effect. Light waves from an approaching object decrease in wavelength, while light from a receding object increases in wavelength. The increase in wavelength of light from a receding object is called **red shift**. This means all colours are shifted more towards the red end of the spectrum, and things appear 'redder'.

A moving source of waves tends to catch up with waves moving in the same direction, and to leave behind waves travelling in the opposite direction. This causes the wavelength to change.

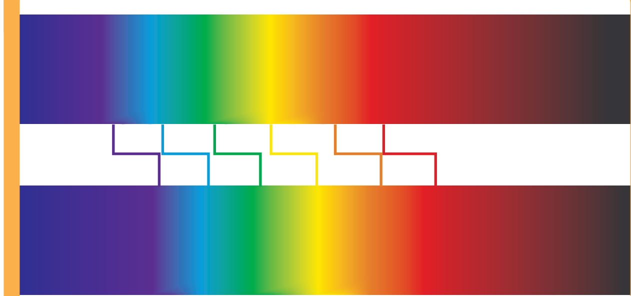
Fig 1.2.2



We do not see any red shift when we look at objects such as cars or aeroplanes that are moving away from us; nor do we see a blue shift when fast-moving vehicles approach us. They just cannot move quickly enough for us to detect any shift. The phenomenon is really only noticeable when the object travels at thousands of kilometres a second. Planes and cars cannot travel this fast, but stars and galaxies can.

Fig 1.2.3

The upper spectrum shows a normal light source, while the lower one is red shifted.



Edwin Hubble found a remarkable connection between galactic distance and red shift. The light from almost all galaxies is red shifted; and the red shift is greatest for the most distant galaxies. This means that the recession speed, the speed at which objects are moving away from us, is greatest for the most distant objects. Apparently, almost everything in the Universe is racing away from us, and the farthest objects are racing away faster than those close to us. This seems to be true regardless of the direction in which we make our observations. Are we at the centre of the Universe? The accepted interpretation is: we are not in a special central place. An observer would see the same effect no matter where they stood—it is space itself that is expanding. Ever since the Big Bang, the Universe has been growing bigger, and every part of it is continuously becoming further away from every other part.

Homework book 1.2 The Doppler effect

Measuring the distances to galaxies

Stars whose distance can be measured using parallax techniques are close to us, in our own Milky Way galaxy. Distances to other stars in our galaxy can be gauged by using their apparent brightness. It is trickier measuring the distances to other galaxies. They are so far away that all the stars in them are too close to each other for us to separate them according to brightness. For a long time, the only way to do this was to assume that all galaxies were equally luminous, and use their apparent brightness as a guide. The assumption is not true, but it was the best anyone could do at the time.

In 1912, astronomer Henrietta Leavitt announced important findings of her studies of stars called Cepheid (pronounced se-fee-id) variables. These studies had shown that the time period over which they regularly grew brighter and dimmer was related to their intrinsic brightness. That is, the more luminous a Cepheid variable is, the longer its period of variability. This is called a ‘period-luminosity relationship’. Leavitt worked with variables in a neighbouring galaxy, so all the stars she studied were almost equally distant from us.

Here was a cosmic tape measure; all astronomers needed was some way to work out the actual distance to any one such variable star. Fortunately, the star after which the entire group was named, delta Cephei, turned out to be close enough that astronomers could measure its distance by parallax. Now, the distance to any galaxy in which Cepheid variables are visible can be measured this way. The biggest distance at which individual stars can be resolved by telescopes is about a billion light years with our current technology.

All the stars in a distant galaxy are about the same distance away from us.

Fig 1.2.4

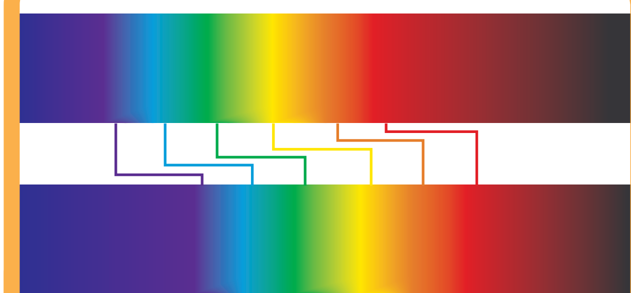


Fig 1.2.5 The red shift of a distant quasar. Compare this to the red shift shown in Figure 1.2.3.

Red shift was the next big step in measuring galactic distances. Because red shift is easier to observe than the brightness of a Cepheid variable in a distant galaxy, the cosmic red shift became the best way to measure the distance to very distant objects. The basic assumption that astronomers have to make is that all red shift effects are caused by the motion, away from the observer, of the luminous object.

Based on this technique, the most distant objects ever seen are quasars, because quasars have the biggest red shifts of any observed objects.

Why is the night sky dark?

This is a tough question to answer. Often referred to as Olbers' paradox, it was first recorded as being asked by Johannes Kepler about 400 years ago. The problem is: if there is an infinite number of stars in the Universe, there should be a star anywhere you look. The sky should be about as bright as the Sun, all the time, in every direction you look. But it obviously is not. Where is all that starlight?

The explanation involves a combination of two factors, one having a bigger effect than the other. The minor factor is that the light from distant stars in the expanding Universe is red shifted, so we cannot see all the light they emit—it arrives as infra-red or even microwaves rather than as visible light. But many stars also emit significant amounts of ultraviolet and even X-rays, which could be red shifted to become visible light. So, this does not explain the darkness out there completely.

The more important factor involves the age of the Universe. It just is not old enough for the light from really distant objects to have reached us yet. The starlight that should make the night sky blaze is still on its way, far from us.

How far is it to the edge of the Universe?

Olbers' paradox tells us that we cannot see the edge of the Universe. There is a limit to how far we can see, imposed on us by the technology we use to make the observations. Thus, there is an 'observable Universe', which is presumably only a small part of the whole thing. The best telescopes that we have tend to show that there are galaxies, ever fainter and less distinct, all the way out to the observable limit.

The red shifts of these galaxies give amazing distances, to a claimed thirteen billion light years. What is impressive about this claim is that 'further away' in astronomy also means 'longer ago'. The light we now see from this galaxy, 13 billion light years away, started its journey to us 13 billion years ago. It is a little awe-inspiring to realise that looking at the night sky also means looking back in time. The claim that this particular galaxy is 13 billion light years away suggests it is very close to the 'observable edge' of our Universe.

1.2 Questions

FOCUS

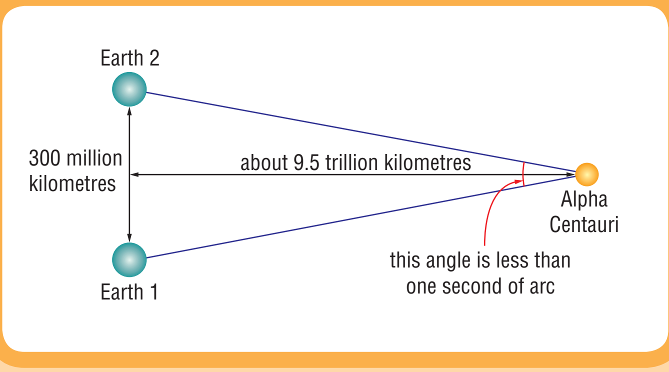
Use your book

Measuring the distances to stars

1 One of the nearest stars is Alpha Centauri, at a distance of 4.365 light years. What angle would astronomers have to measure when working out how far away Alpha Centauri is? Figure 1.2.6 shows the relative positions and distances of the Earth and the star at two times, six months apart.

The relative positions of Earth and Alpha Centauri over a six-month period. This diagram is not to scale.

Fig 1.2.6



2 Astronomers in previous centuries often referred to the 'fixed stars'.

a Why did early astronomers believe that stars were fixed?

b Explain why astronomers no longer believe that stars are 'fixed' in place.

Red shift and the expanding Universe

3 In our world, we cannot observe red shift or blue shift for vehicles, even fast-moving ones. Imagine you are in a world where a vehicle travelling at 80 kilometres an hour gives an observable shift in colour. Describe how vehicles travelling along a suburban street might appear if you were observing them:

a from the side of the road

b from inside a vehicle travelling along the street at the speed limit.

4 Not all galaxies are receding from us. Some of our nearest neighbours are actually moving toward us. It seems that our Milky Way galaxy may collide with the Andromeda galaxy, M31, in the far future. M31 is about 2.9 million light years away, and if a collision occurs it will probably happen between 5 and 10 billion years from now.

a Would you expect M31 to be red shifted or blue shifted? Explain.

b Use the information above to estimate the speed at which M31 is approaching our galaxy.

c There is great uncertainty about any sideways speed that M31 may have. Why would astronomers be confident about knowing how fast M31 is approaching us, but not about how fast it is moving sideways?

Measuring the distances to galaxies

5 If a galaxy gave out more light (was more luminous) than the average, how would the measured distance be affected?

6 The distance to a nearby galaxy is best measured using variable stars. You watch each individual variable star and measure how its brightness changes. Give your ideas about why this method would not work for really distant galaxies.

Why is the night sky dark?

7 One explanation of Olbers' paradox is that stars may not be distributed evenly around the sky. So, for example, instead of a million stars scattered around in a volume of sky, lighting it all up, those million stars may be lined up one behind the other. Thus we would see only the front star and the sky around it would look dark. Why do you think this is not accepted as an explanation by astronomers?

How far is it to the edge of the Universe?

8 A galaxy 13 billion light years away is claimed to be 'near the edge of the observable Universe'. Justify this claim.

9 Use calculations to estimate the volume of the observable Universe. In what units should you report your answer?

Use your head

10 You already know that the apparent or observed brightness of any light decreases with distance. The actual decrease in apparent brightness follows an 'inverse square law'. This means that if you double the distance to a light source, its apparent brightness decreases to one quarter of what it was. If you increase the distance by a factor of three, its apparent brightness decreases to $^1/_{3^2}$ or $^1/_9$. If you increase the distance five times, its apparent brightness drops to $^1/_{5^2}$ or $^1/_{25}$ times its original value.

Consider two identical stars. Star A is 20 light years away. Star B is 200 light years away. How much brighter or dimmer is B than A?

11 Measuring the brightness of astronomical objects can give information other than distance. For example, some astronomical objects, such as asteroids, reflect light. The brightness of an asteroid can be used to estimate its size. What other information would astronomers have to know, or work out, in order to estimate the size of an asteroid by measuring its apparent brightness?

12 Astronomers can work out the speed of a star or galaxy by its red shift. The mathematical relationship that they use is a fairly simple one, unless the speed is close to the speed of light. The table below shows the wavelengths of particular light wavelengths. The 'rest wavelength' is the wavelength you would measure if the star was at rest compared to the Earth. The 'measured wavelength' is the red shifted or blue shifted wavelength observed in the light emitted by a moving star.

The unit nm stands for nanometres, where $1 \text{ nm} = 10^{-9}$ m or $\frac{1}{1\,000\,000}$ mm.

The velocity of light is $C = 3 \times 10^8 \text{ m s}^{-1}$.

Star	Rest wavelength (λ)	Measured wavelength (λ)
A	700 nm	685 nm
B	852 nm	883 nm
C	522 nm	548 nm
D	600 nm	660 nm

a Three of the stars are moving away from us, while one is moving towards us. Which one must be moving towards us? How can you tell? If the velocity of light is c, then the velocity of the star towards or away from the observer is given by:

$$\text{velocity} = \frac{\lambda \text{ measured} - \lambda \text{ rest}}{\lambda \text{ rest}} \times c$$

b According to the evidence, which of the stars is moving fastest?

c What is the slowest star's velocity?

Investigating questions

13 Photographers use light meters to determine the brightness of the subject of their photograph. Using such a light meter, design an experiment to determine whether the 'inverse square' law for the brightness of a light source is really true.

1·2 FOCUS [Practical activity]

Measuring distance using a parallax method

Prac 1 Focus 1.2

DYO

Purpose

To measure the distance to an object using a parallax method.

Requirements

Tape measure, protractor, plasticine, pencils, pins or tacks.

Procedure

1 In your group, discuss how you can use geometry to work out the distance to an object using a parallax method and a 1.0 metre baseline. *Write down how your group intends to proceed.* If you need inspiration, Figure 1.2.7 shows you one way to set up the equipment.

2 Set up an object and a baseline, and use your method to find the distance to the object. Using a suitable table, *write down your results.*

3 Measure the actual distance to your object using a measuring tape or a metre rule. *Add this information to your table.*

4 Discuss what effect, if any, using a longer baseline might have on the accuracy of your measurement.
Make a prediction and test it. *Write down your results.*

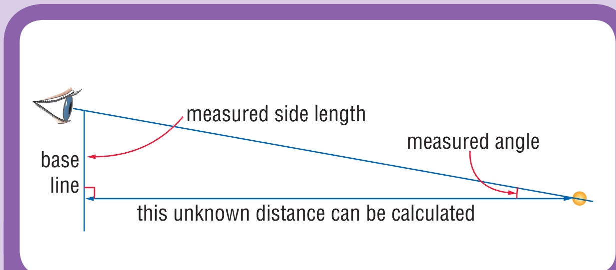


Fig 1.2.7 If you know one angle and one side length within a right-angled triangle, you can work out any other angle using geometry.

Questions

1 How effective was this method in measuring the distance to a nearby object?

2 Explain the effect (if any) of increasing the length of your baseline.

3 What difficulties might an astronomer have faced when using a similar method to measure the distance to the (relatively close) star Sirius?

FOCUS 1.3

Finding Earth resources

Context

Our State relies heavily on the mining and petroleum industries for jobs, exports and government revenues. Resource exploration has never been more critical. For thousands of years, humans relied on chance to discover the location of Earth resources. Kicking a rock or digging a hole were probably the main exploration techniques for many centuries. However, just about all the resources that could be found by chance have already been located and exploited. Exploration now involves tools that use a wide range of physical and chemical techniques to locate resources that are not immediately visible at ground level.

Remote exploration methods

Aeroplanes and satellites offer opportunities for exploration companies to assess the potential of huge areas in a short time. Helicopters and aeroplanes travel at tens or hundreds of metres per second, while satellites travel at several kilometres per second. The drawback to using these vehicles is their remoteness from the ground being explored. Large-scale aerial or satellite surveys are used to create maps showing possible locations of interest. Once a remote survey has pinpointed a promising location, drilling and survey teams can be used to assess the actual nature and extent of any mineral or petroleum deposits.

Aeromagnetic surveys

Magnetometers can detect small variations in the Earth's magnetic field. Some minerals are themselves magnetic, and this increases the overall magnetic field strength in their vicinity. Originally developed by the military to detect submarines by the magnetic anomalies they create, aeromagnetic surveys allow companies searching for magnetic metal ores such as iron ore to locate promising places to drill test holes. They can also be used to search for unusual rock strata and predict likely oil or gas reservoirs.

The probes on the wings and tail of this aeroplane sample the Earth's magnetic field and look for magnetic anomalies (unexpected differences). *Fig 1.3.1*

Gravity surveys

The acceleration due to gravity is roughly constant around the world, with a value around 9.8 m s^{-2} at the Earth's surface. 'Roughly constant' of course means that small local variations are to be expected. One cause of higher-than-expected values is a sudden change in the density of the rock. Many useful metal ores are significantly denser than the rocks around them, and thus create gravitational anomalies. The differences tend to be very small, however, so mapping the locations of mass concentrations requires very accurate measurement of the acceleration due to gravity.

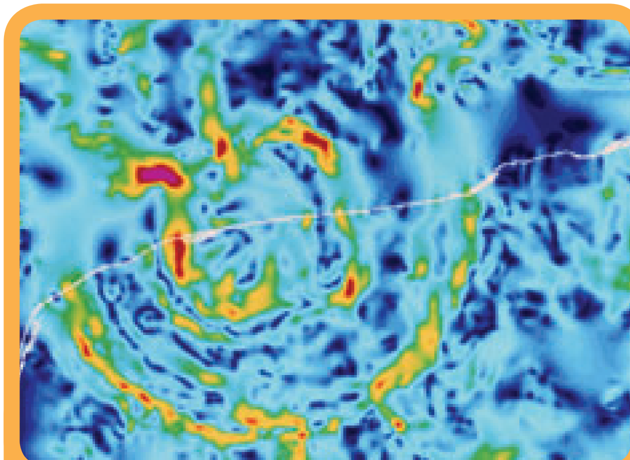


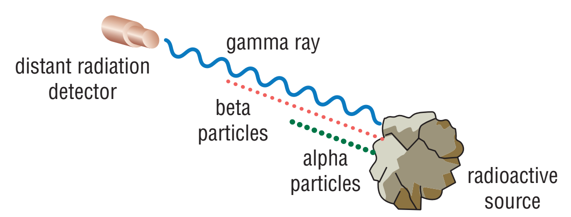
Fig 1.3.2 Gravity data can be used to make maps with contours that show where and how rapidly the acceleration due to gravity changes.

Combining maps based on different types of data can be very useful. For example, a company searching for a dense, magnetic ore body would compare the locations and intensities of gravitational and magnetic anomalies.

Homework book 1.3 Measuring gravity

Radiometric surveys

There are three common types of radiation: alpha, beta and gamma radiation. Alpha radiation cannot penetrate more than a few centimetres of air, while beta can travel through several metres of air or a few millimetres of rock. Only gamma rays are able to penetrate through a few centimetres of soil or rock and then travel a hundred metres or so through air to reach detectors on an aeroplane. Thus the only useful remote radiation measurements involve gamma rays. Even so, such surveys can reveal only surface deposits of radioactive material such as uranium ore, or some less radioactive deposits, such as mineral sands.



Gamma radiation travels further than other types of radiation. *Fig 1.3.3*

Resistivity and induced polarisation

The electrical properties of rock can be of interest to exploration teams. Measuring resistivity involves finding out how efficient a substance (such as metal ore) is at conducting an electric current. In general, better conductors have lower resistivity values. Many metal ores are significantly better electrical conductors than the surrounding rock, and are detectable by this method.

Another electrical property is how easily the rock can be electrically charged. If one end of an ore body can be charged positively while the other end becomes negative, the ore body has been polarised—that is, its positive and negative ends are 'poles'. The ease with which the rock takes on a charge, and the speed with which it loses that charge, can identify the location and extent of an ore body.

Aerial and satellite photography

Aerial photography has been used for surveys and mapping for many years. While most photography involves visible light, infra-red images can be very useful. In particular, infra-red photographs can distinguish between different types of vegetation. Because different plants have varying requirements for nutrients and trace elements, infra-red photographs can show clearly where the type of soil changes. This can indicate the boundaries of the underlying rock types in places where the vegetation cover is not directly visible from the air. Infra-red images are often printed in 'false colour' to increase the contrast between zones that reflect infra-red differently.

Satellite-based cameras can make images of large tracts of land at once. The price that must be paid for this is reduced resolution. An aerial photograph taken from a height of 6 kilometres might resolve (show clearly) objects up to a metre in size, whereas a satellite image taken from hundreds or thousands of kilometres above the ground may resolve only objects that are tens or hundreds of metres in size.

An infra-red image taken by a surveying satellite *Fig 1.3.4*

Onsite mapping methods

Once remote sensing techniques have identified promising sites, the next step in locating viable deposits involves onsite mapping. Again, different techniques yield different results and the exploration manager must choose carefully which methods are most suited to the resource in question.

Some remote sensing methods, such as gravity, magnetic and radioactive surveys, are also useful at ground level on the site itself. Exploration teams can use them to map underground resources with more precision than is possible from a remote survey. For example, an aeroplane travelling at a hundred metres per second and sampling magnetic data once every second will produce data points 100 metres apart. A ground vehicle travelling at 5 metres per second and sampling at the same rate can produce data points 5 metres apart. Other onsite techniques, not suited to remote sensing, are described below.

Prac 1 p. 18

Science Snippet

When does a rock become an ore?

Any rock could be an ore of some element or other. To be considered an ore of an element, the rock has to contain a high enough proportion of that element. The sought-after element has to be present in a compound or alloy from which the element can be extracted with minimum effort and cost. Basically, the element contained in the rock has to be saleable at a price that covers the cost of mining, transport, processing, and government charges and taxes, with enough profit margin to make the effort worthwhile. As technology progresses, new ore extraction processes often turn yesterday's rock into today's ore.

Seismic surveys

Seismic methods involve sending sound waves through rock to detect where refraction or reflection happen. Such places indicate a speed change for the sound wave, and therefore a change in the type of rock. Until recently, seismic teams drilled shallow holes in which they set off small explosions to make the sound waves.

Explosives have been superseded by more environmentally friendly energy sources. These include 'thumpers' on land, and machines that create and implode large bubbles under water. The images produced by seismic surveys show the relationships within rock strata in considerable detail. Seismic surveys are especially useful for petroleum and gas exploration. They can locate structures, called stratigraphic traps, where oil and gas may collect.

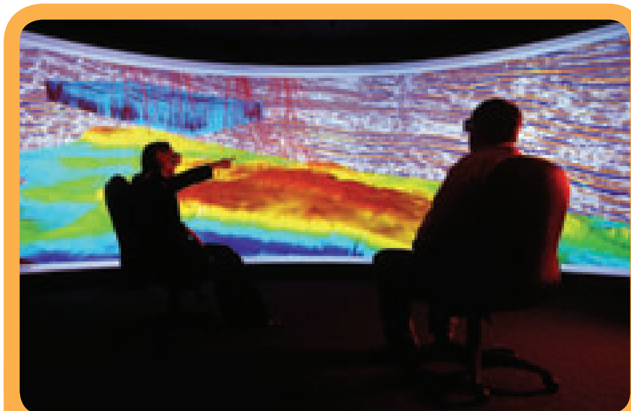


Fig 1.3.5 Exploration teams build up images based on the ways in which rock strata reflect and refract sound waves.

Fig 1.3.6 This truck records sound waves produced some distance away by a 'thumper'.

Geochemical survey

The elements and compounds found in soil and rock can point clearly to where useful resources lie buried. The surface soils in Western Australia tend to be very old, and most areas have been weathered and leached by rainfall for millions of years. Thus the soil that overlies a rich mineral deposit may show only tiny traces of the element of interest.

Analytical tools for geochemical analysis include the mass spectrometer, which can separate the atoms of individual elements and determine their relative abundance. Mass spectrometers can detect one atom of any element when it is mixed in with a million or, in some instruments, even a billion atoms of other elements. Other chemical assay tools use the light emitted by hot ions, or the light absorbed by cold ions, to identify minerals.

Science Snippet

Anomalies at Boddington

A study of geochemical anomalies by the Australian Geological Survey led, in the early 1980s, to the development of a gold mine near Boddington. This was unusual because the find was entirely the result of chemical analysis of surface rock samples. During the period 1989–91, this mine was the biggest single producer of gold in Australia. Over its working life, the operation produced and processed over 100 million tonnes of ore and extracted more than 4.5 million ounces (over 130 tonnes) of gold.

Mass spectrometers can reliably detect one part per billion of any element.

Fig 1.3.7

The analysis of hydrocarbons in petroleum exploration involves another high-tech tool, the gas chromatograph. This tool passes gas molecules through a special filter, which slows some molecules down more than others, and so separates a mixture of gases into discrete components. The samples used in all these techniques are small in size, and are completely destroyed by the analysis process.

Downhole logging methods

Once remote and onsite mapping techniques have identified specific areas of interest, the final step in locating viable deposits involves drilling at the most likely-looking sites, and seeing what's down the hole.

The drilling process is expensive and time-consuming, but is the only way to know for certain what lies below. Some drills produce rock chips as they work, and bring the chips to the surface by circulating mud down the hole and back up again. The chips allow geologists to identify and test rock from hundreds or thousands of metres down. Another drill type produces a core—a solid tube of rock that can be lifted to the surface to see how thick the rock layers are.

Once a hole has been drilled, special tools can be lowered into the shaft to carry out tests on the rock wall. As we have already seen, any radioactive material below the surface can only be detected by downhole logging. Various other tools can test resistivity, temperature, magnetism—almost any property you could imagine.

Fig 1.3.8 This is a downhole tool used to measure temperature.

1·3 FOCUS [Questions]

Use your book

Remote exploration methods

1 Magnetic surveys can be carried out by low-flying aircraft but not by satellite. Suggest why this is so.

2 If you stand next to a mountain that contains a large, dense ore body, and drop a stone, would you expect the stone to fall sideways towards the ore body? Explain your answer.

3 Explain why only surface deposits of radioactive materials can be located using aerial radiometric surveys.

4 What value (to an exploration company) might there be in using satellite images whose resolution is a kilometre or so?

Onsite mapping methods

5 Seismic surveys are more useful in petroleum exploration than in metal ore exploration. Explain.

6 Resistivity surveys are more useful in metal ore exploration than in petroleum exploration. Explain.

7 Explain why geochemical surveys do not always pinpoint potential mine sites.

>>

Downhole logging methods

8 The table below shows how resistivity varies with depth in a section of a drill hole. The drill site was selected using magnetic and gravity anomaly data. Your handbook states that the resistivity of granite, a non-conducting rock, is about 8×10^8 ohm metre. Prepare a brief report to the exploration manager, identifying the depth range or ranges at which you would recommend taking samples for chemical assay.

Depth (metres)	Resistivity (ohm metres)
200	4×10^8
210	5×10^8
220	9×10^{-4}
230	2×10^{-3}
240	3×10^8
250	3×10^{-5}

9 Downhole logging tends to be an accurate but expensive way to find out what is under a given lease. Suggest why:

a it is a very accurate method

b it is a very expensive method.

Use your head

10 Living things can be a guide to the nature of the soil and rock they live on. Why do you think that resource exploration teams concentrate on vegetation rather than animal life in their search for minerals?

11 As new and more efficient methods were developed for extracting gold from its ore, mining companies found it profitable to 'mine' the waste heaps that had already been treated to remove most (but not all) of the gold. Is this likely to happen with iron ore mines as well? Explain.

Investigating questions

12 Whale beaching events have been linked to the noise generated by shipping and by submarine sonar systems. Is there any evidence that underwater seismic exploration has an adverse effect on whale health?

13 What methods are most useful for hydrogeological surveys?

14 Do exploration companies search for particular resources such as gold or coal, or do they just grab a piece of land and find out what's under it? Why do they work the way they do?

FOCUS 1•3

[Practical activity]

Prac 1 Focus 1.3

DYO

Magnetic surveys

Purpose

To simulate aerial and ground magnetic surveys.

Requirements

Plastic tray containing clean dry sand, magnets, clear plastic sheets, marker pens, magnetic field strength probe.

Procedure

1 Bury the magnets in the sand and smooth over the top so their location is not obvious. Exchange your tray with another group. Do not uncover the magnets until you are instructed to do so.

2 Draw a rectangular grid on one of the clear plastic sheets, with the lines 4 cm apart. Your sheet should be covered with a series of 4 cm squares. Mark each intersection with a number. Repeat this on the other sheet, this time using a 2 cm spacing between the lines to make more, smaller squares.

3 Lay the 4 cm squared sheet over the sand tray and measure and record the magnetic field strength at each numbered intersection. *Record the results in a suitable table.*

4 Repeat, using the 2 cm squared sheet. *Record the results in a suitable table.*

5 Use the two sets of results to create rough maps of the field strength values around the tray.

Questions

1 Which set of results was easier to turn into a map? Why?

2 Which map would be more suited to locating drill rigs to investigate what lies beneath the sand surface? Why?

3 Use the map or maps to locate sites for drill holes. How many test holes do you need to work out where the magnets are and what their orientations are?

FOCUS 1.4 Future shocks

Context The Universe has evolved over time. The Big Bang model tells us that in the period immediately following the Big Bang, the Universe was highly compressed and incredibly hot. For the first fraction of a second, it was too hot for particles such as electrons and protons to exist. As it expanded and cooled, various types of matter and different physical laws became the norm. So the Universe we see around us today is very different from the Universe just after the moment of creation. We can speculate about what it will be like in the far distant future.

Time and the Universe

The Sun was not formed during or immediately following the Big Bang. The evidence points to the Universe being almost 14 billion years old, while our Sun is less than 5 billion years old. Thus the Universe was already ancient when the Sun appeared. In its extreme youth, the Universe was full of very hot hydrogen and helium. The life cycles of generations of stars (see Focus 1.1) created the more massive atoms, such as carbon, oxygen, aluminium and iron, that are relatively abundant on the Earth's surface.

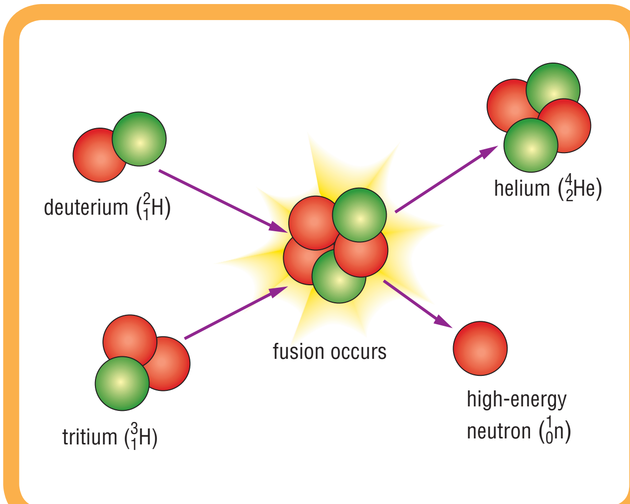


Fig 1.4.1 Fusion creates heavier atoms and releases energy.

White and red dwarfs

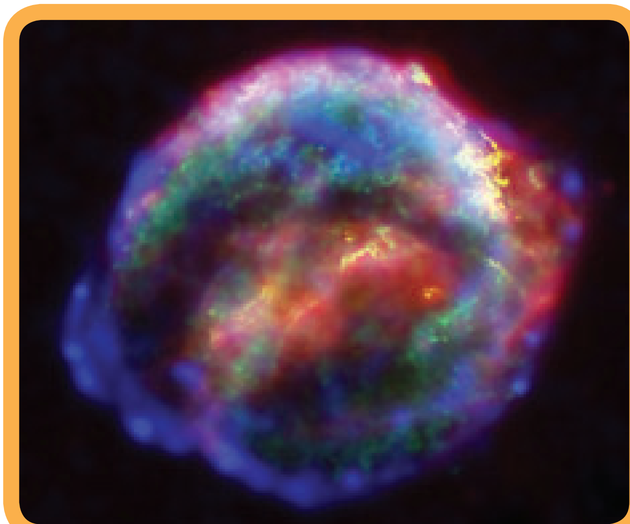
White dwarfs are the exposed cores of stars whose fusion has stopped. Small-to-medium mass stars such as our Sun create white dwarfs after the nuclear fuel in their cores runs out, and their fusion stops. Gravity takes over and the outer layers collapse into the core. What happens in detail at this point depends on the star's mass.

Fig 1.4.2 One day the Sun may look like this.

The gravity in a very low-mass star is not strong enough to collapse it to the point at which helium can undergo fusion. The collapse causes a fast fusion reaction in the hydrogen from the outer layers. This causes the outer layers to puff out, creating a red giant. The core becomes a white-hot ball of helium. The outer layers drift off into space, forming a planetary nebula, leaving the white-hot core, now a white dwarf, which slowly cools. It becomes a red dwarf, then fades into darkness.

Stars with higher mass, such as our Sun, go through a second core fusion phase in which helium atoms fuse into beryllium and eventually carbon. When the helium runs out, it goes through a second collapse, producing a planetary nebula and a cooling white dwarf.

Stars with mass of more than about eight solar masses go through several collapses and subsequent core fusion that creates increasingly larger elements. Finally, the star becomes a supernova, leaving behind a pulsar or, if it is very massive, a black hole rather than a white dwarf.



This spectacular structure is what remains of a supernova. *Fig 1.4.3*

Science Snippet

Gravitational lensing

Black holes neither emit nor reflect light. They are invisible but not undetectable. We detect black holes that have accretion discs around them when matter falling into the black hole heats up and emits emr, especially X-rays. They are also detectable through their gravity. A star wobbling around 'nothing' is probably orbiting a black hole. Most peculiarly of all, black holes can be detected if they are between the observer and a more distant object such as a star or a galaxy. The black hole warps the space around it, and light passing by it changes direction as it moves through the warped area. This creates false or multiple images of the object. Several such 'gravitational lensing' observations have been interpreted as black hole candidates.

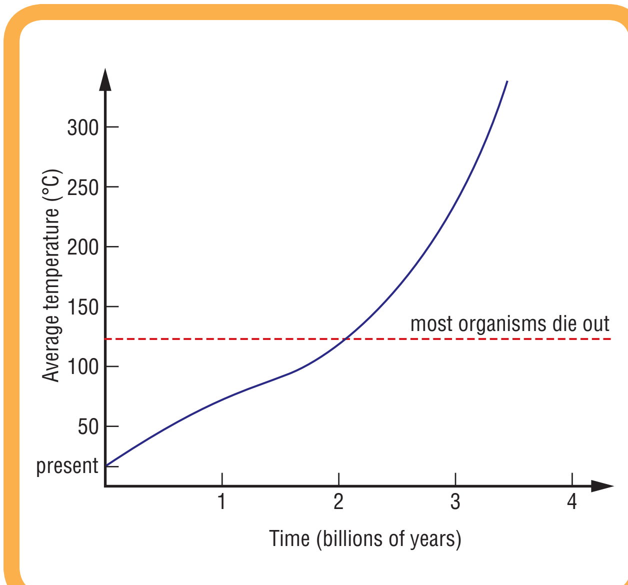
In close binary or double stars where one component is a white dwarf, irregular outbursts of energy from the white dwarf can occur. The nearness of the two stars means that matter is pulled away from the companion star and into the white dwarf. Matter collects as a compressed layer on the surface of the dwarf until a flash of fusion occurs, using up all the accumulated hydrogen in a bomb-like blast. This is known as a nova, which is a type of variable star.

The fate of life on Earth

Living things will almost certainly go on living and evolving for a long time to come. Estimates of the average time between appearance and extinction for any species in the geological record range between one and ten million years. Most species die out in relatively short time periods called 'mass extinctions'. The rate at which species are disappearing suggests that we are in the middle of a mass extinction event right now. This implies strongly that if you could travel through time to ten or a hundred million years in the future, you would find very few species alive then that are alive now. Of course, the Earth has never before supported self-aware organisms able to predict and plan for the future, so just possibly, humans might still be around.

There is evidence that the Sun has been getting brighter (that is, hotter) over the past four billion years. It is probably about 30 per cent brighter now than it was when life first appeared on Earth. This temperature increase will almost certainly continue. As the Sun gets hotter, so too will the Earth. At some point in the far future, the Earth will be too hot to support any kind of life. While estimates of when this will occur vary, most scientists who have studied the problem agree on the major ideas.

It will take perhaps half a billion years for the Earth to get too hot to support complex life forms such as mammals or fish. For a long time after that, conditions will be such that only thermophilic (heat-loving) bacteria will inhabit the Earth. So the Earth's far future life forms will be bacteria, very much like the organisms that inhabited the Earth billions of years ago. Eventually, perhaps a billion years from now, the



The Earth will get hotter as time passes. *Fig 1.4.4* warming Sun will completely vaporise the oceans. Once liquid water cannot exist on the Earth, life of any kind will be impossible.

Water molecules are chemically stable near the Earth's surface. In the upper atmosphere, however, intense ultraviolet radiation from the Sun can break water up into oxygen and hydrogen molecules. Most re-combine to re-form water, but some hydrogen molecules move fast enough to escape from the atmosphere. Over long time periods, this process will eventually remove all the Earth's water. There is evidence that a similar process occurred long ago on Mars, whose gravity is weaker than the Earth's.

The Earth will continue to exist for a long time as a hot, dead, dehydrated ball of rock.

The ultimate fate of the Earth and Sun

Most likely, Earth processes will go on for billions of years, much as they have done over the last several billion. One of the main driving forces behind plate tectonics is probably thermal energy trapped deep underground. This energy is produced by the radioactive decay of naturally occurring radioactive isotopes, a process that will go on for a very long time, but will eventually stop. Another important factor is the absorption of water into the oceanic crust, which allows the basalt rock to bend as it enters a subduction zone. When plate tectonic activity finally stops, erosion will reduce mountains to shallow seas—if any water remains in the oceans.

The Sun will go on fusing hydrogen into helium in its core, and radiating energy, for billions of years. The best estimate is that the Sun is about halfway through its time on the 'main sequence' (see Focus 1.1). So one day in around five billion years' time, the fusion in the Sun's core will switch off, starved of fuel. With no energy coming from fusion in the core, the outer part of the Sun will collapse inwards because of gravity. This will compress the hydrogen that remains in the Sun's outer layers. Rapid fusion will result, and the energy released will push the outer layers away from the core again. As the outer layers expand, they will cool down, becoming red hot rather than white hot.

Thus the Sun will become a red giant star, so big that Mercury's orbit will fit entirely inside it. Mercury will then cease to exist. Venus and Earth will become much hotter than they are now; almost certainly, that will be the end of life on Earth.

Science Snippet

Constants around the Universe

A small number of physical values, such as the charges and masses of electrons, protons and neutrons and the velocity of emr, have always the same whenever and wherever they were measured. Does this mean that they are going to be the same in another solar system, or in another galaxy? Have their values been constant through time? Will their values be the same in the future? Most scientists accept them as 'universal', but there are disturbing hints that some may not be constant over time. One problem shared by all scientists is that we humans have a very small piece of the Universe in which we can make direct measurements.

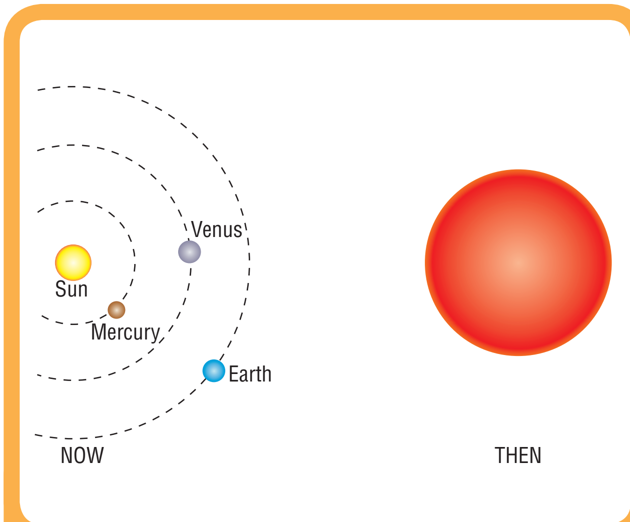
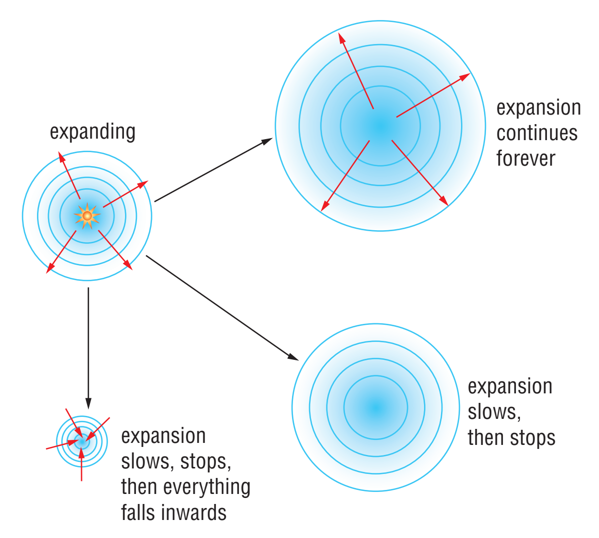


Fig 1.4.5 The Sun is going to expand its volume enormously when its core hydrogen runs out.

The Sun is sufficiently massive to restart fusion after becoming a red giant. It will slowly lose its outer layers, perhaps forming a beautiful planetary nebula. The next few hundred million years will see a quiet phase, which will end when the Sun becomes unstable and will expand and shrink erratically. Some time in this phase, it will engulf the Earth and the other inner planets. After about one billion years, the core will run out of helium, and fusion will again stop. The collapse that follows will be final, because the Sun is not sufficiently massive to fuse carbon. Its outer layers gone, the white-hot core that remains will slowly cool. It will pass from white dwarf to red dwarf, and eventually cool down to invisibility. What remains of the Solar System will continue to orbit the black, cold cinder that was the Sun.

The ultimate fate of the Universe

Fig 1.4.6 The Universe may follow one of several paths in the distant future.



The Big Bang theory grew from the observation that the Universe is expanding. Gravitational attraction pulls inwards on all parts of the Universe, and scientists could see three possible endings. If gravity was not strong enough to stop the expansion, the Universe would continue to expand forever, although at an ever-decreasing rate. If gravity was just strong enough to overcome the expansion, the Universe would slow its expansion and eventually just stop. If gravity was a little stronger than that, then the Universe would start to fall back inwards, leading, in a far, far distant future, to a Big Crunch.

Careful study of special stars called 'Type Ia supernovas' in distant galaxies led to a totally unexpected result. Gravity is not slowing the expansion of the Universe. Type Ia supernova behaviour shows that expansion is actually speeding up. This makes the expanded, stopped Universe or the Big Crunch scenario very unlikely. The implication of the increasing expansion rate is that there must be an unsuspected source of energy. This must be big enough to overcome gravity and actually push the parts of the Universe apart. Scientists have called this 'dark energy', but naming it and understanding it are quite different things. Dark energy and its origins remain mysterious.

Its effect may be that the Universe will continue to expand forever, and that some day in the remote future observers will be able to see only the galaxy they are in.

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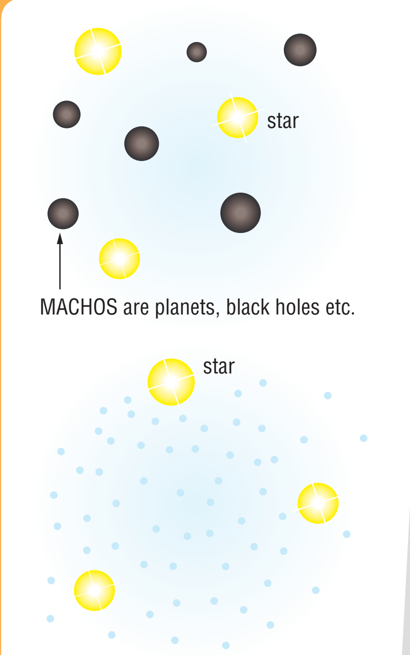


Fig 1.4.7 Dark matter may consist of Massive Compact Halo Objects (MACHOs) or Weakly Interacting Massive Particles (WIMPs).

Science Snippet

Dark matter

Observations show that the stars on the edges of a galaxy move faster than expected. There must be extra matter in the galaxy, invisible to us, that controls the motions of the outer stars. This invisible matter is called 'dark matter' and is a separate problem to 'dark energy'. Calculations suggest that there is more dark matter in the Universe than there is visible matter. Possible explanations for dark matter include actual lumps of matter such as asteroids, planets and black holes. Astronomers call such stuff 'massive compact halo objects' or MACHOS. Another possible way to explain dark matter is as a thinly spread collection of subatomic particles, called 'weakly interacting massive particles' or WIMPS.

Homework book 1.4 Density
Homework book 1.5 Black holes

1.4 FOCUS [Questions]

Use your book

Time and the Universe

1 If only hydrogen and a little helium were formed in the Big Bang, where did all the other elements come from?

White and red dwarfs

2 Describe the processes that result in the formation of:
  a a white dwarf
  b a red dwarf.

3 Why are planetary nebulas always found surrounding a white dwarf star?

The fate of life on Earth

4 Most species that become extinct do so during short periods called 'mass extinctions'. Suggest why species do not become extinct at an even rate through Earth's history.

5 The time during which the Earth can support organisms more complex than bacteria seems to be limited.
   a Approximately how long is this time period, in years?
   b What fraction of this time has already passed?
   c For how long are humans likely to inhabit the Earth?

6 What might the Earth's atmosphere be like in a billion or so years' time, after the oceans have evaporated?

The ultimate fate of the Earth and Sun

7 Will humans be around to see the Sun become a red giant? Explain.

8 Describe briefly what a time traveller might find if they could visit the Earth as it will be in 10 billion years' time.

The ultimate fate of the Universe

9 What is a 'Big Crunch'? Is such an event likely?

10 Explain briefly the significance, or importance, of 'dark matter'.

Use your head

11 Scientists speculating about the far future of the Earth have suggested that the last-ever living things may one day exist deep under a mountain near the South Pole. Explain.

12 The Earth is already losing water from the oceans, at a current rate of about one millimetre every million years. At this rate, how long would it take to lower sea level by 10 metres? How much deeper might the first oceans have been?

13 When the Sun becomes a red giant, it will expand so that, as seen from Earth, it will almost fill the whole day-time sky. It will also become cooler, with its surface temperature dropping to perhaps half what it is now. Once this happens, the Earth's surface temperature will rise to more than 2000°C, which is higher than the melting point of any type of rock. Why will the Earth's temperature rise even though the Sun's surface temperature has dropped?

Investigating questions

14 Many science fiction authors have speculated about the end of the world. Choose one such science fiction story or movie, and briefly explain whether the science in the story matches up to current scientific thinking.

15 There are several possible endings to the story of the Universe. Which is the most likely? What is the evidence that makes this possibility the most likely one?

1·4 FOCUS [Practical activity]

This is your life!

Prac 1 Focus 1.4

DYO

Purpose

To show the significant phases in the life of the Earth, the Sun and the Universe on a timeline.

Requirements

Butcher's paper, adhesive tape, marker pens, access to research sources such as a library, the Internet etc.

Procedure

1 As a class, decide which groups will work on the Earth's timeline, which on the Sun's timeline, and which on the Universe's timeline.

2 In your group, decide on the tasks that need to be performed and allocate them to members of the group. In each case, *write down the roles.*

3 Carry out your research. Accumulate your information, and decide a suitable scale to display all the events in your timeline.

4 *Create and display your timeline.*

5 Study other groups' timelines.

Questions

1 Which events in the Earth's timeline do you consider to be the most significant? Briefly justify your choices.

2 Which events in the Sun's timeline do you consider to be the most significant? Briefly justify your choices.

3 Which events in the Universe's timeline do you consider to be the most significant? Briefly justify your choices.

Review questions

Second-hand data

1 Your exploration team is tasked with finding an ore body containing a new mineral, mightyoddstuffite. This mineral is very valuable, so you need to make sure that you know how much of there is—if and when you find a deposit. Mightyoddstuffite is a very dense, electrically conducting mineral that is easily charged electrically. It contains a radioactive element that emits beta and gamma rays as it decays. In known deposits in Brazil and Kazakhstan, mightyoddstuffite occurs in wide sheets, several metres thick, both on the surface and at depths to 250 metres below the surface.

Considering the properties of mightyoddstuffite, and your exploration budget, plan how you will direct your exploration team to locate any deposits in your search area, and to prove the extent of these deposits.

2 Your laboratory has six samples of mightyoddstuffite, of different sizes. The table below shows the masses and sizes of each sample. You can calculate the density of any object by using the formula:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Thus, if the mass is given in kilograms and the volume in cubic metres, the density is in kilograms per cubic metre. If the mass is in grams and the volume is in cubic centimetres, the density is in grams per cubic centimetre.

a For samples A, B, C and D, calculate the volume of each sample, in cm^3. You may have to research how to work out the volume of a particular shape.

b Make a table showing the mass and volume of each sample.

c Plot a graph of the mass of each sample (y-axis) against the sample volume (x-axis).

d Draw a 'line of best fit' by eye—that is, use a ruler to make a straight line that goes as close as possible to all the points.

e You can work out the gradient of this line using the formula gradient = $\frac{\text{rise}}{\text{run}}$. Calculate the gradient of your line of best fit, and include the unit in your answer.

f Is the gradient of this graph connected to the density of mightyoddstuffite? Explain your answer.

Sample	Mass (grams)	Shape and size
A	73.5	Cube, 2.0 cm × 2.0 cm × 2.0 cm
B	277	Rectangular prism, 3.0 cm × 2.5 cm × 4.0 cm
C	315	Sphere, radius 2.0 cm
D	159	Cylinder, height 4.5 cm, diameter of base 2.2 cm
E	101	Irregular chunk, volume 11 cm^3
F	35.0	Irregular chunk, volume 3.8 cm^3

Open-ended questions/experimental design

3 Figure 1.5.1 shows a view of deep space.

a After conducting some research, estimate the number of stars in this field of galaxies. Every time you make an assumption about something, write down what your assumption is.

b How confident are you about your estimate? Make a list of the main reasons for not being confident—that is, what might have contributed to errors in making your estimate?

c Compare your estimate, and your assumptions, with those of other students or groups. Could you improve your estimation technique by working with others? Explain.

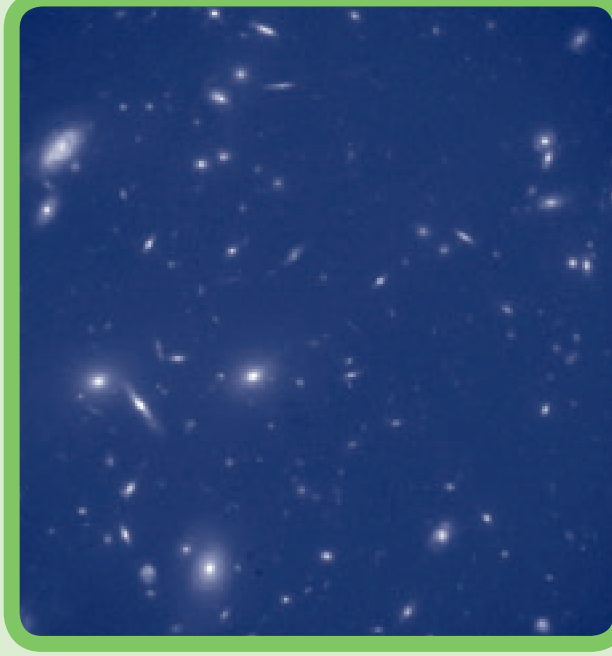
d What else would you have to know or find out in order to use your answer to **a** to estimate the number of stars in the visible Universe?

4 The same rock types and minerals seem to turn up all over the world. For example, the iron ore magnetite occurs in Australia, Canada and Africa.

How alike are rocks or minerals of one type if you obtain them from different locations? Design an experiment to see how much one property (eg density or radioactivity) of one type of rock (eg granite or limestone) or one type of mineral (eg galena or quartz) varies.

Every visible object in this photograph is a distant galaxy.

Fig 1.5.1



Extended investigation/research

5 You have learnt that some stars, such as RR Lyrae stars, and novas, are variable—that is, their brightness (luminosity) can vary significantly.

a What kinds of variability occur in stars?

b Are only some stars variable? Most of them? All of them? Explain.

c What causes variability in stars?

6 What are cosmic rays, where do they come from and why are they important to us?

Homework book 1.6 Sci-words

Energy and change

2

Curriculum guide learning focus

- using equations to quantify concepts of mechanical and electrical energy
- representing motion graphically
- using concepts and models to understand transfer of mechanical and electrical energy
- speed, velocity and Newton's Laws of Motion
- stability and equilibrium
- transferring mechanical energy
- electric power and efficiency of transfer
- energy transfer by waves
- the use of energy in systems such as levers
- energy sources, use and conservation

This section on Energy and Change also contains work that will help students with the outcomes of Investigating, Communicating Scientifically, Science in Daily Life, Acting Responsibly and Science in Society.

Outcome level descriptions

The outcome level descriptions for Energy and Change covered in this section are mainly EC 5 and EC 6.

FOCUS 2.1 Speed and velocity

Context

In everyday language, words such as 'distance', 'displacement' and 'speed' have certain meanings. In science sometimes these terms take on very specific meanings. For instance, this morning you might have left your home and gone to school and then come home again after school. If you live two kilometres from school then you would have travelled a total distance of four kilometres. A physicist might say that although your total distance travelled is four kilometres, your total displacement during the day was zero. How can this be? Read on to find out.

Distance and displacement

Suppose you tie one end of a ball of string onto the doorknob of your house as you leave for school one morning. As you walk to school you let the string fall behind you so that the length of string when you arrive at school is a perfect measure of the distance you have walked.

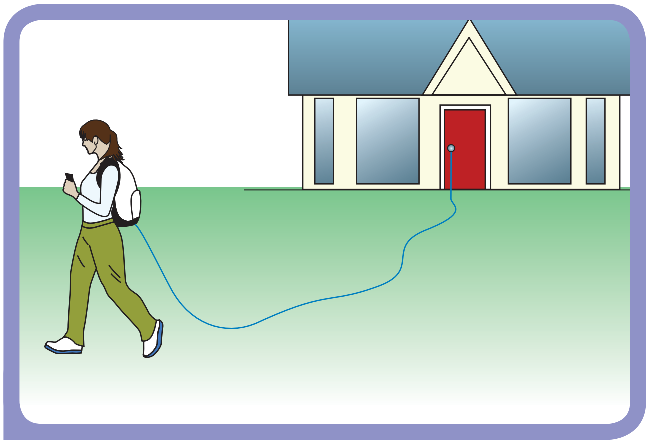
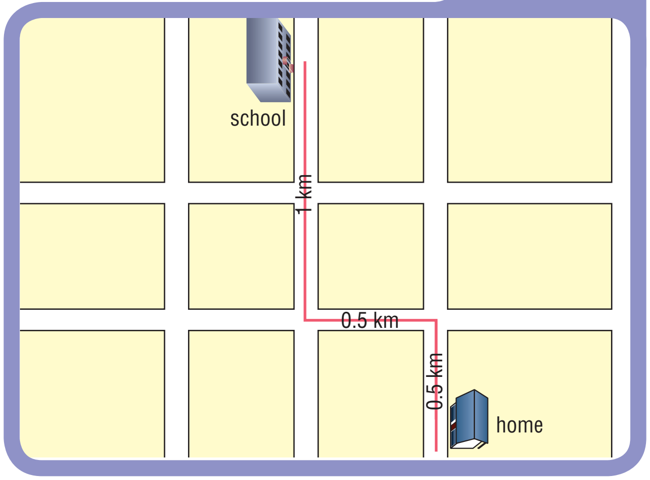


Fig 2.1.1 The length of string behind the student is the same as the distance she has walked.

Because it is unlikely that you would walk in a perfectly straight line to school, your direction and therefore the direction of the string path will change many times during the journey from home to school. When you get to school you could wind the string back up while counting the number of metres of string that you have left behind you. This is the **distance** that you have walked to get to school. On the map in Figure 2.1.2 the red line shows the distance walked by a student from home to school.

The distance travelled is a measure of the path taken to complete a journey. *Fig 2.1.2*



In physics there is a word to describe the straight-line distance between your starting and finishing point. This word is **displacement**. The black line in Figure 2.1.3 shows the student's displacement from home when she gets to school.

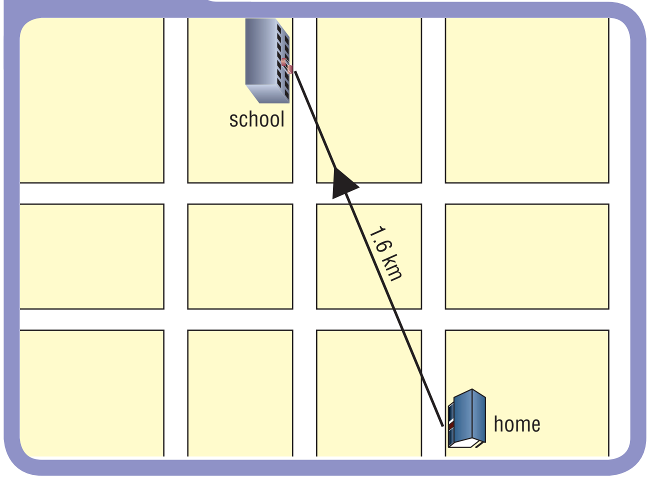
Interestingly, if the distance you walk from home to school is 2 kilometres, the distance you travel from home to school and back home again is 4 kilometres. But what would your displacement be? You know that your displacement is the straight-line distance between your starting and finishing points.
If you start at home and finish the day's journey at home, your starting and finishing points are the same position (home) then your displacement for the day is actually 0 km.

Science Snippet

As the crow flies

Have you ever heard the expression 'as the crow flies' when discussing the distance between two places? The expression is used to recognise that when a bird flies between two points, it does not have to stick to roads like we do, and so can fly in a straight line between two points. The expression 'as the crow flies' means moving in a straight line between two locations.

Fig 2.1.3 The displacement of the student is the straight-line distance from home to school.



Speed and velocity

In Western Australia, the speed limits on most city roads range from 40 to 60 kilometres per hour. The unit 'kilometres per hour' can be abbreviated in different ways, for instance km/h or just km h^{-1}. If you were travelling at a constant 60 kilometres per hour, in your first hour you would travel 60 kilometres. At the end of your second hour you would have travelled 120 kilometres and so on. You might have heard of other units for describing speed, for instance miles per hour, but in physics we generally describe speed in units of either km/h or metres per second (m/s or m s^{-1}).

Speed can be thought of as how quickly an object's distance increases. Speed is the **rate of change of distance**. It can be calculated by using the formula:

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

or

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

For instance, in Figure 2.1.2 the student walked a distance of 2 kilometres from home to school. Calculate the speed the student walked at if it took exactly half an hour to make the trip.

$v = ?$

$s = 2$ km

$t = 0.5$ hours

$$v = \frac{s}{t} = \frac{2}{0.5} = 4 \text{ km/h}$$

The student's speed was 4 km/h.

Velocity is similar to speed except it is a measure of how quickly displacement changes. Velocity is defined as the **rate of change of displacement**.

It can be calculated by using the formula

$$\text{Velocity} = \frac{\text{displacement}}{\text{time}}$$

or

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

Referring back to Figure 2.1.3, you can see that although the student travelled a distance of 2 kilometres to school, her displacement was only 1.6 kilometres in a north-easterly direction.

Her velocity is therefore:

$$v = \frac{s}{t} = \frac{1.6}{0.5} = 3.2 \text{ km/h}$$

The student's velocity was 3.2 km/h north-east.

Notice that when expressing displacement it is important to state the direction in which the displacement occurred. The direction runs *from* the starting point *to* the finishing point.

Comparing speed and velocity

The student featured in this Focus has been described as travelling 2 kilometres to school and then 2 kilometres back home. When the student has returned home her total distance travelled is 4 kilometres but her total displacement during the day is 0 kilometres. This information allows you to calculate the student's speed and velocity for her overall journey from home to school and back again, which took 1 hour.

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SPEED	VELOCITY
$v = \frac{s}{t}$	$v = \frac{s}{t}$
$\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{4}{1} = 4 \text{ km h}^{-1}$	$\text{Velocity} = \frac{\text{displacement}}{\text{time}} = \frac{0}{1} = 0 \text{ km h}^{-1}$

Calculating displacement or time

You can use the formula $v = {}^{s}/_{t}$ to calculate the displacement of a moving object if you know its velocity over a given time. You first need to rearrange the formula so that your equation allows you to solve for displacement (s). You can use the solutions

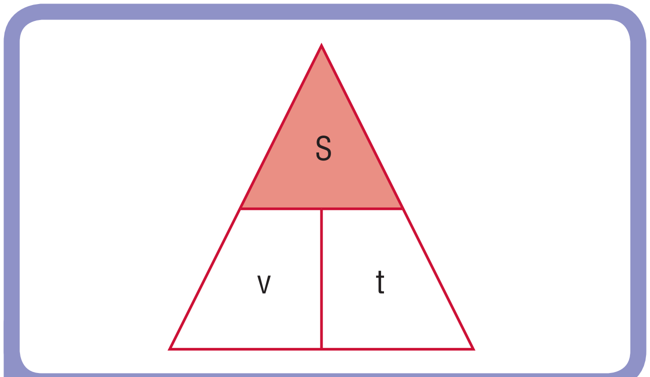

Fig 2.1.4 You can use this solutions triangle to solve for displacement (s). Place your finger over the variable to be solved, which is S, leaving v to be multiplied by t.

triangle in Figure 2.1.4 as a short cut if you find it difficult to rearrange equations.

Using the solutions triangle, put your finger over the variable (quantity) you wish to solve for and then just read the position of the remaining variables to determine their positions as denominator or numerator.

If you are given velocity and time and you want to calculate displacement, the formula you will use becomes:

$$s = vt$$

and if you are given displacement and velocity and you want to calculate time, the formula you will use becomes:

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

Example

Calculate the displacement in metres of a train which travelled east for 30 minutes at a speed of 145 km/h.

$$v = 145 \text{ km/h}$$
$$t = 0.5$$
$$s = v \times t$$
$$= 145 \times 0.5$$
$$= 72.5 \text{ km east}$$

Converting between units of speed

It will sometimes be necessary to convert from units of kilometres per hour to units of metres per second. You can use the simple method to convert between these two units.

$$\text{km/h} \underset{\times 3.6}{\overset{\div 3.6}{\rightleftarrows}} \text{m/s}$$

Suppose you want to convert a velocity of 60 km/h into m/s. The conversion chart above shows that to convert from km/h to m/s requires you to divide the speed by 3.6. This means that:

$$\text{Velocity in km h}^{-1} = \frac{\text{velocity in m/s}}{3.6}$$
$$= \frac{60}{3.6}$$
$$= 16.7 \text{ m/s}$$

Graphing motion

The slope of the graph shows that the cyclist was travelling at 5 ms^{-1}. *Fig 2.1.5*

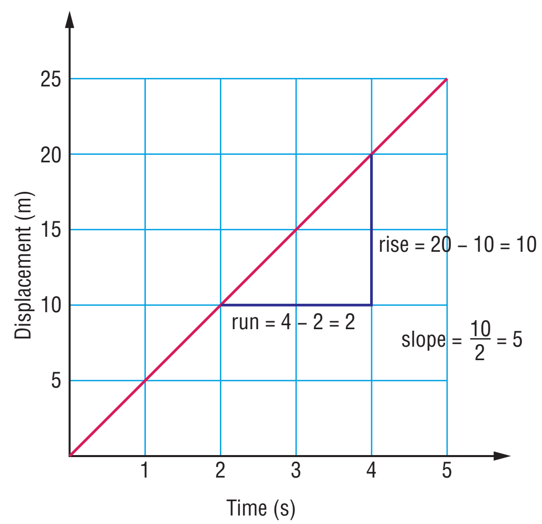

Figure 2.1.5 shows how displacement might change as a cyclist travels at a constant velocity from home to the shops. Notice that each second of travel results in an extra 5 metres of displacement. The velocity of the cyclist is therefore 5 metres per second (5 m/s). You can calculate the velocity of the cyclist on a graph like this by calculating the gradient (slope) of the line as shown on the graph. In maths you have probably learnt that:

$$\text{Gradient (slope)} = \frac{\text{rise}}{\text{run}}$$

For this graph the slope is therefore $^{10}/_{2} = 5$. The slope of the line is equal to the velocity. So the velocity is 5 m s^{-1}.

A displacement–time graph like in Figure 2.1.6 indicates a vehicle that is stationary (not moving). This is because the rise is zero, so the slope is zero. Therefore the velocity is zero.

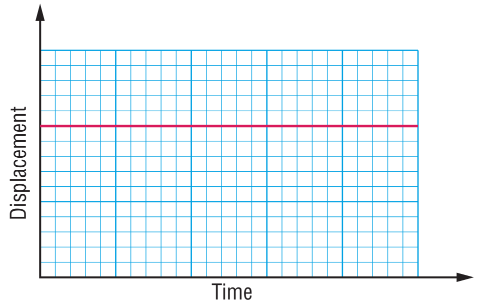

Fig 2.1.6 A horizontal line on a displacement–time graph means that displacement is not changing over time. This type of graph would therefore indicate a velocity of 0 m/s.

The greater the slope of displacement time graph therefore, the greater the velocity, as shown in Figure 2.1.7.

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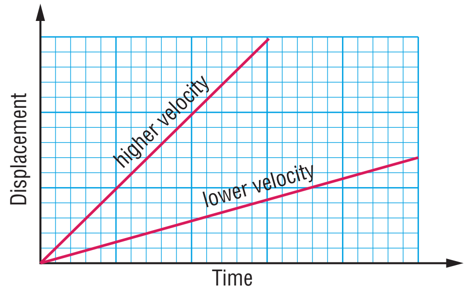
Interactive Animation

Drag and Drop Interactive

Fig 2.1.7 A higher velocity would be represented as a steeper slope on a displacement–time graph.



Homework book 2.1 Distance–time graphs

2·1 FOCUS [Questions]

Use your book

Distance and displacement

1 What is the difference between the quantities distance and displacement?

2 Supposing that you were to walk 3 km north and then 3 km east in 2 hours. What would be your distance travelled and what would be your displacement from your starting point?

3 A description of distance travelled might be 22 km. What extra bit of information is required when you describe displacement?

Speed and velocity

4 Write down the definitions of speed and velocity.

5 What is the formula for velocity?

6 Write down two units for speed.

7 Calculate the speed and velocity for the journey undertaken in question 2. Show your working out, like in the examples provided in this Focus.

Calculating displacement or time

8 Sam can maintain an average jogging speed of 4 km/h. Calculate the time it takes her to run the City to Surf Marathon (a total distance of 13.5 km) if she maintains this speed during the race.

9 How far will a cyclist travel if he maintains a speed of 5 m/s for 10 minutes?

Converting between units of speed

10 The speed limit on many West Australian roads is 60 km/h. Convert this speed to a speed in m/s.

11 A fighter aircraft flying a Mach 1 travels at 340 m/s (the speed of sound). What is its speed in km/h?

12 How many times faster is an aircraft flying at the speed of sound than a car on the freeway travelling at 100 km/h?

Use your head

13 The displacement–time graph shown in Figure 2.1.8 was produced when Jane, Indira and Charlotte ran the 100-metre sprint as part of a science class activity.

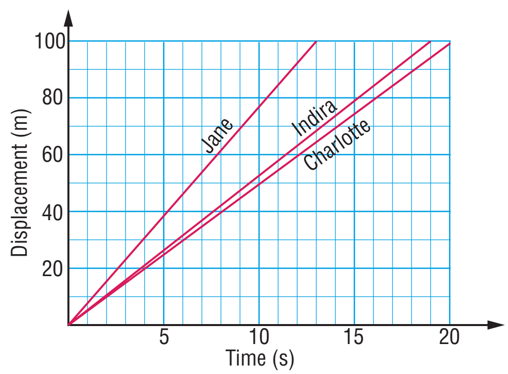


Fig 2.1.8 Graph for question 13

a Who won the race and how can you tell?

b Use the graph to calculate Indira's velocity during the activity.

c Who was the slowest runner in this race? How do you know?

14 Draw a displacement time graph for someone who walks 200 m north in 2 minutes, then runs 100 m south in 20 seconds, then walks 300 m north in 3 minutes.

Investigating questions

15 What is a sonic boom, when does it occur and why does it occur?

16 How do radar guns or multa-nova cameras work?

17 What is echolocation in bats or dolphins, and how does the animal use it?

18 What does 'sonar' stand for, and where and how is it used?

19 Find a way of measuring the velocity of a model car or other vehicle over a set distance. You could use electronic devices. Construct or set up your timing device, then conduct experiments to measure the velocity of your vehicle.

DYO

2•1 FOCUS [Practical activities]

Measuring velocity

Prac 1 Focus 2.1

Purpose

To measure the velocity of a vehicle travelling at a constant velocity by using a ticker tape timer.

Requirements

Ticker tape timer, ticker tape.

Background on the ticker tape timer

The ticker tape timer is a device that causes an arm (see Figure 2.1.9) to vibrate up and down. Each time it moves down it makes contact with a platform. Between the arm and the platform is carbon paper. When paper tape (called ticker tape) is pulled between the carbon paper and the platform a mark is left on the tape then each time the vibrating arm makes contact with the platform. Because the arm vibrates 50 times per second, the spacing between dots represents $^{1}/_{50}$ of a second.

Procedure

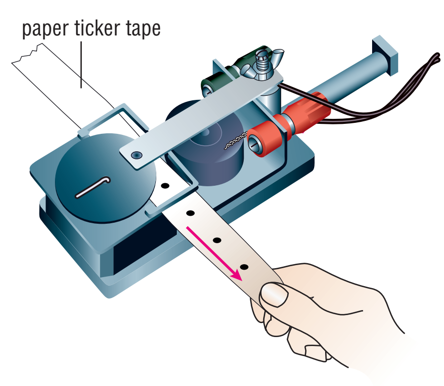
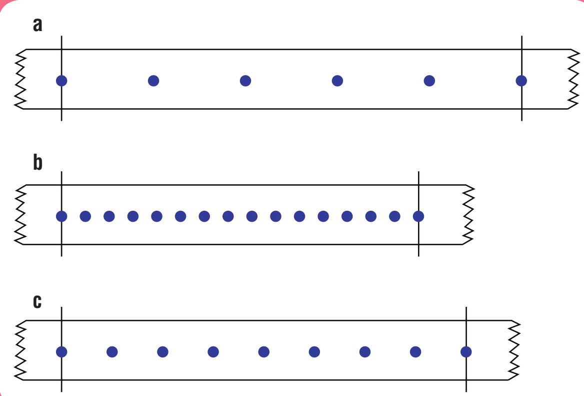


Fig 2.1.9 Ticker tape timer, with tape being pulled through by hand

Section of ticker tape *Fig 2.1.10*



1. With the ticker tape timer try to pull the tape through at a steady speed. The section of tape that represents a constant velocity will be indicated as a section of tape with dots evenly spaced. Ensure that you produce at least a 30 cm section of tape with dots evenly spaced.
2. Get two other members of your group to do the same, but ensure that the speed at which they pull the tape through differs from yours.
3. *Draw two lines on the first and last dot of a section of tape where the dots are evenly spaced.*
4. *Copy the following table into your notes.*

>>

Student	Displacement (s) in cm	Time (t) in s	Velocity in cm/s

5 Measure the distance between the two lines. This is the displacement (s) that you will be using in your calculation. Record this in your table.

6 Count the number of spaces between these two lines. Because each space represents a time of 1/50 (or 0.02) of a second, counting the number of spaces and then multiplying this number by 0.02 will give you the time taken (t) for the second of tape between the lines to be produced. *Record this in your table.*

7 Use your measurements of s and t for each of the tapes to calculate the velocity with which you pulled each tape through the ticker tape timer. *Record this in your table.*

Questions

1 Why were you asked in this experiment to find a section of tape that showed dots spaced evenly?

2 What might dots with increasing spacing represent?

Prac 2
Focus 2.1

Graphing motion

Purpose

To collect and graph displacement and time data for sprinters.

Requirements

Trundle wheel or tape measure, 10 timekeeper volunteers, 10 witch-hat markers or other markers, 10 stopclocks, two or three volunteer runners.

Procedure

1 Use the trundle wheel or tape measure to space out the volunteer timekeepers at 10 metre intervals from the starting point. At least 50 metres of track and 5 timekeepers are necessary to do this Prac. Each timekeeper will need a stopclock.

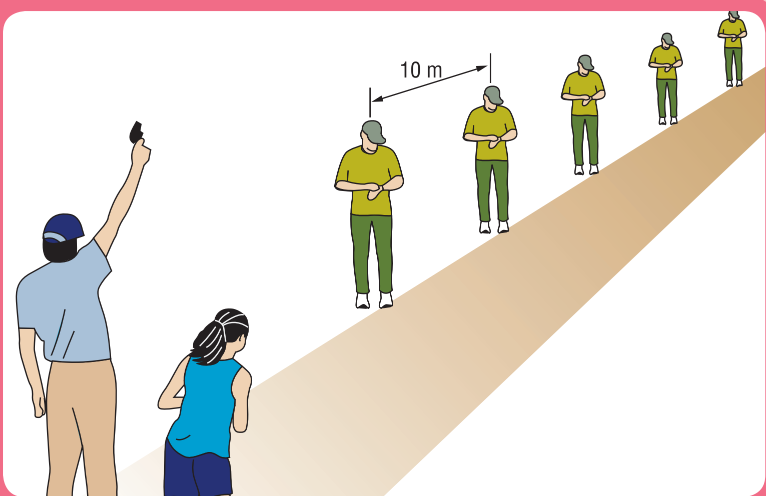
2 The teacher raises their hand to indicate to the timekeepers that the first runner is about to run.

3 When the teacher drops their arm the first runner leaves the 0 metre marker. At the same time each of the timekeepers start their stopclocks.

4 Each timekeeper stops their stopclock as the runner passes them. *Copy the table below into your notes and record the time there.*

Displacement (m)	Time to reach marker (s)		
	Runner 1	Runner 2	Runner 3
0			
10			
20			
30			
40			
50			
60			
70			
80			
90			
100			

Fig 2.1.11 How to set up the experiment



5 *Draw a graph of displacement–time for each of the runners. Displacement should go on the y-axis and time on the x-axis.*

6 Find the straightest section of each line on this graph and calculate the gradient of each of these lines.

Questions

1 What were the slopes of each of the lines on your graph?

2 Which of the runners ran with the greatest velocity? How do you know this?

3 Were there any parts of each of the graphs where the plotted points did not produce straight lines? Was this constant velocity?

FOCUS 2.2 Newton's First Law of Motion

Context

Think about the last time you were in a car parked at set of traffic lights. The lights turned green and the car began to move, its speed increasing. When a car increases its velocity it is undergoing acceleration. And if you are in a car that is accelerating you often feel as though there is a force pushing you backwards into your seat. When a car stops **(decelerates)** suddenly, on the other hand, you may feel as though a force is causing you to be thrown forwards. Do you remember the last time you were in a car that was turning a corner sharply? You may have noticed the feeling of being thrown sideways as the car turned. In this Focus you will investigate why you experience these forces during accelerations, decelerations and turns.

Fig 2.2.1 The high accelerations and tight turns of stunt aircraft can cause stunt pilots to experience dangerously large forces.

Force

You may recall that a force can be thought of as a push or a pull. Forces can cause the following changes to objects they act on. They can:

- cause an object to accelerate—that is, to increase its velocity
- cause an object to decelerate—that is, to decrease its velocity
- cause an object to change its direction
- cause a change of shape.

In order for a force to do these things, however, two conditions must be met.

a The force must be unbalanced. In order for a force to cause a change of velocity, direction or shape there must be an unbalanced force in the direction of the change. If the force is balanced by another force, the forces cancel each other out because they are acting in opposite directions.

Fig 2.2.2 This box will experience a change in its motion because the forces acting are not balanced. The larger force to the left will cause the box to accelerate to the left.

b The force must be external. Can you move a car by sitting inside it and pushing on the steering wheel? Of course, the answer is no. If you wanted to push a car, you would have to stand outside the car and push it.

Fig 2.2.3

Unlike the boy pushing on the box from the outside in Figure 2.2.2, the man in this picture will not move the boat because the force he applies is not external to the boat.

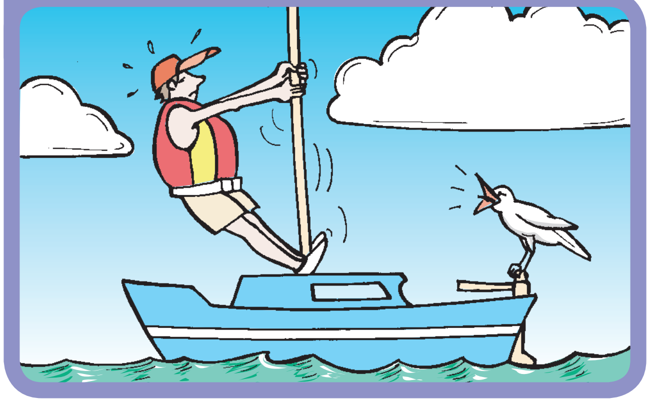


Fig 2.2.4

The dinner-table party trick relying on inertia

To fully understand how forces can do these things you need to learn about the work of a famous physicist who in the 1680s studied the ways in which bodies move. He determined many laws that describe motion, but perhaps his most famous are referred to as **Newton's Three Laws of Motion**.

Science Snippet

Variables and Newton's apple

The world of science owes a great debt to Isaac Newton. His studies of the motion of bodies have given us many important laws that describe the ways in which objects move on Earth and in space. One of these laws explains gravity. It is said that Newton came up with the idea of gravity one day as he was sitting under an apple tree at his home. Observing a falling apple gave him the idea that perhaps gravity might not only bring an apple down to Earth but also keep moons orbiting planets, planets orbiting stars and so on. A descendant of the original tree can be seen growing outside the main gate of Trinity College, Cambridge, below the room Newton lived in when he studied there.

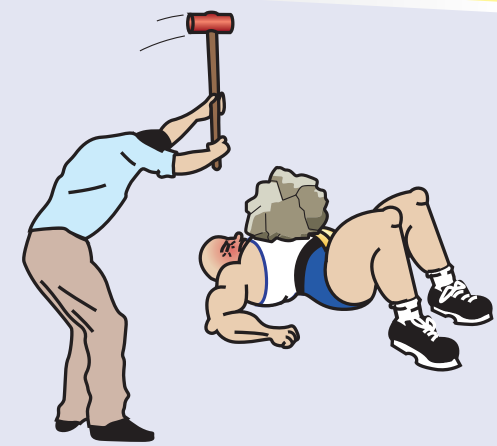
Newton's First Law of Motion

Newton's First Law of motion is sometimes called the law of inertia. **Inertia** is a property of matter by which things tend to keep on doing what they are already doing. Imagine a heavy box at rest (not moving) on the floor. Because the box has inertia, it will continue to remain at rest until it is acted on by an external unbalanced force. A famous party trick that uses the principle of inertia is shown in Figure 2.2.4. If the tablecloth is pulled away quickly the dinner setting pieces, all of which have inertia, remain doing what they were already doing—that is, they tend to remain at rest.

Science Snippet

The strongman

A famous carnival trick involved a strongman with a large boulder on his chest. His assistant would hit the boulder with a sledge-hammer, breaking the boulder, to the astonishment of the crowd. This trick is more about inertia than strength. True, the strongman did have to be strong enough to support the boulder on his chest in the first place. But the boulder, being massive, had much inertia, so it did not want to start moving. As long as the boulder was hit hard and quickly enough it would not move downwards before breaking, meaning that the strongman would feel little, if any, extra force on his chest.



A famous carnival trick—the strongman and the boulder

Fig 2.2.5

Newton's First Law also applies to moving bodies. If a body is travelling in a straight line at a constant speed, it will tend to continue moving in a straight line at a constant speed. But if an external unbalanced force starts acting on it, its motion will change.

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p. 37

For instance, imagine you are in a car moving at a constant speed in a straight line. If the driver of the car were to suddenly apply the brakes, what would you feel? You would feel as though you were being thrown forwards. Actually you are not being 'thrown forwards'. Your body simply has a tendency to keep on doing what it is already doing—that is, moving in a straight line at a constant speed. The car, however, is slowing down around you and your seat belt in particular stops you from continuing to move forwards onto the dashboard or through the front windshield.

Fig 2.2.6 A passenger in a car demonstrates Newton's First Law when the car slows down rapidly.

Remember the last time you were parked at a set of traffic lights. The lights turned green and the driver accelerated forward. You might remember feeling that you were being pushed back into your seat. Actually there was no force pushing you backwards. You were at rest and so had a tendency to remain at rest. The car, however, was accelerating forwards and because you were in the car, the car seat would have exerted a forward force on you. This forward force was the force that caused you to accelerate forwards, but from your perspective you felt as though you were being pushed back into the seat.

When a car accelerates you feel as if you are being pushed back into your seat. Fig 2.2.8

Science Snippet

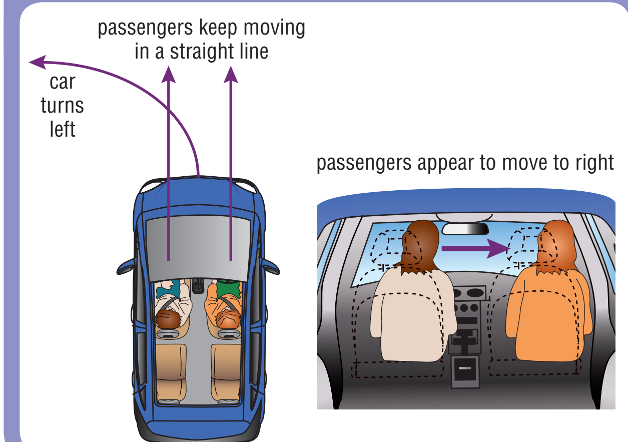
Crash test dummies

Car manufacturers use model humans to investigate what happens when a car is involved in high-speed impacts. These tests have resulted in improvements to car design that ultimately save lives. The dummies are used to measure the force of impact. High-speed photography dramatically demonstrates Newton's First Law in a crash as the dummies keep moving until they hit something.

Fig 2.2.7 The crash test dummy on this motorbike clearly shows the effect of inertia.

Lastly, when your car turns left you feel as though you are being pushed to the right-hand side of the car. Again, this is not the case. Your body simply has a tendency to keep on moving in a straight line at a constant speed. The car, however, is turning away

Fig 2.2.9 You feel as though you are being pushed to the right as the car turns left.



from under you. The seatbelt and seat supply a force to the left to keep you turning with the car, but you feel as though you are being pushed to the right.

What you have learnt here can be summarised into a single law. Newton's First Law can be stated as:

> A body will stay at rest or continue to move in a straight line at a constant speed until an external unbalanced force acts on it.

Homework book 2.2 Plotting car performance data

Homework book 2.3 Calculating F = ma

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2.2 FOCUS [Questions]

Use your book

Force

1 What is a force?

2 What can forces do to the objects they act on?

3 What is meant by an 'externally applied' force?

4 Describe an example of a force that fails to change an object because it is not externally applied.

5 Why does a force have to be unbalanced in order to produce a change?

6 Describe an example of a force that does not change an object because it is balanced.

7 What is an acceleration?

8 What is a deceleration?

Newton's First Law of Motion

9 What is inertia?

10 State Newton's First Law of Motion.

11 Why do you feel as though you are pushed back into your seat as your car accelerates?

12 Why do you feel as if you have been thrown forwards when you are in a car that is braking suddenly?

Use your head

13 What stops you from becoming injured when you are in a car that decelerates rapidly?

14 Use Newton's First Law and your knowledge of the composition of space to suggest why a meteor in space can maintain a constant speed through space. Remember that a meteor has no means of propulsion.

15 Do you think it is safe to hold a baby in your arms while you are a passenger in a car? Why or why not?

16 Why do you think seat belts and airbags are important in vehicles?

17 Before astronauts went into space they had to experience a feeling of weightlessness. Scientists came up with a way to simulate weightlessness. They flew an aircraft upwards at a shallow angle of ascent, then slowly levelled off. The astronauts were sitting without seat belts on seats in a padded compartment in the plane.
   - a Explain what would happen and why they would feel weightless.
   - b This method would not work if the plane was flying up at a steep angle and suddenly levelled off. Explain why.
   - c Would this method work if the plane was put into a shallow dive and then suddenly levelled off? Explain.

Investigating questions

18 Research how the following work and make a comment on how Newton's First Law of Motion applies:
   - a a centrifuge
   - b the spin dryer from a washing machine.

19 Use the Internet to find how a satellite is placed in orbit around the Earth. What does 'in orbit' mean?

20 What is a 'whiplash' injury suffered in a traffic accident, why does it occur, and how are car seats designed to counteract this?

2·2 FOCUS [Practical activities]

Prac 1 Focus 2.2

Lazy coins

Purpose

To investigate inertia of coins and masses.

Requirements

Sheet of A4 or A3 paper, five 20 cent coins, five 50 gm masses, piece of plywood or masonite about the size of a ruler.

Procedure

1. Place a piece of A4 or A3 paper on the edge of a desk so that about 5 cm of one of the shorter sides hangs off the edge of the desk.
2. Place a 20 cent coin on the opposite end of the paper.
3. Take hold of the end of the paper hanging from the end of the desk and pull it very quickly. If you do this fast enough the coin should remain unmoved.
4. Repeat steps 1–3 but this time place a second 20 cent piece on top of the first. Keep going to see how many coins you can do the experiment with.
5. Try repeating the activity (back to a single coin) but this time pull on the paper slowly rather than quickly.
6. Now make a stack of about five 50 g masses. Place a file or a book about 50 cm behind the stack. With a bit of waste plywood or masonite, try to hit the bottom mass out towards the book without toppling the other masses over. (Don't use a ruler because it will dent the edge.)

Questions

1. Write a sentence to explain why you could leave the coin or coins almost unmoved when you pulled the paper quickly, and why you did not topple the masses when you hit the bottom mass out.
2. Write a sentence to explain why you could not leave the coin or coins unmoved when you pulled the paper slowly.
3. What force acted between the paper and the coins as the paper slid beneath the coins?
4. What property is possessed by the coin or coins that allows them to remain almost stationary when paper is pulled quickly from under them?

Prac 2 Focus 2.2

Crash test food

Purpose

To build a capsule that will allow a grape (or egg if you can afford it) to be dropped from at least 2 metres without splitting.

Requirements

Your choice of materials, grapes or eggs (or whatever your teacher suggests), metre rule or tape measure, balance.

Procedure

1. You are to design (using commonly available materials) a capsule to hold a fresh, uncooked hen's egg, or a grape (or other food) so that the capsule can be dropped from a height of 2 metres without damaging the egg or grape. The following specifications must be adhered to.
   - **a** The container must be small enough to fit into a space 30 cm × 30 cm × 30 cm.
   - **b** The container must not exceed a weight of 200 grams.
   - **c** The capsule must allow for the egg or grape to be inserted into the capsule just prior to the test.
   - **d** The egg or grape must be easily removed from the capsule after the test.
2. Show your design to your teacher and when you are given permission, test out your capsule. Your teacher will tell you how the testing will be conducted. (You may only have one try if each group conducts the test of their capsule in front of the class.)

Questions

1. Make a comment about the design feature of the most successful capsule in the class.
2. Explain the relevance of this task to Newton's First Law of Motion.

Extension task

You can increase the height dropped of the more successful capsules in the class.

SAFETY NOTE: Ensure that you are supervised by your teacher if you are using a ladder or any other apparatus to increase the height from which your capsule is dropped.

FOCUS 2.3

Newton's Second Law of Motion

Context

In the last Focus you read about how bodies have a tendency to keep doing what they are already doing. If they are at rest they tend to continue to be at rest. If they are moving in a straight line at a constant speed they will continue to move in a straight line at a constant speed. You learnt that an external unbalanced force will cause a change to either of these two conditions. In this Focus you will learn how external unbalanced forces can cause these changes.

Unbalanced forces

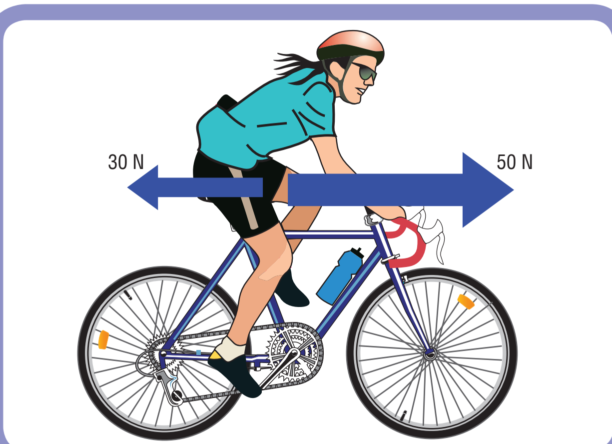
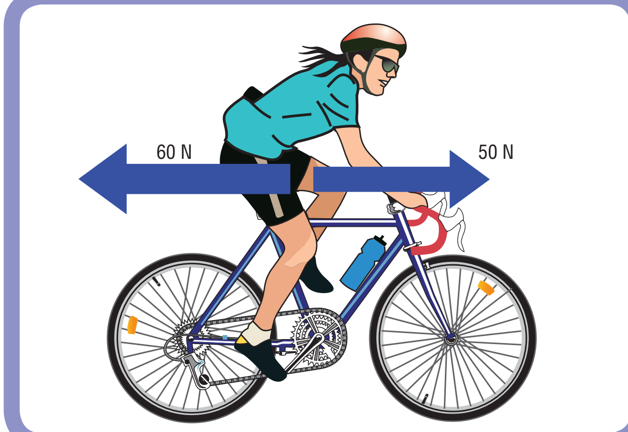


Fig 2.3.1 This bike will accelerate.

In Figure 2.3.1 the bike experiences an unbalanced force of 20 newtons in a forward direction. The bike will therefore accelerate in a forward direction because of the effect of this unbalanced forward force. In Figure 2.3.2, however, you can see that the girl is not pedalling hard enough to overcome all the friction acting on the bike. Because friction is now bigger than the forward force, the unbalanced force acting on the bike is 10 newtons in the opposite direction from the direction that the bike is moving. The bike will therefore not be able to maintain a constant velocity but will decelerate. To **decelerate** means to 'decrease in velocity over time' or simply 'slow down'.

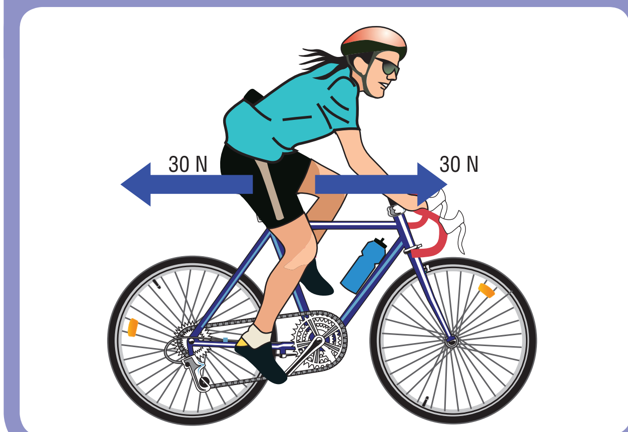
Fig 2.3.2 This bike will decelerate.



What do you think might happen if the girl's forward pedalling force is exactly the same size as the frictional force in the opposite direction? Because the forward and reverse forces balance each other there is no unbalanced force acting on the bike. The bike will not accelerate or decelerate but will continue in a straight line with a constant speed. This is shown in Figure 2.3.3.

Interactive CW Animation

Fig 2.3.3 This bike will continue moving in a straight line at a constant speed.



Friction

In each of the diagrams on page 38 you can see that frictional forces act in the opposite direction to that of movement. The friction in a bike is the result of several factors, the most obvious of which are the result of the moving parts of the bike that are in contact with one another, the friction of the wheels on the ground and the air resistance on the bike and the rider. Friction is also the reason why vehicles can turn corners, as shown in Figure 2.3.4.

Homework book 2.4 All over in 200 milliseconds!

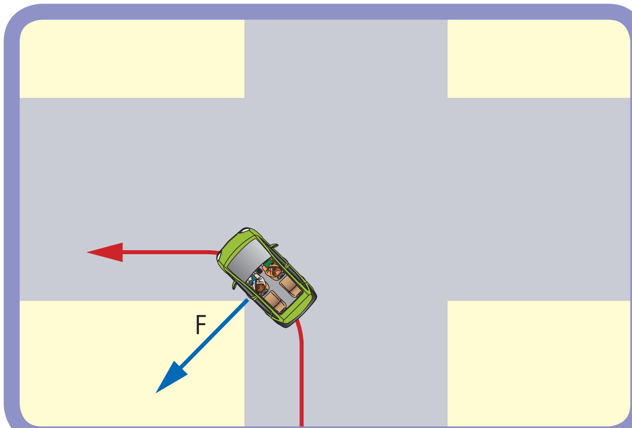


Fig 2.3.4

Because it is no longer travelling in a straight line, an external unbalanced force is acting on a car when it turns a corner. The force to turn the car comes from the friction between the tyres and the road.

Newton's Second Law of Motion

Newton's First Law of Motion predicts that we can change the rest state or uniform motion of a body if we apply an external unbalanced force to it. Newton's Second Law tells us what happens if we apply that force. The Second Law states that:

> An external unbalanced force will cause an object to accelerate in the direction of the force.

Before you can explore this law, you need to know more about acceleration.

Prac 1 p. 43

Acceleration

Acceleration is defined as the rate of change of velocity. It can be calculated using the formula:

$$\text{Acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$$

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

Example 1

A car is parked at a set of traffic lights. Calculate its acceleration if it increases its velocity from 0 m s^{-1} to 16 m s^{-1} in 10 seconds.

$u = 0$ m s^{-1}

$t = 10$

$a = ?$

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

$v = 16$ m s^{-1}

$$a = \frac{16 - 0}{10}$$

$= 1.6$ m s^{-2}

The units for acceleration

Notice in the example above that the unit for acceleration is m s^{-2}. This means metres per second per second. In the example this means that the car changed its velocity by 1.6 m s^{-1} each second. At the end of the first second the car would have reached a velocity of 1.6 m s^{-1}. By the end of the second second, its velocity would be 3.2 m s^{-1}. By the end of the third second of travel it would be travelling at 4.8 m s^{-1} and so on.

Example 2

The car in the above question approaches another set of traffic lights. It reduces its velocity from 22 m s^{-1} to 12 m s^{-1} in 4 s. What is its acceleration?

$u = 22$ m s^{-1}

$v = 12$ m s^{-1}

$t = 4$ s

$a = ?$

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

$$= \frac{12 - 22}{4}$$

$= -2.5$ m s^{-2}

Note: the answer is negative, indicating that the car is not accelerating but decelerating towards the traffic lights. So in each second the car slows by 2.5 m s^{-1}. After two seconds it is going 5 m s^{-1} slower, so it is doing about 17 m s^{-1} at that time.

Calculating final velocity

The formula for acceleration can be rearranged to solve for final velocity. This means that if you are given the acceleration, time and initial velocity you can calculate the final velocity by using:

$$v = u + at$$

Check that you understand how this formula was obtained from the previous one.

Example 3

Find the final velocity of a cyclist travelling at 3 m s^{-1} if she accelerates at 1.2 m s^{-2} for 5 seconds.

$$u = 3 \text{ m s}^{-1}$$
$$t = 5 \text{ s}$$
$$a = 1.2 \text{ m s}^{-2}$$

$$\begin{aligned} v &= u + at \\ &= 3 + (1.2)(5) \\ &= 3 + 6 \\ &= 9 \text{ m s}^{-1} \end{aligned}$$

So the final velocity is 9 metres per second.

Using the Second Law

The Second Law links force and acceleration through the formula:

$$\text{Force} = \text{mass} \times \text{acceleration}$$
$$F = m \times a$$

Force will be in newtons as long as the mass is in kilograms and the acceleration is in metres per second per second.

Example 4

Calculate the size of the force that would cause a 20 kg shopping trolley to accelerate at 2 m s^{-2}.

$$F = ?$$
$$m = 20 \text{ kg}$$
$$a = 2 \text{ m s}^{-2}$$

$$\begin{aligned} F &= m \times a \\ &= (20)(2) \\ &= 40 \text{ newtons} \end{aligned}$$

Remember, you can use a solutions triangle to rearrange this formula to solve for either mass or acceleration.

Science Snippet

Acceleration due to gravity

It seems quite amazing but all objects fall to the Earth with the same acceleration. It does not matter what the mass of a body is. If we ignore the effect of air resistance the acceleration of all objects falling towards the Earth is about 10 m s^{-2} (9.81 m s^{-2} to be more accurate). Some objects will fall more slowly if there is a high surface area and therefore high air resistance. For example, a feather will fall more slowly in air than a ball. But for most objects no difference is observed.

Example 5

What would be the acceleration of a skateboarder and her skateboard if their combined mass of 55 kg was acted on by an accelerating force of 60 N?

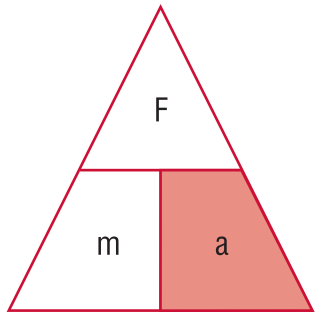


Fig 2.3.5 If solving for 'a' using the solutions triangle, you can see that when you place your finger over the variable to be solved, which is 'a', 'F' becomes the numerator and 'm' becomes the denominator.

$$F = 60 \text{ N}$$
$$m = 55 \text{ kg}$$
$$a = ?$$

$$\begin{aligned} a &= \frac{F}{m} \\ &= \frac{60}{55} \\ &= 1.1 \text{ m s}^{-2} \end{aligned}$$

Calculating gravitational acceleration

You can now combine your knowledge of acceleration and gravity to solve some simple calculations involving freely falling bodies. For instance, your weight is a force that measures the amount by which gravity pulls your mass downwards. To calculate mass simply multiply your mass (in kg) by acceleration due to gravity (9.81 m s^{-2}).

$$\text{Weight} = \text{mass} \times \text{acceleration due to gravity}$$
$$F_{wt} = m \times g$$

Note: this is the same as F = ma, except g has been substituted for a.

Science Snippet

Galileo, the feather and the Moon

An interesting experiment was performed on the Moon by astronaut David Scott. A feather and a hammer were dropped to see which would hit the ground first. A famous Italian scientist Galileo had first proposed the idea (nearly four hundred years before the Moon landing) that all objects should fall at the same rate. The experiment would not work on Earth because of the atmosphere. Scott's experiment clearly showed them hitting the ground at the same time. You may be able to see video of this experiment on the Internet.

Example 6

Calculate Ted's weight if his mass is 72 kg.

$F_{wt} = ?$
$m = 72 \text{ kg}$
$g = 9.81 \text{ m s}^{-2}$

$F_{wt} = m \times g$
$= (72)(9.81)$
$= 706.3 \text{ N}$

Example 7

A worker accidentally drops a 500 g spanner while working on scaffolding on the side of a building. What is the speed of the spanner after it has fallen for 5 seconds? (Hint: it does not matter about the mass of the spanner because in freefall *all* bodies accelerate downwards at 9.81 m s^{-2}.)

$u = 0 \text{ m s}^{-1}$
$t = 5 \text{ s}$
$g = 9.81 \text{ m s}^{-2}$
$v = ?$

$v = u + gt$
$= 0 + (9.81)(5)$
$= 0 + 49.05$
$= 49.05 \text{ m s}^{-1}$

Homework book 2.5 Losing and gaining weight

Prac 1 p. 44

Science Snippet

Terminal velocity

You have read about how all objects will freefall with an acceleration of 9.81 m s^{-2}. This will happen in the absence of friction. Consider what happens when a skydiver jumps out of a plane. The skydiver will accelerate downwards with an acceleration of 9.81 m s^{-2} until air resistance begins to exert a significant upward force on the skydiver. Eventually the upward force of air resistance will match the downward weight force of the diver. When this happens there will no longer be an unbalanced force on the skydiver and the diver will fall downwards at a constant velocity called 'terminal velocity'.

Acceleration graphs

When an accelerating object is graphed showing displacement against time, an upward curving line appears, as in Figure 2.3.6. This shows that the change

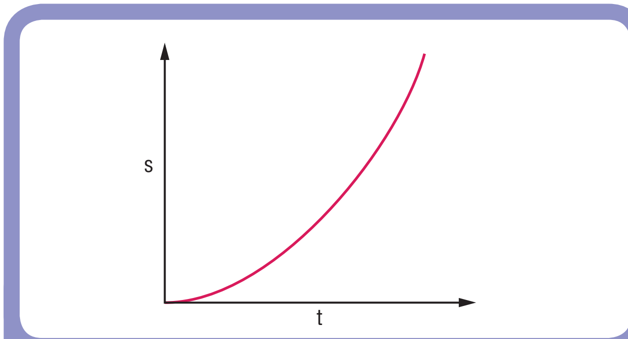
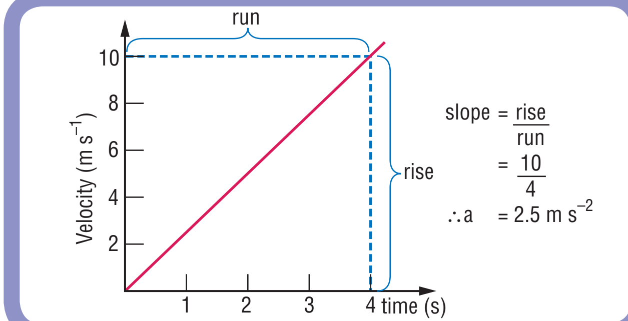


Fig 2.3.6 A curved line that increases in slope over time shows constant acceleration.

in displacement increases as time goes by. The slope of the line becomes greater towards the end and therefore velocity is greater towards the end of the graph. This change in velocity is what we mean by acceleration.

You can graph how an object's velocity changes over time. Figure 2.3.7 shows this for an object that is accelerating at a constant rate. The slope of a velocity–time graph gives the acceleration.

On a velocity–time graph, the slope of the line indicates the acceleration of the vehicle. *Fig 2.3.7*



Consider the three graphs in Figure 2.3.8. These show an object that is not accelerating, and two that are. The steeper the slope, the greater the acceleration.

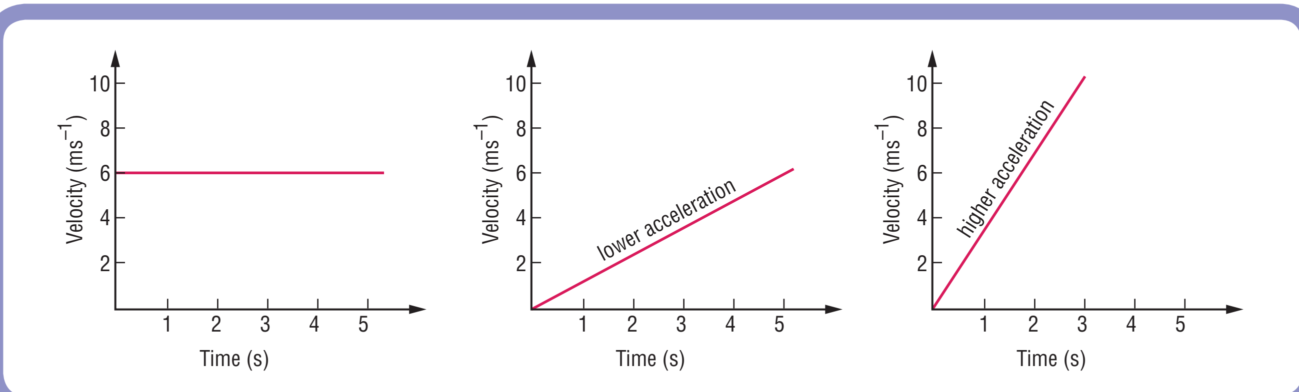


Fig 2.3.8 Velocity–time graphs showing no acceleration (constant velocity), low acceleration and higher acceleration

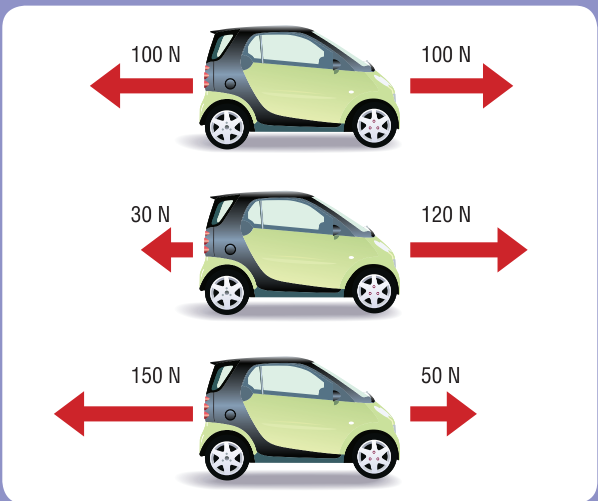
2.3 FOCUS [Questions]

Use your book

Unbalanced forces

1 Give the magnitude and direction of the unbalanced force in each of the diagrams in Figure 2.3.9.

Fig 2.3.9 Diagram for question 1



2 What produces the force that helps you to run around in a circle? In which direction does the force act?

3 Which forces cancel each other on the diagram in Figure 2.3.10? What will be the effect of the combination of forces on the motion of this aircraft? Hint: look at the size of each arrow.

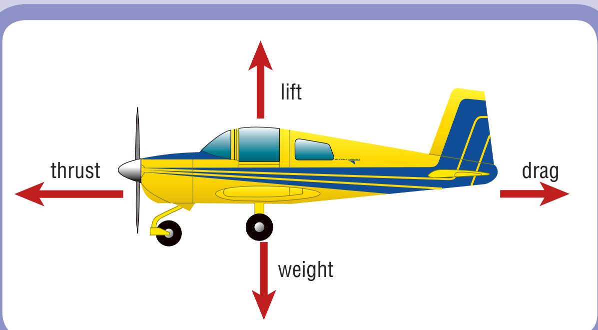


Diagram for question 3 *Fig 2.3.10*

Acceleration

4 A mini racer at a carnival is known to be able to increase its velocity from 16 m/s to 25 m/s in 4 s. What is its acceleration?

5 Calculate the acceleration of a car with a mass of 1 tonne (1000 kg) if it changes speed from 65 km/h to rest uniformly in 5 seconds? (Hint: Remember to convert the unit of velocity from km/h to m/s.)

6 By paying attention to his bike's speedometer as he practises for a bike race, Charles knows that he can accelerate from 10 km/h to 20 km/h in 6 seconds. What is Charles' acceleration?

7 A girl on a scooter travels at a constant 16 m s^{-1}. Calculate the final velocity of the scooter if she accelerates at 1.5 m s^{-2} for 6 s.

Using the Second Law

8 A skateboarder pushes his back foot off on the ground and applies a force of 75 N. If the total mass of the skateboarder and skateboard is 75 kg, what will be the acceleration of the skateboarder?

Calculating gravitational acceleration

9 Draw a table to record the mass and weight of you and the members of three other students in your class. Measure each person's mass and then complete the table.

10 Calculate the speed of a bungee jumper 5 seconds after jumping off a bridge (ignore the effects of air resistance in your calculation).

11 What is terminal velocity and when is it achieved?

Acceleration graphs

12 Calculate the acceleration of the vehicle from the graph in Figure 2.3.11.

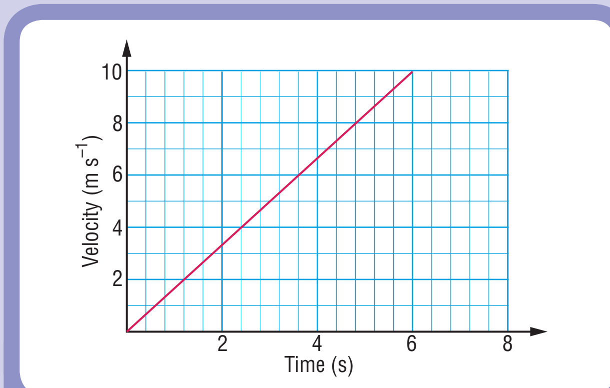
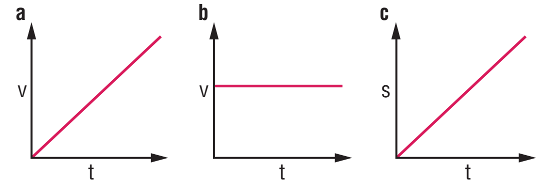


Fig 2.3.11 Graph for question 12

13 The graphs in Figure 2.3.12 were drawn after data was collected from the motion of a moving vehicle. Which graphs represent accelerations?

Graphs for question 13 *Fig 2.3.12*



Use your head

14 What are some of the causes of friction in a bicycle?

15 A car mechanic is checking the steering and braking of a car. He notices that when he brakes suddenly he feels as though he is thrown forwards but slightly sideways. He concludes that the brakes or steering need adjustment. Explain why he could have concluded this in terms of the physics you have learnt in this Focus.

16 The unit of acceleration is metres per second per second (m s^{-2}). Explain what this unit means.

17 Why does air resistance stop a body in freefall on Earth from accelerating at a constant 9.81 m s^{-2}.

18 A friend of yours tells you that her weight is 55 kg. What is wrong with your friend's comment?

Investigating questions

19 Investigate the different types of drag involved in an aircraft in flight. How do wind tunnels help engineers to understand the drag on a moving aircraft, and what do aircraft designers do to reduce the amount of drag on a moving aircraft?

20 Design an experiment to test whether different objects dropped at the same time hit the ground at the same time. Your method has to show clearly that the objects are dropped at exactly the same time and fall the same distance. Detecting when they hit is also important in your design. Try out your experiment with your teacher's permission.

DYO

21 NASA has a wonderful website called Glenn Learning Technologies Project (LTP). There are activities on Newton's Laws. Go to the *Science Aspects 4* Companion Website at **www.pearsoned.com.au/schools** for a link to the 'Newton Car' activity.

Web Destinations

2·3 FOCUS [Practical activities]

Building an accelerometer

Prac 1 Focus 2.3

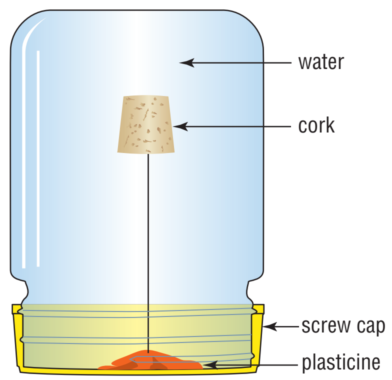
Purpose

To investigate how an accelerometer is able to indicate the direction of an accelerating force.

Requirements

Cork, string, plastic jar or bottle with lid, plasticine, dynamics trolley or similar.

An accelerometer *Fig 2.3.13*



Procedure

1 Set up the apparatus to construct the accelerometer as shown in Figure 2.3.13.

2 Attach the accelerometer to a trolley and observe what happens as the trolley accelerates. You could let the trolley roll down a slope onto a level surface.

3 Make a note of what happens to the cork as the accelerometer accelerates, and what happens as it decelerates.

4 Stand at one end of a long bench and see if you can keep the accelerometer moving at a constant speed for some period of time by pushing it.

Questions

1 What happened to the cork as the accelerometer accelerated? Is this what you would have predicted would happen?

2 What happened to the cork as the accelerometer decelerated? Is this what you would have predicted would happen?

>>

3 What happened to the cork as the accelerometer moved at a constant speed? Is this what you would have predicted would happen?

4 Try to explain your observations in questions 1, 2 and 3 by using the ideas from this Focus and the previous Focus.

Prac 2
Focus 2.3

Measuring 'g'

Purpose

To measure acceleration due to gravity, g.

Requirements

Brass weights, ticker tape timer and ticker tape, adhesive tape, retort stand and clamp.

Procedure

1 Set up the apparatus as shown in Figure 2.3.14 with the ticker tape timer clamped edge down to a retort stand on the bench, held against a door or similar so that the 50 g mass can fall at least 1 metre.

2 Start the timer and then allow the brass mass to fall, pulling ticker tape through the timer. The brass mass must fall unobstructed for at least 1 metre.

3 Lay the 1 metre length of ticker tape flat on your desk.

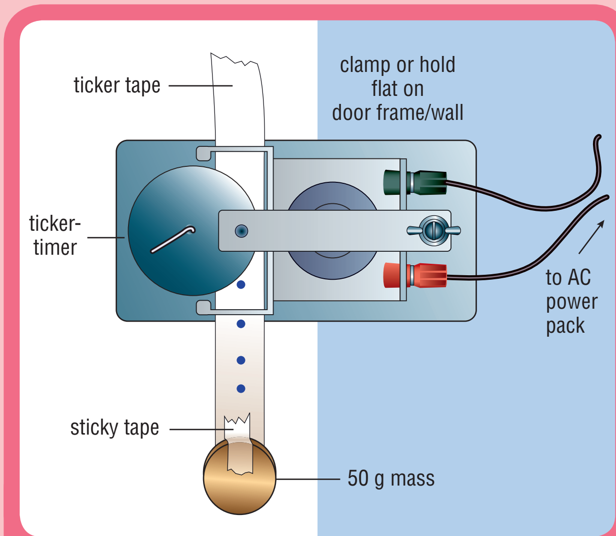


Fig 2.3.14 Ticker tape timer set-up for measuring g

4 Pick a dot close to the beginning of the ticker tape run and *draw a line through it. Draw another line through the second dot from this one as shown in Figure 2.3.15.*

5 Repeat step 4 for a sequence of dots close to the end of the run so that you end up with tape looking like Figure 2.3.15.

6 Measure the distance between the three dots at the beginning and end of the tape and *label each distance S1 and S2 as shown in Figure 2.3.15.*

7 Because it takes $^{1}/_{50}$ (0.02) seconds to make two dots on ticker tape (refer back to Prac 1 in Focus 2.1 if you need a reminder about the ticker tape timer), the time needed to make three dots must be $^{2}/_{50}$ (0.04) seconds. This means that the first three dots you have marked took 0.04 s and the last three dots also took 0.04 s to make.

8 Calculate the initial velocity of the brass mass:

initial velocity (u) = $^{S1}/_{0.04}$

and the final velocity of the brass mass:

final velocity (v) = $^{S2}/_{0.04}$

9 Count the number of spaces between the middle dot of S1 and the middle dot of S2. Convert this to time as shown in step 7. Call this time (t).

10 Calculate the acceleration of the brass mass as it fell by applying the formula $g = \frac{v - u}{t}$.

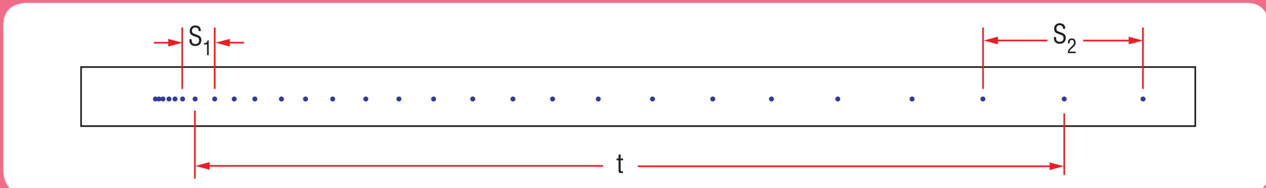
Questions

1 Compare the value of g you have calculated with the value of g discussed in this Focus. Is your calculated value larger or smaller? Why?

2 Give reasons why there may be a difference between your calculated value for g and the actual value for g.

3 How could you improve this experiment to allow you to get a more accurate value for g?

Full section of tape *Fig 2.3.15*



FOCUS 2.4

Newton's Third Law of Motion

Context

Have you ever sat on a revolving chair and tried to push someone standing on the ground? You may have been roller-skating and pushed on a friend while you were standing still on your skates. If you have, you will have felt yourself move, as well as the person you pushed. These situations can be explained by Newton's Third Law of Motion—and so can rockets, jet engines and walking.

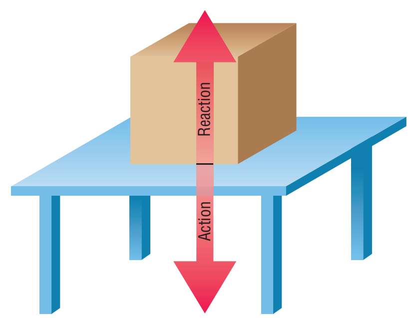
Actions and reactions

Consider a box sitting on a table as shown in Figure 2.4.1. The box is not accelerating up, down or to the side. It is at rest. Now remember what you learnt in the last two Foci. If an object is at rest there cannot be any unbalanced forces acting on it. If the box is exerting a force on the table that is equal to its weight, the table must be exerting the same sized force (but in the opposite direction) back on the base of the box. We will call the force the box exerts on the table the **action**. The force the table exerts back on the box is the **reaction**.

Newton's Third Law of Motion is:

> For every action there is an equal and opposite reaction.

Fig 2.4.1 Action–reaction of a box on table



Newton's Third Law applies to many situations in everyday life. Some of these can be seen in Figures 2.4.2 to 2.4.5. Look through these figures now and try to identify where the action and reaction should appear on the diagram. Then read on to the next paragraph, which explains what is happening in each diagram.

When you catch a ball, the force that you exert in stopping the ball is equal to the force that the ball exerts on you. This is why catching a cricket ball can sometimes be painful. The girl is able to walk because friction allows her to push backwards on the ground. The ground in turn pushes back on her feet, by the same force but in the opposite direction. When a car tyre turns it produces a backward force on the road. The road then provides a force in a forward direction.

Swimming involves pushing backwards on the water, which in turn provides a forward force onto the swimmer.

Prac 1 p. 48

Homework book 2.6 Newton's astronaut

Science Snippet

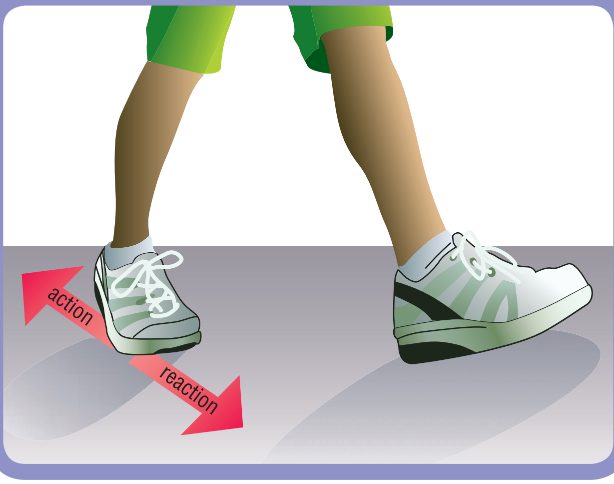
Space walking

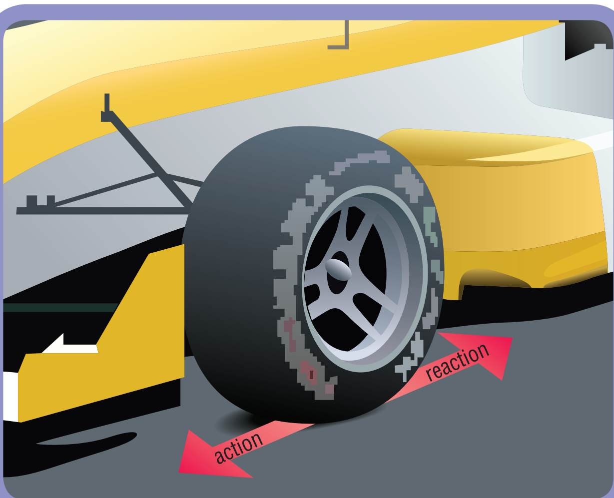
If you were in space and away from a space ship, when you moved your arms or legs you would actually create very little movement in any direction because in space there is actually nothing to 'push' against.

Fig 2.4.2 The action the ball exerts on the boy's hand is equal to his hand's reaction on the ball.

The pushing action on the ground is equal to the ground's reaction back on the girl's feet.

Fig 2.4.3





The action of the tyre on the road is equal to the reaction of the road back on the tyre.

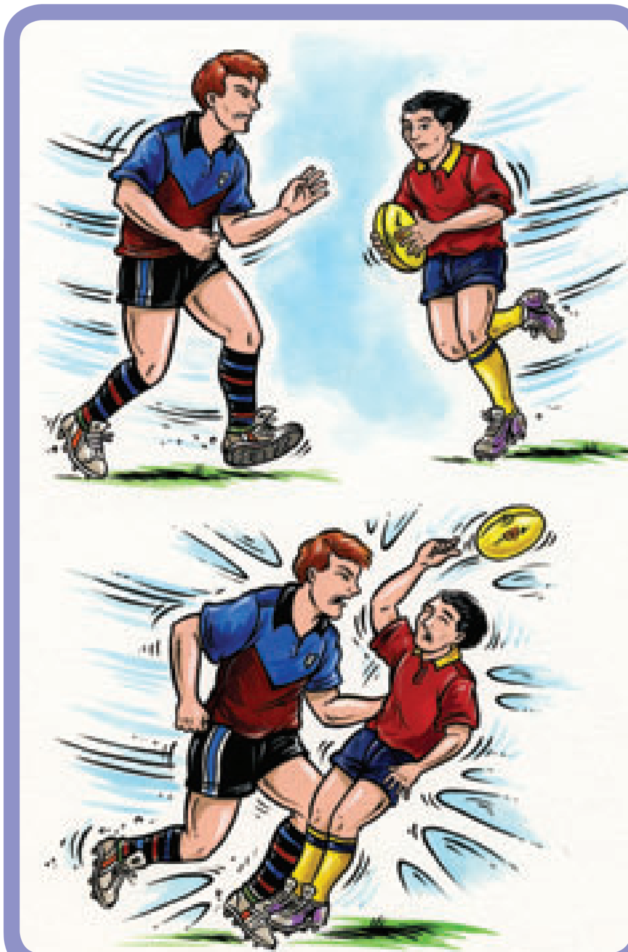
Fig 2.4.4

Fig 2.4.5

The action of the swimmer pushing against the water is equal to the reaction of the water back on the swimmer.

A question of size

Imagine that two football players are running towards one another. One of them is very massive, while the other is not.



A collision between large and small objects

Fig 2.4.6

Because the action on one is equal to the reaction of the other, each player exerts the same force on the other. The equation below shows the more massive player is accelerated a smaller amount while the less massive player is accelerated a larger amount. So the smaller object seems to be bumped away faster and further.

$$\text{Force (more massive player)} = \text{force (less massive player)}$$

$$\text{Large mass} \times \text{smaller acceleration} = \text{small mass} \times \text{larger acceleration}$$

$$m \times a = m \times a$$

Rockets and jets

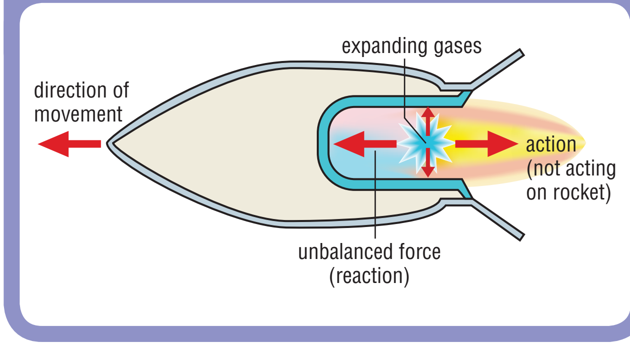
In Figure 2.4.8 you can see the chamber in the rocket where the chemical reaction occurs. As the fuel burns, the expanding gas pushes in all directions in the reaction chamber. Because there is an exhaust outlet, a stream of hot gas can escape from the chamber. You can see that the gas that escapes is not pushing backwards on any part of the rocket. You can consider this the 'action'. However, there is an unbalanced force in the chamber because there is a push by the gases on the rocket forwards. It is this unbalanced force that pushes the rocket forwards. This can be considered the 'reaction'. This forward push is called **thrust**. Think of this as an example of the Third Law. The action is the escaping exhaust gases and the reaction is the forward thrust.

Fig 2.4.7 The space shuttle is an excellent example of Newton's Third Law.

The backward forces produced by the gases equals the forward force on the rocket. Because the mass of gas exhaust is very small compared to the mass of the space shuttle, it accelerates backwards at a very high velocity, whereas the space shuttle has a very big mass but accelerates at a relatively smaller velocity.

Jet engines work in a similar way to rocket engines. The blades of the jet engine rotate very fast and suck air into the combustion chamber of the engine. All this air helps the fuel inside the engine to burn very fast and very hot. The hot gases produced in the combustion chamber are under high pressure and leave the back of the engine at a very high speed. The force of these gases moving backwards is equal to the forward force on the jet engine but because the forces are unbalanced in their action on the engine, the plane is pushed forwards.

Fig 2.4.8 The exhaust leaving the rocket creates an unbalanced forwards force in the rocket.



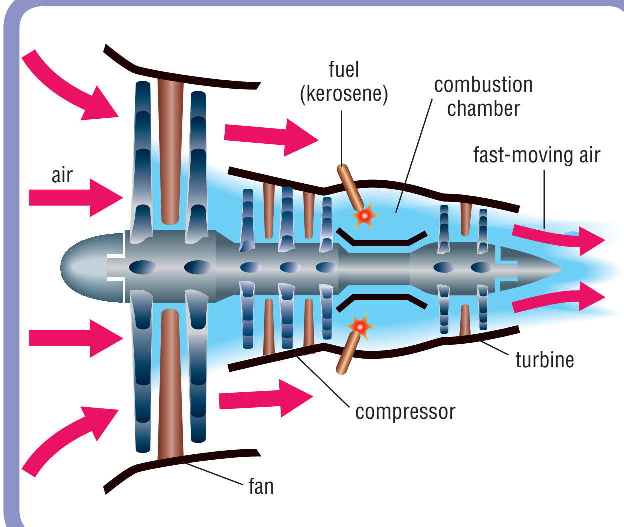
Science Snippet

Natural jets

Octopus and squid use a form of jet propulsion to move through the water. Water is sucked into special bladders, which are then forced out under pressure, propelling the animal rapidly through the water.

Prac 2 p. 49

A jet engine Fig 2.4.9



2·4 FOCUS [Questions]

Use your book

Actions and reactions

1. State Newton's Third Law of Motion.
2. List three pairs of action and reaction forces.
3. Do a quick sketch of a swimmer, like in Figure 2.4.5. On your sketch show the direction of the action force and the reaction force.
4. Use Newton's Third Law to explain how a rocket lifts off.

A question of size

5. Explain why, when two balls that are identical in composition but have different masses collide, the smaller mass ball bounces off faster.

Rockets and jets

6. Explain why there is a forward force on a rocket.

Use your head

7. Explain why a rifle recoils backwards when fired.
8. Which travels at the higher velocity when a rifle is fired, the bullet in a forward direction or the rifle backwards? Explain your answer.
9. Use Newton's Third Law to explain why it is sometimes very difficult to walk on slippery ice.
10. Why do you think that a rocket would accelerate as it uses up more and more fuel? Use one of Newton's Laws to help you.
11. Explain why a balloon that is filled with air 'takes off like a rocket' when it is let go.

Investigating questions

12. NASA has a website called Glenn Learning Technologies Project (LTP). There are activities on Newton's Laws. Go to the *Science Aspects 4* Companion Website at **www.pearsoned.com.au/schools** for a link to the 'Rocket pinwheel' activity.
13. Conduct an Internet search on the development of the jet engine and liquid fuel rocket.
14. Write a brief article on Werner Von Braun and his contribution to space travel.

DYO

2·4 FOCUS [Practical activities]

Prac 1 Focus 2.4

Testing reaction

Purpose

To find out whether or not a table produces a reaction force.

Requirements

Some heavy textbooks.

Procedure

1. Pick a strong volunteer.
2. Get them to extend their left arm outwards so that their elbow is not bent and their arm is perpendicular to their body. They are to turn the palm of this hand upwards.
3. Place three textbooks on the palm of their outstretched arm. Tell them to keep their arm straight and perpendicular to their bodies at all times. Observe carefully their reaction, and ask them how they feel. *Note this down.*
4. After one minute place another two textbooks on their palm. Observe carefully their reaction, and ask them how they feel. *Note this down.*
5. After another minute allow the volunteer to put their arm down.

Questions

1. Did the subject report feeling a downward force on their palm?
2. What did the subject say they had to do to keep the book at rest (not moving up or down)?
3. What did the subject say they had to do to when extra books were added?
4. Do you believe that a table exerts a reaction force on an object on it?
5. Does the reaction force change as more mass is added?

Prac 2
Focus 2.4

Water rockets

Purpose

To build a water rocket.

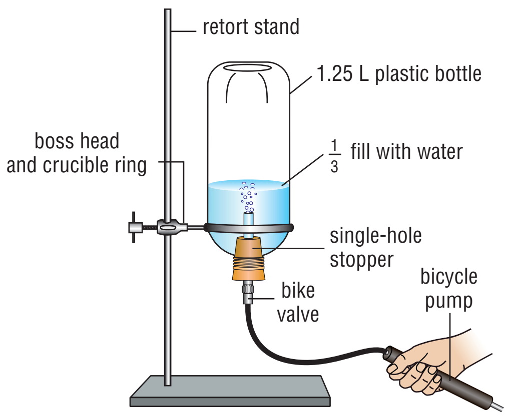
Requirements

1.25 L plastic cool-drink bottle, single-hole stopper to fit the nozzle of the bottle, bike valve (must form tight fit in stopper), retort stand, crucible ring or filter funnel stand, boss head, air pump or bicycle pump.

Procedure

1. Set up the apparatus as shown in Figure 2.4.10, or a design agreed to by your teacher. You can add fins to the rocket for better stability if you manage to make it fly quite high.

A water rocket *Fig 2.4.10*



Note that the cool-drink bottle must not be held by the retort clamp. It must just be resting on the clamp. A laboratory crucible ring or filter funnel stand is better than a clamp for this so that the bottle can rest on the ring.

SAFETY NOTE: Stand well back from the rocket while you are pumping it as it can take off suddenly and quite fast. Do not lean over it while you are pumping.

2. When you are ready, start pumping air into the bottle using the pump. If you are using a bike pump, wear clothes that you don't mind getting dirty and ensure that you wear safety glasses.
3. If the rocket is not working well, try different amounts of water and slightly tighter fits between the valve and the stopper to see if it will go higher.

Questions

1. Explain why the rocket takes off. Use the information in this Focus and relate your answer to Newton's Third Law of Motion.
2. If your teacher agrees, you could design an investigation to determine how the altitude reached changes as the amount of water in the rocket is varied.

DYO

FOCUS 2.5 Stability and equilibrium

Context

In the last few Foci you learnt about how forces, if balanced, can cause an object to remain in a state of rest or straight-line motion. Ensuring that forces are balanced is very important to people who design and build structures such as houses and bridges, because if the forces in structures like these are not balanced, those structures will fall down.

Centre of gravity

In order to analyse the ideas of balance, stability and equilibrium, all of which are central to the design of buildings and other structures, you need to learn a little about how a body's weight is distributed. Remember, weight is the attraction of a mass towards the Earth. Take the simple example of a metre rule suspended at the 50 centimetre mark. Every point of the ruler has mass and is therefore attracted towards the Earth, as shown on the diagram in Figure 2.5.1.

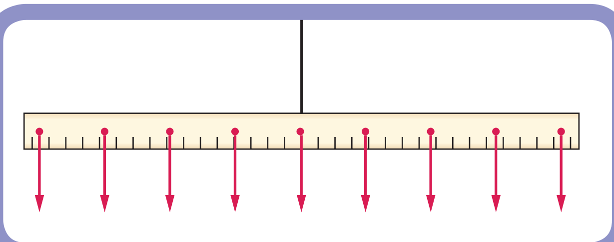


Fig 2.5.1 Each point of the ruler has weight and is attracted towards the Earth.

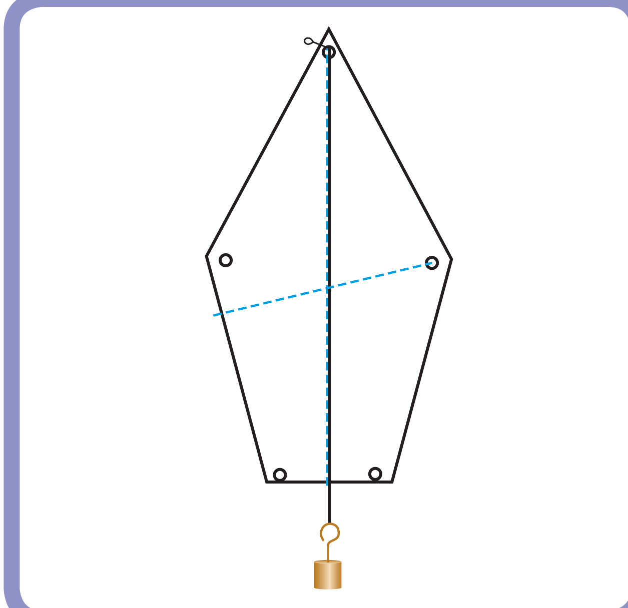
Because the ruler is a simple shape (uniform), you can consider the entire weight of the ruler to act through its centre. This is called the centre of gravity. Notice that the ruler balances as shown in Figure 2.5.1 because it is tied to a string and suspended from its centre of gravity. Do you think that the ruler would balance if it were tied to the 30 centimetre or 70 centimetre mark? The **centre of gravity** of an object is the point through which the weight of the object can be considered to be acting.

Prac 1 p. 55

The position of the centre of gravity of an object depends on the shape of the object. For simplicity, consider some simple two-dimensional shapes, like the shapes that you can cut out of a piece of paper. To find the centre of gravity of a two-dimensional shape, just cut the shape out of stiff cardboard and make several holes (using a nail or a hole punch, for instance) along the edge of the shape. Now, if you allow the shape to hang from a nail through one of the holes, the centre of gravity will lie at some point on a vertical line directly under the nail. You can use some string and a brass weight to indicate this vertical line, which can be marked out by pencil. This is called a **plumb line**.

If you repeat this process again you will find that two plumb lines will intersect at a point. If you draw a third plumb line, it also will intersect at this same point. This point is the centre of gravity of the shape. You can repeat this procedure a number of times to check that the vertical lines for any particular shape will always intersect at the same point. Keep in mind though that some unusual shapes, such as a metal washer, have their centre of gravity outside the shape itself. What you have found so far in this Focus is that when you suspend an object from a point, the centre of gravity always falls below the point of suspension.

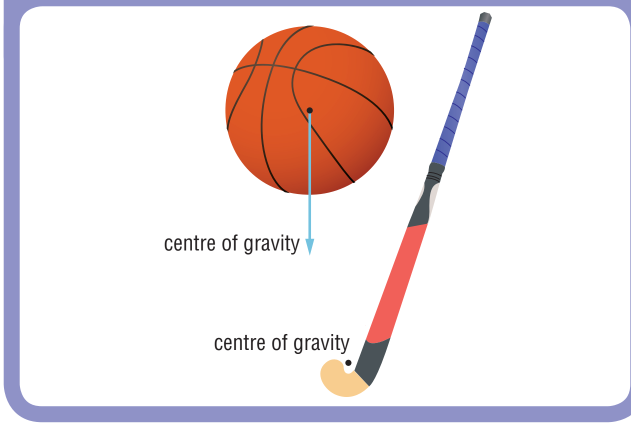
The centre of gravity is the point of intersection. *Fig 2.5.2*



The centre of gravity of everyday objects

For symmetrical objects the centre of gravity is generally through the centre of the object. Non-symmetrical objects have centres of gravity that can be more difficult to predict. Compare the two objects in Figure 2.5.3.

Fig 2.5.3 Compare the positions of the centre of gravity in these two objects.



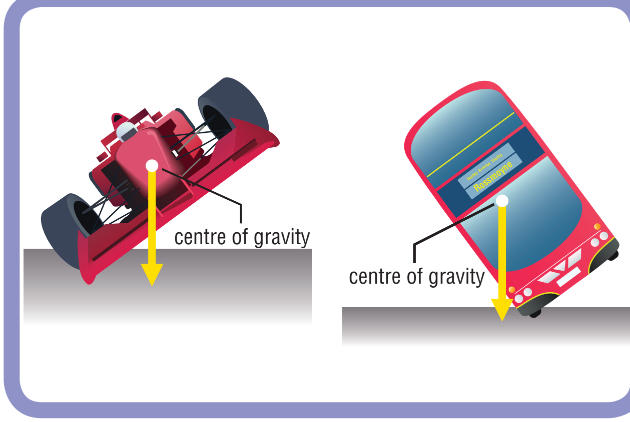
Compare the large truck and the racing car in Figure 2.5.5. You can see the centre of gravity of the truck lies outside the wheel base on the road. This truck can topple over. The racing car will not fall over because the centre of gravity lies inside its wheel base.

As a general rule, objects that are more stable have:

a a low centre of gravity

b a wide base of support.

Which of these two vehicles is more stable? Fig 2.5.5



Stability

What do you think is meant by the term 'stable'? Discuss the meaning with your other group members. Look at the pictures in Figure 2.5.4 and decide which of the objects are stable.

You probably have a sense as to what stability means even though you might find it difficult to put into words. Something is stable if its centre of gravity falls inside its base. If its centre of gravity is outside its base then the object will fall over.

Science Snippet

Can't stand, can't stand up!

Stand up straight with your legs about as far apart as they normally would be when you are standing. Now try lifting one leg sideways off the ground without shifting your weight. You can't, can you? This is because the plumb line from your centre of gravity, which passes between your feet, would not be supported and you would fall over. Now sit in your chair. Try getting up without leaning forwards first. You must keep your back vertical and your feet together. Why can't you do it?

Equilibrium

Consider some of the situations you have learnt about in the last few Foci that involve objects and vehicles for which all forces are balanced. Remember, if all forces acting in opposite directions are balanced, the rest state or constant motion in a straight line will be maintained. There will not be a change in their motion, such as accelerating, decelerating or changing direction, because all opposite forces balance. This situation is called equilibrium. **Equilibrium** is another word for balance, and balance means that the situation is stable, or unchanging.

Fig 2.5.4 Which of these objects is the most stable and why?

There are two conditions necessary for an object to be in equilibrium.

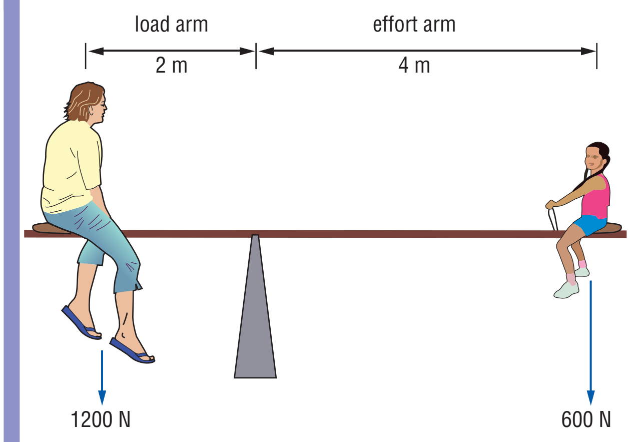
1 The sum of all forces in one direction must equal the sum of all forces in the opposite direction.
2 The sum of the clockwise moments must equal the sum of the anticlockwise moments.

Moments

To clarify the second condition for equilibrium, which is called the **principle of moments**, consider the situations depicted in Figure 2.5.6. Each pair of pictures illustrates a job that needs to be done. Decide whether you would choose the tool provided in Picture 1 or the tool provided in Picture 2 to do the job.

If you nominated Picture 1 for Situation 1 and Picture 2 for Situation 2 you are on the right track (see page 53 for clarification of this). The hammer and the stick in Figure 2.5.6 are called **simple machines**. They are both examples of the simple machine called a **lever**. The seesaw in Figure 2.5.7 is also a lever.

Fig 2.5.7 In this lever the child is much lighter than the adult but is still able to balance the seesaw because she sits further along the arm of the seesaw.



SITUATION 1: Using a claw hammer to remove a nail from a piece of timber

Picture 1

Picture 2

SITUATION 2: Applying a lever to move a heavy rock

Picture 1

Picture 2

Fig 2.5.6 Choosing the right tool

It can be considered to consist of two arms (an **effort arm** and a **load arm**). Each arm rotates about a pivot, which can also be called the **fulcrum** or turning point.

Notice that in Figure 2.5.8 the larger adult sitting on the left-hand arm of the seesaw tends to turn the load arm of the lever into an anticlockwise rotation, while the lighter girl tends to turn the effort arm of the lever into a clockwise rotation.

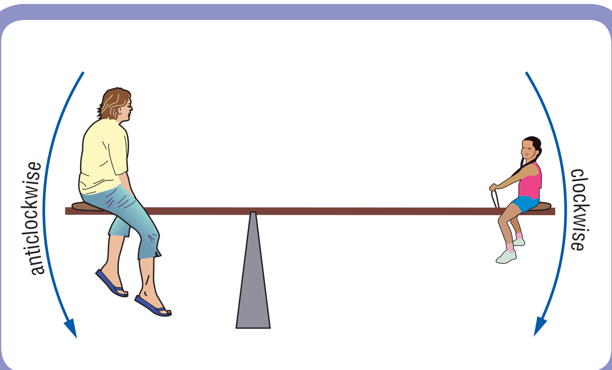


Fig 2.5.8 The turning effect about a fulcrum

A **moment** in physics is described as the product of a perpendicular force and the distance to the turning point. Moments can also be called **torque** or **turning effect**.

$$\text{Moment} = \text{perpendicular force} \times \text{distance to turning point}$$

$$M = F \times r$$

Look back at Figure 2.5.7. If you use the formula above:

To find the clockwise moment

$$M = F \times r$$
$$= 600 \times 4$$
$$= 2400 \text{ N m}$$

To find the anticlockwise moment

$$M = F \times r$$
$$= 1200 \times 2$$
$$= 2400 \text{ N m}$$

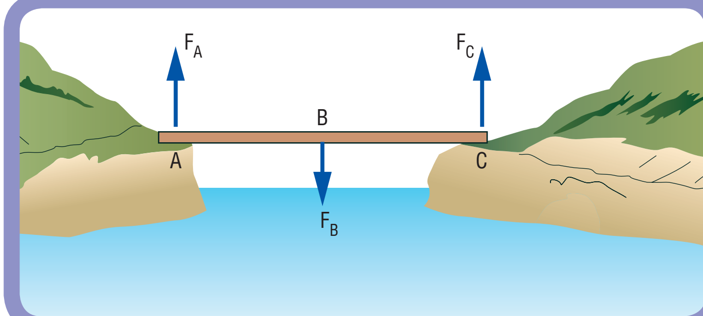
Notice that the two moments are equal. The moment produced on the left-hand side of the lever by the adult is equal to the moment produced on the right-hand side of the lever by the lighter girl. The seesaw is therefore balanced or in equilibrium.

Homework book 2.7 Moved by the moment

Using moments to solve a problem

The idea of clockwise and anti clockwise moments being equal is also called the **principle of moments** and is very important to the work of a structural engineer. Consider Figure 2.5.9. The reason that this bridge stays up is that the two embankments A and C provide upwards forces, while the weight of the bridge through its centre of mass acts downwards at B. It is very important for engineers to know what sort of upward forces will be required to support the bridge. To do this they can use the principle of moments. Imagine for a moment that the right hand embankment was invisible, like in Figure 2.5.10. You can now see that the rest of the bridge system is like a lever with the turning point (fulcrum) at the left-hand embankment. The force at C provides an anticlockwise moment and the weight of the bridge provides a clockwise moment.

A bridge spanning a gap showing the forces acting *Fig 2.5.9*



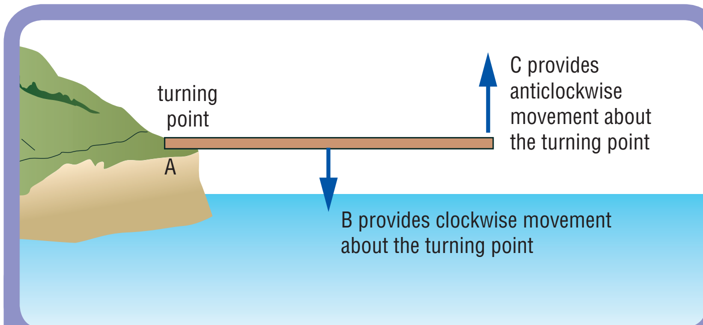


Fig 2.5.10 Considering moments for a bridge

In Figure 2.5.10 if you take A as your turning point then:

Sum of the clockwise moments about A = sum of the anticlockwise moments about A

$$F_B \times r_{AB} = F_C \times r_{AC}$$

$$F_C = \frac{F_B \times r_{AB}}{r_{AC}}$$

The engineer can now apply the first condition of equilibrium to find the support required at the other end of the bridge. Because the bridge is at rest, the sum of all the forces up must equal the sum of all the forces down. So:

Sum of all forces up = sum of all forces down

$$F_A + F_C = F_B$$
$$F_A = F_B - F_C$$

Prac 2 p. 55

Homework book 2.8 Ground force

Drag and Drop CW Interactive

2.5 FOCUS [Questions]

Use your book

Centre of gravity

1 What is the centre of gravity of an object?

2 Briefly describe how the centre of gravity of an object can be found.

Stability

3 Define the term 'stability'.

4 When does an object become unstable?

5 When you are standing why can't you lift one foot off the ground without shifting the position of your centre of gravity?

6 What are two characteristics of stable objects?

7 Give a possible reason why formula 1 racing cars are built low to the ground with the wheels wide apart.

Equilibrium

8 What is meant by the term 'equilibrium'?

9 What are the two conditions for equilibrium?

10 What is the principle of moments?

11 How do you calculate the moment of a force?

Use your head

12 What kind of adjustments do you have to make to the position of your centre of gravity when walking?

13 How do your arms assist you when you are walking and running?

14 Why is it not possible to get out of a chair without moving forwards first?

15 When using a spanner to loosen a stubborn nut, why would you prefer to use a spanner with a longer handle?

16 Calculate the moment of the force provided by the girl in lifting the heavy rock shown in Figure 2.5.11.

Diagram for question 16 *Fig 2.5.11*

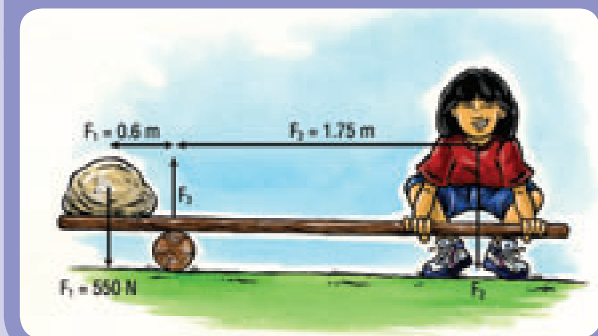
17 Consider Figure 2.5.12, where a lever is being pushed down to support the rock while keeping the lever horizontal.

Calculate:

a the force needed to keep the lever and load balanced in this way

b the reaction force of the fulcrum back on the lever.

Fig 2.5.12 Diagram for question 17



Investigating question

18 Design and carry out an investigation of a lever to find how the effort changes (for a constant load and load arm) when the length of the effort arm increases. Write a report showing your data and your conclusion.

DYO

2·5 FOCUS [Practical activities]

Prac 1 Focus 2.5

All torque

Purpose

To investigate moments (or torque).

Requirements

Cotton thread, metre ruler, plasticine, electronic or triple beam balance.

Procedure

Part A

1. Make a loop in a piece of cotton thread that fits snugly over a ruler.
2. Find the point at which the ruler can be suspended from the string so that it is perfectly horizontal.
3. Take a small pieces of plasticine about the size of a 5 cent piece and stick it on one end of the ruler.
4. Adjust the position of the string so that the ruler just balances again. What do you observe?

Part B

5. Position the cotton at the 50 cm mark of the ruler. Use a small piece of plasticine stuck to one side of the ruler to ensure that both sides balance again.
6. Use the electronic or triple beam balance to measure out a 10 g piece of plasticine. Stick this piece onto the 70 cm mark of the ruler. What happens to the ruler?
7. Use the balance to measure out a 5 g piece of plasticine. Estimate where this piece would have to be placed to balance the ruler again. Now find that position.

Questions

1. What happened to the position of the string required to balance the ruler after the first piece of plasticine was stuck to the end of the ruler? Draw a diagram of the ruler, cotton and plasticine to illustrate this final position.
2. When the ruler was balanced at the 50 cm mark, could you predict the position that a 5 g piece of plasticine would have to be placed in order to balance the 10 g piece of plasticine at the 70 cm mark?
3. What was this final position?
4. Explain why the ruler balanced in this way.
5. How does this investigation relate to torque?

Prac 2 Focus 2.5

DYO

Solved in a moment

Purpose

To design and carry out an investigation that will check the formula:

$$F_C = \frac{F_B \times r_{AB}}{r_{AC}}$$

by measuring the force (F_C).

Requirements

Some equipment that may help you is a spring balance, a metre rule or similar piece of wood (for the bridge), a set of slotted masses in a holder (to give the bridge a large mass).

Procedure

In discussing Fig 2.5.10 a formula was derived, which was:

$$F_C = \frac{F_B \times r_{AB}}{r_{AC}}$$

Design and carry out an investigation that will check this formula by measuring the force (F_C). Submit your plan for the investigation to your teacher to check before starting the Prac. Write a report of your findings, presenting your data and conclusion.

FOCUS 2·6

Transferring mechanical energy

Context

In Focus 2.3 you learnt that equations could be used to describe the acceleration of bodies in relation to Newton's Second Law of Motion. You learnt how to modify those equations to describe the motion of bodies falling with an acceleration of 9.81 ms^{-2}. In this Focus you will see how the concepts of kinetic and potential energy can help you to understand the motion of bodies in freefall.

Reviewing work, energy and power

In previous Foci you learnt that:

- when work is done, energy is used
- the total amount of work done is equal to the amount of energy expended
- work and energy are measured in units of joules
- work is calculated by multiplying the force exerted by the distance that an object moves in the direction of the force ($W = F \times s$)
- power is a measure of how quickly work is done ($P = {}^{W}/_{t}$).

Example 1

Calculate the work done by Jae if she applies a force of 75 newtons to move a shopping trolley a distance of 50 metres.

Fig 2.6.1 Moving a trolley with a force of 75 N

$$F = 75\text{ N}$$
$$s = 50\text{ m}$$
$$W = ?$$

$$\begin{aligned} W &= F \times s \\ &= 75 \times 50 \\ &= 3750\text{ joules} \end{aligned}$$

Because Jae has done 3750 joules of work on the trolley she has used up 3750 joules of energy.

Remember, in order for work to be done a force must move the body it is acting on in the direction of the force. In Figure 2.6.2, no work is being done because the wall is not being moved.

Fig 2.6.2 As the wall is not moving, the boy is not doing any work on the wall. He may be using energy but he is not doing work on the wall.

Example 2

How much power did Jae consume if she pushed the trolley the 50 m in 45 seconds?

$W = 3750\text{ J}$

$t = 45\text{ s}$

$P = ?$

$$P = \frac{W}{t}$$

$$= \frac{3750}{54}$$

$$= 83.33\text{ watts}$$

Review of kinetic and potential energy

Kinetic energy

Energy stored in moving objects such as basketballs, people, cars, aircraft and even electrons is called **kinetic energy**. In order to be able to store kinetic energy a body must have mass (m) and speed (v).

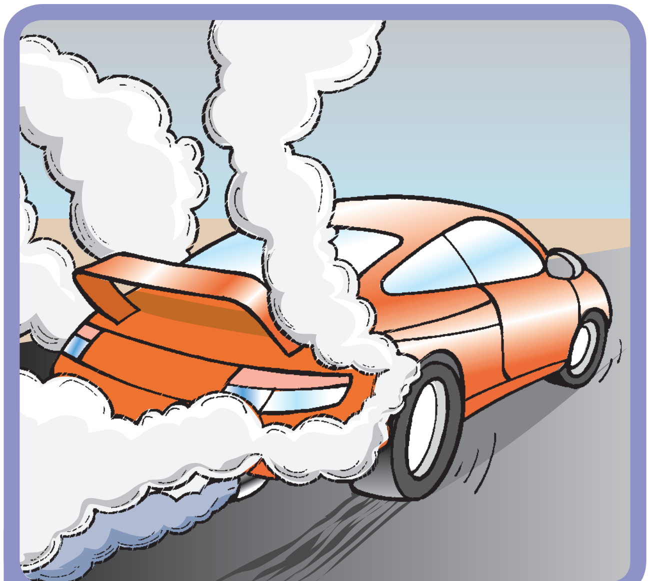


Fig 2.6.3 There is much kinetic energy stored in a moving vehicle.

To calculate the amount of kinetic energy you can apply the formula:

$$E_k = \frac{1}{2}\,m\,v^2$$

In this formula:

- m is the mass of the object in kilograms (kg)
- v is the speed of the object in metres per second ($m\ s^{-1}$)
- E_k is the kinetic energy in joules (J).

Example 3

Find the kinetic energy of a family car that has a mass of 980 kg when travelling at a speed of 20 $m\ s^{-1}$.

$m = 980\text{ kg}$

$v = 20\text{ m s}^{-1}$

$E_k = ?$

$$E_k = \frac{1}{2}\,m\,v^2$$

$$= \frac{1}{2}(980)\,(20)^2$$

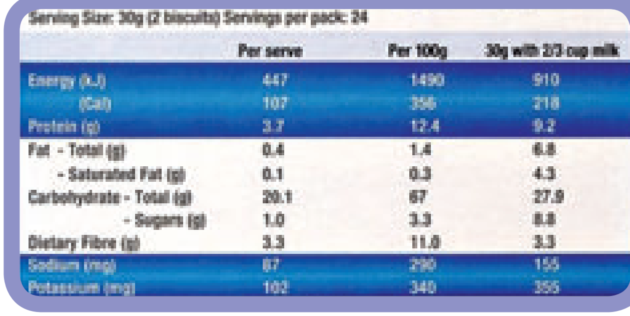
$$= \frac{1}{2} \times 980 \times 400$$

$$= 196\,000\text{ J}$$

Potential energy

Potential energy is the energy that something possesses as a result of its state or position. For instance, the **chemical potential energy** in fuels such as petrol can provide energy when the petrol is burnt. Food contains chemical potential energy, which is released by respiration in your cells.

The food that you consume contains energy stored as potential energy. *Fig 2.6.4*



Serving Size: 30g (2 biscuits) Servings per pack: 24

	Per serve	Per 100g	30g with 2/3 cup milk
Energy (kJ)	447	1490	910
(Cal)	107	356	218
Protein (g)	3.7	12.4	9.2
Fat - Total (g)	0.4	1.4	6.8
- Saturated Fat (g)	0.1	0.3	4.3
Carbohydrate - Total (g)	20.1	67	27.9
- Sugars (g)	1.0	3.3	8.8
Dietary Fibre (g)	3.3	11.0	3.3
Sodium (mg)	87	290	155
Potassium (mg)	102	340	355

A rubber band has **elastic potential energy** because when stretched it has the potential to do work on a model glider like the one in Figure 2.6.5. The elastic potential energy in this case will be transferred to the glider as kinetic energy.

Fig 2.6.5 The stored elastic potential energy of the rubber band can be transferred to the model glider.

Gravitational potential energy

In this Focus you will concentrate on gravitational potential energy. An object lifted above the ground has gravitational potential energy because when it is released it falls. To calculate gravitational potential energy you can use the formula:

$$E_p = mg\Delta h$$

In this formula:

- m is the mass of the object in kilograms (kg)
- g is acceleration due to gravity. Close to Earth this has a value of approximately 9.8 m s^{-2} (Remember, m s^{-2} represents acceleration in units of metres per second per second.)
- Δh is the change in height of an object in metres (m). We call this 'delta h'. Delta means the difference between two values, or the change in value of some variable
- E_p is the potential energy in joules (J).

Example 4

Find the potential energy of a ball with a mass of 0.5 kg when held at the top of a 6 metre ladder.

$$m = 0.5 \text{ kg}$$
$$g = 9.8 \text{ m s}^{-2}$$
$$\Delta h = 6 \text{ m}$$
$$E_p = ?$$

$$\begin{aligned} E_p &= mg\Delta h \\ &= (0.5)\,(9.8)(6) \\ &= 29.4 \text{ J} \end{aligned}$$

Alternative methods to a solution

In physics, you can arrive at the same solution to a question by using different methods. As an example, consider how to calculate work using two different methods.

Example 5

How much work does Tony do if he uses a single pulley to hoist up a 60 kg bag of cement from the ground to a height of 2.5 metres?

Method 1

Using the work formula you know that Tony would have to exert a force equal to the weight of the bag Fwt, through the given vertical distance (s):

$$\begin{aligned} Fwt &= mg \\ &= (60)(9.8) \\ &= 588 \text{ N} \end{aligned}$$

Fig 2.6.6 Using a pulley to do some work

Therefore:

$$\begin{aligned} W &= F \times s \\ &= 588 \times 2.5 \\ &= 1470 \text{ J} \end{aligned}$$

Method 2

Acknowledging that the work done must equal the increase in potential energy of the bag of cement as it is lifted through 2.5 metres:

$$\begin{aligned} E_p &= mg\Delta h \\ &= (60)(9.8)(2.5) \\ &= 1470 \text{ J} \end{aligned}$$

In the question above you can see that two different approaches allow you to arrive at the correct answer. In the first example you calculated the work done in lifting the cement bag through 2.5 metres. In the second example you calculated the increase of potential energy of the bag as it increased its height by 2.5 metres. Because the work done is equal to the energy consumed, both approaches gave the same answer. You can see how much quicker the second method is.

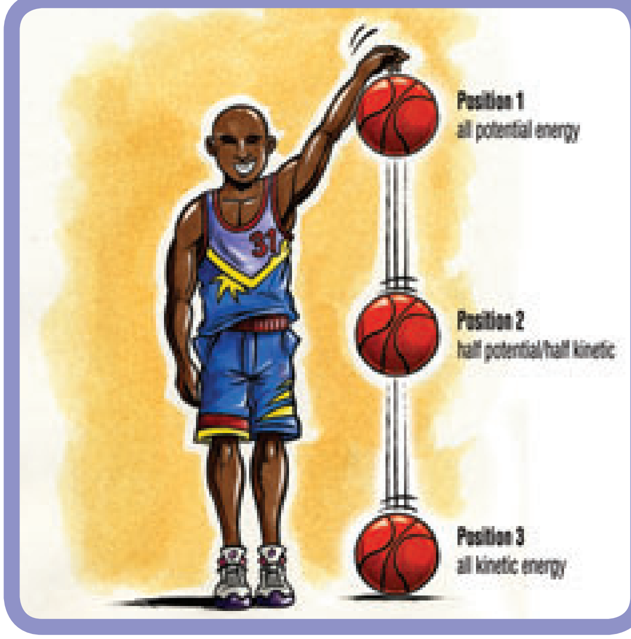
Homework book 2.9 Work and energy

Total mechanical energy

Think about the total mechanical energy of a ball held high above your head. When the ball is held stationary above your head it has maximum potential energy and because it is stationary it has no kinetic energy. When the ball is allowed to fall, its potential energy must be decreasing, but its kinetic energy is increasing as its velocity rises. The instant it hits the ground it no longer has any potential energy because it is not above the ground. But it is travelling fastest at that instant in time, so it has its highest kinetic energy. The total amount of energy of the ball ($E_p + E_k$), called **total mechanical energy**, is a constant. The fact that the total mechanical energy of the ball is constant is consistent with the **Law of Conservation of Energy**. This law tells you that energy cannot be created nor destroyed but only changed from one form to another. So you can think of the potential energy as changing into kinetic energy during the fall.

The amount of potential energy and kinetic energy of the ball varies as it falls, but the total mechanical energy ($E_p + E_k$) remains the same.

Fig 2.6.7



The total mechanical energy of a system can therefore be summarised by the equation:

$$\text{Total mechanical energy} = \text{potential energy} + \text{kinetic energy}$$

$$E_T = E_p + E_k$$
$$= mg\Delta h + \frac{1}{2} m v^2$$

The following example illustrates how this equation can be used.

Example 6

A 0.5 kg rock is held 5 metres above the ground. Calculate its:

a potential energy at this height
b total mechanical energy at this height
c mechanical energy after it falls 2.5 metres
d kinetic energy after falling 2.5 metres
e speed after falling 2.5 metres.

Solution

a To find the ball's potential energy at 5 m off the ground.

$$E_p = mg\Delta h$$
$$= (0.5)(9.8)(5)$$
$$= 24.5 \text{ J}$$

b Since the ball is held 5 metres off the ground (stationary) it has no kinetic energy. Therefore:

$$\text{Total mechanical energy} = \text{potential energy} + \text{kinetic energy}$$
$$= mg\Delta h + \frac{1}{2} m v^2$$
$$= 24.5 + 0$$
$$= 24.5 \text{ J}$$

c After falling 2.5 metres its total mechanical energy will still be 24.5 J.

d To find its kinetic energy after falling 2.5 metres, you need to rearrange the total mechanical energy formula.

$$\text{Total mechanical energy} = \text{potential energy} + \text{kinetic energy}$$
$$\therefore \text{kinetic energy} = \text{total mechanical energy} - \text{potential energy}$$
$$E_k = E_T - mg\Delta h$$
$$= 24.5 - (0.5)(9.8)(2.5)$$
$$= 24.5 - 12.25$$
$$= 12.25 \text{ J}$$

e Since $E_k = \frac{1}{2} m v^2$

$$= \sqrt{\frac{2E_k}{m}}$$
$$v = \sqrt{\frac{2E_k}{m}}$$
$$= \sqrt{\frac{2 \times 12.25}{0.5}}$$
$$= 7 \text{ m s}^{-1}$$

Example 7

A 0.2 kg beach volleyball comes off a player's hand directly upwards at 11.5 m s^{-1}. Calculate:

a the height to which the ball will rise above the player's hand
b its velocity at half this height.

Solution

a You know that as the ball leaves the player's hand, relative to the hand it has maximum kinetic energy and no potential energy. This means that as it leaves the player's hand its kinetic energy is equal to its total mechanical energy.

$$\text{Total mechanical energy} = \text{potential energy} + \text{kinetic energy}$$

$$E_T = mg\Delta h + \frac{1}{2}v^2$$

$$E_T = 0 + \frac{1}{2}m\,v^2$$

$$E_T = \frac{1}{2}(0.2)(11.5)^2$$

$$= 13.22 \text{ J}$$

At its maximum height all its total mechanical energy is potential energy (because kinetic energy will be zero). Therefore at maximum height above the hand:

$$E_T = E_p$$

$$= mg\Delta h$$

$$\Delta h = \frac{E_T}{mg}$$

$$= \frac{13.22}{(0.2)(9.8)}$$

$$= 6.75 \text{ m}$$

b To find the velocity of the ball at half this height ($^{6.75}/_{2}$ = 3.37 m) you know that the mechanical energy of the ball does not change. Therefore:

$$E_T = \frac{1}{2}m\,v^2 + mg\Delta h$$

$$13.22 = \frac{1}{2}(0.2)v^2 + (0.2)(9.8)(3.37)$$

$$\frac{1}{2}(0.2)v^2 = 13.22 - (0.2)(9.8)(3.37)$$

$$v^2 = \frac{13.22 - (0.2)(9.8)(3.37)}{1/2(0.2)}$$

$$= 66.15$$

$$v = 8.1 \text{ m s}^{-1}$$

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Drag and Drop CW Interactive

2.6 Questions

FOCUS

Use your book

Reviewing work, energy and power

1 What is the relationship between work and energy?

2 In what unit are work and energy measured?

3 Define power.

4 How much work is done if a cyclist exerts an average force of 100 N in pedalling her bike a distance of 3000 metres?

5 How much power did the cyclist in question 4 generate if she completed the 3 km in 15 minutes?

Review of kinetic and potential energy

6 What is the difference between kinetic and potential energy?

7 What is the kinetic energy of a 1 tonne (1000 kg) family car when travelling at 65 km/h?

Gravitational potential energy

8 What is the potential energy of a 2 kg bag of rice positioned on a shelf 2 metres above the floor?

Total mechanical energy

9 If the bag of rice in question 8 were to fall from the shelf, how much kinetic energy would it gain as it fell?

10 What would be the velocity of the bag of rice in question 8 just before it hit the ground?

11 What is the Law of Conservation of Energy?

12 Use words and a formula to illustrate the Law of Conservation of Energy for a bouncing ball.

Use your head

13 A bungee jumper jumps off a bridge. Is it important to know the mass of the jumper if you want to calculate how far she falls in 10 seconds? Why or why not?

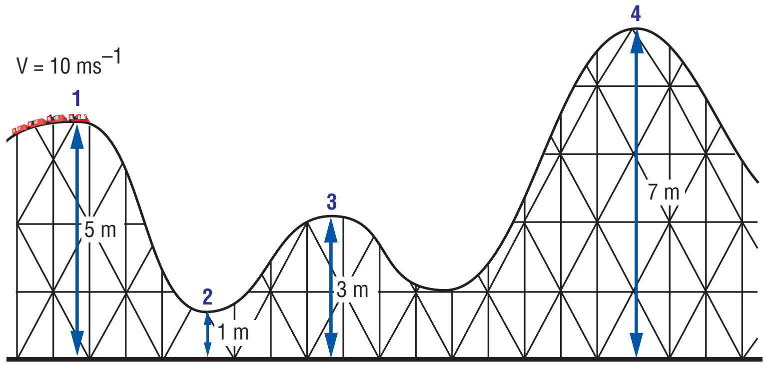
14 Mario throws in the air a tennis ball with a mass of about 200 g. When the ball leaves his hand it travels at a velocity of 5.5 m/s upwards. How high will the ball rise above Mario's hand?

15 A helicopter is hovering 200 metres off the ground when a loose object from inside the cabin falls out. Assuming the initial velocity of the object while in the cabin is 0 m/s and ignoring any air resistance, calculate the velocity of the object just before it hits the ground.

16 Consider the roller coaster shown in Figure 2.6.8. The coaster had a mass of 1000 kg and five passengers of total mass 350 kg were on board, and the coaster was at rest at the start. Assume no energy is lost in friction.

- **a** How much total energy does the coaster have at the start?
- **b** How much kinetic energy does the coaster have at point 2?
- **c** Prove that the coaster can make it over hill 3.
- **d** Show by calculation how fast the coaster needed to be going at the start to make it over hill 4.
- **e** In real life the coaster would need to be going much faster at the start than your calculated speed in **d** above. Explain why.
- **f** If the coaster could take more passengers, how would this affect your calculated figure in **d**?
- **g** If you were the engineer planning the minimum starting speed needed to get over hill 4, what would you do to calculate this?

>>



Information for question 16 *Fig 2.6.8*

Investigating question

17 Investigate the design of roller coasters and the real factors that must be taken in to account, considering safety, as well as how high the hills can be.

2·6 FOCUS

[Practical activity]

Prac 1 Focus 2.6

High roller

Purpose

To build a model roller coaster and study the effect of friction on its performance.

Requirements

3 m plastic track such as computer cable channel or plastic tubing, marble or ball bearing, retort stands, metre rule, electronic balance.

Procedure

1. Build a track similar to the one in Figure 2.6.9, or to any design you negotiate with your teacher.

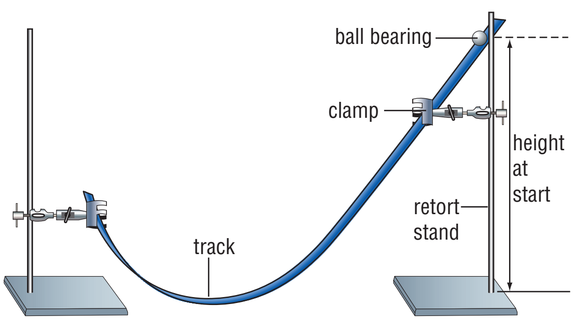


Fig 2.6.9 How to set up your roller coaster

2. Test out your track a few times to make sure the ball bearing stays on the track.
3. Measure the mass of your ball bearing. Calculate the total energy the ball bearing will have if you let it go from a stationary start at the top of the track.
4. Calculate how high up the end of the track the ball bearing should run if there is no friction in the system.
5. Test out how high the ball bearing actually rises up the end of the track. *Write down the height.*
6. Try a different-sized ball bearing and compare the final heights reached.
7. Galileo predicted that, in the absence of friction, the shape and length of the end of the track would not change the height reached. You can test out this idea if you have time.

Questions

1. Why are your theoretical and measured heights in parts 4 and 5 different?
2. Did the different-sized balls reach different heights?
3. Work out a value for the percentage of energy lost in friction in this system.
4. If you tested out Galileo's statement, did the experiment find the same as Galileo predicted? Explain any difference you found.

FOCUS 2.7

Electric power

Context

We tend to take electric energy for granted, believing that it will always be available and cheap. How true this is remains to be seen. It's up to us to understand how energy works, how we buy and pay for it, and how we can arrange our lives so that we use less. In this Focus you will learn an important law and some concepts relating to electric power that will help you achieve this.

Ohm's law

If a potential difference (often called 'voltage') is applied across a device in a circuit, the result is usually that a current will flow through the device. How much current flows depends on the potential difference, and on a property of the device called **resistance**. You came across this in *Science Aspects 2*, where it was described as the 'difficulty electrons have in moving around a circuit'. The relationship between potential difference, current and resistance in metallic conductors was worked out by Georg Ohm almost 200 years ago. This relationship has been known as **Ohm's law** ever since.

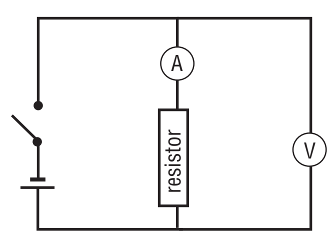


Fig 2.7.1 The ammeter in this circuit measures current and the voltmeter measures potential difference. Together, they provide enough information for you to work out the resistance.

How do you work out the resistance after measuring the current and the potential difference? Ohm's law can be written as an equation:

$$V = IR$$

In this equation, V represents the potential difference across a resistor, I represents the current through the resistor, and R represents the resistance. If V is measured in volts (V) and I is in amperes (A), the unit of resistance is the ohm (Ω).

We can manipulate this equation to get expressions for current and resistance as well as for potential difference. Thus:

$$V = IR$$

becomes

$$I = \frac{V}{R}$$

and

$$R = \frac{V}{I}$$

For example: if you apply 2.5 volts to a circuit component and measure the current through it to be 0.060 amperes, what is that component's resistance?

$$V = IR$$

so

$$R = \frac{V}{I}$$

$$= \frac{0.25\ \text{V}}{0.060\ \text{A}}$$

$$a = 41.7\ \Omega$$

The simplest practical way to measure the resistance of a circuit component is to use a **multimeter**. This device combines the function of an ammeter with that of a voltmeter, and has a switch that lets you select either. You can then measure the current through a resistor, and the potential difference

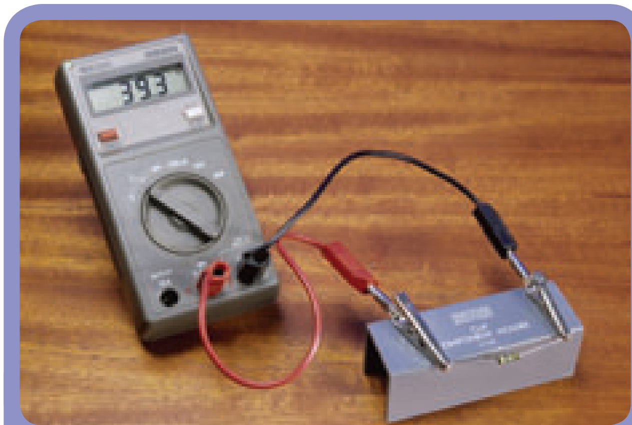


Fig 2.7.2 This multimeter has a digital readout.

across it. Multimeters require you to select AC or DC when measuring current or potential difference. If you select the wrong one, the meter will not work.

Multimeters also have a setting for measuring resistance directly. On this setting, a battery inside the meter applies a potential difference across the resistor. The meter then measures the current flow at that potential.

Many circuit components have resistance values that change significantly if the temperature of the component changes. It has been found that as many components or conductors heat up, the resistance increases. Larger currents heat up components more than smaller currents, which means that the resistance may depend, to some extent, on the current.

If the resistance of a component changes significantly when the current changes, that component is 'non-ohmic'. Ohmic components have resistance values that change very little over a range of currents or temperatures. The same component can be ohmic over a small range of temperatures, but non-ohmic when the temperature range is large. Note that the equation V = IR is true for all components, whether ohmic or non-ohmic.

Prac 1 p. 66

Electric power

Most people use the word 'power' quite loosely. In physics, power is defined as the rate at which work is done, or the rate at which energy changes. In mathematical terms:

$$\text{Power} = \frac{\text{work done}}{\text{time taken}}$$

or

$$\text{Power} = \frac{\text{energy change}}{\text{time taken}}$$

In an electric circuit, the power is given by the relationship:

$$\text{Power} = \text{potential difference} \times \text{current}$$

or

$$P = VI$$

Note that if the potential difference is in volts (V) and the current is in amperes (A), the power is given in watts (W). Many household electrical appliances such as refrigerators and television sets are rated, not in watts, but in volt-amperes (VA). For example, a refrigerator may be rated as 1800 VA. This really means that it is rated at 1800 watts, and so uses 1800 joules of energy every second that it operates.

Fig 2.7.3 There is usually a plate on the back of an appliance, which gives its power rating.

The power consumption of a lamp that draws a 400 mA current when operating at 250 V is thus:

$$\begin{aligned} P &= VO \\ &= (250\ \text{V}) \times (0.400\ \text{A}) \\ &= 100\ \text{W} \end{aligned}$$

Note that you must work in amperes even though the current is recorded in milliamperes.

Electrical energy

Energy is what we have to supply to a machine so that it will work. We measure energy in joules. Power is related to energy, because power is the rate at which we use or supply energy. Mathematically:

$$\text{Power} = \frac{\text{energy}}{\text{time}} \text{ or } P = \frac{E}{t}$$

The unit of power is the joule per second, also called the **watt**. If you know or have measured the power used by an appliance, you can use the time for which it operates to work out the energy used.

Thus, energy = power × time, or E = Pt. Since electrical power is given by P = VI, electrical energy is the product of power and time, or E = Pt = VIt.

For example, if a computer is rated at 500 watt, what energy does it use over a six-hour period?

The answer starts with the relationship between energy and power:

$$\begin{aligned} \text{Energy} &= \text{power} \times \text{time} \\ &= (500\ \text{W}) \times (6\ \text{hours}) \\ &= (500\ \text{J/s}) \times (6 \times 3600)\ \text{s} \\ &= 10\,800\,000\ \text{J or } 1.08 \times 10^7\ \text{J} \end{aligned}$$

Over 10 million joules seems like a lot of energy. At present prices, this much electrical energy would cost a consumer in the metropolitan area less than 50 cents. Electrical energy that we get through the mains is very

Fig 2.7.4 The number and variety of electrical appliances available to us increases every year.

cheap compared with other ways of getting energy. Probably the most expensive common energy source is batteries, especially the 'use once and throw away' sort.

Note that although we call them power stations, the generator stations that create our mains supply are really 'energy stations'. We use, and pay for, the electrical energy from the generator. **Power** is a measure of how quickly we use energy, not how much we use. In most Australian homes, the big energy users tend to be space heating and cooling, and providing hot water for washing and cleaning. You could probably save a substantial amount of energy (and thus cost) by having shorter, cooler showers!

Our large generators run on fossil fuels whose combustion creates large amounts of carbon dioxide. Reducing our energy use would mean reducing the amount of greenhouse gas being pumped into the air by our generating stations. For example, we could adopt more efficient lighting, such as fluorescent tubes rather than incandescent light bulbs.

Alternatives to fossil fuels as energy sources include wind, solar, tidal, geothermal and nuclear. Some communities supply a proportion of their energy needs using one or more of these alternative sources. Over time, our society as a whole may be forced to change its energy sources as well as moving to more efficient appliances.

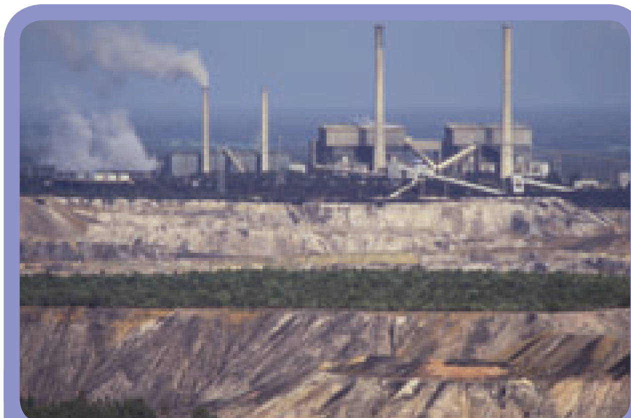


Fig 2.7.5 The coal-fired power station at Muja provides electricity for most of the south-west region of WA.

Fig 2.7.6 One wind generator can provide a limited amount of electrical energy. Bigger towns and cities would need 'wind farms' of many windmills working together.

Fig 2.7.7 High-tension power lines do not enhance the view.

Science Snippet

High-tension power lines

When an electric current flows, some of the energy carried by the moving charges transfers to the atoms of the conductor. This heats up the conductor and wastes some of the energy. Power-generating authorities usually 'step up' the potential to tens or even hundreds of thousands of volts. This reduces heating losses in the transmission lines, but creates other problems. The high-tension power lines used for long-distance power supply have to be high above the ground, to avoid current 'arcing' to the Earth. They also produce strong magnetic fields. Some people believe that such fields have a harmful effect on anyone living nearby.

Efficiency and energy rating

Making appliances more energy-efficient is about saving money and the environment, a win–win situation if we can achieve it. Efficiency is usually quoted as a percentage or a fraction, and indicates the ratio of useful energy to the total energy used.

For example, a standard light bulb is about 3 per cent efficient. This means that the bulb emits 3 joules of energy as light for every 100 joules of electrical energy fed into it. Fluorescent tubes are around 12–15 per cent efficient. So 97 per cent of energy you pay for when using a light bulb is wasted, while around 85 per cent is wasted by a fluorescent tube.

These numbers both look very high, meaning that most of the energy we pay for we cannot use. But the costs of using these types of lighting are very different. The running cost of a standard light bulb is five times higher than the cost of a fluorescent tube providing the same amount of light. And then there's the hidden cost to the environment. Generating electrical energy produces greenhouse gases.

To calculate the efficiency of an electrical component you need to work out the ratio:

$$\text{Efficiency} = \frac{\text{useful power}}{\text{total power}}$$

or

$$\text{Efficiency} = \frac{\text{useful energy}}{\text{total energy}}$$

Thus, a microwave oven that can transfer 200 joules to a cake out of a total of 1000 joules provided by the mains supply would have:

$$\text{Efficiency} = \frac{\text{useful energy}}{\text{total energy}}$$

$$= \frac{200\text{ J}}{1000\text{ J}} \times 100\%$$

$$= 20\%$$

Drag and Drop CW Interactive

Household appliances such as washing machines and refrigerators now display energy ratings so that you can choose more efficient designs if you wish.

Fig 2.7.8 An energy rating helps the consumer to choose an appliance according to its efficiency.

Efficiency is not just about the power rating. A refrigerator with a high power rating may be more efficient than one with a lower power rating. How could that happen? Remember, we pay for energy, not power.

Energy is related to power through time. Thus, an appliance that operates at high power for short periods of time may be more efficient (use less energy) than one that operates at a lower power but has to stay on longer.

Science Snippet

Power mains have potential

The potential of the mains supply varies from one country to another, and sometimes even within a single country. In Australia the standard potential is 240 volts. In the USA, mains potential is 110 volts. Is our higher potential a problem? The answer is, probably not. For a given power load, higher potential means lower current. Lower current means less heating effect, and also lower costs involved in buying the thinner wire needed. Thus using a higher potential makes house wiring more affordable, and less likely to catch fire. However, the risk of electrocution may be increased.

Prac 2 p. 67

Homework book 2.10 Energy can light up your life

2·7 FOCUS [Questions]

Use your book

Ohm's law

1. A mathematical statement of Ohm's law is V = IR. Express this in words.
2. Max connected a 9 V battery to a circuit component and measured the current to be 0.45 A.
   - **a** What was the resistance of this component?
   - **b** Max then adjusted the potential difference across the component to 4.5 V. What would the current and the resistance be now? Explain your reasoning.
3. A room heater has a resistance of 36 and operates at 240 volts.
   - **a** What current does it draw when operating normally?
   - **b** Is it likely to be an ohmic resistor? Explain.

Electric power

4. Draw a diagram showing how you would connect the appropriate equipment to measure the power available from a battery or dry cell.

>>

5 A room heater in the USA has a power rating of 1600 W and operates at 110 volts. What current does it draw when operating normally?

6 A power station is described as having a capacity of 60 megawatts.
  a Explain what this statement means.
  b The station's output is through high-tension mains at 330 000 volts. What current would that involve when the station is at its peak output?

Electrical energy

7 Which would affect your energy bill more, leaving a 1 kW heater running overnight, or leaving a 100 W light bulb on overnight? Explain.

8 Max left a 60 watt lamp on while taking a business trip. If the lamp used 30 megajoules of energy, for how long was Max away? Give your answer to the nearest day.

Efficiency and energy rating

9 A solar cell is quoted as being 15 per cent efficient. Explain what this means.

10 A 1000 watt electric motor produces heat at the rate of 645 watts. A 1000 watt electric heater produces heat at the rate of 1000 watts. Which is more efficient? Explain.

Use your head

11 The table on the right shows some data about three appliances. Copy the table into your notes, then fill in the blank spaces in your table.

Appliance	Power rating (watts)	Normal current (amperes)	Normal potential difference (volts)	Normal resistance (ohms)
A	400	2.5		
B	1800		240	320
C		3.33	12	
D	625			125

12 Consider a 75 watt electric light bulb.
  a If the bulb is made for the Australian market, what values of potential difference, current and resistance does the bulb have when operating normally?
  b If the bulb is made for the American market, what values of potential difference, current and resistance does the bulb have when operating normally?

13 What happens to the energy that we get from a power station? Consider first the waste energy (there's always waste energy—no machine is 100 per cent efficient), then consider the useful energy. What is the difference between 'waste' energy and 'useful' energy?

Investigating questions

14 How much electrical energy do you, personally, use in a week?

15 On average, the Sun delivers solar energy at the rate of about 400 watts for every square metre.
  a How many square metres would you personally need to gather solar energy?
  b How many square metres would be needed to allow the same energy use for everybody on Earth?
  c What fraction of the Earth's land surface would that be?
  d Compare your answers with those of other people doing this investigation. Can you explain any differences?

FOCUS 2·7

[Practical activities]

Prac 1
Focus 2.7

DYO

Ohm sweet ohm

Purpose

To determine the relationship between current, potential difference and resistance.

Requirements

Power pack or dry cells, resistors (eg 50 Ω), ammeter, voltmeter, connecting wires, multimeter, switch.

Procedure

1 Set up the power source, a resistor, the ammeter and the voltmeter so as to measure the current through the resistor and the potential difference across it. Note that the ammeter must be in series with the component being measured, while the voltmeter must be in parallel.

>>

Note also that ammeters and voltmeters have a polarity; that is, it makes a difference which way the terminals are connected.

2 Take readings at various potential settings, eg 2 V, 4 V etc. Do not allow the current to flow in your circuit for more than a few seconds at a time. *Record a range of current and potential readings for the same resistor in a suitable table.*

3 Use the multimeter to measure the resistance of the resistor, and *write down your measurement.*

4 *Plot a graph using the potential and current values from your results. Plot potential (voltage) on the vertical (y) axis and current on the horizontal (x) axis.*

5 *Using a ruler, draw a line to connect the first point on the graph to the last point.*

6 Do the other points that you plotted make a straight line? Calculate the gradient of the line that you have drawn, using the method $^{rise}/_{run}$. *Write down your answer.*

Questions

1 What relationship did you find out about current, potential difference and resistance?

2 The relationship that you found was true for the resistor that you used. What would you have to do to be confident that it applies to most resistors?

3 Was your resistor ohmic or non-ohmic? How can you tell?

4 Why were you instructed not to allow the current to flow for more than a few seconds at a time?

Prac 2
Focus 2.7

DYO

Power and energy in a lamp

Purpose

To determine the relationship between current, potential difference, power and energy.

Requirements

Power pack or dry cells, low-voltage lamp (eg 12 V, 12 W), ammeter, voltmeter, connecting wires, stopwatch or clock.

Procedure

1 Set up the power source, the lamp, ammeter and voltmeter so as to measure the current through the lamp and the potential difference across it. Have your teacher check your circuit first before going any further.

2 Set the power pack to the potential rating of the lamp. For example, if the lamp is marked ‘6V, 10W’ you should set the power pack to 6 volts. Do not exceed the potential rating. *Draw up a table to record a measurement of V and I every 30 seconds over 5 minutes.*

3 Start the stopwatch, switch on, and take readings of the current and potential difference. Leave the switch on. *Record your measurements.*

4 Take readings every 30 seconds for 5 minutes. *Record your measurements.*

5 Calculate the average current and the average potential difference. *Show all your working.*

6 Calculate the average power of the lamp. *Show all your working.*

7 Calculate the energy emitted by the lamp during the time that you made your measurements. *Show all your working.*

Questions

1 Did your measured power match the rated power of the lamp? Comment on your result.

2 Why were you instructed to measure the current and potential difference several times and find the average?

3 If the lamp is about 3 per cent efficient, what would be its output of visible light? Give your answer both in terms of power, and the energy in a 5-minute period.

4 Would you expect to get the same power if you used a lower potential (voltage) setting? Explain.

5 If you apply 12 V to a lamp rated at 2 V, what would happen? Why?

6 If you apply 2 V to a lamp rated at 12 V, what would happen? Why?

FOCUS 2·8 Waves

Context

Water waves are easy to observe. Just dip your finger in a glass of water and watch the ripples spread, or go to the beach and see the water washing up and down the sand. But there are waves all around us that we rarely think about. These waves exist in the air, in solid rock and even in the vacuum of space. Whether we can see them or not, all waves have some common behaviours or properties.

Fig 2.8.1 Waves like these can carry energy for thousands of kilometres.

Waves

Waves transfer energy without transferring matter as well. An ocean wave washing up on the beach delivers energy. That energy was originally in wind that blew across the ocean hundreds or thousands of kilometres away. Energy enters the water far from the beach, but the water washing up and down the beach travels only a few metres.

Other waves follow the same pattern. When the speakers of your CD player or your headphones pump energy into the air, that energy travels to you as sound waves. The Sun emits waves of electromagnetic radiation such as radio waves, visible light and ultraviolet radiation. These waves travel through a vacuum.

Thus, all waves need a source of energy. This energy source creates a disturbance that propagates, or travels through, a medium. Consider a sudden movement of the plates in the Earth's crust. The energy released by the shifting plates propagates as an earthquake wave through solid rock. In this case, the energy source is the shift in position of the plates, and the medium is the rock through which the wave travels.

In this Focus, you will consider waves in general, by looking closely at properties that are associated with all waves. Then you will look at the similarities and differences between two major wave types, mechanical waves and electromagnetic waves.

Wave properties

Energy from a source often enters the medium at regular time intervals. Each interval is one period of the wave. We represent the period represented mathematically as T. For example, if energy is injected into a wave every 0.1 seconds, the wave period is T = 0.1 s. Ocean waves typically have periods of about 10 seconds; the period of a sound wave may be about 0.001 second, or 10^{-3} s; and the period of a light wave may be around 0.000 000 000 000 01 s, or 10^{-14} s.

A property associated with period is the frequency of a wave. **Frequency** tells you how many complete waves are created in one second. Period and frequency are reciprocal, so that mathematically:

$$\text{Frequency} = \frac{1}{\text{period}}$$

or in symbols:

$$f = \frac{1}{T}$$

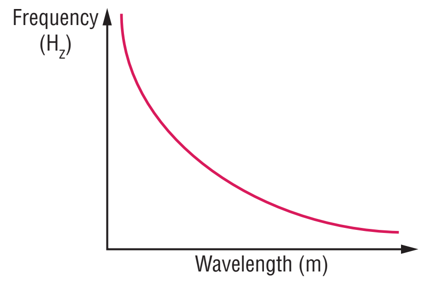
The unit of frequency is $^1/_{\text{seconds}}$ or s^{-1}. This is hard to talk about so the unit used around the world is the hertz, Hz. One hertz is one s^{-1}. For example, the frequency of a sound wave having a period of 0.005 seconds is given by:

$$\begin{aligned} f &= \frac{1}{T} \\ &= \frac{1}{0.005}\ s^{-1} \\ &= 200\ \text{Hz} \end{aligned}$$

Wavelength is the distance between one wave and the next, measured in the direction that energy travels. We represent wavelength in equations by the Greek letter λ (lambda). It is measured in distance units such as metres. Like period and frequency, wavelength varies tremendously between different waves.

Thus, ocean waves may have wavelengths of tens or hundreds of metres, while visible light can have wavelengths around $^{1}/_{1000}$ millimetre.

Fig 2.8.2 The graph shows the relationship between frequency and wavelength for light in a vacuum. Can you explain why the graph has this curved shape?



Frequency and wavelength are connected to the speed of the wave. The speed at which energy travels through the medium is given by:

Speed = frequency × wavelength

or

$$v = f\lambda$$

Thus, for a sound wave travelling through air with a wavelength of 28 cm and a frequency of 1250 Hz, the speed would be:

$$v = f\lambda$$
$$v = 1250 \text{ Hz} \times 0.28 \text{ m}$$
$$= 350 \text{ m s}^{-1}$$

Another property that all waves share is **amplitude**. This is the distance moved by the molecules in the medium as the wave passes through. The relationship between amplitude, crest height and trough depth in an ocean wave is shown in Figure 2.8.3. The amplitude

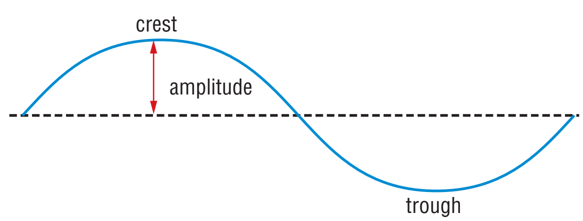


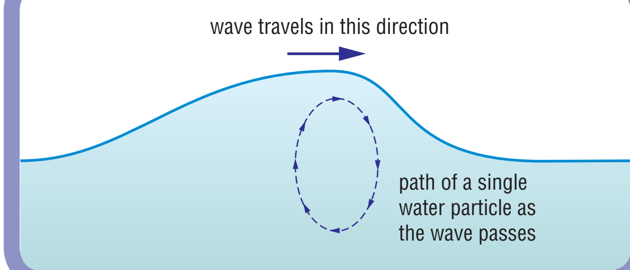
Fig 2.8.3 The amplitude is about half the vertical distance from the top of the crest to the bottom of the trough.

of a mechanical wave is closely related to the energy that the wave transmits. The greater the amplitude, the more energy the wave can deliver.

Transverse and longitudinal waves

In order to propagate, mechanical waves such as sound waves, earthquake waves and water waves need a **medium** made of particles, such as air, water or rock. Because of their dependence on particles to transmit the energy, mechanical waves cannot travel through a vacuum. Electromagnetic waves do not need a medium, and in fact propagate best through a **vacuum**.

Fig 2.8.4 The particles in a water wave move mostly up and down. The wave itself travels horizontally.



We can classify waves according to the way the particles of the medium vibrate. In a **transverse** wave, the particles vibrate in a direction perpendicular to the direction in which the energy travels. In a **longitudinal** wave, the particles vibrate parallel to the direction in which the energy travels.

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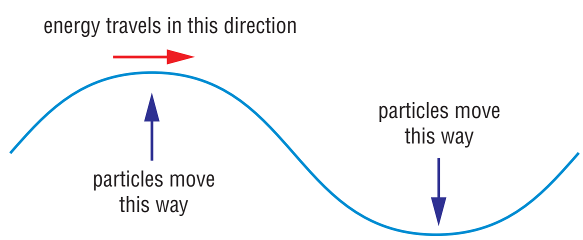
Fig 2.8.5 In a transverse wave, the medium moves perpendicularly to the direction of energy travel.

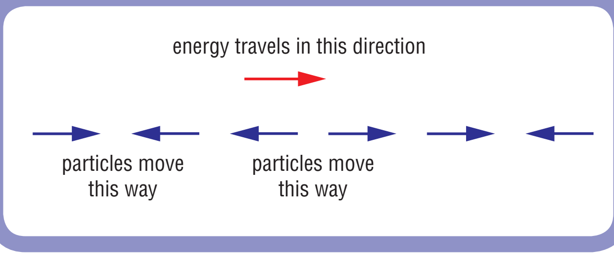


Water waves are approximately transverse. A floating cork bobs up and down as a wave passes under it. Even a large floating object such as a ship does this. This happens because the energy travels parallel to the surface of the ocean, but each water molecule moves up and down with almost no sideways motion.

Sound waves are longitudinal. Consider a sound wave passing through air. The air molecules move first in the direction the energy is travelling, then back in the opposite direction. Each air molecule moves a short distance each way, and ends up where it started. In any wave, it is the energy that travels from the source to the receiver, as shown in Figure 2.8.6.

Drag and Drop CW Interactive

Fig 2.8.6 In a longitudinal wave, the medium moves parallel to the direction of energy travel.



Science Snippet

Catching a wave—the science of surfing

Imagine coasting down a hill on a bicycle or a skateboard. To begin, you have to climb to the top of the hill and then you can trade your gravitational potential energy for kinetic energy as you coast down the hill. When you get to the bottom, you will be coasting pretty fast, but you will have to climb back up to repeat the ride. Surfing uses the same principle. A surfer trades potential for kinetic energy while sliding down the wave. There are differences. Firstly, the wave comes along and lifts the surfer so there is no need to climb a hill. And secondly, the wave moves forward underneath the surfer. The best ride happens when the surfer slides down the wave as fast as the wave, moving forwards, lifts them up.

Interactive CW Animation

Electromagnetic waves

When a charged particle such as an electron accelerates, it emits energy as 'electromagnetic radiation', or emr. In most cases, the accelerating charged particles are electrons. The waves associated with emr are very different from the waves you see at the beach. An electromagnetic wave consists of an electric field that grows and then shrinks, and a magnetic field that grows and then shrinks. These fields oscillate at right angles to the direction of energy transfer. For this reason, emr is classified as a transverse wave.

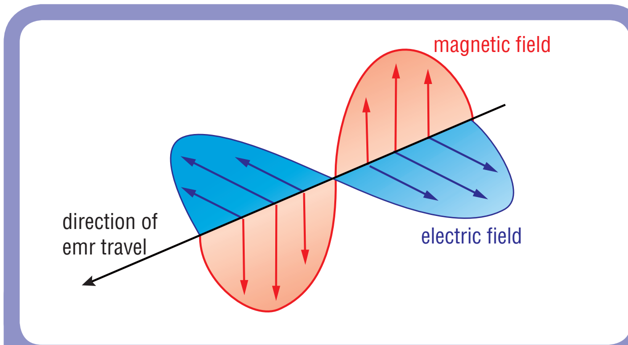
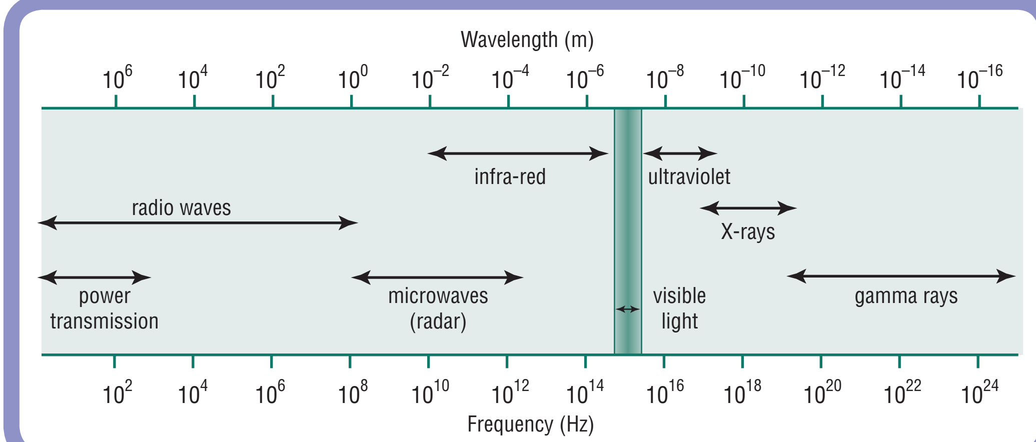


Fig 2.8.7 The magnetic and electric fields oscillate at right angles to each other, and to the direction in which the energy travels.

When scientists first became aware of emr, they assumed that space must contain something able to move. They called this the 'ether' but despite many experiments there is no evidence that the ether exists. Unlike all the other wave types you have looked at, electromagnetic radiation is a wave that does not need a medium. In fact, emr travels most efficiently in a vacuum, and slows down or is absorbed when it passes into a material medium such as air or water.

The entire electromagnetic spectrum—radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and so on—can be produced by accelerating electrons. If electrons oscillate in a wire, that wire becomes a radio aerial and emits radio waves.

The electromagnetic spectrum Fig 2.8.8

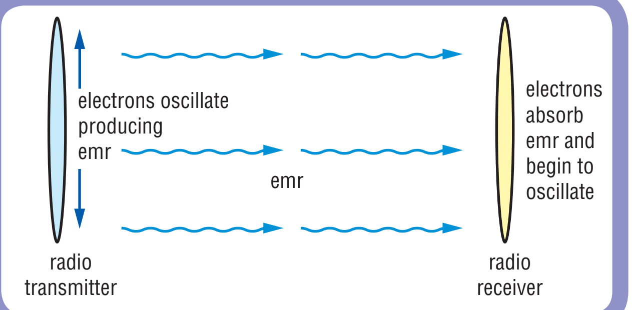


When electrons move between energy levels in atoms or molecules, the emitted emr may be infrared or visible or ultraviolet. X-rays are produced when high-speed (that is, high-energy) electrons collide with matter and decelerate rapidly.

Waves, electricity and magnetism

The alternating mains current to which you connect your appliances involves electrons oscillating in a conductor. The current behaves like a wave of charge, sloshing back and forth in the conductor in the same way that water can slosh around in a bath.

Fig 2.8.9 Waves and particles can interact in a symmetrical way.



Science Snippet

Mobile phones and you

When you speak into it, your mobile phone emits a microwave signal that is amplified and sent on by the nearest repeater tower. Your phone also picks up a microwave signal from the other person's phone. Think about this for a moment. Wherever you are, the phones around you bathe you in microwaves as they work. It is like living in a low-powered microwave oven! The good news is that the levels involved are very low and as far as we know, very low levels of microwaves are safe. However, the power at which your phone transmits is much, much greater at the moment it 'shakes hands' with the nearest mobile phone tower. It is a good idea to hold your phone away from your head until the call is established.

Symmetry is an important idea in physics. For example, if accelerating electrons produce emr, it is reasonable to expect that emr can make electrons accelerate. And so it does. Waves of emr passing a piece of wire can accelerate electrons along the wire. This wire is then acting as a receiving aerial.

The electromagnetic waves that excite the electrons in the wire create an alternating current. The frequency of this current depends on the frequency of the emr that creates it. Radio and television work because the emr emitted by the source varies according to the information being sent. This variation may be in its amplitude (in the case of AM radio), or its frequency (in the case of FM and TV).

Homework book 2.11 Electronic communication

2·8 FOCUS [Questions]

Use your book

Waves

1 Thunder is a sound wave created by lightning. How does lightning supply the energy source for thunder, and what is the medium through which thunder propagates?

2 What evidence is there that water waves do not transfer water over hundreds or thousands of kilometres?

Wave properties

3 Think back to when you have seen ocean waves at the beach or in a movie. Which is greater—the amplitude or the wavelength? Estimate the values of amplitude and wavelength for the type of ocean wave that you might see breaking on a beach.

4 The speed of sound in air varies with the temperature, and is around 350 m s^{-1} on a summer's day. Most young adult humans can detect sounds from a frequency of about 20 Hz to a wavelength of about 17.5 mm. What would be the:

a wavelength of a 20 Hz sound?

b frequency of a sound having a wavelength of 17.5 mm?

Transverse and longitudinal waves

5 Earthquakes produce both longitudinal and transverse waves, which travel from the epicentre at different speeds. After an earthquake, how could the people at an observatory that detected two different waves at two different times work out how far away the epicentre was? What would they have to know or assume in order to do the calculation?

Electromagnetic waves

6 An FM radio station sends out a signal of frequency 99.6 MHz. What are the speed and wavelength of this signal?

7 People with normal colour vision can detect emr of wavelengths between 400 nm (violet light) and 700 nm (red light). Note that 1 nm (nanometre) = 10^{-9} m.

a What is the wavelength, in metres and in nanometres, of emr having frequency 1.0×10^{14} Hz?

b Is emr of frequency 1.0×10^{14} Hz visible, infrared or ultraviolet? Show your reasoning.

>>

Waves, electricity and magnetism

8 **a** The frequency of the power mains in Australia is 50 Hz. If the speed of the wave in the conductor is about the speed of light, 3×10^8 m s^{-1}, what is the approximate wavelength of AC in Australia?

b The mains frequency in the USA is 60 Hz. Would the wavelength of AC be larger than, the same as, or smaller than the wavelength in Australia? Explain.

Use your head

9 You have probably seen advertising images in magazines or on television in which a person has their hair blown back by the sound from a stereo. Is this possible, or just an advertising gimmick? Explain.

10 The speed of a wave in water depends on the depth—the shallower the water, the slower the wave travels. While a water wave is in deep water, it does not ‘break’. As a water wave approaches a beach, it breaks. Explain this difference. (Hint: consider the front, middle and back of the wave in each case.)

11 The speed of sound, even in one medium, such as air, is not a constant. The table at top right shows the speed of sound in air at different temperatures.

a What is the approximate change in the speed of sound for every 10°C change in temperature?

Medium	Speed of sound (m s^{-1})
Air at 0°C	330
Air at 25°C	346
Air at 100°C	387

b Use your answer to **a** to estimate the speed of sound in winter in Antarctica when the temperature is –40°C.

c Use your answer to **a** to estimate the speed of sound in an oven set at 280°C.

Investigating questions

12 In the context of radio waves, what do AM and FM stand for? Is digital radio different again? What advantages or disadvantages does each system have compared with the others?

13 Radar uses microwaves to find the location or speed of a target. How does this actually work? For example, how can a police officer know that a car up the road is breaking the speed limit?

14 What is difference between ‘supersonic’ and ‘ultrasonic’?

FOCUS 2·8

[Practical activity]

Prac 1 Focus 2.8

DYO

Making waves

Purpose

To investigate the speeds of longitudinal and transverse waves in the same medium.

Requirements

Slinky spring, stopwatch.

Procedure

1. In your group, find out how to send a longitudinal wave along a stretched slinky spring. *Write or draw a description of your method.*
2. In your group, find out how to send a transverse wave along a stretched slinky spring. *Write or draw a description of your method.*
3. Decide how you could measure the speed of a wave in the slinky spring. Consider especially how you would minimise errors in your measurement. *Write or draw a description of your method.*
4. Measure the speed of both longitudinal and transverse waves in your stretched slinky spring. *Record your results.*
5. Does increasing the amplitude of the transverse wave in the slinky spring have any effect on its speed? *Record your results.*

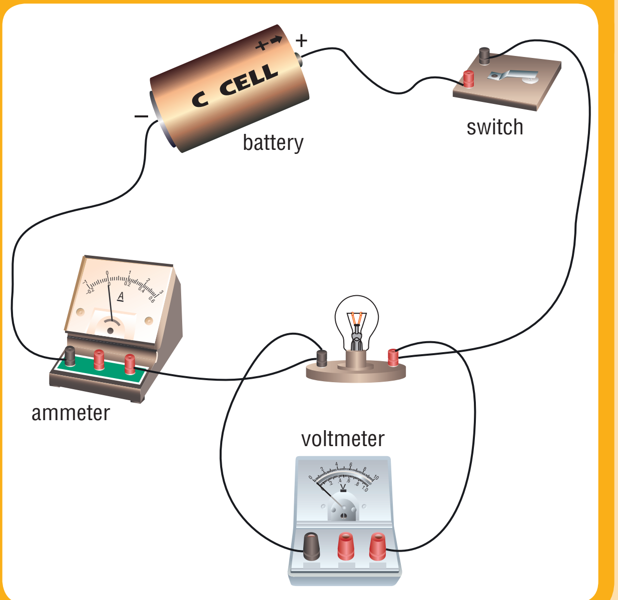
Questions

1. At a given tension, is the speed of the two types of wave significantly different in this medium? How confident are you of your answer?
2. What effect, if any, does increasing the tension have on the speed of longitudinal waves in this medium? How confident are you of your answer?
3. What effect, if any, does increasing the tension have on the speed of transverse waves in this medium? How confident are you of your answer?
4. Design an experiment to investigate whether the tension (amount of stretch of the slinky spring) has any effect on the speed.

Second-hand data

1 After reading *Science Aspects 4*, Sarah decided that she would test Ohm's law. She constructed the investigation apparatus as shown in Figure 2.9.1.

Fig 2.9.1 Sarah's investigation set-up



Sarah kept on adding 1.5 V dry cells between the lead terminals. She recorded the total voltage supplied to the circuit as well as the total current reading on the ammeter. She then repeated the investigation but replaced the first bulb with a different bulb. Sarah collected data for three bulbs. Sarah recorded her findings on the table below.

Sarah's investigation hypothesis: The current in a simple series circuit is directly proportional to the applied voltage.

Data from Sarah's investigation

Voltage (volts)	Current (amps)		
1.5	0.3	0.2	0.4
3.0	0.6	0.4	0.8
4.5	0.9	0.6	1.2
6.0	1.2	0.8	1.6
7.5	1.5	1.0	2.0
9.0	1.8	1.2	2.4

Draw a graph of the results shown in the table. Place current on the x-axis and voltage on the y-axis and graph the data from all three on the one set of axes.

- **a** What did the results of this investigation show?
- **b** Did the results of this investigation support Sarah's hypothesis?
- **c** Calculate the resistances of each of the bulbs using the graph for each bulb.
- **d** Which bulb had the biggest resistance?
- **e** List the dependent, independent and controlled variables in this investigation.
- **f** Was Sarah's investigation fair? Why or why not?
- **g** Did the bulbs display ohmic behaviour?

2 As part of a school assessment Carl wanted to find out how the effort required to support a load on a lever changed as the length of the load arm increased. He set the apparatus up as shown in Figure 2.9.2.

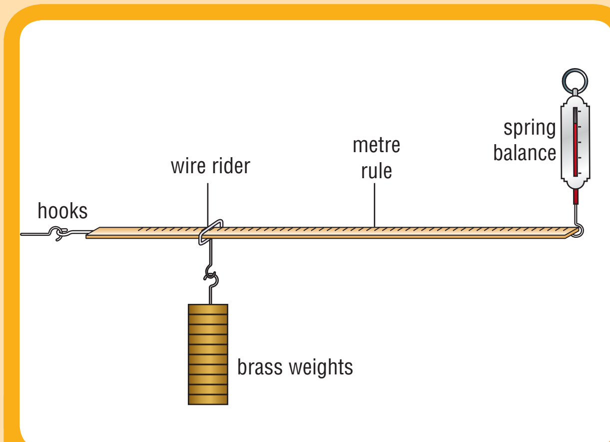


Fig 2.9.2 Carl's apparatus to test how the effort on a lever changes as the length of the load arm is increased

Carl used a fixed mass of 200 g as the load in his investigation. He started the investigation by placing the centre of the 200 g mass on the 20 cm mark of the metre rule. He then recorded the force registered on the spring balance. He then repeated these steps for the masses placed at the 40, 60 and 80 cm positions. The results he collected are represented in the table on the next page.

Review questions

Position of masses (cm)	Force on spring balance (N)
20	0.39
40	0.78
60	1.18
80	1.57

Draw a graph of how the force required at the end of the ruler changed as the distance of the load from the fulcrum increased.

a When Carl moved the 200 g masses from the 20 cm to the 80 cm mark, was he increasing or decreasing the length of the load arm?

b What conclusion should Carl have reached in looking at the data he obtained from this investigation?

c What were the dependent and independent variables in this investigation?

d Which variables did Carl control in this investigation?

e Predict the force on the spring balance when the 200 g mass is positioned at the 1 metre mark.

Open-ended questions/experimental design

3 Design and conduct an investigation to determine how the drop height of a ball affects the height of its bounce. You will need to:

a choose one type of ball

b select a surface that the ball will bounce on

c decide how to accurately measure drop height and rebound height

d tabulate your data and draw a graph to display the data

e decide on the best way to describe the graph

f try to quantify the relationship between drop height and bounce height

g try to give a science explanation for your results.

Extension task

You may want to repeat the investigation but this time with another ball. Plot this second set of data on the same graph as above.

Extended investigation/research

4 Review the literature on the Leaning Tower of Pisa from your library or the Internet. Find information about:

- the history of the Leaning Tower of Pisa
- when work commenced and ceased through its construction
- why work ceased when it did
- when it started to lean
- why it started to lean
- what has been done to correct and/or reduce the extent of its lean at various times.

Having evaluated the information, come to a conclusion about whether or not the tower is going to fall over by 2026. Remember to address as many of the issues that you have learnt about in these Foci (such as forces, gravity, centre of gravity, stability and equilibrium, balance, moments) in your answer. Your conclusion must be defendable on scientific grounds.

Homework book 2.12 Energy and Change crossword

Homework book 2.13 Sci-words

Fig 2.9.3 The Leaning Tower of Pisa

3 Life and Living

Curriculum guide learning focus

- interaction between the respiratory and circulatory systems at a cellular level
- cellular reproduction by mitosis and meiosis
- human reproductive structure and function, and pregnancy
- chemical basis of inheritance and methods of inheritance
- predicting the outcome of genetic crosses
- relationships between diversity, natural selection and evolution
- classification and evolutionary relationships
- methods of studying ecosystems in the field
- manipulation of DNA and its use in health and industry
- the ethics, benefits and problems of DNA manipulation

This section on Life and Living also contains work that will help students with the outcomes of Investigating, Communicating Scientifically, Science in Daily Life, Acting Responsibly and Science in Society.

Outcome level descriptions

The outcome level descriptions for Life and Living covered in this section are mainly LL 5 and LL 6.

FOCUS 3·1 Gas exchange

Context Mammals must obtain oxygen and remove carbon dioxide waste to sustain life processes. How are these substances carried around the body, and how do they get there? These concepts will be discussed in this Focus through the study of the human respiratory and circulatory systems.

The respiratory system

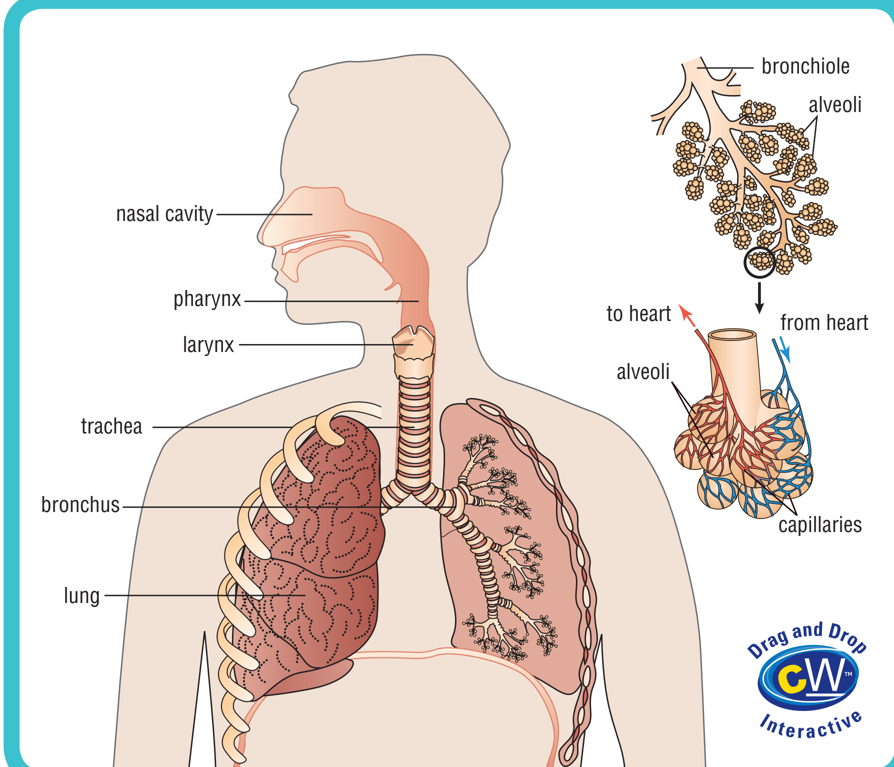
The respiratory system includes the lungs, the pathways connecting them to the outside environment, and structures in the chest involved with moving air in and out of the lungs. The primary function of the respiratory system is to supply the blood with oxygen and to remove carbon dioxide. The respiratory system exchanges gases through the process of breathing. When we breathe, we inhale oxygen and exhale carbon dioxide. The circulatory system transports the oxygen and carbon dioxide between the lungs and the tissues of the body.

In humans, in the process of breathing, air enters the body through the nose and is warmed, filtered and passed through the nasal cavity. Air passes the pharynx (which has the epiglottis, which prevents food from entering the trachea). The upper part of the trachea contains the larynx. The vocal cords are two bands of tissue that extend across the opening of the larynx. After passing the larynx, the air moves into the bronchi, which carry air in and out of the lungs. The bronchi are reinforced to prevent their collapse and are lined with mucus-producing cells and epithelial cells, which are covered in cilia. Bronchi branch into smaller and smaller tubes known as bronchioles. Bronchioles end in grape-like sac clusters known as alveoli. Alveoli are surrounded by a network of very thin-walled capillaries through which gas exchange can easily occur.

Working in conjunction with the circulatory system, the oxygen-rich blood travels from the lungs through the pulmonary veins into the left side of the heart. From there, blood is pumped to the rest of the body. Blood that contains less oxygen but is carbon dioxide rich returns to the right side of the heart through two large veins called the superior vena cava and the inferior vena cava. This blood is then pumped through the pulmonary artery to the lungs, where oxygen is picked up and carbon dioxide is released. This process is repeated continually.

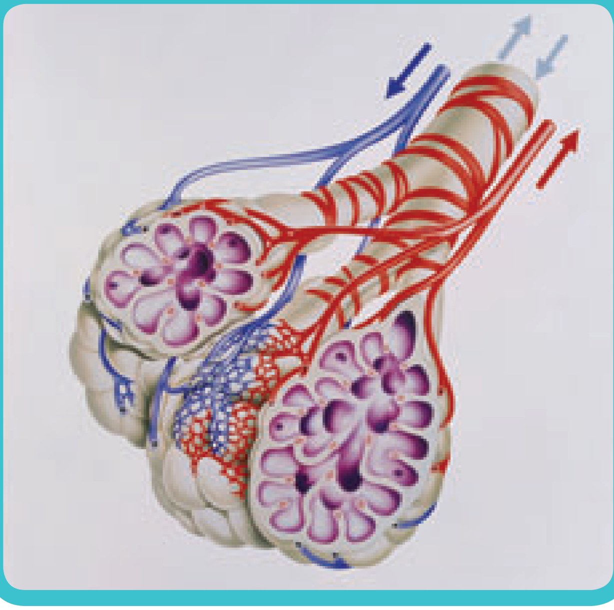
The major passages and structures of the respiratory system are the nasal cavity, pharynx, larynx, trachea and lungs. The lungs contain the bronchi, bronchioles and alveoli.

Fig 3.1.1



The relationship between the alveoli and the capillaries

Fig 3.1.2



Moving in and out

Cells require oxygen for metabolic activity involving the release of energy. Before it can be used for this process, however, oxygen needs to be transported from the atmosphere to the cells. Breathing, also called **ventilation**, is the initial process in transporting the air from the atmosphere into the lungs, where gas exchange occurs. The average adult breathes 9 to 20 times each minute, ventilating about 5 to 6 litres of air during this time. However, your breathing will increase or decrease depending on what you do. For example, if you perform strenuous exercise, your breathing rate and depth will increase; however, when you are sleeping your breathing slows. In each case your body's demand for oxygen varies, which in turn increases or decreases your rate of respiration.

The term 'respiration' can be defined broadly to include four related but separate processes: ventilation; **gas exchange** between the air and the blood; gas exchange between the blood and the tissues; and **cellular respiration**. Ventilation is a mechanical process, commonly called breathing, in which the lungs expand, taking air into the lungs, and compress, expelling the air. The second process, gas exchange between the alveolar air and blood, is sometimes called **external respiration**. The third process is the exchange of the gases between the blood and the tissues, sometimes called **internal respiration**. The fourth process is the utilisation of oxygen by the cells in the process of cellular respiration to release energy. Be careful not to confuse the various types of respiration. Even in books you may see the term 'respiration' used when only cellular respiration is meant.

Ventilation is a mechanical process in which air is moved in and out of the lungs. As the air brought into the lungs has a higher concentration of oxygen than that of the blood, oxygen moves from the air to the blood in a process called diffusion. Similarly, carbon dioxide moves from the blood to the alveolar air by diffusion.

Diffusion across membranes

Gas exchange between the air and blood occurs by the process of diffusion, through the millions of tiny alveoli. **Diffusion** is the process in which particles move from an area of higher concentration to one of lower concentration. This process occurs in both gases and liquids. You can see it happening when you put a tea bag into a cup of hot water, or you spray perfume into one corner of the room and smell it in another. Figure 3.1.3 shows that the molecules that give coffee its colour spread out until they are evenly distributed through the water. As the coffee dissolves the molecules closer to the coffee bag are more concentrated than those near the surface of the water or edges of the beaker. The difference in concentration that brings about diffusion is called the concentration gradient.

Prac 1 p. 82

Fig 3.1.3 Diffusion of coffee in a beaker of hot water

Diffusion occurs in the lungs because the concentration of gases in the blood is not the same as in the air of the lungs. If the concentration of oxygen molecules is greater in the air of the alveoli than inside the capillaries, more oxygen molecules will move into the blood until the concentrations are equal. At the same time as oxygen is diffusing into the

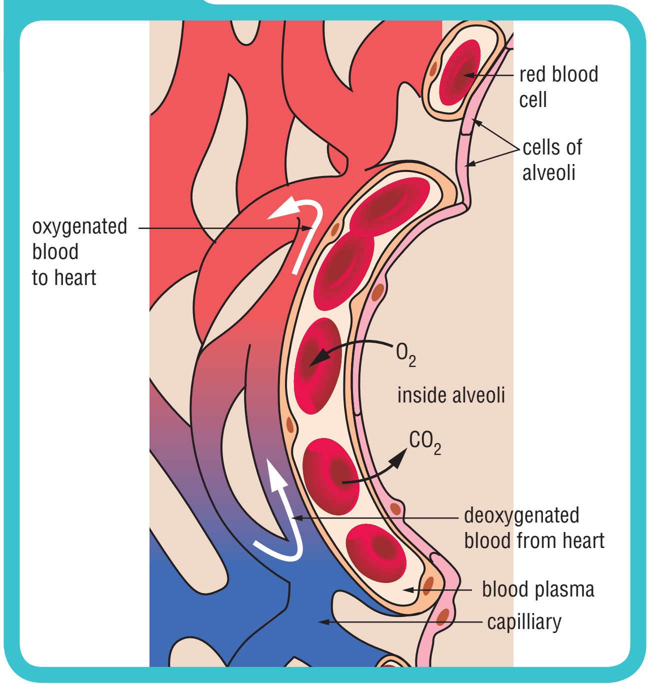


Fig 3.1.4 Gas exchange between the air inside the alveoli and the blood

capillaries, carbon dioxide is travelling in the opposite direction. This diffusion between the blood and air in the alveoli occurs very rapidly because there is a large surface area within the lungs and a very short diffusion distance between the blood and the air.

To assist in the process of respiration the respiratory surfaces are covered with thin, moist epithelial cells that allow oxygen and carbon dioxide to exchange. Those gases can cross cell membranes only when they are dissolved in water, so respiratory surfaces must be moist. As a result of this exchange there is a greater concentration of oxygen in the inspired air than in the expired air, and a greater concentration of carbon dioxide is expired than was inspired. This then means that the blood leaving the lungs through the pulmonary veins has a higher concentration of oxygen and a lower concentration of carbon dioxide than when it first entered the lungs through the pulmonary arteries.

Science Snippet

Breathing without lungs

There are many different ways that organisms obtain the oxygen they require for respiration. Simple animals that lack specialised exchange surfaces have flattened, tubular, or thin-shaped body plans, which are the most efficient for gas exchange. Flatworms and annelids, for example, use their outer body surfaces as gas exchange surfaces. Even some amphibians can use their skin as a respiratory surface as well as their lungs. Frogs eliminate carbon dioxide 2.5 times as fast through their skin as they do through their lungs.

Ventilation

The diaphragm flattens out when stimulated by a nervous impulse. The chest cavity contains the lungs. The volume of the cavity expands with the downward movement of the diaphragm, thus expanding the lungs. The rib muscles also contract when stimulated, which pulls the rib cage up and out, at the same time expanding the thoracic cavity.

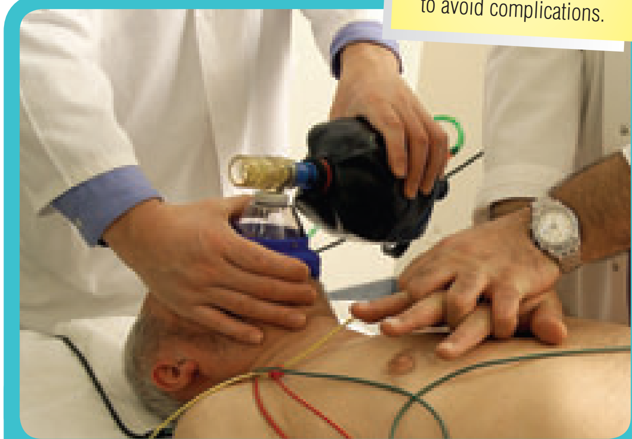


Fig 3.1.5 Artificial ventilation is a process in which the patient is assisted to breathe.

This movement reduces pressure in the chest. When the volume is increased in the thoracic cavity, air rushes into the lungs to equalise the pressure. This nervous stimulation is quick, and when it is over, the diaphragm and rib muscles relax and a person exhales.

Alveoli have thin elastic walls and can therefore expand as the chest cavity increases in size and pulls the lungs outwards. This allows air to flow into them when they expand. They recoil and collapse during exhalation.

Science Snippet

Artificial ventilation

Artificial ventilation may be used if somebody is in respiratory failure. However, there are many other times you may need assistance with ventilation, such as after an operation, if you are unconscious, if you are very sick and unable to protect your airway, or if you are so severely exhausted that respiratory failure may occur. The aim of mechanical or artificial ventilation is to improve gas exchange, to reduce the work of breathing and to avoid complications.

Science Snippet

Breathing problems

Although the automatic breathing regulation system allows you to breathe while you sleep, it sometimes malfunctions. Apnoea is the stoppage of breathing for as long as 10 seconds, in some individuals as often as 300 times per night. This failure to respond to elevated blood levels of carbon dioxide may result from a viral infection of the brain or a tumour, or it may develop spontaneously. A malfunction of the breathing centres in newborns may result in SIDS (sudden infant death syndrome).

Breathing control

To achieve oxygen delivery and carbon dioxide removal, the nervous system controls the flow of air in and out of the lungs while maintaining a regular rate and pattern of breathing. Regulation is controlled by the respiratory centre, a cluster of nerve cells in the brain. These cells simultaneously send signals to the muscles involved in inhalation: the diaphragm and rib muscles.

Breathing is an unconscious process carried out on a constant basis and is necessary for survival. Under normal conditions, a person takes 9 to 20 breaths per minute, although newborn infants breathe at a faster rate, at approximately 30 to 50 breaths per minute. The breathing rate set by the respiratory centre can be altered by conscious control, for example by holding the breath. This alteration occurs when the part of the brain involved in thinking, the cerebral cortex, sends signals to the diaphragm and rib muscles to momentarily ignore the signals from the respiratory centre. If a person holds their breath too long, carbon dioxide accumulates in the blood, which then causes the blood to become more acidic. The increased acidity interferes with the action of enzymes, which are specialised proteins that coordinate all biochemical reactions in the body.

To prevent too much acid from building up in the blood, special receptors called chemoreceptors, which are located in the brain and in the blood vessels of the neck, monitor the acid level in the blood. When acid levels are too high, these chemoreceptors send nervous signals to the respiratory centre, which overrides the signals from the cerebral cortex, forcing a person to exhale and then resume breathing.

The blood acid level is brought back to normal levels by exhalation, which expels the carbon dioxide. Irreversible damage to tissues occurs, followed by the failure of all body systems and, ultimately, death if the respiratory system's tasks are interrupted for more than a few minutes.

Carbon dioxide transport

Carbon dioxide concentration in metabolically active cells is much greater than in capillaries, so carbon dioxide diffuses from the body cells into red blood cells in the capillaries. Water in the red blood cells reacts with carbon dioxide to form the hydrogencarbonate ion, most of which diffuses back into the plasma. Packaging some of the carbon dioxide in red blood cells keeps the concentration of carbon dioxide in the body cells higher than in the blood, so diffusion of even more carbon dioxide from the cells into the capillaries continues. In the alveolar capillaries, carbon dioxide diffuses out into the alveolar air. This causes the hydrogencarbonate ion reaction to reverse and steadily release the carbon dioxide.

Oxygen transport

The presence of haemoglobin in the blood increases its oxygen-carrying capacity significantly. Haemoglobin is the pigment of red blood cells that transports oxygen and carbon dioxide. Oxygenated blood is blood with a high quantity of oxyhaemoglobin. Oxyhaemoglobin is bright red and is the reason that the blood in arteries (moving away from the heart), with the exception of the pulmonary arteries, is bright red. Haemoglobin is a darker red, and is the reason that the blood in the veins, with the exception of the pulmonary veins, is a darker red colour.

Fig 3.1.6 Feedback diagram of oxygen and carbon dioxide regulation

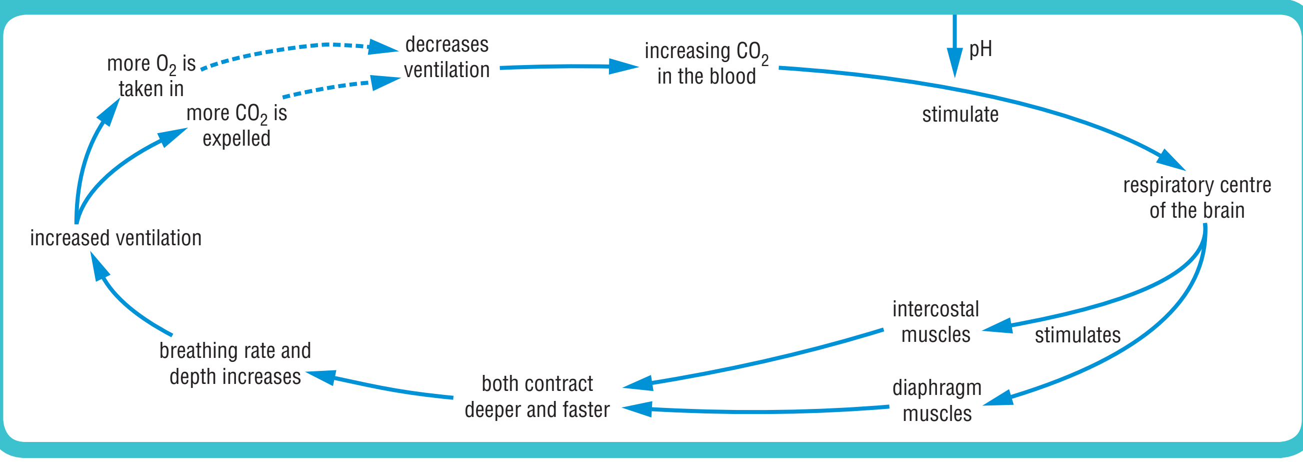
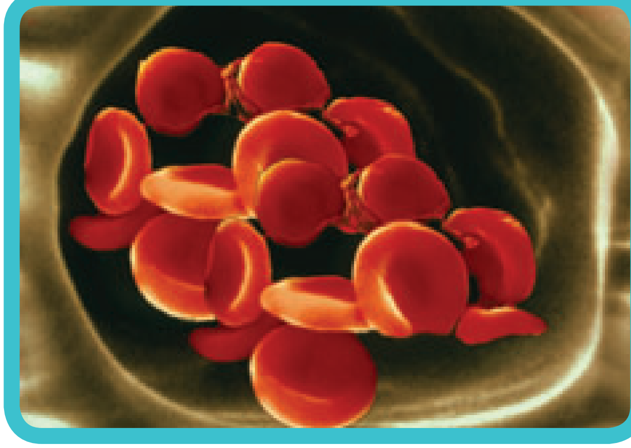


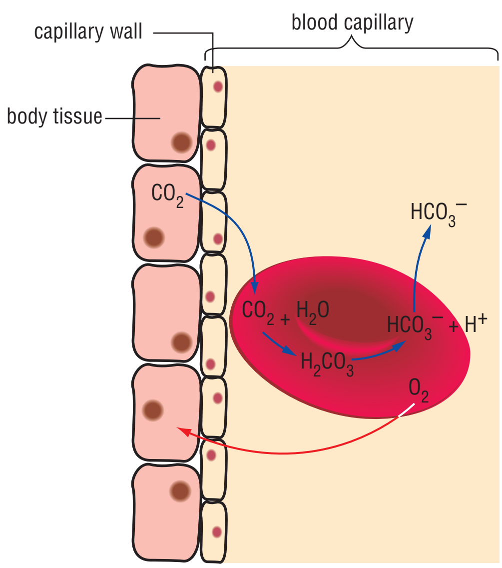
Fig 3.1.7 Red blood cells carry oxygen around the body to cells and tissues.



Within the capillaries surrounding the alveoli of the lungs, where oxygen concentration is quite high, oxygen diffuses readily into the blood, combining with the haemoglobin. As the tissues of the body are continually using oxygen, the concentration within the tissues is quite low. When blood flows through the capillaries surrounding the tissues of the body, the red blood cells readily give up their oxygen, which diffuses into the fluid surrounding the cells and then into the cells themselves.

Homework book 3.1 Regulation of heart rate and breathing

Fig 3.1.8 Oxygen and carbon dioxide movement between capillaries and tissue



Respiratory problems

Some of the most common symptoms of respiratory disorders are coughing, shortness of breath, chest pain, wheezing, bluish discoloration of the lips and/or skin, a crowing sound when breathing, coughing up of blood and respiratory failure. These symptoms do not necessarily indicate a respiratory problem; they can be a sign of another problem. For example, chest pain may be due to a heart or an intestinal problem.

The condition of the airways and the pressure difference between the lungs and atmosphere are important factors in the flow of air in and out of lungs. Many diseases affect the condition of the airways, such as asthma, bronchitis and cystic fibrosis (which causes excessive mucus production that clogs the airways). Diseases and disorders of the respiratory system can affect any part of the respiratory tract and their effects may range from mild to life-threatening. They include colds, hay fever and asthma, bronchitis, emphysema, pneumonia, tuberculosis, laryngitis and lung cancer. Abnormalities of breathing function—such as obstruction, weak breathing, muscle weakness, lung diseases, including pneumonia, and congenital abnormalities—can lead to the failure of respiratory processes.

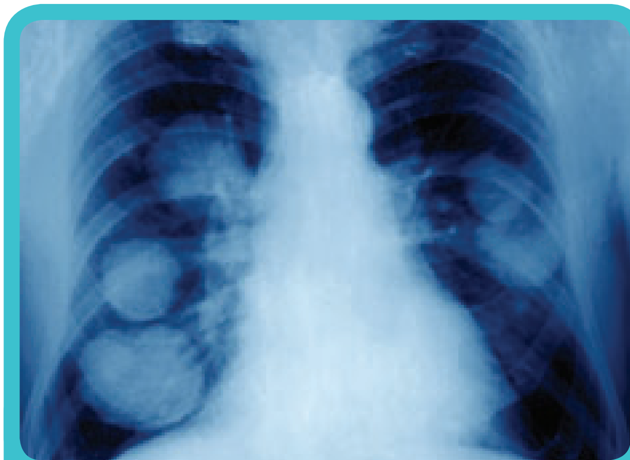


Fig 3.1.9 Smoking can cause problems such as laryngitis or lung cancer. The damaged lungs in this X-ray show the long-term effects of smoking.

Acidosis is a condition resulting from higher-than-normal acid levels in the body fluids. It is not a disease but may be one of the indicators of a disease. Respiratory acidosis is due to a failure by the lungs to remove carbon dioxide, therefore reducing the pH in the body. Several conditions, such as chest injury, blockage of the upper air passages and severe lung disease, may result in respiratory acidosis. Blockage of the air passages may be due to bronchitis, asthma or airway obstruction and may result in mild or severe acidosis.

Alkalosis is a condition resulting from a higher-than-normal base or alkali levels in the body fluids. Respiratory alkalosis results from decreased carbon dioxide levels caused by such conditions as hyperventilation (a faster breathing rate), anxiety and fever. The pH becomes elevated in the body. Symptoms of respiratory alkalosis include dizziness, light-headedness and numbing of the hands and feet. Treatments include breathing into a paper bag or a mask, which induces rebreathing of carbon dioxide.

Fig 3.1.10

Why do you think you would need to take oxygen with you if you were climbing to high altitudes?

Respiratory failure is any condition that affects breathing function or the lungs themselves, leading to an inability of the lungs to function properly. In respiratory failure, the level of oxygen in the blood becomes dangerously low and/or the level of carbon dioxide becomes dangerously high. There are two ways this can happen. Either the process by which oxygen and carbon dioxide are exchanged between the blood and the air spaces of the lungs breaks down, or the movement of air in and out of the lungs (ventilation) does not take place properly.

Science Snippet

Breathing by machine

A patient whose breathing remains very poor after first aid or treatment will require a ventilator to aid breathing. A plastic tube is placed through the nose or mouth into the windpipe and is attached to a machine that forces air into the lungs. This can be a lifesaving treatment and is continued until the patient's own lungs can take over the work of breathing.

3·1 FOCUS [Questions]

Use your book

The respiratory system

1 What structures are included in the respiratory system?

2 List in order the major passages and structures through which inspired air passes from the nostrils to the alveoli of the lungs.

3 What is the primary function of the respiratory system?

4 Through what vessel is the blood pumped from the heart to the lungs?

Moving in and out

5 How often does the average adult take a breath?

6 Explain the difference between internal respiration, external respiration and cellular respiration.

7 Define the term 'ventilation'.

8 What is artificial ventilation?

Diffusion across membranes

9 What is the physical process by which gas exchange occurs in the body?

10 Define the process of diffusion.

11 Why does diffusion of oxygen occur in the lungs?

Breathing control

12 Can you consciously change your breathing rate?

13 Explain the mechanism that forces you to breathe when you are trying to hold your breath for as long as possible.

Carbon dioxide transport

14 How does the body 'package' carbon dioxide for removal from the body?

Oxygen transport

15 What is haemoglobin and what is its function?

16 How does the appearance of blood tell you that it is oxygenated?

Respiratory problems

17 What are some of the symptoms of respiratory disorders?

>>

18 What conditions affect the flow of air in the lungs?

19 Why may higher-than-normal acid levels be an indicator of disease?

Use your head

20 The lungs are able to achieve sufficient gas exchange for efficient body functioning because of their large surface area. Explain how such a large surface area can be achieved in the small space available.

21 Consider the oxygen levels of the blood in the pulmonary artery, pulmonary vein, aorta and femoral artery.

- **a** Order the four samples from approximate highest oxygen level to approximate lowest oxygen level.
- **b** Would there be any other difference in the blood found in these organs?

22 How would a respiratory disorder such as asthma affect your ability to exercise? Explain how the mechanism by which cystic fibrosis limits exercise ability differs from that for asthma.

Investigating questions

23 Research why it would be dangerous to work in a closed garage with the car engine running. Be sure to explain the chemical basis of the problems caused by breathing the exhaust fumes.

DYO

24 Research what equipment you would need to take with you to ensure respiratory health if you were climbing to high altitudes. At what altitude is this additional equipment needed?

FOCUS 3·1

[Practical activity]

Prac 1 Focus 3.1

Diffusion

Purpose

To model the movement of substances across membranes in the body.

Requirements

Two 30 cm lengths of dialysis tubing, two 500 mL beakers, distilled water, measuring cylinder, labels, two eye droppers, iodine solution, starch solution, funnel, glucose solution, testape, two test tubes.

Procedure

1. Place both pieces of dialysis tubing in a beaker of distilled water and soak for a few minutes.
2. Tie a firm knot at one end of both pieces of dialysis tubing.
3. Fill both beakers with 300 mL water then label both beakers.
4. Add five drops of iodine to one of the beakers.
5. Fill one of the dialysis tubes with starch solution (you may wish to use a funnel to do this) then tie the top to seal the tubing. Wash the tube under water to remove any excess solution that may have spilt on the outside.
6. Place this tube in the beaker containing water and iodine.
7. Fill the second dialysis tube with glucose solution then tie the top of the tubing. Wash the outside of the tube to remove any excess solution that may have spilt.
8. Place this tube in the beaker containing only water.
9. Observe the colour of the liquid in each tube and test the liquid in the beakers with a piece of testape. *Record your results.*
10. Place some starch solution in a test tube and add several drops of iodine. *Record your observations.*
11. Place some glucose solution in a test tube and dip some testape in it. *Record your observations.*
12. After 30 minutes test the liquid in the beakers again and *record any observations.*
13. You may choose to leave the solutions overnight to see what happens over a longer period of time.

Questions

1. What was being tested for in each solution?
2. In which direction did various substances move and how did you infer this?
3. Suggest why this may have been able to occur. A diagram may assist your explanation here.
4. How is the dialysis tubing similar to the tissues in your body?
5. Design an experiment similar to this that tests the movement of carbon dioxide through tissues. (Hint: you may wish to use limewater, carbonate and hydrochloric acid.)

FOCUS 3.2 Cellular reproduction

Context For a species to survive, it needs to be able to reproduce. All organisms have characteristics that enable them to survive successfully in their environment. The inheritance of these characteristics in both simple and complex organisms occurs through sexual or asexual reproduction. In this Focus you will study these processes at a cellular level.

Cell division

A fundamental property of all living organisms is their ability to grow. At the cellular level this occurs through the synthesis of proteins, carbohydrates, lipids and other compounds. As a cell grows, the membrane surrounding the cell must expand to allow for the cell's increasing volume. A cell cannot continue to grow indefinitely, however, as it will not be able to continue to effectively exchange materials with its environment. It is for this reason that cell growth must be accompanied by cell division, where a cell will produce two daughter cells.

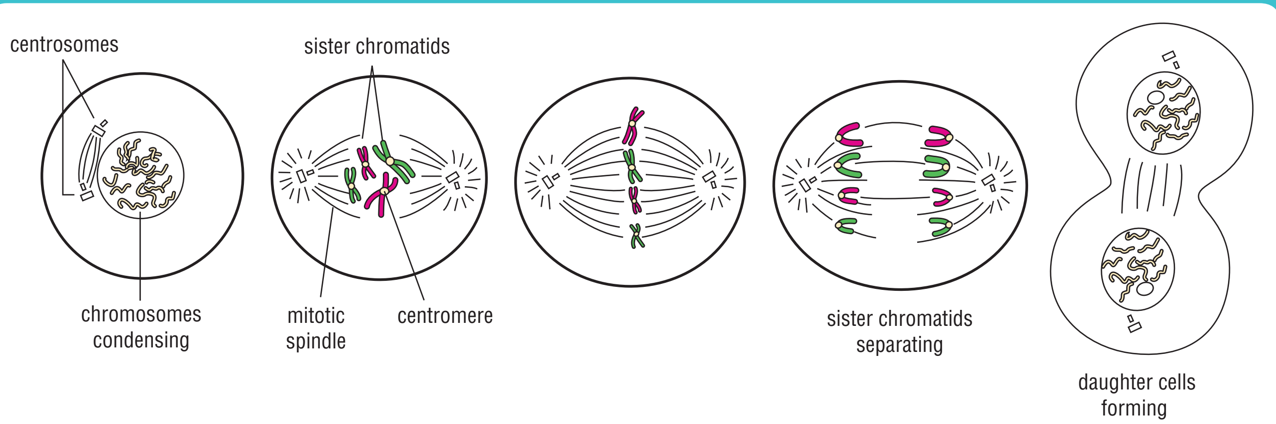
For single-celled organisms such as bacteria, cell division results in an increase in the total number of organisms in a population. In multicellular organisms, cell division either increases the number of cells in the organism, leading to growth of the organism, or replaces cells that have died. For example, in an adult human, millions of stem cells within bone marrow divide every second to maintain a constant number of red blood cells in the body. The new cells replace the approximately one per cent of blood cells that die each day.

An important feature of this division process is the faithful genetic duplication of the parent cell, containing the same (or almost the same) genetic sequences. Therefore, in the generation of two daughter cells from a single parent cell, all the genetic information present in the nucleus of the parent cell must be duplicated and carefully split between the two daughter cells until the division of that cell into two. This process or sequence of events is called the **cell cycle**.

The most dramatic event in the life of a cell is the process of cell division, which can be seen through a microscope. The division phase or M phase (mitotic phase) consists of two processes, in which the nucleus divides first, and then the cytoplasm. This nuclear division is called mitosis. In mitosis, the mitotic spindle separates the duplicated, condensed chromosomes into two daughter nuclei and the cytoplasm then divides to separate the two identical daughter cells (see Figure 3.2.1).

Before mitosis begins, during **interphase** the DNA replicates itself. In 1953 James Watson and Francis Crick proposed a DNA model in which a pair of templates is wound into a double helix shape.

Mitosis, the process of cell division, is the most distinctive part of the cell cycle. **Fig 3.2.1**



Each template is like a chain and is complementary to the other. Before duplication, each of these chains unwinds and separates. Each chain then acts as a template for the formation onto itself of a new companion chain, so that eventually there are two pairs of chains where previously there was only one. You can see this in Figure 3.2.2. In this process the base pairs duplicate exactly according to the base pairing rules. A pairs with T, and G with C (A, T, C and G stand for adenine, thymine, cytosine and guanine **nucleotides**). The hydrogen bonds that join the complementary bases can be seen in Figure 3.2.2.

Fig 3.2.2 In 1953, Watson and Crick proposed the DNA double helix model. In their model of replication the double-stranded helix unwinds, and each parent strand serves as a template for the synthesis of a complementary daughter strand.

Mitosis

Mitosis can be described as a series of five phases, based primarily on the appearance and behaviour of the chromosomes. These five phases are **prophase**, **prometaphase** or late prophase, **metaphase**, **anaphase** and **telophase**. These phases are represented in Figure 3.2.3. As you follow the phases that represent mitosis you should remember that the overall purpose of this process is to ensure that each of the two daughter nuclei receive one copy of each duplicated chromosome.

In prophase, the chromosomes begin to condense to the point of being visible threads; each chromosome has been duplicated and now consists of two sister **chromatids** (Figure 3.2.3b). The sister chromatids are tightly attached to each other at a constricted region called the **centromere**. As the chromosomes condense, the nucleolus gradually disappears. During prophase the **centrioles** within the cell (discussed in Focus 3.1 of *Science Aspects 3*) made of microtubules disassemble and begin to reassemble to form the **mitotic spindle**. This apparatus will distribute the chromosomes to the daughter cells.

The start of prometaphase is marked by the fragmentation of the nuclear membrane, which allows the mitotic spindle to enter the nuclear area. Eventually the two centrosomes (a cloud of material that surrounds the centrioles) are at opposite poles of the cell (Figure 3.2.3c). Forces exerted within the assembly of the microtubules throw the chromosomes into agitated motion and gradually move them toward the centre of the cell.

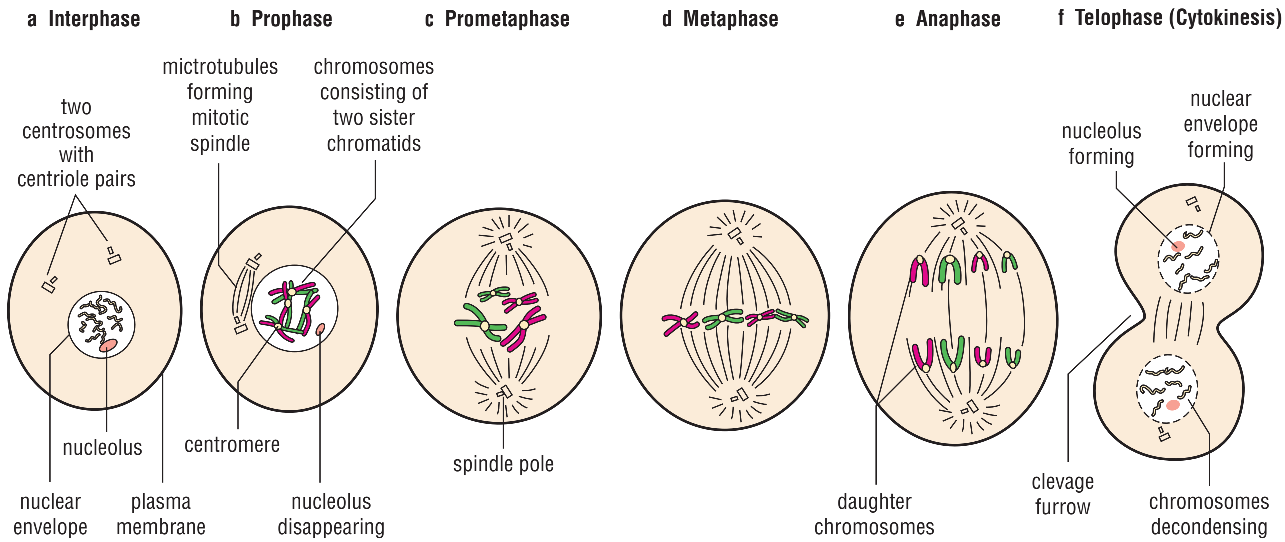
The cell is said to have entered metaphase when the chromosomes are all aligned at the **metaphase plate**, the plane of equal distance between the two poles of the mitotic spindle (Figure 3.2.3d). The chromosomes appear to be relatively stationary at metaphase, though this appearance is misleading, as sister chromatids are already being tugged towards their respective poles. They appear stationary because the forces acting on them are equal in magnitude and opposite in direction.

Anaphase is usually the shortest phase of mitosis. The two sister chromatids of each chromosome separate and move towards opposite poles of the cell (Figure 3.2.3e). All chromatid pairs start to separate at the same time, with the daughter chromosomes moving towards the spindle poles. The poles themselves also begin to move away from each other.

By the beginning of telophase, the daughter chromosomes have arrived at the poles of the spindle (Figure 3.2.3f). During telophase the chromosomes uncoil, the spindle disappears and nuclear membranes form around the two groups of daughter chromosomes, completing the mitotic process as the cytoplasm divides in a process called **cytokinesis**. Cytokinesis usually starts during late anaphase or telophase, as the nuclei are re-forming. In animals the cytoplasmic division is called cleavage. Cleavage begins as a slight indentation that deepens into a cleavage furrow, which is always perpendicular to the mitotic spindle, thereby ensuring that the two sets of chromosomes will be separated into their respective daughter cells. The furrow continues to deepen until opposite surfaces make contact and the cell splits in two.

Prac 1 p. 90

Fig 3.2.3 The phases of mitosis in an animal cell. Only four chromosomes have been drawn so that detail not visible on the micrograph in Figure 3.2.4 can be seen.



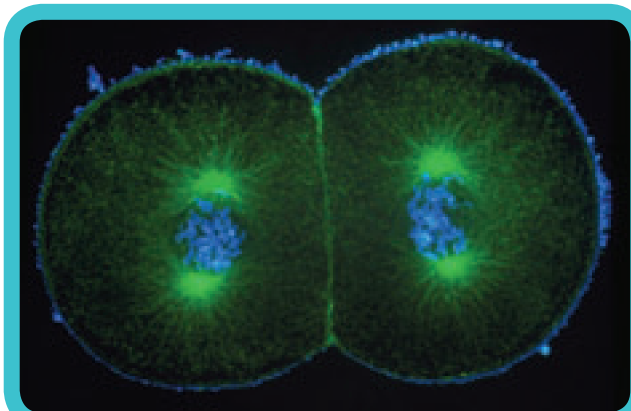


Fig 3.2.4 The micrographs show mitosis in cells from sea urchin embryo. The mitotic spindle can be seen in the metaphase and anaphase micrographs.

Because mitosis involves the formation of identical chromatids, the daughter cells of every mitotic division are genetically identical, or nearly so. Mitotic division is an excellent way to perpetuate specific genetic traits faithfully, and is the basis for all **asexual reproduction**. In asexual reproduction new individuals are generated by a single parent organism, either unicellular or multicellular. Asexual reproduction is widespread in nature and though it always involves mitosis, the details are different with each type of organism.

Asexual reproduction, in an evolutionary sense, can be an efficient and successful mode of perpetuating the species. As long as the population's environment remains constant, asexual reproduction is adequate for maintaining the survival of the population. If a population is already well adapted to its environment, the genetic predictability of asexual reproduction suits the stable environment. If the environment changes, however, such a population is not well equipped to deal with this change and new conditions. In a changing environment, a sexually reproducing population will usually have the advantage.

Sexual reproduction

The fundamental characteristic of asexual reproduction is that all offspring are genetically similar to the single parent organism from which they formed through mitosis. **Sexual reproduction**, however, involves the mixing of genetic information from two parent organisms and results in offspring that are genetically dissimilar, from both each other and their parents. That is why we cannot anticipate exactly the combination of genetic information a particular offspring will receive from its two parents. Biologists have concluded that the offspring resulting from sexual reproduction must have some distinct advantages as most plants, animals and some microorganisms reproduce this way. They believe sexual reproduction arose through natural selection because of the survival advantages it offered.

The major advantage of sexual reproduction over asexual reproduction is that the sexual process can combine in a single individual the advantageous characteristics that have arisen in two

Humans reproduce through sexual reproduction, generating great variation in the population.

Fig 3.2.5

separate individuals. In this way, sexual reproduction can generate great variety among the individuals that make up a population.

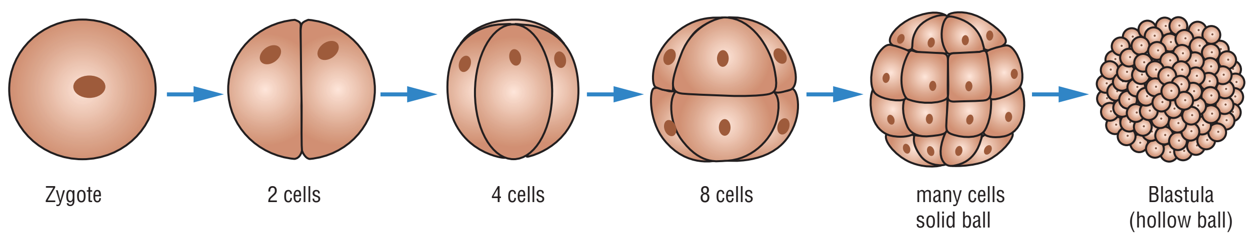
Genetic modifications ultimately depend on the occurrence of **mutations**, which are the unpredictable alterations in the DNA that involve changes in the nucleotide sequence. These changes can result either from base changes or from the rearrangement of DNA segments. Mutations are rare events and beneficial mutations are even rarer. When a beneficial mutation occurs, it is clearly an advantage to the population if the mutation is preserved. It can be even more advantageous if several desirable mutations combine in a single individual; and there lies the fundamental advantage of sexual reproduction. Although mutations occur in both asexual and sexual species, only sexual reproduction can readily bring together beneficial mutations that originally occurred in two separate individuals.

The basis of sexual reproduction is that it brings together in a single individual the genetic information contributed by two parents. At some point in the life cycle, every sexually reproducing species has cells with two sets of chromosomes, one set inherited from each parent (or the male and female gonads of hermaphrodites). The corresponding chromosomes, one from each set, are called **homologous chromosomes**. This is shown in Figure 3.2.7. Two homologous chromosomes carry the same line-up of genes, although for a given gene, the two versions may be slightly different in their nucleotide sequence. Because the offspring has two sets of chromosomes, said to be **diploid**, each parent must contribute only a single copy of its chromosomes, called **haploid**. Haploid cells that are specialised for reproduction are called **gametes**, and the process that produces them is **gametogenesis**.

Biologists distinguish between male and female individuals on the basis of the gametes that they produce. Gametes produced by the female are called eggs or **ova**. They are specialised for the storage of nutrients, are relatively large and cannot move without assistance. The male gametes, called **sperm**, are much smaller than the ovum, have a whip-like flagella and are specialised for movement. The union of the sperm and ovum is called **fertilisation**. The fertilised egg that results, called a **zygote**, is diploid, having received one chromosome set from the sperm and one from the ovum. In the next stages of the life cycle for multicellular organisms, fertilisation is followed by **development**. Development involves a series of mitotic divisions and then progressive specialisation of various groups of cells to form a multicellular embryo and eventually an adult. The female ovum is very much larger than the male sperm and has enough cytoplasm to sustain many rounds of division after fertilisation. Each division during early development parcels the cytoplasm into smaller cells. Eventually, a hollow ball of cells, called the blastula, is produced. This is shown in Figure 3.2.6.

Cleavage of a fertilised egg into progressively smaller cells

Fig 3.2.6



Meiosis

The gametes required for sexual reproduction are haploid cells and therefore cannot be generated from diploid cells, through the process of mitosis. This is because the daughter cells of mitotic division are genetically identical to the parent cell, and therefore have a diploid chromosome number. The zygote formed from this union would have twice the number of required chromosomes. Since we know this is not the case, another kind of division must occur to maintain the consistency of chromosome number from generation to generation. That process, first described in the 1880s, is called **meiosis**.

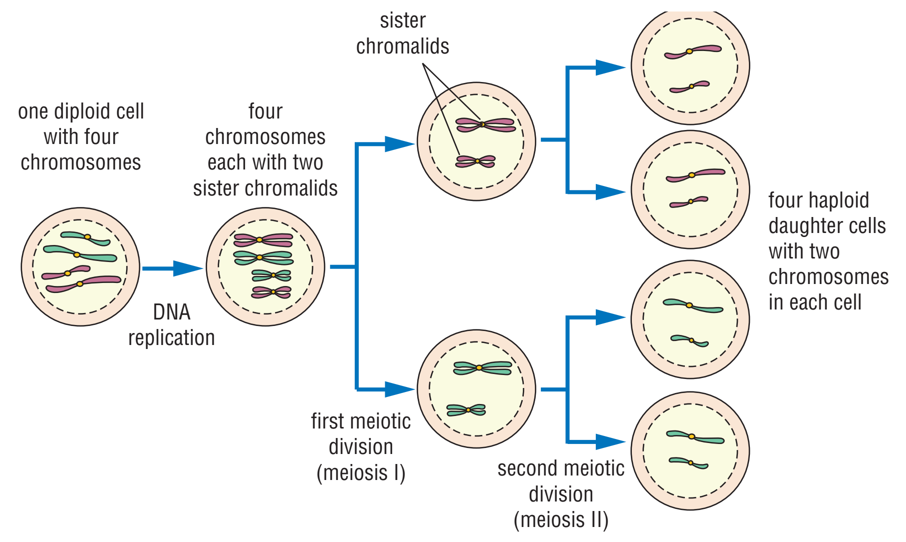


Fig 3.2.7 The process of meiosis involves a single round of DNA replication in a diploid cell followed by two successive cell division events.

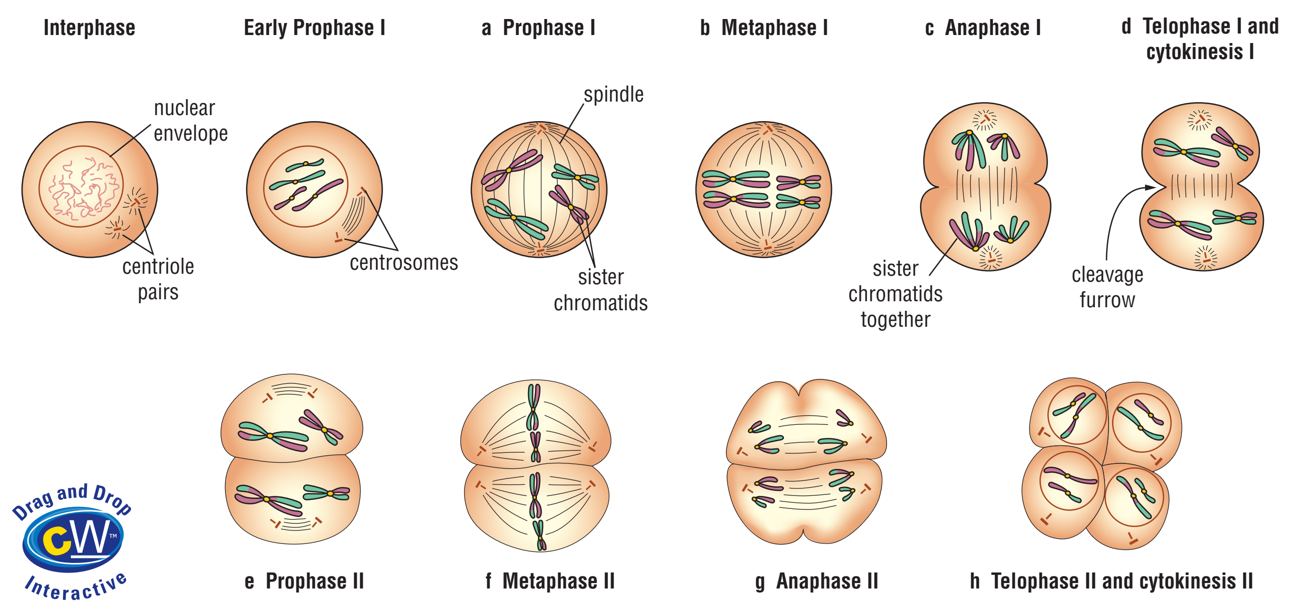
Meiosis can be described as two successive nuclear divisions following a single duplication of the chromosomes. The products of this process are four daughter cells, with only one set of chromosomes per nucleus. Figure 3.2.7 outlines this process, starting with a diploid cell with only one set of chromosomes. During the first meiotic division the homologous chromosomes separate, but sister chromatids remain attached. In the second meiotic division, sister chromatids separate, resulting in four haploid daughter cells with two chromosomes each. In Figure 3.2.7 you should note that each haploid cell has one chromosome from each homologous pair that was present in the diploid cell.

The interphase prior to meiosis is similar to mitotic interphase in that the DNA replicates and the chromosomes double. Meiosis consists of two successive divisions, called meiosis I and II, with no intervening chromosome duplication. This is the feature of meiosis that is of the greatest genetic significance because it is at this stage in the life cycle of the organism that the two alleles for each gene part company. It is this separation of alleles that makes possible the eventual 're-combination' of different pairs of alleles at fertilisation.

During prophase, the chromosomes, already duplicated during interphase, condense and the two centrosomes migrate to opposite ends (poles) of the cell (Figure 3.2.8a). Each chromosome consists of two sister chromatids. During metaphase homologous chromosomes pair up and align at the metaphase plate (Figure 3.2.8b). During anaphase, homologous chromosomes separate, but sister chromatids remain attached at the centromere (Figure 3.2.8c). Telophase then follows, with the sister chromatids arriving at the poles of the spindle (Figure 3.2.8d). The spindle disappears and nuclear membranes form around the two groups of sister chromatids, completing the first stage of meiosis as the cytoplasm divides in a process called cytokinesis. In meiosis II, chromosomes recondense during prophase (Figure 3.2.8e) and a second metaphase plate forms during metaphase (Figure 3.2.8f). Sister chromatids at last separate during anaphase (Figure 3.2.8g) and after telophase (Figure 3.2.8h) and cytokinesis. The result is four haploid daughter cells, each containing one chromosome of each homologous pair. Meiosis in plants is similar, except for the absence of centrioles and the mechanism of cytokinesis.

Homework book 3.2 Cell division

Interactive CW Animation



Meiosis I and II in an animal cell **Fig 3.2.8**

Gamete formation

The process of meiosis is similar in all organisms, although other aspects of gamete formation vary. In male animals, meiosis leads to four haploid cells of the same size. These cells subsequently differentiate into sperm cells by losing most of their cytoplasm and acquiring long flagella and other specialised structures, as shown in Figure 3.2.10. In female animals, however, only one of the four haploid cells survives and gives rise to a functional egg cell, as shown in Figure 3.2.10. This is because the two cell divisions are unequal, with only one of the daughter cells receiving the bulk of the cytoplasm of the original diploid cell. The other three cells, called polar bodies, are much smaller and they degenerate. By the time meiosis is complete the egg cell is 'mature' and ready for fertilisation.

Both gametes are highly specialised cellular structures for fertilisation. In animals, enzymes are released from the membrane-bound sac at the front of the sperm. These enzymes dissolve the egg cell's outer coat and specific proteins on the sperm's surface bind to receptors on the egg cell after fusion of the plasma membranes of sperm and egg. The sperm nucleus enters the egg and fuses with the egg nucleus, generating a diploid cell, the zygote. This fusion of the plasma membranes triggers important changes in the egg. The fertilised egg quickly develops a barrier to prevent the entry of additional sperm and undergoes a burst of metabolic activity in preparation for embryonic development.

Science Snippet

The big egg

A human egg cell has a diameter of about 100 μm, giving it a volume more than 100 times larger than that of the diploid cell from which it arose. Now consider the size of a hen's egg, and how much larger it is than the cell from which it arose.

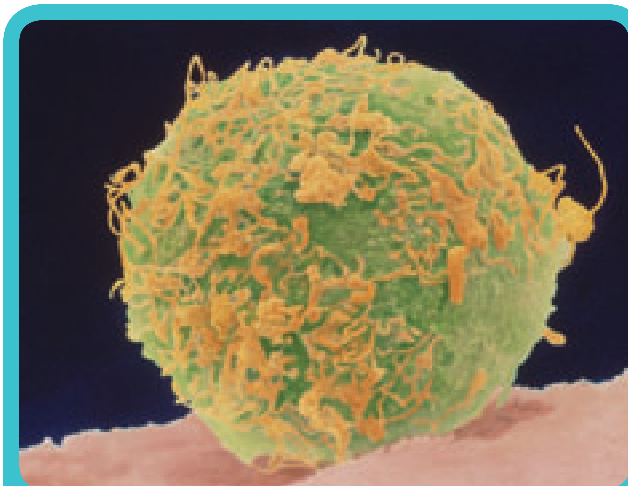
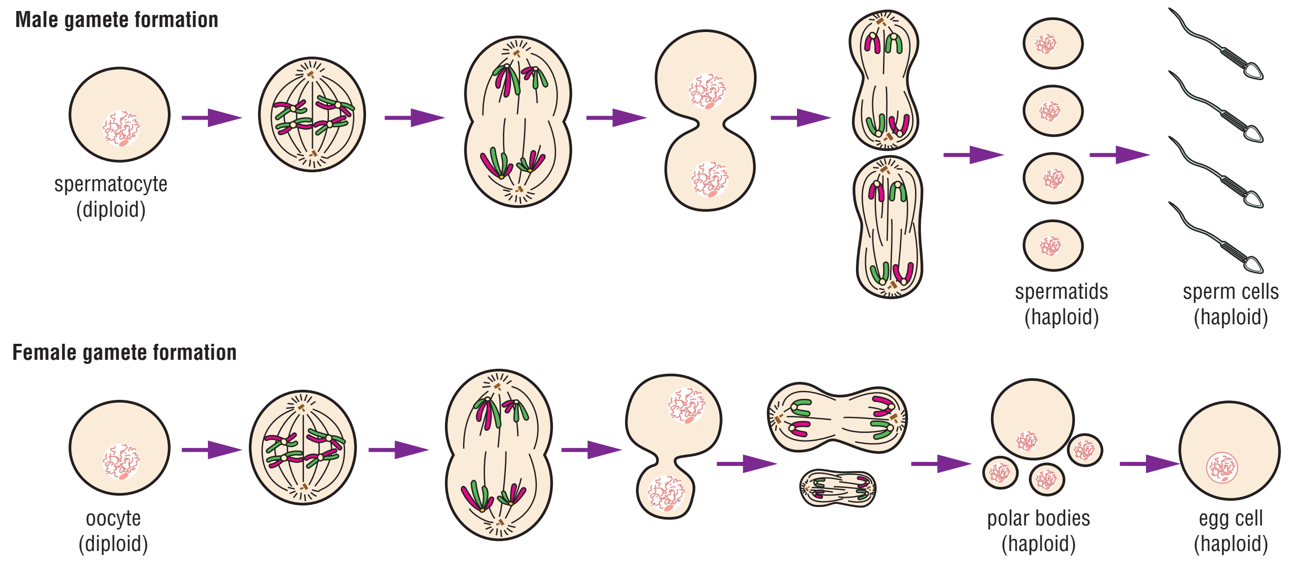


Fig 3.2.9 The fusion of ovum and sperm

Fig 3.2.10 In the male (a), all four haploid products of meiosis are retained and mature into sperm. In the female (b), both meiotic divisions are asymmetric, forming one large egg cell.



As discussed above, meiosis preserves the chromosome number in sexually reproducing organisms. If not for the process of meiosis, gametes would have as many chromosomes as all of the other cells in the body, and the chromosome number would double with each generation. In humans each gamete has 23 chromosomes, while body cells have 46 chromosomes. This is important to ensure that each generation has the same number of chromosomes. The failure of chromosomes to separate in the second division is called **non-disjunction**. When this occurs the resulting cells have too many chromosomes or, alternatively, too few chromosomes. When this occurs the offspring may have certain disorders such as Down syndrome, Fragile-X or Turner syndrome.

Homework book 3.3 Mutations

Person with Trisomy 21, also called Down syndrome. Fig 3.2.11

3·2 FOCUS [Questions]

Use your book

Cell division

1 Why does cell division occur?
2 When single-celled organisms divide, what is the result?
3 In 1953, Watson and Crick proposed a model of replication. What was this model?
4 What is the name of the process of nuclear division resulting in two daughter nuclei?
5 Name the base pair for each of the following nucleotides: adenine, cytosine, thymine and guanine.

Mitosis

6 List the phases involved in mitosis.
7 Draw the phases of mitosis into your notebook.
8 What process is the basis for asexual reproduction and why?
9 When is asexual reproduction advantageous in a population?

>>

Sexual reproduction

10 What is the major difference in the organisms produced by asexual and sexual reproduction?

11 What is the evolutionary advantage of sexual reproduction over asexual reproduction?

12 What are mutations and what effect can they have on organisms?

13 What is the difference between diploid and haploid cells?

14 What are the gametes produced by the male and female called?

15 What is the union of the sperm and ovum called?

Meiosis

16 Give a simple description of meiosis.

17 How are the process and outcome of meiosis different from mitosis?

18 In what type of cell does meiosis occur?

Gamete formation

19 Are ovum and sperm diploid or haploid?

20 What is non-disjunction?

Use your head

21 Down syndrome is a genetic disorder associated with heart and respiratory defects and varying degrees of mental retardation, in addition to other problems. It results from the presence of an entire extra chromosome (chromosome 21) in each of the diploid cells of the afflicted person. The extra chromosome usually derives from a mistake in meiosis, during the formation of the egg or sperm by one of the parents. What kind of mistake in meiosis do you think probably would lead to a gamete with an extra copy of one of the chromosomes?

22 After reading this Focus you should be able to identify a cell as diploid or haploid. For each of the following state if the cell would be diploid or haploid:

a a zygote immediately after fertilisation
b a daughter cell following mitosis
c a sperm cell
d a cardiac muscle cell
e a nucleus in mitotic prophase
f the cell during metaphase 11 of meiosis.

23 Describe several places where mitosis and meiosis would occur in a flowering plant.

Investigating questions

24 Investigate what tests are available for a mother to determine possible genetic abnormalities of her unborn child. Are there risks associated with these tests?

25 Research the biologists Watson and Crick. Who were they and what did they do?

26 Design a display of meiosis. This may be in the form of a poster or computer presentation, or you could build a model using lollies. Use your imagination!

DYO

27 Ask your teacher for some microscope slides of plant tissues. See if you can find meiosis occurring.

DYO

FOCUS 3·2 [Practical activity]

Observing mitosis

Prac 1
Focus 3.2

Purpose

To observe cells in the process of mitosis on prepared slides under the microscope.

Requirements

Prepared slides of plant cells showing mitosis, microscope.

Procedure

1 Select a slide from those provided.

2 Use the low power objective on your microscope to look for thin layers of cells and then use the high power objective to observe mitotic stages in individual cells. Try to find cells at each of the mitotic stages of division.

3 *Draw diagrams of cells in each of these phases.*

4 Go to the *Science Aspects 4* Companion Website at **www.pearsoned.com.au/schools** for a link to a site that shows the stages of mitotic division.

Questions

1 Label each of your drawings with the phase of mitosis and order them chronologically.

2 How do you know that you are looking at cells undergoing mitosis and not meiosis?

3 Why could you not see chromosomes in all of the cells?

FOCUS 3.3 Reproduction and pregnancy

Context The reproductive system is responsible for producing, storing and releasing specialised cells called gametes, then transporting them to a place where fertilisation can occur. The fertilised egg, now called a zygote, begins to divide, becoming an embryo. The embryo must be maintained within the body during the critical stage of development called pregnancy.

The human reproductive system

The reproductive system is different in the male and female of the species. Sexually mature males and females produce sex cells. These cells are called gametes and are brought together and fuse in the process of fertilisation, forming a zygote, which then develops into a new organism. All the cells in the body are the mitotic descendants of the single fertilised zygote. The structure of the male and female reproductive systems are briefly described here; further detail can be found in Focus 4.4 of *Science Aspects 2*.

The main components of the male reproductive system are detailed in Figure 3.3.1. When looking at this system you can identify the journey of the male sex cells. From the testes, the sperm cells, or spermatozoa, travel along the epididymis, vas deferens and the urethra before leaving the body. Accessory organs, the seminal vesicles, prostate gland and the bulbourethral glands, secrete liquids into the vas deferens and urethra. Externally, the structures that are visible include the scrotum, which encloses the testes, and the penis, an erectile organ that surrounds part of the urethra. Together they constitute the external genitalia of the male.

The main components of the female reproductive system are detailed in Figure 3.3.2. The female reproductive system consists of ovaries and secondary sex organs, including the vagina, uterine tubes, uterus and mammary glands. Eggs are produced in the ovary of the female before birth. Following puberty, when ova begin to mature, usually one ovum is released each month in a process called **ovulation**. After ovulation, the finger-like projections of the fallopian tube are lined with cilia, which draw the ovum into the fallopian tube, where fertilisation can take place. If the egg is fertilised, it passes into the uterus, where

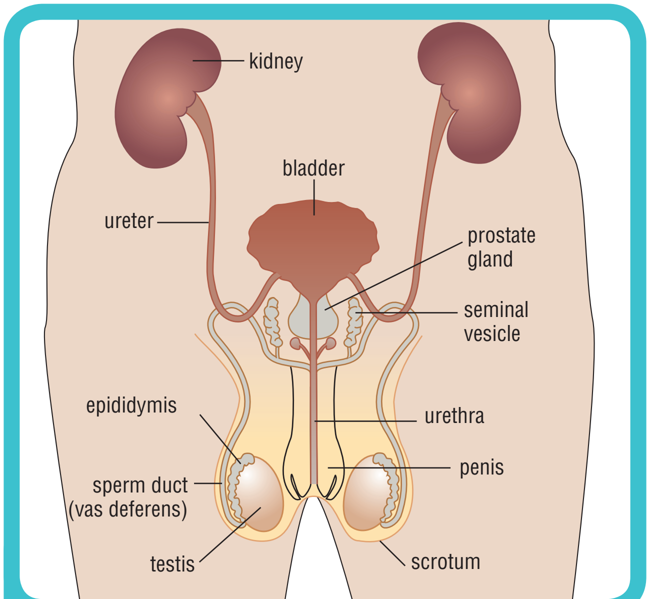
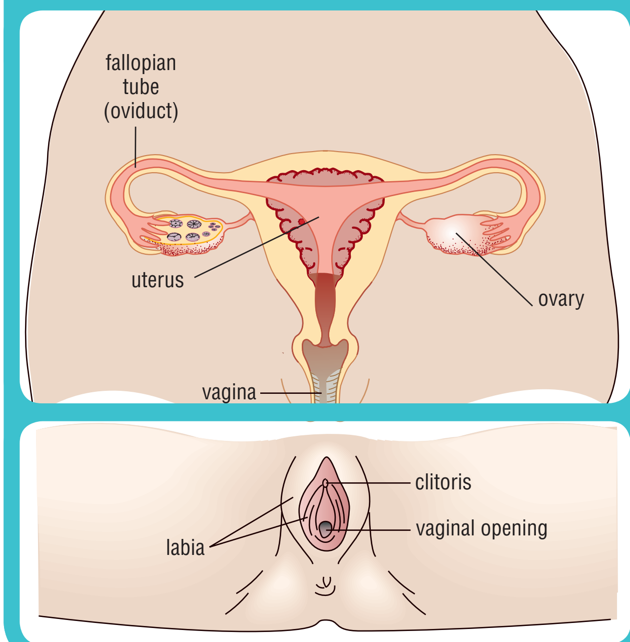


Fig 3.3.1 The male reproductive organs

Fig 3.3.2 The female reproductive organs



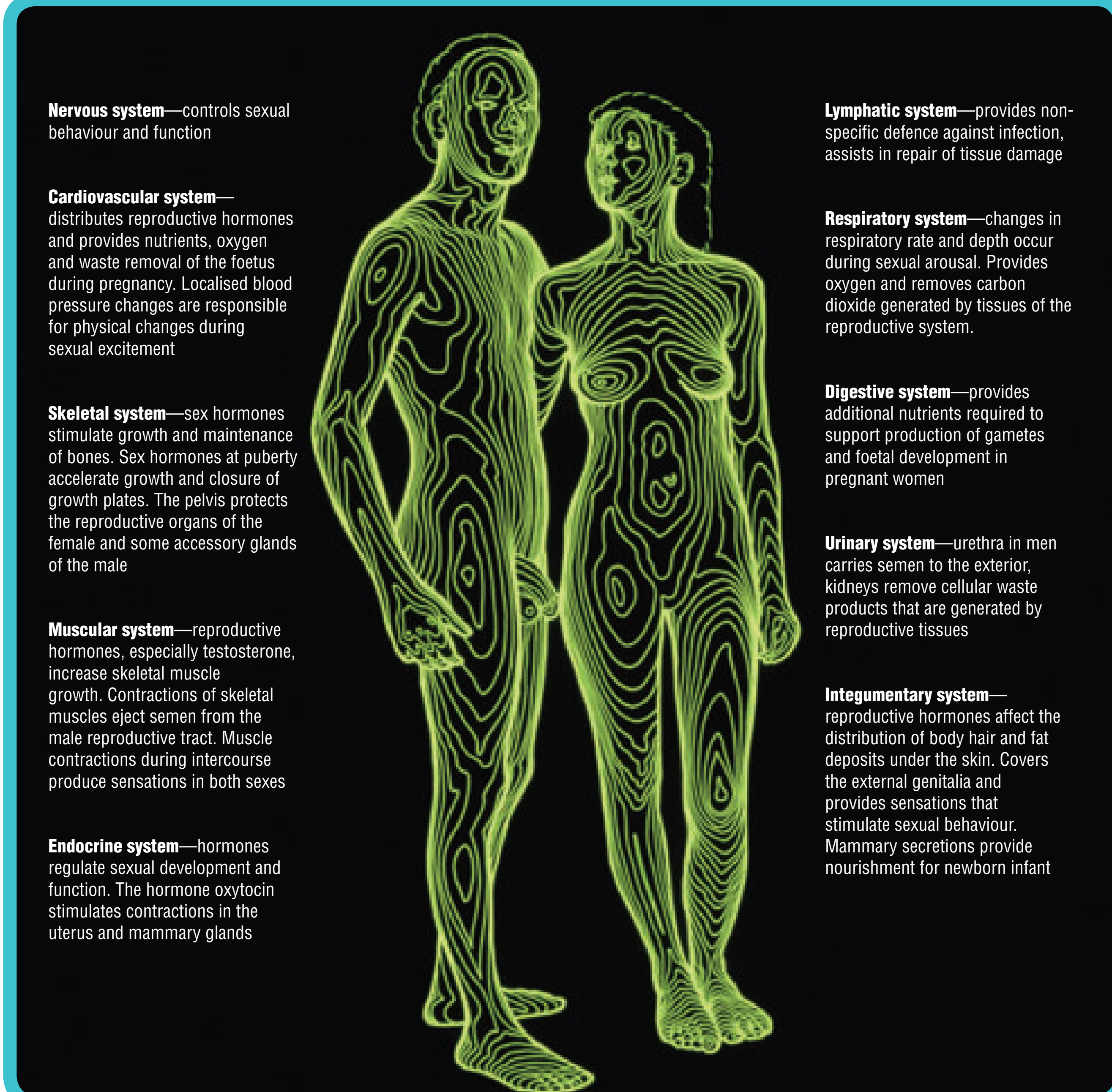
implantation occurs in the blood-rich inner layer of the uterus called the endometrium. The outer end of the uterus is called the cervix. Beyond that is a canal called the vagina; this is where the male deposits semen during sexual intercourse. The primary hormones involved in controlling the monthly preparation of the endometrium and maturation of the ovum include follicle stimulating hormone (FSH) and luteinising hormone (LH) from the pituitary gland, in addition to oestrogen and progesterone from the ovaries.

Interactions between systems

The interactions between the various systems of the human body and the reproductive system are summarised in Figure 3.3.3. Human reproduction is a complex process that involves the interaction of multiple systems. As you may already be aware, hormones play a major role in coordinating the events

The functional relationships between the reproductive system and other systems of the body

Fig 3.3.3



of the reproductive system. For reproduction to be successful a variety of physical, psychological and physiological factors are relied upon and must be in harmony with each other. An example is the male sperm. To be successful there must be an adequate sperm count, the semen must have the correct pH and nutrients, and the erection and ejaculation must be in the correct sequence and timing. For these steps to occur, the reproductive, digestive, endocrine, cardiovascular, nervous and urinary systems must be all functioning normally.

Even when everything is normal and fertilisation does occur at the appropriate time and place, a normal baby will not be born unless the zygote, a single diploid cell formed after fertilisation, develops into a full-term foetus weighing about 3 to 4 kilograms. The rest of this Focus details the struggle from fertilisation to birth, identifying the structures and mechanisms of control that determine developmental success.

From fertilisation to birth

Pregnancy and childbirth are natural events in human biology and generally progress smoothly without complications. Development of the baby (prenatal development) is amazingly precise and although childbirth is traumatic, it takes place in many instances without the aid of a doctor. Clinically, the time from conception to birth is referred to as the **gestation period**, and is approximately 267 days. If the date of conception is unknown, the end of the gestation period is calculated as 283 days from the first day of the last menstrual period. Gestation is generally divided into three phases, or trimesters, each lasting three months. The following section will explain each phase in greater detail.

The process must of course begin with the fertilisation of the ovum to form the diploid **zygote**. The events of the two weeks after fertilisation include the transportation of the zygote through the fallopian tube, mitotic divisions and implantation into the endometrial lining of the uterus. During this phase of development the zygote is self-supporting.

Over the next six weeks of pregnancy **differentiation** into specific body organs occurs, the placenta and umbilical cord form and the surrounding membranes develop. These membranes provide sustenance and protection to the embryo for the period of gestation. The embryonic stage of development lasts from the beginning of the third week to the end of the eighth week. It is at this stage that the developing organism can be correctly called an **embryo**. From nine weeks until birth the developing offspring is called a **foetus**. Tremendous growth and the specialisation of body structures occurs during this time. The first trimester (12 weeks) is also the most precarious time of development. If the needs of the developing embryo are not met, the pregnancy may not continue.

Science Snippet

Double trouble?

Twins occur about once in 85 pregnancies. They can occur in two different ways. Dizygotic or fraternal twins result when two ova are released in the same cycle and are fertilised by different sperm. Monozygotic or identical twins result when a single zygote divides.

Drag and Drop CW Interactive

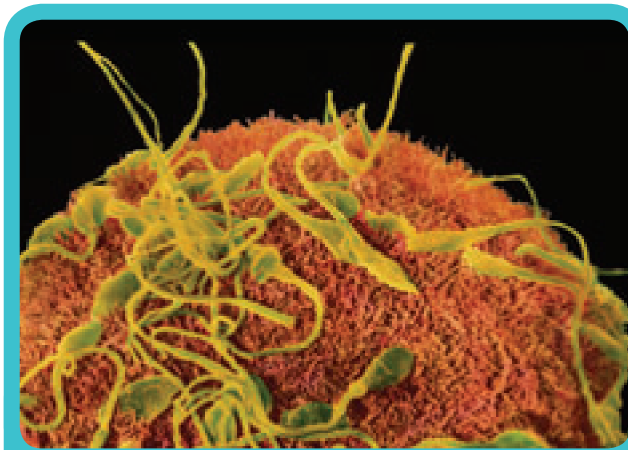


Fig 3.3.4 The fertilisation of the ovum

The embryo, unlike the zygote, is not self-sustaining and must obtain support and sustenance from the mother. For development to continue several needs must be met, including:

- formation of a vascular connection between the mother and developing embryo so that nutrients and oxygen can be provided and metabolic wastes, including carbon dioxide, can be removed
- provision of a constant, protective environment around the embryo that is conducive to development
- establishment of structural organisation for development
- provision of structural support for the embryo, both internally and externally
- coordination of the events of development through genetic expression.

The first two of these needs are met by the mother, through the supportive structures surrounding the embryo. The last three are dependant on the embryo itself. If these needs are not met, a spontaneous abortion, called a **miscarriage**, generally occurs.

Serious developmental defects cause the embryo to be spontaneously aborted, about 25 per cent of these being due to chromosomal abnormalities. Other factors that are not supportive of the embryonic needs and may cause miscarriage include environmental factors such as infection or drugs. If the mother's maternal immune response is not suppressed it may regard the implanting embryo as a foreign body and, through immune responses, reject the tissue.

During the second trimester, all the organ systems that have fundamentally formed will near functional completion, and the foetus will grow rapidly, ending the second trimester with a mass of about 0.6 kg. During the third trimester all the organ systems become functional, the rate of growth decreases and weight increases. At birth, a foetus reaching its full-term body mass is approximately 3.2 kg.

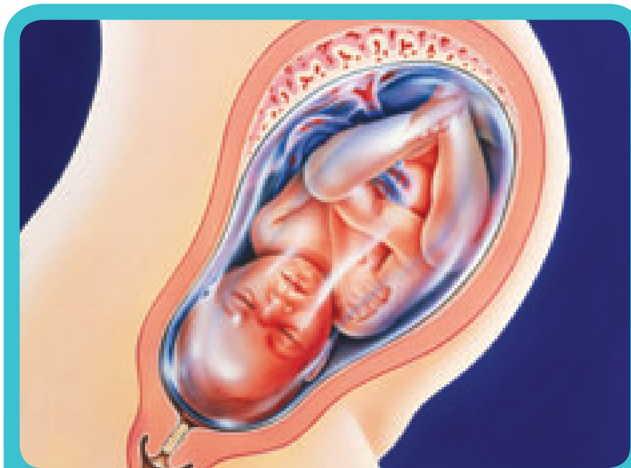


Fig 3.3.5 The developing foetus in the womb

The developing embryo and foetus are completely reliant on the mother and her body systems for nutrients, respiration and waste removal. She must perform these functions for the developing infant in addition to those required for her support. Although this is not a burden in the first trimester, over the next two trimesters the burden placed on her increases significantly. To survive in these conditions her body makes compensatory adjustments.

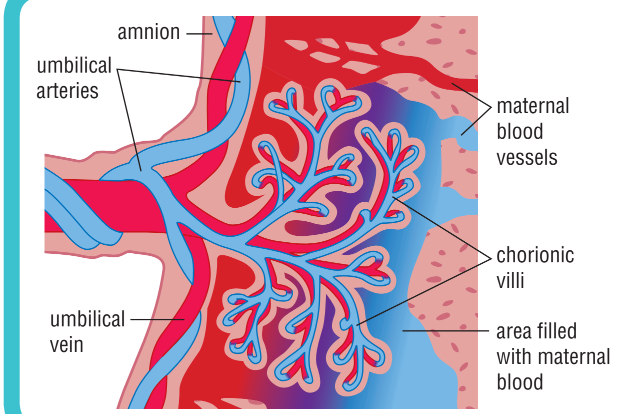
Practically the mother needs to breathe, eat and excrete for both herself and her unborn child. The following changes occur in the mother's body.

- Her tidal volume and respiratory rate increase. This ensures that the extra oxygen required is obtained and the excess carbon dioxide is removed.
- Her blood volume increases by almost 50 per cent by the end of the gestation period. This occurs because blood flowing to the placenta reduces the volume of blood serving the rest of her organs. The activity of the foetus reduces the amount of oxygen in her blood and increases the volume of carbon dioxide. This drop in oxygen to tissues stimulates them to release the hormone erythropoietin. This hormone stimulates the mitotic division of stem cells and erythroblasts in the bone marrow and accelerates the maturation of red blood cells. More red blood cells then enter the circulation, improving the delivery of oxygen to the tissues.
- Her requirements for nutrients, vitamins and minerals increase up to 30 per cent.
- The filtration rate through the kidneys increases by approximately 50 per cent. This is linked directly to the increase of blood volume and accelerates the removal of metabolic waste produced by the foetus. Because the volume of urine increases and the weight of the uterus presses down on the bladder, pregnant women need to urinate more frequently.
- The uterus vastly increases in size through the elongation and enlargement of existing cells.

Exchange of materials across the placenta

The placenta is a vascular organ of pregnancy by which the unborn child is attached to the mother's uterine wall and through which exchange of materials occurs. The placenta is formed in part from the mother's tissues, and in part from embryonic tissue, as shown in Figure 3.3.6. Blood does not flow directly

The circulation of blood within the placenta *Fig 3.3.6*



between the mother and unborn child. Because membranes of the mother and child are very close in the placenta, some substances diffuse readily.

The placenta forms in the following way. Several days after conception, when the zygote adheres to the wall of the uterus (endometrium), part of the outer cell mass that will form the placenta becomes elaborately folded. As the endometrium is broken down here, the mother's blood vessels are broken down and blood seeps into the spaces between the folds. Gradually circulation is set up, with the mother's blood flowing in from the ends of the arteries and out through the veins. Foetal blood vessels develop within the folds of the placenta and these connect to the blood vessels in the body of the embryo through the umbilical cord. But the mother's blood vessels and the embryo's blood vessels never connect to each other directly.

The umbilical arteries deliver foetal blood to vessels within the placenta. The blood circulates within the villi and returns to the foetus via the umbilical vein. The mother's blood is brought to, and drains from, cavities within the placenta. The cavities in the placenta overlying the foetal capillaries become very thin to allow the diffusion of nutrients and oxygen from the mother's blood, and to allow foetal wastes to pass back to the mother's blood. In this way the mother's blood and foetal blood are brought close together, although they never mix within the placenta.

The placenta is not only a passive transport medium between mother and child; it also secretes hormones, including human chorionic gonadotropin (HCG), oestrogen, progesterone, growth hormone and placental prolactin. The placenta also produces enzymes and has a very high metabolic activity rate, utilising about one-third of the glucose and oxygen supplied by the mother. HCG is the earliest hormone to be produced and is first secreted on day six of gestation. HCG maintains the ovarian follicle from which the ovum burst, and ensures that it continues to manufacture progesterone and oestrogen until the placenta is able to produce adequate amounts on its own, which usually occurs around the third month of gestation. The levels of HCG are then no longer required and begin to decline. HCG also crosses the placenta into the mother's blood and is the basis for many pregnancy tests.

Science Snippet

Passing the placenta

Most drugs ingested by a woman while pregnant, such as nicotine, drugs and alcohol, can readily pass through the placenta and may be detrimental to the developing foetus.

Science Snippet

Bad blood

Rh red blood cell type is important in pregnancy when the mother is Rh– and the unborn baby is Rh+. An Rh– mother produces antibodies to Rh+ blood if it enters her system. When birthing a baby, placental rupture normally occurs. This causes some foetal blood to enter the mother's system, causing the development of antibodies in the mother's blood. When the next pregnancy occurs, the mother's anti-Rh+ antibodies cross the placenta. There they attack the foetal blood cells, causing them to burst and the foetus to die in the womb or be very ill at birth.

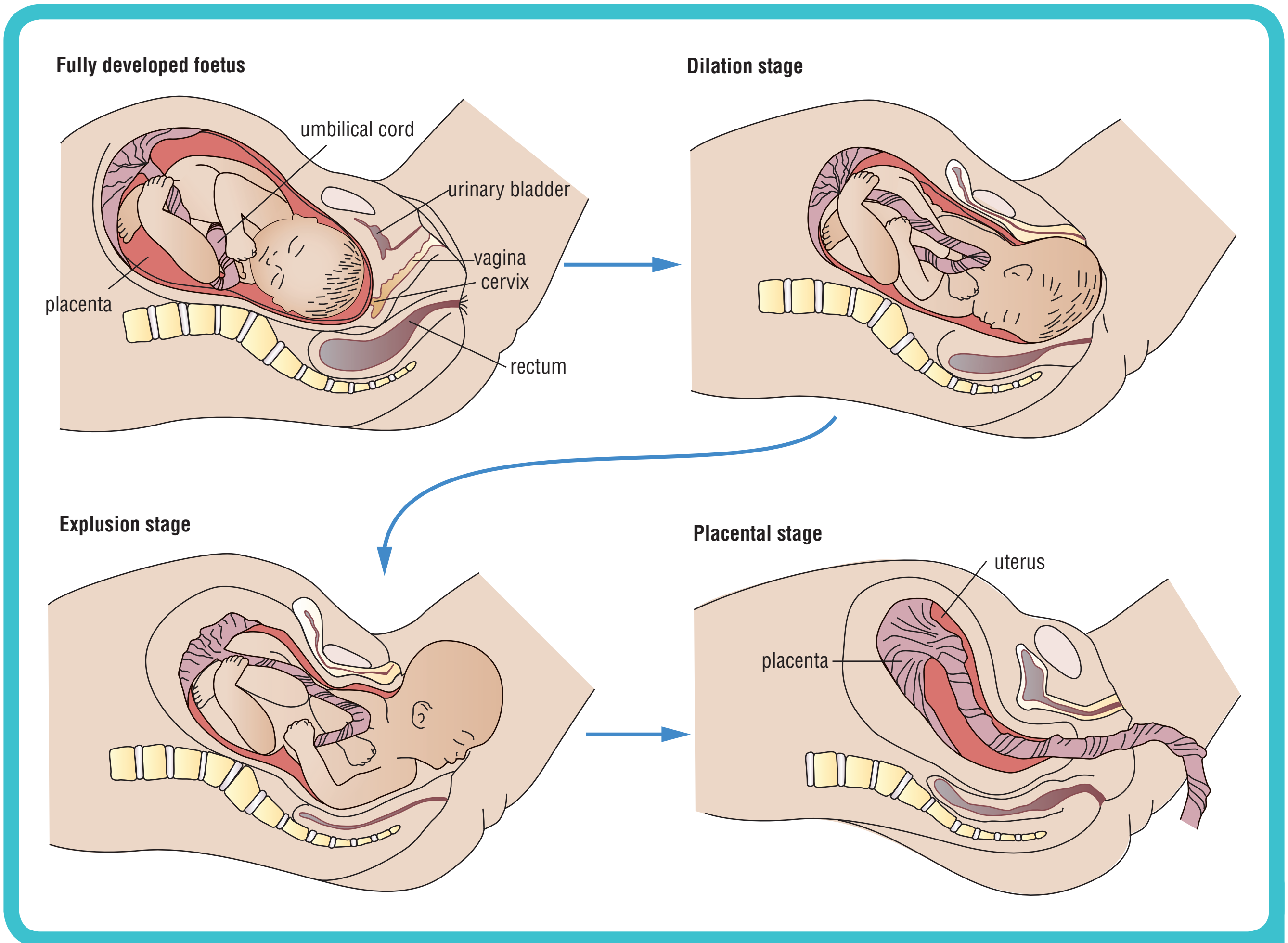
Homework book 3.4 The placenta

Labour and parturition

The goal of labour is the forcible expulsion of the foetus, a process known as **parturition** or, more commonly, childbirth. During parturition the baby and structures such as the placenta and membranes are expelled from the uterus. Labour and birth are the final stage of gestation and require the action of the hormone oxytocin, secreted by the pituitary gland and prostaglandins, produced in the uterus.

Labour has traditionally been described in three stages: the dilation stage, the expulsion stage and the placental stage. During the dilation stage and the onset of true labour, the cervix dilates completely and contractions occur every 10 to 30 minutes, each contraction beginning near the top of the uterus and sweeping in a wave towards the cervix. These contractions are strong and occur at regular intervals. As parturition approaches the contractions increase in force and frequency, changing the position of the foetus and moving it toward the cervical canal. Late in this process the amnion breaks, which is often referred to as 'the waters breaking'.

The expulsion stage begins with the complete dilation of the cervix as the approaching foetus pushes through. The arrival of the newborn infant is known as birth, or delivery. During the placental stage of labour, muscle tension builds in the walls of the uterus, which gradually decreases in size. This contraction of the uterus tears the connection between the lining of the uterus and the placenta. The placenta and associated tissues are then expelled from the uterus. This completes the stages of parturition and is the beginning of a new developmental stage called postnatal development.



The stages of labour and birth, from the positioning of the foetus to the expulsion of the placenta

Fig 3.3.7

Reproductive problems

Infertility, the inability to have children, is a cause of great distress for many couples. Females are more prone to dysfunctions and diseases of the reproductive system because of cyclic reproductive events, problems associated with pregnancy and the susceptibility of infection and tumours.

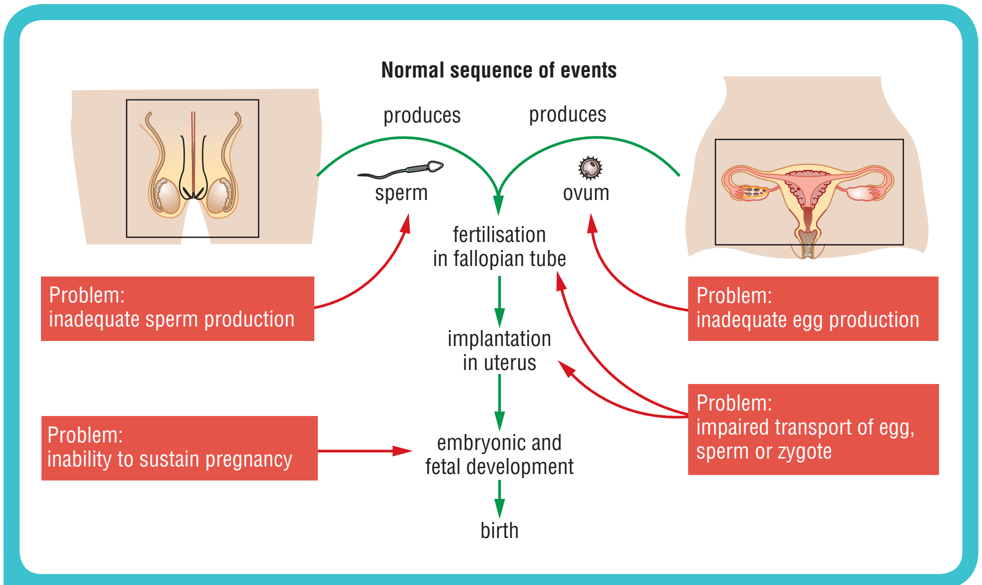


Fig 3.3.8 Causes of infertility

The onset of menopause can also cause complications due to changes in hormone levels. An infertile woman is unable to produce fertile eggs or support a developing embryo. An infertile man is unable to produce a sufficient number of viable sperm for fertilisation.

Unfortunately, not every pregnancy is an idyllic event and problems do occur, the most severe causing spontaneous abortion. Foetuses with less severe defects may survive to delivery. For the continuing development of the unborn child several needs must be met. Genetic problems, such as spontaneous mutation, cause problems with the maturity of the foetus and the needs of the foetus are therefore not met. Spontaneous mutations are the result of random errors in the process of DNA replication and the majority of these zygotes die before completing development. Congenital malformations are structural abnormalities present at birth and include conditions such as spina bifida and cleft lip. Congenital malformations occur in approximately 6 per cent of all newborn infants, with only 2 per cent being categorised as severe. The causes of congenital conditions include genetic inheritance, mutation (genetic change) and environmental factors.

Homework book 3.5 Preparation for and hormonal control of pregnancy

3·3 FOCUS [Questions]

Use your book

The human reproductive system

1 Describe the journey that sperm take through the male reproductive system.

2 Describe the journey that an ovum takes through the female reproductive system after ovulation.

Interactions between systems

3 Describe the relationship between the reproductive system and the cardiovascular system.

4 Describe the relationship between the reproductive system and the skeletal system.

5 Describe the relationship between the reproductive system and the integumentary system.

From fertilisation to birth

6 What happens in fertilisation?

7 What is the difference between an embryo and a foetus in terms of age and structure?

8 What are the five needs of an embryo that must be met to avoid spontaneous abortion?

9 List five changes that occur in the mother's functioning during pregnancy

Exchange of materials across the placenta

10 Is the placenta formed from the tissues of the mother or the foetus?

11 Does the blood of the mother and the blood of the foetus mix within the placenta?

12 What is exchanged through the placenta?

13 What are the functions of HCG?

Labour and parturition

14 What is the process known as parturition?

15 What are the three stages of labour?

16 At what stage does the mother experience her 'waters breaking'?

Reproductive problems

17 What does the term 'infertility' mean?

18 What are congenital malformations?

19 What are the possible causes of congenital malformations?

Use your head

20 During pregnancy, especially in the first trimester, it is recommended that women should not drink alcohol, smoke or take drugs and that they be careful to check any medication they take. What do you think is the main reason for this advice?

21 What do you think could be the advantage of the normally acidic conditions of the vagina?

22 Explain why carbon dioxide and oxygen exchange occurs quite rapidly in the placenta. Your answer should refer to the concept of diffusion, and the relationship between structure and function.

Investigating questions

23 As a result of some sexually transmitted diseases such as gonorrhoea, scar tissue can block the fallopian tubes. How does this affect a woman's ability to conceive a child? What options would this woman have if she wanted to have a child?

24 Research and compare:

a X-ray and ultrasound

b amniocentesis and chorionic villus sampling.

25 Copy Figure 3.3.8, showing the causes of infertility, into your notebook. For each problem find information in your library or on the Internet about treatment options.

26 What effect does a vasectomy have on sperm production?

FOCUS 3.4 DNA, genes and inheritance

Context Inheritance is the passage of hereditary traits carried on the genes of chromosomes from one generation to another. As a science, the study of genetics is quite young. It is, however, a rapidly growing and exciting field of science to be involved in—and it is important to be informed and watch for bias and unethical use of genetic research. Knowledge is a powerful tool and can help you to make informed decisions about your health and the health of your family.

Fig 3.4.1 Although we inherit our characteristics from our parents, we do not look exactly like them.

Genetics

Genetics is the branch of biology that deals with inheritance. The genetic inheritance of an individual begins with conception. The molecule called DNA (deoxyribonucleic acid) provides the physical mechanism of heredity in all living creatures. DNA carries the information used to build a new body, to differentiate its different parts and to control all cellular functioning. DNA molecules exist inside almost all of the cells in the body, and in all the reproductive cells (gametes). Human red blood cells are an exception, since they lack a nucleus.

The finer structure of DNA is too small to be seen directly, but it has been inferred through a process called X-ray diffraction. Watson and Crick unravelled the molecular structure of DNA in 1953. The DNA molecule consists of a sequence of units, each unit called a **nucleotide**, which consists of a phosphate and sugar group with a nitrogen base attached. The alternating sugar and phosphate groups form the 'backbone' of the DNA molecule.

As can be seen in Figure 3.4.2, the structure of DNA is like a twisted ladder, a shape called a double helix. The sides of the ladder of this double helix structure are made from alternating sugar and

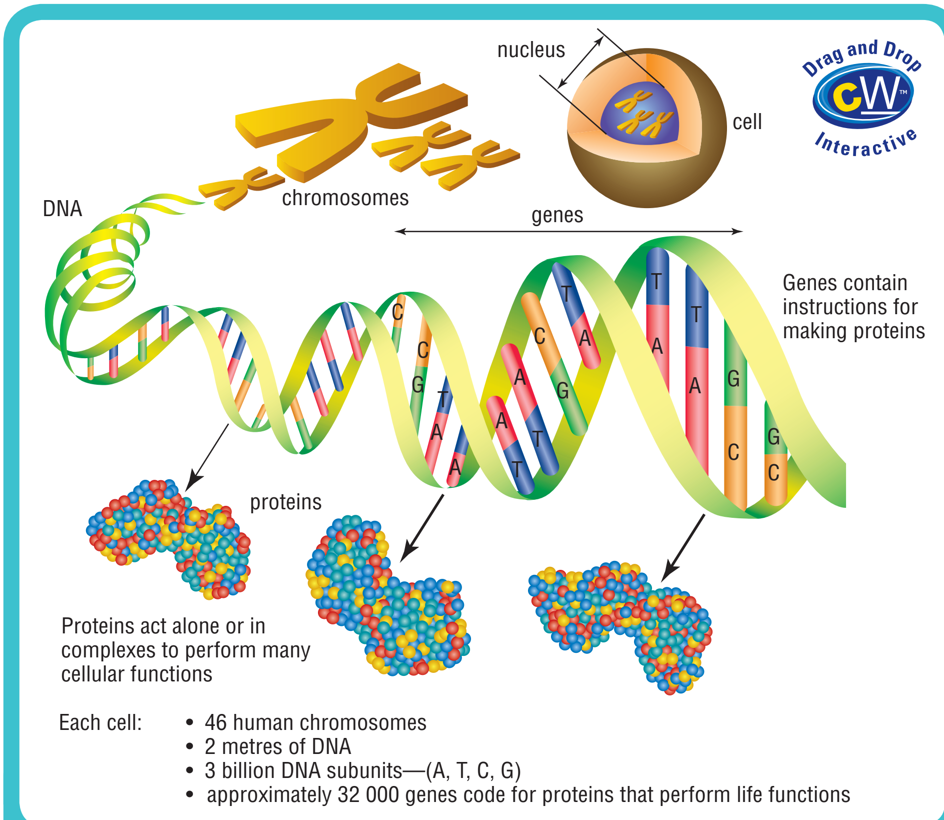


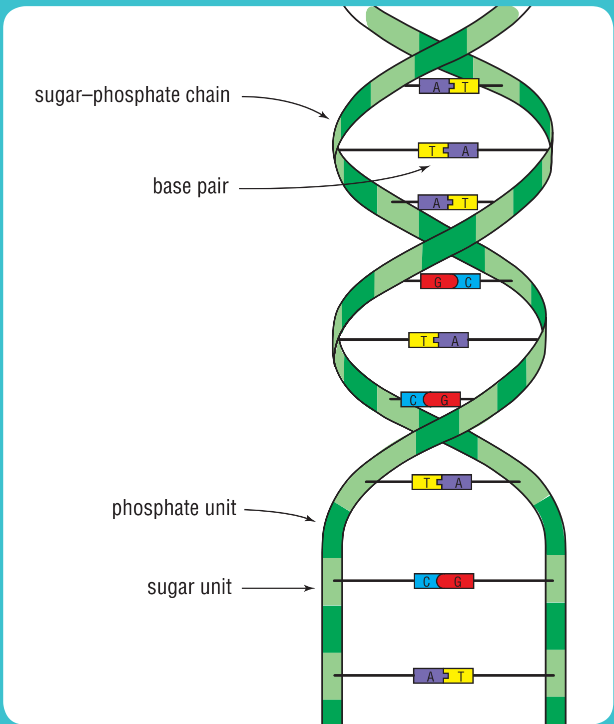
Fig 3.4.2 The structure of DNA and proteins that determine the characteristics that control life functions

phosphate units. The rungs of the ladder are the nitrogen bases. The full DNA molecule consists of two paired complementary strands, each consisting of a sequence of nucleotides. The nucleotides of opposite strands, as can be seen in Figure 3.4.3, are bonded together. The two strands together exist as the double helix.

Prac 1 p. 104

The structure of DNA showing the nucleotides of opposite strands

Fig 3.4.3



The DNA is carried in structures called chromosomes, which are sometimes visible with a light microscope at different stages of the cell cycle, as described in Focus 3.2. Each species has a different number of chromosomes. For example, each human has 46. Twenty-three chromosomes are inherited from each parent. This does not produce 46 different chromosomes, but 23 pairs of **homologous** chromosomes. Each member of a homologous pair, with the exception of the sex chromosomes, looks like the other and has similar genes, such as those coding for particular characteristics like hair colour or height.

These homologous pairs of chromosomes can be **karyotyped** and identified as can be seen in Figure 3.4.4. As you can see, a karyotype is simply a photograph or diagram of chromosomes, usually arranged in pairs and in order of size. Each diploid cell that contains 46 chromosomes has a pair of each chromosome. One chromosome of each pair was supplied by the female gamete and the other by the male gamete. The first 22 pairs of chromosomes are called **autosomal chromosomes**. The 23rd pair of chromosomes are the sex chromosomes, which may look different and carry different genes. In a female these consist of two X chromosomes, and in the male there is only one X chromosome and one Y chromosome.

A human karyotype displaying the 23 pairs of homologous chromosomes

Fig 3.4.4

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A **gene** is a portion of DNA in a chromosome. The position of genes on a chromosome is called the **locus**. There may be a number of alternative forms of each gene that can occupy a locus. These are called **alleles**. These alleles affect the same characteristic, but express that characteristic differently. For example, one gene may specify red hair, another fair hair and another brown hair. One allele of each pair originates from the female parent and the other from the male parent. Basically, a gene is a portion of a DNA molecule that contains information for the production of one kind of protein molecule.

The role of proteins can be explained very simply by saying that our bodies are built from proteins, and our cell chemistry is controlled by proteins. Different parts of the body develop their distinct characteristics because of the kinds of proteins from which they are made, and the proteins that control the cell chemistry.

Skin, for example, consists mainly of a protein called keratin, and oxygen is carried in the red blood cells by a protein called haemoglobin. Coding for proteins by DNA ultimately enables the fertilised ovum to develop into a functioning adult. Approximately 32 000 genes encode for proteins that perform the life functions inside your body!

So how do genes in the DNA encode for proteins? The answer is that the sequence of nucleotides in a gene specifies the sequence of amino acids in the protein. DNA contains four types of nucleotides, which differ only in the nitrogen base part of the nucleotide unit; the sugar and phosphate groups remain the same in all four types. The four types of nitrogen base are adenine (A), cytosine (C), guanine (G), and thymine (T). In the double helix, an A base in one strand always pairs with a T base in the other; and a C always pairs with a G, as seen in Figure 3.4.3. Therefore if the base sequence in one strand was … AGGCTCCTA ..., the complementary strand would be … TCCGAGGAT …

Genotype and phenotype

Your DNA contains a combination of genes that are known as your **genotype**. The expression of those genes results in the observable characteristics or the appearance of a person, which is referred to as the **phenotype**. In the rest of this Focus you will look at the inheritance of characteristics that are controlled in a very simple way by only one pair of genes. More complex inheritance will be discussed in Focus 3.5.

The three possible genotypes for a characteristic controlled by a single gene pair are **homozygous dominant**, **heterozygous** and **homozygous recessive**. If the alleles for a particular trait are homozygous, the characteristic expresses itself in a specific manner. For example, two alleles for attached earlobes result in a person with attached earlobes. If the alleles for a particular trait are heterozygous, the phenotype will be determined by the allele that expresses itself and how the genes for that trait will interact. Often one of the alleles expresses itself as the **dominant allele**, whereas one does not and is the recessive allele. The combinations of dominant and recessive alleles are responsible for hereditary traits.

In describing genotypes we use letter symbols to refer to the alleles of an organism. The dominant alleles are represented by capital letters and the recessive alleles are represented by lower-case letters.

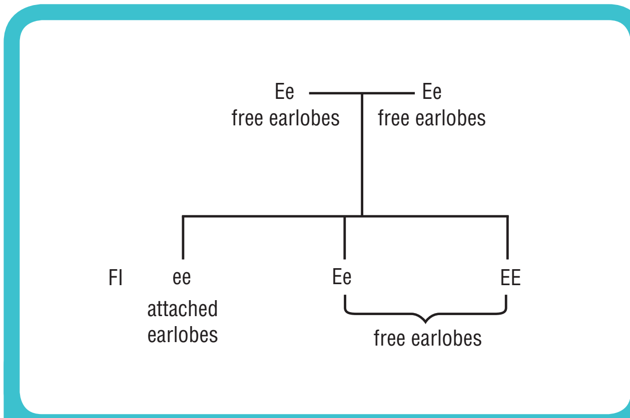
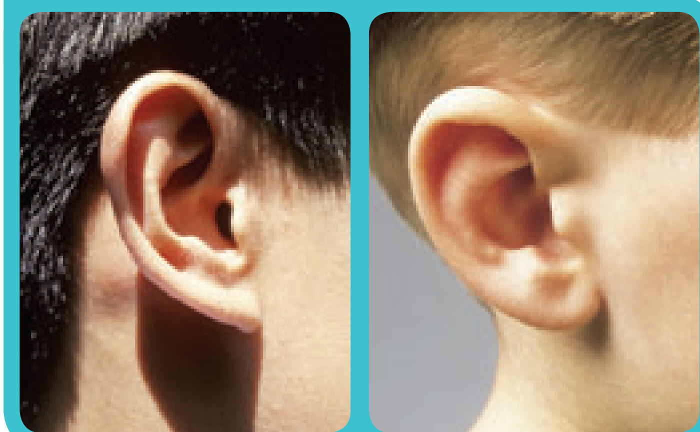


Fig 3.4.5 Inheritance of free earlobes is a dominant trait. Two parents with free earlobes can have a child with attached earlobes.

Therefore, the genotype of a person who is homozygous for free earlobes due to the dominant allele is symbolised as EE; a heterozygous pair is symbolised as Ee. In both of these instances the phenotypes of the individuals would be free earlobes, since there is a dominant allele in each genotype. A person who inherited two recessive alleles for earlobes has the genotype ee and will have attached earlobes. The phenotype for this characteristic can be seen in Figure 3.4.6.

Fig 3.4.6 The phenotype displaying free and attached earlobes



As you may have already realised, there are three possible genotypes when one gene pairing involves dominant and recessive alleles. They are homozygous dominant (EE), heterozygous (Ee), and homozygous recessive (ee). Only two phenotypes are possible, however, as the dominant allele is expressed in both the homozygous dominant (EE) and the heterozygous

(Ee) individuals. The recessive allele is expressed only in the homozygous recessive (ee) condition.

Calculating probability

In simple inheritance physical characteristics are determined by interactions between a single pair of alleles. The frequency and appearance of an inherited disorder resulting from simple inheritance can be predicted using a Punnett square. A Punnett square is simply a convenient way to express probability. Through this method we can predict the probability of over 1200 inherited conditions, such as deafness, albinism, cystic fibrosis, colour blindness and Duchenne muscular dystrophy.

The Punnett square in Figure 3.4.7 demonstrates that the probability of a particular genotype is one in four (0.25) for homozygous dominant and homozygous recessive, and one in two (0.50) for heterozygous dominant. The Punnett square in Figure 3.4.8 demonstrates that the probability of a particular genotype is all the same (1.0) for heterozygous dominant, when one parent is homozygous dominant and the other is homozygous recessive.

Fig 3.4.7 Punnett square showing the probability inheritance of a condition if both parents are heterozygous

Heterozygous female (Aa)

Heterozygous male (Aa)

	A	a
A	AA	Aa
a	Aa	aa

Fig 3.4.8 Punnett square showing the probability inheritance of a condition if one parent is homozygous dominant and the other homozygous recessive

Homozygous dominant female (AA)

Homozygous recessive male (aa)

	A	A
a	Aa	Aa
a	Aa	Aa

A genetic study in which a single characteristic is followed from parents to offspring is known as a **monohybrid cross**. A genetic study in which two characteristics are followed from parents to offspring is referred to as a **dihybrid** cross. The term **hybrid** refers to an offspring descended from parents with different genotypes.

Pedigrees

A **pedigree** is a symbolic family tree showing males and females and individuals who show a particular characteristic or disease. Figure 3.4.9 shows the symbols used for drawing pedigrees.

To determine the inheritance patterns of many human traits, geneticists have historically had little more than a pedigree to go on, and this often does not include mating combinations required to determine the genotype of a characteristic. DNA is now an important tool in the study of genetics and can support the information predicted in family trees.

On the basis of the information given in a pedigree, geneticists attempt to determine the mode of inheritance of a trait. There are two types of questions the pedigree might be used to answer. First, are there patterns within the pedigree that are consistent with a particular mode of inheritance? Second, are there patterns within the pedigree that are inconsistent with a particular mode of inheritance? There may

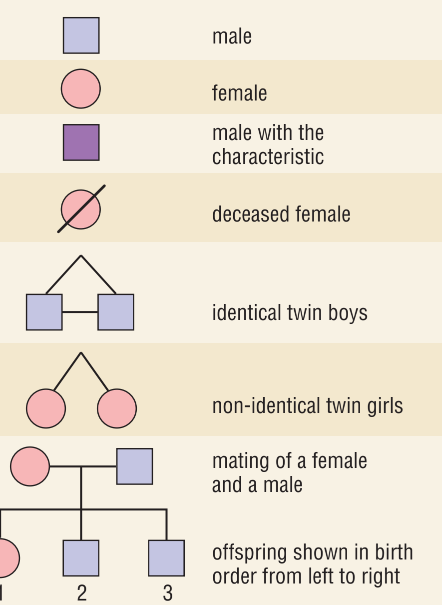


Fig 3.4.9 Symbols used for drawing pedigrees

be instances, however, where it is not possible to determine the mode of inheritance from a pedigree with any degree of certainty.

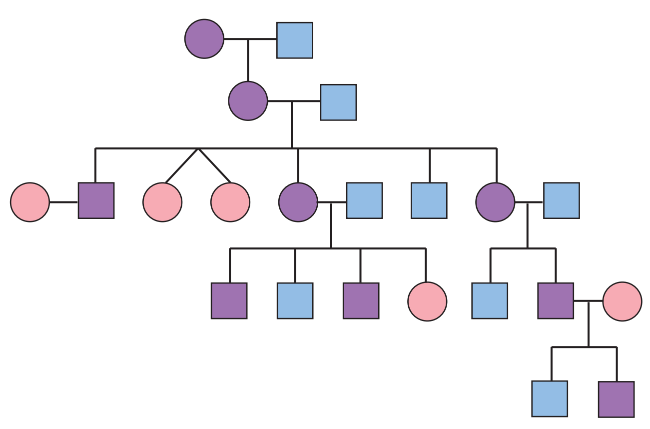
When you look at a pedigree how do you know if the characteristic is autosomal recessive or dominant? The following table should help you to determine whether a characteristic is recessive or dominant in a pedigree.

The pedigree in Figure 3.4.10 is for the characteristic polydactyly (extra digits on hands and/or feet), which is caused by an autosomal dominant gene. You may wish to refer to the table at the bottom of the page to determine how this is so for yourself, or read on to the next paragraph.

The pedigree in Figure 3.4.10 shows that polydactyly occurs in every generation; that is, every affected child has an affected parent and no generations have been skipped. This alone suggests dominant inheritance. (The trait also appears equally in both sexes—this suggests autosomal rather than sex-linked inheritance, as you will learn in Focus 3.5.) In addition to this, many pedigrees have been studied and found to be consistent with the hypothesis that polydactyly is caused by an autosomal dominant gene.

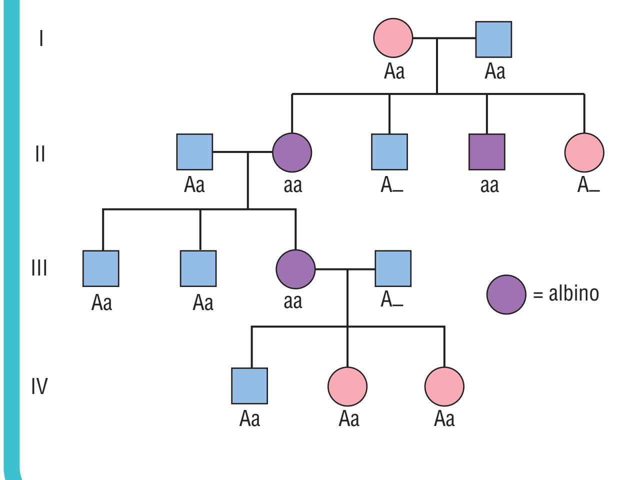
Figure 3.4.11 demonstrates how the homozygous recessive trait of albinism can be expressed in a child of parents who are heterozygous dominant.

Certain traits that are located on the sex-determining chromosome are called sex-linked characteristics. Colour blindness and haemophilia are examples of sex-linked traits. This will be discussed in more detail in Focus 3.5.



Part of a pedigree displaying the trait for polydactyly **Fig 3.4.10**

Inheritance of albinism **Fig 3.4.11**



Homework book 3.6 DNA secrets

Autosomal recessive inheritance	Autosomal dominant inheritance
• The trait often skips generations. • There is almost an equal number of affected males and females. • The trait is often found in pedigrees with incestuous matings. • If both parents are affected, all children produced are affected. • Most affected individuals have unaffected parents. • In most cases where an unaffected individual mates with an affected individual, all children produced are unaffected. When at least one child is affected (indicating that the unaffected parent is heterozygous for the condition), approximately half the children are affected. • Examples include albinism, curly hair, cystic fibrosis, thalassaemia, Tay-Sachs disease and haemochromatosis.	• Traits generally do not skip generations. • An affected person mating with an unaffected person produces approximately 50 per cent affected offspring (indicating that the affected person is also heterozygous for the condition). • There is almost an equal number of affected males and females. • Examples include the ability to roll your tongue, the type of ear wax and Huntington's disease.

FOCUS 3·4 [Questions]

Use your book

Genetics

1 Define the following terms:
- **a** genetics
- **b** gene
- **c** allele
- **d** karyotype.

2 How do genes in the DNA encode for proteins?

3 Who were the first scientists to unravel the structure of DNA?

4 What is the twisted ladder structure of DNA called?

5 What are the first 22 chromosomes called?

6 What are the four types of nucleotides?

Genotype and phenotype

7 When describing genotypes what is it traditional to use?

8 Define the following terms:
- **a** genotype
- **b** phenotype
- **c** dominant
- **d** recessive
- **e** homozygous
- **f** heterozygous.

9 List two dominant traits and two recessive traits in humans.

Calculating probability

10 What is a Punnett square used for in genetics?

11 Using Figure 3.4.7, a Punnett square showing probability of inheritance between two heterozygous organisms, determine the probability of:
- **a** producing offspring with a heterozygous genotype
- **b** producing offspring with a homozygous genotype
- **c** producing offspring that are homozygous recessive
- **d** producing offspring that are heterozygous dominant.

12 What is the name of the genetic study in which a single characteristic is followed from parents to offspring?

Pedigrees

13 Give four indications in a pedigree that could help you decide whether a characteristic is dominant.

Use your head

14 The ability to roll your tongue is an autosomal dominant trait. What would be the phenotype of a person heterozygous for this trait?

15 Draw a Punnett square to predict the genotypes and phenotypes of the offspring of parents, one of whom is heterozygous for the autosomal dominant trait ‘D’, and the other homozygous recessive.

16 Polled cattle do not have horns. This is a dominant phenotype arising from the action of an autosomal gene P. Horned cattle are therefore pp homozygotes.
- **a** If a polled bull and a polled cow have a horned calf, what are the genotypes of the parents?
- **b** If the same bull was bred with many horned cows, what would the proportions of polled and horned offspring overall be? Show full working.

Investigating questions

17 Research an autosomal dominant or recessive trait, draw a pedigree for the trait and determine the probability of the trait being passed on by the last offspring.

18 Gene tests are now used to support the evidence in pedigrees. Determine where or when gene testing may be useful.

FOCUS 3·4 [Practical activities]

Prac 1
Focus 3.4

Modelling DNA

Purpose

To re-create the structure of DNA and label the basic features of a DNA strand.

Requirements

Choose your own equipment. You may choose to use cardboard, sticky tape, blu-tac, paperclips, liquorice, marshmallows, jelly babies, beads, foam, blocks, toothpicks or wire.

>>

Procedure

1. Draw a diagram (plan) of what you want your DNA to look like.
2. Construct your model.
3. Label your model, include sugar, phosphate and bases A, C, T and G.
4. Clean up any mess you have made and show your model to your teacher.

Questions

1. Briefly describe the structure of the DNA molecule.
2. How do the DNA molecules differ from each other?
3. How do you think this reflects how DNA of other cells relate to each other?

Prac 2
Focus 3.4

Extraction of DNA from fruit

Purpose

To isolate the DNA from fruit samples.

Requirements

Various fruit samples, including kiwifruit, strawberries and banana, one small plastic bag, 20 mL ‘extraction solution’, ice (to make an ice water bath), 250 mL beaker for water bath, one small square of gauze, one funnel, one small test tube, water, 2 mL 95% ethanol (collect this just before it is needed as it may evaporate before you use it), one pipette, glass Pasteur pipette with loop to pick up DNA, petri dish, 10 mL measuring cylinder.

Procedure

1. Choose one type of fruit from which to extract the DNA.
2. Place the fruit sample in the plastic bag.
3. Add 20 mL of extraction solution to the bag.
4. Carefully remove as much air as possible by squeezing the bag while being careful not to lose any liquid, then close the bag by tying it.
5. Squash and break up the fruit in the bag while mixing it with the extraction solution for about five minutes.
6. Using the ice water bath, cool the bag by placing it into the bath. After one minute remove the bag for 30 seconds. Repeat this procedure three times.
7. Use the gauze square in a funnel to filter the mixture. More than one group can filter through a funnel with the gauze in place.
8. Put 2 mL of the filtered liquid mixture in a test tube.
9. Add 2 mL of cold ethanol to the test tube using a pipette. This should be added gently down the side of the test tube. **Do not shake the tube**.
10. DNA strands should form at the top of the tube and can be removed using a glass pipette with a loop.
11. Repeat this procedure with other fruit samples.
12. Pack up all your equipment and clean your workspace.

Questions

1. What did the sample you extracted look like and is this what you expected?
2. What is the purpose of the extraction solution?
3. How successful was the extraction of the DNA from each of the fruit samples?
4. Could you improve the method if you were to repeat the experiment?
5. Draw a labelled diagram that shows the DNA molecule. Clearly identify a nucleotide, phosphate molecule, deoxyribose sugar and four bases.

FOCUS 3.5

Complex inheritance

Context

In Focus 3.4 you were introduced to the concepts of inheritance through reproduction. In this Focus you will build on those concepts and examine mutation, variation and sex-linked and polygenic inheritance in a population, in addition to the effect of environment on inheritance and phenotype.

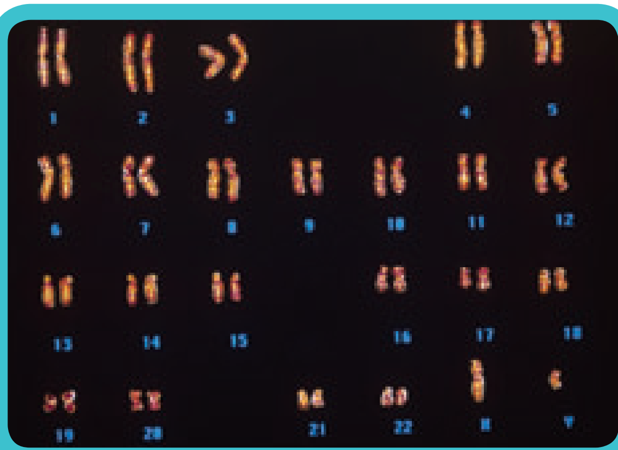


Fig 3.5.1 The X and Y chromosomes are quite different from each other.

Sex-linked inheritance

The fundamental characteristic of sexual reproduction is that all offspring are produced through the mixing of genetic information from two parent organisms, with the result that offspring are genetically different from each other and the parents. An important feature to note is that offspring of sexual reproduction are different. We cannot know exactly what combination of genetic information a particular offspring will receive from its two parents. We can predict the likely outcome, but we can never know what it will be.

As discussed in the previous Focus, in humans the first 22 chromosomes are called **autosomal** chromosomes and are responsible for many of the inherited traits that you recognise, such as eye colour, skin pigment and hair colour. The 23rd pair of chromosomes, the **sex chromosomes**, look different and carry different genes. These chromosomes are called the sex chromosomes, because they determine the genetic sex of the individual. Unlike the other chromosomal pairs, the sex chromosomes are not necessarily identical in their appearance and gene content.

There are two different sex chromosomes, an **X chromosome** and a **Y chromosome**. The Y chromosome is considerably smaller than the X chromosome, and it contains fewer genes. Among the genes, however, there are dominant alleles that specify that an individual with this chromosome will be male. The normal male genotype is XY, meaning one X chromosome and one Y chromosome. A normal female will be XX, meaning there are two X chromosomes.

The ova produced by a woman always carry the X chromosome. It is the male sperm, carrying the X or Y chromosome, that therefore determines the sex of the offspring. As can be seen from Figure 3.5.2, the ratio of the sexes in the offspring should be 1:1.

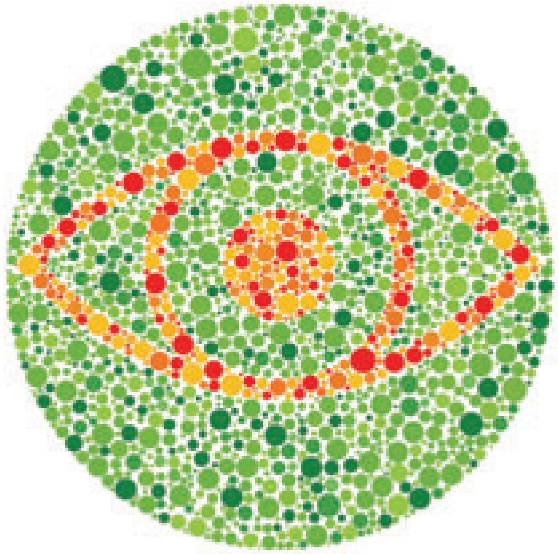
Fig 3.5.2 A Punnett square displaying the probability of producing male or female offspring

		Female (XX)	
		X	X
Male (XY)	X	XX	XX
	Y	XY	XY

The X chromosome carries genes that affect body structures and functions. These characteristics are called **X-linked**, because in most cases there is no corresponding allele on the Y chromosome. Genes carried only on the Y chromosome are called Y-linked. Few examples of this have been definitely demonstrated. Generally, the characteristics carried on X or Y chromosome are called sex-linked. The inheritance of the characteristics regulated by X-linked genes does not follow the same pattern as alleles on autosomal chromosomes. One of the best known of these single allele characteristics is colour blindness. Colour-blind individuals are unable to distinguish certain colours. The standard tests for colour blindness involve being able to pick out numbers or letters out of a complex and colourful picture, such as Figure 3.5.3.

The standard test for colour blindness requires individuals to look at a diagram like this and distinguish the image.

Fig 3.5.3



Colour blindness is a clear example of X-linked inheritance. A relatively common form of colour blindness (80 in 1000 male births) is associated with the presence of a dominant or recessive gene on the X chromosome. Normal colour vision is determined by the presence of the dominant gene, which you can call B rather than C so that you do not mix up upper case C and lower case c. Colour blindness

Heterozygous (carrier) female (X^BX^b)

		X^B	X^b
Normal male (X^BY)	X^B	X^BX^B Normal female	X^BX^b Normal female
	Y	X^BY Normal male	X^bY Colour-blind male

Fig 3.5.4 The inheritance of the sex-linked trait, colour blindness. If the mother is heterozygous for the condition, as in this case, half the sons will be colour-blind.

results from the recessive gene b. A female, with her two X chromosomes, can be either homozygous X^BX^B or heterozygous X^BX^b, and still have normal colour vision. She will be colour blind only if she has two recessive alleles, X^bX^b. A male with only one X chromosome displays the trait that the chromosome carries. The Punnett square for this X-linked trait can be seen in Figure 3.5.4, demonstrating that sons produced by a normal father and a heterozygous mother have a 50 per cent chance of being colour blind, whereas daughters have normal colour vision.

There are a number of conditions that are X-linked, including types of haemophilia, diabetes and muscular dystrophy. When you look at a pedigree, how do you know if the characteristic is X-linked recessive or dominant? The simple table at the bottom of the page should help you to determine a X-linked recessive or dominant characteristic in a pedigree.

Homework book 3.7 Pedigree analyis

X-linked recessive inheritance	X-linked dominant inheritance
• Most affected individuals are male. • Affected males result from mothers who are affected or who are known to be carriers (heterozygotes), and have affected brothers, fathers or maternal uncles. • Affected females come from affected fathers and affected or carrier mothers. • The sons of affected mothers should be affected. • Approximately half the sons of carrier females should be affected. • Examples include haemophilia and Duchenne muscular dystrophy.	• Traits do not skip generations. • Affected sons must come from affected mothers. • Approximately half of the children of an affected heterozygous female are affected. • Affected females come from affected mothers or fathers. • All the daughters, but none of the sons, of an affected father are affected. • Very few conditions show sex-linked dominant inheritance; Rett syndrome is one example.

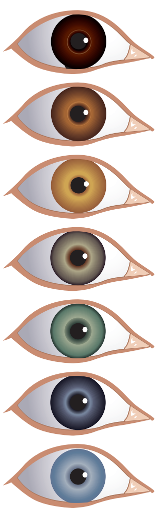
Polygenic inheritance

Characteristics can be due a simple method of inheritance like those you have studied in the last Focus. They are determined by interactions between a single pair of alleles. As has been discussed, the frequency and appearance of a characteristic resulting from simple inheritance can be determined using a Punnett square. But there is another method by which characteristics can be inherited. This is polygenic inheritance, also called quantitative inheritance or continuous variation.

Polygenic inheritance involves interactions between many genes for the same characteristic. Because multiple alleles are involved, the frequency of occurrence cannot be determined by using a simple Punnett square. For this reason it is very difficult to work out exactly how these are inherited because you cannot easily follow the genes from generation to generation. Some examples of this are inheritance of height, skin colour and eye colour, and many diseases, such as coronary artery disease and developmental disorders resulting in foetal death or malformation.

To see how a range of phenotypes could occur with several genes involved, consider eye colour. It appears that there are about three gene pairs affecting eye colour. Each pair has two alleles, and each allele has a dominant gene specifying a brown pigment in the eye, while the other allele seems to code for no brown colour, which looks blue. How do we get different eye colours from this? It appears that it works something like in Figure 3.5.5.

Eye colour is the result of polygenic inheritance. **Fig 3.5.5**



Eye colour	Possible genotype	Phenotype
	BBBBBB	dark brown
	BBBBBb	medium brown
	BBBBbb	light brown
	BBBbbb	hazel
	BBbbbb	blue-green
	Bbbbbb	blue-grey
	bbbbbb	light blue

Similar differences in factors such as height can be explained if you consider many pairs of genes like this. You can have a large range of different genotypes from many genes for the same characteristic.

Genotype, environment and disease

In most cases, characteristics are not solely caused by the genes that are inherited, but by the interaction between the genes and the environment. This means that an individual with a particular genetic tendency to a disease will not necessarily develop it; they are said to have a **genetic predisposition** to the disease.

Fig 3.5.6 Regular check-ups are important for those with a genetic predisposition to polygenic disorders such as breast and ovarian cancer.

This is another reason that it is difficult to track the inheritance of conditions through successive generations. Although these conditions may be the result of a genetic predisposition—meaning that they are likely but not guaranteed to occur—steps can be taken to prevent a crisis. For example, cholesterol levels are monitored and controlled through diet and medication where necessary, in order to prevent coronary artery disease.

The genotype of an individual determines the limits of development, while their environment determines the degree to which those limits will be developed. The degree to which a gene is expressed in an individual's phenotype is called expressivity and the proportion of individuals in a population carrying the gene that shows the trait is called penetrance. In nature, each characteristic is influenced by many environmental variables, some increasing expression and others decreasing expression.

Science Snippet

Breast cancer

Breast cancer is the most common cancer experienced by Australian women, including Aboriginal and Torres Strait Islander women, but the incidence rate is lower than for the non-Indigenous population. Men can develop breast cancer, but it is rare. The incidence of breast cancer is increasing.

A good example of the environment affecting the expression of a gene can be seen in some cats and rabbits. There are many well-known examples within oriental cats and rabbit breeds of alleles being masked or enhanced by temperature. You may have already seen this without even being aware of it. The darker pigmented fur occurring on the extremities of cat breeds such as the Siamese and Burmese (see Figure 3.5.7) are a result of the expression of the mutant Cs allele. The mutant Cs allele produces pigment only at lower temperatures and is affected by the lower temperatures on the extremities of these animals. The higher temperature of the main body surface means that the pigment is not produced by the Cs allele and it is almost inactive.

Fig 3.5.7 The chocolate point Burmese is a result of the expression of the mutant Cs allele.

Identical twins, although they have the same DNA, also express characteristics differently. It is therefore the environment that causes this difference. Differences may include muscular development, body weight, number of freckles and intellectual achievement.

Mutation

A **mutation** is a change in a gene or chromosome in a cell that can be passed on to daughter cells produced by mitosis or meiosis of this cell. Mutation is the process by which a gene (or chromosome) changes structurally and therefore the phenotype changes as a result. Without mutation and the alleles it produces, the biological diversity that exists today would not have evolved.

Mutations, put simply, are the permanent alterations in a cell's DNA that affect the nucleotide sequence of one or more genes. They can be helpful or harmful to a species, but are usually harmful. The simplest is a point mutation, the change in a single nucleotide. Examples of different types of mutation can be seen in Figure 3.5.8. Mutations are most likely to involve cells undergoing cell division. A single cell, a group of cells, or an entire individual may be affected. An entire individual may be affected if mutations occur during meiosis or early in development. For example, a mutation that affects a gamete will be inherited by a child of that individual.

Fig 3.5.8 The types of mutation that involve changes in the structure of the chromosome

Normal	… AGGCTCCTA …
Deletion	… AGGTCCTA …
Duplication	… AGGCCTCCTA …
Inversion	… ACCTCGGTA …

The rate of gene mutation is low. However, as each individual has a large number of genes, mutations are constantly occurring within a species. The rate at which mutations occur can be increased through exposure to mutagens such as radiation, chemicals or temperatures above the normal range for the organism.

Variation and evolution

Mutation ultimately provides genetic diversity; this is the raw material of evolution. Mutation rates are usually very low and, even if different alleles mutate at different rates, this by itself will not lead to rapid changes in populations.

Why would a diploid organism take a random sample of its DNA and combine it with a random sample of someone else's DNA to produce offspring? The asexual way of life seems like an efficient way to reproduce yourself. What is the evolutionary benefit to organisms to develop sexual processes? Why is it better to combine the gametes of two individuals to produce a new generation of offspring?

Sexual reproduction allows for the provision of much more variation in organisms. Not only is just half the genome of an individual passed on to every organism produced sexually, but that half is a random jumble, which may provide some advantage to the offspring. A sexual organism can achieve a significant amount of variation through recombination of DNA and fertilisation. In a changing environment a sexually reproducing organism increases the likelihood that it will adapt to changes that occur.

A haploid asexual organism accrues mutations as they occur over time in an individual. A sexually reproducing organism can combine several beneficial mutations in each generation by recombination and fertilisation. Therefore, sexually reproducing organisms can adapt at a much more rapid rate than asexually reproducing organisms.

Mutation is more likely to produce detrimental changes than beneficial ones. An asexual organism gathers more harmful mutations as time goes by. Sexually reproducing organisms can eliminate harmful mutations each generation by either forming recombined offspring that are relatively free of mutation or by producing offspring with many detrimental mutations that then die, removing the harmful mutations from the population.

Homework book 3.8 Punnett squares as genetic tools

FOCUS 3·5 [Questions]

Use your book

Sex-linked inheritance

1 What is the name given to the first 22 chromosomes?

2 Which pair of chromosomes may look very different from each other and carry different genes?

3 Which gametes determine the sex of the offspring?

4 How are X-linked genes inherited? Give an example.

5 Explain any two ways to check whether a characteristic is X-linked dominant or X-linked recessive in a pedigree.

Polygenic inheritance

6 What is polygenic inheritance?

7 What types of characteristics are passed on by polygenic inheritance?

Genotype, environment and disease

8 Which two factors operating together determine whether a characteristic develops in an individual?

9 If a person has a genetic predisposition to a condition, does this mean that they will necessarily develop it?

10 Define 'expressivity' and 'penetrance'.

Mutation

11 What does the term 'mutation' mean in genetics?

12 What process has relied upon mutations to produce diversity and variation within a population?

13 What are the four types of mutation discussed in this Focus? Give an example of each.

14 Are mutations common within the population?

Variation and evolution

15 What provides genetic diversity within a population?

16 What benefits does sexual reproduction have within a population?

17 What variables may affect a person's phenotype?

Use your head

18 Mr Bloggs has four daughters and complains that it is his wife's fault that he does not have any sons. What advice could you give him?

19 Construct a Punnett square to show the possible genotypes for colour blindness of a X^BY male and an X^BX^b female.

20 A colour-blind man and a woman with normal vision have two children. The elder is a colour-blind boy. The younger is a girl with normal vision.

a Draw a pedigree for this family.

b What is the probability of the parents having another colour-blind boy?

c What is the probability of the parents having boy with normal vision?

d Is there a possibility that these parents could produce a colour-blind girl?

21 State the features of a genetic disorder that would lead to the belief that it is a form of sex-linked inheritance.

22 How is it possible for two individuals with the same genotype to have different phenotypic characteristics?

Investigating questions

23 In Figure 3.5.2 it is shown that the sex ratio of offspring should be 1:1. Research the male and female births recorded in two different countries and give reasons as to why this may not be the case.

24 Research an X-linked dominant or X-linked recessive trait, draw a pedigree for the trait and determine the probability of the trait being passed on by the last offspring.

25 Research how parentage can be determined through following mutations in the Y chromosome.

26 A professor of genetics at Oxford University, Bryan Sykes, has written a book called *The Seven Daughters of Eve*. He also has a website. His research suggests that mitochondrial DNA can be used to track family descent on the mother's side. Read the book or check out his website. Find out why he thinks this and write half a page explaining what ribosomal DNA is and how it is used to infer relationships.

FOCUS 3·6 Diversity

Context

Diversity means difference. Each species is genetically different from others. In this Focus you will look at the process of classification and the use of keys to identify species using these differences. You will learn about how biological classification systems show relationships. You will also look at the importance of diversity to the survival of each species and to the survival of ecosystems, including sustainability of human populations.

Classification and relationships

Modern biological classification systems are largely based on structure. Structure was chosen because it was the most reliable feature to use. In other words, it consistently put particular organisms in the same groups when different scientists applied it—so the systems worked by helping people to correctly identify organisms and to classify newly discovered organisms.

Classification based on structure reveals how organisms are related to each other. This is because structures develop due to the effects of both genotype and the environment. Species with similar structures are likely to have inherited some of the same genes that control those structures. It is not always true that similar structures are due to the same genes. For example, dolphins and sharks have a similar streamlined body structure and a fin. The influence of the environment has shaped these body structures to look similar, even though the genes may not be the same. A closer study of these two animals reveals large differences in other structures, showing they are not very similar other than at the phylum level. However, often the genes *are* the same when two organisms show similarities, and this is more often the case at the lower levels of classification.

Organisms with the same genes must be related, because genes are copied from previously existing genes. This means organisms that share genes can be traced back to common ancestors at some stage. Older systems of classification were mainly based on appearance but modern classification systems are increasingly using genetic information. The actual genes or body proteins involved are now being taken into account in deciding which groups organisms should be in.

Not all systems of classifying organisms are identical, mainly because genetic information is not complete, so differing opinions can put particular organisms into different groups. However, most systems are very similar, and nearly all biologists agree on the major groups that should be formed. As more research is done, it is likely that systems will change to better reflect the genetic relationships between organisms.

Once a system of classification is devised it is used to identify organisms. This is due to the fact that to construct the system of classification, all the known

Sharks and dolphins are not closely related but look similar due to their evolution in similar environments.

Fig 3.6.1

organisms in the world at the time are considered in choosing characteristics to classify the groups. However, many new species are discovered every day and occasionally even new families of organism are discovered. Hence modifications continually need to be made to classification systems.

Classifying species

At the lower levels of classification it becomes harder to separate organisms into different groups. For example, it is often difficult to separate organisms in the same genus into different species. In the past, the test was to see if two organisms could interbreed to produce fertile offspring under natural conditions. If they could not do this, they were considered separate species.

There are problems with using this definition of a species. One problem concerns populations that are separated by large distances. These populations may be able to interbreed to produce fertile offspring if they come together at some time in the future due to geological or climatic changes. If we could not call them separate species then, what about now? Another problem is that where the home ranges of some species overlap, they may interbreed to produce offspring, some of which are fertile. These fertile offspring are given the name hybrid.

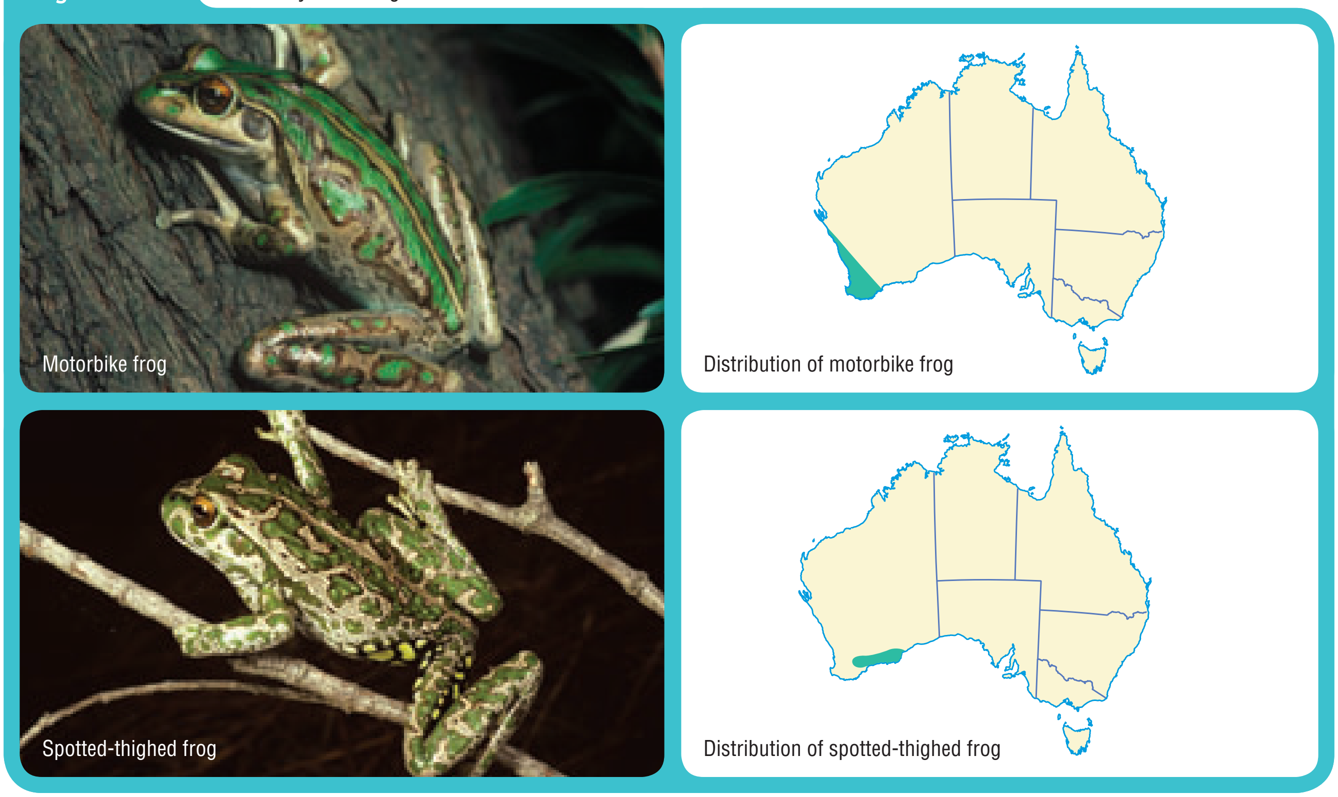
The interbreeding test is still used to classify at the species level, but now we can study the DNA of each species and also identify the similarities in the amino acid arrangement in the proteins they make. Since proteins are made by genes, identical proteins must mean identical genes.

Classifying flowering plants

Flowering plants form the class Angiospermae, commonly called angiosperms. There is enormous diversity in this class, which contains most of the plants you commonly see. The class is divided into two sub-classes, monocotyledons and dicotyledons. The monocots have leaves with parallel leaf veins and their flower parts are in threes, or multiples of three. The dicots have leaves with a network leaf vein pattern and their flower parts are in fours or fives, or multiples of these.

These sub-classes are then classified into families. There are about 20 families of monocots in Western Australia and about 100 families of dicots. With experience, it is simple to name the family to which a flowering plant belongs. A family of plants has only a few distinctive characteristics, which are generally easy to recognise. The flower structure is the most

Fig 3.6.2 These two species of frog interbreed where they occur together.



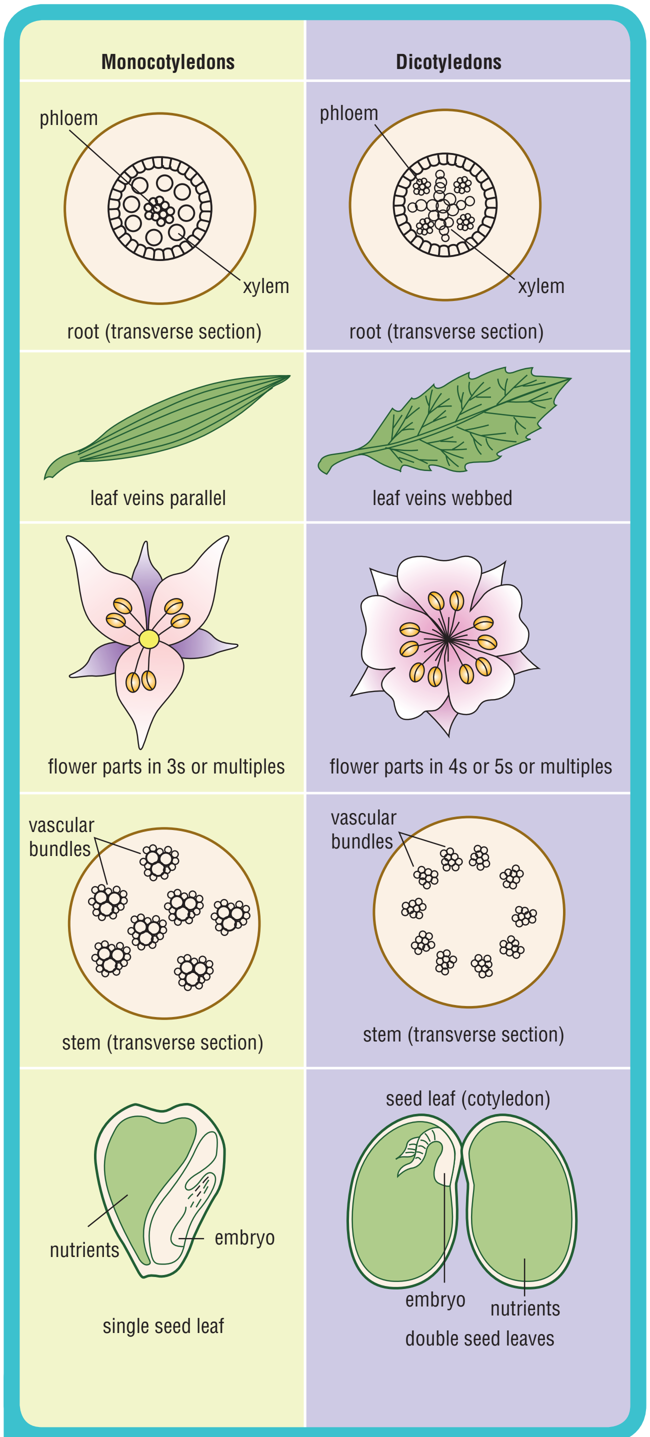
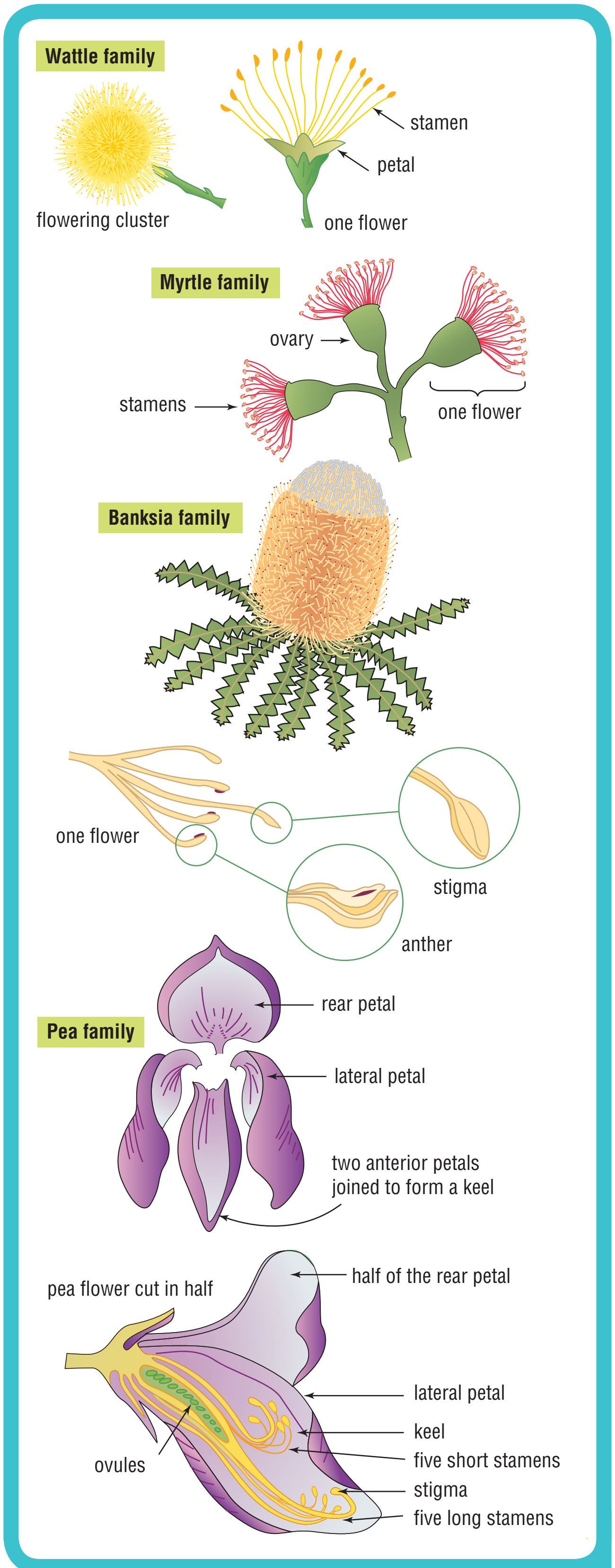


Fig 3.6.3 There are distinctive differences between dicots and monocots.



Four families of flowering plants *Fig 3.6.4*

stable characteristic in flowering plants, so it is the major feature used to classify them. Leaves are rarely used, as so many are similar.

For example, examine the differences in the four families shown in Figure 3.6.4.

Keys

To assist in the process of identification, devices called **keys** are produced by biologists. A key can be in several forms. In the field, ecologists usually use keys to find the name of a species. However, to be able to do this, they must start at the phylum level and gradually work downwards. If there are keys in existence for the particular species with which the ecologist is working, the name can be found. Trained biologists are usually able to start keying out an organism at the family level or the genus level. They probably already know the organism's phylum, class and order. This is one of the benefits of constructing a system of classification.

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Revising classification systems

Professional scientists are employed by government bodies to update systems of classification as well as classify newly discovered species. The Western Australian Herbarium in Perth employs officers whose job it is to identify and classify all the plants discovered in the State. Specimens are sent to them from all around the State by a variety of people. They also have to consider whether the system of classification suits newly discovered species, or whether the classification of a whole group may have to be revised in the light of new genetic evidence of relationships between species.

Diversity and survival

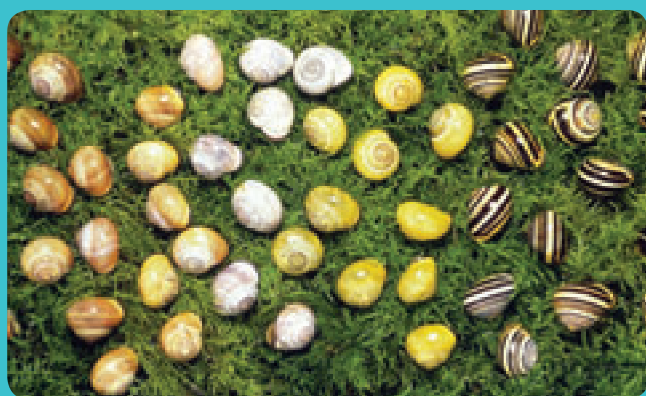
Diversity in a species

Diversity is a key factor in the survival of a species over long periods of geological time. This can be briefly explained in the following way. The modern theory of evolution by natural selection is based on genetic diversity being present in a species. An example in insects is the inherited differences in their ability to survive insecticides. Without diversity, natural selection cannot operate as the driving force of evolution. This means a species cannot become adapted to changing environments, and runs the risk of becoming extinct.

Natural selection is the process in which an environmental factor acts on a population and results in some organisms in the population having more surviving offspring than others. The environmental factor that causes this is called the **selective agent**. The selective agent usually (but not always) acts by killing individuals that do not have features that are able to cope with it. The organisms that survive pass on their features to the next generation. So the next generation inherits the features that can cope with the selective agent. The organisms that survive are said to have been **selected**. The differences in the individuals is the diversity.

The selective agent acts on the phenotype of an organism. The genes that interact with the environment and produce this phenotype are therefore also being selected for. So changing the phenotypes in a population leads to change in the genes in the population as well. The proportion of particular genes therefore changes over the generations as certain phenotypes are selected. This is what Darwin did not know, because the science of genetics developed many decades after his death. Now we understand a lot more about how natural selection leads to evolutionary change.

An example is shown in Figure 3.6.5. The song thrush preys on a snail called *Cepaea nemoralis*, which has great variability in its shell colour.

The song thrush (left) is a selective agent acting on the phenotype of the brown-lipped snail (right), which means that it selects the genes affecting the phenotype. *Fig 3.6.5*

The bird smashes the shell open on a stone anvil. The snails are basically a yellowish background colour or a brownish background colour, and some are heavily striped while others are not. Collections around anvils of snail shells in areas where the background is brown leaf litter on the forest floor show a higher ratio of yellowish snails to brownish snails than in areas with heavy grass cover that is well lit. Experiments with marked snails show the same results. This suggests that camouflage effects have resulted in the bird selecting out the less camouflaged snails. The brownish snails are well hidden against the brown leaf litter, while the yellowish snails are better hidden in the well-lit greenish-yellow colour of grasslands.

In a rapidly changing environment, a population that has enough diversity should include some members with features that can cope with the selective agent. This has been shown conclusively by many experiments on organisms. Two common examples are the selection of insecticide-resistant insects and antibiotic-resistant bacteria. So diversity in genotype and phenotype appear to be vital for the long-term survival of many species.

Homework book 3.9 Natural selection of snails

Diversity in an ecosystem

Diversity also refers to the range of different species in a community. We use the term 'biodiversity' to describe this. Having many different species makes a community more stable and less likely to be affected by environmental changes. For example, it is much harder for weeds to invade a complex community with many species than one with only a few. This is because with only a few species the weeds have more chance of having a feature that can give them an advantage in competition with the native plants. But with many different native species it is less likely that the weeds will be superior to them all.

Sustainability and diversity

The Australian Government has produced a document called the 'National Conservation Strategy for Australia'. This document specifies four conservation objectives, which are to:

1 maintain essential ecological processes and life support systems
2 preserve genetic diversity
3 ensure the sustainable utilisation of species and ecosystems
4 maintain and enhance environmental qualities.

Sustainable utilisation refers to the use of organisms and ecosystems in such a way that they are not damaged and we can continue to use them. A key factor in this is retaining the biodiversity in an ecosystem. When ecosystems lose species, they become less likely to survive. In many ecosystems there are **keystone** species, which are critical to the survival of the whole ecosystem. For example, earthworms enrich the soil and enable plants to grow, which then supports all the other organisms. Lose the earthworms and the ecosystem is in danger of collapsing.

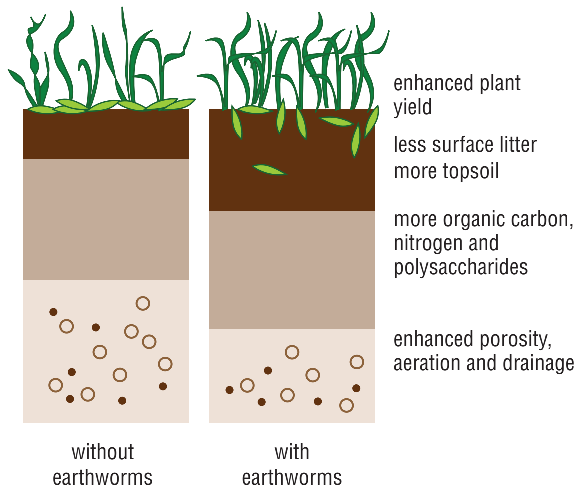
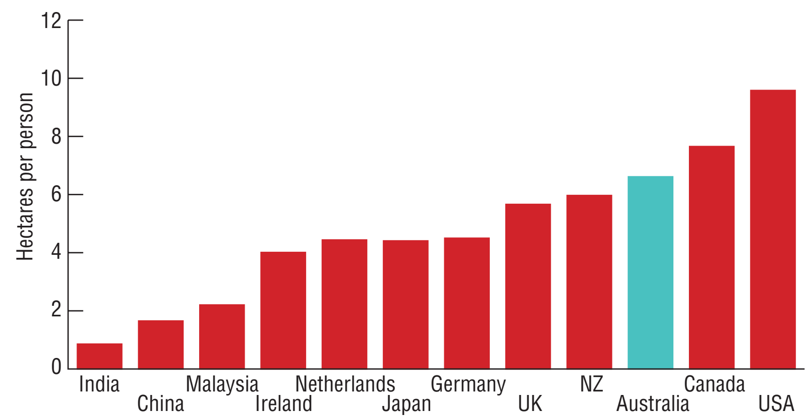


Fig 3.6.6 Earthworms are keystone species in many ecosystems.

Research into keystone species in all ecosystems is essential if we are to truly understand how to manage those ecosystems better. Basic research is necessary to inform all development proposals.

Another tool that can help humans to live sustainably is 'eco footprint' analysis. The **ecological footprint** of a population is the area of land and water required to supply the resources needed for survival and to cope with the wastes produced (as the methods used to calculate the land area needed are complex, there is not the space here to discuss them). The area of land needed to support each Australian is about 7.5 hectares, compared with the world average of about 2.2 hectares. Using this tool, there are some cities, such as London and Tokyo, that need an area of land greater in size than the entire country in which they are located. These figures show that it is time to change how we live. Planners should aim to reduce our eco footprints to about 2 hectares.



The ecological footprint of Australians is much higher than the footprints of people in many other countries.

Fig 3.6.7

3·6 FOCUS [Questions]

Use your book

Classification and relationships

1 Why were early classification systems based on structure?

2 What do classification systems reveal about organisms besides how similar they look?

3 Why would organisms that look similar be likely to have the same genes?

Classifying species

4 What methods can be used to test if two organisms are different species?

5 What difficulties may occur with the interbreeding test for species?

Classifying flowering plants

6 What are the main differences between monocots and dicots?

7 What is the main feature used to classify flowering plants, and why is this used?

8 Where are newly discovered plants sent to be classified?

Diversity in a species

9 Why is diversity vital for the long-term survival of a species?

Diversity in an ecosystem

10 Use an example to explain how biodiversity improves the chances of an ecosystem surviving.

Sustainability and diversity

11 What are keystone species and why are they important?

12 What is ecological footprint analysis?

Use your head

13 Consider the following table showing the classification of some animals in the phylum Chordata.

Class	Order	Family	Animal
Mammalia	Primates	Hominidae	Human
Chondrichthyes	Lamniformes	Lamnidae	Great white shark
Mammalia	Primates	Pongidae	Chimpanzee
Mammalia	Cetacea	Delphinidae	Common dolphin
Mammalia	Chiroptera	Vespertilionidae	Gould's wattled bat
Aves	Strigiformes	Strigidae	Boobook owl

a Which two animals are most closely related, and why did you choose these?

b Which two animals are most distantly related, and why did you choose these?

c Which animals would probably have the greatest percentage of similar genes?

d Which two animals are most alike, and why did you choose these?

14 Explain how you can determine which two animals are more alike out of a bat, a bird and a dog.

15 Consider Figure 3.6.4. Describe some differences in the flower parts of the four families of flowering plants shown.

Investigating question

16 Choose a family of WA flowering plants. Describe the main characteristics of the family, then name five genera in the family and describe the differences between these genera.

FOCUS 3·6

[Practical activity]

Prac 1 Focus 3.6

Getting to know the family

Purpose

To use a key to identify some genera from an important family of native plants, the 'myrtle' family, family Myrtaceae.

Requirements

Specimens from genera in the family key shown below, 'Stanley trimmer' for cutting through fruits, forceps, petri dish, hand lens or stereomicroscope, books with illustrations or photos of the family, access to Internet resources such as 'Nature Base'.

Procedure

1. Your task is to use the key to identify the name of the genus to which each of the plants belongs. This will involve cutting into some flowers and fruits. Your teacher will show you how to do this, or will display cut sections for you to observe. You will be using the hand lens or microscope to observe flower parts. You will need to know the names of the parts of a flower to do this activity.
2. Collect one specimen from the selection at the front of the room. *Note its number down. You must write down each of the choices you make for the specimen as you proceed through the key. Finally, write down the name of the genus.*
3. Use the books or the Internet to see if your specimen looks like the images shown for that genus. If you appear to be incorrect, go back over your choices to see if you made an error.
4. Repeat steps 2 and 3 for as many other specimens as you can in the time you have.

Questions

1. What is a genus? Explain by using eucalypts as an example.
2. What are some common features of members of this family?
3. Do any of these genera seem to have more in common with some genera than with others?
4. This family is a member of the dicotyledons. How would monocots be different?
5. Would the genera in this family have any genes the same? Explain your answer.

Key to some genera in family Myrtaceae

1a	Ovary with between 3 and 10 sections	go to 2
1b	Ovary with 1 section	go to 8
2a	Stamens separate	go to 3
2b	Stamens in 3 to 5 bundles, joined for part of length of stamen	go to 7
3a	Flowers with no stalk. Stamens no longer than petals	go to 4
3b	Stamens longer than petals, in two rows	go to 5
3c	Stamens larger than petals, in single row	Kunzea
4a	Leaves in pairs and opposite each other	Baeckea
4b	Leaves alternating	Leptospermum
5a	Flowers with no stalk, in a cylindrical column. Fruit woody. Shrubs	Callistemon
5b	Trees with flowers at ends of branches and each with a stalk	go to 6
6a	Flower with petals. Trees	Angophora
6b	Flower bud covered by a cap that falls off when flower opens. Trees	Eucalyptus
7a	Flowers with no stalk and in cylindrical heads or ball-shaped heads. Stamens in five bundles joined at the base for less than $^{1}/_{4}$ length of the stamen	Melaleuca
7b	Flowers with stalks growing from leaf base. Trees	Tristania
7c	Stamens joined over $^{3}/_{4}$ length. 3–4 stamens per bundle. Small shrubs	Beaufortia
8a	Flowers waxy and in open groups of 2 to 4 each with stalks at tip of branches. Shrubs less than 2 m	Chamelaucium
8b	Flowers in terminal heads often covered by petal-like coloured bracts	Darwinia

FOCUS 3.7 Studying ecosystems

Context

This Focus is about how ecologists study ecosystems. Ecologists need to find out how various undisturbed ecosystems function. From this information they can predict how developments such as mining may affect an area, and they can measure the effects when the development occurs. They can study the effects of climate change and natural cycles in the weather.

Another reason for studying ecosystems may be to preserve natural populations as they are cropped. For example, knowledge of the fishing catch level assists in determining whether the fish population can remain stable by replacing itself through breeding.

Sampling

It is rarely possible to count the whole population of a species. Ecologists simply do not have the time, money or ability to do this for all species. All the methods used for determining populations rely on the process of sampling. A **sample** is a small proportion of the population, which ecologists try to ensure is representative of the whole population. An **estimate** of the population can then be calculated from the samples taken.

The samples used must be **random**. This means that any organism has the same chance of being picked. In this way there is no chance that the personal bias of the researcher can affect the result.

Fig 3.7.1 Taking samples of fish in Kakadu National Park

Estimating population size

Capture–recapture

Populations are measured using various methods. One method is called the **capture–recapture** method. This is suitable for animals that do not stay in one place. In this method, scientists capture a small sample of the population and tag them in some way, such as with a leg band, paint spot or ear tag.

Fig 3.7.2 Inserting an electronic tag into a young salmon

The tagged animals are then released. Some time later, perhaps a few days or weeks, the scientists return to the area and catch another sample. They count how many they catch, and how many of this second sample have tags. Using an equation, they can calculate the population size. The equation used is:

$$P = T \times \frac{S_2}{R}$$

where P is the calculated population, T is the number tagged in the first capture, S_2 is the number caught in the second capture, and R is the recapture, the number in the second capture that had a tag.

As an example, assume ecologists were trying to estimate the population of fish in a lake. If they caught 50 fish and tagged them, and on returning a few days later they caught 40 fish, of which four had tags, then the population would be:

$$P = \frac{50 \times 40}{4}$$
$$= 500 \text{ fish}$$

The capture–recapture technique is based on four assumptions.

1 The death rate of tagged individuals is the same as that of untagged individuals. If tagged individuals were more likely to die, the calculation would be inaccurate.
2 Once an individual is tagged, it is not more likely or less likely to be caught again. If it were easier to catch tagged individuals, the calculations would underestimate the real population size.
3 Tagged individuals will redistribute evenly throughout the total population and area. If they do not, and, say, collect in the place at which the second sample is taken, a much smaller estimate of population will be calculated.
4 The number of births or individuals immigrating to the area is very small in the time between tagging and recapture.

Prac 1 p. 122

Quadrats

Another method of population estimation involves the use of quadrats. A **quadrat** is a sampling area of a particular size and usually of a square shape. For some populations, especially plants, this method is particularly suitable. An area is divided up into equal-size areas, called quadrats, as shown in Figure 3.7.3.

In this example, an area 800 metres by 800 metres is sampled to calculate the population of a species of tree. The total area has been divided up into 64 quadrats, each 100 metres by 100 metres.

Next the researchers must decide how many samples they are going to take. In this case they decide that 10 samples are enough so they need to select 10 squares out of the 64. To do this they must use a method that gives any one of the 64 squares an equal chance of being chosen. One method could be to write the numbers 1 to 64 on separate pieces of paper, put

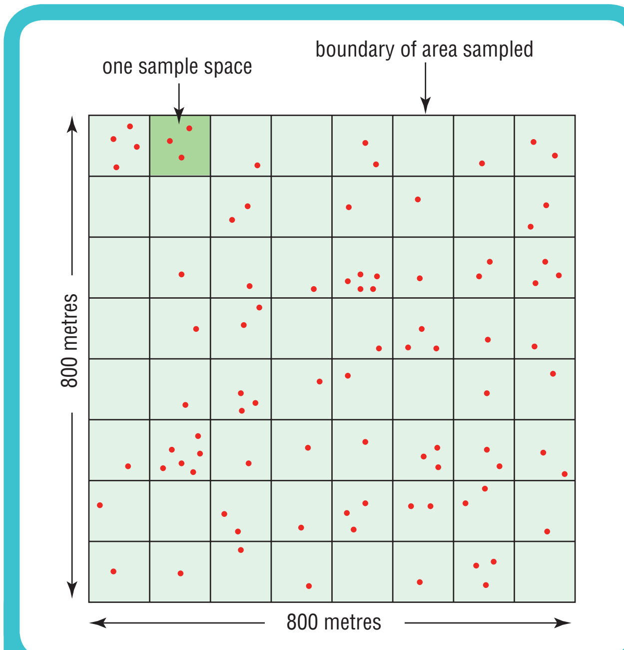


Fig 3.7.3 The sample area is divided into many equal-sized squares.

them into a box, and draw out 10. Other methods are to use a computer with a random number generator, or to use a book of tables of random numbers.

When the 10 numbers have been chosen, the researchers must go to the area and locate the correct quadrats. One way to do this is to find the correct position, size and orientation of the quadrat, using a measuring tape and a compass and a GPS. When each quadrat has been located it is usually marked out by hammering in four stakes and marking out the area with a rope boundary.

The number of organisms of the population being investigated is counted in each quadrat and the following equation used to calculate the population of the organism.

$$P = \frac{T \times A}{S}$$

where P is the calculated population, T is the total number of plants counted in the 10 samples, A is the total area and S is the total area occupied by the ten sample quadrats.

In Figure 3.7.3, imagine that 16 trees were counted in the 10 sample areas. The population would be calculated in the following way:

$$P = \frac{16 \times (800 \times 800)}{(10 \times (100 \times 100))}$$
$$= 102.4$$

Since there cannot be 0.4 of a tree, the estimate of the total population would be 102 trees.

Quadrat size

In sampling an area, it is important to consider the quadrat size. Obviously it would be difficult to estimate vegetation densities of huge trees and small shrubs using the same-size quadrat. If the quadrat used for large trees were used for small shrubs, the researchers would take too long to count the shrubs. So biologists use different-size quadrats even within one area to cater for different vegetation categories. One common standard is to use the quadrat sizes shown in the following table.

Type of vegetation	Quadrat size
Trees (more than 5 m high with one stem)	100 m^2
Shrubs (0.5 m to 8 m high with many stems)	20 m^2
Saplings (trees < 5 m high)	20 m^2
Herbs and small non-woody plants	1 m^2

Fig 3.7.4 Using a small quadrat to estimate weed density in a lawn

Estimating density

Ecologists studying a population often want to know more than just how many individuals are in the ecosystem. They want to know how common the species is in the ecosystem. This tells them how likely it would be to find one of the species in the sample area. Ecologists need to be able to compare the populations in different areas. To do this they estimate the density of the species in each place.

Density

The **density** of a species at a site is the total number of individuals per unit area or volume. Using the example in Figure 3.7.3 the density of the tree species would be:

$$\text{Density} = \frac{\text{number of individuals}}{\text{area (or volume)}}$$

$$= \frac{102}{800 \times 800}$$

$$= 0.00016 \text{ small plants/m}^2$$

This number seems very small. In practice, the ecologists would not be interested in the number of trees per square metre because this a very small unit. They would probably choose a unit like the number of trees per hectare, which is an area of 10 000 square metres. In this case the density would 1.6 trees per hectare.

Density of populations living in water may be expressed in terms of volume. For bacteria and other small organisms, the units chosen may be numbers per millilitre of liquid. For larger organisms, a larger unit of volume may be used.

Prac 2 p. 123

Relative density

Density can also be expressed in relative terms. **Relative density**, is calculated as follows:

$$\text{Relative density} = \frac{\text{density of a species}}{\text{total density of all species}} \times 100$$

This calculation will give a percentage. For example, a relative density of 1 per cent for a species means that 1 per cent of the total density is due to that species. This gives an idea of how common a species is compared with all the others in the area.

Cover

Another calculation that can be useful is **cover**. This is calculated as follows:

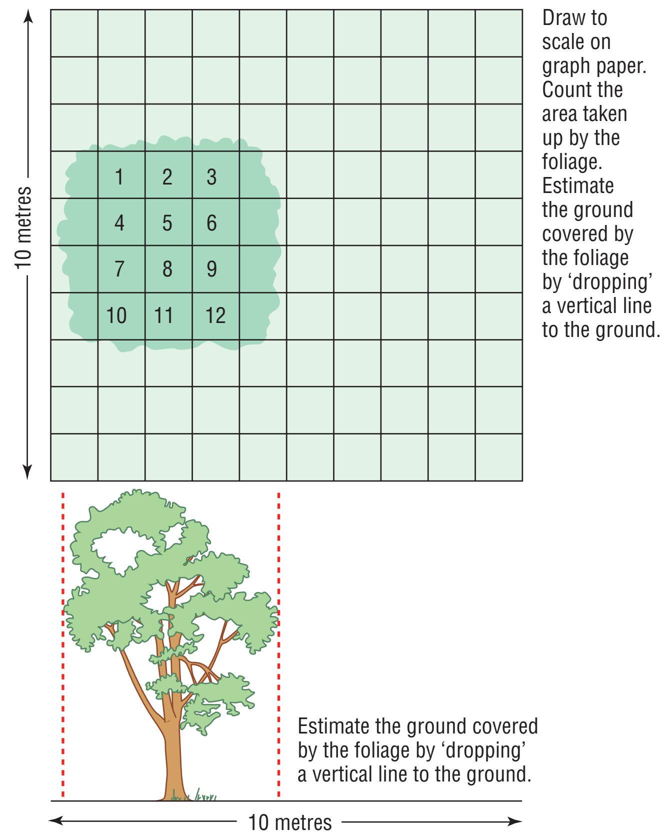
$$\text{Cover} = \frac{\text{total area covered by a species}}{\text{total area sampled}} \times 100$$

This calculation gives an idea of the amount of ground covered by a particular species in an area. For small shrubs you can stand above them and measure the foliage area with a metre rule. For large trees it is more difficult. The cover for a large tree can be imagined as the amount of shadow on the ground if the Sun was directly overhead. You have to estimate this from an imaginary vertical line dropped down from the tree when viewed from the side. Figure 3.7.5 shows how to determine cover for a tree species. The estimate for this species is about 18 per cent, because about 18 squares out of 100 are covered by foliage.

Another way this can be done for large species is by aerial photographs. Computer analysis also can be enlisted for large species and large areas such as forests.

Cover is estimated by projecting a vertical line from the foliage to the ground.

Fig 3.7.5



Line transect technique

Another useful technique for field work is the **line transect** method. In this technique a string line is run through an area, and all species of plant touching the line are counted in the sample. This method is very useful for giving a visual impression of the vegetation in an area. An example is shown in Figure 3.7.6. This shows the height and distance covered by each plant species along a line transect through an area of bushland in Western Australia. A fire had been through the area many years before and the ecologists were trying to assess if it had changed the height and types of vegetation in the area.

Relative density and cover can also be calculated using this technique. In this case the calculations are slightly different.

$$\text{Relative density} = \frac{\text{total number of individuals of a species}}{\text{total individuals of all species}} \times 100$$

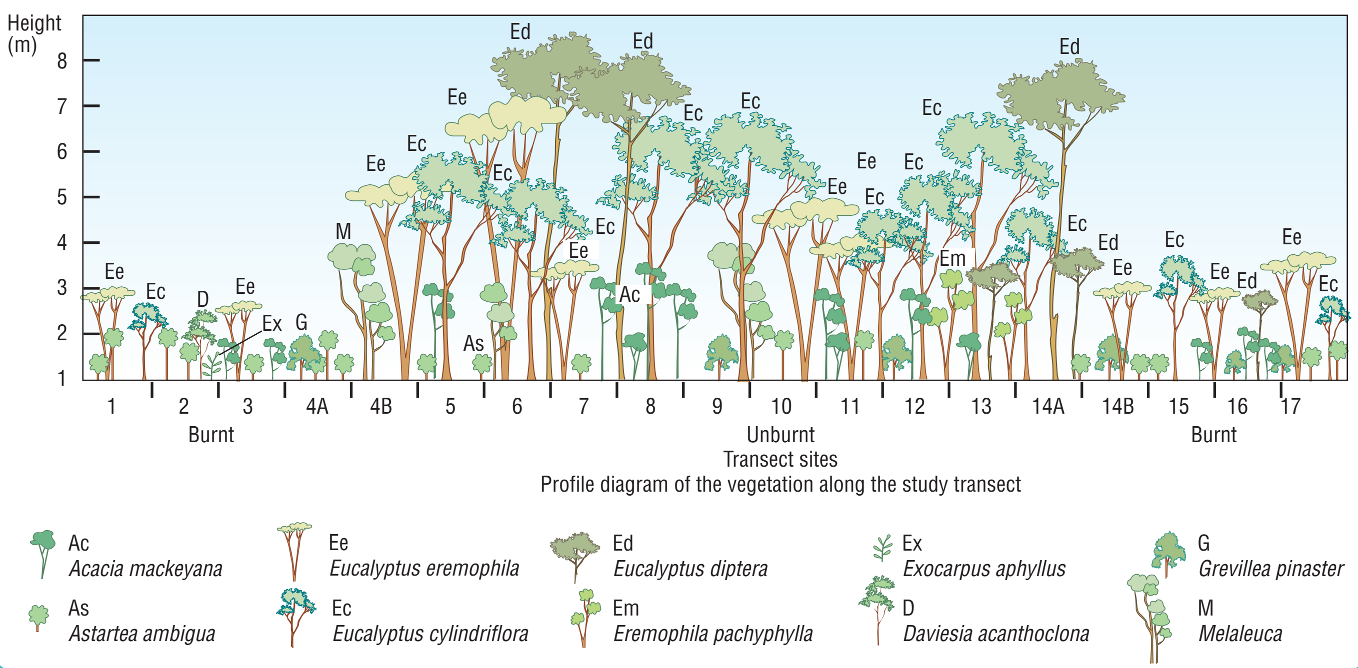
$$\text{Cover} = \frac{\text{total length of transect covered by a species}}{\text{total length of transect}} \times 100$$

In both cases it is the plants touching the line that are counted.

A refinement of the line transect method is the **belt transect** method, where the area one metre to one side of the whole transect is considered. In this case

This is a profile drawing along a line transect that shows the effect of fire in a community.

Fig 3.7.6



the principles applied to quadrats are relevant and calculations of relative density and cover can be made.

Pyramids of biomass and energy

So far in this Focus you have seen how populations can be studied by calculating their size or the distribution of the individuals across the habitat. Other very useful tools for assessing an ecosystem are the pyramids of biomass and energy. In *Science Aspects 2* you learnt about **pyramids of biomass**. These are diagrams that show the total mass of organisms at each level in a food chain. Figure 3.7.7 shows an example for the food chain:

grass → grasshoppers → frogs → tiger snakes

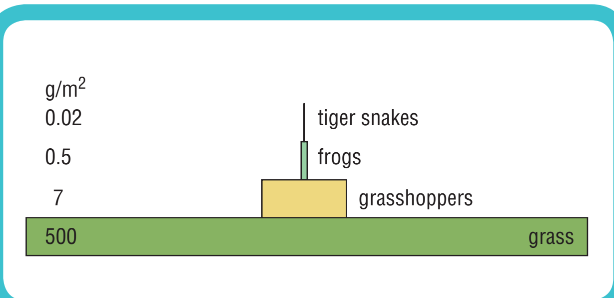
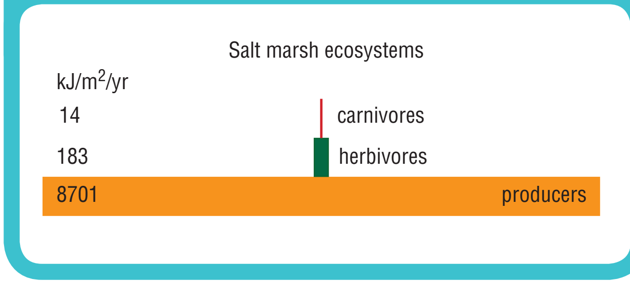


Fig 3.7.7 A pyramid of biomass

A pyramid of biomass like this can be useful because it shows how well the ecosystem supports life. So comparing pyramids of biomass from different ecosystems gives a guide to how well they support life. This also helps us to see if a particular ecosystem is damaged by development such as mining. A pyramid of biomass before and after mining could show if the area has been **rehabilitated**, or returned to its original ability to support life.

Homework book 3.10 Quadrats and sample size

Fig 3.7.8 A pyramid of energy



A **pyramid of energy** is a diagram showing the total amount of energy at each level in the food chain. This is more useful than a pyramid of biomass because it gives a better estimate of the productivity of a habitat. Pyramids of biomass can give a false impression of an ecosystem because they are usually done at a moment in time, usually a period of days. Rapid changes in population sizes at the time the pyramid is being done can result in a pyramid that is misleading. It could show a bigger mass of herbivores than producers, for example. A pyramid of energy will not have this problem, because it shows only how much energy is actually flowing, and it is usually done over a year. So it is comparing different ecosystems over the same time period.

3·7 FOCUS [Questions]

Use your book

Sampling

1 **a** What are samples?
b Why are samples used?

2 **a** What is a random sample?
b Why is it necessary to use random samples?

Capture–recapture

3 What assumptions have to be made for the capture–recapture technique of estimating populations to be accurate?

4 A scientist used the capture–recapture method to estimate the population of periwinkles on rocks along a beach. If the number tagged was 1000, and out of 500 in the second sample only 50 had tags, calculate the population size.

Quadrat size

5 Explain why different quadrat sizes are recommended when estimating density of plant species.

6 For each of the following species give the quadrat size that could be used to conduct a survey to determine the density of the species: jarrah trees, fern plants, bottlebrush shrubs and earthworms.

Relative density

7 In a certain area of bush, the density of jarrah trees was 20 per hectare and the density of all trees was 37 per hectare. What is the relative density of jarrah trees?

>>

Cover

8 Ten samples of one hectare each had a cover of jarrah trees equal to three hectares in total. Calculate the cover of jarrah trees.

9 Using Figure 3.7.6, calculate the relative density and cover of the species *Eucalyptus cylindriflora*.

Pyramids of biomass and energy

10 What is a pyramid of biomass, and why is it useful?

11 How is a pyramid of energy superior to a pyramid of biomass?

Use your head

12 A scientist studying the population of fish in the Swan River decided to collect samples from his favourite fishing spots. Would these be random samples? Explain your reasoning.

13 An aerial survey of a lake counted 500 black swans. The lake was almost circular in shape and had a diameter of about 600 metres. What was the density of black swans in:

- a swans per square metre?
- b swans per hectare?

14 If the capture–recapture technique was used on a population that had a very high birth rate and a high immigration rate, what would probably happen to the estimate of the population size?

15 Calculate the density of humans in your classroom or your home at this moment.

16 Consider an ecosystem such as a freshwater lake, where the water temperature is rapidly changing in early summer, and there is a sudden increased fertiliser run-off into the lake. Imagine you are a biologist studying the ecosystem, and you decide to do a pyramid of biomass. How may these conditions give you a false view of the productivity of this ecosystem?

Investigating question

17 Imagine you are doing a population estimate for the organism in Figure 3.7.3. Write the numbers 1 to 64 on separate pieces of identical paper. Mix the pieces up in a container and choose 10 without looking. Assume the squares are numbered from 1 in the top left of Figure 3.7.3 across to 8 for the first row. The next row is 9 to 16, and so on.

- a Record how many organisms in each sample square.
- b Find the total number in ten samples.
- c Calculate the population, using the formula.
- d How close was your estimate to the actual population?
- e Compare your results with those of five other students and show the smallest estimate and the largest estimate of the population.
- f Calculate the average of the six estimates.

FOCUS 3.7 [Practical activities]

Modelling capture–recapture

Prac 1 Focus 3.7

Purpose

To use a model to understand the principles of the capture–recapture method of estimating population size.

Requirements

300 pieces of white plastic (eg spaghetti or beads), 500 mL container (eg margarine), 30 pieces of black plastic.

Procedure

1 Place 300 white pieces of plastic into the container.

2 Draw out a handful (about 20 or 30) without looking. This is the ‘capture’.

3 Count out the same number of black pieces as the number of white pieces that you removed in step 2. Place the black pieces into the same container as the remaining white pieces. This is the number ‘tagged’. *Record this number in your notes.*

4 Shake up the container to spread the black pieces evenly among the white pieces. Be careful not to spill any pieces out of the container.

5 Without looking, again take out a handful of pieces (about 20 or 30). Count the total number, and record how many are black. *Record these numbers in your notes.*

6 Calculate your estimate of the population size using the equation in this Focus subtitled ‘Capture–recapture’ (on page 117).

7 *Write your results on the board and then copy all the results from the different groups in the class.*

>>

8 Calculate an average estimate of population size from the class results. *Record this in your notes.*

Questions

1 How accurate was your estimate of the population size?

2 Which was closer to the correct answer—your estimate of the population size, or the class average?

3 For most groups in the class, what is the answer to question 2?

4 What would this model assume about the following for real animals in the field:

a the behaviour of marked individuals (why do step 4 in the procedure above)?

b their survival between marking and recapturing?

c the chance of the marked individuals being recaptured?

Prac 2
Focus 3.7

Determining density with quadrats

Purpose

To determine the density of a plant species using quadrats.

Requirements

1 metre square quadrats made from wooden stakes and polypropylene rope, coloured marker, compass, hammer or rock.

Procedure

1 Your teacher will give you an area where you are to calculate the density of a particular plant species. The class will sample along a line at intervals of 5 m. Find the sample site along the line assigned to you by your teacher.

2 Turn your back to the area to be sampled. Throw the coloured marker over your shoulder.

3 Without trampling down the vegetation, walk to the marker. Place your compass on the marker and find north-west. This is where you will hammer in the first stake. Hammer in the other three stakes so that the quadrat sides run north-south and east-west.

4 Count the number of the plant species inside your quadrat. Count the plant in your quadrat if the stem or main root bowl is inside the quadrat. The whole plant does not have to be inside the quadrat. *Record the total number.*

5 Pull out the stakes and pack up your quadrat. Make sure you have all your equipment. Return to the assembly point indicated by your teacher.

6 When back in class *add your results to the class results table on the board. Copy the class results table.*

Questions

1 Calculate the density of the plants in your quadrat, and all the other quadrats.

2 Calculate the average density of the plants.

3 How close did your group results come to the average?

4 How confident are you that the class results give a fair estimate of the plant density? Explain your answer.

5 Describe another way in which you could have sampled these plants.

FOCUS 3.8

Genetics and health

Context

Genetic and reproductive technologies play an increasingly important role in our health. This Focus is about some of these, such as IVF, stem cell research, cloning, gene splicing, gene therapy and germline genetic engineering. The ethics of these technologies are an important consideration. Is it morally acceptable to conduct experiments and create therapies such as these?

In vitro fertilisation

In vitro fertilisation, or IVF, is a process of joining egg and sperm outside the human body. In vitro means 'in glass', which refers to the glass dish in which the reproductive cells are joined. Eggs are removed from the mother's ovaries, and sperm from the father is then added to the dish containing the eggs.

IVF is used when the mother cannot naturally have children, which may be due to blocked oviducts, or defective eggs or sperm. Sometimes a couple who have defective sperm or eggs may use donor sperm or eggs. The zygote formed from fertilisation is allowed to develop to a ball of cells called a **blastocyst**. This is then inserted into the mother's uterus. Usually several fertilised eggs are inserted because many do not implant in the wall of the uterus, and die. Often this has to be repeated over many months or years, at great cost, before there is a successful pregnancy.

Fig 3.8.1 The steps involved in IVF

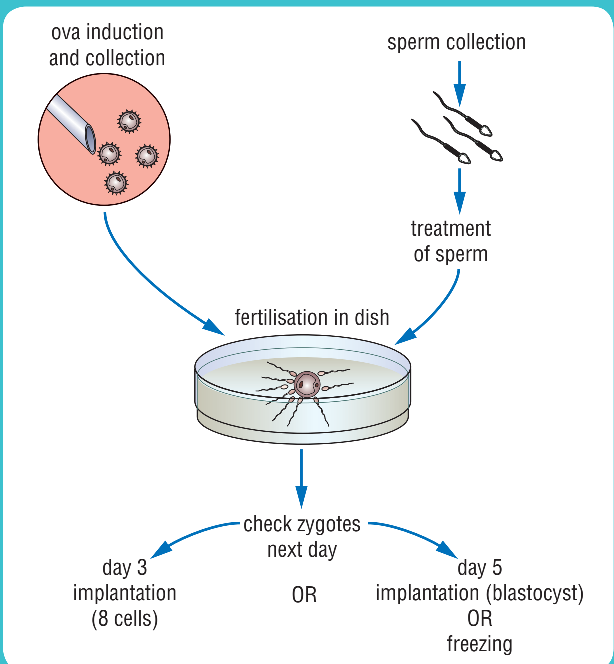


Fig 3.8.2 Observing the embryo at the four-cell stage

Stem cells

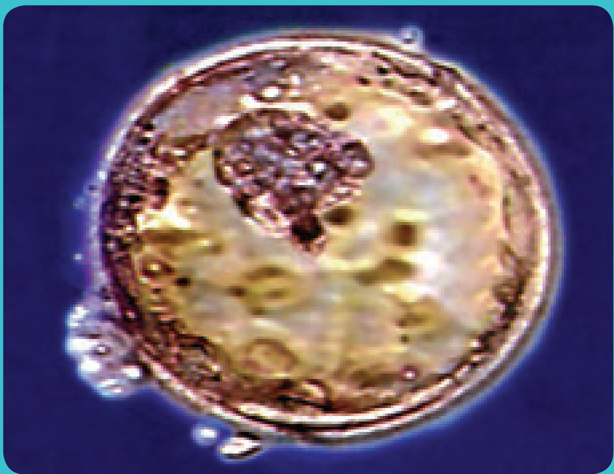
Stem cells are generalised cells that can divide and grow into specific cell types, such as nerves, heart muscle or bone. There are two main types of stem cells, embryonic and adult.

The embryonic cells are taken from the blastocyst, the ball of cells formed before implantation in IVF. This destroys the blastocyst, so it cannot be used for IVF. Adult stem cells can be obtained from several places, such as bone marrow and umbilical cord blood.

Stem cells currently used for therapy are adult stem cells from bone marrow that are transplanted into leukaemia patients. Embryonic stem cells are being tested for repairing defective tissues and organs. One area of use currently is in regrowing nerve cells in the spinal cords of accident victims, when they have been severed. There is also research into regrowing teeth, curing some forms of deafness and blindness, repairing heart muscle damaged in heart attacks and curing the muscle-wasting disease called amyotrophic lateral sclerosis (ALS). Many others applications are being proposed at present.

Stem cells can be obtained from a blastocyst. The stem cells are the spherical lump of cells (near the top) inside the blastocyst.

Fig 3.8.3



Cloning

Cloning means making copies of an existing cell or person. This has been done successfully with animals such as sheep, but no humans have been cloned. Currently, most countries ban this. In this technique, an egg cell has its nucleus removed. Another cell with the genetic material to be cloned has its nucleus removed and placed in the remains of the egg cell. This cell to be cloned can come from most body cells.

If this cell is then placed into a woman's uterus, it could develop into a normal human baby. This is called **reproductive cloning**. This baby would be identical to the person from whom the nuclear material had been removed. So if it was the husband's DNA, the child would be identical to the husband. This technique could be useful, for example where a man was sterile and could not produce sperm. DNA from the man's skin could be added to the egg.

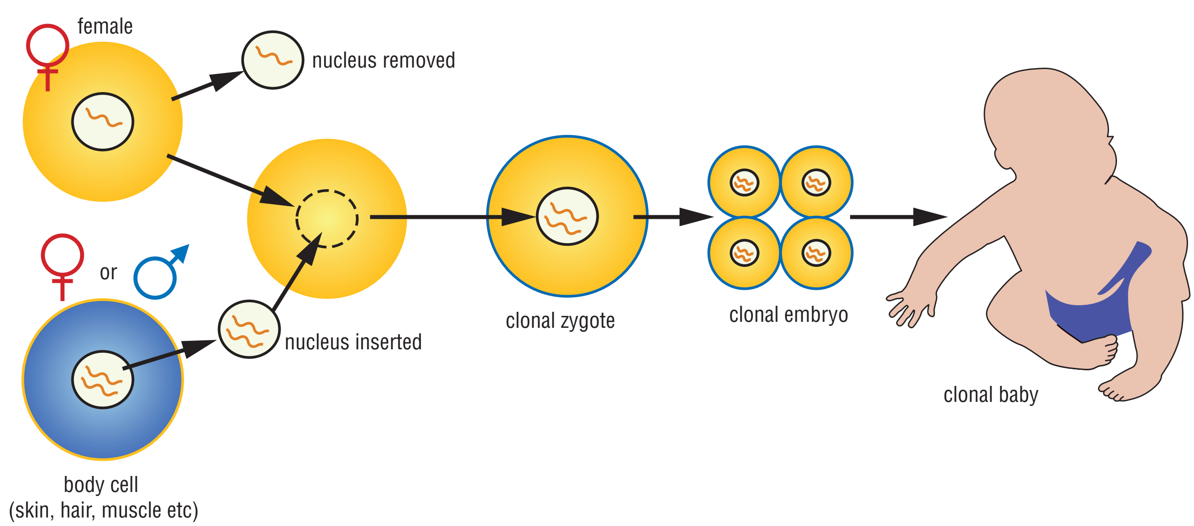
Another use of this technique is **therapeutic cloning**. This would be used to produce a blastocyst and then the stem cells would be removed and grown into organs that were defective in the person whose DNA was added to the original egg cell. These organs would be identical genetically with the DNA donor's body and so would not suffer from rejection if the organs were transplanted into them.

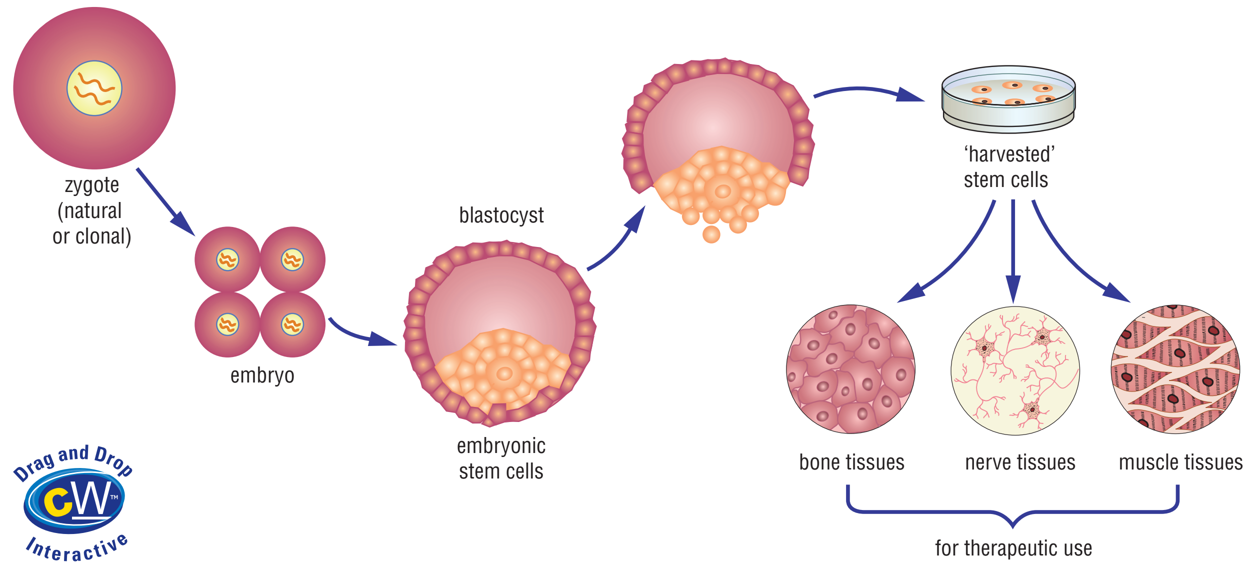
Science Snippet

Strange new world

If humans were cloned, imagine some of the problems that could arise. For example, what if your father secretly cloned himself and then he died. Would you grow up as an older brother to your father? Or would we have to invent some other term for this sort of relationship?

Fig 3.8.4 Steps involved in reproductive cloning





Steps involved in therapeutic cloning using embryonic stem cells **Fig 3.8.5**

Gene splicing

Gene splicing involves joining pieces of DNA from different organisms together. At present it is used to make bacteria produce materials such as human hormones. An example is the hormone insulin, which helps us to use sugar but which is lacking in people with the disease diabetes. Another example is the human growth hormone, which helps our bones grow.

The process involves using some enzymes that cut bacterial DNA at particular places in the base sequence. If a piece of human DNA is then added with another enzyme called ligase, it is joined into the original piece of bacterial DNA. This bacterial DNA then starts to make human insulin when it is placed back inside the bacterial cells. So a large vat of bacteria will start to produce human insulin. This is extracted and marketed by drug companies.

Gene therapy

Gene therapy is an experimental technique for correcting defective genes. At present there are no human examples of this therapy, but research has shown some promise.

Fig 3.8.6 Gene splicing

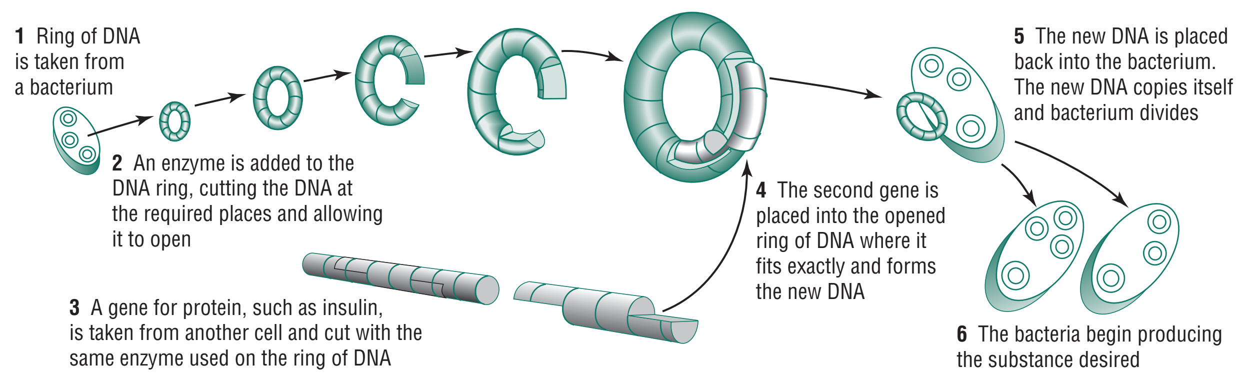
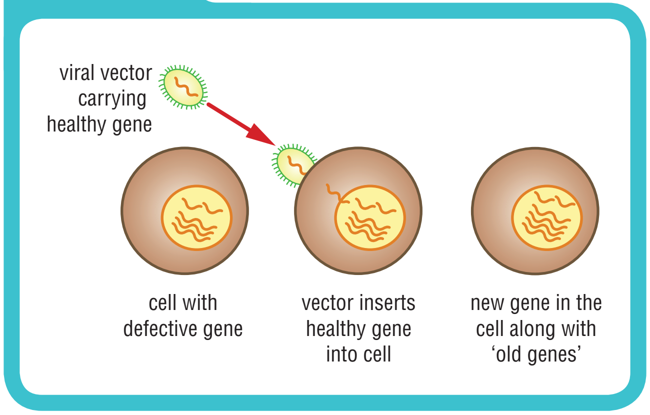


Fig 3.8.7 Gene therapy involves using viruses to insert DNA into people with defective DNA.

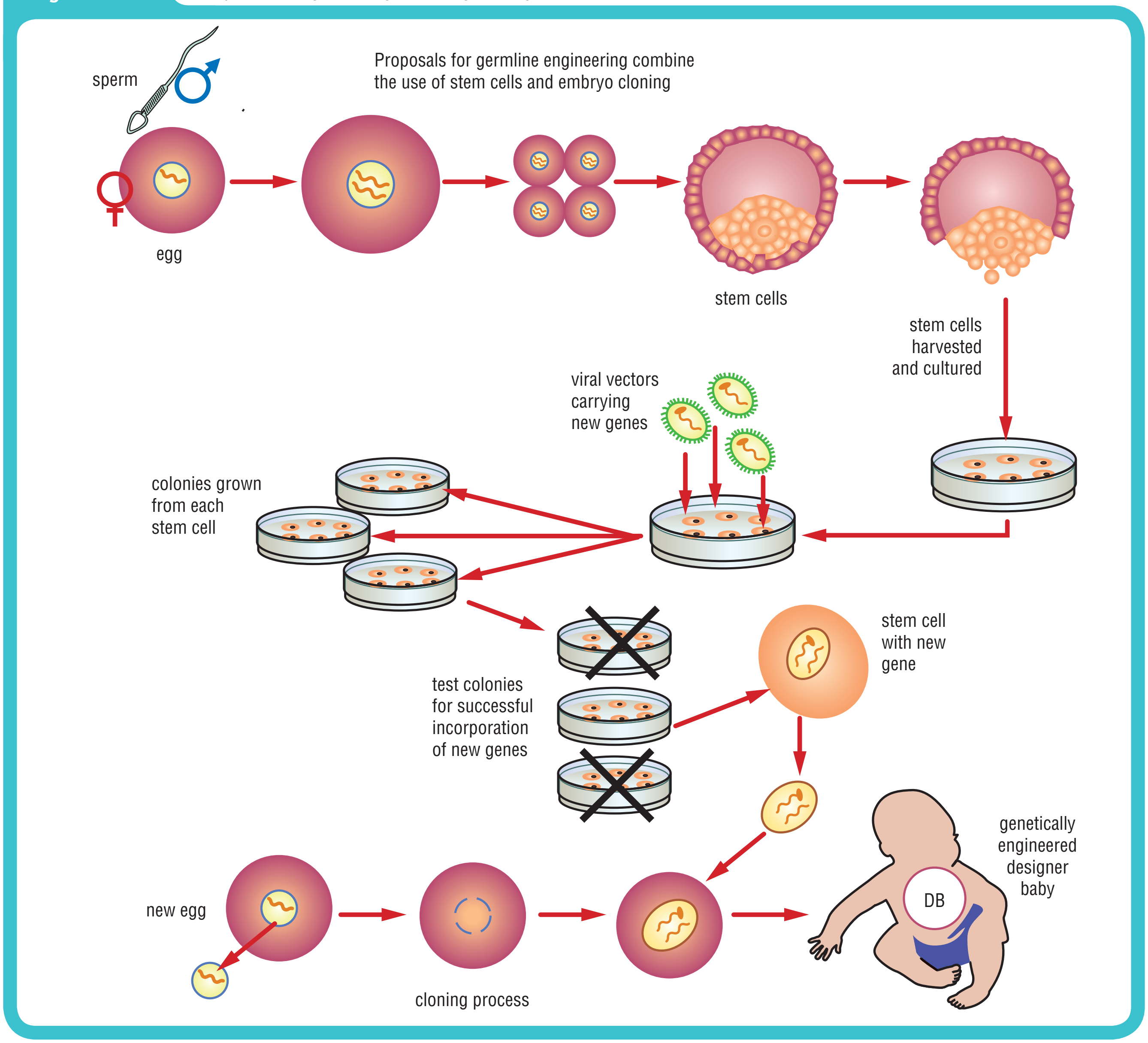


To correct the faulty genes, a good copy of the gene is inserted somewhere into the chromosome set. The most common method of inserting the gene is to use a virus that has been genetically altered to carry normal human DNA. Viruses infect human cells by inserting their DNA into the human cell. When they do this the human cell starts making the correct protein. Various kinds of viruses have been tried.

Germline genetic engineering

Germline genetic engineering involves the combination of cloning using embryonic stem cells, gene therapy procedures and IVF. It may be used to insert desirable genes via viruses carrying the selected human genes. This approach may be used to repair

Fig 3.8.8 The process of germline genetic engineering



faulty genes, but may also be used to insert genes for intelligence, athleticism and any other feature a parent may wish. At present this process is banned in humans.

This is the so called 'designer baby' method. If it became widespread in its use, there are many ethical questions to be considered. What may happen to the human species? Will certain features be removed? If it is expensive, will only the rich be able to produce superior babies? Should parents be allowed to select all the features they desire in their children? These are questions our society will need to answer. They are questions which may well affect you as a parent.

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Homework book 3.11 Engineering humans

FOCUS 3.8 [Questions]

Use your book

In vitro fertilisation

1 What is IVF and in what situations could it be used?

2 In IVF what is placed in the mother's uterus?

Stem cells

3 What are stem cells, and what is the source of these cells?

4 What happens to a blastocyst from which stem cells are removed?

5 Give four illnesses or diseases that can be fixed now, or that may be able to be fixed in the future using stem cells.

Cloning

6 What is cloning?

7 How is cloning done at present?

8 Explain reproductive cloning and give an example of when it could be used.

9 What is therapeutic cloning?

Gene splicing

10 What is gene splicing?

11 What is gene splicing used for at present?

Gene therapy

12 What is gene therapy?

13 How is gene therapy likely to be done if the current research methods are shown to work?

Germline genetic engineering

14 What three techniques of genetic engineering are used in the process of germline genetic engineering?

Use your head

15 A man who had the mumps became sterile because of the illness. He and his wife wish to have children. What could be done to help him become a father of a child who inherits his genes (assume the process is legal)?

16 In question 15, would the child also inherit the genes of the mother? Explain your answer.

17 A woman whose oviducts became severely scarred and blocked by infection when she was young was having trouble becoming pregnant. What advice may a doctor give her and her husband about having children?

18 If organs for transplantation are unavailable in the future, what methods might be tried to save patients?

19 In the future severe genetic illnesses may be fixed by deliberately infecting patients with viruses. Explain how this may cure them.

20 Two parents decide they want to have a very intelligent child. What could they do to achieve this? (Assume the process is legal.)

Investigating questions

21 Why could therapeutic or reproductive cloning of a human not be done using red blood cells?

22 Use the Internet to find some ethical reasons in favour of and opposed to germline genetic engineering.

Web Destinations CW

23 Try some animations on gene splicing on the Internet.

3·8 FOCUS

Practical activity

Prac 1 Focus 3.8

GATTACA ever nearer

Purpose

To discuss some genetic and reproductive therapies and technologies and to enable you to begin to develop your own opinion on the ethics of each.

Requirements

None, though Internet access may be useful. Your teacher may show you the film *GATTACA* as an introduction.

Procedure

1. You are going to discuss the six genetic technologies in this focus. You will be using a discussion strategy called 'Jigsaw'. The class forms into groups of a minimum of six students. These groups are your Home Groups. Each person in the Home Group is given a number from 1 to 6 (or however many there are in the group—there may have to be two students with the same number). Your teacher will then assign each number to a technology from this Focus. You now move to a different group with all the students who have the same number as you. This is the Expert Group. Your job is to discuss your technology in your Expert Group and record what is said, then report back to your Home Group.
2. Move to your Home Group and remember the number and technology your teacher gives you.
3. Move to your Expert Group. In your Expert Group your task is to discuss the positives and negatives of the technology you have been given, and to *record how many of the group were in favour of the technology.*
4. Move back to your Home Group. Each expert in the Home Group reports on what their Expert Group said.

Each person in the Home Group must record what was said by each expert on each technology. This is easiest done in a table like the one shown below. *Make a copy of this table in your notes but leave enough space to record all the comments.*

Questions

1. There are four different letters in the movie title *GATTACA*. They were carefully chosen and are meant to refer to DNA. What do the letters stand for?
2. Which technologies are supported by the majority of the class?
3. Which technologies are not supported by the majority of the class? What is the main reason given for being opposed to these?
4. Are there any technologies which are opposed by everyone in the class?
5. Whether you are opposed to any of these technologies or not, imagine you have a parent with an illness which could be cured by cloning using embryonic stem cells. How would you feel if your vote helped to ban the technique, even though your parent may be in favour of it? How do you think you might feel if a child of yours had the illness and you knew that they would die without the therapy?
6. In the movie *GATTACA*, Vincent is condemned to a life of not living his dreams because of a perception that genes are all we are. What do you think are the dangers of that view of humanity?

Technology	Positives	Negatives	Decision—for/against
IVF			
Stem cells			
Cloning			
Gene splicing			
Gene therapy			
Germline genetic engineering			

FOCUS 3.9 Genetics and industry

Context

Genetics is important in industry, and its use is increasing. In this Focus you will look at selective breeding of plants and animals, genetically modified foods, forensic science and conservation genetics.

Selective breeding

Selective breeding is the process in which we choose which individuals will be the parents to pass on their genes. It is also called artificial selection, as opposed to natural selection, because humans are making the choices rather than the environment. It has been widely practised in agriculture for hundreds of years, even though the genetics underlying it was not fully understood until the last hundred years. Almost all farm animals and plants are the result of this process. So are pets and garden plants.

Selective breeding is used in two main ways. The first is called **cross-breeding**. This is the process of combining in the offspring a desirable feature of one individual with a different desirable feature from another individual. An example is the creation of the dog breed labradoodle. This is a cross of a labrador and a poodle, combining the features of both dogs.

Another example is the production of the crop plant lupin, which is a stock feed on farms. Early lupin plants had seed pods that shattered and scattered their seeds, so farmers could not harvest the seeds and store them for stock feed or to sow the seeds. Dr John Gladstones from the University of Western Australia searched through fields of lupins until he found two plants where the seeds had only partially shattered. Studies of these plants showed that two independently inherited recessive genes affected the seed pods in different ways to stop them shattering. He cross-bred these and managed to produce a plant with completely non-shattering pods. But these plants had bitter-tasting seeds that animals did not eat, so he crossed these with lupins that had sweet-tasting seeds. This produced a sweet-tasting, non-shattering lupin. He then crossed these plants with lupins that had white flowers, so they were easy to identify in a field.

The labradoodle is the result of a cross between a labrador and a poodle. **Fig 3.9.1**

Fig 3.9.2 Lupin seed pods

Science Snippet

Mice go green

Mice which have had a gene from a jellyfish spliced into them will glow green when they are placed in ultraviolet light. The concept is to use this as a marker to identify animals which have had other genes spliced into them but where there is no obvious sign they are different.

Another method of selective breeding is **inbreeding**, or **linebreeding**. In this process, related parents are allowed to cross, for example offspring from the F1 are allowed to breed together. This is not often used in animal breeding, as there can be a reduction in the health of the offspring. There is a higher incidence of deformities, sterility and genetic disease. For example, in dogs, hip problems and a form of blindness can occur in labradors, and heart disease can occur in King Charles spaniels.

In plant breeding there do not seem to be as many problems with breeding closely related plants, but this can depend on whether the species is self-pollinating or cross-pollinating.

GM foods

Genetically modified organisms (GMOs) are produced by transferring genes from one organism to another. Many of these are food plants. Often these genes come from totally different species. For example, we can breed crop plants that produce long-chain omega 3 fatty acids, which are oils that lower cholesterol and reduce heart and blood vessel diseases. Genetic engineers have spliced genes from seaweeds, which make these oils, into our crop plants.

Fig 3.9.4 This mouse contains a gene from a jellyfish, which makes it glow in UV light.

Fig 3.9.3 Sheep with an extra copy of the sheep gene for growth hormone grow larger.

Another example of GM technology is the production of canola that is resistant to the weed-killer Roundup (glyphosate). A strain of soil bacteria was discovered that was naturally resistant to Roundup. The gene from the bacteria was inserted into the canola. This means Roundup can be sprayed on the canola crop to kill weeds, but not the canola plants. Cotton has been engineered to produce a natural pesticide that kills one of its predators, the heliothis caterpillar.

There is great debate about GM foods. Many consumers seem apprehensive about eating GM foods, and so our farmers are reluctant to grow GM crops and produce GM livestock.

Benefits of GM foods

Some benefits of GM foods are possible increased yield and therefore food production. There could be a reduction in the need to spray pesticides if the plants can be made to naturally produce their own pesticides. This should reduce problems such as build up of pesticides in ecosystems and spray drift causing death of harmless and beneficial animals. Another possible benefit is the possible use of GM foods to be engineered to deliver vaccines which we can eat.

Problems with GM foods

It is difficult to be sure if a new gene has been successfully introduced into the organism you are trying to change. So scientists insert a second gene, called a marker gene, that is easily detected. Resistance to particular antibiotics such as ampicillin can be used as a marker. The effectiveness of antibiotics could be reduced if genes for such resistance enter food webs.

Another concern is the possibility of creating food that causes allergic reactions in consumers. Yet another possible problem is that genes for resistance to herbicides may escape into weed species, making control with herbicides ineffective and greatly increasing the doses needed to kill them. Animal welfare is a concern as well, since genetically altering them could affect their quality of life. For example, pigs that grow very fast have been engineered, but they suffer from illnesses such as arthritis and ulcers.

Forensic science

Forensic science is the use of science to solve crime. This involves teamwork. At the scene of the crime, the crime scene investigators (CSI) study the area carefully. They record information by taking photographs, fingerprints, palm prints and sole prints, and collecting fibres from clothing or material, fragments of paint and glass and body fluids. They may apply special techniques such as the use of luminol, which detects traces of blood. Luminol glows when it comes into contact with blood.

DNA profiling

DNA profiling is also known as **DNA typing**, and **DNA fingerprinting** because DNA is unique, just as fingerprints are. DNA can be extracted from any body cells or fluid, such as blood, saliva, sweat, hair roots and skin. It is now possible to use even tiny amounts because a technique called polymerase chain reaction (PCR) can copy tiny fragments to give enough DNA to test.

Forensic scientists study only a small part of a person's DNA, but this is enough to determine the likelihood that it came from a particular person. If the DNA sections do not match, they must have come from different people. If they do match, there is still a very slight chance that they may have come from different people. The scientists can give a probability that the two matching samples would have come from different people.

To create a DNA print, or profile, the DNA is extracted from the cells. The DNA is cut into shorter pieces using restriction enzymes. With DNA from different people, the enzymes will cut the DNA at different places, so the fragments will be different lengths.

The DNA fragments are then separated on a gel using a process called **electrophoresis**. An electrical current is applied to the gel, and the fragments move

The process of DNA fingerprinting

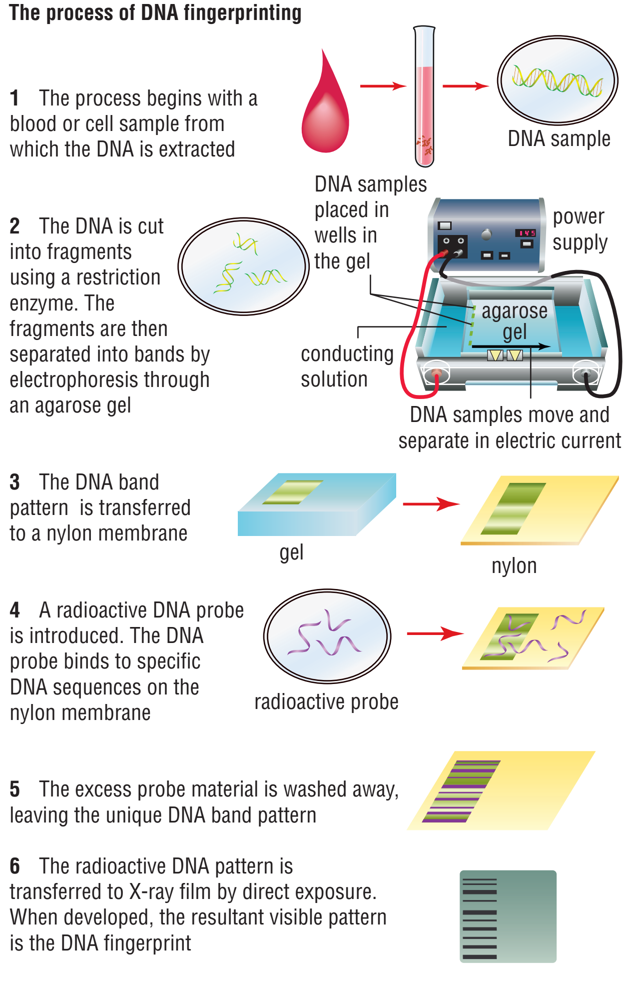

Fig 3.9.5 The sequence of steps involved in DNA fingerprinting

Science Snippet

Mitochondrial DNA

Another technique that can be used in forensics is a study of the DNA found in mitochondria. Mitochondria contain their own DNA, which is completely different from the nuclear DNA. All the mitochondrial DNA is inherited from a person's mother. The genes in this particular section of DNA mutate at a rate that means it is very unlikely that unrelated persons will have the same mutation in their mitochondrial DNA.

from one end of the gel to the other at different rates, creating a pattern of bands. How fast and how far they move depends mainly on their electrical charge and their size. The DNA bands are then transferred to a membrane. To enable us to see the bands, the membrane is exposed to radioactive probes, which attach to the DNA on the membrane. When X-ray film is placed over the membrane, the radioactive material duplicates the DNA banding pattern on the film, creating a DNA print.

By comparing the DNA print made from cells found at the scene of a crime to a DNA print made from cells taken from a suspect, investigators can determine whether the body fluid or tissue found at the scene belongs to the suspect.

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Conservation genetics

Conservation genetics is the branch of biology that aims to conserve populations, usually of endangered or threatened species, through the use of genetics. Scientists try to understand the genetic relationships of the organisms so that management techniques can then be developed to conserve the species.

Conservation genetics can involve many specialist scientists who work in fields such as ecology, molecular biology, classification and evolutionary biology. They study aspects of the species such as its evolutionary relationships, its breeding patterns and whether it forms hybrids with closely related groups. They check whether there is enough diversity to ensure that inbreeding problems do not arise, such as reduction in the health of offspring due to deformities.

One of the key aspects to identify in conservation genetics is the amount of genetic diversity in the population. As you learnt in Focus 3.6, a population that has enough diversity should have some members with features that can cope with the changes brought about by environmental change. So some survive and the species continues. If there are many environmental factors that change and are a threat to a species, the population obviously needs a large amount of genetic diversity to cope with these possible selective agents. The **minimum population size** depends on the species and the environment in which it is found. As an example, some studies on frogs have shown that about 500 individuals is the smallest population that can survive in the long term.

Many genetics theories are based on studies done on 'model' organisms. These organisms, such as fruit flies and rodents, reproduce very quickly in the laboratory. Conclusions obtained from experiments on these organisms can then be applied to the threatened species. Computer software developed and used by geneticists is based on these model organisms.

Homework book 3.12 Control of cane toads

Fig 3.9.6 A scientist using a genetic analyser.

FOCUS 3·9 [Questions]

Use your book

Selective breeding

1 Explain what is meant by selective breeding.
2 Explain what is meant by outbreeding and give an example.
3 What is inbreeding, and what problems can occur with it?

GM foods

4 Explain what is meant by a GM food and give an example.
5 What are four possible benefits of GM foods?
6 What are four possible problems with GM foods?

Forensic science

7 What is forensic science?
8 What kind of information do crime scene investigators collect?

>>

DNA profiling

9 From where can DNA be extracted?

10 If two DNA profiles are the same, what can you conclude?

11 Briefly describe the process of electrophoresis.

12 What is mitochondrial DNA and what use is it in forensics?

Conservation genetics

13 What is conservation genetics?

14 What kind of information is studied in conservation genetics?

15 What is meant by the minimum population size?

Use your head

16 Dr John Gladstones wanted to develop lupins with pods that did not shatter. Give a good science reason to explain why he decided to search in fields of lupins.

17 Gladstones found two different genes for non-shattering lupin pods and both were recessive. If Gladstones crossed these with normal dominant lupins, the offspring would have shattering pods because shattering was dominant. Give an outline of a breeding plan you could use to produce offspring with non-shattering pods.

18 In what ways do you think DNA profiling could be useful in the following areas: parentage—paternity and maternity, wildlife conservation, airport quarantine, evolution.

19 What are some reasons why scientists developing GM foods should include genetic markers in the GM organisms?

20 Why is genetic diversity so important in conservation genetics?

21 Explain how DNA fingerprinting could prove that someone did not commit a crime.

Investigating question

22 Go to the *Science Aspects 4* Companion Website at **www.pearsoned.com.au/schools** for a link to some animations on DNA fingerprinting. What is the importance of PCR and electrophoresis in this process?

Web Destinations CW

FOCUS 3•9

[Practical activity]

Prac 1 Focus 3.9

DYO

Electrophoresis

Purpose

To use the Internet to find and use a method of electrophoresis to separate chemicals in food colours.

Requirements

Depends on method discovered, but will probably need aluminium foil, petri dish, power pack or 9 V batteries, agar, 1% sodium hydrogen carbonate solution, glycerol, Pasteur pipettes, tweezers, razor blade, fast-food container, 100 mL beaker, electronic balance, two alligator clips, two electrical leads with banana plugs.

Procedure

1 This step may have already been done by your teacher. If not, search the Internet to locate a likely method of electrophoresis that is financially possible for your school.

2 Build your electrophoresis apparatus following the method you discovered.

3 Add food colours to different places on a filter paper. Cut out pieces to fit the wells in the gel. Add them to the wells so that there is a different colour in each well.

4 Run the electrophoresis equipment. This may need to run for several hours. Your teacher will turn it off later in the day.

SAFETY NOTE: Do not touch the liquid in the electrophoresis experiment while it is running. You may suffer an electric shock.

Questions

1 To which electrode did the sample move, and what charge does the sample seem to have?

2 Why are there coloured bands in different places on the gel?

3 Which molecule was the largest, and which was the smallest?

Extension task

Search the Internet for a method of DNA electrophoresis.

Review questions

Second-hand data

1 Conservation geneticists can grow rare or threatened tree species in areas called arboretums. Seeds of a species are collected from plants in the wild. If they are going to use this technique, research has suggested that the following three guidelines should be adopted.

- Seed should be taken from a minimum of 10 parent trees in the wild.
- This seed should also be taken from trees that are at least 100 m apart.
- Seed should not be taken from isolated individuals if possible.

For each of these three guidelines use your knowledge of genetics and evolution to explain why the guideline should be followed.

2 Huntington's disease is a terrible condition of humans, which causes death after a slow deterioration over many years in muscle control and mental function. Sufferers usually do not show symptoms of the disease until they are between 35 and 40 years of age. It is caused by a dominant gene.

Explain why the gene for Huntington's disease could never be removed from the population by natural selection. Be sure to give a detailed explanation of natural selection.

Open-ended questions/experimental design

3 One of the criticisms of genetically modifying organisms is that GM crop species are less diverse and so massive areas of crop could be wiped out by insects or fungal diseases.

Carefully explain the scientific argument underlying this criticism. You must show a knowledge of genetics and evolutionary processes.

Extended investigation/research

4 Health departments are worried about the decreasing effectiveness of antibiotics against bacteria. Resistance has emerged in many bacteria and this seriously threatens patients' lives, especially in hospital environments. Your task is to research this problem and present a report covering the following areas:

a the evolutionary process by which bacteria become resistant to antibiotics

b why this occurs in hospitals

c how general practitioners and their patients' expectations exacerbate the problem

d how the livestock industry may be aggravating the problem.

5 Cystic fibrosis is probably the most common inherited disease. Research this disease and present a report demonstrating the knowledge you have gained from the relevant Foci in this section. Your report must:

a cover the biochemical defect responsible for the condition

b explain why the condition affects the process of breathing and digestion

c include pedigrees that demonstrate the method of inheritance of the condition.

Homework book 3.13 Life and Living crossword

Homework book 3.14 Sci-words

Natural and processed materials

4

Curriculum guide learning focus

- electron configuration of atoms and its relationship to the periodic table
- the octet rule and its use in understanding covalent and ionic bonding
- oxidation and reduction reactions and use of these in metal extraction
- writing formulas and equations
- families of substances and their chemical reactions
- use of moles in quantifying chemical reactions
- calculating the percentage composition and empirical formula of substances
- laws of gas behaviour and the calculation of gas quantity using chemical equations
- the role of chemistry in gold and petroleum production, and corrosion control

This section on Natural and Processed Materials also contains work that will help students with the outcomes of Investigating, Communicating Scientifically, Science in Daily Life, Acting Responsibly and Science in Society.

Outcome level descriptions

The outcome level descriptions for Natural and Processed Materials covered in this section are mainly NPM 6.

FOCUS 4.1 Electron configuration

Context

In about 400 BC the Greek philosopher Democritus suggested that all substances consisted of tiny particles called atoms. This was the first step in one of the greatest scientific journeys of all time. In 1808 John Dalton's atomic theory proposed that atoms of the same element were alike. In 1897 Sir JJ Thompson discovered the electron in the atom. Many scientists, such as Sir Ernest Rutherford, Niels Bohr and Sir James Chadwick, made contributions to our current understanding of the atom. The journey is not over. Our understanding of the structure of atoms is still being developed. In your own journey with atoms you have already explored the basic building blocks of atoms—protons, neutrons and electrons.

In this Focus you return to the structure of the atom but your attention is going to be on electrons and how they are arranged in atoms. As you will find, chemical reactions involve the interaction of electrons between different atoms. An understanding of how electrons are arranged in atoms is vital to understanding chemical reactions and the structure of one of the most important tools in science—the periodic table.

Describing atoms

In *Science Aspects 2*, Focus 5.6 you learnt how the structure of atoms was described in terms of their number of **protons**, **neutrons** and **electrons**. The key points from this Focus were as follows.

- All atoms of the same element contain the same number of protons in the nuclei. The number of protons in the nucleus is called the **atomic number** and is given the symbol 'Z'.
- In a **neutral atom** the number of electrons in the electron cloud of the atom is equal to the number of protons in the nucleus.
- Atoms of the same element can have slightly different numbers of neutrons. The number of neutrons and protons in the nucleus is called the **mass number** and is given the symbol 'A'. Atoms of the same element that have different numbers of neutrons are called **isotopes** of that element.
- The structure of an atom can be represented using the chemical symbol for the element (E), atomic number (Z) and mass number (A) by using the symbol $^{A}_{Z}E$. For example, the most abundant form of the carbon atom is carbon-12 (where 12 is the mass number) and carbon-14 is an isotope.

Interactive CW Animation

Science Snippet

Protons, neutrons and electrons—is that the real story?

Modern quantum theory continues to develop our understanding of the atom. For most purposes, protons, neutrons and electrons can be considered the main particles in atoms. However, these particles can be further divided up into almost 50 other unstable particles, including quarks, leptons, antiparticles, gluons and photons. It is thought that there are still more particles to be discovered!

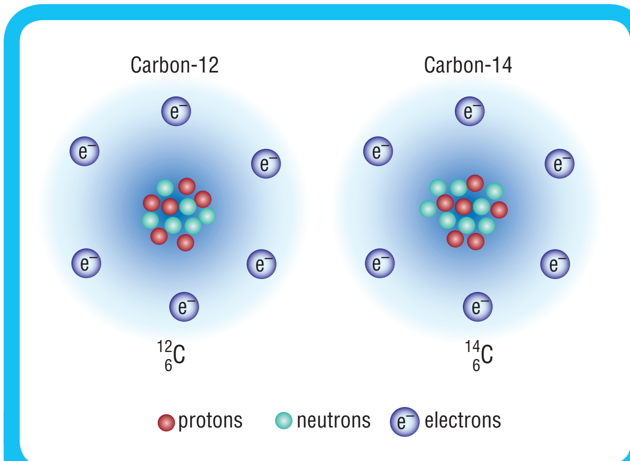


Fig 4.1.1 Carbon-14 is an isotope of carbon-12. They are chemically identical but carbon-14 has two additional neutrons in the nucleus. They both have six electrons and protons.

If you would like some more practice in using the $^{A}_{Z}E$ format you can review Activity 5.6 from the *Science Aspects 2* Homework Book.

How are the electrons arranged in the electron cloud?

Electrons were discovered in 1897 by Sir J J Thompson. He suggested that these negatively charged particles were embedded into the positively charged atom so that overall the charges were balanced out. This became known as the 'plum pudding' model of the atom and while it was a 'tasty' idea it was soon shown to be incorrect. Scientists such as Ernest Rutherford showed that atoms were mainly empty space with a dense nucleus containing the protons and neutrons, while they thought the electrons probably orbited the nucleus in much the same way that planets orbit a sun. Rutherford's model of the atom was essentially correct but it was soon established that the orbiting electrons would spiral into the nucleus. Another model to explain how electrons were arranged in the electron cloud had to be found.

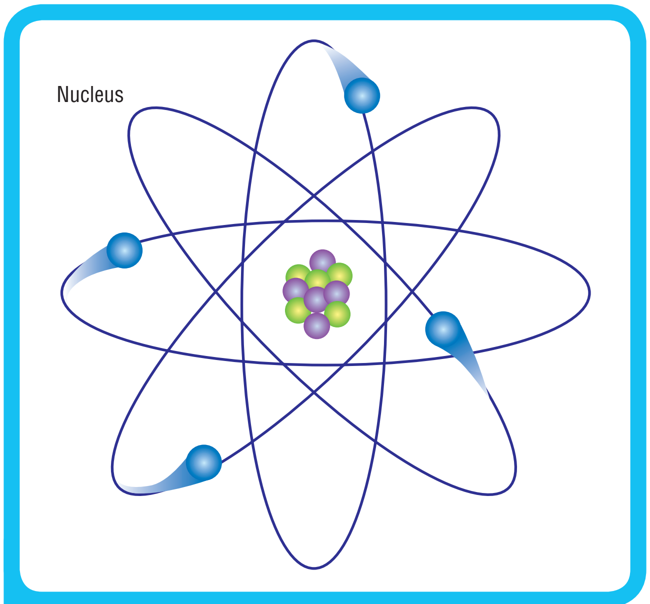


Fig 4.1.2 The Rutherford view of the atom is essentially the same as our view today except that we now know that electrons do not orbit the nucleus like planets orbit the Sun.

QuickTime Video

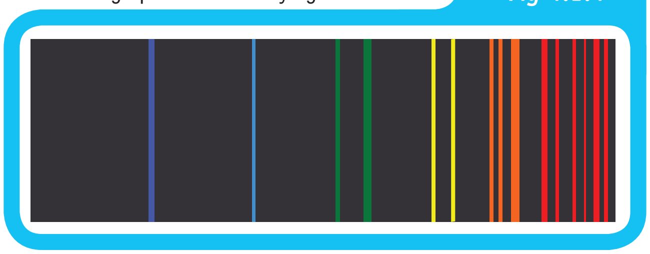
The Bohr model of the atom

Niels Bohr was a scientist who had studied with Ernest Rutherford and understood his model of the atom very well. He explored the arrangement of the electrons in the nuclei by starting with the simplest atom possible—the hydrogen atom. Hydrogen has only one electron, so examining how this electron behaves gave him insight into how atoms with many electrons would behave. To study the electron in hydrogen, Bohr excited a sample of hydrogen gas by subjecting the gas to a high voltage. The 'excited' gas sample then emitted visible light which could be spread to give a spectrum. This is known as an **emission spectrum**.

Fig 4.1.3 The emission spectrum of hydrogen shows some distinct lines. The lines represent the energy given off as excited electrons fall back from higher to lower energy levels in the electron cloud.

Niels Bohr proposed that electrons moved around atoms within specific energy levels and that electrons could not exist between these energy levels. He also proposed that for electrons to move from their lowest energy level (called **ground state**) to a higher energy level they needed to absorb an exact amount of energy. When these electrons moved to a higher energy level the atom was said to be **excited**. Each coloured line in the emission spectrum corresponded to the energy that was released when electrons fell back to lower energy levels. This became known as the Bohr model of the atom and was a major step forward in understanding how electrons are arranged around the atom. While some aspects of Bohr's model of the atom had to be modified because it had trouble explaining what happened with atoms

Fig 4.1.4 The emission spectrum becomes more complex as the number of electrons in the electron cloud increases. Each coloured line represents excited electrons falling back to a lower energy level. Each element has its own unique emission spectrum and can be used as a 'fingerprint' for identifying that element.



with more than one electron, it formed the basis for understanding that electrons occur within particular energy levels. This has become known as the **quantum mechanics** model.

The colours emitted when electrons are excited and then fall back to lower energy levels can be used to identify some chemical elements and is the basis of flame tests. When small amounts of metal salts are placed in a Bunsen burner flame they often produce a characteristic colour. The colours are different from metal salt to metal salt because of the different number of electrons in each of the atoms. The colours formed in fireworks are also a result of excited electron movements (called **transitions**) from higher to lower energy levels.

Prac 1 p. 146

Homework book 4.1 Development of atomic theory

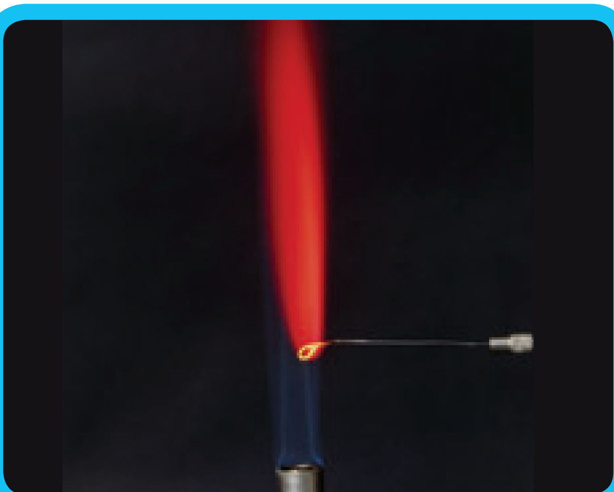


Fig 4.1.5 The characteristic colours seen in flame tests (top) and fireworks are a result of excited electrons moving from higher to lower energy levels within the electron clouds of atoms.

Electron shells

Niels Bohr's work helped scientists to understand that electrons are arranged within levels or layers around the nucleus. They do not orbit the nucleus like planets orbit our Sun but rather they can be found anywhere within specified energy regions called **electron shells**. These electron shells are labelled K, L, M and N and have been numbered 1, 2, 3 and 4. The numbers (1–4 and above) are called **principal quantum numbers** (n) and allow us to keep track of electrons in atoms from the simple hydrogen atom right through to complex atoms containing many electrons.

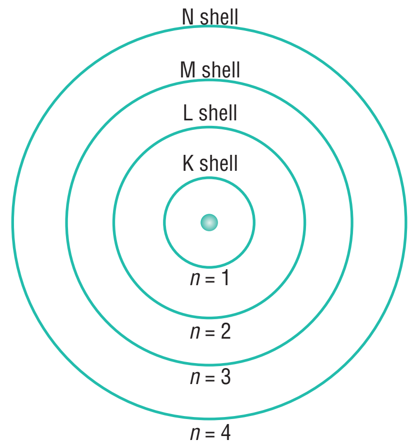


Fig 4.1.6 Electrons are arranged around the nucleus in shells or energy levels.

These shells are at different energy levels. The K shell (principal quantum number 1) is at the lowest energy level, and the energy levels increase through to the N shell. The coloured lines in emission spectra represent particular electron movements (called transitions) from higher to lower shells within the electron cloud.

Electron configuration

Electrons arrange themselves in these shells by filling the lower energy shells first and then moving up to progressively higher shells. The way these electrons are arranged within the shells is called the **electron configuration** of the atom. The number of electrons that can occupy each shell is controlled by a strict set of rules. The maximum number of electrons in an electron shell or energy level is given by the formula $2n^2$, where n is the principal quantum number—1, 2, 3 etc. The maximum number of electrons that can occupy any shell is summarised in the following table.

Shell	Principal quantum number (n)	Maximum number of electrons ($2n^2$)
K	1	2 × 12 = 2
L	2	2 × 22 = 8
M	3	2 × 32 = 18
N	4	2 × 42 = 32

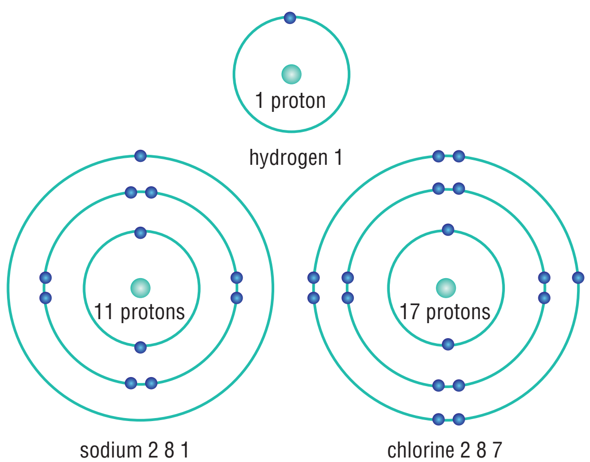
To help you to understand electron configuration better, the table opposite shows how electrons are arranged in the first four energy levels. Look at the table carefully and pay particular attention to the noble gases, which are shown in bold print. The noble gases are found at the extreme right of the periodic table (group viii).

The **electron configuration** of an atom is simply the number of electrons in each shell written in order, with a small space separating the number of electrons in each shell. For example, the simplest electron configurations for hydrogen (Z = 1), sodium (Z = 11) and chlorine (Z = 17) are:

- electron configuration for hydrogen, H = 1
- electron configuration for sodium, Na = 2 8 1
- electron configuration for chlorine, Cl = 2 8 7.

The electron configuration of atoms can also be represented by a model through **electron shell diagrams**. These diagrams show the electron shells as rings around the nucleus. These types of diagrams are useful for allowing you to visualise the electron configuration but they can also give you the false impression that the electrons are orbiting the nucleus.

Fig 4.1.7 Electron shell diagrams help us to visualise electron configurations.



Atomic number	Element	Electron shell (energy level) 1	2	3	4
1	Hydrogen	1			
2	**Helium**	**2**			
3	Lithium	2	1		
4	Beryllium	2	2		
5	Boron	2	3		
6	Carbon	2	4		
7	Nitrogen	2	5		
8	Oxygen	2	6		
9	Fluorine	2	7		
10	**Neon**	**2**	**8**		
11	Sodium	2	8	1	
12	Magnesium	2	8	2	
13	Aluminium	2	8	3	
14	Silicon	2	8	4	
15	Phosphorus	2	8	5	
16	Sulfur	2	8	6	
17	Chlorine	2	8	7	
18	**Argon**	**2**	**8**	**8**	
19	Potassium	2	8	8	1
20	Calcium	2	8	8	2
21	Scandium	2	8	9	2
22	Titanium	2	8	10	2
23	Vanadium	2	8	11	2
24	Chromium	2	8	12	2
25	Manganese	2	8	13	2
26	Iron	2	8	14	2
27	Cobalt	2	8	15	2
28	Nickel	2	8	16	2
29	Copper	2	8	17	2
30	Zinc	2	8	18	2
31	Gallium	2	8	18	3
32	Germanium	2	8	18	4
33	Arsenic	2	8	18	5
34	Selenium	2	8	18	6
35	Bromine	2	8	18	7
36	**Krypton**	**2**	**8**	**18**	**8**

Electron configuration and the periodic table

If you look at the table above, can you see some patterns in how the electrons arrange themselves as the atomic number increases? For the first two shells the filling is very straightforward but you might have noticed that after the second shell the third and fourth shells start filling together. You will explore the reasons for this in your upper school chemistry courses. Look carefully at the electron configuration for the noble gases shown in the last table. They are:

- Helium 2
- Neon 2 8
- Argon 2 8 8
- Krypton 2 8 18 8.

When writing electron configurations you show the number of electrons in each of the energy shells in order. Electrons in atoms always start filling from the lowest energy level to higher energy levels.

With the exception of helium, all of the noble gases have eight electrons in their outermost electron shell. Noble gases have a very important place in the periodic table. They are found on the extreme right of the periodic table in group VIII. All noble gases are extremely unreactive and do not generally form bonds, not even with themselves. For this reason they exist as single atoms of gases (monatomic). Their stability and non-reactivity is a property of their very stable electron configuration. As you will explore in a later Focus, it is the tendency of non-noble gas atoms to attain noble gas-like electron configurations that determines a lot of the chemistry and bonding between atoms.

There is a very close relationship between the way the periodic table is structured and the electron configuration of atoms. As you are aware already, chemical elements are arranged in **groups** within the periodic table. Elements within groups behave and react with other substances in similar ways. Could it be that their electron configurations allow them to form chemical bonds in similar ways? Figure 4.1.8 shows how the main groups of the periodic table and the number of electrons in their outermost **electron shell**. Can you see a pattern?

In groups I to VIII the group number corresponds to the number of electrons in the outermost shell of the electron cloud. The noble gases all have eight electrons in their outermost electron shell.

Fig 4.1.8

	I	II											III	IV	V	VI	VII	VIII
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac**	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 Ds	111 Rg							

*Lanthanides 58–71	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	Ho 67	68 Er	69 Tm	70 Yb	71 Lu
**Actinides 90–103	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Key

liquid at room temperature

gas at room temperature

metals

metalloids

non-metals

1 — atomic number

H — symbol

Interactive CW Animation

Did you notice in groups I to VIII that the group numbers correspond to the number of electrons in the outmost electron shell of each of the elements? The electrons in the outer shell of the atom are called valence electrons. For example, all the elements in group I have only one electron in their outermost shell. Group I elements are said to have one **valence electron**. If you look back to the second table in this Focus (see page 140) and study the electron configuration for lithium, sodium and potassium, you will notice that all these elements have one electron in their outer shell. Group I elements are called the **alkali metals** because they all react with water to form **alkaline solutions**. They also show a range of other similar chemical and physical properties such as their density, reactivity with water and low densities. They also form +1 ions.

QuickTime CW Video

Group II elements all have two valence electrons. They are called the **alkaline earth metals** because they were first extracted from compounds out of the earth. They are not as reactive as group I elements and tend to form +2 ions.

Group IV elements all have four valence electrons. This is sometimes called the **carbon group** as it contains carbon, the element essential to all life. Elements within this group tend to share their electron rather than lose or gain them.

Group VII elements are called **halogens**. They are very reactive elements that are found as diatomic gases. They are generally found in salts as –1 ions. Iodine is a grey-black solid that readily sublimes to a purple vapour. Chlorine is a green gas at room temperature and bromine is a red-brown liquid that readily forms a vapour.

As you have seen already, the group VIII elements are called **noble gases**. They are extremely unreactive monatomic gases with very low melting and boiling points.

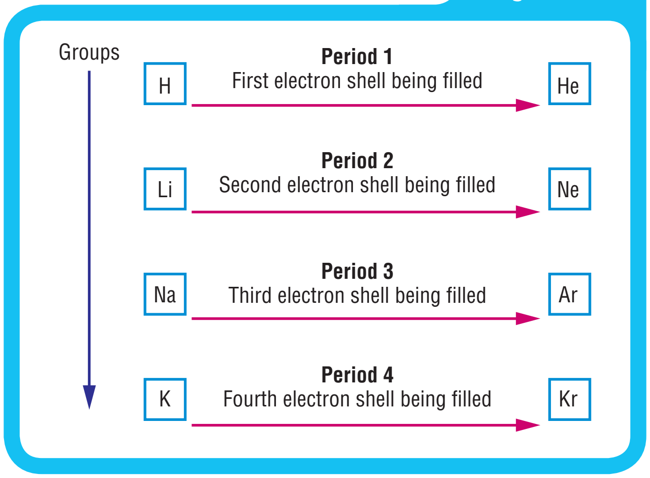
Fig 4.1.10 Noble gases such as argon are used to fill light bulbs. Argon is completely unreactive and helps to prevent the filament from burning out.

Each horizontal row of the periodic table is called a **period**. A period represents the filling of an energy level. When an electron shell is filled, the filling of a new shell commences, shown in a new row in the periodic table. The filling of electron shells in such

Fig 4.1.9 Iodine, chlorine and bromine are group VII elements.

Periods are horizontal rows in the periodic table, while groups are found vertically in the table.

Fig 4.1.11



a regular way accounts for the recurring trends in properties of elements in groups. This is known as the **periodic nature** or **periodicity** of the periodic table.

Metals and non-metals

On many periodic tables you will find a step line starting underneath boron (Z = 5) and stepping down to astatine (Z = 85). You can see this in Figure 4.1.8. This line separates metals from non-metals. Metals are found to the left of the line and non-metals to the right of the line. This change from metal to non-metal is gradual, so elements such as silicon (Z = 14) and germanium (Z = 32) have properties of metals and non-metals. They are called **metalloids** or **semi-metals**.

Science Snippet

Magnificent Mendeleyev

On 17 February 1869, Dmitri Mendeleyev jotted down the symbols for the chemical elements in such a way that they ended up grouped on the page according to known regularities or 'periodicities' of behaviour. The modern periodic table was born and it is thought to be one of the greatest breakthroughs in chemistry ever. Mendeleyev's table was so good that he was soon predicting the properties of chemical elements that had not even been discovered, including gallium, scandium and germanium. Within 20 years of his prediction all three elements had been discovered and they matched his predictions closely. Mendeleyev went on to predict a total of 10 new chemical elements, of which eight were discovered and confirmed as he predicted. There have been attempts over the years to improve his table, including ideas to make it three-dimensional. Most of these ideas have not caught on and most chemists agree that Mendeleyev's original table remains the undisputed cornerstone of chemistry.

The large block of elements between groups II and III are known as the **transition metals**. They are all metals that have unique properties such as very high melting points and the ability to form brightly coloured compounds. You will explore this unique group of elements in your upper school chemistry course.

Homework book 4.2 Periodic table highlights

Homework book 4.3 Figuring out electron configurations

4·1 FOCUS [Questions]

Drag and Drop CW Interactive

Use your book

Describing atoms

1. Atoms can be described using the symbols. Explain what is meant by the letters E, A and Z, and give two specific examples.
2. What is meant by an isotope of a chemical element? Support your answer with at least two examples of different elements and their isotopes. How are the electrons arranged in the electron cloud?
3. Describe Sir JJ Thompson's model of the atom. Explain why Ernest Rutherford's work soon proved this model to be incorrect.

The Bohr model of the atom

4. Explain why Niels Bohr chose to study the arrangement of electrons in the hydrogen atom first.
5. What is meant by an atom in an 'excited state'?
6. An emission spectrum of a hydrogen atom shows some coloured lines on a black background. What do the coloured lines represent in terms of the movement of electrons?
7. Describe the emission spectrum of more complex atoms compared with hydrogen. Why are they different?
8. Explain why different metal salts produce different colours during a flame test.

Electron shells

9. Explain how electron shells can be identified in terms of letters and numbers.
10. What is the major difference between electrons that would be in the M shell compared with electrons in the K shell?

Electron configuration

11. Describe what is meant by an 'electron configuration' for an atom.

>>

12 What is the relationship that determines the number of electrons that can occur in each of the K, L, M and N shells?

13 Beryllium (Z = 4) has an electron configuration of 2 2. Explain what these numbers mean.

14 Demonstrate what is so special about the electron configuration of the noble gases by writing out the electron configuration for neon, argon and krypton.

15 Draw electron shell diagrams for neon (Z = 10) and argon (Z = 18).

Electron configuration and the periodic table

16 Give reasons why the group VIII elements, the noble gases, are considered to be in such an important place in the periodic table.

17 What is the relationship between the group number in the periodic table and the number of electrons in the outermost shell of the elements in that group?

18 Use a simple diagram to describe the difference between a group and a period in the periodic table.

19 What are valence electrons? In your answer, describe the number of valence electrons in group I, II, IV, VII and VIII elements.

Metals and non-metals

20 Copy Figure 4.1.12 into your notes and show on your drawing the following regions of the periodic table: metals, non-metals, transition metals, metalloids (semi-metals).

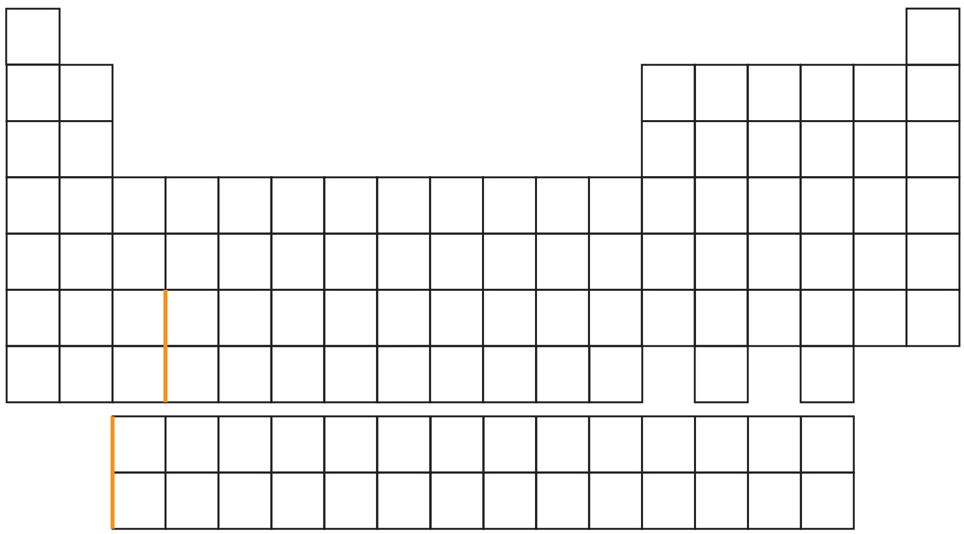


Diagram for question 20 **Fig 4.1.12**

Use your head

21 Copy and complete the following table:

Atom	^a_zE	Atomic number (Z)	Mass number (A)	Number of protons	Number of neutrons	Number of electrons (neutral atom)
Uranium 238	$^{238}_{92}U$	92	238			
Uranium 236		92			146	
Gold		70			118	
Lead		82	207			
Radium				88	138	

22 Copy and complete the following table, which shows the arrangement of electrons in a number of atoms. An example has been done for you. Refer to a periodic table as required.

Atom	Number of electrons in K shell (max. = 2)	Number of electrons in L shell (max. = 8)	Number of electron in M shell (max. = 18)	Electron configuration	Valence electrons	Periodic table group	Period number
Carbon	2	4	0	2 4	4	IV	2
Oxygen							
Magnesium							
Chlorine							
Neon							
Aluminium							
Sulfur							
Nitrogen							
Argon							

23 Use electron shell diagrams to represent oxygen, neon, aluminium and sulfur.

24 The diagrams in Figure 4.1.13 show the electron configuration using the electron shell model for two separate boron atoms (atomic number 5).

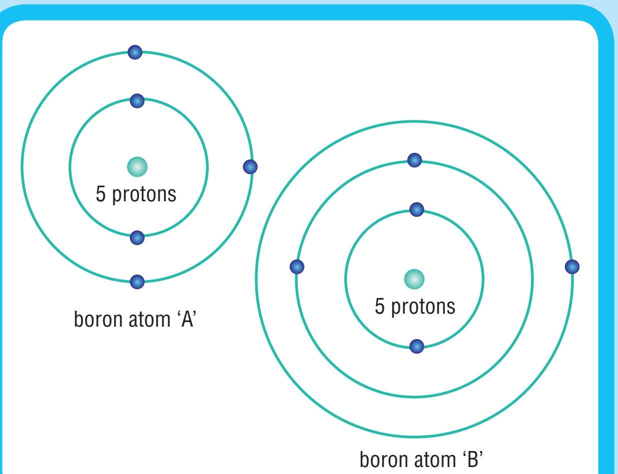


Fig 4.1.13 Diagram for question 24

a Which of the boron atoms (A or B) is in ground state?

b Which of the boron atoms is 'excited'? How do you know?

c Excited atoms can produce 'emission spectrum'. Explain how these are produced.

25 A brief description of four chemical elements A to D is given below. For each of the elements, identify which group they belong to. Explain your reasoning.

a Element A is a very reactive metal. It forms +1 ions when it reacts with elements out of group VII.

b Element B is a gas. It is very unreactive even under intense pressure and heat.

c Element C is not as reactive as element A and forms +2 ions when it reacts with group VI and VII elements.

d Element D is a diatomic gas. It is very reactive with group I metals and forms –1 ions.

Investigating questions

26 Many scientists have contributed to our current understanding of the structure of the atoms and modern quantum theory. They include Max Plank, Albert Einstein, Wolfgang Pauli, Louis de Broglie, Erwin Schrödinger and Werner Heisenberg. Research some of their contributions. Alternatively, you could construct a timeline that illustrates the development of our understanding of the structure of the atom and quantum theory.

27 **a** Research the groups of the periodic table in more detail with a particular focus on groups I, II, VI, VII and VIII. What are the common properties within each of these groups? Are there any trends in certain properties as you go down a group?

b Research periods of the periodic table to see if you can identify any trends in the properties of the elements as you go across a period.

4.1 FOCUS [Practical activity]

Prac 1
Focus 4.1

Flame tests

Purpose

To explore some of the characteristic colours that are emitted by ions when their electrons are excited to higher energy levels. Excited electrons fall back to lower energy levels emitting the energy they absorbed in the first place. This emitted energy is in the forms of quanta or packets of energy called photons. Often these photons are in the visible spectrum and a colour unique to that ion can be seen in the flame. This is the basis for flame testing, which can be used as a means of identifying ions.

SAFETY NOTE: Safety glasses must be worn at all times. Concentrated acid must be handled very carefully. Take great care when heating. Do not contaminate substances by putting the flame loop directly into them. Your teacher will supply small vials to use or you can put a small amount of each solid onto a piece of filter paper for testing.

Requirements

Bench protector, nichrome wire about 10 cm long with a small loop twisted at one end, concentrated hydrochloric acid, Bunsen burner, chloride salts of a range of ions including lithium chloride, sodium chloride, potassium chloride, calcium chloride, copper II chloride and barium chloride. An alternative to avoid concentrated acid is to make up solutions of the salts and place them in spray bottles, to spray into the Bunsen burner flame.

Procedure

If using metal loops

1 Place a bench protector on your benchtop. The loop needs to be cleaned before each use. This can be done by dipping the loop into concentrated hydrochloric acid and then placing it into a blue flame. If the flame does not change colour then the loop is clean. If there is any colour change then repeat the cleaning until placing the loop in the flame does not produce a colour change.

2 To flame-test a material, dip the loop into the concentrated hydrochloric acid and then dip the loop into the metal salt that you are testing. Hold the loop in a blue Bunsen flame and record the colour of the flame.

3 Clean the loop using the procedure from step 1. This needs to be done between each flame test.

4 Repeat steps 2 and 3 above until you have tested and recorded all of the metal salts provided by your teacher.

If using spray bottles

1 Proceed from station to station trying the labelled spray bottles there. One quick spray into a blue Bunsen flame is all that is needed. Check your observations on the table shown below.

Questions

1 Compare your flame test results with the table below. What might be the reason for any differences?

2 The loop is placed in the concentrated hydrochloric acid before it is placed in the salt so that the acid reacts with the metal chloride salt to produce ions of the salt. The concentrated hydrochloric acid is also used to clean the loop between tests. What does this tell you about the ‘flame test’ colour of chloride ions?

3 Why did the loop have to be cleaned carefully before each test?

4 Why do you think different metal ions produce different flame test colours?

5 Describe how flame testing could be used as method of identifying unknown metal salts.

Ion	Flame colour
Lithium (Li^+)	Red
Sodium (Na^+)	Yellow-orange
Potassium (K^+)	Lilac
Calcium (Ca^{2+})	Brick red
Barium (Ba^{2+})	Light green
Copper (Cu^{2+})	Blue-green

FOCUS 4.2 Covalent and ionic bonding

Context All chemical reactions involve the electrons of atoms interacting and forming new bonds. Atoms do not form bonds in a random way. Bonds form because of the interaction of the outer shell (valence) electrons of each atom. These interactions bring about the formation of more stable electron arrangements. In this Focus we will use your understanding of electron configurations and the periodic table to further your understanding of how and why atoms link together. You will explore how electrons can be transferred or shared between atoms to form new bonds and substances.

Chemical compound review

If you have access to *Science Aspects 2* you might like to review Foci 5.6 to 5.8 before you commence this Focus. These foci explore the ways in which two or more atoms can join together by ionic or covalent bonding.

Why do chemicals form compounds?

In the last Focus you explored the special place that noble gases have in the periodic table. They are very unreactive and stable elements. This stability is due to their filled outer shell electron configuration.

All chemical reactions involve electrons from the reactants interacting with each other to produce more stable electron configurations. It has been found that, in most instances, after elements have reacted, each of the atoms within the molecule has achieved electron configurations of the noble gases. As you will see in your upper school chemistry course of study there are some important exceptions to this, including the transition metals and some other isolated examples.

In most cases this means that after reacting, the atoms have eight electrons in their outer shell. This is referred to as the **octet rule**. Hydrogen is an important exception to the octet rule, as it achieves only a maximum of two electrons, which is the noble gas configuration of helium.

The two ways in which atoms can achieve noble gas configurations are by:

1 sharing electrons between atoms (covalent bonds)
2 transferring electrons between atoms (ionic bonds).

Science Snippet

Scrambled eggs and curly hair

So what do curly hair and scrambled eggs have in common? Covalent bonds, of course. Eggs are made mainly of proteins dissolved in water, the most abundant of which is albumin, constituting most of the egg white. Proteins are made up of a variety of combinations of up to 20 different amino acids, which form polymer chains folded densely in a unique and relatively stable 3-D structure. On heating, the egg dehydrates and the protein chains unfold and denature. The heat causes sulfur-hydrogen (–SH) groups on the amino acid cysteine to oxidise and form covalent bonds between neighbouring molecules. These strong, stable bonds are called disulfide bridges, and this cross-linking causes the chains to form networks, so the egg hardens. Disulfide bridges also contribute to the high-tensile strength of fingernails and the shape of hair. To 'perm' hair, the disulfide bridges are broken by a reducing agent. The hair is then styled into the desired shape and an oxidising agent is used to reintroduce the covalent bonds and maintain the new shape.

Covalent bonds

In covalent bond formation, noble gas configurations are attained when outer shell electrons interact between atoms so that electrons are shared between atoms. This shared region of electrons is called a covalent bond and in most cases results in a filled outer shell (octet) for both atoms. Atoms generally share electrons in pairs and can share up to three pairs of electrons between them. Atoms can form covalent bonds with themselves or with different atoms.

Covalent molecules (elements)

The periodic table structure allows you to generalise about how elements in a group will react and bond. This is because all elements in the same group have the same number of valence electrons. To examine this further you will explore the formation of the diatomic molecules of the group VII elements. All the group VII elements form elemental diatomic molecules (F_2, Cl_2, Br_2 and I_2). By understanding the bonding in any one of these molecules you have an understanding of the bonding in the rest. Shell model diagrams are a good way to see what is happening during covalent bond formation. Consider the covalent bonding in F_2 as shown in Figure 4.2.1.

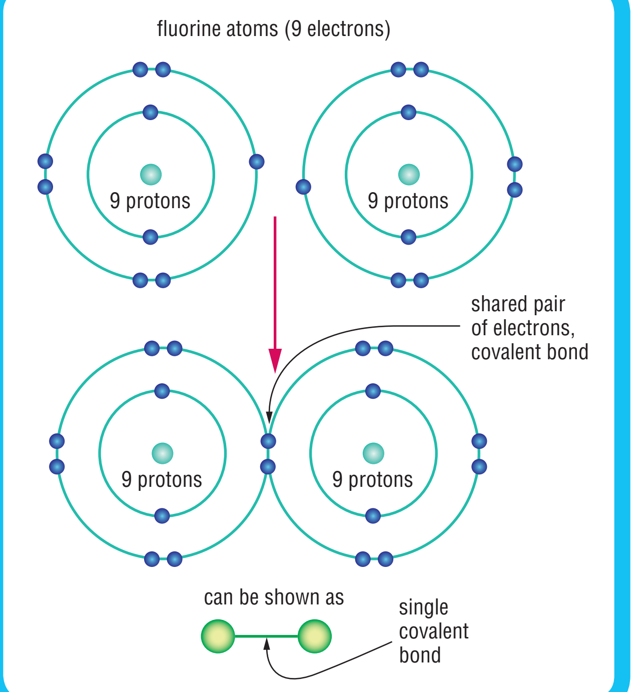
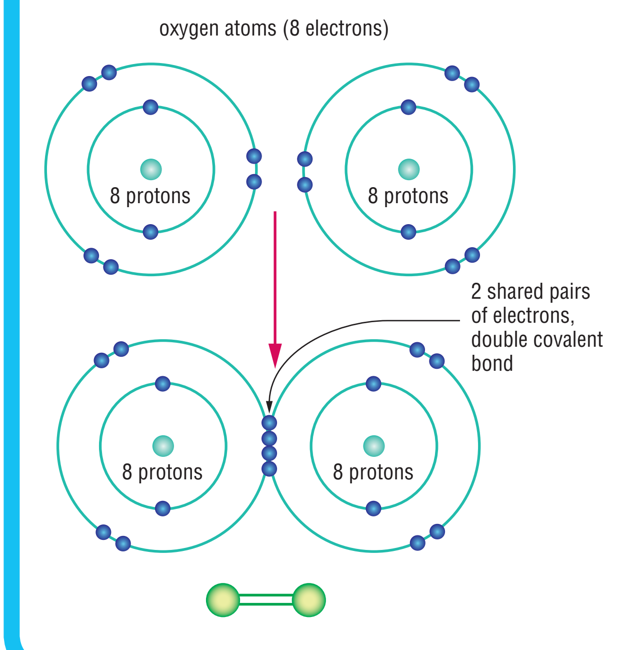


Fig 4.2.1 The covalent bond is the shared pair of electrons that occurs between the two nuclei. Note that by sharing a pair of electrons both atoms now have a filled octet of eight electrons in their outer shell—a noble gas configuration.

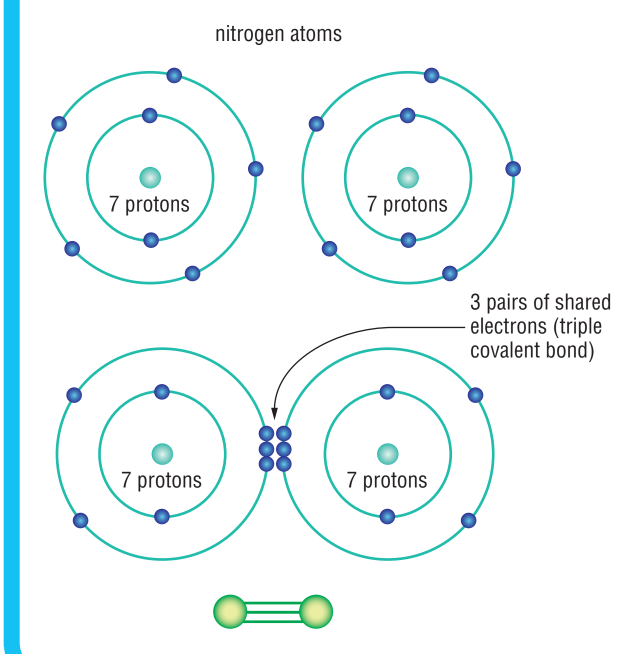
The covalent bond formed between the two fluorine atoms is called a **single covalent bond**, as only a pair of electrons are being shared. As shown in Figure 4.2.1, single covalent bonds can be represented by a single line between the atoms. It is possible for a pair of atoms to share two pairs of electrons such as in the formation of oxygen gas (O_2). This is called a **double covalent bond**. This is shown in Figure 4.2.2. Look carefully at the diagram and check the number of electrons in the outer shell of both atoms as a result of the sharing of the two pairs of electrons.

It is also possible for elements from groups 4 and 5 to form **triple covalent bonds**. Look carefully at Figure 4.2.3, which shows the bonding in nitrogen gas (N_2). Again, notice that by each atom sharing three pairs of electrons, filled outer shells can be obtained for each atom.

Double covalent bonds involve each atom sharing two pairs of electrons to obtain a filled octet. A double covalent bond can be represented as two lines between each atom. Each line indicates a pair of shared electrons. Fig 4.2.2



Triple covalent bonds involve atoms sharing three pairs of electrons. A triple bond can be represented as three lines between each atom. Fig 4.2.3



Covalent molecules (compounds)

Atoms from different elements also combine due to covalent bonds. In fact, of the millions of different compounds in the world, most of them are covalently bonded molecular compounds. To explore the formation of a covalent molecular compound you will start with one of the most important compounds on our planet—water. Figure 4.2.4 shows the bonding in the water molecule. Note that after the formation of the molecule, each of the elements, hydrogen and oxygen, has a noble gas configuration. Remember that hydrogen is an important exception to the octet rule as it only needs two electrons to have its nearest noble gas configuration (helium, Z = 2).

Atoms can also form compounds involving multiple covalent bonds. In carbon dioxide the carbon and oxygen atoms are linked by double covalent bonds.

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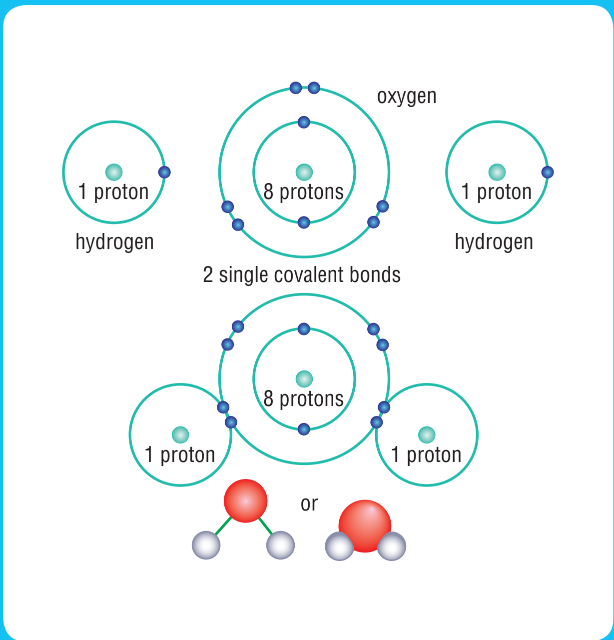
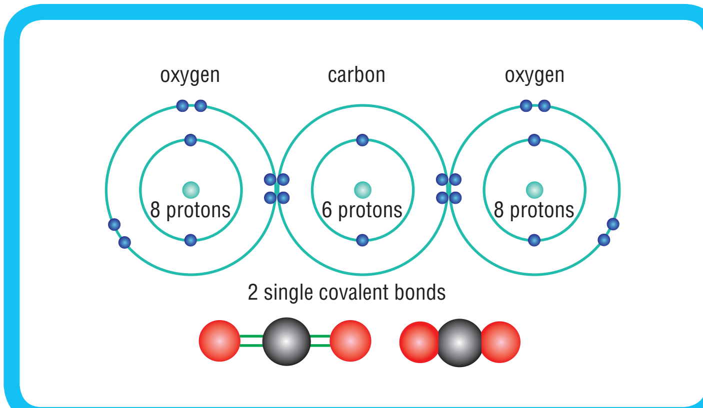
Fig 4.2.4 Water is a covalently bonded molecular compound. Each atom in water achieves a noble gas configuration by sharing electrons.

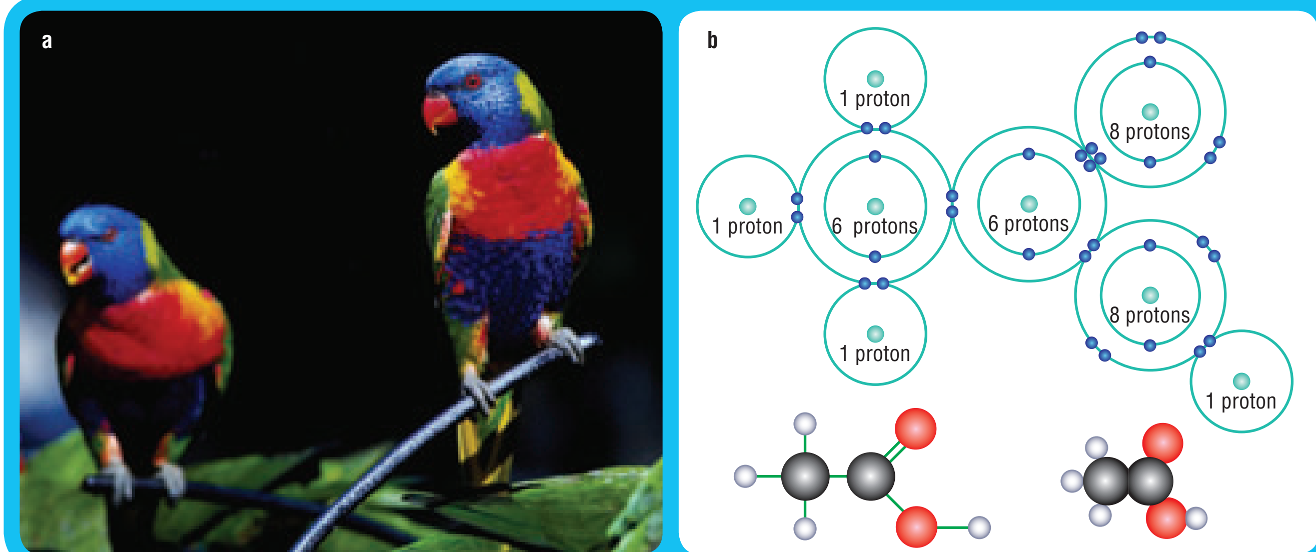




In carbon dioxide the carbon and oxygen are joined by double covalent bonds. Fig 4.2.5

Carbon forms the backbones of the millions of organic compounds that are so vital for our life (see Focus 4.5 in *Science Aspects 3*). Carbon's ability to form covalent bonds with itself, hydrogen atoms and a range of other atoms such as oxygen, nitrogen and others is the main reason this element is so important to life.

Carbon has the ability to form covalent bonds with itself and many other elements. **a** Carbon is an essential element in all life. **b** The molecule shown below is ethanoic acid (CH_3COOH) Fig 4.2.6



Science Snippet

Super ceramics

Ceramics are used for a lot more than coffee cups and toilets. Computer designers, surgeons, engineers and builders are using ceramics in increasing amounts. You are even likely to find ceramics in jet and car engines or inside your mouth as a false tooth. One of the most important physical properties that make them so desirable is their hardness. The hardness of ceramics is attributed to their bonding. New ceramics are made from materials such as aluminium oxide (Al_2O_3) and silicon nitride (Si_3N_4). The atoms in a ceramic are joined together into giant structures by a mixture of covalent bonds (in which electrons are shared between the bonding atoms) and ionic bonds (in which electrons are transferred from one atom to another). If the ceramic is an oxide, most of its bonds are ionic, while in carbide and nitride ceramics, most bonds are covalent.

Ionic bonds

The formation of ions and ionic bonding was introduced in Foci 5.6 and 5.7 of *Science Aspects 2*. If you have this text available, now would be a good time to review this material.

Did you notice that in covalent bonding, all the atoms involved were non-metals? Ionic bonding generally occurs between the metals from groups I, II and sometimes III of the periodic table with elements from groups VI and VII. Unlike covalent bonding, during ionic bond formation electrons are transferred between atoms and not shared. The periodic table allows you to see patterns in the way elements bond. For example, consider the bonding that occurs between the group I and group VII elements.

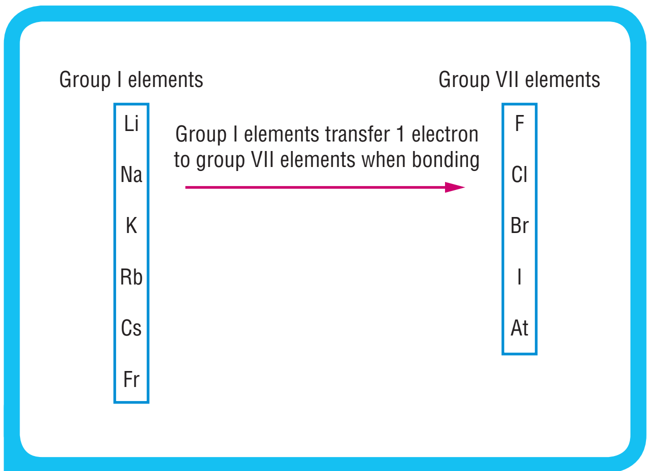
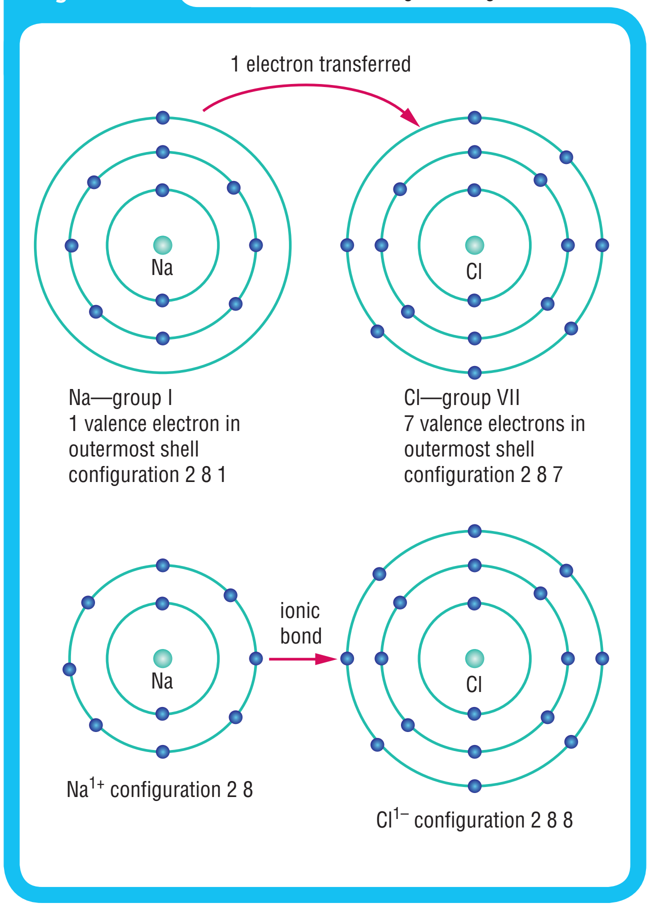


Fig 4.2.7 The periodic table allows you to make generalisations about how elements in one group bond with elements in another group. Group I elements form ionic bonds with group VII elements by transferring an electron.

Look carefully at Figure 4.2.8, which shows the formation of the ionic bond that occurs between sodium and chlorine to form sodium chloride. Note that after the electron is transferred from the sodium to the chlorine, both the sodium and the chlorine have noble gas electron configurations. The ionic bond is the electrostatic attraction that exists between the oppositely charged ions.

Fig 4.2.8 The transfer of one electron from the sodium atom to the chlorine atom forms a sodium ion (Na^{1+}) and a chloride ion (Cl^{1-}). Both ions have a noble gas configuration.

QuickTime CW Video



Group II metals have two valence electrons, which are both transferred when they form an ionic bond with a group VII element. When a group II element, such as magnesium, forms an ionic bond with a group VII element, such as chlorine, it does so in a ratio of one magnesium ion to two chloride ions such that all ions have filled octets (noble gas configurations). The formula for magnesium chloride is represented as $MgCl_2$. This is shown in Figure 4.2.9.

Group II elements can also form ionic bonds with some group VI elements. Carefully follow the sequence of Figure 4.2.10, which shows the formation of magnesium sulfide (MgS).

It is also possible for group III elements such as aluminium to form ionic bonds with group VI and VII elements.

Homework book 4.4 Bonding—it's all about electrons!

Naming ionic compounds and writing chemical formulas

Naming ionic compounds and writing formulas for ionic compounds was first explored in Focus 5.9 of *Science Aspects 2*. Now would be a great time to review this work as the following is only a brief summary of these concepts.

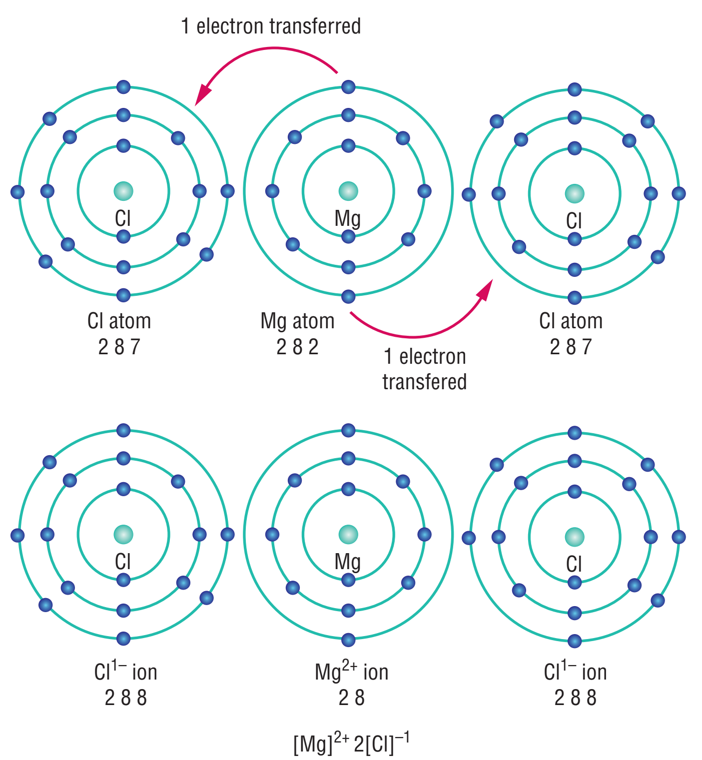


Fig 4.2.9 When magnesium forms an ionic bond with chlorine, magnesium atoms lose two electrons, one to each chlorine atom. Each ion now has an octet in its outer shell.

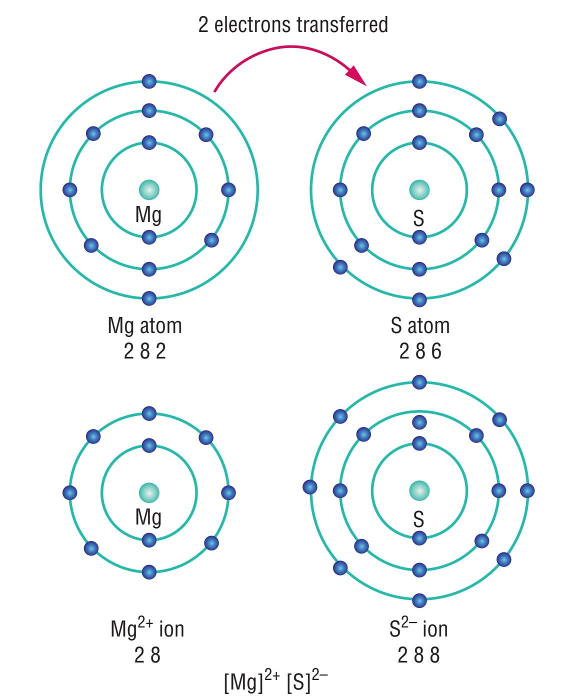


Fig 4.2.10 When group II elements form ionic bonds with group VI elements such as sulfur, the ions bond in a ratio of 1:1 and both ions have filled octets.

When ionic compound are named, there are some important points to note.

1. Some of the metal atoms (from the transition elements) form different types of ions. For example, copper can form copper ions with a +1 or a +2 charge. The +1 ion is called copper (I) and the +2 ion is called copper (II). In a similar way iron forms the ions iron (II) and iron (III) while tin forms for the ions Sn (II) and Sn (IV).
2. When a non-metal atom becomes an ion its name changes to an '–ide' ending. For example, sulfur forms the sulfide ion, oxygen forms the oxide ion.
3. There are several well-known groups of atoms that formed ions. These are called **radicals** or **polyatomic ions**. The main ones are shown in the following table, which shows the common ions that you will be using in your work. They behave as if they were a single ion and are named with their group name. For example, SO_4^{2-} is the sulfate ion, CO_3^{2-} is the carbonate ion and so on. Explore the table now to find some more examples of polyatomic ions.

Positive ions	Symbol	Charge	Negative ions	Symbol	Charge
Hydrogen	H^{1+}	+1	Fluoride	F^{1-}	−1
Sodium	Na^{1+}	+1	Chloride	Cl^{1-}	−1
Silver	Ag^{1+}	+1	Bromide	Br^{1-}	−1
Copper (I)	Cu^{1+}	+1	Iodide	I^{1-}	−1
Lithium	Li^{1+}	+1	Ethanoate	$CH\ COO^{1-}$	−1
Ammonium	NH_4^{1+}	+1	Hydrogen carbonate	HCO_3^{1-}	−1
			Hydroxide	OH^{1-}	−1
Barium	Ba^{2+}	+2	Nitrate	$NO\ ^{1-}$	−1
Calcium	Ca^{2+}	+2			
Copper (II)	Cu^{2+}	+2			
Iron (II)	Fe^{2+}	+2	Oxide	O^{2-}	−2
Lead	Pb^{2+}	+2	Carbonate	CO_3^{2-}	−2
Magnesium	Mg^{2+}	+2	Sulfate	SO_4^{2-}	−2
Tin (II)	Sn^{2+}	+2	Sulfide	S^{2-}	−2
Zinc	Zn^{2+}	+2			
			Phosphate	PO_4^{3-}	−3
Aluminium	Al^{3+}	+3			
Chromium	Cr^{3+}	+3			
Iron (III)	Fe^{3+}	+3			
Tin (IV)	Sn^{4+}	+4			

Using a table of ions and a few simple rules, you can predict the chemical formula for any ionic compound.

- Positive ions will only combine with negative ions.
- Ions will combine in such a way that the total charge is 0.
- When you are using polyatomic ions (radicals), if you use more than one, bracket the whole polyatomic ion and indicate the number of with a subscript.

A couple of examples are shown below. Remember that there is a more detailed treatment of how to write ionic formulas in Focus 5.9 of *Science Aspects 2*.

Type example 1

Interactive CW Animation

What is the chemical formula for copper (II) fluoride?

The relevant ions are Cu^{2+} and F^{1-}.

In order for the total charge to be 0, the ionic lattice will need to combine in a ratio of one copper ion to two fluoride ions.

The formula is CuF_2.

Type example 2

What is the chemical formula for iron (III) sulfate?

The relevant ions are Fe^{3+} and SO_4^{2-}

In order for the total charge to be 0, two Fe^{3+} ions will need to combine with three SO_4^{2-} ions.

The formula is $Fe_2(SO_4)_3$.

Homework book 4.5
Writing formulas of covalent molecules and ionic compounds

Physical properties of covalent and ionic substances

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The type of bonding that occurs between elements is very important in determining physical properties of compounds. This important relationship was explored in detail in Focus 4.1 of *Science Aspects 3*. Take the time to review this Focus now.

FOCUS 4.2 Questions

Use your book

Chemical compound review

1 What is a chemical compound, and how is it different from a chemical element? Illustrate your answer with examples.

2 Describe how the behaviour of atoms is different in the formation of ionic and covalent bonds.

3 Substances that are covalently bonded can be either covalent molecules or covalent network substances. Using simple diagrams, describe the difference between these two types of covalently bonded substances.

Why do chemicals form compounds?

4 What is so special about the electron configuration of noble gases?

5 a Describe what is meant by the 'octet rule'.
  b What does this tell us about the electron configuration of atoms after they form chemical bonds?

Covalent bonds

6 Describe how group VII elements form a single covalent bond to form diatomic elemental molecules using the formation of F_2 gas as an example. Use a diagram to

>>

illustrate your explanation. Explain why the covalent bond formed between the two atoms is called a single covalent bond.

7 Explain the difference between double and triple covalent bonds.

Covalent molecules (compounds)

8 Copy the shell model diagram which shows the formation of the water molecule. Circle the electrons that are being shared between each of the atoms. Use this diagram to explain what is so special about the electron configuration of all the atoms in the water molecule.

9 Repeat as for question 8 but this time use the carbon dioxide molecule.

Ionic bonds

10 Which groups of the periodic table are mainly involved in the formation of ionic bonds? (Note: you do not have to consider the transition metals at this stage.)

11 Consider the formation of sodium chloride. Explain what is so special about the electron configuration of the sodium and chloride ions after the formation of sodium chloride.

12 Use an electron shell diagram to show the formation of lithium fluoride.

13 Use an electron shell diagram to show the formation of the ionic compound, calcium chloride ($CaCl_2$).

Naming ionic compounds and writing chemical formulas

14 Summarise the key requirements when writing the chemical formulas of ionic compounds.

15 Use your summary from question 14 to write the chemical formulas for the following compounds: copper (II) chloride, iron (III) oxide and zinc bromide.

Physical properties of covalent and ionic substances

16 Summarise the main properties of covalent molecular, covalent network and ionic solids. Use a table to present your summary.

Use your head

17 Use electron shell diagrams to show the covalent bonding in the following molecules:

- **a** hydrogen (H_2)
- **b** oxygen (O_2)
- **c** hydrogen iodide (HI)
- **d** hydrogen sulfide (H_2S)
- **e** methane (CH_4)
- **f** sulfur dioxide (SO_2)
- **g** ammonia (NH_3)
- **h** carbon tetrachloride (CCl_4).

18 Draw electron shell diagrams to show how electrons are transferred during the formation of the following ionic substances:

- **a** sodium fluoride
- **b** calcium chloride
- **c** magnesium sulfide
- **d** calcium sulfide
- **e** aluminium chloride
- **f** aluminium oxide.

19 Write the chemical formulas for the following ionic solids:

- **a** potassium carbonate
- **b** calcium sulfate
- **c** ammonium carbonate
- **d** aluminium iodide
- **e** copper (II) nitrate
- **f** silver phosphate
- **g** barium sulfate.

20 An organic chemist found that a molecule of a covalent compound contained two carbon atoms, one oxygen atom and six hydrogen atoms. Studies of the melting point and boiling point showed that the substance was a covalently bonded molecule.

- **a** How do the melting point and boiling point help to determine if the substance was a covalent molecule?
- **b** Imagine that further studies indicate that the oxygen atom is bonded in between the two carbon atoms. Draw an electron shell diagram showing a possible structure for the substance.

Investigating questions

21 Many covalent molecular substances are known by their common names, not their chemical names. Use reference books or a search engine to find the chemical names and formulas for the following substances:

- **a** alcohol
- **b** sugar
- **c** nail polish remover
- **d** acetylene.

22 In the same way, many ionic solids are known by their common names. Find the chemical names and formulas of the following ionic substances:

- **a** spirit of salts
- **b** lime
- **c** plaster of Paris
- **d** rust
- **e** table salt
- **f** limestone
- **g** baking soda
- **h** caustic soda.

FOCUS 4·2

Practical activities

Prac 1 Focus 4.2

Building molecular models

Purpose

To explore the formation and shapes of some covalent molecular substances by building models of some compounds.

Requirements

Per group: molecule building kit. Each type of atom is represented by a different colour. A colour code will be supplied with the kit.

Procedure

1. Build each of the molecules of the following compounds: hydrogen gas (H_2), chlorine gas (Cl_2), hydrogen chloride (HCl), water (H_2O), ammonia (NH_3), methane (CH_4), difluromethane (CH_2F_2), hydrogen sulfide (H_2S), ethane (C_2H_6), chloroethane (C_2H_5Cl) and ethanol (CH_3CH_2OH).
2. *Draw a diagram of each of the molecules and describe the bonding that exists between the molecules.* An example using methanol (CH_3OH) has been done for you. (Note: two diagrams have been shown. One is called a 'ball and stick' model and the other is called a 'space-filled' model. The diagram you use will depend on the type of kit you have.)

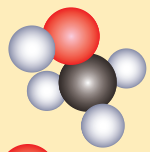
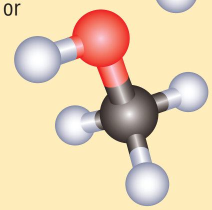
Covalent molecule	Diagram	Bonding description
Methanol CH_3OH	 or 	Single covalent bonds between all atoms in the molecule

Fig 4.2.11 How to record your models

For these molecules can you see a relationship between the pairs of electrons around the central atom and their shape? Discuss this with your teacher and other class members.

Questions

1. For molecules such as methane describe the shape of the molecule. Can you explain why the bonds might arrange themselves in this shape?
2. Choose any three molecules you constructed and draw electron shell diagrams for the molecule.

Extension task

Web Destinations CW

Go to the *Science Aspects 4* Companion Website at **www.pearsoned.com.au/schools** for a link to the free chemistry drawing software ACD Chem Sketch. Use this software to construct both 'ball and stick' and 'space-filled' models for the molecules you constructed. How do they compare?

Prac 2 Focus 4.2

DYO

Testing properties of covalent molecular compounds and ionic solids

Purpose

Covalent molecular and ionic solids have very different physical properties. These differences in properties can be explained in terms of how the atoms are bonded within the solid. In this investigation you will explore and establish some of these physical properties for yourself and then use your understanding of bonding to try to explain them.

Requirements

Design your own investigation. You will need to check with your teacher on procedures for ordering equipment. You can use a variety of ionic and covalent molecular solids such as those suggested below:

- ionic solids: sodium chloride (NaCl), copper (II) sulfate ($CuSO_4$), potassium iodide (KI)
- covalent molecular solids: naphthalene ($C_{10}H_8$), sucrose ($C_{12}H_{22}O_{11}$), sulfur (S).

Procedure

Test the following properties:

- electrical conductivity in the solid state
- electrical conductivity in the molten state
- electrical conductivity in solution
- solubility.

You may also test other physical properties with the approval of your teacher.

SAFETY NOTE: Safety glasses must be worn at all times. Use a bench protector and take great care when heating substances. Your teacher may choose to demonstrate the conductivity in the molten state. Sulfur must be heated in a fume hood.

Your design must show a clear understanding of the safety issues involved.

You must check with your teacher for approval of your methods.

Questions

1. Write a summary of the physical properties of covalent molecular substances compared with ionic solids.
2. Justify the physical properties you identified for covalent molecular and ionic solids in terms of their bonding. This information could be presented in a table.

a Salt (sodium chloride) **b** Limestone (calcium carbonate) **c** Drain cleaner (sodium hydroxide)

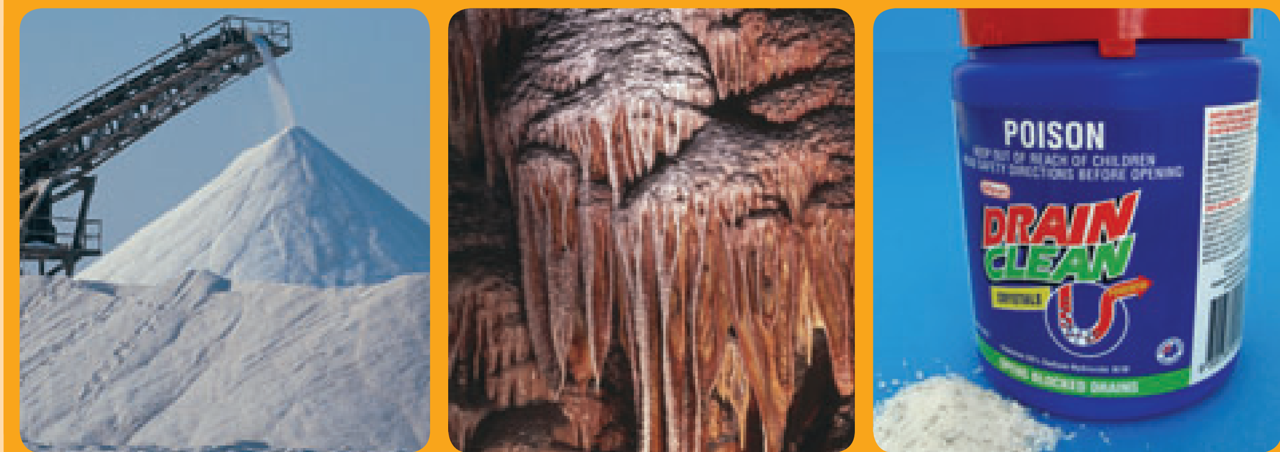


Fig 4.2.12 Ionic substances

a Glass **b** PVC **c** Medicines

Fig 4.2.13 Covalent substances

FOCUS 4.3 Redox

Context

Have you ever seen or been involved with a redox reaction? If you leave an apple half eaten for a few minutes it starts to go brown. That is a redox reaction. The burning of any fossil fuel or even the process of chemical respiration where 'food' is burnt in your body is a redox reaction. Many of the metals that we use in everyday life are refined using redox reactions. The corrosion of these metals, such as the rusting of iron, is also a redox reaction. Anything that operates by battery makes use of a redox reaction. Hydrogen fuel cells, which are being seen as the portable energy source of the future, also use redox reactions.

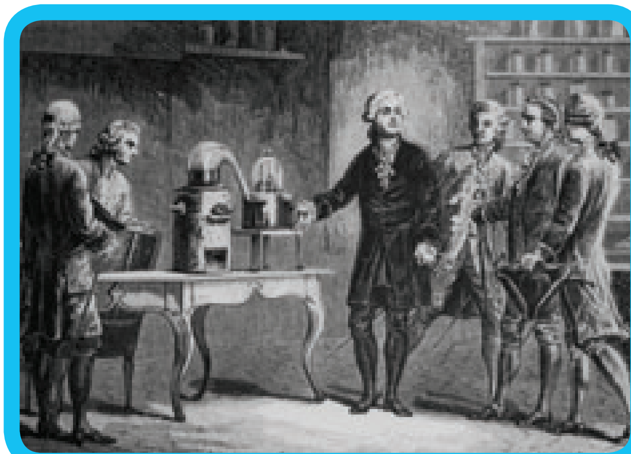
As you will explore in this Focus, the word 'redox' is a combination of two terms—reduction and oxidation. These two processes must occur together and involve the movement of electrons between substances. As you have seen in the last two Foci, electrons play a vital role in all the chemical reactions that make up our existence.

Fig 4.3.1 We are surrounded by reduction and oxidation (redox) reactions, from corrosion to combustion to the reactions that produce and store electrical energy in a car battery.

The history of oxidation and reduction

As a science, chemistry has developed over many centuries. This means that as our understanding of chemistry has improved we have expanded some of the definitions and terms that we use. The processes of oxidation and reduction are good examples of this. With more than 20 per cent of our atmosphere being oxygen, it is no surprise that many of the earlier chemists spent a lot of time investigating the reactions of substances in air. The French nobleman Antoine Lavoisier, often referred to as the 'father of modern chemistry', was the first chemist to identify oxygen as an element.

Much of Lavoisier's work focused on oxygen. He determined that combustion was a reaction of organic materials with oxygen from the air and that rusting was the reaction of iron with oxygen from the air. He also demonstrated that a number of elements



Antoine Lavoisier (1743–94), shown here conducting an experiment in his Paris laboratory, was the first chemist to identify oxygen as a chemical element and to study the process of oxidation.

Fig 4.3.2

could react with oxygen to form **oxides**. One of these reactions was the reaction of mercury to form red mercury (II) oxide. In this reaction the silver mercury metal gains oxygen to become red mercury (II) oxide. We now write this as:

$$2Hg\ (l) + O_2\ (g) \rightarrow 2HgO\ (s)$$

The term **oxidation** was born soon after Lavoisier's early work and referred to the combination of a chemical element with oxygen. In a similar way, metals such as magnesium and zinc can be oxidised to their corresponding oxides.

$$2Mg\ (s) + O_2\ (g) \rightarrow 2MgO\ (s)$$

$$2Zn\ (s) + O_2\ (g) \rightarrow 2ZnO\ (s)$$

The reverse process, the loss of oxygen from a compound, is referred to as **reduction**. For example, many ores contain the oxide of the metal. Iron ore (haematite) is Fe_2O_3. When this ore is heated with carbon monoxide in a blast furnace, the oxygen is lost from the ore. The iron oxide has been **reduced** by the carbon monoxide.

loss of oxygen → reduction

$$Fe_2O_3\ (s) + 3CO\ (g) \rightarrow 2Fe\ (s) + 3CO_2\ (g)$$

gain of oxygen → oxidation

Fig 4.3.3 Oxidation occurs when substances gain oxygen and reduction occurs when substances lose oxygen.

The definitions of oxidation and reduction were soon changed to include reactions involving hydrogen. If a substance lost hydrogen it was said to be oxidised and if it gained hydrogen it was said to be reduced. Consider the reaction between hydrogen sulfide and oxygen shown in Figure 4.3.4.

Fig 4.3.4 The definitions of oxidation and reduction reactions were expanded to include hydrogen.

loss of hydrogen → oxidation

$$2H_2S\ (g) + O_2\ (g) \rightarrow 2S\ (s) + 3H_2O\ (g)$$

gain of hydrogen → reduction

One thing soon became obvious to chemists studying and defining oxidation and reduction. They always occur together. If a substance undergoes oxidation, another substance undergoes reduction. This is an important concept in oxidation and reduction reactions—they always occur together and at the same time. Because the processes of oxidation and reduction occur together they are often called **redox** reactions, to indicate this close relationship.

Redox reactions involve the transfer of electrons

At the end of the 19th century electrons had been discovered and modern atomic theory was born. It soon became apparent how important electrons were in all aspects of chemical reactions and bonding between atoms. The terms 'reduction' and 'oxidation' were soon changed to focus on the transfer of electrons between substances.

Oxidation occurs when substances donate electrons and **reduction** occurs when substances gain electrons. To explore this further, consider a chemical reaction that you have probably seen before, the burning of magnesium ribbon in air. A balanced chemical equation for this reaction is shown as:

$$2Mg\ (s) + O_2\ (g) \rightarrow 2MgO\ (s)$$

The magnesium oxide is an ionic solid consisting of magnesium ions (Mg^{2+}) and oxide (O^{2-}) ions. To help us identify what is occurring we will write this equation as:

$$2Mg\ (s) + O_2\ (g) \rightarrow 2Mg^{2+}\ (s) + 2O^{2-}\ (s)$$

As shown in Figure 4.3.5, with the equation written, it is easier to see that the magnesium has donated two of its electrons (oxidation) to the oxygen that has accepted them (reduction).

When magnesium is burnt, the magnesium donates two electrons, which are accepted by the oxygen molecule. The magnesium has been oxidised, while the oxygen has been reduced.

Fig 4.3.5

2e⁻ gain of electrons → reduction

$$Mg\,(s) + O_2\,(g) \longrightarrow 2Mg^{2+}\,(s) + 2O^{2-}\,(g)$$

loss of electrons → oxidation

To explore oxidation and reduction reactions further, consider the production of hydrogen gas from the reaction of zinc metal with an acid. To simplify the equation, the acid will just be represented as H^+ ions. Look carefully at Figure 4.3.6 and follow the electron transfer that is occurring in this reaction.

When you look at reactions shown like this it is easy to see that oxidation and reduction reactions must occur together. When discussing redox (reduction–oxidation) reactions, terms including **reducing agent** and **oxidising agent** are used.

2e⁻ gain of electrons → reduction

$$Zn\,(s) + 2H^+\,(aq) \longrightarrow Zn^{2+}\,(aq) + H_2\,(g)$$

loss of electrons → oxidation

Fig 4.3.6 Redox reaction of zinc and hydrogen ions from an acid

Science Snippet

Flower power!

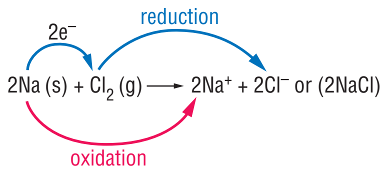
Ask scientists to name the most important chemical reaction in the world and most will tell you photosynthesis. The key to photosynthesis is the ability of green plants to split water molecules into oxygen, hydrogen ions and electrons. This reaction is a redox process and is the most successful solar energy conversion process on the surface of earth. Scientists are exploring the potential of **artificial photosynthesis** as a potential source of renewable energy. Artificial photosynthesis could be used as 'clean' way to produce hydrogen, which could be used in hydrogen fuel cells (see the Science Snippet on page 159). Scientists are close to finding out the structure of the catalytic core that is common to all green plants in chlorophyll. Knowing the structure of this catalytic core could open up the potential to run the world on 'green power'.

The reducing agent is the substance that causes another substance to be reduced and is itself oxidised. The oxidising agent causes another to be oxidised and is itself reduced.

To summarise the main points covered so far, follow Figure 4.3.7, which shows the reaction between sodium and chlorine gas to form sodium chloride. Note how NaCl is represented as its ions Na^+ and Cl^- so that the processes of oxidation and reduction can be more clearly represented.

Homework book 4.6 Recognising redox reactions

Fig 4.3.7 A summary of the processes occurring during the redox reaction to produce sodium chloride from sodium and chlorine



Substance	Electron movement	Oxidised or reduced	Oxidising or reducing agent?
Sodium	Donates electrons	Oxidised	Reducing agent
Chlorine	Accepts electrons	Reduced	Oxidising agent

Half equations

As you have seen already redox reactions are made up of two separate processes that occur simultaneously. Sometimes it is necessary and convenient to show a redox process as its two processes—a reduction and an oxidation. These are called **half equations**. For example consider the formation of sodium chloride again.

$$2Na\ (s) + Cl_2\ (g) \rightarrow 2NaCl\ (s)$$

The **oxidation half equation** which shows the formation of the sodium ion:

$$Na\ (s) \rightarrow Na^+\ (s) + e^-$$

The **reduction half equation** which shows the formation of the chloride ion:

$$Cl_2 + 2e^- \rightarrow 2\ Cl^-$$

Like any chemical equation, half equations have to be balanced. This means that the number of atoms and the electric charge on both sides of the equation must be balanced. This is why the number 2 is placed in front of both the electrons on the left of the equation and the chloride ion on the right of the equation.

These two half equations can then be added to give the overall redox reaction. When adding half equations together, it is important to make sure that the number of electrons being lost in the oxidation half equation is equal to the number of electrons being gained in the reduction process. Follow this carefully in Figure 4.3.8 as the two half equations below are added. Note how the number of electrons are balanced.

the 2 balances the number of electrons by multiplying the whole half equation by 2

$$2[Na\ (s) \rightarrow Na^+\ (s) + e^-]$$

these are the same electrons — their number must balance

$$Cl_2 + 2e^- \rightarrow 2Cl^-$$

which gives us:

$$2Na\ (s) \rightarrow 2Na^+\ (s) + 2e^-$$

$$Cl_2 + 2e^- \rightarrow 2Cl^-$$

the electrons are removed from both sides to simplify the equation

which we can now add:

$$2Na\ (s) + Cl_2\ (g) + \cancel{2e^-} \rightarrow 2Na^+\ (s) + 2Cl^-\ (s) + \cancel{2e^-}$$

which gives us the overall equation:

$$2Na\ (s) + Cl_2\ (g) \rightarrow 2Na^+\ (s) + 2Cl^-\ (s)\ (\text{or } 2NaCl)$$

Fig 4.3.8 The two half equations can be added to give the overall redox reaction.

As you progress in your chemistry career you will further see the value of developing half equations.

Displacement reactions and the activity series

The ability of substances to donate or accept electrons is not equal. Some substances have a greater tendency to accept electrons than others. These substances are more readily reduced and are better oxidising agents than other materials. Other substances have a greater tendency to donate electrons. These substances are more readily oxidised and are better reducing agents than the other materials.

Science Snippet

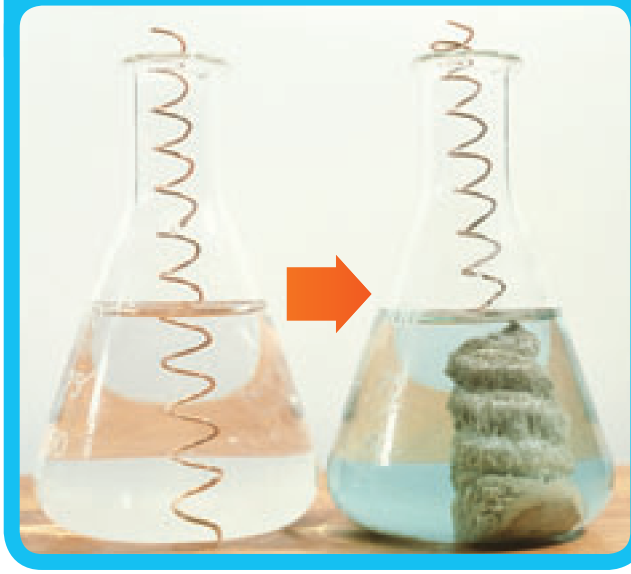
Hydrogen fuel cells

The world's demand for energy just keeps on increasing, placing huge demands on our environment. We have to reduce our energy use and produce energy more cleanly. Hydrogen fuel cells can do both. They are very efficient and produce very little pollution. The redox reaction in a hydrogen fuel cell is very similar to the burning of hydrogen to produce water, except that the construction of the fuel cell ensures that most of the energy from the reaction is converted to electricity. If the hydrogen fuel can be produced using 'green power' (see Science Snippet on page 158), we have a real solution to renewable energy supply!

These differences are commonly observed when certain metals are placed in solutions of different metal ions. Figure 4.3.9 shows what occurs when copper metal is placed in a solution of silver ions (silver nitrate solution).

QuickTime CW Video

Fig 4.3.9 Copper metal in silver solution forms silver metal.



In this reaction it is observed that the solution turns a blue colour, indicating the formation of copper (II) ions, Cu^{2+}, and silver crystals, indicating the formation of solid silver metal, Ag.

The two relevant half equations and overall redox for this reaction are shown below:

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

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

$$2Ag^{+}\ (aq) + Cu\ (s) \rightarrow 2Ag\ (s) + Cu^{2+}\ (aq)$$

In this reaction the copper is said to be a **more active metal** than the silver because it will displace (push out) the silver ion from solution. In general, more reactive metals will displace ions of less active metals out of solution.

Figure 4.3.10 shows the reactivity series, which ranks the activity of a range of metals. Using this series you can make predictions about the potential for displacement reactions when metals and ions are mixed.

Note that in this series, copper is found higher than silver. This allows us to predict that copper metal is more reactive than silver metal. Copper will displace silver ions out of solution.

Fig 4.3.10 Metal activity series. Metals higher in the reactivity table will displace ions of metals lower in the table.

Metal	Ease of oxidation of metal atom	Ease of reduction of metal atom
Potassium	Easiest to oxidise	Most difficult to reduce
Sodium	↑	↓
Calcium		
Aluminium		
Zinc		
Iron		
Nickel		
Tin		
Lead		
Copper		
Mercury		
Silver		
Platinum		
Gold	Most difficult to oxidise	Easiest to reduce

Science Snippet

Redox reactions and metal power!

Another source of energy for the car of the future could be metal! If metals such as iron, aluminium and boron are ground into nano-sized particles they become highly reactive with oxygen in a redox reaction. With a modified engine and a tankful of metal, scientists have determined that a metal-powered car could travel more than three times further than a car on the equivalent volume of petrol. Better still, because of the way that nano particle metal fuels burns, there is no carbon dioxide, no soot and no nitrogen oxides. You can also recycle your fuel! The fuels can be recharged by using hydrogen gas. It is not a new idea. Rocket engines already use metals as a fuel boost. Aluminium is used to boost the shuttle's rocket engines. There is still a lot of work to do but it is a great thought that the car scrap yards of today could be the fuel stations of tomorrow!

Using the activity table to predict displacement reactions

The activity series of the metals can be used to predict whether reactions between metals and solutions of ions will occur. Work through the following type examples.

Type example 1

Magnesium metal in a solution of lead nitrate

Predict whether a displacement reaction will occur when a strip of magnesium is placed in a solution of lead nitrate. If a reaction does occur, write two half equations and a balanced equation to show the redox reaction occurring.

Find magnesium metal and lead ions in the activity table. Note how the magnesium metal (on the left) is higher than the lead ions on the right of the table. This tells you that magnesium metal is more active (easier to oxidise) and will displace the lead ions (which are easier to reduce) out of solution.

The relevant half equations:

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

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

Overall redox reaction:

$$Mg\ (s) + Pb^{2+}\ (aq) \rightarrow Mg^{2+}\ (aq) + Pb\ (s)$$

Note—the nitrate ions are spectators and do not take part in the redox reaction. They can however be added to give an overall equation if required. The nitrate ion (NO_3^-) is added in such a way as to balance the positive charge on both sides of the redox reaction.

$$Mg\ (s) + Pb(NO_3)_2\ (aq) \rightarrow Mg(NO_3)_2\ (aq) + Pb\ (s)$$

Type example 2

Copper metal in zinc ions

Predict whether a displacement reaction will occur when a copper strip is placed in a solution of zinc nitrate. If a reaction does occur, write two half equations and a balanced equation to show the redox reaction occurring.

Find copper metal (on the left) and zinc ions (on the right) of the table. The table tells you that zinc metal is a more active metal than copper. This means that the copper metal will not displace the zinc ions out of solution.

You would predict that a chemical reaction would not occur in this case.

QuickTime cW Video QuickTime cW Video

Prac 1 p. 165

Homework book 4.7 Metal activity series

Redox reactions in action

As discussed in the context statement at the start of the Focus, redox reactions are all around us and indeed inside us as well. However, given the importance of mining and minerals to Western Australia, the remainder of this Focus will explore some applications of redox reactions and how they can be used to extract metals from their ores.

Carbon reduction

The process of carbon reduction is used to extract iron from iron oxide ores such as **hematite** (Fe_2O_3).

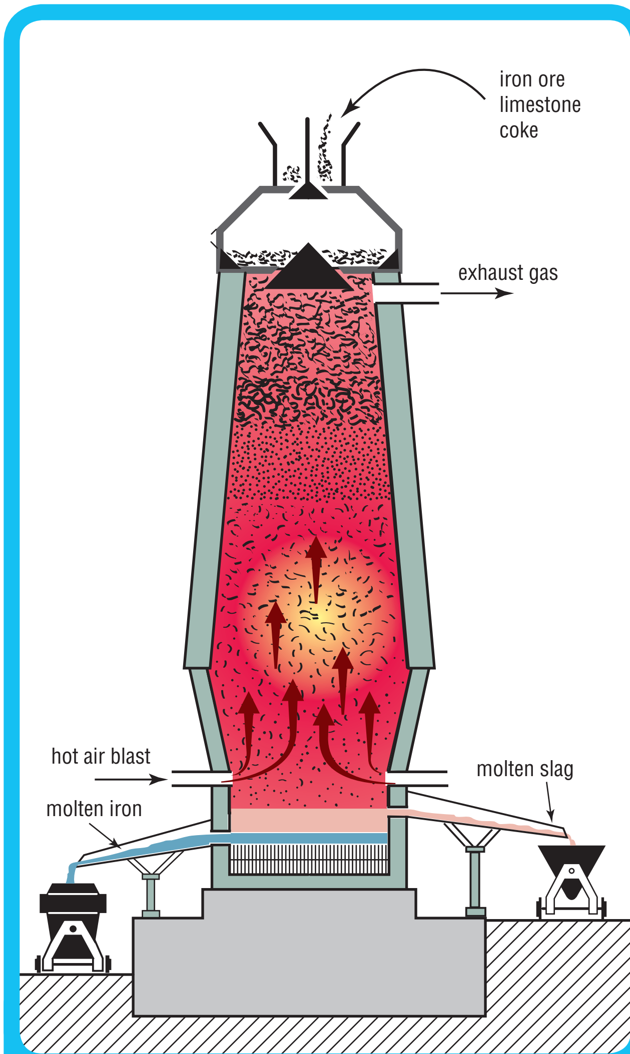


Fig 4.3.11 The raw materials are fed into the top of the blast furnace. The coke (carbon) is used to produce carbon monoxide, which is used to reduce the iron oxide ore to pure iron.

Coke is a hard form of carbon and is used to produce carbon dioxide through the oxidation of carbon to carbon dioxide.

$$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$$

The carbon dioxide is then reduced to carbon monoxide by more carbon.

$$CO_2\ (g) + C\ (s) \rightarrow CO\ (g)$$

The carbon monoxide is then used as the reducing agent for the iron oxide.

Fig 4.3.12 Reaction showing carbon reduction

iron oxide is reduced to iron

$$Fe_2O_3\,(s) + 3CO\,(g) \longrightarrow 2Fe\,(l) + 3CO_2\,(g)$$

carbon monoxide is oxidised to carbon dioxide

Electrolysis of aqueous solutions

Electrolysis is a process that involves the passing of an electric current through an aqueous solution of metal ions or, in some cases, the molten metal salt itself. Electrolysis has a large number of applications, from **electroplating**, where a thin layer of one metal is coated over another metal, to **electrorefining**, which is used to purify metals.

In the electrorefining of copper, **electrodes** are dipped into an acidified solution of copper (II) sulfate. The acidified copper (II) sulfate solution is known as the **aqueous electrolyte**, as it consists of ions of copper (Cu^{2+}) and sulfate (SO_4^{2-}) in solution.

Fig 4.3.13 Electrorefining of copper

The impure copper is made the **positive electrode** or **anode**, while the **negative electrode** or **cathode** is made up of pure steel or pure copper sheets.

At the anode, oxidation occurs so the impure copper anode dissolves away as copper ions are formed. As the anode dissolves away, the impurities in the copper collect at the bottom of the cell. This is referred to as the **anode slime**. The anode slime itself can be a valuable source of other metals and is often processed further.

At the cathode, the copper ions are reduced to copper. The copper formed at the cathode is very pure.

Anode reaction (oxidation):

$$Cu\,(s) \rightarrow Cu^{2+}\,(aq) + 2e^-$$

Cathode reaction (reduction):

$$Cu^{2+}\,(aq) + 2^{e-} \rightarrow Cu\,(s)$$

Overall reaction (redox):

$$\underset{\text{impure copper}}{Cu\,(s)} + Cu^{2+}\,(aq) \rightarrow Cu^{2+}\,(aq) + \underset{\text{pure copper}}{Cu\,(s)}$$

Look carefully at the redox equation for the electrorefining of copper. At first glance it appears that nothing has happened but on closer examination you should notice that the impure copper metal is oxidised into copper ions, which are then reduced back into copper metal at the cathode, leaving the impurities as anode slime.

Electrorefining has applications in the purification of many other metals, including zinc, lead, gold, silver, aluminium, chromium, cobalt and manganese.

Electrolysis of molten compounds

Some metals react with water and cannot be extracted in aqueous solution. These include metals such as the group I elements (alkali metals), calcium and aluminium. The electrolysis is very similar but rather than using aqueous solutions the molten salt is electrolysed directly. Because ionic salts have high melting points, additional energy is required to keep the salts molten. To reduce the melting points of the molten electrolyte, non-aqueous substances can be added to the melt. In the case of aluminium smelting, cryolite (Na_3AlF_6) is added and in the electrorefining of sodium of sodium, calcium chloride is used. In both cases, the additional ions produced in the melt are spectator ions.

In this Focus you will explore the electrorefining of molten compounds for the metals aluminium and sodium.

Case study 1: aluminium smelting process

Aluminium ore (bauxite) is mined at the Huntly and Willowdale mines in Western Australia. Alumina (Al_2O_3) is extracted from the bauxite in refineries located in Kwinana, Pinjarra and Wagerup. Electrorefining of the ore (smelting) occurs in Victoria.

Aluminium metal is produced by the millions of tonnes in Australia. *Fig 4.3.14*

In the smelting process, carbon is used both as the anode and the cathode, as shown in Figure 4.3.15.

Cathode reaction (reduction):

$$Al^{3+}\ (l) + 3e^- \rightarrow Al\ (l)$$

At the anode (oxidation):

$$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g) + 4e^-$$

To write the balanced redox reaction, the number of electrons being donated needs to balance with the number being accepted. Work through the process as shown below and note how the reduction process is multiplied by 4 and the oxidation process is multiplied by 3.

$$4[Al^{3+}\ (l) + 3e^- \rightarrow Al\ (l)]$$

$$3[C\ (s) + O_2\ (g) \rightarrow CO_2\ (g) + 4e^-]$$

$$4Al^{3+}\ (l) + 3C\ (s) + 3O_2\ (g) + 12e^- \rightarrow 4Al\ (l) + 3CO_2\ (g) + 12e^-$$

Overall equation (electrons can be removed from both sides):

$$4Al^{3+}\ (l) + 3C\ (s) + 3O_2\ (g) \rightarrow 4Al\ (l) + 3CO_2\ (g)$$

The molten aluminium is tapped off from the bottom of the tank while the powdered electrolyte and cryolite are fed in at the top. The carbon anodes need to be replaced periodically, as they are oxidised to carbon dioxide.

Case study 2: Extracting sodium metal

Sodium metal is obtained by the electrorefining of molten sodium chloride (NaCl).

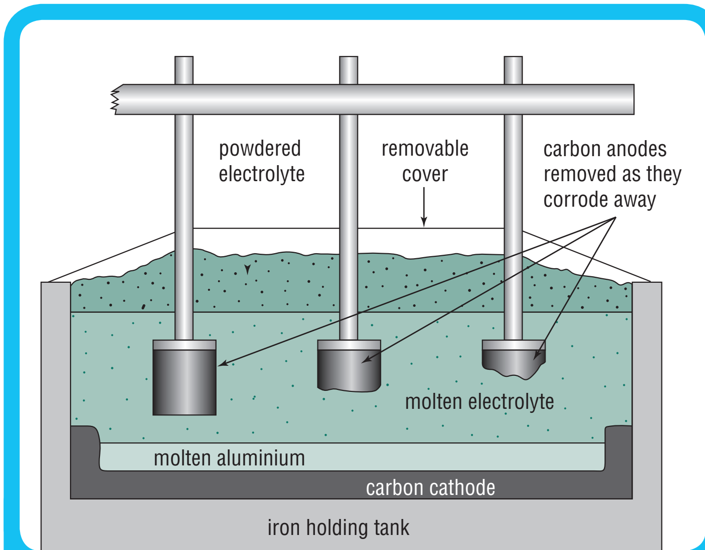


Fig 4.3.15 An electrolytic cell for the production of aluminium

Cathode reaction (reduction):

$$Na^+\ (l) + e^- \rightarrow Na\ (l)$$

Anode reaction (oxidation):

$$2Cl^-\ (l) \rightarrow Cl_2\ (g) + 2e^-$$

To write the balanced redox reaction the oxidation process needs to be multiplied by 2 to balance the electrons.

The sodium metal that is formed is immediately isolated from the atmosphere, as it oxidises rapidly if exposed to air.

$$2[Na^+\ (l) + e^- \rightarrow Na\ (l)]$$

$$2Cl^-\ (l) \rightarrow Cl_2\ (g) + 2\ e^-$$

$$2Na^+\ (l) + 2Cl^-\ (l) + \cancel{2e^-} \rightarrow 2Na\ (l) + Cl_2\ (g) + \cancel{2e^-}$$

$$2Na^+\ (l) + 2Cl^-\ (l) \rightarrow 2Na\ (l) + Cl_2\ (g)$$

FOCUS 4.3 [Questions]

Use your book

The history of oxidation and reduction

1 Give five examples of oxidation and reduction reactions that occur around your home.

2 Explain what the terms 'oxidation' and 'reduction' originally meant.

3 Describe how the original definitions of oxidation and reduction were expanded to include hydrogen. Support your answer with a sample equation.

4 Explain where the term 'redox' comes from. What does this imply about the processes of oxidation and reduction?

Redox reactions involve the transfer of electrons

5 Explain how the definitions of oxidation and reduction have now evolved to include the transfer of electrons.

6 Consider this reaction:

$Mg (s) + 2H^+ (aq) \rightarrow Mg^{2+} (aq) + H_2 (g)$

a Which of the reactants is oxidised? How do you know?

b Which of the reactants is reduced? How do you know?

c Which of the reactants is the reducing agent? Explain.

d Which of the reactants is the oxidising agent? Explain.

Half equations

7 The following equation is an example of a half equation: $S + 2e^- \rightarrow S^{2-}$

a Why is it called a half equation?

b Is the process being shown oxidation or reduction?

8 Consider the following half equation: $Zn \rightarrow Zn^{2+} + e^-$

a Is the process being shown oxidation or reduction?

b The half equation has not been written correctly. Explain what needs to be added to correct this half equation.

9 Add the two half equations from questions 7 and 8 to give the overall redox reactions.

Displacement reactions and the activity series

10 Explain what is meant by a 'displacement' reaction.

11 Copper is said to be a more active metal than silver. Explain what this means.

12 A nickel strip is placed in a solution of copper (II) ions. Use the activity series to predict if the nickel will displace the copper ions.

Redox reactions in action

13 Iron is extracted from its ore using the process of 'carbon reduction'. What are the reducing and oxidising agents in this process?

14 Define what is meant by 'electrolysis'. What are some of its applications in industry?

15 In the electrorefining of copper the overall equation for the process is:

$Cu (s) + Cu^{2+} (aq) \rightarrow Cu^{2+} (aq) + Cu (s)$

It would appear from this equation that nothing is occurring. Explain how copper is purified in this process.

16 Why do some metals have to be produced by the electrolysis of molten compounds as opposed to an aqueous solution?

Use your head

17 In the reactions shown below, state whether the substance shown first in the equation has been oxidised or reduced.

a $2Zn (s) + O_2 (g) \rightarrow 2ZnO (s)$

b $PbO (s) + CO (g) \rightarrow Pb (s) + CO_2 (g)$

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

d $H_2 (g) + S (s) \rightarrow H_2S (g)$

18 Copy the redox reactions below, circle the two substances involved in the oxidation process and link them with an arrow. Do the same for the two substances involved in the reduction process.

a $Fe (s) + 2H^+ (aq) \rightarrow Fe^{2+} (aq) + H_2 (g)$

b $Cu^{2+} (aq) + Fe (s) \rightarrow Cu (s) + Fe^{2+} (aq)$

19 Balance each of the following half equations by adding electrons or coefficients, and indicate whether they are oxidation or reduction reactions. (Note: it is possible that no balancing is required. If this is the case, state 'balanced already'.)

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

b $Ag^+ + e^- \rightarrow Ag$

c $F_2 + e^- \rightarrow F^-$

d $Ca^{2+} + e^- \rightarrow Ca$

e $Cr \rightarrow Cr^{3+} + e^-$

f $Cl^- \rightarrow Cl_2 + 2e^-$

20 Use Figure 4.3.10 showing the activity series of metals to describe the changes that you might observe in each of the following cases:

a a copper metal strip is dropped into a solution containing zinc ions

>>

- **b** an aluminium metal washer is placed in a solution containing nickel ions
- **c** a coin made of silver is placed into a solution of zinc ions
- **d** a copper spring is placed into a solution containing magnesium ions.

21 For the reactions that occur in question 20, write out the two half equations and the balanced redox equation.

Investigating questions

22 Another electrolytic process mentioned in this Focus is electroplating. Explain how you would electroplate a spoon made of copper with silver metal.

23 Very active metals such as the group I metals are easily oxidised. Explain how these metals have to be stored. What is the reaction that occurs when these metals react with oxygen? Support your answer by showing this reaction with at least one of these metals.

24 Steel products used in roofs, gutters, sheds and rainwater tanks can made from a product called 'Zincalume'. To make this product, steel is passed through a number of processes to produce a corrosion-resistant building material.

- **a** Research the process that is used to produce Zincalume and write a brief report on it.
- **b** Describe the properties of Zincalume that make it a useful material in house construction.

25 Outboard motors used on boats are made up of a variety of metals that are susceptible to corrosion. This corrosion is made worse as the lower part of the engine spends a good deal of time immersed in salt water, which is an electrolyte. To prevent excessive corrosion the motor has a **sacrificial anode** placed in the lower arm of the motor. Research answers to the following questions.

- **a** What are the main metals that are affected by salt water? How are the metals affected? Include any relevant chemical equations.
- **b** What is the role of the sacrificial anode?
- **c** Without a sacrificial anode, what could be reduced and what would be oxidised in the corrosion process?
- **d** When a sacrificial anode is present, what would be oxidised and what would be reduced?
- **e** Describe other uses for sacrificial anodes.
- **f** What metals are suitable for use as sacrificial anodes? Where do these metals sit in the metal activity series (Figure 4.3.10) in relationship to the metals that need to be protected from corrosion?

4•3 FOCUS [Practical activity]

Metal displacement reactions

Prac 1
Focus 4.3

Purpose

To examine some metal displacement reactions and compare the theoretical predictions with actual observations.

Requirements (per group)

Test tubes and rack; pea-sized samples of copper, lead, magnesium and zinc; 0.1 M solutions of the following in dropper bottles—copper (II) nitrate ($Cu(NO_3)_2$), lead (II) nitrate ($Pb(NO_3)_2$), magnesium nitrate ($Mg(NO_3)_2$) and zinc nitrate ($Zn(NO_3)_2$).

Procedure

1. Place a piece of zinc in three test tubes. Cover these with about 10 mL of solutions of magnesium nitrate, lead nitrate and copper (II) nitrate.
2. Leave these reactions to sit and *note any reactions that occur in a suitable table. If you do not see any reaction then record this.*
3. Repeat step 1 using the same solutions but using magnesium metal.
4. Leave these reactions to sit and *note any reactions that occur in your table.*
5. Repeat the investigation using the same solutions and lead.
6. Leave these reactions to sit and *note any reactions that occur in your table.*
7. Repeat using copper metal and *record your results in your table.*

Questions

1. Process one metal at a time. Use the metal activity series (Figure 4.3.10) to predict where a reaction should have occurred. How did it compare with your observations?
2. For all of the combinations that reacted write:
   - **a** the oxidation half equation
   - **b** the reduction half equation
   - **c** the overall redox equation.

FOCUS 4•4 Chemical equations

Context In this Focus you will study some of the tools available to chemists to understand chemical reactions, including general equations and the metal activity series. Both of these tools allow you to predict whether or not a chemical reaction will occur. This Focus will also expand your skills in representing chemical equations through the writing of a balanced chemical equation.

The nature of chemical reactions

In Foci 5.10 and 5.11 of *Science Aspects 2* you looked at chemical equations and reactions in detail. You might like to review these Foci before you proceed.

Below is a summary of some of the main symbols and terminology used when writing chemical equations. You would have seen some of them before.

1 The physical state of the reactants and products is shown in brackets after the formula for each reactant and products: (s) = solid, (l) = liquid, (g) = gas, (aq) = solution in water. For example, in the reaction between solid magnesium with an acid solution to form hydrogen gas and an aqueous solution of magnesium chloride you would write:

$$Mg\ (s) + 2HCl\ (aq) \rightarrow H_2\ (g) + MgCl_2\ (aq)$$

2 In some chemical reactions a **catalyst** is used (see Focus 5.10 in *Science Aspects 2*). A catalyst speeds up the rate of a chemical reaction without itself being consumed in the reaction. As the catalyst is not a reactant or a product, it is shown written above the arrow connecting the reactants and products. For example, the manganese dioxide (MnO_2) catalysed decomposition of hydrogen peroxide to produce oxygen gas and water is written as follows:

$$2H_2O_2\ (l) \xrightarrow{MnO_2} 2H_2O\ (l) + O_2\ (g)$$

3 When substances dissolve in water, the water is not directly considered a reactant and like the catalysts can be shown above the arrow. A good example of this is the dissolving of ionic solids, where the ionic lattice breaks down into its ions when dissolved in water. For example dissolving iron (II) sulfate in water is written as follows:

$$FeSO_4\ (s) \xrightarrow{H_2O} Fe^{2+}\ (aq) + SO_4^{2-}\ (aq)$$

4 Many reactions require heat to get them started. Heat is often represented in chemistry using the Greek letter, delta (Δ) and is shown above the arrow. For example copper (II) carbonate decomposes when heated. This can be written as follows:

$$CuCO_3\ (s) \xrightarrow{\Delta} CuO\ (s) + CO_2\ (g)$$

Science Snippet

Chemical reactions are a sign of life!

One of the most controversial pieces of chemical evidence for the existence of life on Mars was obtained in 1977. In this experiment, radioactive-carbon labelled nutrients were mixed with soil from Mars. The scientists then tested for radioactive methane and produced a positive result! This suggested that a chemical reaction had occurred, which converted the nutrients to methane. There had to be something living in the Martian soil to do this!

Unfortunately other experiments failed to show any sign of life so the result was declared a 'false positive'.

Balancing chemical equations

The balancing of chemical equations was first considered in Focus 5.11 of *Science Aspects 2*. Review this Focus before going further.

Chemical equations must be balanced to ensure that the law of conservation of mass is obeyed. The number and types of atoms on the reactant side must equal the same number and type of atoms on the product side. As you have seen in your previous chemistry work, the formula for a substance is determined by its type of bonding and position in the periodic table. This means that the only way you can balance a chemical equation is by adding numbers (coefficients) to the front of reactants or products.

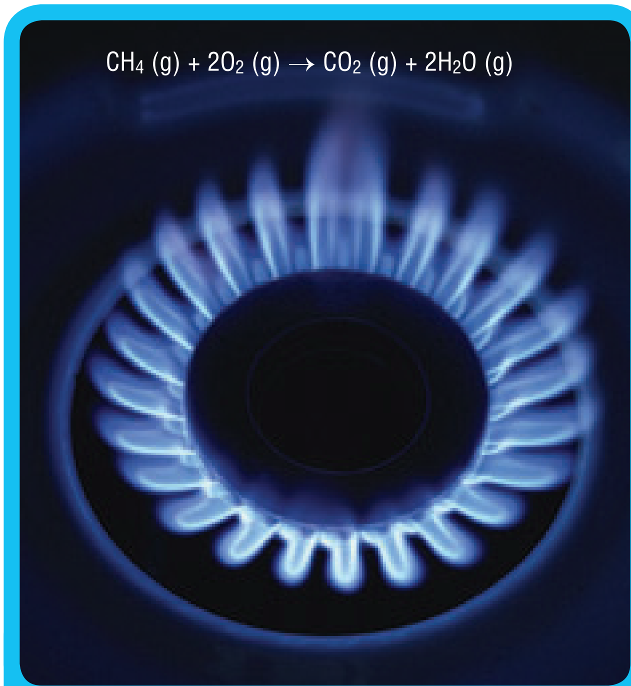


Fig 4.4.1 A balanced chemical equation for the combustion of methane. The co-efficients are added to the front of the correct chemical formula to make sure that the number and types of atoms on both sides of the equation are correct. This is called **balancing an equation**.

It is vital when you are balancing chemical equations that you get the formulas for all reactants and products correct. If you have some concerns about this you might like to review Focus 5.9 of *Science Aspects 2* before you continue.

Interactive CW Animation Interactive CW Animation

Balancing chemical equations review

As you gain experience with balancing chemical equations you can omit some of the steps that are reviewed below from Focus 5.11 of *Science Aspects 2*. In italics below the steps are further suggestions and shortcuts that you can use as your skills develop.

The steps outlined are guidelines and generalisations only, and have been written to cover a large range of reactions. Like many skills in life, practice is the key to success!

1 Write the equations in words to determine the reactants and products.

This is one of the first steps you might omit. If you wish, you can start writing chemical formulas as soon as you start to balance the equation.

2 Write the chemical equation using the correct chemical formula. Refer to your ion table where required. Use the symbols (aq), (s), (l) and (g) to indicate the phases of the reactants and products.

Also show catalysts or water above the arrow as required. Writing a balanced chemical equation is not just about balancing numbers. It is an opportunity for you to demonstrate your understanding of chemical formulas, states of matter, catalysts etc.

3 Count the number and types of atoms on both sides of the equation.

This will allow you to see which atoms need to be balanced. If you are working with polyatomic ions (radicals), which do not change from the reactants to the products side, you will find it useful to consider them as a group. For example, if you have sulfate ions (SO_4^{2-}) on both sides, think of the sulfate as an 'element' and balance the sulfates as a single group.

4 Attempt to balance the equation by putting numbers in front of the formulas to make sure that the total number of atoms of reactants is the same as the total number of atoms of products.

This is the tricky bit in some cases. Begin with the element, other than hydrogen or oxygen, that has the greatest number of atoms in any reactant or product. You can use a table such as shown in Focus 5.11 of *Science Aspects 2* but only for a short time.

5 Balance the equation. Make sure you never change the formula of a chemical substance to balance an equation. Always use the correct formula.

After balancing atoms other than hydrogen or oxygen, balance the hydrogen or oxygen that is in the reaction as a compound. If hydrogen or oxygen is there as an element, balance this last. Do not be tempted to change formulas—even if you are desperate! You must use the correct chemical formulas at all times.

Do a final check of all atoms and ion groups to make sure they are balanced and that you have shown the phases for all reactants and products.

Look at the overall equation you have now. Are your coefficients in the lowest possible ratio? Another example can be seen in Figure 4.4.2.

Homework book 4.8 Balancing chemical equations

Hydrochloric acid reacts with aluminium to produce aluminium chloride and hydrogen gas. Write a balanced chemical equation for this reaction.

1 The word equation has already been given to you in the question.

2 Write out the unbalanced chemical equation showing the phases.

$Al\ (s) + HCl\ (aq) \rightarrow AlCl_3\ (aq) + H_2\ (g)$

3 Check the number and type of atoms on both sides of the equation. A table is shown below. You do not have to use a table at all and you should aim to do this atom check in your head.

Atom balance table

Element	Reactant atoms	Reactant products
Al	1 (2)	1 (2)
H	1 (3) (6)	2 (6)
Cl	1 (3) (6)	3 (6)

4 Attempt to balance the equation by putting numbers in front of the formulas to make sure that the total number of atoms of reactants is the same as the total number of atoms of products.

Using the guidelines, the Cl atoms are balanced by adding a 3 in front of the HCl:

$Al\ (s) + 3HCl\ (aq) \rightarrow AlCl_3\ (aq) + H_2\ (g)$

Check out the figures in brackets in the atom balance table above. Note that while the Cl atoms are balanced, the hydrogen atoms are not balanced.

Attempt to balance the H atoms. This can only be done by putting a 6 in front of the HCl and a 3 in front of an H_2.

$Al\ (s) + 6HCl\ (aq) \rightarrow AlCl_3\ (aq) + 3H_2\ (g)$

Check out the balance table now, making sure that you're reading the last set of brackets. To balance the Cl atoms, 2 is added in front of the $AlCl_3$ and the Al.

$2Al\ (s) + HCl\ (aq) \rightarrow 2AlCl_3\ (aq) + H_2\ (g)$

Check out the balance table. All types and atoms are not balanced.

5 Balance the equation. Make sure you never change the formula of a chemical substance to balance an equation. Always use the correct formula.

$2Al\ (s) + 6HCl\ (aq) \rightarrow 2AlCl_3\ (aq) + 3H_2\ (g)$

As your skills in balancing a chemical equation develop, steps can be left out.

Fig 4.4.2

Molecular and ionic equations

Balanced chemical equations provide you with a range of information. As you shall see in Foci to follow, a balanced chemical equation tells you the ratio in which reactants will combine and products will form. This will be explored in more detail in the next Focus. A chemical equation also gives you information about the bonds that are broken and formed or, in the case of equations involving ions, which of the ions are involved in the reaction.

In many equations involving ions, some of the ions are not changed during the chemical reaction. You can recognise these in a chemical equation because they appear unchanged on both sides of the chemical equation. These ions are called **spectator ions**. If you are trying to focus your attention on the chemistry of what is occurring, you can leave the spectator ions out of the equation to write what is know as the **net ionic equation**.

Type example

What is the net ionic equation for the reaction of hydrochloric acid with magnesium to produce magnesium chloride and hydrogen gas?

1 Write a balanced equation in the usual way—this is known as the molecular equation. In molecular equations, ionic compounds are written as neutral formulas (eg $MgCl_2$ (aq)) rather than as ions (eg Mg^{2+} (aq) and $2Cl^-$ (aq)).

$$Mg\ (s) + 2HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2\ (g)$$

2 Expand aqueous solutions to clearly identify ions on both sides of the equation. For example, HCl (aq) is H^+ (aq) and Cl^- (aq) and $MgCl_2$ (aq) becomes Mg^{2+} (aq) and $2Cl^-$ (aq). This is known as the **ionic equation**.

$$Mg\ (s) + 2H^+\ (aq) + 2Cl^-\ (aq) \rightarrow Mg^{2+}\ (aq) + 2Cl^-\ (aq) + H_2\ (g)$$

3 Cross out ions that appear unchanged on both sides of the equation (spectator ions).

$$Mg\ (s) + 2H^+\ (aq) + \cancel{2Cl^-\ (aq)} \rightarrow Mg^{2+}\ (aq) + \cancel{2Cl^-\ (aq)} + H_2\ (g)$$

4 Write out the remainder of the equation. This is known as the **net ionic equation** as it shows the overall or 'net' equation.

$$Mg\ (s) + 2H^+\ (aq) \rightarrow Mg^{2+}\ (aq) + H_2\ (g)$$

Now consider the reaction shown in Figure 4.4.3.

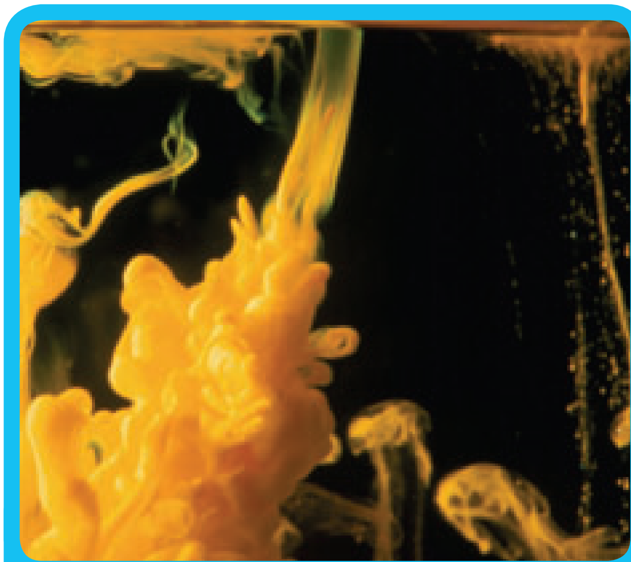


Fig 4.4.3 A precipitate of lead iodide is formed when solutions of lead nitrate and potassium iodide are mixed. How would you write a net ionic equation for this reaction?

To write the equation for the reaction shown in Figure 4.4.3, you would follow the steps below.

1 Write a balanced chemical equation for this reaction (the molecular equation).

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

2 Expand aqueous solutions to clearly identify the ions on both sides of the equations (the ionic equation).

$$Pb^{2+}\ (aq) + 2NO_3^-\ (aq) + 2K^+\ (aq) + I^-\ (aq) \rightarrow PbI_2\ (s) + 2K^+\ (aq) + 2NO_3^-\ (aq)$$

3 Cross out ions that appear unchanged on both sides of the equation (spectator ions).

$$Pb^{2+}\ (aq) + \cancel{2NO_3^-\ (aq)} + \cancel{2K^+\ (aq)} + I^-\ (aq) \rightarrow PbI_2\ (s) + \cancel{2K^+\ (aq)} + \cancel{2NO_3^-\ (aq)}$$

4 Write out the remainder of the equation. This is the net ionic equation.

$$Pb^{2+}\ (aq) + 2I^-\ (aq) \rightarrow PbI_2\ (s)$$

Homework book 4.9 Net ionic equations

Types of chemical reaction

There are many different types of chemical reactions and it would just be impossible to know or have seen them all. It is possible, however, to be familiar with a number of **general equations**. General equations group reactants into broad groups such as metals, acids, carbonates and so on. If you know how these substances react generally then you can accurately predict how specific substances will react. Where possible in this Focus, general equations are used to show the reactions of a broad range of chemical reaction types, including:

1 acid reactions including:
   ii acid–metal
   iii acid–metal hydroxide
   iv acid–metal oxide
   v acid–carbonate
   vi acid–hydrogencarbonate
2 precipitation reactions
3 displacement (redox) reactions.

Acid reactions

Acids are a very important group of chemicals with a range of special chemical properties. You might like to review Foci 5.4 and 5.5 of *Science Aspects 2* before you continue.

In each of the tables that follow you can see the general equations between the reaction of acids and a number of common chemical groups. The first equation gives you the general word equation, then there is an example of a specific word equation, an example of a specific molecular equation, the net ionic equation, if applicable, and one for you to practise on.

Note: the term 'salt' is used frequently in general equations. This term is used to describe an ionic compound formed in which metals ions (or ammonium) replace one or more of the hydrogen atoms of an acid. For example, sodium chloride is considered to be a salt because when hydrochloric acid is reacted with sodium hydroxide, the sodium ion replaces the hydrogen in hydrochloric acid to produce sodium chloride.

Acid–metal reactions

Acids react with some metals to produce a salt and hydrogen gas.

General word equation:

Acid + metal → salt + hydrogen gas

Specific word equation:

Hydrochloric acid + calcium chloride → calcium + hydrogen gas

Specific molecular equation:

$$2HCl\ (aq) + Ca\ (s) \rightarrow CaCl_2\ (aq) + H_2\ (g)$$

Net ionic equation:

$$2H^+\ (aq) + Ca\ (s) \rightarrow Ca^{2+}\ (aq) + H_2\ (g)$$

One for you to try: Nitric acid reacts with magnesium to produce magnesium nitrate and hydrogen gas.

Acid–metal hydroxide reactions (neutralisation reactions)

Acids react with metal hydroxides to produce a salt plus water. This is known as a neutralisation reaction.

General word equation:

acid + metal hydroxide → salt + water

Specific word equation:

nitric acid + magnesium hydroxide → magnesium nitrate + water

Specific molecular equation:

$$2HNO_3\,(aq) + Mg(OH)_2\,(aq) \rightarrow Mg(NO_3)_2\,(aq) + 2H_2O\,(l)$$

Net ionic equation:

$$H^+\,(aq) + OH^-\,(aq) \rightarrow H_2O\,(l)$$

One for you to try: Sulfuric acid reacts with calcium hydroxide to produce the salt calcium sulfate and water.

Acid–metal oxide reactions

Acids react with metal oxides to produce a salt and water

General word equation:

acid + metal oxide → salt + water

Specific word equation:

sulfuric acid + zinc oxide → zinc sulfate + water

Specific molecular equation:

$$H_2SO_4\,(aq) + ZnO\,(s) \rightarrow ZnSO_4\,(aq) + H_2O\,(l)$$

Net ionic equation:

$$2H^+\,(aq) + ZnO\,(s) \rightarrow Zn^{2+}\,(aq) + H_2O\,(l)$$

One for you to try: Magnesium oxide reacts with hydrochloric acid to produce magnesium chloride plus water.

Acid–carbonate reactions

Acids react with carbonates to produce a salt and water and carbon dioxide.

General word equation:

acid + carbonate → salt + water + carbon dioxide

Specific word equation:

hydrochloric acid + calcium carbonate → calcium chloride + water + carbon dioxide

Specific molecular equation:

$$2HCl\,(aq) + CaCO_3\,(s) \rightarrow CaCl_2\,(aq) + H_2O\,(l) + CO_2\,(g)$$

Net ionic equation:

$$2H^+\,(aq) + CaCO_3\,(s) \rightarrow Ca^{2+}\,(aq) + H_2O\,(l) + CO_2\,(g)$$

One for you to try: Sulfuric acid reacts with magnesium carbonate to produce magnesium sulfate, water and carbon dioxide.

Acid–hydrogencarbonate reactions

Acids react with hydrogencarbonates to produce a salt, water and carbon dioxide.

General word equation:

acid + hydrogencarbonate → salt + water + carbon dioxide

Specific word equation:

phosphoric acid + sodium hydrogenarbonate + sodium phosphate + water + carbon dioxide

Specific molecular equation:

$$H_3PO_4\,(aq) + 3NaHCO_3\,(s) \rightarrow Na_3PO_4\,(aq) + 3H_2O\,(l) + 3CO_2\,(g)$$

Net ionic equation:

$$3H^+\,(aq) + 3NaHCO_3\,(s) \rightarrow 3Na^+\,(aq) + 3H_2O\,(l) + 3CO_2\,(g)$$

One for you to try: Sulfuric acid reacts with calcium hydrogen carbonate to produce calcium sulfate, water and carbon dioxide.

Precipitation reactions

When two soluble ionic solutions are mixed it is possible that one of the new combinations of ions produces an **insoluble** salt. These types of reactions are known as **precipitation reactions**. Figure 4.4.3, which shows the formation of a yellow precipitate of lead iodide, is an example of a precipitation reaction. Precipitation reactions were explored in detail in Focus 4.2 of *Science Aspects 3*. You might like to review this section before proceeding.

Another example of a precipitation reaction is shown in Figure 4.4.4.

Fig 4.4.4

A white precipitate of silver chloride is produced when silver nitrate is added to sodium chloride. Silver nitrate is often used as a quick test for sea water contamination, as it produces a white precipitate if chloride ions are present.

To predict whether a precipitate should form, you use the following solubility rules table.

Solubility rules table

1	All K^+, Na^+ and NH_4^+ salts are **soluble**
2	All NO_3^- salts are **soluble**
3	All Cl^-, Br^-, I^- salts are **soluble except** Ag^+ and Pb^{2+} salts of these ions
4	All SO_4^{2-} are **soluble except** Ba^{2+}, Pb^{2+}, Ca^{2+} and Ag^+ salts of these ions
5	All CO_3^{2-} salts are **insoluble except** Na^+, K^+ and NH_4^+ salts of these ions
6	All OH^- compounds are **insoluble except** Na^+, K^+, Ba^{2+} and NH_4^+ compounds of this ion
7	All S^{2-} salts are **insoluble except** Na^+, K^+ and NH_4^+ salts of these ions
8	$CaSO_4$ and $Ca(OH)_2$ are **slightly soluble** $PbCl_2$ and PbI_2 are **slightly soluble**

The solubility rules table, like the periodic table, is a tool for you to use when you are working with these types of problems. Consider the following example to see how we would use the table.

Interactive CW Animation

Using the solubility rules

Barium nitrate and sodium sulfate solutions are mixed. Will a precipitate form? If yes, write a molecular and net ionic equation to represent the reaction.

1 Write down the formula for each solution being mixed. They can both be indicated as (aq) because they are soluble:

$$Ba(NO_3)_2\ (aq) + Na_2SO_4\ (aq)$$

2 Look at the two possible new combinations of ions, one at a time, and check out the solubility table to see if an insoluble substance is produced.

The solubility rules indicate that, of the two possible products $BaSO_4$ and $NaNO_3$, the $BaSO_4$ is insoluble.

3 Write out an equation that identifies the insoluble substance formed with an (s). You can also use the symbol (ppt), which indicates that it precipitates or falls out of solution. The other possible combination can be represented with an (aq) to indicate that it remains in solution and is soluble.

$$Ba(NO_3)_2\ (aq) + Na_2SO_4\ (aq) \rightarrow BaSO_4\ (s) + 2NaNO_3\ (aq)$$

4 Write out the net ionic equation by leaving out the spectator ions on both sides of the equation.

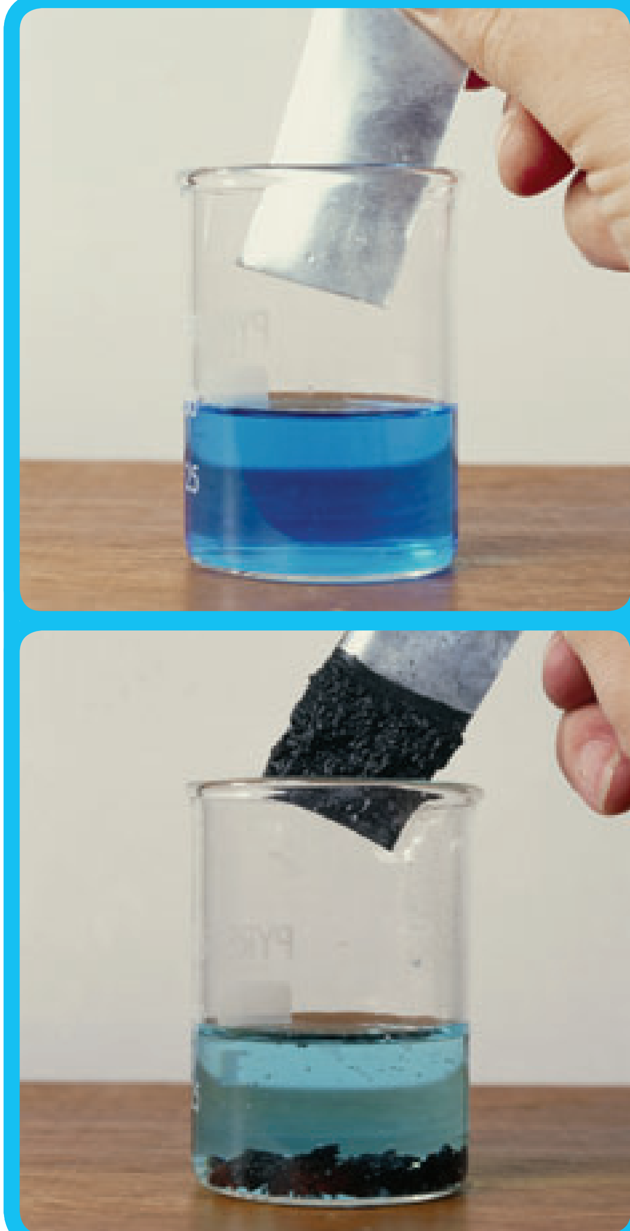
$$Ba^{2+}\ (aq) + SO_4^{2-}\ (aq) \rightarrow BaSO_4\ (s)$$

Displacement reactions

Displacement reactions were first explored in Focus 4.3. You might like to revisit this Focus before proceeding. In this Focus you explored how more active metals displace the ions of less active metals out of solution. Figure 4.3.10 in Focus 4.3 allowed you to predict the activity of metals and is known as the reactivity series of metals. The higher a metal is in the table the more active it is and you can assume that it will displace the ion of a metal lower in the table. You can see an example in Figure 4.4.5.

Zinc is higher than copper in the metal activity series. It will displace copper ions out of solution.

Fig 4.4.5



In Figure 4.4.5, how do you explain what happens when the piece of zinc metal is placed in the copper (II) sulfate solution? Looking at Figure 4.3.10 in Focus 4.3, you will note that the zinc is higher than the copper in the metal activity series. This means that zinc will oxidise to zinc ions, while the copper ions will be displaced out of the solution by being reduced to copper metal.

zinc + copper (II) sulfate → zinc sulfate + copper

Molecular equation:

$$Zn\ (s) + CuSO_4\ (aq) \rightarrow ZnSO_4\ (aq) + Cu\ (s)$$

The sulfate ion is a spectator ion. This allows you to write the net ionic equation as:

$$Zn\ (s) + Cu^{2+}\ (aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$$

Consider another example. If a piece of lead is placed in a solution of magnesium sulfate, what would be the balanced chemical equation for any chemical reaction that occurs? Using Figure 4.3.10 in Focus 4.3, you can observe that lead is lower than magnesium. This means that the lead will not displace magnesium ions out of solution. No reaction occurs.

$$Pb\ (s) + MgSO_4\ (aq) \rightarrow \text{no reaction}$$

Reactions of metals with acids

Metals are widely used in the community for a huge range of purposes. It is important that you understand their reactivity with acids. The 'Acid–metal reactions' section (page 169) stated that acids react with some metals to produce a salt and hydrogen gas. How do you know which metals react with acid? The acid referred to in this general equation is dilute acid. To help you make these predictions accurately you should again refer to the metal activity series. Figure 4.4.6 shows the metals in exactly the same sequence as in Figure 4.3.10 in Focus 4.3. This time, however, the series shows the potential of the metals to react to different degrees with dilute hydrochloric and sulfuric acids (but not nitric acid).

Metal	Reaction with dilute acid
Potassium Sodium	React violently with dilute acid to produce hydrogen gas
Calcium Aluminium Zinc Iron Nickel Tin	React with cold dilute acid to produce hydrogen gas
Lead	Reacts very slowly—hardly visible
Copper Mercury Silver Platinum Gold	No reaction with dilute acid

Fig 4.4.6 The reactivity of metals with dilute hydrochloric and sulfuric acids. Metals below (and including) copper will not react with dilute acids to produce hydrogen gas.

Figure 4.4.6 allows you to predict that all metals below copper will not react with dilute acid to produce a salt and hydrogen gas. It also tells you that metals towards the top of the table react more vigorously than those that are lower. Lead, for example, reacts very slowly with dilute acids. Similar trends occur in the reactivity of these metals with water and oxygen. You will explore these trends further in your upper school chemistry program.

Prac 1 p. 175

FOCUS 4·4 [Questions]

Use your book

The nature of chemical reactions

1 Explain how a chemical equation is important in supporting the 'Law of Conservation of Matter'.

2 Describe how you would demonstrate the following when writing a chemical equation. Demonstrate your answer with an example.

- **a** A catalyst is being used in the reaction.
- **b** The reactants and products are in a variety of physical states, including solid, liquid and aqueous phases.
- **c** A chemical reaction requires heat.

Balancing chemical equations

3 Why is it important to balance a chemical equation? In your answer make sure that you refer to the 'law of conservation of mass'.

4 The table on the following page shows the sequence of steps for writing the balanced equation for the reaction between aluminium hydroxide and sulfuric acid to produce aluminium sulfate and water. Briefly explain the purpose of each step.

>>

Step	Information to give in this step
1	aluminium hydroxide + sulfuric acid $\rightarrow$ aluminum sulfate + water
2	$Al(OH)_3$ (s) + H_2SO_4 (aq) $\rightarrow$ $Al_2(SO_4)_3$ (aq) + H_2O (l)
3	(see table below)
4	$2Al(OH)_3$ (s) + $3H_2SO_4$ (aq) $\rightarrow$ $Al_2(SO_4)_3$ (aq) + H_2O (l)
5	$2Al(OH)_3$ (s) + $3H_2SO_4$ (aq) $\rightarrow$ $Al_2(SO_4)_3$ (aq) + $6H_2O$ (l)

Atom	Reactant	Product
Al	1	2
O (not sulfate)	3	1
H	5	2
SO_4^{2-}	1	3

Molecular and ionic equations

5 Sodium hydroxide is reacted with hydrochloric acid to produce sodium chloride and water. Below are three chemical equations that can be used to represent this reaction.

$NaOH$ (aq) + HCl (aq) $\rightarrow$ $NaCl$ (aq) + H_2O (l)

Na^+ (aq) + OH^- (aq) + H^+ (aq) + Cl^- (aq) $\rightarrow$ Na^+ (aq) + Cl^- (aq) + H_2O (l)

H^+ (aq) + OH^- (aq) $\rightarrow$ H_2O (l)

Classify these equations as molecular, ionic and net ionic and explain the difference between each of these types.

6 Zinc metal is added to hydrochloric acid to produce zinc chloride and hydrogen gas. The molecular equation for this reaction is shown below.

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

a Write the ionic equation for this reaction.
b Write the net ionic equation for this reaction.

Types of chemical reaction

7 What is meant by a 'general equation', and what is the advantage of knowing general equations?

Acid reactions

8 Below are some balanced chemical equations. Identify and write down the appropriate 'general equation' that would have been used to write each equation.

a HNO_3 (aq) + $NaOH$ (aq) $\rightarrow$ $NaNO_3$ (aq) + H_2O (l)
b $2HCl$ (aq) + $MgCO_3$ (s) $\rightarrow$ $MgCl_2$ (aq) + CO_2 (g) + H_2O (l)
c H_2SO_4 (aq) + Na_2O (s) $\rightarrow$ Na_2SO_4 (aq) + H_2O (l)

Precipitation reactions

9 **a** How it is possible for two soluble reactants to form a precipitate?
b How do you predict whether or not a precipitate will form?

Displacement reactions

10 Describe how you would use the metal activity series shown in Figure 4.3.10 in Focus 4.3 to predict whether a metal would displace metal ions out of a solution.

11 **a** Use Figure 4.4.6 to predict what happens when dilute hydrochloric acid is added to each of the following metals: silver, zinc, magnesium and sodium.
b Which of the metals do you predict will react the most vigorously with hydrochloric acid?

Use your head

12 Balance the following incomplete equations. The formulas for the substances are correct.

a N_2 (g) + H_2 (g) $\rightarrow$ NH_3 (g)
b H_2 (g) + Cl_2 (g) $\rightarrow$ HCl (g)
c K (s) + H_2O (l) $\rightarrow$ KOH (aq) + H_2 (g)
d $NaOH$ (aq) + H_3PO_4 (aq) $\rightarrow$ Na_3PO_3 (aq) + H_2O (l)
e $CaCO_3$ (s) + HNO_3 (aq) $\rightarrow$ $Ca(NO_3)_2$ (aq) + CO_2 (g) + H_2O (l)
f Cu (s) + HNO_3 (aq) $\rightarrow$ $Cu(NO_3)_2$ (aq) + NO_2 (g) + H_2O (l)
g CH_4 (g) + O_2 (g) $\rightarrow$ CO_2 (g) + H_2O (g)

13 Use the tables in the acid reactions section to write a complete word and balanced molecular equation for the following acid reactions:

a nitric acid is reacted with calcium hydroxide
b zinc oxide is reacted with nitric acid
c aluminium is reacted with hydrochloric acid
d sodium carbonate is reacted with hydrochloric acid
e copper hydrogen carbonate is reacted with sulfuric acid.

14 Use the table showing the solubility rules (page 171) to determine if a precipitate will form when the following solutions are mixed. Where a precipitate is formed write a balanced molecular equation and a net ionic equation. Where a precipitate does not form write 'no reaction'.

a $Pb(NO_3)_2$ (aq) + NH_4Br (aq) $\rightarrow$
b $NaOH$ (aq) + $Ni(NO_3)_2$ (aq) $\rightarrow$
c $CaSO_4$ (aq) + $BaCl_2$ (aq) $\rightarrow$
d $ZnCl_2$ (aq) + K_2CO_3 (aq) $\rightarrow$

15 Katie's teacher has given her a challenge. He has given her an unknown metal and asked her to use the metal activity series and a range of metal ion solutions to work out what the metal might be. She starts by putting a strip of the unknown metal into a copper sulfate solution. The metal displaces the copper out of solution. She then places the strip into a solution of zinc nitrate and notes that no reaction occurs.

>>

a What possible metals could be the unknown metal? Why did you make this decision?

b Describe a further test that Katie could make to determine exactly what the unknown metal could be.

16 Use Figure 4.3.10 from Focus 4.3, or Figure 4.4.6 showing the metal activity series, to determine if a displacement reaction will occur when any of the following are mixed. Where a reaction does occur, write a balanced molecular and net ionic equation.

a Magnesium is placed in a solution of copper sulfate.

b Zinc is added to a lead nitrate solution.

c An iron nail is added to a calcium nitrate solution.

d Aluminium metal is placed in silver nitrate solution.

e Iron pieces are added to tin (II) nitrate solution.

17 Use Figure 4.4.6 to determine if a reaction occurs for the reactants shown below. If a reaction occurs then write a balanced molecular and net ionic equation. If you predict that a reaction does not occur then write 'no reaction'.

a Dilute hydrochloric acid is added to tin.

b Dilute sulfuric acid is added to calcium.

c Dilute hydrochloric acid is added to gold.

d Dilute hydrochloric acid is added to lead.

18 Below are some mixed problems from a range of chemical reactions explored in this Focus. For each of the reactions write a balanced molecular equation and a net ionic reaction where possible. Use any of the tables from this Focus as required. If a reaction does not occur, write 'no reaction'.

a Nitric acid is reacted with lithium hydroxide.

b Sulfuric acid is reacted with copper (II) oxide.

c Phosphoric acid is reacted with ammonium carbonate.

d An aluminium strip is placed in a solution of copper sulfate.

e An iron strip is placed in a solution of zinc nitrate.

f Sodium sulfide solution is added to calcium nitrate.

g Dilute hydrochloric acid is added to iron.

19 As part of a classroom laboratory quiz, the teacher gives two unlabelled beakers of solution to Marika and her group. The beakers contain barium nitrate and sodium nitrate, both of which are colourless solutions. Use the solubility rules to suggest a series of simple steps to identify and correctly label the two beakers. Assume Marika and her group have access to a range of solutions. Explain exactly what solutions they should add and what they would observe. Write a balanced net ionic equation for any reactions that occur in both steps.

Investigating questions

20 'Acid rain' is affecting many limestone buildings in Europe and the United States. Research acid rain to answer the following questions.

a What are the 'acids' that make up acid rain?

b What air pollutants are producing these acids (include any relevant chemical reactions you find)?

c Limestone and marble are the materials most affected by acid rain. What is the chemical formula for these two substances? Indicate the chemical reactions that could occur between the acids in acid rain and the limestone and marble buildings.

21 Drinking water is often purified by a series of processes known as coagulation and flocculation. One of the most common 'coagulants' used in this process is aluminium sulfate (sometimes called filter alum). Research how alum acts to help purify water by 'coagulation'. This process often leaves the water with levels of aluminium that are considered to be dangerous. To reduce the aluminium in water, small amounts of lime are often added to the water. Using chemical equations, describe how lime reduces the amount of aluminium in water that is being purified.

22 The school laboratory assistant was making a solution of a colourless salt when she dropped a copper coin into the solution. She did not realise she had done this until she noticed that the solution turned a green colour. When she removed the coin it was coated in a spongy grey material.

To test her idea of what she had just observed, she added potassium carbonate to the green solution and a green precipitate was formed. She then filtered and dried the precipitate. She then added the precipitate to some hydrochloric acid and noted that it fizzed as it gave off a clear gas, leaving a blue-green solution.

a Describe all the types of chemical reactions she observed.

b Write balanced molecular and net ionic equations for all these reactions.

4•4 [Practical activity]

Classifying chemical reactions

Prac 1
Focus 4.4

Purpose

In this investigation you will explore a variety of chemical reactions, classify them and write balanced chemical equations to represent them.

Requirements

Per group: Two small pieces of zinc, 1M HCl acid, test tube, test tube stopper, wax taper and matches, 5 cm of copper wire (not lacquered), dropper bottle of silver nitrate—0.1M ($AgNO_3$), dropper bottle 1M sodium hydroxide solution ($NaOH$), dropper bottle of phenolphthalein indicator, dropper bottle of sulfuric acid (0.5 M), dropper bottle of nickel (II) nitrate solution ($Ni(NO_3)_2$), dropper bottle of 0.1M sodium carbonate solution (Na_2CO_3), copper (II) carbonate, spatula, small pieces of magnesium, aluminium, lead, copper and tin.

SAFETY NOTE

- **Phenolphthalein is an acid–alkaline indicator. It goes pink in strongly alkaline solutions (about pH 8) and colourless as solutions become more acidic.**
- **Safety glasses must be worn at all times. Acids and bases are corrosives—avoid contact with skin and wash with copious water if you spill any on your skin. Silver nitrate will stain on exposure to light. Complete this activity on paper or a bench protection mat.**

Procedure

1. Add the two pieces of zinc to a test tube and cover with the hydrochloric acid. Collect the gas produced in an inverted test tube. Stopper the tube. Light the wax taper, and hold it under the gas you collected after removing the stopper.

SAFETY NOTE: Do not light the tube with the zinc in it, as it could shower you in acid, or even glass if it explodes. Record your observations of both the acid–zinc tube and the combustion of the collected gas.

2. Place the copper wire in several centimetres of silver nitrate solution. *Note any colour changes of the solution and the formation of any solids on the copper wire.* Leave the reaction for several minutes.
3. Add 2 mL of sodium hydroxide to a test tube and add two drops of phenolphthalein. Slowly add 2 mL of sulfuric acid. *Record any observations.*
4. Add about 2 mL of nickel (II) nitrate solution to a clean test tube. Add an equal amount of sodium carbonate solution. *Record any observations.*
5. Add a small spatula tip of copper (II) carbonate to a test tube and add about 1 mL of hydrochloric acid. *Record any observations.*
6. Add small pieces of your metal samples (magnesium, aluminium, lead, copper and tin) to test tubes containing 5 mL of dilute hydrochloric acid. *Record your observations.*

Questions

Copy the table below into your notes and complete it, using your observations, general equations, the solubility rules and the metal activity series.

Reaction	Word equation	Molecular equation	Net ionic equation
Zinc and hydrochloric acid			
Copper wire in silver nitrate solution			
Sodium hydroxide and sulfuric acid			
Nickel (II) nitrate and sodium carbonate solution.			
Copper (II) carbonate and hydrochloric acid			
Reaction of metals with dilute acid: Mg Al Pb Cu Sn			

FOCUS 4.5

Moles

Context

When we talk about distances in outer space we need to use a unit that takes into account very large numbers. This unit is called a light year. At an atomic level, during chemical reactions, billions of atoms, molecules or ions are involved and, just as in outer space, numbers are large and hard to handle. In chemistry, a special unit is used to measure the number of particles (atoms, molecules, ions or formula units). It is called the **mole** and is the 'currency' of chemistry. The mole is used to measure, compare and calculate in chemistry. The use of the mole in chemistry represents a very special step in your chemistry career … are you ready?

Science Snippet

How did they get such a large number?

The number was first estimated by 19th-century chemists, who tried to estimate the mass of a hydrogen atom. They figured that the mass of a single hydrogen atom was about $^{1}/_{6.02 \times 10^{23}}$ g. From this they figured that 1 g of hydrogen (which was used as an important reference point) would have about 6.02×10^{23} atoms of hydrogen. The reference point for the mole has now been shifted to the carbon atom. One mole is equal to the number of carbon atoms in 12.00 g of carbon-12 and if we really want to get technical, the mole is really about $6.02214199447 \times 10^{23}$ particles—but 6.02×10^{23} is close enough for most of our work!

The mole—just how big is it?

It is common for us to group things using special terms. We talk about 'dozens' of eggs. In this case the number 12 is the base number so if we talk about needing 3 dozen eggs we all understand that it is 36 (3 × 12) eggs. When the objects get more numerous we use different units. For example, if we talk about a 'ream' of paper we are referring to 500 sheets of paper. If someone asks for 4 reams of paper we know they are getting 4 × 500 sheets or 2000 sheets of paper. In chemistry the mole is just another group number—but it is a seriously large number!

One mole = 602 000 000 000 000 000 000 000. This is typically shown as 6.02×10^{23}, to indicate the 6.02 with the decimal place shifted to the right 23 times! It is called **Avogadro's number**, in honour of the Italian scientist Amadeo Avogadro.

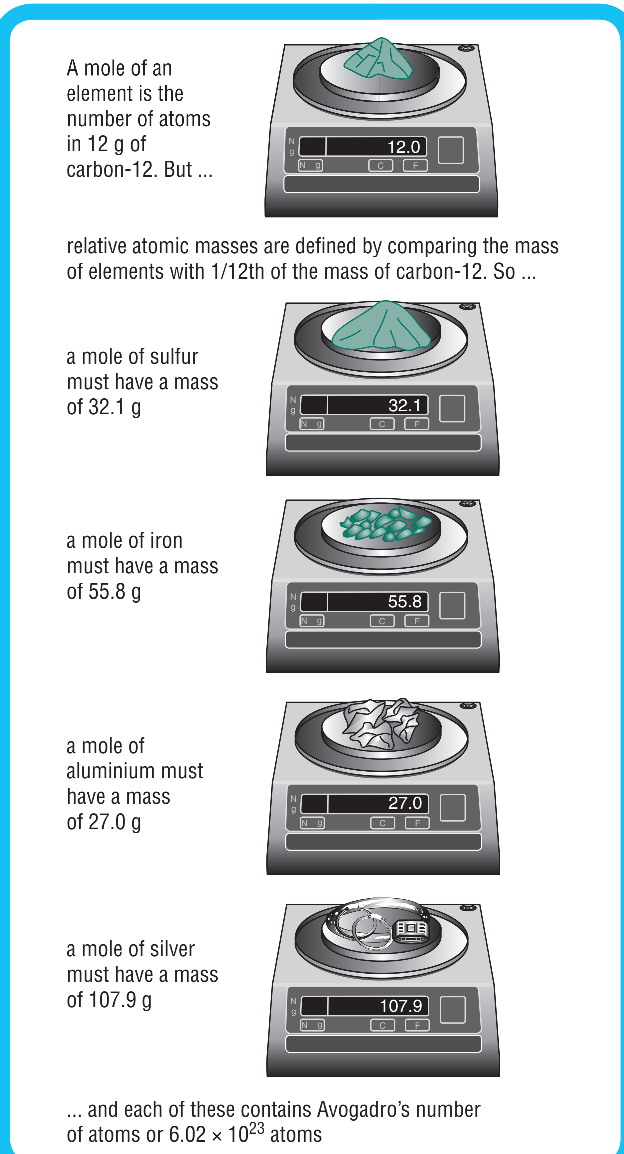


Fig 4.5.1 The mass of one mole of each element is different.

Over the years as our understanding of science and our ability to measure particles has become more precise, the definition of the mole has evolved. The mole is now defined as the number of carbon atoms in 12.00 g of carbon-12 atoms. When you use the mole to measure things in chemistry you end up with amounts that can be easily measured.

A key learning point is that a mole refers to a number of particles in chemistry and, as you know from your chemistry journey to this point, you could have a mole of atoms, molecules, ions or formula units.

Interactive Animation

The periodic table

Alternative group numbers	Group I 1	Group II 2	3	4	5	6	7	8	9	10	11	12	Group III 13	Group IV 14	Group V 15	Group VI 16	Group VII 17	Group VIII 18
Period 1	**H** 1 hydrogen 1.008																	**He** 2 helium 4.003
Period 2	**Li** 3 lithium 6.941	**Be** 4 beryllium 9.012											**B** 5 boron 10.81	**C** 6 carbon 12.01	**N** 7 nitrogen 14.01	**O** 8 oxygen 16.00	**F** 9 fluorine 19.00	**Ne** 10 neon 20.28
Period 3	**Na** 11 sodium 22.99	**Mg** 12 magnesium 24.30											**Al** 13 aluminium 26.99	**Si** 14 silicon 28.09	**P** 15 phosphorus 30.97	**S** 16 sulfur 32.07	**Cl** 17 chlorine 35.45	**Ar** 18 argon 39.95
Period 4	**K** 19 potassium 39.10	**Ca** 20 calcium 40.08	**Sc** 21 scandium 44.96	**Ti** 22 titanium 47.88	**V** 23 vanadium 50.94	**Cr** 24 chromium 52.00	**Mn** 25 manganese 54.85	**Fe** 26 iron 55.85	**Co** 27 cobalt 58.93	**Ni** 28 nickel 58.69	**Cu** 29 copper 63.55	**Zn** 30 zinc 65.39	**Ga** 31 gallium 69.72	**Ge** 32 germanium 72.61	**As** 33 arsenic 74.92	**Se** 34 selenium 78.96	**Br** 35 bromine 79.90	**Kr** 36 krypton 83.80
Period 5	**Rb** 37 rubidium 85.47	**Sr** 38 strontium 87.62	**Y** 39 yttrium 88.91	**Zr** 40 zirconium 91.22	**Nb** 41 niobium 92.91	**Mo** 42 molybdenum 95.94	**Tc** 43 technetium (98)	**Ru** 44 ruthenium 101.1	**Rh** 45 rhodium 102.9	**Pd** 46 palladium 106.4	**Ag** 47 silver 107.9	**Cd** 48 cadmium 112.4	**In** 49 indium 114.8	**Sn** 50 tin 18.7	**Sb** 51 antimony 121.8	**Te** 52 tellurium 127.6	**I** 53 iodine 126.9	**Xe** 54 xenon 131.3
Period 6	**Cs** 55 caesium 132.9	**Ba** 56 barium 137.3	***La** 57 lanthanum 138.9	**Hf** 72 hafnium 178.5	**Ta** 73 tantalum 180.9	**W** 74 tungsten 183.89	**Re** 75 rhenium 186.2	**Os** 76 osmium 190.2	**Ir** 77 iridium 192.2	**Pt** 78 platinum 195.1	**Au** 79 gold 197.0	**Hg** 80 mercury 200.6	**Tl** 81 thallium 204.4	**Pb** 182 lead 207.2	**Bi** 83 bismuth 209.0	**Po** 84 polonium (209)	**At** 85 astatine (210)	**Rn** 86 radon (222)
Period 7	**Fr** 87 franchium (223)	**Ra** 88 radium 226	**§ Ac** 89 actinium (227)	**Rf** 104 rutherfordium (261)	**Db** 105 dubnium (262)	**Sg** 106 seaborgium (266)	**Bh** 107 bohrium (264)	**Hs** 108 hassium (277)	**Mt** 109 meitnerium (268)	**Ds** 110 darmstadium (271)	**Rg** 111 roentgenium (272)							

*Lanthanides series	**Ce** 58 cerium 140.1	**Pr** 59 praseodymium 140.9	**Nd** 60 neodymium 144.2	**Pm** 61 promethium (145)	**Sm** 62 samarium 150.4	**Eu** 63 europium 152.0	**Gd** 64 gadolinium 157.2	**Tb** 65 trebium 158.9	**Dy** 66 dysprosium 162.5	**Ho** 67 holmium 164.9	**Er** 68 erbium 167.3	**Tm** 69 thulium 168.9	**Yb** 70 ytterbium 173.0	**Lu** 71 lutetium 175.0
§ Actinides series	**Th** 90 thorium 232.0	**Pa** 91 protactinium 231.0	**U** 92 uranium 238.0	**Np** 93 neptunium 237	**Pu** 94 plutonium (244)	**Am** 95 americum (243)	**Cm** 96 curium (247)	**Bk** 97 berkelium (247)	**Cf** 98 californium (251)	**Es** 99 einsteinium (252)	**Fm** 100 fremium 257)	**Md** 101 mendelevium (258)	**No** 102 nobelium (259)	**Lr** 103 lawrencium (260)

Legend

- metals
- metalloids
- non-metals
- noble gases (non-reactive non-metals)

H — symbol
1 — atomic number
hydrogen — name
1.008 — atomic mass

A relative atomic mass in brackets is the mass number of the isotope with longest half life.

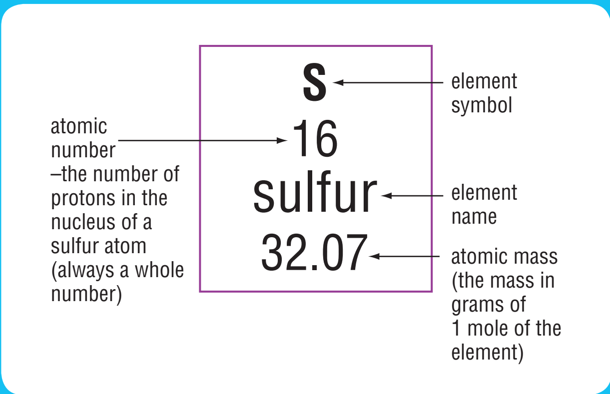
Fig 4.5.2 A periodic table gives you information about the mass of one mole of any element. From this you can work out the mass of one mole of any substance.

Molar mass

A periodic table is a powerful tool for working with the mole. A basic periodic table will show you two important numbers when dealing with atoms. The atomic number is generally shown in the top left of the symbol box while the **atomic mass** of the element is shown elsewhere in the box. Various periodic tables can be arranged slightly differently, so look carefully at the key provided on the table.

The periodic table provides you with important information about all of the chemical elements. One of these important pieces of information is the mass of one mole of the atoms in grams. This is known as the atomic mass.

Fig 4.5.3



From a mole point of view, one of the most important pieces of information is the atomic mass. The atomic mass of an element can be useful on two levels. It gives you an indication of the mass of individual atoms in a unit known as **atomic mass units** (one atomic mass unit is equal to $^1/_{12}$ the mass of a carbon-12 atom) and it also gives us the mass of one mole of the atoms. The terms **atomic weight** and **molar mass** are also used to describe the mass of one mole of atoms of an element.

When you know the molar mass of the chemical elements you can also determine the mass of one mole of any chemical compound. This is going to be important when you start working with chemical reactions, as you use the mole to compare and measure substances during chemical reactions.

The mass of one mole of a compound is called the **formula mass** or **molecular weight** of the compound. To work out the molar mass of a compound you will need your periodic table.

Work through the following type example.

Type example

What is the molar mass of carbon dioxide, CO_2?

1 Break the formula into its elements.

$$CO_2 = 1 \text{ atom of C} + 2 \text{ atoms of oxygen}$$

$$\therefore \begin{matrix}\text{1 mole}\\ CO_2\end{matrix} = \begin{matrix}\text{1 mole of}\\ \text{C atoms}\end{matrix} + \begin{matrix}\text{2 moles of}\\ \text{oxygen atoms}\end{matrix}$$

2 Work out the molar mass of the elements using your periodic table.

$$\begin{matrix}\text{1 mole of}\\ \text{C atoms}\end{matrix} + \begin{matrix}\text{2 moles of}\\ \text{oxygen atom}\end{matrix} = (1 \times 12.01 \text{ g}) + (2 \times 16.00 \text{ g})$$

3 Sum the totals for each of the elements.

$$= (1 \times 12.01 \text{ g}) + (2 \times 16.00 \text{ g})$$
$$= 44.01 \text{ grams per mole}$$

So the **molar mass** of carbon dioxide is 44.01 grams.

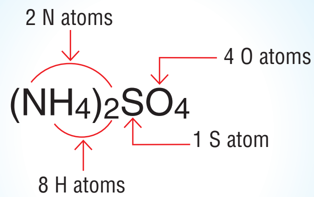
What is the molar mass of ammonium sulfate?

Write out the correct formula: $(NH_4)_2SO_4$

Break it down into its elements.

$2N + 8H + 1S + 4O$

Interactive CW Animation



Work out the molar mass of the component elements and then sum them for the **molar mass of the compound**.

$= (2 \times 14.01) + (8 \times 1.008) + (32.06) + (4 \times 16.00)$

$= 28.02 + 8.06 + 32.06 + 64.00$

$= 132.14$ grams per mole

Fig 4.5.4 Molar masses can be calculated for any compound by breaking the formula down into its element components and adding them.

Mass to moles and moles to mass

The mole is the 'currency of chemistry' because it allows us to compare substances. In chemistry, reactions are about *how many particles* react with another. That is what chemical equations are about—*the numbers of particles*. But different substances have different molar masses. This means that we cannot use masses as a direct measure of how many atoms there are of each.

Therefore, to make a proper comparison, it is necessary to convert masses of substances into the corresponding number of moles. We use the mole during chemical calculations to help us relate reactants to products. We also need to be able to change the number of moles of a substance into its corresponding mass in grams because it is mass that we can measure easily. Chemists use a balance to find the mass of substances for their reactions. They cannot count out individual atoms to react because they can't be seen. We need to know how many particles are in the masses we weigh.

Mass to moles

If you know the molar mass of a substance you can convert any mass of that substance into its number of moles using this relationship:

$$n = \frac{m}{M}$$

where:

- n is the number of moles of the substance (mol)
- m is the mass of the substance (g)
- M is the molar mass of substance (g per mol).

Note that we use symbols such as n, m and M to represent different quantities in chemistry. These are recognised short-cut symbols in chemistry and you should use them wherever possible. It is a good idea to use subscripts to indicate the substance you are talking about. For example, if you are working out how many moles of substance X you have, write this as n_X.

Consider a couple of type examples of converting mass into moles. Follow them through carefully while you are reading. You will find a calculator and a periodic table essential tools in your chemistry calculations.

Type example 1

Joshua buys a kilogram of table salt (NaCl). How many moles of salt does this contain?

$$n(NaCl) = ?$$

$$m = 1 \text{ kg } (1000 \text{ g})$$

$$M(NaCl) = 22.99 + 35.45$$

$$= 58.44 \text{ g per mol}$$

$$n(NaCl) = \frac{m}{M(NaCl)}$$

$$n(NaCl) = \frac{1000}{58.44}$$

$$= 17.11 \text{ moles}$$

There are 17.11 moles of NaCl in 1 kg of salt.

Type example 2

A laboratory technician dissolves 5.00 g of sulfuric acid (H_2SO_4) in 1 litre of water. How many moles of acid have been dissolved?

$$n(H_2SO_4) = ?$$

$$m(H_2SO_4) = 5.00 \text{ g}$$

$$M(H_2SO_4) = (2 \times 1.008) + (1 \times 32.06) + (4 \times 16.00)$$

$$= 98.08 \text{ grams per mole}$$

$$n(H_2SO_4) = \frac{m}{M}$$

$$= \frac{5.00}{98.08}$$

$$= 0.05$$

There are 0.05 moles of sulfuric acid dissolved in the water.

Moles to mass

While the mole is a great unit for chemists it is not a unit we can measure out easily! We can measure out mass, which is why we need to be able to convert moles into mass. We can do this by rearranging the formula above.

Fig 4.5.5 By converting moles into mass we can readily 'mass out' (measure out) the number of moles of any substance we wish. This photograph shows one mole of a range of chemical compounds.

Type example 1

Kate needs 0.25 moles of sucrose sugar ($C_6H_{12}O_6$) for a chemical reaction. How many grams will she need to mass out on the electronic balance?

$$m = ?$$
$$n(C_6H_{12}O_6) = 0.25$$
$$M(C_6H_{12}O_6) = (6 \times 12.01) + (12 \times 1.008) + (6 \times 16.00)$$
$$= 180.16$$
$$m = n \times M$$
$$= 0.25 \times 180.16 = 45.04\text{ g}$$

Kate will need to mass out 45.04 g of sucrose.

Type example 2

A technician is cleaning up an acid spill and calculates that he needs 2.5 moles of calcium hydroxide, $Ca(OH)_2$, to neutralise the acid. What mass of calcium hydroxide needs to be massed out?

$$m = ?$$
$$n(Ca(OH)_2) = 2.5$$
$$M(Ca(OH)_2) = (1 \times 40.08) + (2 \times 16.00) + (2 \times 1.008)$$
$$= 74.10$$
$$m = n \times M$$
$$= 2.5 \times 74.10$$
$$= 185.24\text{ g}$$

The technician will need to mass out 185.24 g of calcium hydroxide.

Chemical calculations from equations

With a knowledge of moles and the skills to convert masses into moles and back again you are ready to take the next step. A balanced chemical equation gives you information about how the atoms rearrange during the chemical change process. It also gives you information about the ratios between the number of particles of reactants and products. This allows you to make calculations and a prediction about the amounts of substances you need or produce during a chemical reaction. This is very important for controlling reactions and minimising costs in business and industry. You are going to explore several types of chemical calculations—moles-to-moles, moles-to-mass and mass-to-mass calculations

Moles-to-moles calculations

There are many levels of understanding of a chemical equation. Consider the production of water from its chemical elements shown in Figure 4.5.6.

The key to chemical calculations is found at the mole level. It gives you the **molar ratio** of reactants to products, which is the key to solving problems in chemistry.

In the production of water, the mole ratio of reactants to products is:

$$n(H_2) : n(O_2) : n(H_2O) = 2:1:2$$

Using this ratio, you can solve problems for *any* number of moles, providing you understand that the ratio of moles of reactants to moles of product stays the same.

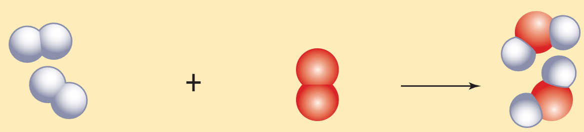
Word equation level	hydrogen gas + oxygen gas ⟶ water gas				
Chemical equation level	$2H_2\ (g) + O_2\ (g) \longrightarrow 2H_2O\ (g)$				
Atomic level	 2 hydrogen molecules	react with	oxygen molecule	to produce	2 water molecules
Multi-atomic level	2000 hydrogen molecules	react with	1000 oxygen molecules	to produce	2000 water molecules
Mole level	2 moles hydrogen molecules	react with	1 mole oxygen molecules	to produce	2 moles water molecules

Fig 4.5.6 Levels of understanding an equation for a reaction

Type example 1

Three moles of oxygen gas are burnt with hydrogen gas to produce water. How many moles of water are produced?

Write a balanced chemical equation.	$2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (g)$
Put the molar ratio under the reactants and products.	2 1 2
Put the information you have under the corresponding reactant or product. If you do not know the information, leave it blank and put an x (for unknown) under the reactant or product you wish to find out about.	3 x
Link the molar ratio with your new ratio—and remember, they have to be the same! You may be able to do this in your head, eg 1 $\rightarrow$ 2 so 3 $\rightarrow$ x so x must be 6. For more complex ratios you can create a ratio problem by putting your unknown line over the top of your known line.	$\frac{3}{1} = \frac{x}{2}$ $3 \times 2 = x$ $x = 6$
State your answer as a sentence.	6 moles of water are produced.

Type example 2

Ammonia can be produced by the reaction between nitrogen and hydrogen according to the equation:

$N_2\ (g) + 3H_2\ (g) \rightarrow 2NH_3\ (g)$

If you need 10 moles of ammonia, how many moles of hydrogen gas will be consumed?

Write a balanced chemical equation.	$N_2\ (g) + 3H_2\ (g) \rightarrow 2NH_3\ (g)$
Put the molar ratio under the reactants and products.	1 3 2
Put the information you have under the corresponding reactant or product. If you do not know the information, leave it blank and put an x (for unknown) under the reactant or product you wish to find out about.	x 10
Link the molar ratio with your new ratio—and remember, they have to be the same! eg 3 $\rightarrow$ 2 so 15 $\rightarrow$ 10 or Put your unknown line over the top of your known line.	$\frac{x}{3} = \frac{10}{2}$ $x = \frac{10}{2} \times 3$ $x = 15$
State your answer as a sentence.	15 moles of hydrogen gas are needed

Moles-to-mass calculations

In these types of calculations you are given information about the reaction in moles and you need to determine the answer as a mass. They are like a moles-to-moles calculation except that you have an additional step of converting the answer at the end into a mass. Always work in moles, as the reactant and product ratios only apply to moles. At the end of the problem you can convert your moles to the mass required.

Follow this next type example carefully.

Type example

Calculate the mass of sodium chloride produced when 1.5 moles of sodium hydroxide react with excess hydrochloric acid.

Write a balanced chemical equation.	$NaOH\ (aq) + HCl\ (aq) \rightarrow H_2O\ (l) + NaCl\ (aq)$
Put the molar ratio under the reactants and products.	1 1 1 1
Put the information you have under the corresponding reactant or product in moles. If you do not know the information, leave it blank and put an x (for unknown) under the reactant or product you wish to find out about.	1.5 x
Link the molar ratio with your new ratio—and remember, they have to be the same! eg 3 → 2 so 15 → 10 or Put your unknown line over the top of your known line.	$\frac{1.5}{1} = \frac{x}{1}$ $x = 1.5$
State your answer as a sentence.	1.5 moles of sodium chloride are produced.
Convert the number of moles into a mass of sodium chloride using the formula $m = n \times M$. You will need to work out the molar mass for the substance.	$M(NaCl) = 22.99 + 35.45 = 58.44$ g per mol $m(NaCl) = n \times M$ $= 1.5 \times 58.44$ $= 87.66$ g 87.66 g of sodium chloride are produced.

Mass-to-moles calculations

In this type of calculation you are given some information about the reaction as a mass and you need an answer in moles. Since the mole is the currency of chemistry, you must change your mass into moles.

If you always remember to **work in moles**, you will find that chemical calculations are a lot simpler. Work through this type example, noting the first step of converting the mass into moles.

Type example

How many moles of hydrogen gas are produced when 20 g of zinc is reacted with hydrochloric acid?

If you are given information as mass, change it to moles using the formula $n = \frac{m}{M}$ If you are dealing with a compound you will also have to work out the molar mass (M) for the substance.	$n(Zn) = \frac{m}{M}$ $= \frac{20}{65.38}$ $= 0.30$ moles
Write a balanced chemical equation.	$Zn\ (s) + 2HCl\ (aq) \rightarrow ZnCl_2\ (aq) + H_2\ (g)$
Put the molar ratio under the reactants and products.	1 2 1 1
Put the information you have under the corresponding reactant or product in moles. If you do not know the information, leave it blank and put an x (for unknown) under the reactant or product you wish to find out about.	0.3 x
Link the molar ratio with your new ratio—and remember, they have to be the same! eg 3 → 2 so 15 → 10 or Put your unknown line over the top of your known line.	$\frac{0.3}{1} = \frac{x}{1}$ $x = 0.3$
State your answer as a sentence.	0.3 moles of hydrogen gas are produced.

Mass-to-mass calculations

In this final type of calculation all of the information we are given and need to calculate is given as masses. Solving the problem is identical to the problem you have just read but with one final step of converting moles into mass at the end. Follow the type example carefully.

Type example

What mass of water is produced when 4.9 g of sulfuric acid reacts with sodium hydroxide?

If you are given information as mass, change it to moles using the formula $n = \frac{m}{n}$ If you are dealing with a compound you will also have to work out the molar mass (M) for the substance.	$M(H_2SO_4) = (2 \times 1.008) + (32.06) + (4 \times 16.00)$ $= 98.08$ $n(H_2SO_4) = \frac{m}{M}$ $= \frac{4.9}{98}$ $= 0.30$ moles
Write a balanced chemical equation.	$H_2SO_4\ (aq) + 2NaOH\ (aq) \longrightarrow Na_2SO_4\ (aq) + 2H_2O\ (l)$
Put the molar ratio under the reactants and products.	1 2 1 2
Put the information you have under the corresponding reactant or product in moles. If you do not know the information, leave it blank and put an x (for unknown) under the reactant or product you wish to find out about.	0.3 x
Link the molar ratio with your new ratio—and remember, they have to be the same! eg 3 ⟶ 2 so 15 ⟶ 10 or Put your unknown line over the top of your known line.	$\frac{0.3}{1} = \frac{x}{2}$ $x = 0.6$
Convert your answer into a mass by finding the molar mass (M) and then using the relationship.	$M(H_2O) = (2 \times 1.008) + 16.00$ $= 18.02$ $m = n \times M$ $m = 10.81$ g
State your answer as a sentence.	10.81 g of water are produced.

Homework book 4.10 The big 'M'—mastering the 'mole'

Prac 1 p. 185

4•5 FOCUS [Questions]

Use your book

The mole—just how big is it?

1 Apart from the mole, describe at least three other units that are used to describe groups of objects.

2 How many atoms of iron are there in a 'mole of iron atoms'?

3 Describe the standard by which the mole is measured.

Molar mass

4 Define what is meant by the 'molar mass' of a substance.

5 Oxygen has a molar mass of 16.00 grams per mole. What does this mean?

Mass to moles and moles to mass

6 What do you understand by the statement 'The mole is the currency of chemistry'?

7 The formula that is used to convert any mass of a pure substance into its corresponding number of moles is shown below. Explain what each of the variables (n, m and M) in the equation means.

$$n = \frac{m}{M}$$

>>

8 Explain how the formula above can be rearranged to give you a formula to find the mass of a substance if you are given the number of moles of it.

Chemical calculations from equations

9 Nitrogen gas from the atmosphere can react with hydrogen gas to produce ammonia gas (a very important gas in the production of fertilisers). The equation can be represented as:

N_2 (g) + $3H_2$ (g) $\rightarrow$ $2NH_3$ (g)

Summarise the information that this equation gives you at an atomic level and a molar level.

10 Explain why it is important to always work in moles when comparing ratios of reactants and products.

Use your head

11 Calculate the molar mass of the following substances:

- **a** iron (Fe)
- **b** hydrogen gas (H_2)
- **c** methane gas (CH_4)
- **d** calcium carbonate ($CaCO_3$)
- **e** sodium phosphate (Na_3PO_4)
- **f** aluminium sulfate ($Al_2(SO_4)_3$).

12 Calculate the number of moles in the following masses:

- **a** 4 g of hydrogen gas (H_2)
- **b** 80 g of sodium hydroxide (NaOH)
- **c** 73 g of hydrogen chloride (HCl)
- **d** 32 g of sulfur dioxide (SO_2)
- **e** 10.6 g of sodium carbonate (Na_2CO_3)
- **f** 0.115 g of sodium chloride (NaCl).

13 Calculate the mass in grams of the following:

- **a** 3 moles of water
- **b** 7.5 moles of lime (CaO)
- **c** 0.5 moles of silver chloride (AgCl)
- **d** 0.04 moles of sodium hydrogen carbonate ($NaHCO_3$).

14 Moles-to-moles calculations—show all working out in full:

a Sodium reacts with water according to the following equation:

$2Na$ (s) + H_2O (l) $\rightarrow$ $2NaOH$ (aq) + H_2 (g)

If 0.4 moles of sodium are reacted, how many moles of sodium hydroxide are produced?

b If, in the reaction above, 0.6 moles of hydrogen gas were produced, how many moles of sodium would have been reacted?

c Magnesium burns brightly in air according to the following equation:

$2Mg$ (s) + O_2 (g) $\rightarrow$ $2MgO$ (s)

How many moles of oxygen gas are required to produce 2.5 moles of magnesium oxide?

d Sodium carbonate reacts with hydrochloric acid according to this equation:

Na_2CO_3 (s) + $2HCl$ (aq) $\rightarrow$ $2NaCl$ (aq) + H_2O (l) + CO_2 (g)

Calculate the number of moles of sodium chloride produced when 0.6 moles of sodium carbonate are reacted with hydrochloric acid.

e Oxygen can be produced when hydrogen peroxide decomposes. The equation for this process is:

$2H_2O_2$ (l) $\rightarrow$ $2H_2O$ + O_2 (g)

If a solution containing 0.6 moles of hydrogen peroxide is decomposed, how many moles of oxygen gas are produced?

15 Moles-to-mass calculations—show all working in full:

a Hydrogen gas burns in oxygen according to the following equation:

$2H_2$ (g) + O_2 (g) $\rightarrow$ $2H_2O$ (l)

What mass of water is produced if one mole of oxygen is burnt in hydrogen?

b When sodium chloride solution is added to silver nitrate solution, a precipitate of silver chloride is produced. The reaction can be shown as:

NaCl (aq) + $AgNO_3$ (aq) $\rightarrow$ AgCl (s) + $NaNO_3$ (aq)

What mass of silver chloride is produced when 0.25 moles of sodium chloride reacts with silver nitrate solution?

c David lights the barbecue, which burns propane gas according to the following equation:

C_3H_8 (g) + $5O_2$ (g) $\rightarrow$ $3CO_2$ (g) + $4H_2O$ (g)

What mass of carbon dioxide is released into the atmosphere if the barbecue burns 1.5 moles of propane gas?

16 Mass-to-mole calculations—show all working in full:

a A teacher is producing hydrogen gas for a class demonstration by reacting zinc metal with hydrochloric acid. The equation for this reaction is:

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

How many moles of hydrogen gas are produced if the teacher uses 50 g of zinc metal in the reaction?

b Calculate the number of moles of carbon dioxide produced when 5.6 g of calcium carbonate is reacted with hydrochloric acid. The equation is:

$CaCO_3$ (s) + $2HCl$ (aq) $\rightarrow$ $CaCl_2$ (aq) + CO_2 (g) + H_2O (l)

c Ammonium sulfate is an important fertiliser that can be produced according to this equation:

$2NH_3$ (g) + H_2SO_4 (aq) $\rightarrow$ $(NH_4)_2SO_4$

>>

How many moles of sulfuric acid are required to produce 1 kg of ammonium sulfate?

17 Mass-to-mass calculations—show all working in full:

a Sulfur dioxide gas is produced as the first part of the production of sulfuric acid. The equation for this is:

$S\ (s) + O_2\ (g) \rightarrow SO_2\ (g)$

What mass of sulfur dioxide gas is produced when 48 g of sulfur is burnt in oxygen?

b Sulfur dioxide gas is burnt in oxygen to produce sulfur trioxide. The equation for this process is:

$2SO_2\ (g) + O_2\ (g) \rightarrow 2SO_3\ (g)$

How many grams of oxygen gas would be needed to react with 96 g of sulfur dioxide gas?

c Silver is produced when copper metal is placed in silver nitrate according to this equation:

$Cu\ (s) + 2AgNO_3\ (aq) \rightarrow Cu\ (NO_3)_2\ (aq) + 2Ag\ (s)$

How many grams of silver would be produced if 15 g of copper was completely consumed in a reaction with silver nitrate?

Investigating questions

18 Who discovered the mole? Research the discovery and development of the mole. Your research should cover individuals such as Amadeo Avogadro and William Ostwald. Also find out when 'International mole day' is celebrated. Why is it celebrated on this day? Why at this time?

19 Find out the current population of the world and express this in exponential notation (eg 1 million = 1.00×10^6). Is there a 'mole of people' living on our planet? If not, what fraction of a mole lives on this planet?

4•5 FOCUS [Practical activity]

Prac 1 Focus 4.5

Determining a mole ratio

Purpose

To explore a simple chemical reaction and to discover the ratio between the moles of reactants and products.

This practical will enable you to determine the molar ratio between the reactants and products in the following chemical reaction, known as a displacement reaction. The reaction you will study can be written as:

$Zn\ (s) + Cu\ (NO_3)_2\ (aq) \rightarrow Zn\ (NO_3)_2\ (aq) + Cu\ (s)$

The nitrate ions are not directly involved in the reaction so they can be removed to give us this overall (net) reaction. The molar ratio is also indicated under the reaction.

$$\underset{\text{1 mole}}{Zn\ (s)} + \underset{\text{1 mole}}{Cu^{2+}\ (aq)} \rightarrow \underset{\text{1 mole}}{Zn^{2+}\ (aq)} + \underset{\text{1 mole}}{Cu\ (s)}$$

As this reaction proceeds the zinc metal forms zinc ions. The zinc loses mass equivalent to the mass of zinc ions that are formed. The copper ions form copper metal (on the zinc).

SAFETY NOTE: Handle all chemicals carefully and wash your hands at the end of the investigation. All waste solutions should be disposed of in an environmentally friendly way. Collect the salts and return them to the laboratory assistant for disposal.

Requirements

Zinc strip about 8 cm long by 1.5 cm wide, steel wool (for cleaning zinc), electronic balance (most accurate one you have available), 50 mL or 100 mL beaker, copper nitrate solution (0.1 M), tweezers, distilled water, acetone (in squirt bottle), filter paper, popstick.

Procedure

1. Polish two pieces of zinc with the steel wool until they are as shiny as possible.
2. Find the mass of the two zinc pieces as accurately as you can. Use the most accurate setting on your electronic balance.
3. Stand the two pieces of zinc into a beaker and add 40 mL or 80 mL of the copper (II) nitrate, depending on your beaker size.
4. Leave the beaker to stand for about 30 minutes. Keep it as still as possible.
5. Carefully lift the zinc strip with copper metal crystals from the beaker with the tweezers and transfer it into another beaker filled with distilled water. Take great care not to dislodge any of the copper metal from the strip. Let it stand in the water for a minute. (If a large amount of copper is dislodged you could find the mass of a piece of filter paper, filter the solution and dry the filter paper in an oven for a few hours, then find the mass again.)
6. Lift the zinc strip out of the water and carefully place it in an empty beaker again, taking care not to dislodge any of the copper metal.

>>

7 Carefully rinse the zinc strip with acetone (without dislodging any copper) and let the strip and copper dry for about 5 to 10 minutes.

8 Find the mass of a piece of filter paper and record this in a table. *You could copy the following table into your notes. Put your initials on the filter paper so you can identify it in a group.*

Step	Item	Mass (g)
a	Initial mass of zinc strip	
b	Initial mass of clean filter paper	
c	Final mass of zinc strip after scraping and drying	
d	Final mass of filter paper with copper	
e	Mass of zinc lost from the zinc strip (steps a–c)	
f	Mass of copper produced (step d)	

9 Carefully scrape off as much of the copper as you can from the piece of zinc onto the filter paper using a clean popstick. Wipe the strip and the pop stick on the clean piece of filter paper to remove as much of the copper as possible.

10 Dry both the filter paper (with the copper on it) and the zinc strip in a drying oven for a few minutes.

11 Find the mass of both the filter paper and the zinc strip and *record these in the table in your notes.*

12 *Calculate the mass of the zinc lost from the zinc strips* (step e in the table).

13 *Calculate the mass of the copper produced* (step f in the table).

Questions

1 Determine the number of moles of copper produced and the number of moles of zinc lost. Use the following atomic weights for copper and zinc:

M(Cu) = 63.55 grams per mole

M(Zn) = 65.36 grams per mole

$$\text{n(Cu) produced} = \frac{\text{mass of copper produced}}{63.55} = \_\_ \text{ mole}$$

$$\text{n(Zn) lost} = \frac{\text{mass of zinc lost}}{65.36} = \_\_ \text{ mole}$$

2 Refer to the chemical equation and molar ratio for this reaction:

$$\underset{\text{1 mole}}{Zn\ (s)} + \underset{\text{1 mole}}{Cu^{2+}\ (aq)} \rightarrow \underset{\text{1 mole}}{Zn^{2+}\ (aq)} + \underset{\text{1 mole}}{Cu\ (s)}$$

Compare the number of moles of zinc lost (which is the zinc ions produced) to the moles of copper produced.

a **From the equation,** what is the following ratio?
$n(Zn^{2+}) : n(Cu)$

b What is the **actual ratio from your results?**
$n(Zn^{2+}) : n(Cu)$

3 Compare the two ratios from question 2. Given that they should be the same, write a paragraph comparing the two. Discuss this with other groups and compare your results.

FOCUS 4·6 Empirical formulas

Context

Both household consumers and industry require information about the chemicals they are using. A mother-to-be may wish to know the percentage of iron in her vitamin supplement to help her developing baby.

A mining company geologist may wish to compare two different ores of iron to see which has the higher percentage of iron. A green-keeper may want to compare two different fertilisers to see which contains the greater percentage of nitrogen.

You are now well equipped to explore the important areas in chemistry of percentage composition and empirical formulas, which are powerful tools for the consumer and chemist.

Percentage composition

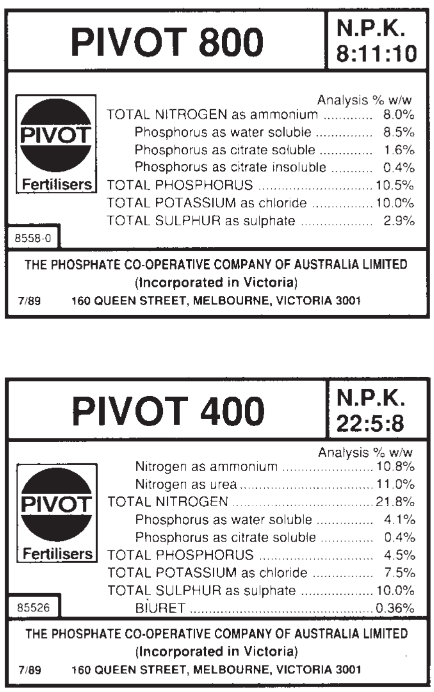


Fig 4.6.1 A knowledge of percentage composition allows you to compare different substances such as fertilisers. Which one of these fertilisers contains the most nitrogen?

The **percentage composition** of a substance gives you a breakdown of the percentage by mass of each of the elements in a substance. An example is tin fluoride, SnF_2, which is found in toothpaste. You can work out the percentage composition of tin fluoride by using your understanding of molar mass, as covered in Focus 4.5. Work through the following calculation of the percentage composition of each element—tin and fluorine. The calculation has been broken down into steps in this example. Have your periodic table on hand to provide you with atomic masses for any element as required.

Note that the general formula that allows you to work out the percentage composition of any element (E) in a substance is:

% of element (E) in a substance containing E

$$= \frac{\text{mass of E in compound}}{\text{molar mass of compound}} \times 100$$

1 Determine the molar mass of the substance.

$$M\,(SnF_2) = 118.7 + (2 \times 19.00)$$
$$= 156.7 \text{ grams per mole}$$

2 Determine the percentage by mass that each of the component elements contributes towards the molar mass.

$$\%\text{ mass Sn} = \frac{118.7}{156.7} \times 100 = 75.7\%$$

$$\%\text{ mass F} = \frac{(2 \times 19.00)}{156.7} \times 100 = 24.3\%$$

For substances that contain more than two elements, you repeat this part of the calculation for each different type of element.

Percentage compositions allow you to make comparisons with other substances. For example, another common source of fluoride in toothpaste is sodium fluoride (NaF). How does this compare with tin fluoride as a source of fluoride? Work through the calculation below for yourself.

Percentage composition of sodium fluoride

$$M(NaF) = 22.99 + 19.00 = 41.99 \text{ g per mole}$$

$$\% \text{ mass Na} = \frac{22.99}{41.99} \times 100 = 54.8\%$$

$$\% \text{ mass F} = \frac{19.00}{41.99} \times 100 = 45.2\%$$

As shown in Figure 4.6.2, it is often useful to show percentage compositions graphically so that quick comparisons of key elements can be made.

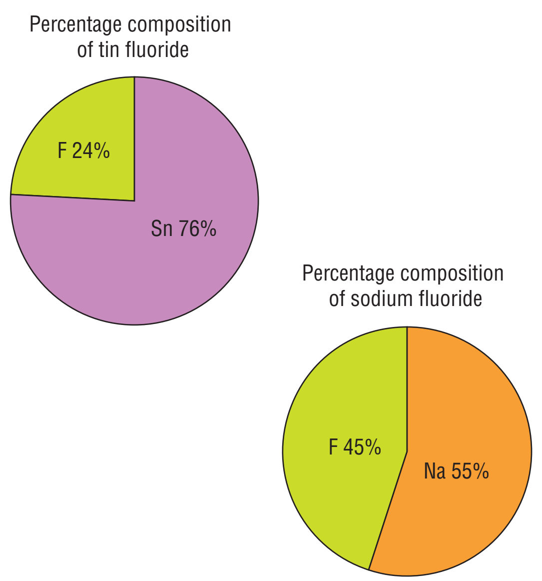


Fig 4.6.2 Percentage compositions are often shown as pie graphs to allow us to quickly compare the composition of substances.

When you are determining the percentage composition of more complex examples, take care to look carefully at the formula to make sure that you include the total mass of all the particular elements in your calculations. Work through the type example, which shows you how to determine the percentage composition by mass of the elements in ethanoic acid (CH_3COOH).

Type example

What is the percentage composition by mass of ethanoic acid?

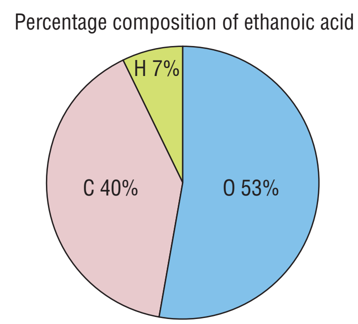
One mole of CH_3COOH contains two moles of C atoms, four moles of H atoms, two moles of O atoms.

$$M(CH_3COOH) = (2 \times 12.01) + (4 \times 1.008) + (2 \times 16.00)$$
$$= 60.05 \text{ grams per mole}$$

$$\% \text{ mass of C} = \frac{(2 \times 12.01)}{60.05} \times 100 = 40.0\%$$

$$\% \text{ mass of H} = \frac{(4 \times 1.008)}{60.05} \times 100 = 6.7\%$$

$$\% \text{ mass of O} = \frac{(2 \times 16.00)}{60.05} \times 100 = 53.3\%$$



Percentage composition of ethanoic acid *Fig 4.6.3*

Percentage composition and mining

In all the percentage composition problems to this point you have made the assumption that the substance is pure. This is often not the case in many situations, for example in mining, where the ore contains a lot of impurities, generally sand and other silicates. In this case two percentage compositions are often referred to.

The first is the standard percentage composition of the pure material, which you have just done.

The second is the percentage of the key metal in an ore, including the impurities. This figure is often very important for helping mining companies make decisions about whether mining a particular ore body is economically viable.

Work carefully through the following type example, which shows both of these percentage composition calculations.

Type example

At a particular copper mine the ore chalcopyrite, $CuFeS_2$, is estimated to be about 10 per cent of the ore body. The remainder of the ore body is silicates and other wastes. Determine:

a the percentage of copper in the chalcopyrite

b the percentage of copper in the ore body.

Percentage of copper in the chalcopyrite:

$$M(CuFeS_2) = M(Cu) + M(Fe) + (2 \times M(s))$$
$$= 63.55 + 55.85 + (2 \times 32.06)$$
$$= 183.52 \text{ grams per mole}$$

$$\% \text{ Cu} = \frac{63.55}{183.52} \times 100$$
$$= 34.63\%$$

Percentage of copper in the ore body:

If 10% of the ore body contains chalcopyrite, 34.63% of this 10% is copper.

$$\% \text{ Cu (ore body)} = \frac{34.63}{100} \times 10.0$$
$$= 3.46\% \text{ of Cu}$$

Fig 4.6.4 In the mining industry, both the percentage composition of the pure ore and the percentage composition of the key metal (copper) in the whole ore body (including the impurities) is an important consideration before mining commences.

In mining, the percentage of the key metal in the ore body can be increased by concentrating the ore. This is done using a variety of techniques, such as crushing and flotation. The concentrated ore is then treated to remove the metal.

Homework book 4.11 Pee-centage composition!

Water of crystallisation

Water molecules are often found associated with the ionic lattice in many ionic compounds. This water is known as the **water of crystallisation** and needs to be included in calculations involving molar masses and percentage composition. Ionic compounds containing water of crystallisation are said to be **hydrated**. This water of crystallisation can only be removed if the ionic substance is heated strongly to produce the **anhydrous** or dry ionic compound. The number of water molecules associated with a formula unit of the ionic substance is given in the name of the compound and is given at the end of the formula. For example, sodium carbonate – 10 – water has the formula $Na_2CO_3.10H_2O$.

In calculations involving percentage composition and water of crystallisation it is often helpful to consider the water as a unit with a molar mass of 18.02 grams per mole (ie $H_2O = (2 \times 1.008) \times 16.00 = 18.02$). Work through the type example below for yourself.

Type example

Determine the percentage by mass of water of crystallisation in copper (II) sulfate – 5 – water, $CuSO_4.5H_2O$.

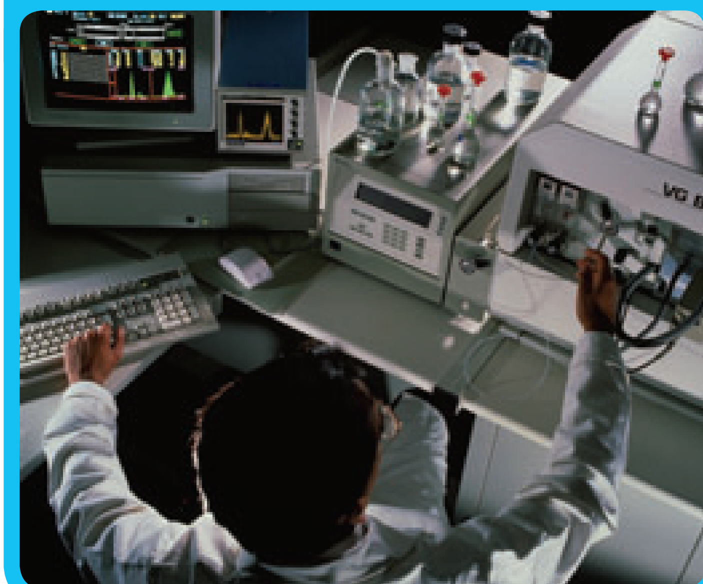
$$M(CuSO_4.5H_2O) = 63.55 + 32.06 + (4 \times 16.00) + (5 \times 18.02)$$
$$= 249.71 \text{ grams per mole}$$

$$\% \text{ H}_2\text{O} = \frac{(5 \times 18.02)}{249.71} \times 100$$
$$= 36.08\%$$

Empirical formula

Many chemists are employed to analyse chemical compounds to determine both **qualitative** and **quantitative** information. These types of chemists are often called **analytical chemists**, as their main

Fig 4.6.5 Analytical chemists use instruments such as this mass spectrometer to determine a range of qualitative and quantitative information.



role involves analysing substances to determine their identity and composition. Qualitative information refers to information such as the type of element found within the substance under investigation, while quantitative information refers to numerical data such as the percentage composition of the substance being investigated. Percentage compositions can be determined only by experimentation.

After a chemist has determined the percentage composition of a substance, they are often required to determine the chemical formula for the substance. This may be to determine the formula of a new unknown substance or to confirm the presence of an existing substance. To determine the chemical formula of a substance, the first step is to determine its **empirical formula**. The empirical formula of a substance is the simplest whole number ratio of atoms (or ions) in a substance and can be determined from the percentage composition. Once the chemist has determined the empirical formula of a substance they require further data, such as the molar mass, to determine the molecular formula. In the following table the empirical and molecular formulas for a number of common compounds are compared. Note that in some cases the empirical and molecular formulas for a substance are the same, while in other cases the molecular formula is a whole-number multiple of the empirical formula.

Name of molecule	Empirical formula (simplest whole number ratio of atoms in the compound)	Molecular formula (actual number of atoms in the compound)
Water	H_2O	H_2O
Hydrogen peroxide	HO	H_2O_2
Methane	CH_4	CH_4
Methyl acrylate	C_2H_3O	$C_4H_6O_2$

Science Snippet

The human 'formula'

If a human body was broken down into single atoms and you wrote the ratio between them as if it were an empirical formula, you would write approximately $H_{15750}N_{310}O_{6500}C_{2250}Ca_{63}P_{48}K_{15}S_{15}Na_{10}Cl_6Mg_3Fe_1$. (This is, of course, not a true empirical formula.) We are carbon-based animals and water is the solvent for most of our biochemical reactions. Alien life might not be carbon- and water-based. The most likely alternative for carbon would be silicon and the most likely alternative for water would be ammonia (NH_3) so the 'formula' for an alien could look very different from ours!

Determining the empirical formula of a substance

You can work out the empirical formula of a substance if you have its percentage composition. Work through type example 1, which shows the major steps and setting out for determining the empirical formula.

To determine the molecular formula from the empirical formula you need to be provided with the molar mass of the substance. Consider type example 1. If you are given the molar mass as being 34.02 grams per mole, what is the molecular formula for the compound?

Empirical formula = HO

Empirical mass (work out as determining for molar mass)
= 1.008 + 16.00

= 17.01

Molar mass = 34.02

Compare the ratio of the molar mass to the empirical mass =

$$\frac{34.02}{17.01} = 2$$

To work out the molecular formula, multiply the empirical formula by this ratio:
$= 2 \times HO = H_2O_2$.

Science Snippet

The tools of a forensic scientist

The forensic scientist is important in solving crimes. Typically they have to deal with a range of materials from crime scenes, including paints, plastic, fibres, glass, soil, legal and illicit drugs, cosmetics and firearms residue. There are many instruments used to identify chemicals, including scanning electron microscopes, infrared spectroscopes, gas chromatographs, mass spectrometers, thin layer chromatograms and X-ray diffractors. And where and when did these highly trained scientists commence their training? The same place you did—Science lessons!

Type example 1

An analytical chemist is trying to identify an unknown transparent liquid. She has determined its percentage composition to be 5.92 per cent hydrogen and 94.08 per cent oxygen.

Empirical formula calculation—major steps and setting out			**Explanatory notes**
Elements	H	O	Spread out the names of the elements in the substance and put all of the working out for that element underneath.
Mass in 100 g	5.92 g	94.08 g	100 g is used because then the mass in 100 g is the same as the percentage composition for each of the elements.
Moles of each element	$\frac{5.92}{1.008} = 5.87$	$\frac{94.08}{16.00} = 5.88$	Convert this mass into a number of moles using the relationship: $\frac{m}{M} = n$
Simplest ratio	$\frac{5.87}{5.87}$ 1	$\frac{5.88}{5.87}$ 1	Divide through by the smallest number of moles.
Empirical formula = HO			This is the simplest whole-number ratio of the atoms in the compound —this is the empirical formula.

Type example 2

Chemical analysis of a white sugar-like substance indicates its percentage composition to be 40.0 per cent carbon, 6.6 per cent hydrogen and 53.3 per cent oxygen. Its molar mass is found to be 180.16 g. What are its empirical and molecular formulas?

Empirical formula calculation—major steps and setting out				**Explanatory notes**
Elements	C	H	O	Spread out the names of the elements in the substance and put all of the working out for that element underneath.
Mass in 100 g	40.0	6.6	53.3	
Moles of each element	$\frac{40.0}{12.01} = 3.33$	$\frac{6.6}{1.008} = 6.55$	$\frac{53.3}{16.00} = 3.33$	Convert this mass into a number of moles using the relationship: $\frac{m}{M} = n$
Simplest ratio	$\frac{3.33}{3.33}$ 1	$\frac{6.55}{3.33}$ 1.97	$\frac{3.33}{3.33}$ 1	Divide through by the smallest number of moles.
Empirical formula = CH_2O				This is the simplest whole-number ratio of the atoms in the compound—this is the empirical formula. It is not unusual to have to round up or down a little.
Empirical mass = 12.01 + (2 × 1.008) + 16.00 = 30.03 grams per mole Molar mass = 180.16				Work out the empirical mass in the same way as you would work out the molar mass of a substance.
Ratio of molar mass to empirical mass = $\frac{180.16}{30.03} = 6$ Molecular formula = 6 × empirical formula = 6 × CH_2O = $C_6H_{12}O_6$				The ratio of the molar mass to the empirical mass is used to work out the molecular formula. Multiply this ratio by the empirical formula to give you the molecular formula.

Type example 3

The police send an analytical chemist a white powder that was found at a crime site. Qualitative analysis shows it to be a hydrocarbon (containing only carbon and hydrogen). Quantitative analysis gives the percentage composition as 93.7 per cent carbon and 6.3 per cent hydrogen and determines that it has a molar mass of 128.16 grams per mole.

Empirical formula calculation—major steps and setting out			**Explanatory notes**
Elements	**C**	**H**	Spread out the names of the elements in the substance and put all of the working out for that element underneath.
Mass in 100 g	93.7 g	6.3 g	
Moles of each element	$\frac{93.7}{12.01} = 7.80$	$\frac{6.3}{1.008} = 6.25$	Convert this mass into a number of moles using the relationship: $\frac{m}{M} = n$
Simplest ratio	$\frac{7.80}{6.25}$ 1.25	$\frac{6.25}{6.25}$ 1	Divide through by the smallest number of moles.
Simplest whole number ratio	$4 \times 1.25 = 5$	$4 \times 1 = 4$	The simplest whole number ratio in this case needs to be multiplied by 4 so that it is a whole number (integer). Multiples of one-third and one-half are also possible.
Empirical formula = C_5H_4			
Empirical formula mass = 64.08 grams per mole			Work out the empirical mass in the same way as you would work out the molar mass of a substance.
Molar mass = 128.16 grams per mole			
Ratio of molar mass to empirical mass = $\frac{128.16}{64.08} = 2$			The ratio of the molar mass to the empirical mass is used to work out the molecular formula. Multiply this ratio by the empirical formula to give you the molecular formula.
Molecular formula = 2 × empirical formula = $2 \times C_5H_4$ = $C_{10}H_8$			

Note: Chemists have a number of ways of working out further information about the structure of substances. In type example 3, the material was found at a crime scene. Instruments including mass spectrometers are used to determine the structure of the molecule. In this case, for example, spectral analysis might reveal that the substance is naphthalene, the main constituent of 'moth balls', which are used to repel cloth eating insects (see Figure 4.6.6).

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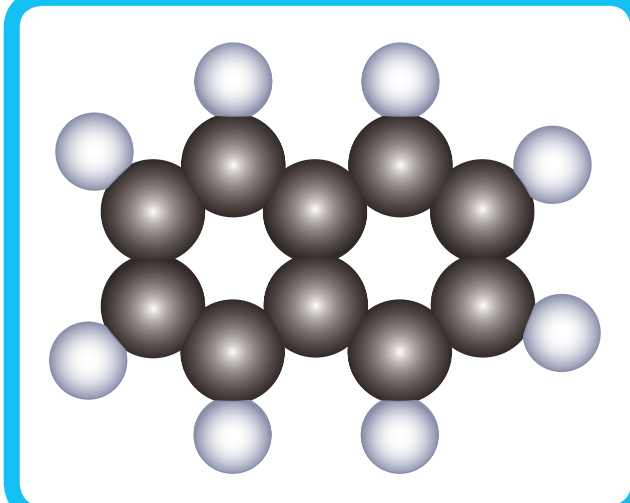
This is naphthalene, $C_{10}H_8$. Analytical chemists use a variety of instruments, such as spectrometers, to determine the actual molecular structure of the unknown substance.

Fig 4.6.6



4·6 [Questions]

Use your book

Percentage composition

1 Describe what is meant by 'percentage composition' of a substance.

2 Demonstrate how to determine the percentage composition of a substance by setting out a type example that shows the percentage composition of sodium chloride (NaCl).

3 Explain the two different types of percentage composition that a company mining iron ore would calculate.

4 What is meant by the 'water of crystallisation' of a hydrated ionic compound? Does it need to be considered when working out the molar mass of the ionic compound?

Empirical formula

5 Define the term 'empirical formula' and use an example to clarify your definition.

6 Benzene has a molecular formula of C_6H_6.
- **a** What is the empirical formula for benzene?
- **b** What is the empirical formula mass for benzene?
- **c** What is the molar mass for benzene?
- **d** What is the ratio of the molar mass to the empirical formula mass for benzene?
- **e** Explain why the ratio of molar mass to the empirical formula mass for a substance is always going to be a whole number.

Use your head

7 Explain why it would be important to know the percentage composition of ore samples in the mineral processing industry.

8 Find the percentage by mass of:
- **a** sulfur in sulfur trioxide (SO_3)
- **b** hydrogen in propane (C_3H_8)
- **c** oxygen in sulfuric acid (H_2SO_4).

9 Find the percentage by mass of each of the elements in the following compounds:
- **a** carbon dioxide (CO_2)
- **b** copper sulfate ($CuSO_4$)
- **c** calcium nitrate ($Ca(NO_3)_2$)
- **d** ammonium phosphate ($(NH_4)_3PO_4$).

10 At an iron ore site near Newman (Western Australia) the major source of iron is the ore hematite (Fe_2O_3). The purity of the ore at the ore body is calculated to be 90 per cent.
- **a** What is the percentage of iron in hematite?
- **b** What is the percentage of iron metal in the entire ore body?

11 Determine the percentage by mass of water in the following hydrated compounds:
- **a** calcium sulfate – 2 – water (calcium sulfate dihydrate)
- **b** magnesium sulfate – 7 – water (magnesium sulfate heptahydrate)
- **c** iron (III) chloride – 6 – water (iron (III) chloride hexahydrate).

12 Determine the percentage of nitrogen in each of the following fertilisers:
- **a** ammonium nitrate, NH_4NO_3
- **b** ammonium sulfate, $(NH_4)_2SO_4$
- **c** urea, CON_2H_4.

13 A substance is analysed and found to contain 27.3 per cent carbon and 72.7 per cent oxygen. What is the empirical formula for the compound?

14 Nicotine, a drug found in cigarettes, has an empirical formula of C_5H_7N. The molar mass is found to be 162 grams per mole. What is the molecular formula for nicotine?

15 A hydrocarbon found in an offshore gas deposit contains 16.3 per cent hydrogen by mass. Further analysis shows the hydrocarbon has a molar mass of 86. What is the molecular formula of the compound?

Investigating questions

16 All of the type examples used in this Focus were of 'percentage composition by mass'. What are some examples of the percentage composition of a substance being given as something other than mass?

17 Nitrogen is an essential element for plant growth. Ammonium nitrate (NH_4NO_3), ammonium sulfate ($(NH_4)_2SO_4$) and urea (CON_2H_4) can all be used as fertilisers, as they contain significant amounts of nitrogen. You have already determined the percentage composition of these substances (see question 11).
- **a** Based on these figures, which of the compounds is the best source of nitrogen?
- **b** What assumption are you making when you make this decision?
- **c** Research the topic of fertilisers to find out what other factors are important when comparing them.

FOCUS 4.6

[Practical activity]

Prac 1 Focus 4.6

Empirical formula of magnesium oxide

Purpose

To determine the empirical formula of the ionic compound, magnesium oxide.

Requirements

Electronic balance, crucible with lid, 2 × 10 cm strips of magnesium, steel wool or emery paper, clay triangle, Bunsen burner, tripod, metal tongs, matches.

SAFETY NOTE: Safety glasses are to be worn at all times. Take care when handling hot equipment.

Procedure

1. *Copy the table below into your notes.*
2. Determine the mass of the crucible and lid. Find all masses to two decimal places if possible. *Record these in your table.*
3. Clean your magnesium strip with steel wool or emery paper. Roll the magnesium up so that it forms a loose coil. Place it in the crucible and determine the mass of the magnesium, crucible and lid. *Record this in your table.*
4. Place the crucible on the clay triangle. Heat the crucible and magnesium with the lid on gently and then strongly. Using metal tongs, carefully lift the lid partly up (slowly so that you do not lose ash from the crucible) every minute or so to allow oxygen into the reaction chamber.
5. Continue heating until all the magnesium is ash. The contents are magnesium oxide.
6. Allow the crucible to cool and then find the mass of the crucible, lid and contents. *Record these in your table.*
7. Repeat and *record the Prac again or combine results from other groups in the class.*

Questions

1. Determine the empirical formula of the magnesium oxide for each trial by converting the masses of magnesium and oxygen to moles. Find the simplest whole-number ratio of magnesium to oxygen.
2. Given that the empirical formula of magnesium oxide is MgO, how does this compare with your empirical formula?
3. What are some possible sources of error (other than your mistakes) and how would they affect your results?

Trial	Mass of crucible and lid (A)	Mass of crucible, lid and magnesium (B)	Mass of magnesium (B – A)	Mass of crucible, lid and magnesium oxide (C)	Mass of magnesium oxide (C – A)	Mass of oxygen in magnesium = mass of magnesium oxide – mass of magnesium
1						
2						

FOCUS 4•7 Gases in chemical equations

Context

When gases are involved in chemical reactions, they behave differently from solids and liquids because they expand to fill any container. The volume filled by the gases before or after the reaction is affected by the temperature and the pressure at the time of the reaction. You can understand this by explaining it using the kinetic theory of matter.

You can calculate the volume of gas involved in reactions by using two important equations. You can then calculate the moles of gas using another important equation based on Avogadro's hypothesis.

Gases and the kinetic theory

The kinetic theory of matter proposes that all matter is made out of tiny particles, which are always moving. The model we use to represent a gas is that the particles are separated from each other by large distances and that they do not attract each other or repel each other. The speed of the particles depends on the temperature. At higher temperature, the particles are moving faster—that is, they have higher kinetic energy. Observations of gases suggest that the particles are moving freely in straight lines until they collide with other particles or the walls of the container. This model is extremely close to the real behaviour of all gases.

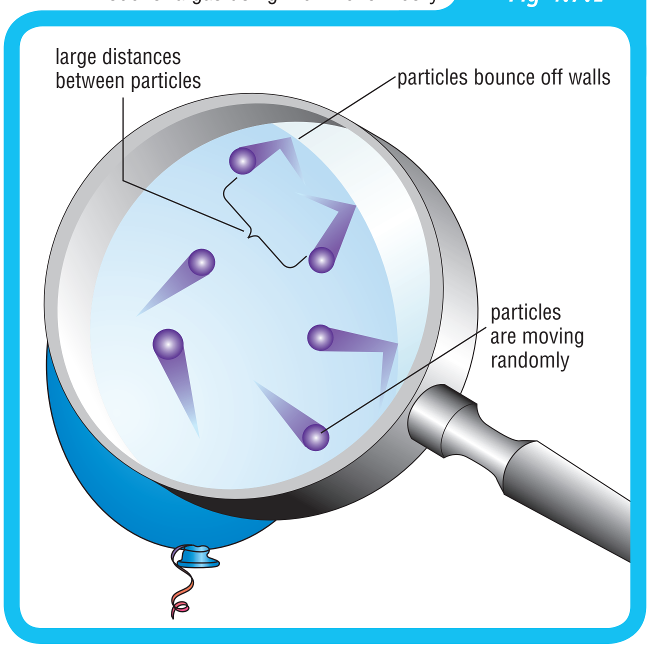
Interactive Animation | QuickTime Video

Gas pressure

Pressure is the force on the walls of a container per unit area. So you can imagine that each little bit of the container wall is being pushed outwards by the gas particles inside, which are hitting the walls. Pressure is measured in several different units, called kilopascals (kPa), millimetres of mercury (mm Hg) or atmospheres (atm). It is also measured in hectapascals (hP) by weather bureaus.

The pressure of Earth's atmosphere at sea level at a temperature of 0°C is about 101.3 kilopascals. This is also equal to 760 millimetres of mercury. These conditions are known as standard temperature and pressure, or STP. A mercury barometer, as shown in Figure 4.7.2, can help you to visualise this.

Model of a gas using the kinetic theory **Fig 4.7.1**



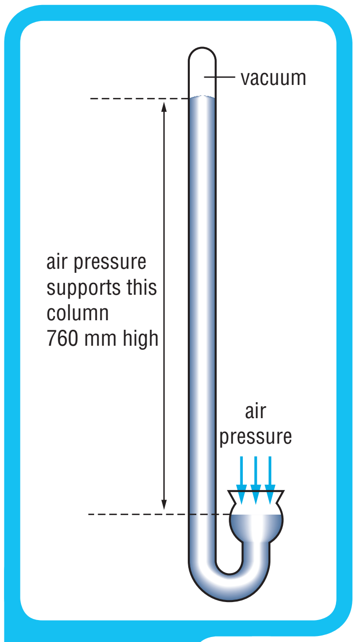


Fig 4.7.2 A mercury barometer measures the air pressure.

Science Snippet

The water barometer

Have you ever wondered why mercury is used in barometers? Mercury is about 13.5 times heavier than water. If water were used, the barometer would be about 10.3 metres high. This barometer would need a tall room to house it.

The vacuum at the top of the barometer means that it is the push of the atmosphere on the mercury in the mouth of the barometer that is supporting the column of mercury. This column is about 760 millimetres high, if the air temperature is 0°C. So the weight of the whole mercury column is being held up by the pressure of the gases in the atmosphere. The gas particles are pushing on the mercury surface in the mouth of the barometer.

Prac 1 p. 201

Gas pressure, volume and moles

The pressure of a gas depends on the number of particles hitting the walls of the container per second. Put another way, the number of moles of a gas in a container affects the pressure. A famous Italian scientist, Avogadro, studied this problem two centuries ago. He concluded that *all* gases behave the same way. There was no difference in the pressure of, say, oxygen or nitrogen, in a container if all the conditions were the same. The modern statement of his hypothesis is that equal volumes of any gas at the same temperature and pressure contain the same number of particles. So equal moles means equal pressure.

We have since discovered that there are very slight differences between different gases, but they are so small as to be unimportant for most purposes.

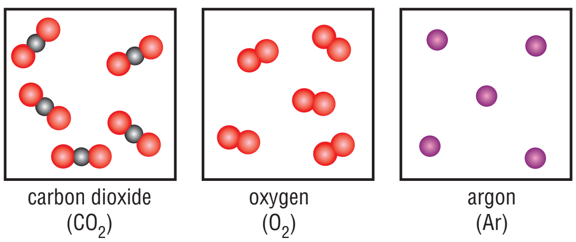
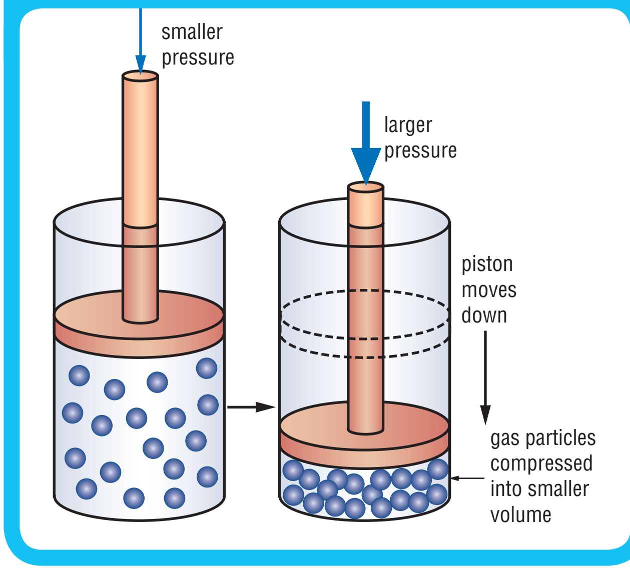


Fig 4.7.3 Equal volumes of different gases contain the same number of particles and therefore have the same pressure.

Gas volume and pressure

Imagine a certain amount of gas in a chamber where the piston can move in or out. This is shown in Figure 4.7.4. An example of a chamber like this would be a syringe. If you put a certain amount of gas in the chamber and then increase the pressure outside, what should happen to the piston? It will move inwards.

Fig 4.7.4 The volume of a gas changes as the outside pressure is changed.



If you keep the temperature constant, the amount by which you change the volume is inversely proportional to the change in the pressure. What this means is that if you increase the pressure, the gas volume will decrease. As an example, if you double the pressure, the volume halves. If you reduce the pressure to one-third the original pressure, the volume is three times larger. A graph of this relationship is shown in Figure 4.7.5.

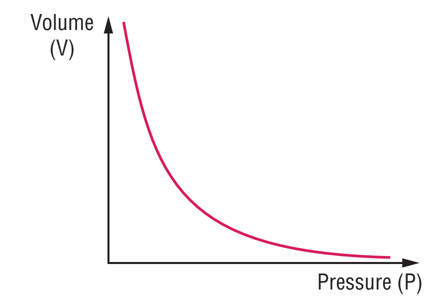
The relationship in the graph in Figure 4.7.5 can be represented by the equation:

$$P_1V_1 = P_2V_2$$

The P_1 and V_1 represent the pressure and volume before you change the pressure. P_2 and V_2 represent the pressure and volume after you have changed the pressure.

Interactive CW Animation

QuickTime CW Video



The relationship between pressure and volume for a gas *Fig 4.7.5*

As an example, consider a 5 litre chamber, like the chamber in Figure 4.7.4, which was filled with air and was at room temperature. The atmospheric pressure was 101.5 kilopascals. If the air pressure rose to 105 kilopascals, what would be the volume of air in the syringe?

$$P_1V_1 = P_2V_2$$

$$101.5 \times 5.00 = 105\ V_2$$

$$V_2 = \frac{101.5 \times 5.00}{105}$$

$$= 4.83\ \text{L}$$

Science Snippet

Escaping submarines

When a submarine sinks, the sailors who escape face a huge problem. The last breath of air in their lungs before they rise to the surface was filled at a very high pressure. As they rise rapidly up to the surface, the pressure drops rapidly. So if they don't breathe out as they rise, the air expands and bursts their lungs. This is a consequence of the pressure and volume law.

Gas volume and temperature

If you put some gas in a chamber such as the one in Figure 4.7.6, and then heat the gas, what do you think would happen to the piston? The piston will move outwards, pushed by the gas particles. This can be explained using the kinetic theory. The average speed of the particles is greater when the gas is heated. So there are more collisions with the piston per second, meaning that the pressure has risen. So the piston is pushed outwards harder than before.

The piston will move outwards until the pressure inside and the pressure outside are equal. The result of this is that the volume of the gas has increased. The gas particles are now filling a larger space.

If the gas in the container had been cooled, what would have happened? The gas particles would have moved more slowly and collided with the piston less often. So the inside pressure would have dropped below the outside pressure. The piston would have been pushed inwards.

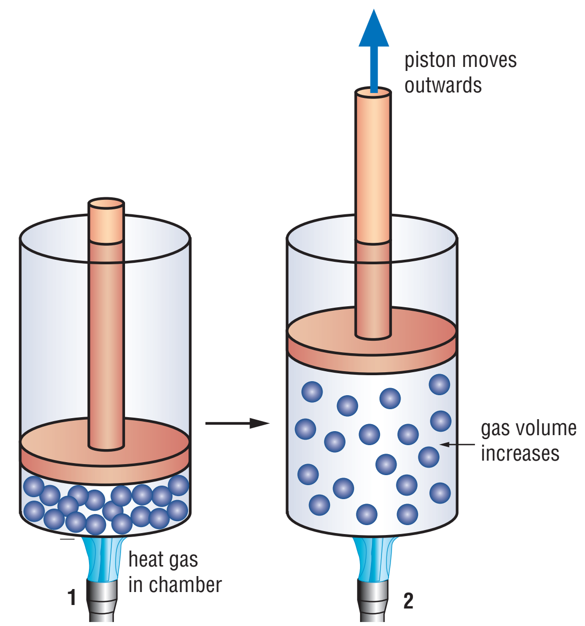
If the gas that is heated is in a sealed container, and cannot expand outwards, the increase in pressure may be enough to cause the container to burst. This is why an old spray can should not be thrown in a fire. The gas cannot escape and the can may explode.

You can calculate the amount by which the volume changes with temperature. However, the temperature scale that you use must be the Kelvin scale, or absolute temperature scale. This scale runs from –273°C upwards. This lower temperature is a theoretical lower limit for temperature. It is hypothesised that all atomic movement ceases at this temperature, and thus it is called absolute zero, 0 K. These ideas can be represented in the equation:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Changing the temperature of a gas results in a change in gas volume.

Fig 4.7.6



An example of what this means is that if the absolute temperature were doubled, the volume of the gas would also double. If you halve the temperature, the gas volume halves.

An example of a calculation is as follows:

If 5 litres of air at a temperature of 20°C is cooled to 0°C, what volume would it then occupy?

The first step is to change the temperature to Kelvin by adding 273 to the temperature in degrees Celsius. So 20°C is 273 + 20 = 293 K.

Interactive CW Animation

$$\frac{5.00}{293} = \frac{V_2}{273}$$

$$V_2 = \frac{5.00}{293} \times 273$$

$$= 4.66\ \text{L}$$

Interactive CW Animation

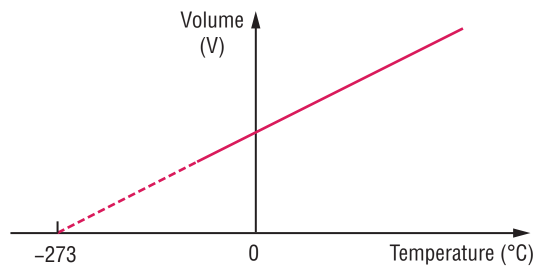


Fig 4.7.7 This graphs shows the relationship between temperature and volume of a gas.

Gas volume and moles

In a chemical equation producing gases, you usually measure the volume of gas produced. So for example, if you reacted calcium carbonate and an acid, you would collect the carbon dioxide gas produced and measure its volume.

Chemical equations show the relationships between the reactants and products in moles. So what you need for your calculations is a relationship between the moles of any gas and its volume. A remarkable fact about gases is that the volumes occupied by one mole of each gas are very close to being identical (at the same temperature and pressure). The volume occupied by a mole of gas is called the molar volume. For all gases, the molar volume is approximately 22.4 litres at 0°C and 1 atmosphere pressure. This is about as much as eleven 2-litre cool-drink bottles.

To calculate the moles of any gas from its volume at STP you can use the equation:

$$n = \frac{V}{22.4} \text{ (only at STP)}$$

As an example, if 1.5 litres of carbon dioxide was produced at 0°C and 1 atmosphere pressure from a reaction between hydrochloric acid and marble chips, how many moles of carbon dioxide were produced?

$$n = \frac{1.5}{22.4} = 0.067 \text{ mol}$$

Prac 2 p. 201

Mass and volume calculations

Mass to volume

In equations involving gases, the volume of gas expected from a certain mass of reactant can be calculated. For example, how could you calculate the volume of carbon dioxide produced at STP when 10.2 g of calcium carbonate is reacted with excess hydrochloric acid? A suggested method is shown in the following table.

Write the equation.	$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$
Write what is known and what is unknown under the equation.	10.2 g V
Find the mole ratio between the known and the unknown.	1 mol $CaCO_3$ to 1 mol CO_2
Calculate moles of known.	$n(CaCO_3) = \frac{m}{M}$ $= \frac{10.2}{40.08 + 12.01 + 48}$ $= 0.102$ mol
Calculate moles of unknown.	$n(CO_2) = 0.102$ mol
Calculate volume of unknown.	$n = \frac{V}{22.4}$ $0.102 = \frac{V}{22.4}$ $V = 2.28$ L

Volume to mass

If the volume of gas is known, but the mass of reactant is unknown, you are converting a volume to a mass. For example, what mass of hydrogen peroxide would be needed to produce 2 litres of oxygen at STP?

Write the equation.	$2H_2O_2 \rightarrow 2H_2O + O_2$
Write what is known and what is unknown under the equation.	x g 2.00 L
Find the mole ratio between the known and the unknown.	2 mol H_2O_2 to 1 mol O_2
Calculate moles of known.	$n = \frac{V}{22.4}$ $= \frac{2.00}{22.4}$ $= 0.0892$ mol
Calculate moles of unknown.	$n(H_2O_2) = 2 \times 0.0892$ $= 0.178$
Calculate mass of unknown.	$n = \frac{m}{M}$ $0.178 = \frac{m}{34.016}$ $n = 6.05$ g

Volume to volume

Where equations involve gases producing other gases, it is easy to determine the volume of the unknown gas. For example, consider the following important reaction from the Haber process of ammonia production:

$$3H_2 + N_2 \rightarrow 2NH_3$$

If 6 litres of hydrogen was used, what volume of ammonia would be produced? This is easy to calculate if you remember Avogadro's hypothesis. Equal volumes of gases must contain the same number of particles. Therefore they contain the same number of moles. This means that volume and moles are directly proportional (at the same temperature and pressure). So the answer to the question above is found by realising that the mole ratio between the two gases will be the same as the volume ratio. The number of moles of ammonia is $^2/_3$, the number of moles of hydrogen, so the volume of ammonia is $^2/_3$ the volume of hydrogen,

$$\frac{2}{3} \times 6 = 4 \text{ litres}$$

Homework book 4.12 LPG and other gases

4•7 FOCUS [Questions]

Use your book

Gases and the kinetic theory

1 List five ideas from the kinetic theory of gases.

Gas pressure

2 What is pressure and in what units is gas pressure usually measured?

Gas pressure, volume and moles

3 State Avogadro's hypothesis concerning the volumes of different gases.

4 If two different gas samples contain the same number of moles, what else can you say about them if the pressure is the same?

Gas volume and pressure

5 If the temperature remains constant, what is the relationship between the volume of a gas and its pressure?

6 A balloon filled with helium had a volume of 10.0 L at an atmospheric pressure of 101.5 kPa. What would its volume be if the air pressure dropped to 98 kPa?

Gas volume and temperature

7 Car tyres heat up while driving. A car tyre cannot really expand much, so explain what would happen to the tyre pressure using the kinetic theory.

8 A 100 mL gas syringe has 95 mL of deadly chlorine gas in it at an air temperature of 5°C. If the air temperature rises to 35°C, could the piston pop out of the syringe?

Gas volume and moles

9 What is the relationship between the moles of any gas and its volume at standard temperature and pressure?

10 If a certain number of moles of hydrogen filled a 5 L balloon at STP, calculate the number of moles of oxygen that would fill the same type of balloon at STP.

11 If 5 L of carbon dioxide was produced at 0°C and 1 atmosphere pressure from a reaction between hydrochloric acid and marble chips, how many moles of carbon dioxide was produced?

Mass to volume

12 Calculate the volume of carbon dioxide at STP produced when 7.5 g of sodium hydrogen carbonate is reacted with excess hydrochloric acid.

Volume to mass

13 What mass of hydrochloric acid would be needed to produce 2 L of hydrogen when reacting with excess zinc at STP?

Volume to volume

14 In the Haber process, how many litres of ammonia could be produced from 100 L of nitrogen, if there was sufficient hydrogen available?

15 How many litres of carbon dioxide and water vapour could be produced by reacting 5 L of methane gas (CH_4) with sufficient oxygen (measured at the same temperature and pressure)?

Use your head

16 **a** A weather balloon with a volume of 10.0 L at sea level air pressure of 101.3 kPa is sent up. Both temperature and air pressure change with altitude. However, imagine only pressure changes. If the air pressure at an altitude of 8000 m is about 33 kPa, how large should the balloon be at that height?

b Imagine now that only temperature changes with altitude. The temperature at 8000 m is about –36°C. What would we estimate the volume of the balloon to be now?

c The correct answer is 26.6 L. What seemed to have more effect on the volume—the pressure drop or the temperature drop?

d Use the kinetic theory to explain why the actual volume is between the two you calculated.

17 How many 4 L balloons could be filled from a gas cylinder of helium if the cylinder is 20.00 L at a pressure of 4000 kPa? Assume the pressure in the balloons will be about 120 kPa.

>>

18 In the flight of Apollo 13 to the moon, an explosion in the oxygen tanks caused an intense scientific effort back on Earth to redesign the spaceships systems to return the crew safely to Earth. One problem was the build-up of carbon dioxide breathed out by the crew. It would have killed them if it was not removed.

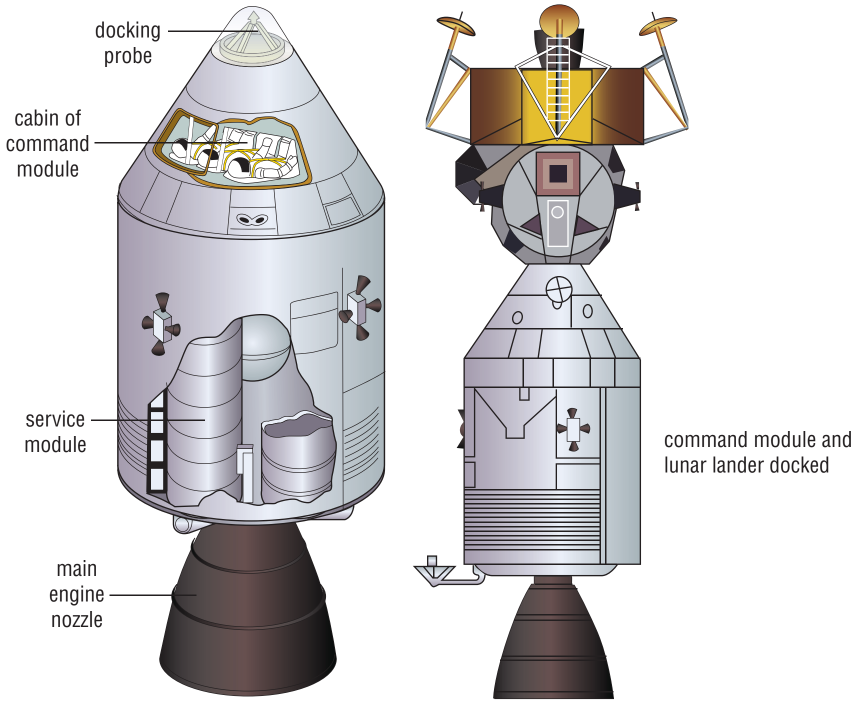
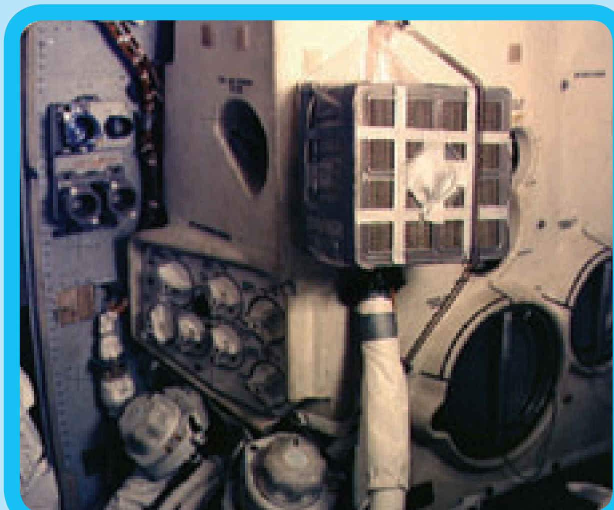


Fig 4.7.8 The Apollo 13 crew were saved by a reaction which removes carbon dioxide gas.



Modified lithium hydroxide canisters *Fig 4.7.9*

The chemical reaction that removed the CO_2 was:

$2LiOH\ (s) + CO_2\ (g) \rightarrow Li_2CO_3\ (s) + H_2O\ (l)$

The crew had to abandon the Command Module due to power loss and enter the lunar lander (LEM). They did this on 13 April 1970 at 10.50 pm. The LiOH canisters on the LEM contained about 1730 g of LiOH.

a How much CO_2 could this remove from the air?

b The three astronauts produced about 1060 g of CO_2 per day in total. How long would the LiOH in the LEM last?

c The crew was four days away from home. Were they going to make it back?

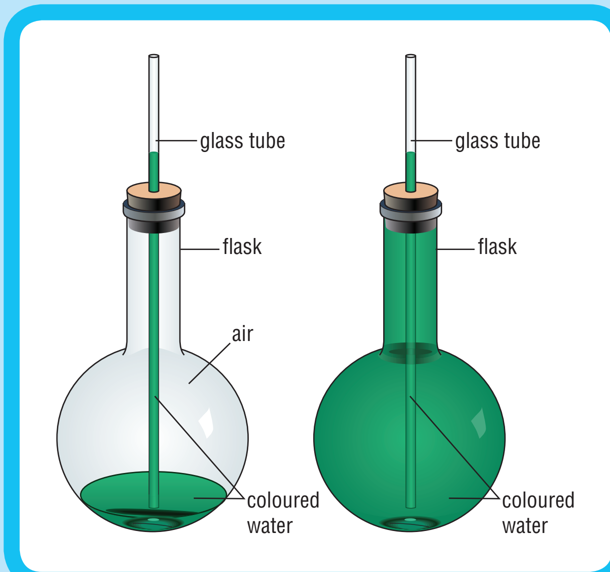
d There were some LiOH canisters on the Command Module, but they were the wrong shape. The crew had to build a suitable holder to use them. They started doing this on 15 April at 3.38 am. At this time, how much LiOH did they need to make it back to Earth?

19 Three identical party balloons are filled with different gases—hydrogen (H_2), methane (CH_4) or oxygen (O_2)—so that they are at the same temperature and pressure.

a What can you say about the number of gas molecules in each balloon? Whose 'hypothesis' explains this?

b What can you conclude about the number of moles of each gas?

c Which balloon would be heaviest? Make a reasonable estimate of the volume of a balloon, and then show by calculation how you decided which was heaviest.



Equipment needed for your experiment **Fig 4.7.10**

Investigating question

20 Consider the two pieces of equipment in Figure 4.7.10.

Design and conduct an experiment to use these pieces of equipment to roughly estimate the pressure increase (in mm of mercury) due to heating air inside the flask to body temperature. To heat these flasks you can hold them in your hands. (Note: Do not use mercury in these flasks—only water.)

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DYO

4•7 FOCUS [Practical activities]

Under pressure

Prac 1 Focus 4.7

Purpose

To observe some effects of air pressure and to measure air pressure.

Requirements

Mercury barometer, aneroid barometer, aluminium can, Bunsen burner, tripod, wire mat, matches, tongs, pneumatic trough or ice-cream container, Magdeburg Hemispheres, vacuum pump and rubber hose.

Procedure

1. Obtain a mercury barometer and use it to measure the air pressure at present. Record this pressure.
2. Use the aneroid barometer to also measure the atmospheric pressure. Record this pressure.
3. Put on some safety glasses. Place a few centimetres of water in the bottom of the aluminium can. Heat this until it boils.

SAFETY NOTE: In step 4 be careful not to spill any boiling water on anyone when you turn the can upside down.

4. Hold the can with tongs and carefully tip the can upside down over the container of water. Push the mouth of the can into the water. Record what you observed.
5. Remove the air from the Magdeburg Hemispheres using the vacuum pump and try to pull the Hemispheres apart.

Questions

1. Explain why the aluminium can was crushed.
2. Explain why the Magdeburg Hemispheres were difficult to pull apart.
3. Try to estimate the total force in newton on the Magdeburg Hemispheres if the air pressure is 10.1 newton per square centimetre (101.3 kPa). If you think about the weight of a certain number of kilograms, approximately how many kilograms would exert a force of this size?

Prac 2
Focus 4.7

Determining molar volume

Purpose

To determine the molar volume of hydrogen gas at room temperature and pressure.

Requirements

100 mL gas syringe, 50 mL test tube, one-hole stopper with glass outlet to fit, rubber hose, 2 mol L^{-1} hydrochloric acid, five pieces of clean magnesium ribbon masses (0.10 g, 0.2 g, 0.3 g, 0.4 g, 0.50 g for class), test tube rack, retort stand, clamp, boss head.

Procedure

1. The class divides into five groups. Each group will use a different mass of magnesium.
2. Have the syringe, tubing and stopper all connected. Clamp the syringe horizontally to a retort. One person in your group should hold the stopper ready to place it into the test tube. Make sure the piston is fully in the gas syringe so that the gas volume is zero.
3. Pour about 2 cm of hydrochloric acid into the test tube in the test tube rack.
4. Be ready to push the stopper into the test tube as soon as the piece of magnesium is dropped into the test tube. Drop your piece of magnesium in and quickly place the stopper in the test tube.
5. Wait until the magnesium stops bubbling then measure the volume of gas in the gas syringe.
6. While waiting for the reaction to stop, copy the following table into your notes. Write the volume of hydrogen measured for your group into the table in your notes.
7. Calculate the moles of magnesium reacting, moles of hydrogen predicted (from the equation and the known moles of magnesium) and the ratio of the volume of hydrogen measured to the moles of hydrogen you predicted. Write these in your table.
8. Exchange results with all other groups in your class, writing them in your table.

Questions

1. Identify some faults in this experimental design, and suggest what improvements could have been made.
2. Were there any sources of measurement error that may have had a significant effect on these results? If so, what were they?
3. Consider your calculations for the ratio in the last column in the table. What similarity is there between them, and what is a reasonable estimate of the ratio?
4. Consider the last column. Write the equation showing the relationship between the moles of a gas and the volume it occupies at STP, and compare it with the result obtained here. Give some reasons why they are not the same.
5. If you had used a reaction that produced oxygen, how similar should the results have been to these for hydrogen?

Mass of Mg (g) reacting	Moles of Mg reacting	PREDICTED moles of H_2 produced	MEASURED volume H_2 produced (L)	Volume H_2/moles of H_2
0.1				
0.2				
0.3				
0.4				
0.5				

FOCUS 4·8 Chemistry in industry

Context

In this Focus you look at some important industries and the role of chemistry in them. The gold industry generates great wealth in Western Australia, and could not have been developed without the aid of chemistry. You will also look at research aimed at finding more environmentally friendly ways to extract gold from the gold ore. The petroleum industry is of huge importance to our economy and depends on chemistry to keep it producing. Lastly, you will look at the role of chemistry in controlling corrosion such as rusting, which constitutes a large cost to our economy.

Gold

Gold is usually found in rock as tiny particles, most of which cannot be clearly seen without a microscope. The task for the chemical engineer is to remove these tiny gold particles from the rock. This involves physical and chemical processes. The basic processes involved are crushing the ore, extracting the gold and refining the gold. There are several different methods of carrying out these processes. The following description is for the most widely used method in Western Australia.

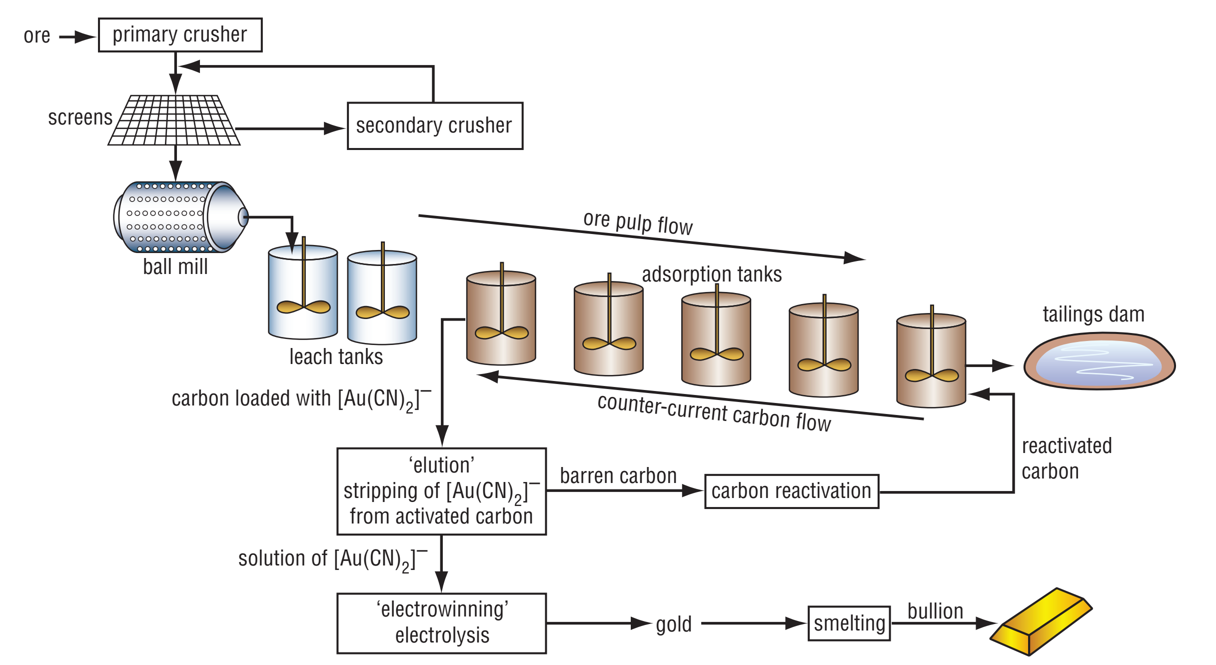
Crushing

The ore is crushed in a three-stage process. In the third stage water is added to the ground rock, which is ground down to particles less than a millimetre in size. The aim is to have a large surface area of rock. This allows the chemicals that are mixed with it in the next process (extraction) to react with the gold and remove it from the rock particles as quickly as possible.

In the third stage of crushing, the particles and water are called a slurry. The slurry is spun in a device called a cyclone, where any heavy coarse material is separated from the finer material and returned to the grinding mill.

The steps involved in extraction of gold from its ore

Fig 4.8.1



A small amount of larger gold particles that have been released from the ore during the crushing and grinding sink to the bottom. This gold is then sent to the gold room for smelting and to be poured into gold bars. The majority of the gold is still in the slurry, which is passed on to tanks for chemical extraction of the gold.

Extraction

The slurry is then passed through the **Carbon in Leach** (CIL) tanks. In these, cyanide (CN^-) is added, along with lime, to maintain a high pH, and oxygen. The cyanide reacts with the solid gold particles and dissolves them into solution as a soluble ion called aurocyanide ion, $Au(CN)_2^-$. The reaction is:

$$4Au\ (s) + 8CN^-\ (aq) + O_2\ (g) + 2H_2O\ (l) \rightarrow 4Au(CN)_2^-\ (aq) + 4OH^-\ (aq)$$

The important point about this reaction is that the gold is now no longer a solid in the rock particles, but is in solution as an ion. It has therefore been removed from the tiny rock particles. You should be able to identify this as an oxidation reaction. The cyanide ion cannot oxidise the gold unless oxygen is present. The lime maintains the basic pH needed.

In the CIL tanks, carbon granules are then added. These granules are very porous, having many fine holes in them. The aurocyanide ions stick to the carbon granules in large amounts because of the massive surface area of the carbon due to these holes. This process is called adsorption.

The next stage is to remove the gold from the carbon. The carbon slurry is then passed to a large column called an elution chamber. Here, under pressure, cyanide and sodium hydroxide are added. This removes the aurocyanide ions from the carbon and returns them to solution.

The aurocyanide solution from elution is then passed to an **electrolytic cell**. The aurocyanide solution has an electric current passed through it in a process called 'electrowinning'. Gold is deposited on the steel negative electrodes of this cell. The gold is removed by washing the steel electrodes with a high-pressure water spray. Some types of cells use steel wool, which is removed then dissolved in acid to free the gold. This means that new steel wool electrodes are used each time.

The reactions involved in the electrolytic cell are:

Cathode reaction:

$$Au(CN)_2^- + e^- \rightarrow Au\ (s) + 2CN^-\ (aq)$$

Anode reaction:

$$4OH^-\ (aq) \rightarrow 2H_2O\ (l) + O_2\ (g) + 4e^-$$

The carbon granules are collected and reactivated by heating to high temperatures. They are then returned to the CIL circuit to be reused.

Froth flotation and roasting

Some ores, such as those from the superpit at Kalgoorlie, have a high amount of sulfides in the rock. These need two additional treatment steps between the grinding of the rock and the CIL tanks. These are froth flotation and roasting.

Froth flotation is a process in which the crushed slurry is fed into a device a bit like a washing machine. Special chemicals are added to the slurry, then air is blown in to the bottom of flotation cells and bubbles rise through the slurry. The gold particles stick to the rising air bubbles and float to the top of the cell. When the air bubbles reach the top of the cell they form a froth. This froth contains nearly all the gold, but also some sulfides, which have to be removed. This is done either by heating to a very high temperature, or by using bacteria that use sulfides as an energy source and remove the sulfides from the slurry. Then the purified rock particles are added to CIL tanks.

Science Snippet

On the job

The process of froth flotation is said to have been invented by a scientist who was pondering the problem while having a few beers in the local pub. The rising bubbles in his glass of beer are said to have given him the idea to try a similar process with slurry—strong evidence that scientists are always on the job, wherever they are.

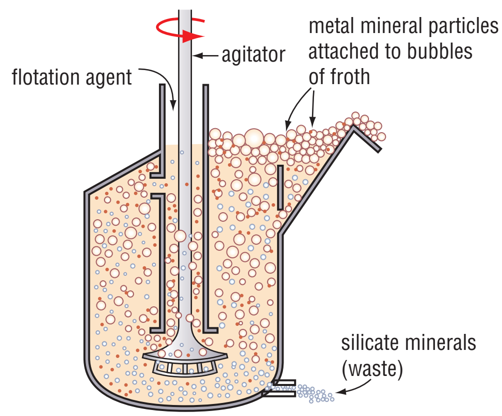


Fig 4.8.2 Froth flotation

Refining

Gold can be further refined to remove impurities such as silver. Chlorine is mixed with molten gold and reacts with the silver to form silver chloride. Another method involves electrolysis, and in another, the gold is dissolved in a mixture of nitric and sulfuric acid to remove the silver, then bubbled through sulfur dioxide gas, causing the gold to precipitate out.

Gold research

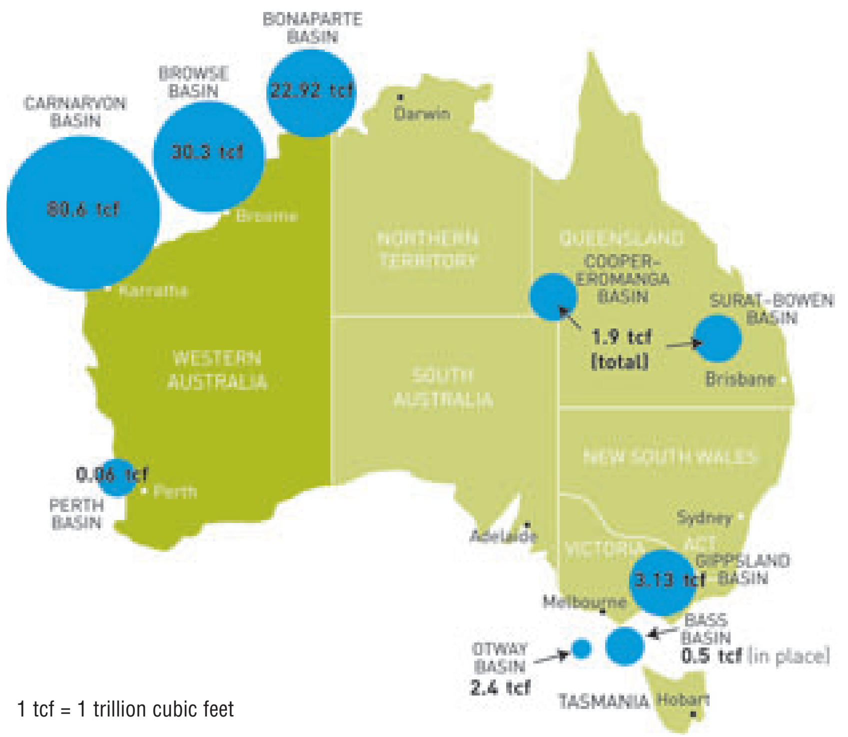
Much chemical research is being done at present into improving the extraction of gold. One line of research is the use of an ion called thiosulfate ion instead of cyanide ion. Cyanide is very poisonous to living things and is currently dumped in big dams called tailings dams. Cyanide remains toxic and could become a problem if it leaks into the groundwater. There is also research being done into improving the CIL system for some types of rock.

Petroleum

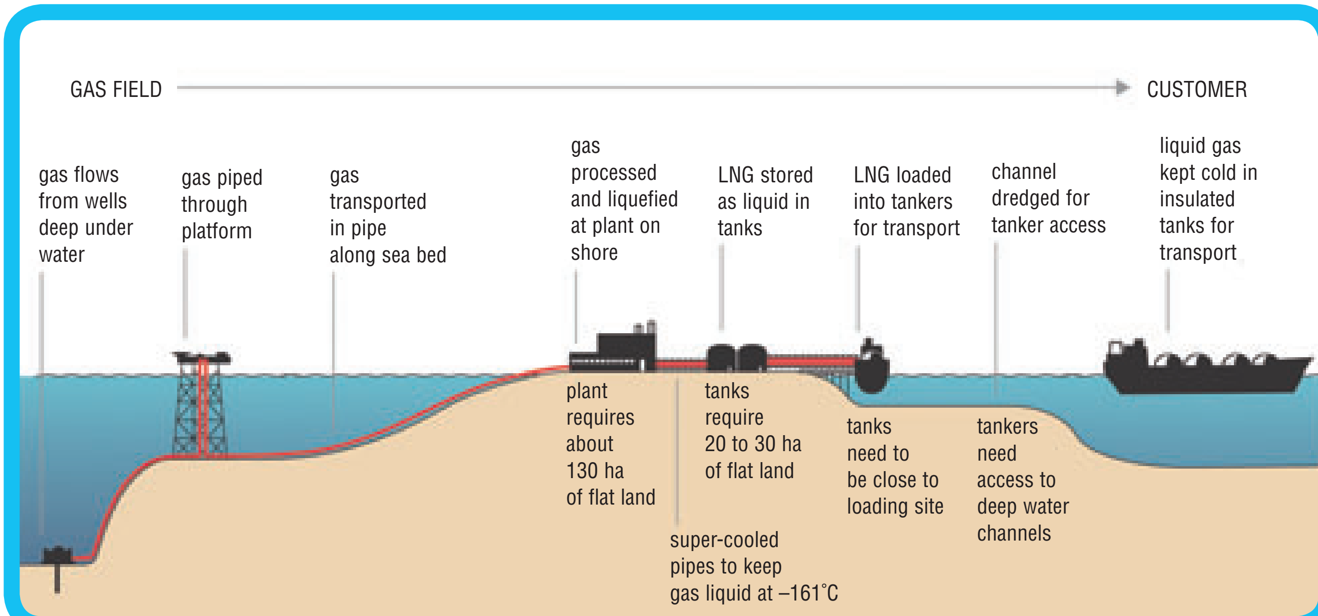
Petroleum includes crude oil, natural gas and condensate. Condensate is a gas in the rock strata, but it forms a liquid when it reaches the surface.

Fig 4.8.4 An offshore oil rig on the North West Shelf extracting oil from rocks beneath the ocean

Fig 4.8.3 The North West Shelf area of Western Australia is the major oil- and gas-producing area in Australia.



Western Australia is Australia's leading oil-producing state and also leads the nation in gas and LNG (liquefied natural gas) production. Petroleum has become a leading contributor to the State's resources sector, accounting for more than one-third of the value of Western Australia's mineral and energy production. About 67 oil and gas fields are producing at present, and more are planned. The value of this production to the State is about 14 billion dollars Australian annually.



The steps involved in exporting LNG from the North West Shelf, using sea-bed pipelines

Fig 4.8.5

Petroleum geochemistry research

Petroleum geochemistry is the study of the organic compounds of petroleum and the rocks in which they are found. Petroleum geochemical research has led to the discovery of new oil fields and to improvements in developing existing fields. Research has also enabled chemists to better predict whether petroleum will be found in particular rock types and geological formations of particular ages. Research also continues into reducing the environmental impact of the petroleum industry.

Current research involves using **biomarkers**. These are the molecular remains of ancient plants, algae and microorganisms in petroleum and sedimentary organic matter. Research helps to establish how the oil was deposited in particular rocks. Chemists are trying to understand how crude oil is formed. There is even debate at present about whether oil is formed from the remains of organisms, or whether it is formed by the effects of heat on rocks. The view that oil forms from the remains of dead organisms has been questioned by some scientists on the basis that oil is found in deep drill holes from below the rock strata in which the earliest known organisms existed.

Corrosion chemistry

Corrosion is the process of materials breaking down chemically. In industry, the corrosion of iron and steel is the main problem. This is commonly called **rusting**, and is a significant cost to industry. A knowledge of oxidation and reduction reactions is vital in understanding how corrosion occurs.

Rusting is a complicated process in which water and oxygen are involved. These combine with the iron in a series of reactions and form a mixture of iron oxides and iron hydroxide. The first process that occurs is the oxidation of iron to iron (II) ions:

$$Fe \rightarrow Fe^{2+} + 2e^-$$

The electrons from this oxidation can flow to where there is more oxygen, which is the surface of the water layer on the iron. The electrons combine with the oxygen and water molecules, which is a reduction process, to form hydroxide ions:

$$4e^- + O_2 + 2H_2O \rightarrow 4OH^-$$

The hydroxide ions, iron (II) ions and oxygen then further react to form iron (III) hydroxide:

Interactive Animation

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$$

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$$

The iron (III) hydroxide then loses water and turns into a mixture of compounds, which are mainly iron oxide and iron (III) hydroxide. This is the rust.

The reason for the continued corrosion of iron is that rust is **porous**. Water and oxygen can pass through the rust layer and thus iron atoms are continuously exposed to reaction. Iron and steel can therefore completely corrode and no pure metal remains. So any structures made from iron can lose their strength through corrosion. Common examples are car bodies, ship hulls, steel water pipes and underground steel tanks.

Rusting is actually faster if the iron is in contact with dissolved ions in solution, as is the case with salt water. The ions allow charge flow more quickly between the sites of oxidation and reduction. Contact between the iron and some metals also speeds up its oxidation.

Science Snippet

Dud plumbers

A mistake often seen in bad plumbing work is the connection of steel water pipes and copper or brass fittings. The copper in the fittings actually acts as a site for reduction and the steel pipe is therefore a site for oxidation. So the steel pipe corrodes faster. This is evidence that everyone can benefit from some knowledge of chemistry.

Rust prevention

A knowledge of oxidation and reduction reactions has been vital for devising methods to prevent rusting and other forms of corrosion. The methods used involve the application of a **protective coating** on the iron, **alloying** the iron with other metals and **cathodic protection**.

Protective coatings that are commonly used are paints, oils, plastic, glass, wax, grease and other materials. This is the main reason why bridges, ships and steel tanks are constantly being painted. The water tanks of hot-water systems used in houses are often covered in glass. This coating is called vitreous enamel. Cars are often waxed after washing to fill any scratches and to prevent paint from deteriorating.

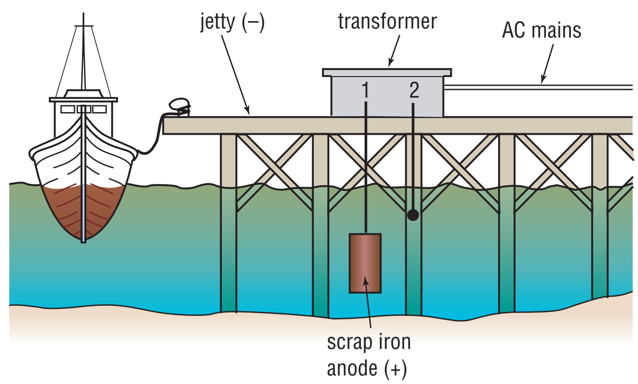
Protective coatings of metal are also used. A common method is to coat the iron surfaces in zinc. This is called galvanising. The fresh zinc reacts with air and forms a layer of zinc carbonate on its surface, which stops any further corrosion. Thus the iron beneath is protected. Galvanised iron is commonly used for garden sheds, roofing and rainwater tanks. Other coatings of metal used are chromium and tin.

Alloying the iron with other metals results in the formation of a protective surface. The first metal found to do this was chromium. About 12 per cent chromium is mixed with the steel. The chromium in the steel reacts with oxygen in the atmosphere to form a thin layer of chrome-containing oxide, called the passive film. If the surface is scratched, the fresh chromium reacts and reforms the protective layer.

Cathodic protection is a way of using electron flow to protect a fixed steel structure such as a jetty, water tank or pipeline. This can be done in two main ways. One way is to connect the steel to the negative terminal of an electric circuit and make the water or soil the positive terminal. The steel will not tend to oxidise because the terminal already has an excess of electrons. The water in contact with the steel will be reduced instead.

The second way is to connect the steel to a piece of metal that oxidises easily, such as magnesium. This metal is called a sacrificial anode, and will corrode instead of the steel. The electrons from the anode flow to the steel and thus make it a terminal that is reducing, not oxidising. This means the iron cannot oxidise. Hot-water systems in the home commonly have magnesium sacrificial anodes, which have to be replaced occasionally as they corrode.

Fig 4.8.6 Jetties, water heaters and pipelines are protected by cathodic protection.



A last method of preventing corrosion is to remove the substances responsible for it. So water, oxygen and any dissolved salts should be kept away from bare metal surfaces as much as possible. As an example, vehicles that are driven in salty areas such as at salt lakes or beach fronts should be washed down to remove the salt, because it speeds up corrosion. The water should then be removed quickly by drying the vehicle in the Sun.

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Homework book 4.13 Stray current corrosion

Drag and Drop CW Interactive

FOCUS 4.8 Questions

Use your book

Crushing

1 What is the aim of crushing the gold ore?

Extraction

2 In the CIL tanks, what is the role of the cyanide in the extraction of gold from the rock?

3 What is the role of the carbon granules in gold extraction?

4 Briefly describe how the gold is removed from the aurocyanide ion solution.

Froth flotation and roasting

5 Why is froth flotation used and what do the gold particles stick to?

6 Why must some gold ores be roasted to a high temperature?

Research

7 Give an example of chemistry being involved in improving the gold industry and protecting our environment.

Petroleum geochemistry research

8 Give two ways in which chemistry may improve the North West Shelf oil and gas industry.

9 What are biomarkers in oil and gas geochemical research?

Corrosion chemistry

10 Why can rusting continue until all the iron has oxidised?

11 Name two chemical factors that can speed up rusting.

Rust prevention

12 How does galvanising protect iron from rusting?

13 How does alloying iron with chromium protect the iron from oxidation?

14 A long rod of magnesium is inserted in the water in the steel tank of a solar hot-water system. Explain how this rod protects the hot water tank from corrosion.

Use your head

15 A family bought a gas storage hot-water system that had a guaranteed life of ten years. After five years the steel tank burst and it was clear that it had rusted through. The steel water tank had a protective inside covering of glass enamel. The installation instructions warned about the need to be careful not to drop the unit or hit the tank. Formulate a hypothesis to explain why this tank corroded five years before it should have. What evidence would you look for to test your hypothesis?

16 Solar hot-water systems often last only a short time in areas where the water has a high concentration of dissolved salts. How can you explain this?

17 How has a knowledge of oxidation and reduction enabled chemists to plan a method to extract gold from rock?

18 How has a knowledge of oxidation and reduction enabled chemists to plan a method to protect iron from rusting?

19 Why would the discovery of oil in rocks below strata in which any fossils have been found lead to some geologists doubting that oil forms from the decay of dead organisms?

Investigating questions

20 Gold dissolves in a liquid called aqua regia. This is a mixture of the concentrated acids nitric acid and hydrochloric acid. Why is aqua regia not used for the extraction of gold from the rock, rather than the cyanide solution?

21 In the Prac 1 set-up opposite, what do you predict would happen if you wound a strip of magnesium around each end of an iron nail? What about if you wound a strip of copper around one end of a nail, and a strip of zinc around the other end? Try these, or any other combinations of zinc, copper and magnesium, using the same agar solution as Prac 1. DYO

22 How could you use the agar solution from Prac 1, a petri dish and a strip of zinc, some copper wire and an iron nail to show the principle of cathodic protection of iron using a sacrificial anode? Show your teacher and try your experiment. DYO

4·8 FOCUS

[Practical activity]

Prac 1 Focus 4.8

Rusting

Purpose

To investigate the rusting of iron and some factors that affect it.

Requirements

Safety glasses, six clean iron nails about 5 cm long, one small test tube, test tube rack, warm agar solution with ferricyanide and phenolphthalein indicators, two pairs pliers, two petri dishes (top half), copper wire (unvarnished) 5 cm long, thin (less than 5 mm wide) zinc strip 5 cm long, magnesium ribbon 5 cm long

SAFETY NOTE: Be careful, the agar solution may be hot. Do not spill it on your skin. The ferricyanide solution is a mild irritant, so do not spill it on your skin.

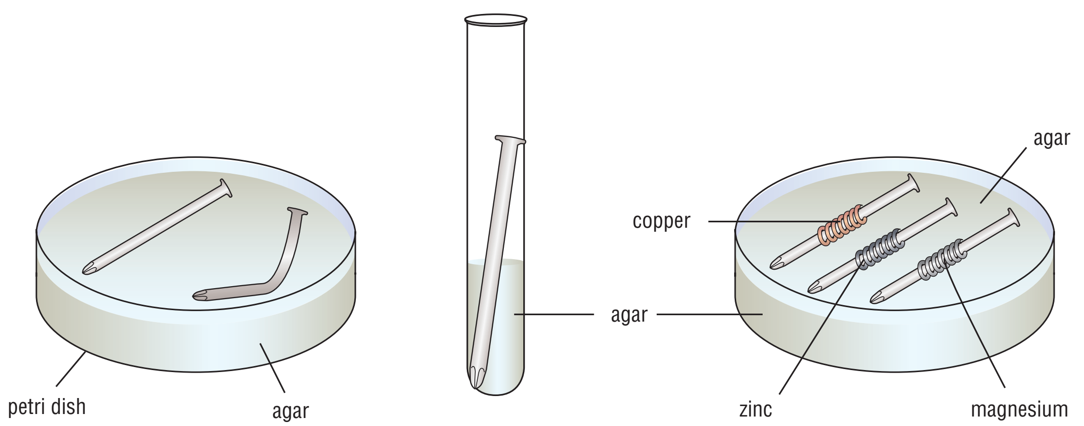
Procedure

1. Put on a pair of safety glasses. Pour about 3 cm of the agar into a test tube. Place a nail in the tube. Leave the test tube aside so the agar can set to a jelly.
2. Bend one of the nails in the middle to form a V-shape. Place this bent nail and a straight nail in one petri dish so they are far apart. Take three more nails and wrap the copper wire around the centre of the first, the zinc around the centre of the second and the magnesium around the centre of the third. Place the three nails with the metal wrappings in the other petri dish, as far apart as possible.
3. Put the agar dishes in a tray then carefully pour some warm agar solution into the two petri dishes without pushing the nails together. Cover the nails completely to a depth of about half a centimetre. Move the tray to the side of the room to allow the agar to set.
4. If the agar sets by the end of the period, observe the dishes and test tube without moving them. *Record any changes you see, especially any blue, pink or white colour changes.* A blue colour indicates the presence of Fe^{2+}, a white colour shows oxidation of the other metals and a pink colour shows the presence of hydroxide ions.
5. The next day look at your dishes and the test tube. *Record any colours you see, especially any blue, pink or white areas.*

Questions

1. Draw a diagram indicating the areas on the nails that were blue, white or pink.
2. On your diagram indicate which areas showed oxidation, which showed reduction and which showed no evidence of either oxidation or reduction.
3. Which nails showed evidence that the iron is corroding?
4. Which nails seemed to be protected from corrosion of the iron?
5. If you wanted to protect iron by cathodic protection, which metals (zinc, magnesium or copper) would appear to do this job?
6. What information did the bent nail give you about the factors affecting corrosion?
7. What information did the nail in the test tube give you about the site of corrosion of iron?

Fig 4.8.7 How to set up your experiment



Review questions

Second-hand data

1 Some students were investigating two copper oxide compounds that they had made by different methods. In order to check that they had made the same compound, they converted each of the oxides into pure copper and measured the mass of the copper. The results are shown in the table below.

Group	Mass of copper oxide (g)	Mass of copper (g)
1	8.0	6.4
2	24.0	19.2
3	37.5	33.3

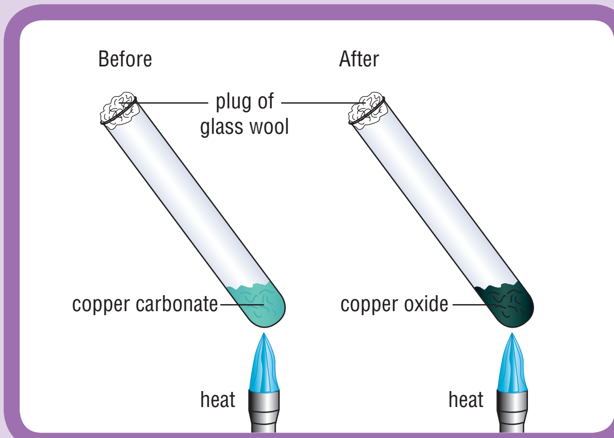
a Determine the percentage composition of the copper oxide produced by each group. Did each group make the same type of copper oxide? Explain your answer.

b If one of the compounds was copper (I) oxide, what was the other one likely to be? Does the data support your conclusion? Explain your answer fully and make sure that you show all your working out.

2 As part of an investigation, students produced carbon dioxide by the thermal decomposition of copper (II) carbonate. In this reaction green copper (II) carbonate produces black copper (II) oxide and carbon dioxide gas.

Shakira recorded the following data:

- mass of dry test tube and glass wool plug = 30.93 g
- mass of dry test tube and glass wool plug + copper (II) carbonate (before heating) = 33.41 g
- mass of dry test tube and glass wool plug + black copper (II) oxide (after heating) = 32.52 g



Thermal decomposition of copper (II) carbonate *Fig 4.9.1*

a Write a balanced chemical equation for this reaction.

b What is the initial mass and number of moles of copper (II) carbonate before heating?

c What is the mass and number of moles of copper (II) oxide produced?

d What is the mass of carbon dioxide produced? How many moles is this?

e What is the ratio between the number of moles of copper (II) carbonate reacted and the number of moles of copper (II) oxide and carbon dioxide produced in this reaction?

f Compare your ratio from **e** to the balanced chemical equation from **a**. How do the ratios compare?

g What is the theoretical volume of carbon dioxide gas produced at STP? Show your calculation.

Open-ended questions/experimental design

3 A metal will displace any metal from a solution of its salt, if the metal of the salt is lower than it in the metal reactivity series.

Design and conduct an investigation to test the statement above. A version of the metal activity table is given in Figure 4.3.10.

You will be supplied with the following:

- pieces of metal—magnesium, lead, iron, copper, zinc
- solutions of magnesium sulfate ($MgSO_4$), lead sulfate ($PbSO_4$), iron (II) sulfate ($FeSO_4$), zinc sulfate ($ZnSO_4$).

In your investigation design you will need to:

a describe how you will carry out the investigation to ensure ‘fair testing’

b design a suitable observations table to record your results.

SAFETY NOTE: Check with your teacher before you commence your investigation. Make sure that you follow safety procedures very carefully, including wearing safety glasses at all times. Note that salts such as lead sulfate are poisonous. Wash your hands carefully before you leave the laboratory.

Following the investigation:

- write a summary of your results, including your version of the 'activity series' of the metals you tested
- compare your metal activity series with that given in Focus 4.4.

4 Design an investigation to explore the molar relationship between the reactants and the production of a chemical reaction. Below are some ideas that might help you with your investigation.

- A good chemical reaction to use is the precipitation reaction that occurs between copper (II) chloride and sodium carbonate. The reaction and molar relationship between reactants and products can be represented as:

  $CuCl_2 + Na_2CO_3 \rightarrow CuCO_3 + 2NaCl$

- Use a small known mass of copper (II) chloride and convert this to a number of moles (a small mass such as 1.5 or 2.0 g is sufficient). Dissolve these masses in about 50 mL of distilled water.
- Use an excess of sodium carbonate (your teacher will help you with this).
- Make sure that the copper carbonate is dried before you find the mass of it.
- By converting the mass of copper carbonate back into a number of moles you can compare this with the number of moles of copper chloride you used.
- You should run a number of trials by using different masses of copper (II) chloride.
- Find the pattern that exists between the number of moles of copper (II) chloride used and the number of moles copper carbonate produced.
- Describe how you ensured that this was a fair investigation.

Extended investigations/research

5 In Focus 4.8 you investigated the **Carbon in Leach** (CIL) process of extracting gold. This process involves the use of large volumes of cyanide ion. Cyanide ion is highly toxic and there are calls to ban its use in the gold industry. The risk of using cyanide ion is illustrated by the Baia Mare tailings spill that occurred in Romania in 2000. The mine was a joint venture between an Australian and a Romanian company. In this spill (which occurred after heavy rain and snow fall) it is estimated that 100 000 cubic metres of cyanide-rich tailings were spilt into the Somes, Tisza and finally the Danube rivers. It is estimated that between 50 and 100 tonnes of cyanide ion as well as other copper-rich heavy metals were lost in the spill. Millions of people were affected by this spill and the biological impact is still being felt today.

There is an increasing call from environmental agencies to minimise the use of cyanide in the gold mining industry and, in fact, Western Australian scientists working through the Parker centre in Perth are working on some alternatives to the use of cyanide.

Use the Internet to research the following aspects of the use of cyanide in gold extraction.

a What were some of the environment impacts of the Romanian cyanide tailing spill in 2000? How many people were directly affected by this spill?

b Have there been any other cyanide spills involving Australian gold mines? If so, give details of the incident(s).

c What is the main function of the Parker Centre in Perth? Describe some of the work they have done in reducing the use of cyanide ion in gold extraction.

6 LNG production and export earns about 14 per cent of all the income that comes from minerals in WA, and approximately 8 per cent of world production of LNG comes from WA, as at 2006. Use the Internet to research the role played by chemistry in this industry. In particular find the answers to the following questions.

a What is the chemical composition of natural gas from WA?

b What processing must be done on the natural gas to convert it to LNG for export?

c What happens to the impurities that must be removed from the natural gas before turning it into LNG, and what plans are there to make their disposal more environmentally friendly?

d What is the LNG used for?

e What are the prospects for both LNG and crude oil production in WA in the future, and what jobs may be available for science and engineering graduates in this industry?

Homework book 4.14 Natural and Processed Materials crossword

Homework book 4.15 Sci-words

Index

Numbers in **bold** refer to definition terms in **bold** type in the text.
Numbers in *italic* refer to illustrations/data tables in the text.

L

M

N

O

P

Alternative group numbers	Group I 1	Group II 2	3	4	5	6	7	8	9	10	11	12	Group III 13	Group IV 14	Group V 15	Group VI 16	Group VII 17	Group VIII 18
Period 1	**H** 1 hydrogen 1.008																	**He** 2 helium 4.003
Period 2	**Li** 3 lithium 6.941	**Be** 4 beryllium 9.012											**B** 5 boron 10.81	**C** 6 carbon 12.01	**N** 7 nitrogen 14.01	**O** 8 oxygen 16.00	**F** 9 fluorine 19.00	**Ne** 10 neon 20.28
Period 3	**Na** 11 sodium 22.99	**Mg** 12 magnesium 24.30											**Al** 13 aluminium 26.99	**Si** 14 silicon 28.09	**P** 15 phosphorus 30.97	**S** 16 sulfur 32.07	**Cl** 17 chlorine 35.45	**Ar** 18 argon 39.95
Period 4	**K** 19 potassium 39.10	**Ca** 20 calcium 40.08	**Sc** 21 scandium 44.96	**Ti** 22 titanium 47.88	**V** 23 vanadium 50.94	**Cr** 24 chromium 52.00	**Mn** 25 manganese 54.85	**Fe** 26 iron 55.85	**Co** 27 cobalt 58.93	**Ni** 28 nickel 58.69	**Cu** 29 copper 63.55	**Zn** 30 zinc 65.39	**Ga** 31 gallium 69.72	**Ge** 32 germanium 72.61	**As** 33 arsenic 74.92	**Se** 34 selenium 78.96	**Br** 35 bromine 79.90	**Kr** 36 krypton 83.80
Period 5	**Rb** 37 rubidium 85.47	**Sr** 38 strontium 87.62	**Y** 39 yttrium 88.91	**Zr** 40 zirconium 91.22	**Nb** 41 niobium 92.91	**Mo** 42 molybdenum 95.94	**Tc** 43 technetium (98)	**Ru** 44 ruthenium 101.1	**Rh** 45 rhodium 102.9	**Pd** 46 palladium 106.4	**Ag** 47 silver 107.9	**Cd** 48 cadmium 112.4	**In** 49 indium 114.8	**Sn** 50 tin 18.7	**Sb** 51 antimony 121.8	**Te** 52 tellurium 127.6	**I** 53 iodine 126.9	**Xe** 54 xenon 131.3
Period 6	**Cs** 55 caesium 132.9	**Ba** 56 barium 137.3	***La** 57 lanthanum 138.9	**Hf** 72 hafnium 178.5	**Ta** 73 tantalum 180.9	**W** 74 tungsten 183.89	**Re** 75 rhenium 186.2	**Os** 76 osmium 190.2	**Ir** 77 iridium 192.2	**Pt** 78 platinum 195.1	**Au** 79 gold 197.0	**Hg** 80 mercury 200.6	**Tl** 81 thallium 204.4	**Pb** 182 lead 207.2	**Bi** 83 bismuth 209.0	**Po** 84 polonium (209)	**At** 85 astatine (210)	**Rn** 86 radon (222)
Period 7	**Fr** 87 franchium (223)	**Ra** 88 radium 226	§**Ac** 89 actinium (227)	**Rf** 104 rutherfordium (261)	**Db** 105 dubnium (262)	**Sg** 106 seaborgium (266)	**Bh** 107 bohrium (264)	**Hs** 108 hassium (277)	**Mt** 109 meitnerium (268)	**Ds** 110 darmstadium (271)	**Rg** 111 roentgenium (272)							

*Lanthanides series	**Ce** 58 cerium 140.1	**Pr** 59 praseodymium 140.9	**Nd** 60 neodymium 144.2	**Pm** 61 promethium (145)	**Sm** 62 samarium 150.4	**Eu** 63 europium 152.0	**Gd** 64 gadolinium 157.2	**Tb** 65 trebium 158.9	**Dy** 66 dysprosium 162.5	**Ho** 67 holmium 164.9	**Er** 68 erbium 167.3	**Tm** 69 thulium 168.9	**Yb** 70 ytterbium 173.0	**Lu** 71 lutetium 175.0
§Actinides series	**Th** 90 thorium 232.0	**Pa** 91 protactinium 231.0	**U** 92 uranium 238.0	**Np** 93 neptunium 237	**Pu** 94 plutonium (244)	**Am** 95 americum (243)	**Cm** 96 curium (247)	**Bk** 97 berkelium (247)	**Cf** 98 californium (251)	**Es** 99 einsteinium (252)	**Fm** 100 fremium 257)	**Md** 101 mendelevium (258)	**No** 102 nobelium (259)	**Lr** 103 lawrencium (260)

Legend

- metals
- metalloids
- non-metals
- noble gases (non-reactive non-metals)

H — symbol
1 — atomic number
hydrogen — name
1.008 — atomic mass

A relative atomic mass in brackets is the mass number of the isotope with longest half life.