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Crystal Ja, "Wifi helps CSIRO scientist win top gong", AAP, 28 October 2010, p. 275

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## 9 Ecosystems



## 10 Plate tectonics

# PEARSON science


## Student Book

Written specifically to meet the requirements of the Australian Curriculum, the student book acts as a guide for both student and teacher.

- Written specifically for the Australian Curriculum Science course
- Utilises an inquiry approach throughout
- Offers content and activities that enhance the development of Achievement Standards. The content is presented in a range of contexts within the three interrelated strands of Science Inquiry Skills, Science as a Human Endeavour and Science Understanding.

## Activity Book

The activity book is a write-in resource designed to enrich students' skills by providing a variety of activities and questions to reinforce learning outcomes.

- Supports and extends the student book
- Caters for a range of learning styles.

## Teacher Companion

The teacher companion makes lesson preparation easy by combining full-colour textbook pages with teaching strategies, ideas for class activities and fully worked solutions.

- Ties the entire **Pearson science** package together
- Includes all answers to the student and activity book.

AUSTRALIAN CURRICULUM

ALWAYS LEARNING

## Pearson Reader

Much more than an e-book, **Pearson Reader** is an interactive online version of your student book linked to rich media resources. Not only does it support you with activities and teaching tools, it allows you to personalise your class version of the student book by adding your own links and content. **Pearson Reader** also enables you to harness the collective intelligence of education professionals by connecting you to other **Pearson Reader** users, building a powerful and continually evolving web book for your students.

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## Professional Learning, Training and Development

Did you know that Pearson also offer teachers a diverse range of training and development programs? We are dedicated to supporting your implementation of **Pearson science**, but it doesn't stop there. We offer specific training for the Australian Curriculum and beyond, such as our session titled 'Skilling Up in Science'.

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PEARSON

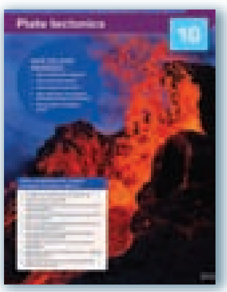
# How to use this book

## PEARSON science 9 Student Book

PEARSON science 9 has been designed for the Australian Curriculum: Science course. It includes content and activities that enhance the development of the Year 9 Achievement Standards within the three interrelated strands of Science Inquiry Skills, Science as a Human Endeavour, and Science Understanding. The content is presented through a range of contexts to engage students and assist them to make connections between science and their lives.

The Cross-curriculum priorities and General Capabilities are addressed throughout the series.

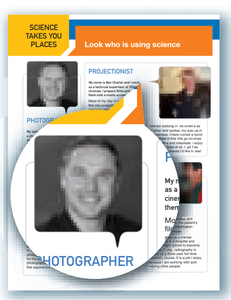
PEARSON science 9 is designed for an inquiry approach to science learning. Its engaging design, unambiguous features and clear easy-to-understand language make this a valuable resource for students of all interests and abilities.




### Chapter opening page

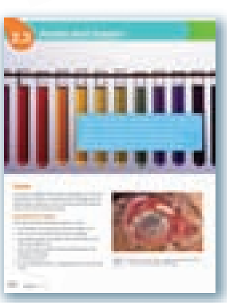
The chapter opener engages students through questions that get them thinking about the content and concepts to come.

The key ideas reflect the elaborations and standards relevant to the chapter.




### Look who is using science

Careers pages spread throughout the book look at careers that involve and use science.



### Unit opening

Each chapter is divided into self-contained units. The unit opener includes an introduction that places the material to come in a meaningful context.

### Photos and illustrations

Stunning and relevant photos and illustrations are clearly referenced from within the text to assist students to understand the idea being developed.

### science 4 fun

Inquiry-based activities using everyday materials assist students to understand key concepts under development.

These can be used as a focus or context for the unit.

Icons indicate whether an activity is suitable to be done at home or requires teacher supervision.

### Skill builder

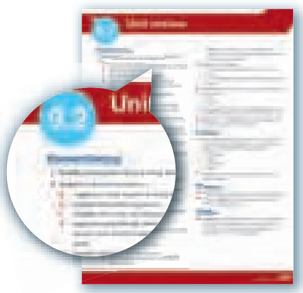
Key skills are outlined in clear steps to support science learning.

### Worked example

Worked examples of problems and techniques assist students to master and apply key skills.

## SciFile

SciFiles include quirky information to engage students.



## Unit review

Each unit finishes with a set of questions and activities organised under the headings of Bloom's Taxonomy of Cognitive Processes. To further students' understanding of the intent of a question and level of explanation expected, bolded verbs are used throughout. A list of all verbs and their meanings can be found on page xii.

The final heading is 'Inquiring'. These questions challenge students to use their inquiry skills to go further with the unit content.

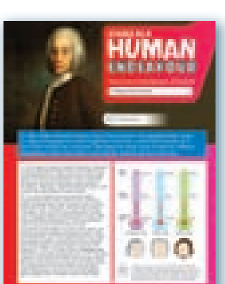
## Practical activities

Practical activities are placed at the end of each unit. Practical activity icons appear throughout the units to indicate suggested times for practical work.

A student-design inquiry icon indicates that an activity includes student input and/or design.

Safety boxes highlight significant hazards.

A safety glasses icon reminds students when appropriate to wear safety glasses.



## Science as a human endeavour

The Science as a Human Endeavour strand is addressed throughout the units and in Science as a Human Endeavour spreads. Many of these are developed and extended in the Activity Book.

## Chapter review

Each chapter finishes with a set of questions and activities organised under the headings of Bloom's Taxonomy of Cognitive Processes.

## Thinking scientifically

Following the Chapter review are Thinking scientifically style questions relevant to that chapter. These test students' science and interpretive skills.

## Glossary

Every chapter concludes with an illustrated glossary that engages students and provides a ready reference for the key terms of the chapter.

## Activity Book icon

This icon indicates a related Activity Book worksheet that enhances or extends this area.

**The PEARSON science 9 package**

Don't forget the other PEARSON science 9 package components that will help engage and excite students in science:

- PEARSON science 9 Activity Book
- PEARSON science 9 Teacher Companion
- PEARSON science 9 Pearson Reader

# Verbs

The verbs below, based on Bloom's Taxonomy, appear in **bold** text throughout this book. The verbs help students know the level of response required for a question and provide a common language and consistent meaning in the Australian Curriculum documents.

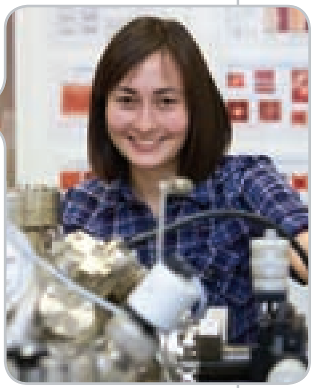
| **Remembering** | |
|---|---|
| **enter** | Place data into a computer program by key strokes or copying from a digital source, e.g. CD, DVD, USB storage device |
| **label** | Add annotations to a diagram or drawing |
| **list** | Write down phrases or items only without further explanation |
| **name** | Present remembered ideas, facts or experiences |
| **present** | Provide information for consideration |
| **recall** | Present remembered ideas, facts or experiences |
| **record** | Store information and observations for later |
| **specify** | State in detail |
| **state** | Provide information without further explanation |
| **Understanding** | |
| **account** | Account for—state reasons for, report on. Give an account of—narrate a series of events or transactions |
| **calculate** | Ascertain/determine from given facts, figures or information (simply repeating calculations that are set out in the text) |
| **clarify** | Make clear or plain |
| **define** | State meaning and identify essential qualities |
| **describe** | Provide characteristics and features |
| **determine** | Find out the size or extent, either by using an equation, counting, estimating, or similar method |
| **discuss** | Identify issues and provide points for and/or against |
| **draw** | Use a pencil to produce a likeness onto a page, or sketch to provide a representation or view |
| **explain** | Provide a sequence to make the relationships between things evident; provide why and/or how |
| **extract** | Choose relevant and/or appropriate details |
| **gather** | Collect items from different sources |
| **modify** | Change in form or amount in some way |
| **outline** | Sketch in general terms; indicate the main features |
| **predict** | Suggest what may happen based on available information |
| **produce** | Provide |
| **propose** | Put forward for consideration or action |
| **rank** | Place in order of size, age, or as instructed |
| **recount** | Retell a series of events |
| **summarise** | Express, concisely, the relevant details |
| **write** | Compose or construct a sentence that explains a feature |
| **Applying** | |
| **apply** | Use, utilise, employ in a particular situation |
| **calculate** | Ascertain/determine from given facts, figures or information |
| **demonstrate** | Show by example |
| **examine** | Inquire into |
| **identify** | Recognise and name |
| **use** | Employ for some purpose |

| | |
|---|---|
| **Analysing** | |
| **analyse** | Identify components and the relationship between them; draw out and relate implications |
| **calculate** | Ascertain/determine from given facts, figures or information (requiring more manipulation than simply applying the maths) |
| **classify** | Arrange or include in classes/categories |
| **compare** | Show how things are similar or different |
| **contrast** | Show how things are different or opposite |
| **critically (analyse/ evaluate)** | Add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/evaluate) |
| **discuss** | Identify issues and provide points for and/or against |
| **distinguish** | Recognise or note/indicate as being distinct or different from; to note differences between |
| **infer** | Recognise and explain patterns and meaning and relationships |
| **interpret** | Draw meaning from |
| **research** | Investigate through literature or practical investigation |
| **Evaluating** | |
| **appreciate** | Make a judgement about the value of |
| **assess** | Make a judgement of value, quality, outcomes, results or size |
| **conclude** | Come to a judgement or result based on the reasoning or arguments that you present |
| **critically (analyse/ evaluate)** | Add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/evaluate) |
| **deduce** | Draw conclusions |
| **evaluate** | Make a judgement based on criteria; determine the value of |
| **extrapolate** | Infer from what is known |
| **justify** | Support using an argument or conclusion |
| **propose** | Put forward (for example a point of view, idea, argument, suggestion) for consideration or action |
| **recommend** | Provide reasons in favour |
| **select** | Choose one or more items, features, objects |
| **Creating** | |
| **construct** | Make; build; put together items or arguments |
| **design** | Provide step for an experiment or procedure |
| **investigate** | Plan, inquire into and draw conclusions about |
| **synthesise** | Put together various elements to make a whole |

SCIENCE TAKES YOU PLACES

# Look who is using science

## NANOSCIENTIST

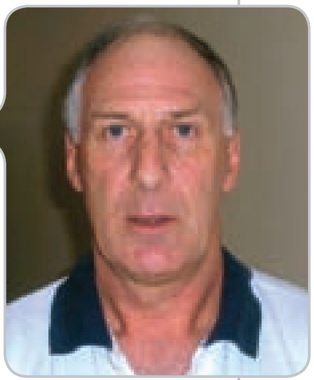


**My name is Jill Miwa. I work in the new and exciting field of nanoscience. I use a special microscope that can 'see' and 'touch' individual atoms and molecules in materials such as silicon that are used in everyday electronic devices such as laptops, televisions and mobile phones.**

I use the microscope to study how atoms and molecules interact with each other. By understanding what happens at such a small scale, scientists like me can design and build faster, smaller electronics.

At the University of New South Wales, we are using our microscope to position atoms into the world's smallest silicon computer chip! I really enjoy working in a research laboratory. It's a fantastic place to work because all the newest technology is at my fingertips, and each day I get to go to work and try to solve the mysteries of how the world around us works.

## ORTHOPAEDIC TECHNICIAN



**My name is Terry James and I am an orthopaedic technician employed by Queensland Health and working at a general hospital. To get to this position I completed a Certificate IV in Orthopaedic Technology. I studied the anatomy of the skeleton and muscles, all aspects of applying casts to broken arms and legs, and the application of traction as a way of getting the bones and muscles of the skeleton back into their correct position.**

In my position as an orthopaedic technician it is very important to have a professional attitude when working with the medical staff to make sure that the best possible outcome is achieved for all patients.

A career within the health sector can be extremely rewarding. It is an achievable goal for anyone interested in the health industry. Once you have employment, funded courses are available and these may lead to opportunities for advancement in the field of orthopaedic technology.

## BEAUTY THERAPIST

**I am Bianca Chamberlin and I run my own business as a beauty therapist.**

The main goal for clients who come to see me is to improve the texture and general health of their skin.

As a beauty therapist I need to understand the structure of cells in order to diagnose and treat the different skin types and conditions I see on a daily basis. I also need to understand the products I use and how they interact with skin cells.

While many of my peers thought it strange for me to study science at school, it gave me a great grounding and understanding for when I started study for my Diploma of Applied Science for my career in beauty therapy.

# The atom

# 1

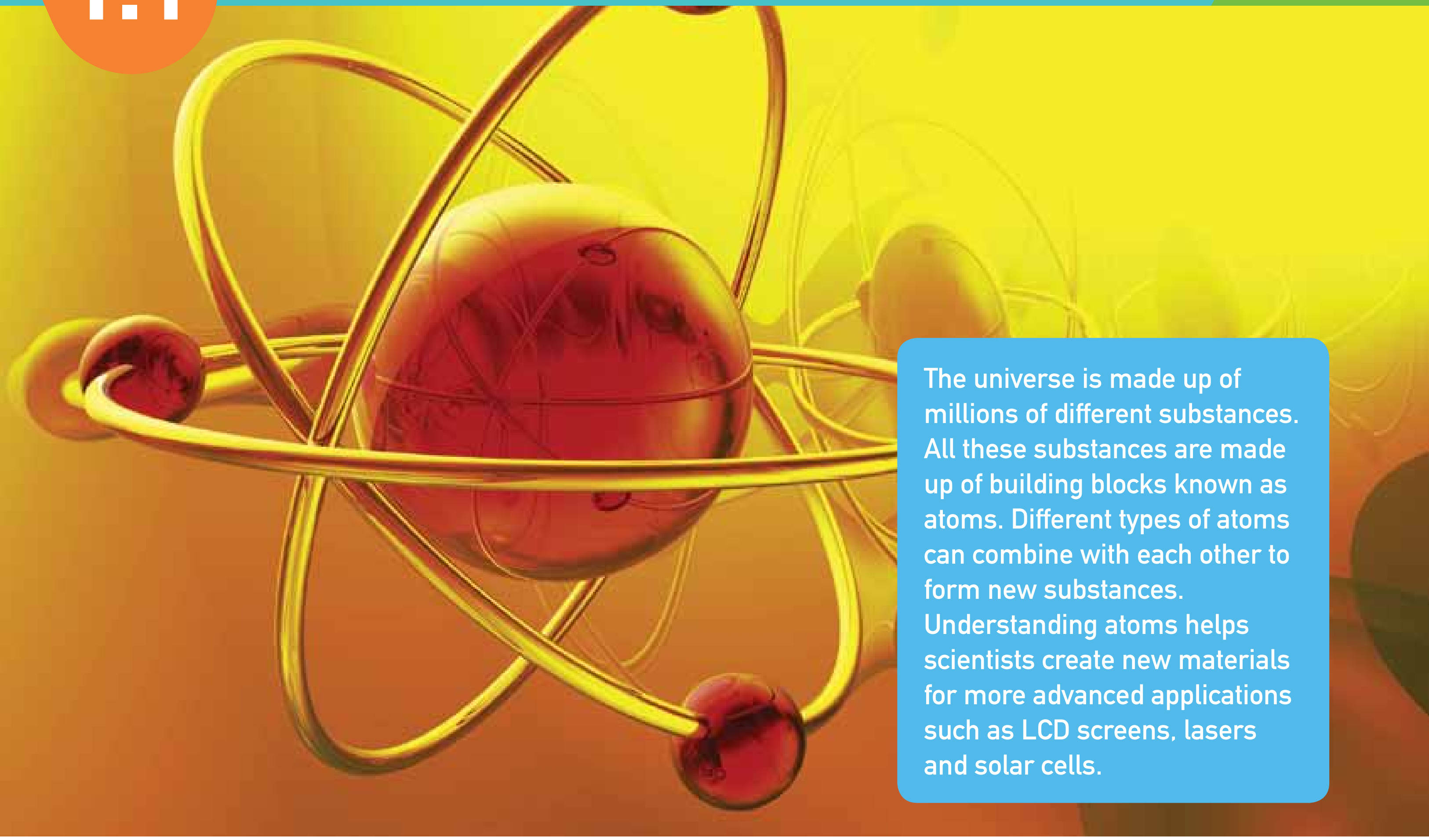
## HAVE YOU EVER WONDERED …

- how fireworks produce different colours?
- what causes stalagmites and stalactites to grow inside caves?
- how lightning is formed?
- how to measure fossil age?
- where nuclear bombs get their destructive power?

## After completing this chapter students should be able to:

- describe the structure of an atom
- outline the development of atomic models
- distinguish between atoms and ions
- use chemical formulas to identify ionic compounds
- distinguish between chemical and nuclear reactions
- compare the properties of protons, neutrons and electrons
- describe how alpha and beta particles and gamma radiation are released from unstable atoms.

# 1.1 Atoms



The universe is made up of millions of different substances. All these substances are made up of building blocks known as atoms. Different types of atoms can combine with each other to form new substances. Understanding atoms helps scientists create new materials for more advanced applications such as LCD screens, lasers and solar cells.

## Atomic building blocks

Look around you and you will see thousands of different materials—paper, plastic, wood, glass, skin and many more. All these different materials are made up of tiny building blocks, known as **atoms**.

Atoms are so small that they cannot be seen by even the most powerful optical microscope. To see atoms, scientists must use a special type of microscope known as a scanning tunnelling microscope or STM. Figure 1.1.1 shows an image of silicon atoms taken with an STM. Atoms can stick together in different combinations to build countless types of different substances.

There are 118 known types of atoms and only 91 of these are found naturally on Earth. The remaining 27 types of atoms must be made in a laboratory. Scientists list the 118 atoms from smallest to largest on the periodic table as shown in Figure 1.1.2. Each square in the **periodic table** represents one type of atom and is labelled with the atom's chemical name and chemical symbol.

**SciFile**

### Temporary elements

The existence of elements 113 to 118 is difficult to confirm because they are so radioactive that they can only exist for a fraction of a second. Until confirmed, these elements are given temporary names and temporary symbols of three letters.

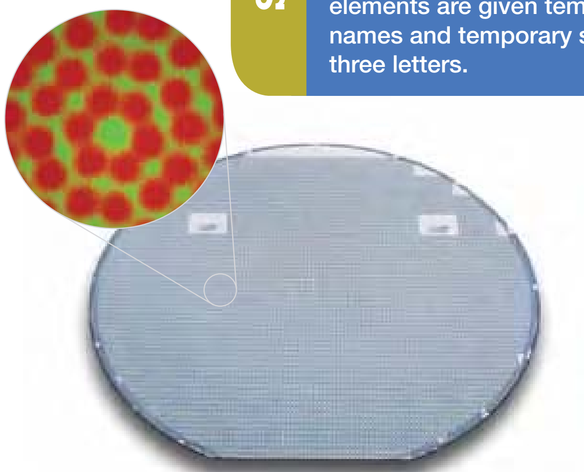


Figure 1.1.1 Billions of silicon atoms stick together like blocks of Lego to create this wafer of pure silicon. Silicon wafers are mostly used in the computer industry to make microchips.

KEY

- Non-metals
- Metals
- Metalloids

atomic number — 13
symbol — **Al**
name — aluminium

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 **H** hydrogen | | | | | | | | | | | | | | | | | 2 **He** helium |
| 3 **Li** lithium | 4 **Be** beryllium | | | | | | | | | | | 5 **B** boron | 6 **C** carbon | 7 **N** nitrogen | 8 **O** oxygen | 9 **F** fluorine | 10 **Ne** neon |
| 11 **Na** sodium | 12 **Mg** magnesium | | | | | | | | | | | 13 **Al** aluminium | 14 **Si** silicon | 15 **P** phosphorus | 16 **S** sulfur | 17 **Cl** chlorine | 18 **Ar** argon |
| 19 **K** potassium | 20 **Ca** calcium | 21 **Sc** scandium | 22 **Ti** titanium | 23 **V** vanadium | 24 **Cr** chromium | 25 **Mn** manganese | 26 **Fe** iron | 27 **Co** cobalt | 28 **Ni** nickel | 29 **Cu** copper | 30 **Zn** zinc | 31 **Ga** gallium | 32 **Ge** germanium | 33 **As** arsenic | 34 **Se** selenium | 35 **Br** bromine | 36 **Kr** krypton |
| 37 **Rb** rubidium | 38 **Sr** strontium | 39 **Y** yttrium | 40 **Zr** zirconium | 41 **Nb** niobium | 42 **Mo** molybdenum | 43 **Tc** technetium | 44 **Ru** ruthenium | 45 **Rh** rhodium | 46 **Pd** palladium | 47 **Ag** silver | 48 **Cd** cadmium | 49 **In** indium | 50 **Sn** tin | 51 **Sb** antimony | 52 **Te** tellurium | 53 **I** iodine | 54 **Xe** xenon |
| 55 **Cs** caesium | 56 **Ba** barium | 57–71 lanthanoids | 72 **Hf** hafnium | 73 **Ta** tantalum | 74 **W** tungsten | 75 **Re** rhenium | 76 **Os** osmium | 77 **Ir** iridium | 78 **Pt** platinum | 79 **Au** gold | 80 **Hg** mercury | 81 **Tl** thallium | 182 **Pb** lead | 83 **Bi** bismuth | 84 **Po** polonium | 85 **At** astatine | 86 **Rn** radon |
| 87 **Fr** franchium | 88 **Ra** radium | 89–103 actinoids | 104 **Rf** rutherfordium | 105 **Db** dubnium | 106 **Sg** seaborgium | 107 **Bh** bohrium | 108 **Hs** hassium | 109 **Mt** meitnerium | 110 **Ds** darmstadium | 111 **Rg** roentgenium | 112 **Cn** copernicium | 113 **Uut** ununtrium | 114 **Uuq** ununquadium | 115 **Uup** ununpentium | 116 **Uuh** ununhexium | 117 **Uus** ununseptium | 118 **Uuo** ununoctium |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lanthanides | 57 **La** lanthanum | 58 **Ce** cerium | 59 **Pr** praseodymium | 60 **Nd** neodymium | 61 **Pm** promethium | 62 **Sm** samarium | 63 **Eu** europium | 64 **Gd** gadolinium | 65 **Tb** terbium | 66 **Dy** dysprosium | 67 **Ho** holmium | 68 **Er** erbium | 69 **Tm** thulium | 70 **Yb** ytterbium | 71 **Lu** lutetium |
| Actinides | 89 **Ac** actinium | 90 **Th** thorium | 91 **Pa** protactinium | 92 **U** uranium | 93 **Np** neptunium | 94 **Pu** plutonium | 95 **Am** americum | 96 **Cm** curium | 97 **Bk** berkelium | 98 **Cf** californium | 99 **Es** einsteinium | 100 **Fm** fremium | 101 **Md** mendelevium | 102 **No** nobelium | 103 **Lr** lawrencium |

**Figure 1.1.2** The periodic table of elements. Most chemical symbols are made up of one or two letters. The first is always capitalised and the second is lowercase.

## Atoms in elements and compounds

When atoms stick together they can form either clusters of atoms known as **molecules** or large grid-like structures known as **crystal lattices**. Examples of both are shown in Figure 1.1.3. For example, water ($H_2O$) is made up of molecules. Every water molecule is identical and contains two hydrogen atoms (H) and one oxygen atom (O). On the other hand, a grain of beach sand is a crystal lattice of silicon (Si) and oxygen (O) atoms. The number of atoms in the lattice depends on the size of the grain of sand.

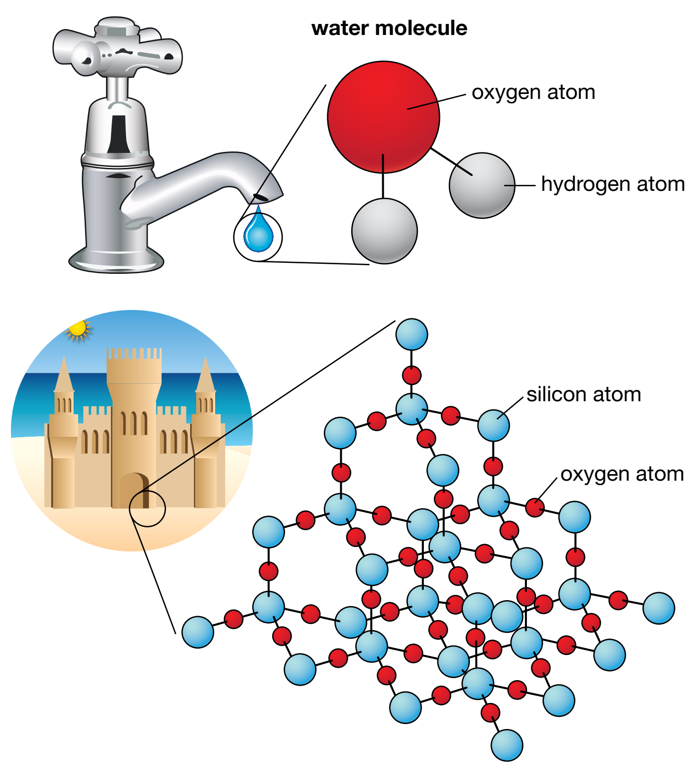



**Figure 1.1.3** Atoms can form molecules like the water molecule, or large crystal lattices like the silicon and oxygen atoms in beach sand.

**SciFile**

**The atomic universe**

Approximately 98% of the atoms in the universe are either hydrogen (H) or helium (He) atoms. These atoms make up the Sun and the stars. The other types of atoms make up only 2% of all the atoms in the universe.

## Elements

If a substance is made up of just one type of atom, it is referred to as an **element**. Molecular elements are made up of small molecules like the ones shown in Figure 1.1.4. Carbon is a unique element because carbon atoms can form extremely large molecules. A buckyball is made up of 60 carbon atoms ($C_{60}$) in the shape of a soccer ball, and a nanotube can have thousands of carbon atoms forming a long cylinder.

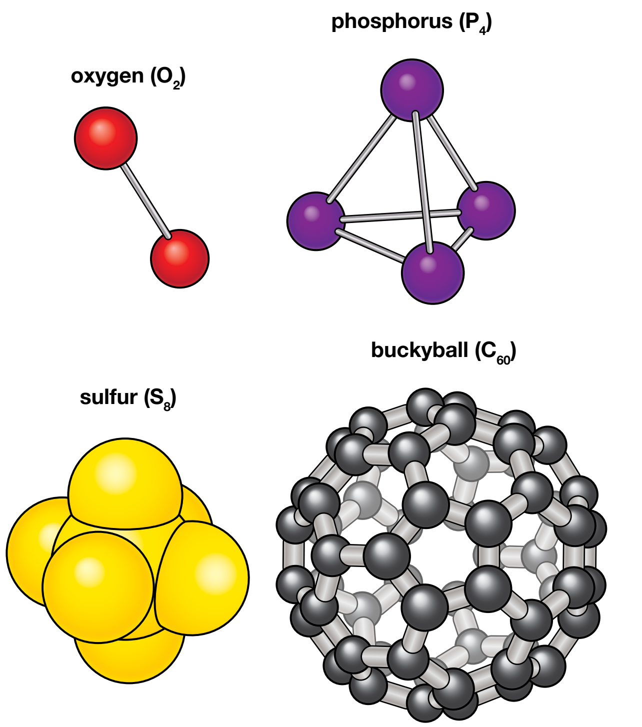



Figure 1.1.4 In these molecular elements, each molecule is made up of just one type of atom. This diagram shows two different ways of showing the structure of molecules.

Carbon is also the only non-metallic element that can also form crystal lattices. The diamond found in jewellery and the graphite in pencil 'leads' are two forms of carbon crystal lattices. Metallic elements always form crystal lattices. Figure 1.1.5 shows a comparison of these two types of lattices.

## Compounds

If a substance is made up of molecules or a crystal lattice with different types of atoms, then it is known as a **compound**. The molecules that make up compounds range from small to very large. For example, the sugar molecule in Figure 1.1.6 is made up of just 24 atoms. In contrast, a single molecule of DNA inside your cells is made up of billions of atoms and can be stretched to over a metre in length.

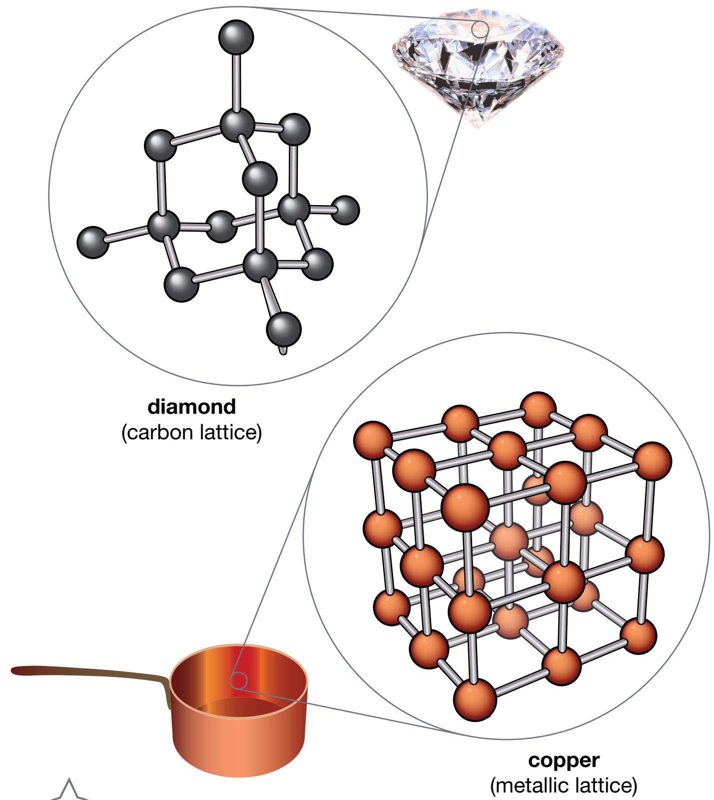



Figure 1.1.5 Crystal lattices made of carbon atoms or copper atoms

Many compounds are crystal lattices. Common table salt is a lattice of sodium (Na) and chlorine (Cl) arranged into a three-dimensional grid, as shown in Figure 1.1.6.

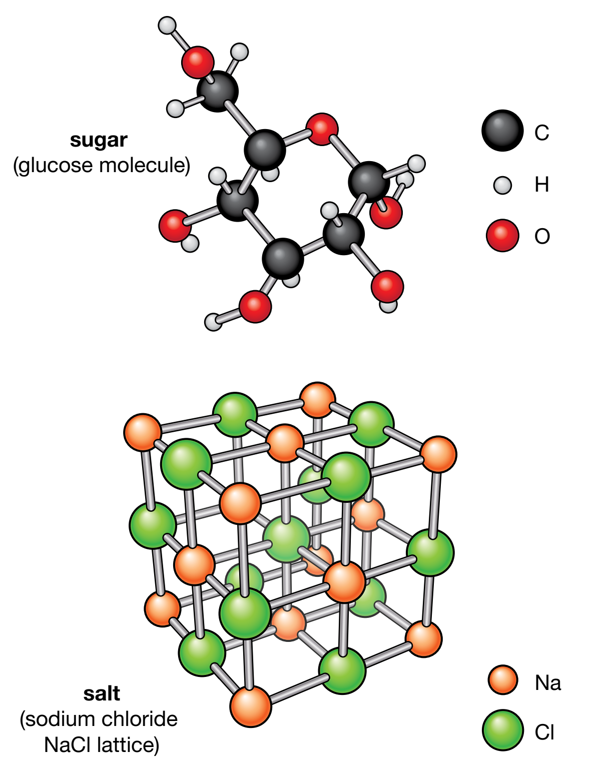



Figure 1.1.6 A sugar molecule and a sodium chloride lattice are both compounds because they both contain more than one type of atom.

# Inside atoms

Scientists once thought that atoms were hard and unbreakable. Today, they know that atoms are made up of even smaller particles known as subatomic particles. Each atom is made up of three types of subatomic particles: **protons**, **neutrons** and **electrons**.

The protons and neutrons form a cluster that sits at the centre of the atom, as shown in Figure 1.1.7. This cluster is known as the **nucleus**. The electrons are much smaller and move very fast around the nucleus in shells. These shells form an electron cloud that surrounds the nucleus.

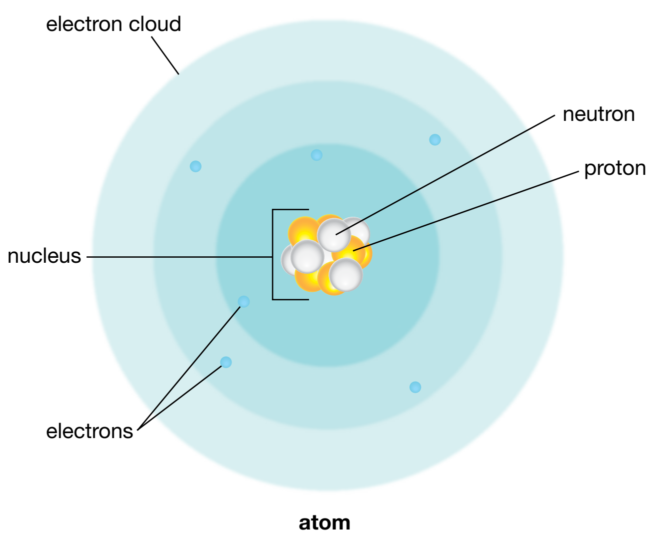



**Figure 1.1.7** Atoms are made up of subatomic particles known as protons, neutrons and electrons.

Table 1.1.1 summarises some of the important properties (characteristics) of protons, neutrons and electrons. Protons and neutrons are similar in size. However, protons have a positive electric charge while neutrons have no electric charge. Electrons are approximately 1800 times smaller than protons and neutrons, and have a negative electric charge.

**Table 1.1.1 Properties of subatomic particles**

| Subatomic particle | Location | Mass compared with the mass of an electron | Electric charge |
|---|---|---|---|
| Proton | Nucleus | x 1800 | +1 |
| Neutron | Nucleus | x 1800 | 0 |
| Electron | Electron cloud around the nucleus | x 1 | –1 |

The negatively charged electron causes it to be attracted to the positively charged protons in the nucleus. This is because opposite electric charges attract each other, a bit like the way opposite poles of a magnet attract each other. As a result, the electrons are held in their clouds around the nucleus.

**SciFile**

### The origin of atoms

The word 'atom' comes from the ancient Greek philosopher Democritus. He described them as *atomos*, which means unbreakable or indivisible.

**INQUIRY science 4 fun**

## Electrostatic attraction

Can you use electrostatic force to stick a balloon to the wall?

Yes

**Collect this ...**

- a balloon
- a head of clean, dry hair

**Do this ...**

1 Inflate the balloon and tie a knot in it.
2 Rub the balloon vigorously on the hair.
3 Gently place the balloon in contact with a wall and see if it will stay.

**Record this ...**

**Describe** what you saw.

**Explain** why you think this happened.

# Atomic nuclei

It is the number of protons in the nucleus that defines the type of atom, and therefore which element it belongs to. For example, all hydrogen (H) atoms have 1 proton in their nucleus, helium (He) atoms have 2 protons, lithium (Li) atoms have 3 protons, and so on. Scientists refer to the number of protons in the nucleus as the **atomic number**. The total number of protons and neutrons in the nucleus is the atom's **mass number**.

SKILL BUILDER

## Writing atomic symbols

To show the mass number and atomic number of an atom, scientists write an atomic symbol. The atomic symbol for helium is:

$$\text{Mass number} \rightarrow 4 \quad \text{Atomic number} \rightarrow 2 \quad {}^{4}_{2}\text{He}$$

The **atomic symbol** is made up of the chemical symbol for helium (He), with the mass number above and the atomic number below. From this symbol it is possible to work out the number of neutrons in the nucleus by subtracting the atomic number from the mass number.

Number of neutrons = 4 – 2 = 2

It is also possible to work out the number of electrons, which is equal to the atomic number:

Number of electrons = atomic number = 2

Therefore the atomic symbol can be used to obtain a complete description of the structure of the atom, which is illustrated in Figure 1.1.8.

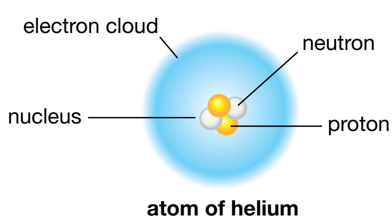



Figure 1.1.8 This helium atom has two protons and two neutrons. So its atomic number is 2 and its mass number is 4. Helium also has 2 electrons but these are not normally shown in the electron cloud.

### WORKED EXAMPLE
Atomic symbols and atomic structure

**Problem**

Determine the number of protons, electrons and neutrons in:

$${}^{39}_{19}\text{K}$$

**Solution**

1 Number of protons = atomic number = 19

2 Number of electrons = atomic number = 19

3 Number of neutrons = mass number – atomic number
= 39 – 19
= 20

1.1

## Isotopes

Atoms of the same element may have different numbers of neutrons. For example, most helium atoms have 2 protons and 2 neutrons. These atoms have a mass number of 4 and so are known as helium-4. However, helium-3 atoms also exist. Helium-3 atoms contain 2 protons but only 1 neutron, so their mass number is 3. Atoms that have the same number of protons but different numbers of neutrons are referred to as **isotopes**.

Almost every element has two isotopes and sometimes many more. Hydrogen has three isotopes: hydrogen-1, hydrogen-2 and hydrogen-3. These are shown in Figure 1.1.9. The most common isotope is hydrogen-1, which has a single proton as its nucleus. It makes up 99.98% of hydrogen atoms on Earth and is sometimes referred to as protium. Hydrogen-2 is more commonly known as deuterium and has 1 proton and 1 neutron. Hydrogen-3 is known as tritium and has 1 proton and 2 neutrons. These isotopes of hydrogen are used in nuclear power plants to make the generation of power more efficient.

1.2

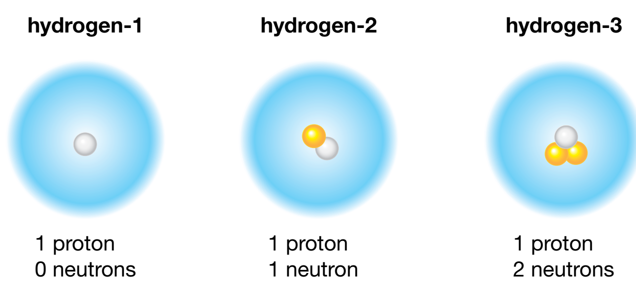



Figure 1.1.9 These isotopes of hydrogen all have the same number of protons but different numbers of neutrons.

# Electrons and the nucleus

The number of electrons surrounding the nucleus of an atom is exactly equal to the number of protons in the nucleus. As a result, atoms are charge **neutral** (have no charge) because the positive charge of the protons is exactly balanced by the negative charge of the electrons.

Although each electron is 1800 times smaller than a proton, together the electrons form 'clouds' around the nucleus. The clouds can be 100 or even 1000 times wider than the nucleus. This means that if the nucleus was the size of a golf ball, the electrons would form clouds the size of a football stadium. It also means that most of an atom is empty space.

**Mini-Me**
If all the electrons in your body collapsed onto the nuclei, you would shrink to the size of a flea. But you would still weigh the same.

SciFile

The New Zealand scientist Ernest Rutherford discovered that the nucleus only takes up a small fraction of the space inside an atom. In his famous experiment, Rutherford fired a beam of helium nuclei (alpha particles) at a thin sheet of gold foil. This is shown in Figure 1.1.10. To his surprise, most of the nuclei passed straight through the foil and only a small fraction were deflected back. Up until that point, most scientists had believed that atoms were completely solid. Rutherford realised that atoms are mostly empty space. However, they had a small, positively charged nucleus surrounded by a cloud of electrons.

1 p11

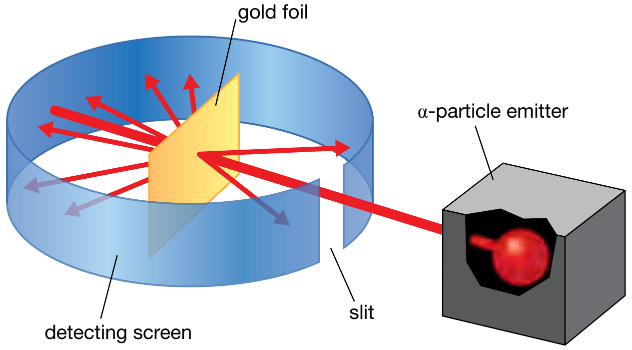



Figure 1.1.10 In Rutherford's famous experiment, a beam of helium nuclei (alpha particles) was fired at gold foil. Most of the alpha particles went straight through and only a small number were deflected. He concluded that atoms are mostly empty with a small, positively charged nucleus and a large negatively charged electron cloud.

## Electron shells

The electrons in an atom are attracted to the nucleus by the positive charge of the protons. However, the electrons never fall into the nucleus. This is because the electrons are trapped inside **electron shells**, which surround the nucleus like the layers of an onion, as shown in Figure 1.1.11.

**Jumpy electrons**
Electrons in atoms move constantly and can even jump up and down between the electron shells. When the electrons move between the electron shells, they produce coloured light. This is how fireworks produce their spectacular coloured light displays and also how neon signs work.

SciFile

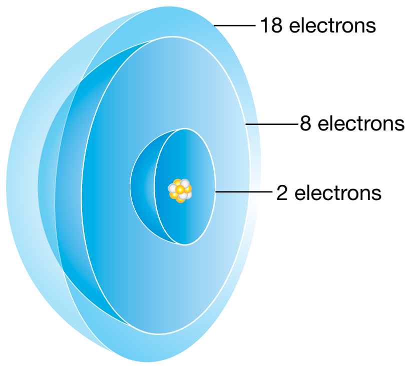



Figure 1.1.11 The electrons that surround an atom cannot move around freely. They are held in electron shells that surround the nucleus like layers of an onion. The number of electrons that each shell can hold depends on the size of the electron shell.

Many of the electron shells in an atom are empty. The biggest known element at present has 118 electrons in 6 shells. The 1st electron shell is the innermost shell. It is the smallest electron shell and can only contain 2 electrons. Once the 1st electron shell is full, electrons start to fill the 2nd electron shell, which can hold up to 8 electrons. The 3rd electron shell holds up to 18 electrons. The 4th electron shell can hold 32 electrons.

The number of electrons in each shell of an atom is known as its **electron configuration**. For example, carbon has 6 protons and therefore 6 electrons. The first 2 electrons fill the 1st electron shell, and the remaining 4 electrons go into the 2nd electron shell. Therefore the electron configuration for carbon is 2,4 as shown by the electron shell diagram in Figure 1.1.12.

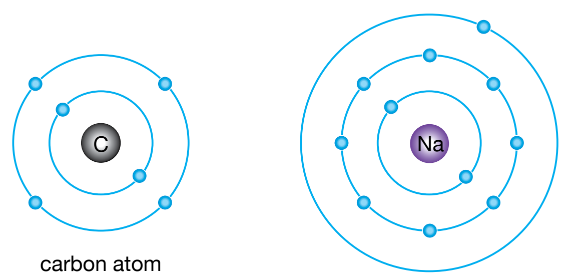



Figure 1.1.12 The electron configuration of an atom can be represented by electron shell diagrams. The electron shells are always filled from the innermost shell to the outermost shell. Carbon has only two shells occupied. Sodium has three shells occupied.

The electron configuration for a sodium atom is 2,8,1. This is because sodium atoms contain 11 electrons. The first 2 electrons fill the 1st electron shell, the next 8 electrons fill the 2nd electron shell, and the remaining electron goes into the 3rd electron shell.

2 p12
1.4

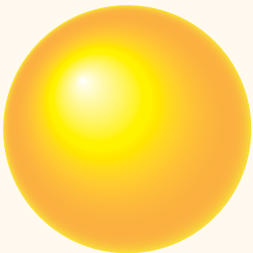
# SCIENCE AS A HUMAN ENDEAVOUR

## Nature and development of science

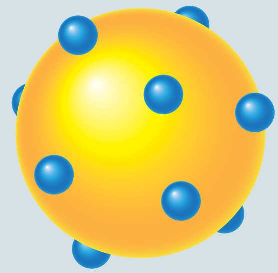
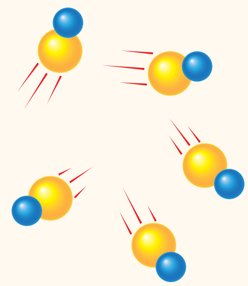
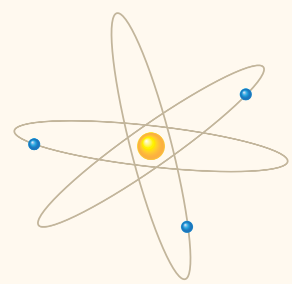
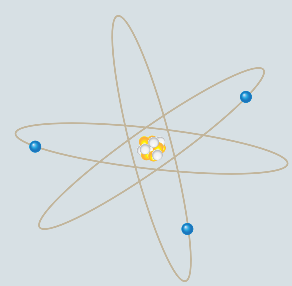
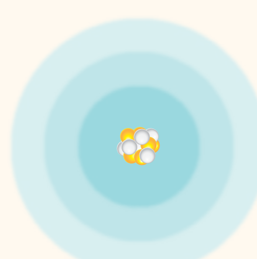
### History of the atomic model

**Figure 1.1.13** Model of a lattice

The internal structure of an atom cannot be seen with any microscope. Therefore scientists must rely on indirect observations to build a model of what is inside an atom. As technology has advanced, scientists' understanding of atoms has increased and the **atomic model** has evolved.

| Year | Observation and theory | Model |
|---|---|---|
| Early BCE | The ancient Greeks believed that all matter was made up of only four fundamental elements: earth, fire, air and water. This was the basis of the continuum model, which predicted that regardless of the number of times you halve a piece of matter, it can always be broken down into even smaller pieces. |  Continuum model |
| 460–370 BCE | Greek philosopher Democritus suggested that matter was not continuous but made up of tiny, solid and unbreakable particles. He was the first to use the term *atomos* meaning 'indivisible'. |  Solid-ball model |

1.3

| Year | Observation and theory | Model |
|---|---|---|
| 1904 | British scientist Joseph John Thompson (J.J. Thompson) discovered the electron and its negative charge in 1897. However, Thompson knew that there must also be a source of positive charge in the atom to make the atom charge neutral. Therefore, in 1904 he proposed the plum pudding model. In this model, an atom is thought of as a round ball of positive charge with negatively charged electrons embedded in it (like plums or sultanas in a plum pudding). |  Plum pudding model |
| 1904 | Hungarian scientist Philipp Lenard described atoms as mostly empty spaces filled with fast-moving ‘dynamides’. These were neutrally charged particles made up of a heavy positive particle stuck to a light negative particle. |  Dynamide model |
| 1911 | New Zealand scientist Ernest Rutherford performed an experiment where he fired a beam of positively charged alpha particles at gold foil. He found that while most of the alpha particles went through the foil, a small number were deflected. This led to the development of a nuclear model of the atom in which most of the mass is believed to be contained in a small positive nucleus surrounded by a large space occupied by negative electrons. |  Nuclear model |
| 1913 | Danish scientist Niels Bohr modified Rutherford’s model and proposed that electrons can only travel along certain pathways around the nucleus, called orbits. As a result, this model is sometimes called the planetary model. This model explained why different elements produce different-coloured light when heated. This observation is due to the electrons moving from higher to lower orbits and emitting coloured light in the process. |  Planetary model |
| 1932 | English scientist James Chadwick discovered the neutron, showing that the nucleus was not just a mass of positive charge but a cluster of positively charged protons and charge-neutral neutrons. |  Planetary model with neutrons |
| 1932–today | Today, scientists have concluded that the position of an electron in an atom can never be known exactly. This means that it is impossible for electrons to revolve around the nucleus in specific orbits as suggested by Niels Bohr. Instead, the electrons form clouds around the nucleus. Scientists can predict the shape of these clouds but never the exact location of electrons within them. |  Electron cloud model |

# 1.1 Unit review

## Remembering

1 **List** the three subatomic particles that make up atoms.

2 **State** Rutherford's famous discovery about the structure of the atom.

3 **Recall** the maximum number of electrons that can be held in the 1st, 2nd and 3rd electron shells.

4 **Name** the force that attracts the electrons to the nucleus.

5 **State** the name of the atomic model proposed by:
- a Ernest Rutherford
- b Niels Bohr
- c Philipp Lenard
- d Joseph John Thompson.

## Understanding

6 **Define** the term *isotope*.

7 **Define** the terms *atomic number* and *mass number*.

8 **Explain** why electrons:
- a form a cloud around the nucleus
- b don't fall into the nucleus.

9 **Explain** why an atom is electrically neutral.

10 **Describe** Rutherford's experiment and how it allowed him to understand more about the structure of an atom.

11 **Explain** what the atomic number tells you about the structure of an atom.

## Applying

12 **Identify** which atoms in Figure 1.1.14 are isotopes of the same element.

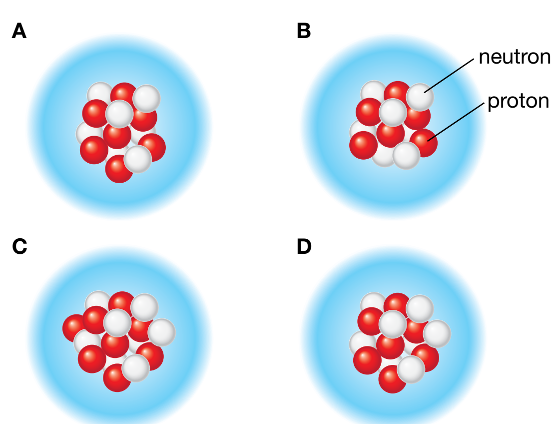



Figure 1.1.14

13 **Identify** the atomic symbol for the isotopes carbon-12, carbon-13 and carbon-14. (Hint: All carbon atoms have 6 protons.)

14 **Identify** the electron configuration of a magnesium atom (atomic number = 12).

## Analysing

15 **Compare** elements and compounds.

16 **Calculate** the number of protons, neutrons and electrons in the following atoms:
- a ${}^{4}_{2}\mathrm{He}$
- b ${}^{16}_{8}\mathrm{O}$
- c ${}^{28}_{14}\mathrm{Si}$
- d ${}^{207}_{82}\mathrm{Pb}$
- e ${}^{238}_{92}\mathrm{U}$

## Evaluating

17 **Evaluate** the view that atoms are like blocks of Lego.

18 **Propose** why scientists have developed atomic symbols to help communicate their results.

## Creating

19 **Construct** the electron shell diagram of a sulfur atom that has the electron configuration 2,8,6.

20 **Construct** a timeline showing the major developments towards the modern atomic model.

## Inquiring

1 Research the life and achievements of a scientist who has contributed to the understanding of the atomic model.

2 a Construct electron configuration diagrams for fluorine, neon and sodium.
- b Compare and contrast the three.
- c Use the available resources to research the following physical properties of each.
  - i Is it a metal or a non-metal?
  - ii Does it form molecules or crystal lattices, or exist as single atoms?
  - iii Is it a solid, a liquid or a gas at room temperature?
  - iv Does it react easily with other chemicals?
- d List three uses of each element.

# 1.1 Practical activities

## 1 Experimenting like Rutherford

### Purpose

To estimate the size of an unseen object through indirect observation.

### Materials

- a large cereal box with the top and bottom open
- objects of various shapes and sizes that can fit inside the box
- 5 marbles

### Procedure

1. This activity requires you to work in pairs.
2. Place the open cereal box on the desk as shown in Figure 1.1.15.

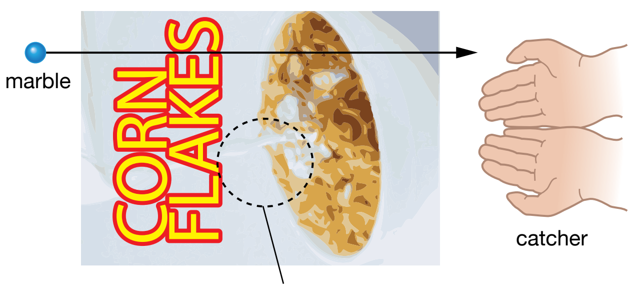



Figure 1.1.15

3. The first person places an object in the box without the other person seeing the object.
4. The second person then rolls the 5 marbles through the box and tries to estimate the size of the object.
5. Record your estimates in the table below and compare them to the real size of the object.
6. Repeat this process three more times, so that each member of the pair has two turns at determining the nature of the hidden object.

### Results

Record your results in a table like this one.

| | Estimated size | Real size |
|---|---|---|
| Object 1 | | |
| Object 2 | | |

### Discussion

1. **Explain** how this experiment is similar to Rutherford's experiment.
2. **Propose** the factors that might have influenced the accuracy of your estimates.
3. **Propose** other properties of the object that may be determined by indirect observation using this technique.

# 1.1 Practical activities

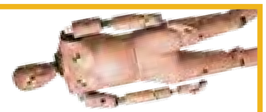
## 2 Indirect observation of electron shells

### Purpose

To observe coloured light produced when electrons jump from one electron shell to another.

### Materials

- cotton buds or small cotton balls
- chloride solutions of barium, sodium, copper, potassium and calcium
- 5 small beakers
- 1 large beaker of water
- Bunsen burner
- tongs



**SAFETY**

Some of the chemicals in this prac are toxic. Make sure you wear safety glasses and gloves when handling chemicals. Avoid contact with skin, mouth and eyes. Wash your hands thoroughly at the end of the practical.

### Procedure

1. Copy the table from the results section into your notes.
2. Pour about 2 to 5 mL of the chloride solutions into labelled beakers—one per beaker. Label the beakers so you can identify each solution.
3. Light the Bunsen burner, leaving it on the yellow safety flame until you are ready to insert a saturated cotton bud or ball. Fill another beaker with water.
4. With the tongs pick up the cotton bud or ball and soak it in the barium chloride solution.
5. Place the soaked cotton bud in the blue flame of the Bunsen burner for about 2 seconds and observe the flame colour. Immediately remove the cotton bud or ball and drop it in the beaker of water. Do not let it catch fire. Record the results in your table.
6. Repeat the procedure for the remaining solutions.

### Results

Copy the following table into your workbook and complete it.

| Solution | Metal element | Observation |
|---|---|---|
| Barium chloride | | |
| Sodium chloride | | |
| Copper chloride | | |
| Potassium chloride | | |
| Calcium chloride | | |

### Discussion

1. Different-coloured light is produced depending on whether the electron shells are far apart or close together.
   - When the electron shells are far apart, green, blue or violet light is produced.
   - When the electron shells are close together, red, orange or yellow light is produced.

   **Use** your results to **classify** the compounds in your experiment as having electron shells that are either ‘far apart’ or ‘close together’.
2. **Propose** what compounds you might use to make green and purple fireworks.

# 1.2 Ions

Understanding more about how the electrons move inside an atom allows scientists to control how atoms react with each other. This control has led to the development of products such as artificial bones and wonder drugs that cure life-threatening diseases.

## Atoms and ions

Atoms are electrically neutral (have no charge) because they contain an equal number of positive protons and negative electrons. However, if an electron is removed or added, the atom becomes charged and is now called an **ion**. When an electron is removed from an atom, that atom becomes a positively charged ion. A positive ion is known as a **cation**. If an electron is added to an atom, that atom becomes a negatively charged ion. A negative ion is known as an **anion**.

### SciFile

**Walking on air**

The outer electrons of atoms repel each other when the atoms come very close together. This means that when you walk, the atoms on the sole of your shoe never really touch the ground. They are always separated from the atoms in the ground by a tiny distance—forced apart by the electrostatic repulsion.

## Cations

A cation is formed when an atom loses electrons. An atom will tend to form cations if its outermost electron shell is mostly empty. The atom will usually lose all the electrons in the outermost shell so that only filled shells remain, as demonstrated in Figure 1.2.1.

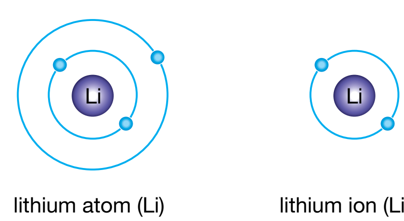



**Figure 1.2.1** Lithium forms a cation because its outermost shell is mostly empty.

Almost all cations come from metal atoms. This is because metal atoms have few electrons in their outermost electron shell and these electrons are only weakly bound to the atom. Table 1.2.1 lists some common cations.

**Table 1.2.1 Common cations**

| Charge | Cation name | Chemical symbol |
|---|---|---|
| +1 | Hydrogen ion | $H^+$ |
| | Lithium ion | $Li^+$ |
| | Sodium ion | $Na^+$ |
| | Potassium ion | $K^+$ |
| | Copper(I) ion | $Cu^+$ |
| +2 | Copper(II) ion | $Cu^{2+}$ |
| | Beryllium ion | $Be^{2+}$ |
| | Magnesium ion | $Mg^{2+}$ |
| | Iron(II) ion | $Fe^{2+}$ |
| +3 | Iron(III) ion | $Fe^{3+}$ |
| | Aluminium ion | $Al^{3+}$ |

An important non-metallic cation comes from hydrogen (H). Hydrogen ions ($H^+$) are formed whenever an acid is dissolved in water.

As you can see from Table 1.2.1, the symbols used to represent cations are made up of the atomic symbol and the charge on the ion. For example, sodium atoms (Na) lose one electron, so the sodium ion has a charge of +1. This is represented by the symbol $Na^+$. Magnesium (Mg) atoms lose two electrons and so the magnesium ion is represented as $Mg^{2+}$.

SKILL BUILDER

### Naming ions

The name of a cation is the same as the name of the atom. However, in some cases an atom can form more than one type of cation, depending on how many electrons it loses. For example, copper atoms (Cu) may lose one or two electrons to produce the copper ions $Cu^+$ and $Cu^{2+}$. To distinguish between these two ions, scientists add a roman numeral to the ion name that indicates the number of electrons lost. Therefore, the copper ion $Cu^+$ is referred to as the copper(I) ion. The ion $Cu^{2+}$ is referred to as the copper(II) ion. Iron (Fe) can also form two types of cations: iron(II) $Fe^{2+}$ or iron(III) $Fe^{3+}$.

Anions are named differently. The chemical name for an anion is similar to the name of the atom but ends in *-ide*. For example, chlorine atoms (Cl) form chloride ions $Cl^-$; oxygen atoms (O) form oxide ions $O^{2-}$ and nitrogen atoms (N) form nitride ions $N^{3-}$.

## Anions

An anion is produced when an atom gains electrons. This will occur if the outermost electron shell of the atom is almost full. In that case, the atom gains additional electrons until the shell is filled. This is shown in Figure 1.2.2.

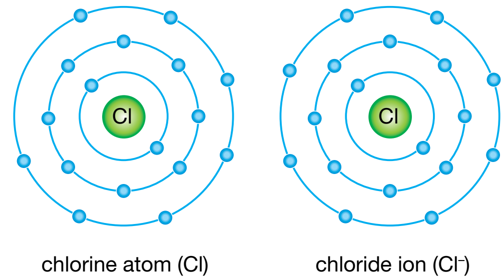



**Figure 1.2.2** Chlorine forms an anion because its outermost shell is almost full. The extra electron completes the electron shell.

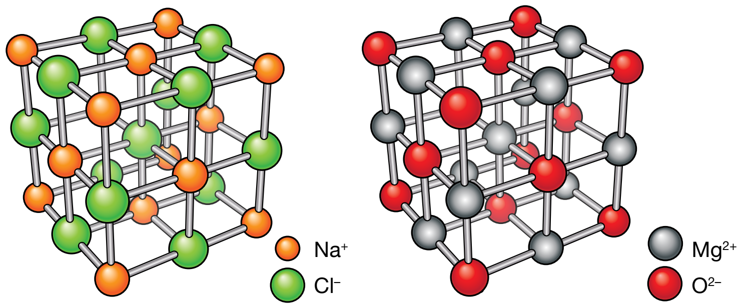
All anions come from non-metallic atoms. These atoms gain electrons in their outer electron shell. Table 1.2.2 lists some common anions. The symbols used to represent anions are similar to those used for cations. They are made up of the chemical symbol for the atom and the charge of the ion. For example, a chlorine atom gains one electron and so it has a charge of –1. Therefore, the ion is represented by the symbol $Cl^-$. An oxygen atom (O) gains two electrons, so the ion is represented as $O^{2-}$.

**Table 1.2.2 Common anions**

| Charge | Anion name | Chemical symbol |
|---|---|---|
| –1 | Fluoride | $F^-$ |
| | Chloride | $Cl^-$ |
| | Bromide | $Br^-$ |
| | Iodide | $I^-$ |
| –2 | Oxide | $O^{2-}$ |
| | Sulfide | $S^{2-}$ |
| –3 | Nitride | $N^{3-}$ |
| | Phosphide | $P^{3-}$ |

## Ionic compounds

When anions and cations come together, they form compounds made up of large crystal lattices. These compounds are known as **ionic compounds**. Common table salt is an ionic compound with the chemical name sodium chloride (NaCl). Other ionic compounds are lithium chloride (LiCl), potassium fluoride (KF) and magnesium oxide (MgO). Figure 1.2.3 shows two examples.




salt, or sodium chloride (NaCl)

magnesium oxide (MgO)

**Figure 1.2.3** Sodium chloride and magnesium oxide are ionic compounds.

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## Chemical names and formulas

Naming ionic compounds is very easy. You simply write the name of the cation followed by the name of the anion. For example, the ionic compound known as calcium oxide is made up of calcium cations ($Ca^{2+}$) and oxide anions ($O^{2-}$). The ionic compound known as copper(I) chloride is made up of copper(I) cations ($Cu^{+}$) and chloride anions ($Cl^{-}$).

Writing the chemical formula is slightly more difficult. When writing the chemical formula for an ionic compound, you must ensure that there is an equal number of positive and negative charges so that the total charge is zero. In the case of sodium chloride, the sodium ion has a charge of +1 and the chloride ion has a charge of –1. Therefore, the chemical formula is just NaCl because you only need one of each to balance the charges fully. The charges are not shown in the chemical formula because the total charge is zero.

However, in the case of magnesium chloride, the magnesium ion has a charge of +2 and the chloride ion has a charge of –1. Therefore, two chloride ions are needed to balance the charge of each magnesium ion. This is represented in the chemical formula by writing $MgCl_2$.

## Ionic bonding

Cations and anions are attracted to each other because they have opposite electric charges. When cations come close to anions, they stick together, forming an **ionic bond** as shown in Figure 1.2.4.

The ionic bonds holding crystal lattices together are very strong. Therefore, ionic compounds usually:

- are hard
- are brittle
- have high melting points.

SKILL BUILDER

### Writing ionic formulas

To determine the chemical formula of iron(III) oxide, you need to:

1 Identify the cation and anion, and write the chemical symbols for each.

| | |
|---|---|
| $Fe^{3+}$ | $O^{2-}$ |
| iron(III) cation | oxide anion |

2 Swap the charges on the ions, writing them at the bottom this time.

$Fe_{2-}$ $O_{3+}$

3 Remove the charges and write the two symbols together.

$Fe_2O_3$

4 Check to see if the numbers can be divided by the same number (common factor). If so, divide both by the common factor. In this case, 2 and 3 do not have a common factor, so the chemical formula remains:

$Fe_2O_3$

Opposite charges attract

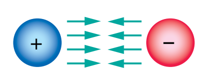



**Figure 1.2.4** In ionic compounds, the ions are held together by the electrostatic attraction of their opposite charges. An ionic bond is formed.

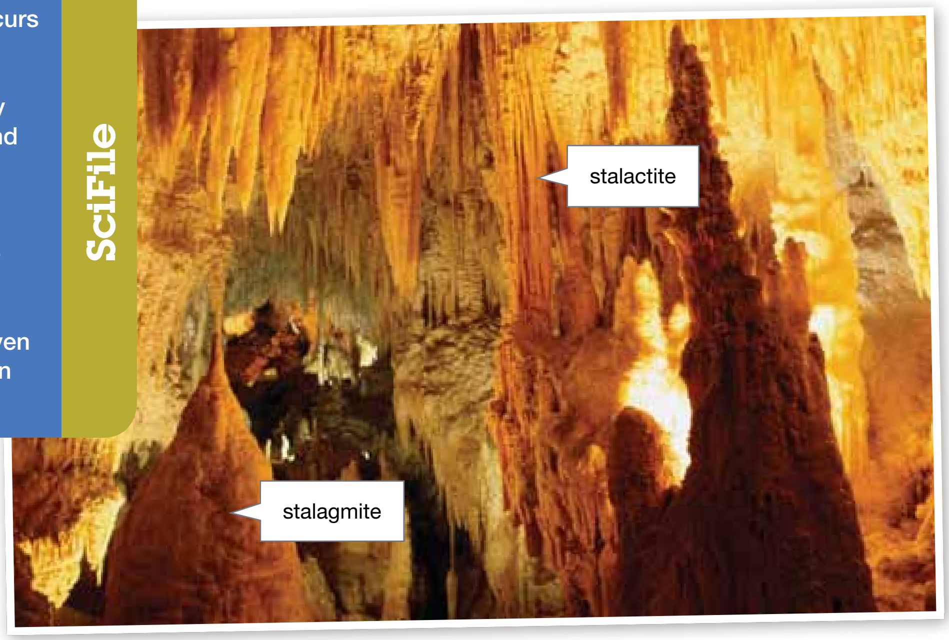
Ionic compounds are hard because it takes a lot of force to break the ionic bonds. They are brittle because the ionic bonds hold the ions in fixed positions and this means the lattice shatters rather than bends. They have high melting points because high temperatures are required to break the strong ionic bonds and allow the ions to flow freely as a liquid. Ionic compounds are also often brightly coloured, like the ones in Figure 1.2.5.

**Figure 1.2.5** These brightly coloured crystals are all examples of ionic compounds.

**Cave crystals**

The process of recrystallisation occurs continually in caves to form stalagmites and stalactites. Stalagmites and stalactites are very large crystals that form when ground water seeps through the roof of a cave, bringing with it dissolved calcium compounds. The drops of water deposit small amounts of the calcium compound crystals on the roof of the cave and on the floor directly below. Over hundreds or even thousands of years this process can grow crystals over 50 metres high.

SciFile




## Ions in solution

Some ionic compounds are soluble (dissolve) in water, while others are insoluble (do not dissolve). How easily an ionic compound dissolves is known as its **solubility**.

When an ionic compound dissolves in water, the water particles surround the cations and anions. This is shown in Figure 1.2.6. This breaks the crystal lattice apart and prevents the ions from sticking back together. The ions are then spread evenly throughout the water and they are said to be *in solution*. If the water is then removed through boiling or evaporation, the ions can stick together once more. This process is known as recrystallisation. An example of recrystallised crystals is shown in Figure 1.2.7.

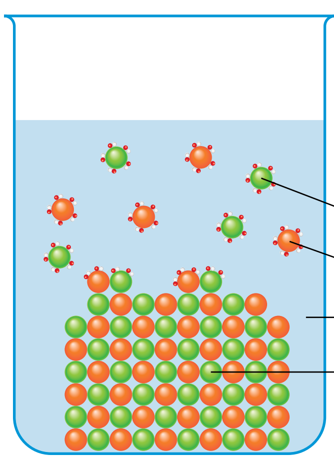



Figure 1.2.6 When an ionic compound dissolves in water, the water particles surround the ions and distribute them evenly throughout the solution.

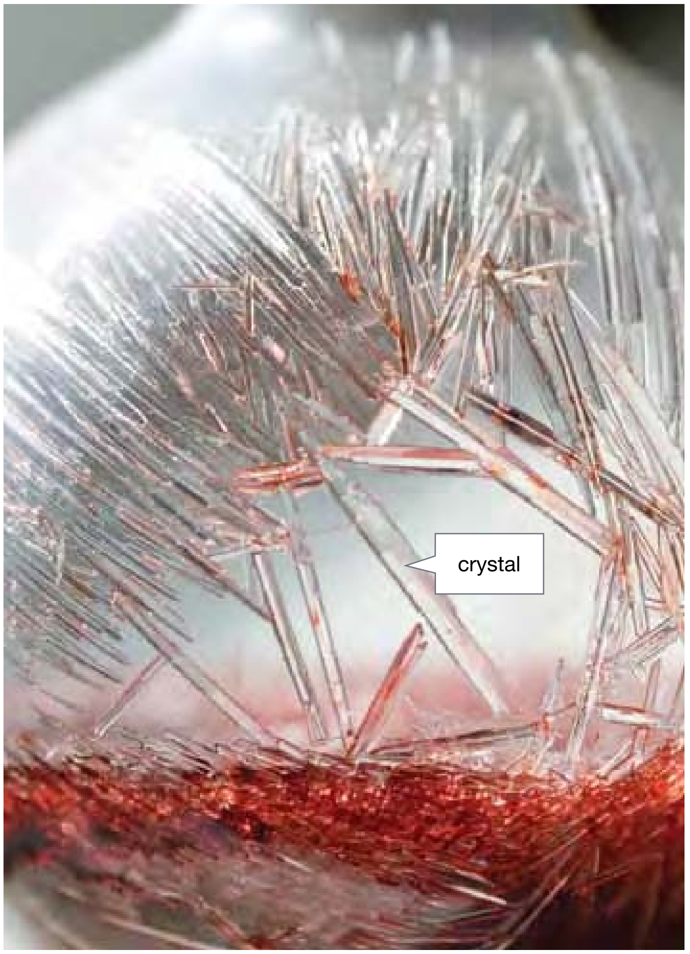



Figure 1.2.7 When an ionic compound dissolves in water, it forms a clear solution. When the water is removed by evaporation or boiling, the ionic compound recrystallises.

## Inquiry science 4 fun

### Recrystallising ionic compounds

How does the rate of recrystallisation affect the shape of crystals?

**Collect this ...**

- table salt (or any other soluble ionic compound)
- beaker or other glass container
- water
- spoon or stirring rod
- two watch-glasses or small dishes.
- magnifying glass (optional)

**Do this ...**

1. Fill the beaker with water and dissolve as much salt as possible, stirring as you go.
2. Pour a small amount of the salt solution into each of the watch-glasses or dishes.
3. Place one watch-glass in a cool dark place and the other in a warm sunny place.
4. Leave both solutions to evaporate completely.
5. Examine the shape of the crystals in both watch-glasses.

**Record this ...**

**Describe** what you saw.

**Explain** why you think this happened.

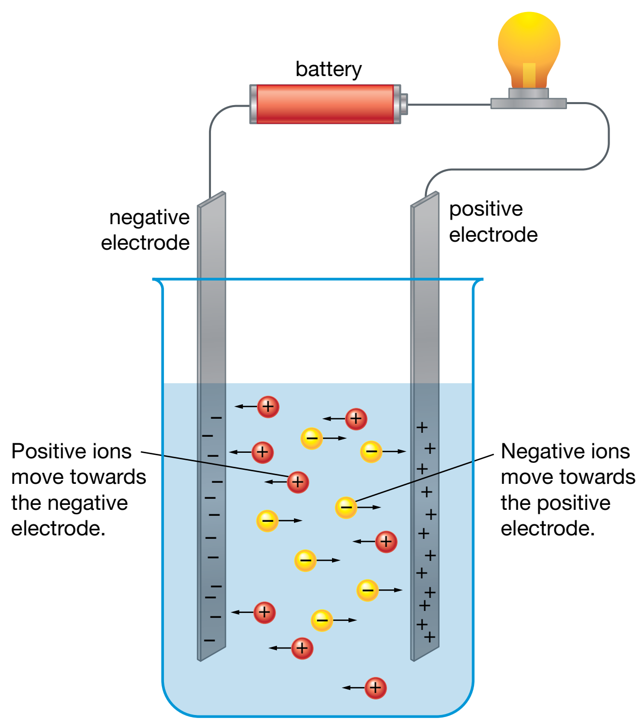



Figure 1.2.8 When positive and negative electrodes are put into a solution of an ionic compound, the cations (+) move towards the negative electrode and the anions (–) move towards the positive electrode. This allows electrical current to flow around the circuit.

When ions are in solution, they can move freely through the liquid. This means that they can create a flow of electrical charge and therefore they conduct electricity. If positive and negative electrodes are placed in the solution, the cations (+) will move towards the negative electrode and the anions (–) will move towards the positive electrode, as shown in Figure 1.2.8. This allows the electrical current to flow through the entire circuit. Only liquids that contain ions will allow electrical current to flow. Liquids such as oil or kerosene do not contain ions and therefore do not conduct electricity.

**SciFile**

**Lightning**

When lightning strikes during a thunderstorm it is because electrical charges in the clouds have become so strong that they ionise the atoms in the air. These regions of charged air particles allow the static charge in the clouds to travel down to the Earth's surface, producing a spectacular flash of light.

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# 1.2 Unit review

## Remembering

1 **List** the chemical names and symbols of three cations and three anions.

2 **Name** a non-metallic cation.

3 **State** how the end of the chemical name is changed to distinguish an anion from its atom.

4 **State** whether ionic compounds form molecules or crystal lattices or both.

5 **Recall** the term used to describe how well an ionic compound dissolves in water.

6 Name the following ions.
- a $K^+$
- b $Br^-$
- c $S^{2-}$

## Understanding

7 **Define** the terms *cation* and *anion*.

8 a **Explain** when the name of a cation might be followed by a roman numeral.
- b **State** an example.

9 **Outline** what happens when an ionic compound dissolves in water.

10 **Explain** why an electrical current can be passed through a solution of a dissolved ionic compound.

## Applying

11 **Identify** three ionic compounds that you might find around the home.

12 **Apply** your knowledge of ions to **explain** how the following are produced.
- a $Cl^-$
- b $Na^+$
- c $O^{2-}$
- d $Ca^{2+}$
- e $Al^{3+}$

13 **Identify** the ionic compound formed and its chemical formula when the following form ionic bonds.
- a sodium cations ($Na^+$) and chloride anions ($Cl^-$)
- b magnesium cations ($Mg^{2+}$) and oxide anions ($O^{2-}$)
- c aluminium cations ($Al^{3+}$) and fluoride anions ($Fl^-$)
- d copper(II) cations ($Cu^{2+}$) and bromide anions ($Br^-$)
- e iron(III) cations ($Fe^{3+}$) and oxide anions ($O^{2-}$)

## Analysing

14 **Compare** atoms and ions.

15 **Compare** the names of the ions:
- a $Fe^{2+}$ and $Fe^{3+}$
- b $Cr^{4+}$ and $Cr^{6+}$

## Evaluating

16 An unknown element 'X' forms a cation with charge +3. Another unknown element 'Y' forms an anion with charge –2.
- a **Evaluate** which element is most likely to be:
  - i metallic
  - ii non-metallic.
- b **Propose** the chemical formula for the ionic compound formed from X and Y.

17 When ionic compounds are heated to high temperatures, they melt to form a liquid.
- a **Assess** whether or not this liquid will conduct electricity.
- b **Justify** your answer.

## Creating

18 **Construct** a labelled diagram of a solution of copper(II) chloride with positive and negative electrodes. Indicate on the diagram the direction in which the ions will move through the solution.

19 **Construct** electron shell diagrams of the following atoms and then write the symbol for the ion they form.
- a sodium (Na) 2,8,1
- b fluorine (F) 2,7
- c oxygen (O) 2,6

## Inquiring

1 Research the term *ionic liquids*. What are they and how could they be useful?

2 The ionosphere is the uppermost part of our atmosphere and contains ions. Research how the ionosphere is formed and how it is useful to humans.

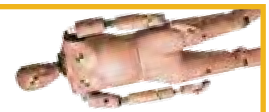
3 Design an experiment to test the hypothesis that ionic compounds such as salt cannot be dissolved in non-ionic solvents such as methylated spirits, glycerol or kerosene.

# 1.2 Practical activities

## 1 Making ionic compounds

### Purpose

To observe how two different ionic compounds can be created from two ionic compounds in solution.



**SAFETY**

Some of the chemicals in this prac are toxic. Be sure to wear safety glasses and gloves when handling chemicals. Avoid contact with skin, mouth and eyes. Wash your hands thoroughly at the end of the practical.

### Materials

- 0.1 M solution of sodium sulfide ($Na_2S$)
- 0.1 M solution of copper(II) chloride ($CuCl_2$)
- 3 large test-tubes in a test-tube rack
- small funnel
- filter paper
- pipette
- a 20 mL measuring cylinder
- 2 watch-glasses
- optional: hand lens or microscope

### Procedure

1. Copy the table from the results section into your workbook.
2. Use the pipette to measure out 10 mL of the sodium sulfide solution and pour this into a large test-tube.
3. Rinse the measuring cylinder.
4. Measure out 10 mL of the copper(II) chloride solution and add it to a different test-tube.
5. Create the insoluble compound copper(II) sulfide by pouring the sodium sulfide into the test-tube with the copper(II) chloride solution.
6. Place the funnel into the third test-tube and add a fluted filter paper to it.
7. Separate the solid copper(II) sulfide from the liquid by pouring the mixture through the filter paper.
8. Place the filter paper on a watch-glass, but open the paper up and leave it to dry overnight.
9. Observe the copper(II) sulfide using your eyes, a hand lens or a microscope.
10. Pour some of the filtrate solution from the test-tube into a watch-glass and leave it in a warm place to evaporate overnight. This should recrystallise an ionic solid.
11. Observe the crystals on the watch-glass, using your eyes, a hand lens or a microscope.

### Results

Construct and complete the following table.

| | Observations |
|---|---|
| The 0.1 M solution of sodium sulfide | |
| The 0.1 M solution of copper(II) chloride | |
| The mixture of the two solutions | |
| The solid copper(II) sulfide after filtration | |
| The remaining solution (filtrate) after filtration | |
| The copper(II) sulfide after drying | |
| The recrystallised ionic compound | |

### Discussion

1. **List** all the cations and anions involved in this experiment.
2. a **Describe** what happened when the two initial solutions were mixed.
   b **Explain** why this happened.
3. **Deduce** which ions went into making the solid in the filter paper and then write its chemical formula.
4. **Deduce** which ions must have been left in solution after the solutions were mixed.
5. **Predict** the chemical name and chemical formula of the recrystallised solid.
6. **Propose** whether the re-cystallised compound is pure or not. Use your observations to support your answer.

## 2 Detecting ions by indirect observation

### Purpose

To use electrical conduction to determine whether common household compounds form ions.

### Materials

- 250 mL beaker
- distilled water
- sugar (sucrose)
- salt
- tea bag
- coffee
- vinegar
- vegetable oil
- 1.5V battery or DC voltage source
- wires with alligator clips
- ammeter
- electrodes

### Procedure

1 Copy the table from the results section into your workbook.

2 Use the wire to connect the voltage source, ammeter and electrodes in a circuit as shown in Figure 1.2.9.

3 Fill a beaker with distilled water.

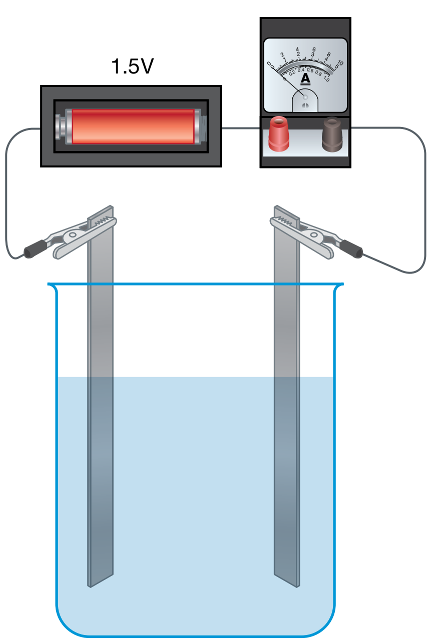



Figure 1.2.9

4 Place the electrodes in the water and record the current.

5 Replace the distilled water with a salt water solution and repeat the measurement with the ammeter.

6 Rinse the beaker and the electrodes with distilled water.

7 Make up separate solutions of sugar, coffee and tea using distilled water.

8 Repeat the measurement of current for all the other solutions, remembering to rinse the beaker and electrodes with distilled water each time.

### Extension

9 Repeat step 4 but try a globe in place of an ammeter. Will the globe light up?

### Results

Construct and complete the following table.

| Solution | Current detected? (Yes/No) | Ions present? (Yes/No) |
|---|---|---|
| Distilled water | | |
| Salt water solution | | |
| Sugar solution | | |
| Coffee solution | | |
| Tea solution | | |
| Vinegar | | |
| Vegetable oil | | |

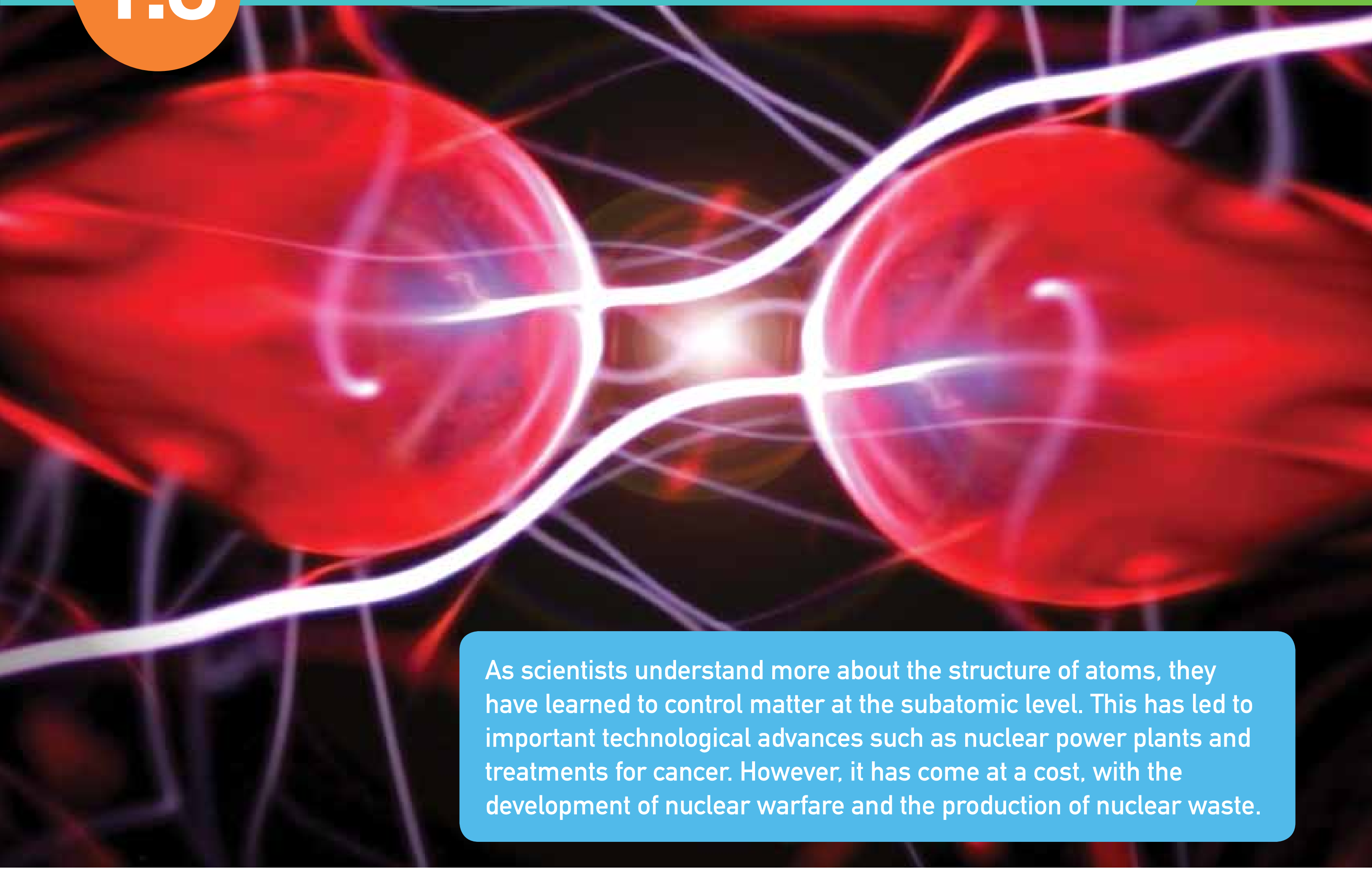
### Discussion

1 **List** all the solutions in which ions were present and all the solutions in which ions were not present.

2 **Explain** why a current flowing indicates the presence of ions.

3 In the cases where no current flowed, **propose** whether the compounds form atoms, molecules or lattices in solution. **Justify** your answer.

# 1.3 Nuclear decay and radiation



As scientists understand more about the structure of atoms, they have learned to control matter at the subatomic level. This has led to important technological advances such as nuclear power plants and treatments for cancer. However, it has come at a cost, with the development of nuclear warfare and the production of nuclear waste.

## Nuclear decay

A nucleus is a cluster of protons and neutrons that sits at the centre of an atom, surrounded by a cloud of tiny electrons. However, the nucleus is not just standing still. The protons and neutrons are constantly moving, vibrating, pulsating, rotating and rearranging, causing some to emit **electromagnetic radiation** called gamma rays. Occasionally, some nuclei even eject particles at high speed. This emission of electromagnetic radiation or particles is known as a **nuclear reaction** or **nuclear decay**.

During nuclear decay, atoms may change from one element to another. This change to another element is known as **transmutation**. Transmutation never occurs during everyday chemical reactions such as those that happen when you breathe, bake a cake or burn paper. It only occurs during nuclear decay.

An example of nuclear decay is an atom of sodium (Na) metal changing into the noble gas, neon (Ne). You can see this in Figure 1.3.1.

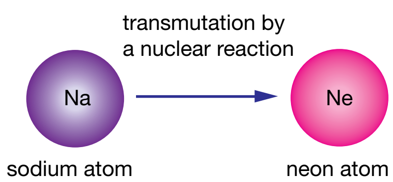



Figure 1.3.1 When a sodium (Na) atom undergoes nuclear decay, it changes into a different atom entirely—neon (Ne). This process is known as transmutation.

**SciFile**

**Ambitious alchemists**

In the Middle Ages, people known as alchemists tried to turn lead into gold through magic and various chemical reactions. Today, scientists know the alchemists' attempts were pointless and that only transmutation could convert lead into gold.

# Types of nuclear decay

There are three types of nuclear decay. These are alpha decay, beta decay and gamma decay.

## Alpha decay

During **alpha decay**, a nucleus ejects an **alpha particle**, which is a cluster of two protons and two neutrons. The alpha particle is given the symbol α. However, the particle is identical to a helium-4 nucleus, and so it may also be referred to as ${}^{4}_{2}He^{2+}$.

Alpha decay only occurs in atoms with very heavy nuclei—this is usually where the mass number (protons plus neutrons) is greater than 100. For example, the radioisotope uranium-238 (${}^{238}_{92}U$) undergoes alpha decay as shown in Figure 1.3.3.

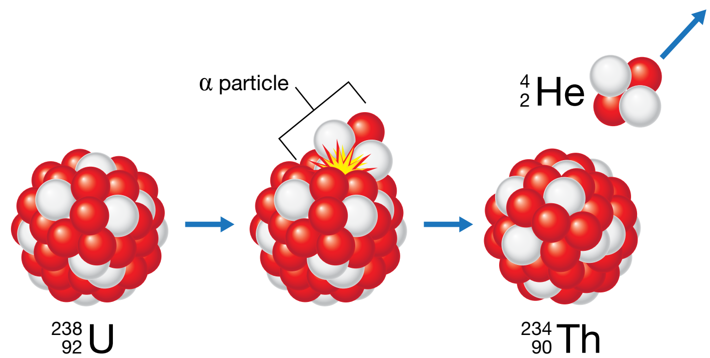



**Figure 1.3.3** When a uranium-238 nucleus undergoes alpha decay, it becomes a thorium-234 atom. The element uranium has become the element thorium.

Initially, the uranium-238 atom has 92 protons and 146 neutrons. When the uranium-238 ejects an alpha particle, the nucleus loses 2 protons and 2 neutrons. Therefore, the atom becomes a thorium-234 atom with 90 protons and 144 neutrons. In other words, the atomic number has decreased by 2 while the mass number has decreased by 4. Through this nuclear reaction, the uranium atoms become thorium atoms, an entirely different element.

## Beta decay

**Beta decay** occurs when the nucleus ejects a **beta particle**, which is given the symbol β. Beta particles are identical to electrons and therefore are very small and have a negative charge. When the nucleus undergoes beta decay, a neutron is converted into a proton. This increases the atomic number by one, meaning a new element is formed. However, the mass number does not change because the total number of protons and neutrons stays the same.

# Radioisotopes

Most of the atoms that make up the world around you contain **stable nuclei**. This means that the nuclei will never undergo nuclear decay. However, a tiny fraction of atoms have **unstable nuclei**. These unstable atoms could eject particles or electromagnetic waves from their nucleus at any moment and undergo nuclear decay. These unstable atoms are known as **radioisotopes**.

Each type of atom may have several isotopes but only some isotopes are **radioactive**. Isotopes are atoms that have the same number of protons but a different number of neutrons. For example, carbon has three naturally occurring isotopes called carbon-12, carbon-13 and carbon-14, as shown in Figure 1.3.2. They are all types of carbon atoms because they all contain 6 protons. However, carbon-12 has 6 neutrons, carbon-13 has 7 neutrons and carbon-14 has 8 neutrons. As extra neutrons are added to a nucleus, it becomes unstable. For example, carbon-12 and carbon-13 are stable but carbon-14 is unstable and therefore is radioactive.

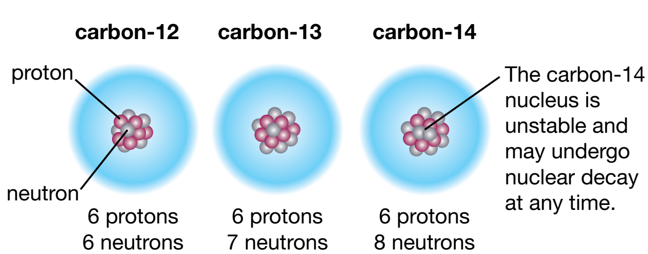



**Figure 1.3.2** Carbon has three naturally occurring isotopes: carbon-12, carbon-13 and carbon-14. The nucleus of carbon-14 is unstable, so carbon-14 is a radioisotope.

Carbon-14 undergoes beta decay as shown in Figure 1.3.4. The carbon-14 atom has 6 protons and 8 neutrons. When the atom ejects a beta particle (β), one of the neutrons becomes a proton. This turns the atom into a stable nitrogen-14 atom with 7 protons and 7 neutrons.

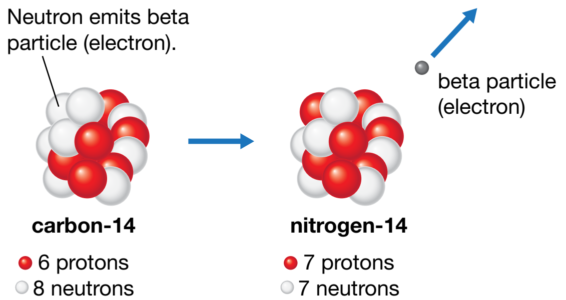



Figure 1.3.4 When a carbon-14 nucleus undergoes beta decay, it becomes a nitrogen-14 atom and emits a beta particle.

## Gamma decay

Sometimes the protons and neutrons simply rearrange inside the nucleus but do not emit a particle. Instead they emit a form of electromagnetic wave known as **gamma rays**. This process is known as **gamma decay**. Gamma rays are given the symbol γ. They are like X-rays but are more powerful. The three different types of decay are summarised in Table 1.3.1.

Table 1.3.1 Summary of the products of nuclear decay

| | Symbol | Equivalent to | Speed | Charge |
|---|---|---|---|---|
| Alpha particle | α | a helium nucleus | 10% the speed of light | +2 |
| Beta particle | β | an electron | 90% the speed of light | –1 |
| Gamma ray | γ | a high-energy X-ray | speed of light | 0 |

# Half-life

The rate at which nuclear decay takes place is measured by a radioisotope's **half-life**. The half-life of a radioisotope is the time it takes for half the nuclei to decay. For example, the radioisotope radon-222 decays into polonium-218 with a half-life of 4 days. This means that from 100 radon-222 atoms, 50 would decay over 4 days. Of the remaining 50 nuclei, 25 would decay over the next 4 days. And if you waited another 4 days, only 12 or 13 radon-222 atoms would remain. You can see this illustrated in Figure 1.3.5.

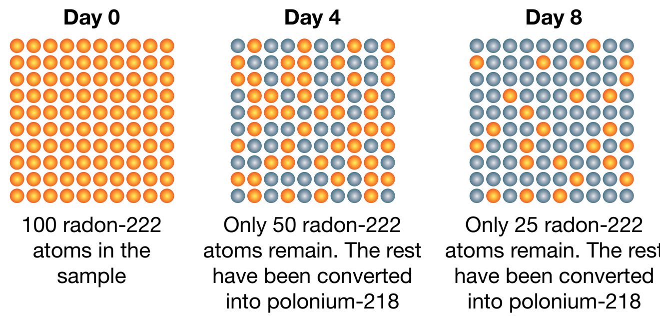



Figure 1.3.5 The number of radon atoms halves every four days.

The half-life of radioisotopes varies from a fraction of a second to millions of years. Table 1.3.2 lists the half-lives of some common radioisotopes.

Table 1.3.2 Half-lives of common radioisotopes

| Radioisotope | Half-life |
|---|---|
| Gold-200 | 48 minutes |
| Radon-222 | 4 days |
| Iodine-131 | 8 days |
| Cobalt-60 | 5.3 years |
| Americium-241 | 460 years |
| Carbon-14 | 5730 years |
| Plutonium-239 | 24 000 years |
| Uranium-238 | 4.5 million years |

## Carbon dating

Understanding the half-life of radioisotopes has proved very useful to historians and archaeologists. The half-life of carbon-14 is used to determine the age of fossils (like the one in Figure 1.3.6) and ancient materials through a process known as **carbon dating**.

Figure 1.3.6 Archaeologists use carbon dating to determine the age of fossils and artefacts. Artefacts are objects made by humans, such as tools.

Carbon dating relies on the fact that all living things contain a small amount of carbon-14. The amount remains constant throughout the lifetime of the plant or animal. This is because carbon-14 is constantly being absorbed by the organism through its food and air. However, when the organism dies, carbon-14 is no longer absorbed. At that point, the small amounts of carbon-14 in the organism begin to decay into nitrogen-14 with a half-life of 5730 years, as plotted in Figure 1.3.7.

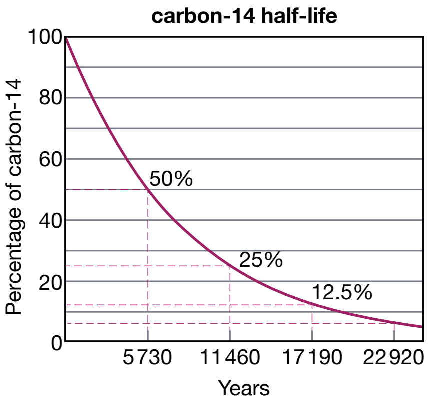



**Figure 1.3.7** The percentage of carbon-14 atoms in a plant or animal halves every 5730 years after it dies.

This means an animal that died 5730 years ago will have half the amount of carbon-14 compared with one living today. An animal that died 11 460 years ago will have a quarter the amount of carbon-14 and so on. Therefore, by measuring the amount of carbon-14 in fossils and bones, scientists can get an accurate idea of when the animal lived.

Trees and other plants also contain carbon-14. This means that scientists can also use this technique to calculate the age of tools, paper and fabrics made from plants.

1 p31
1.6

# Nuclear radiation

The term **nuclear radiation** describes any rays or particles emitted (released) by atomic nuclei. The term includes alpha particles, beta particles and gamma rays. Nuclear radiation can be extremely harmful, especially to living organisms. However, it can also be useful in medicine, industrial processes and scientific research.

# Biological effects of radiation

Alpha particles, beta particles and gamma rays are particularly damaging to the cells of living organisms. This is because radiation can enter the cells. Once inside, the radiation destroys biological molecules and causes unwanted chemical reactions.

Alpha particles, beta particles and gamma rays are referred to as **ionising radiation** because they can remove electrons from atoms and molecules. Exposing cells to ionising radiation can cause cells to die or mutate.

## Effects of cell death

Cell death occurs when ionising radiation enters the cell and destroys the biological molecules beyond repair. This may result in **radiation burns** or **radiation sickness**.

Radiation burns like the ones in Figure 1.3.8 are caused by short exposure to a very large amount of ionising radiation. The radiation damages the cells on the surface of skin or other organs, causing redness and blistering. However, the side effects are not immediately obvious. It may take 1 or 2 days for itching and redness to appear and then 1 to 3 weeks before the appearance of burns and blisters.

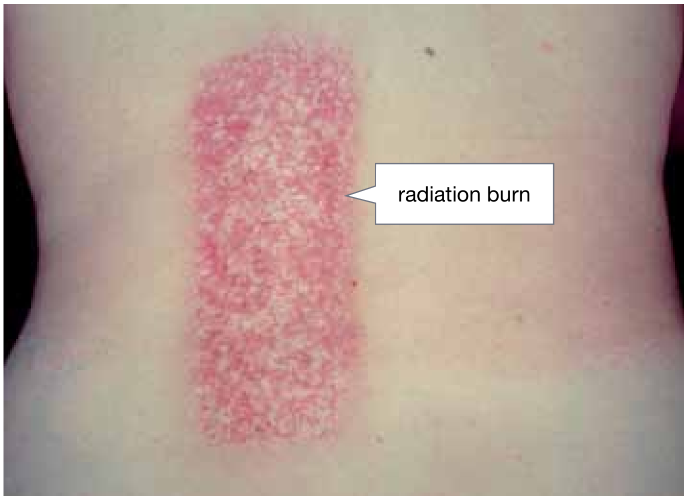



**Figure 1.3.8** Radiation burns can be just as severe as burns caused by a fire.

Radiation sickness may result from exposure to a large amount of radiation in a short amount of time, or a lower amount of radiation over a longer period of time. The symptoms include nausea, vomiting, fever, hair loss and diarrhoea. The symptoms may not appear immediately but will appear more quickly if the person has absorbed a larger amount of radiation.

## Effects of cell mutation

Cell **mutation** occurs when the ionising radiation damages the DNA inside the cell without causing the cell to die. The DNA inside a cell contains all the genetic information that tells the cell how to function properly. If the DNA is damaged, the cell is reprogrammed and may cause the cell to develop into a cancer, like the skin cancer in Figure 1.3.9. A cell mutation can be caused by even a small amount of radiation. However, the likelihood of cell mutation increases as the exposure to ionising radiation increases.

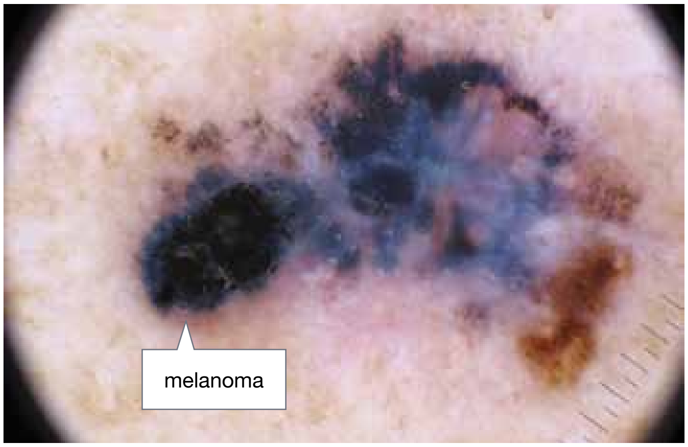



Figure 1.3.9 If ionising radiation damages the DNA in cells, it can cause them to turn into cancers. This malignant melanoma is one type of skin cancer.

If the ionising radiation causes a mutation in sperm or ova (egg cells), the offspring of the organism may be affected. This is known as genetic or inherited mutation. Different animals experience different levels of inherited mutations. For example, the mutations in the offspring of mice and fruit flies are increased significantly if the parents have been exposed to radiation.

However, in humans it is unclear whether large doses of radiation produce mutations in children. Scientists who studied the survivors of the nuclear bombs dropped on Nagasaki and Hiroshima in Japan in 1945 found that children of the survivors did not show an increase in genetic mutations. On the other hand, studies of men who worked with radioactive materials showed that the workers were more likely to have children with leukaemia.

## Dose

Whether or not an exposure to radiation is harmful depends on the type of radiation and the amount of radiation. The amount of radiation absorbed is known as the **dose**. Every day you receive harmless doses of radiation from radioisotopes in the ground and radiation that comes to Earth from distant stars. However, people who work with radioactive materials may be exposed to higher doses of radiation if they do not take the correct safety precautions.

A dose of radiation is measured in units called **sieverts**, which have the symbol Sv. A dose of 1 Sv is an extremely large dose that will cause severe radiation sickness. Therefore, scientists usually measure doses in microsieverts (μSv), which is one millionth of a sievert.

Every year you receive approximately 1400 μSv of radiation from isotopes in the ground (**terrestrial radiation**) and 300 μSv from outer space (**cosmic radiation**). These doses are considered extremely small and harmless.

However, the damage caused by exposure to radiation also depends on the type of radiation. Table 1.3.3 lists some of the properties of alpha, beta and gamma radiation.

Table 1.3.3 Summary of nuclear radiation

| Radiation | Mass of particles | Speed | Penetration depth | Ionisation ability |
|---|---|---|---|---|
| Alpha radiation | 7000 times heavier than a beta particle | 10% the speed of light | Stopped by dead skin or a layer of paper | 20 electrons per $\alpha$ particle |
| Beta radiation | Same mass as an electron | 90% the speed of light | Stopped by a 1 mm sheet of aluminium | 1 electron per $\beta$ particle |
| Gamma radiation | No mass | 100% the speed of light | Stopped by several centimetres of lead or concrete | 1 electron per $\gamma$ ray |

**SciFile**

**Mutants aren't monsters**

The mutations caused by radiation are not the monstrous creatures seen in science fiction movies. Instead, radiation exposure simply increases the frequency of naturally occurring mutations (such as albinism, which causes an absence of colour in the skin and hair). The peacock in the photo is an albino.

## Alpha radiation

Alpha particles are large, heavy and slow compared to beta particles and gamma rays. This makes them 20 times better at ionising molecules. However, their large size also means that **alpha radiation** can only travel a few centimetres in air and is easily blocked by a thin sheet of paper or even a layer of dead skin, as illustrated in Figure 1.3.10. As a result, radioisotopes that emit alpha radiation can be handled relatively safely. On the other hand, if isotopes emitting (releasing) alpha radiation get inside the body, the effects can be fatal. Radioactive gases that emit alpha radiation are particularly dangerous when breathed into the lungs.

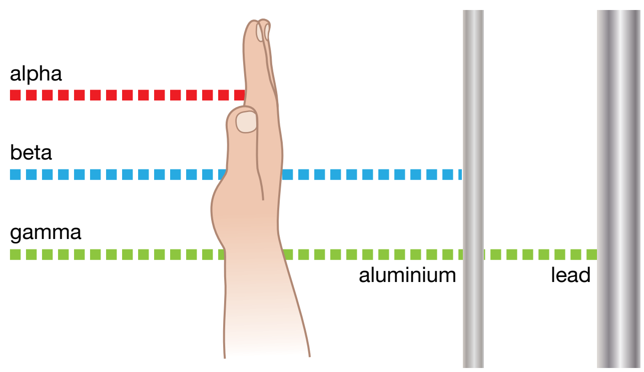
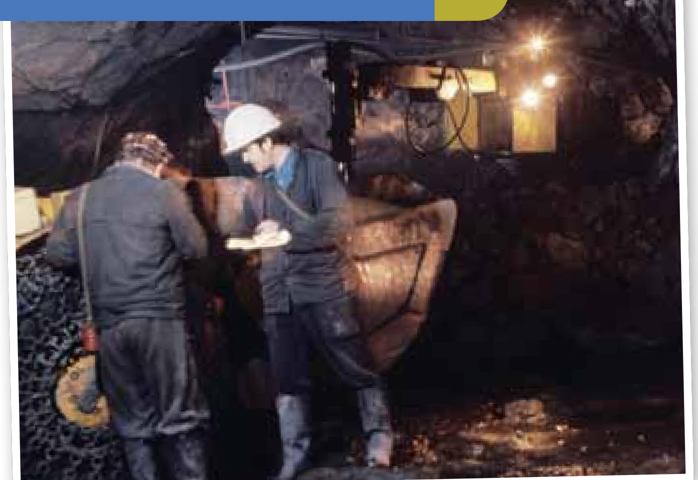



**Figure 1.3.10** Alpha particles are stopped by a sheet of paper or dead skin. Beta particles are stopped by a 1 mm plate of aluminium. Gamma rays are only stopped by thick lead or concrete.

**SciFile**

### Deadly mines

In the 1940s and 1950s it was discovered that the workers in uranium mines were twice as likely to die of lung cancer. This was due to accumulation of the radioactive gas radon-222 in the mines. Radon-222 emits alpha radiation that damages the cells inside the lungs. Today, mines must be ventilated properly to prevent radon-222 accumulating.



## Beta radiation

The beta particles that make up beta radiation are small and fast. This means that **beta radiation** penetrates (enters) the skin more deeply than alpha radiation. As a result, beta radiation is more likely to cause radiation burns to the skin and eyes, like the burns shown in Figure 1.3.11. However, beta radiation can be blocked by a thin plate of aluminium.

**Figure 1.3.11** Beta and gamma radiation are the most likely source of radiation burns following a nuclear explosion. This person was burnt by radiation from the atomic bomb dropped on Hiroshima in 1945.

## Gamma radiation

**Gamma radiation** can travel through skin, bone and aluminium, making it extremely dangerous to humans. Only a thick layer of concrete or lead will block the radiation. This is because gamma radiation is made up of electromagnetic waves rather than particles. This means gamma rays do not have any mass or charge and travel at the speed of light. Other forms of electromagnetic waves include radio waves, microwaves, visible light, ultraviolet light and X-rays. However, only gamma rays, X-rays and certain types of ultraviolet light are powerful enough to ionise molecules and cause cell damage.

# Useful radiation

While radiation should be handled with care, it can also be very beneficial if used correctly. Radiation is often used for medical treatments and diagnosis, industrial applications and scientific research.

## Medical applications

Although radiation causes cancers to grow, it is also one of the most important tools for the treatment of cancers. This style of treatment is known as radiotherapy. During radiotherapy, the cancerous tumour is exposed to high concentrations of radiation. This radiation is used to kill the cells in the tumour and stop them multiplying. However, healthy cells may also be damaged during this process. As a result, radiotherapy comes with serious side effects including skin irritation, ulcers, swelling, nausea, hair loss, heart disease and secondary cancers.

Radioisotopes can also be used for medical diagnosis. In particular, radioisotopes can be used to obtain detailed images of the organs inside the body, like the one in Figure 1.3.12. This process is called nuclear imaging. To obtain a picture of the internal organs, radioisotopes are injected into the body. These radioisotopes collect in the organs and emit a very low dose of gamma radiation that can be detected outside the body to build up an image of the organs.

**Figure 1.3.12** Doctors inject the patient with radioisotopes to obtain images of organs inside the body, like this false-coloured PET scan. Brighter areas show a build-up of radioisotope.

## Industrial applications

There are a wide variety of industrial applications for radiation. Radiation is commonly used in the process of sterilisation to kill bacteria in medical equipment and even in food. This means that things like bandages and needles can be sterilised without the need for harmful chemicals. Foods treated with radiation lasts longer before rotting or going stale.

Radiation can also be used to ‘look’ inside objects in the same way that X-rays can be used to look inside you. This is useful in exploring for minerals, oil, gas and water. A similar process is also used to determine the thickness of materials such as paper or metal foils, using the technique shown in Figure 1.3.13.

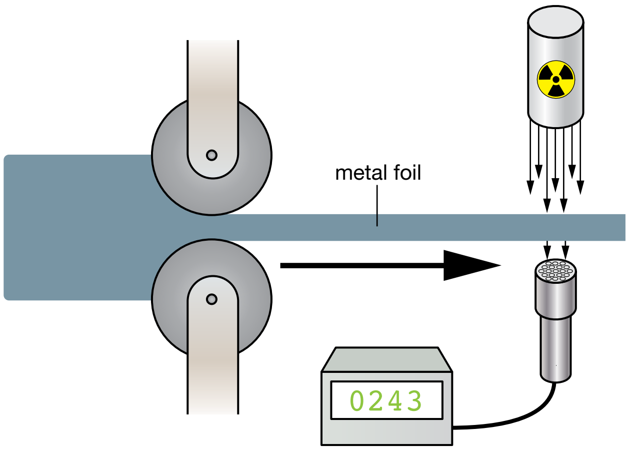



**Figure 1.3.13** Engineers can accurately measure the thickness of materials by measuring how much radiation can pass through them.

You can even find radiation being used in your home if you have a certain type of smoke detector. These detectors have a small amount of americium-241, which produces alpha radiation. If there is smoke in the air, the alpha particles are blocked and the alarm sounds (Figure 1.3.14).

**Figure 1.3.14** Some smoke detectors use the radioactive element americium-241 to detect smoke particles in the air.

# SCIENCE AS A HUMAN ENDEAVOUR

## Use and influence of science

### The power of the nucleus

Figure 1.3.15 Nuclear power provides many countries with much of their electricity.

**There are two types of nuclear reactions that have changed the face of the Earth and caused intense political, environmental and social debate. They are fission and fusion reactions.**

### Fission and fusion

In a **fission** reaction, a large nucleus splits into two almost equally sized pieces. During a **fusion** reaction, two small nuclei come together to form a larger nucleus. In both cases, the reactions release huge amounts of energy that can be extremely useful or extremely destructive.

### Fission reactions

The most famous fission reaction involves uranium-235. If this radioisotope absorbs a neutron, it forms the highly unstable isotope uranium-236. The uranium-236 then splits into two smaller atoms, krypton-92 and barium-141, releasing a huge amount of energy.

This reaction, shown in Figure 1.3.16, is used to supply 15% of the world's electricity demand and power military naval vessels. However, the reaction creates radioactive waste that cannot be destroyed and must be stored deep underground.

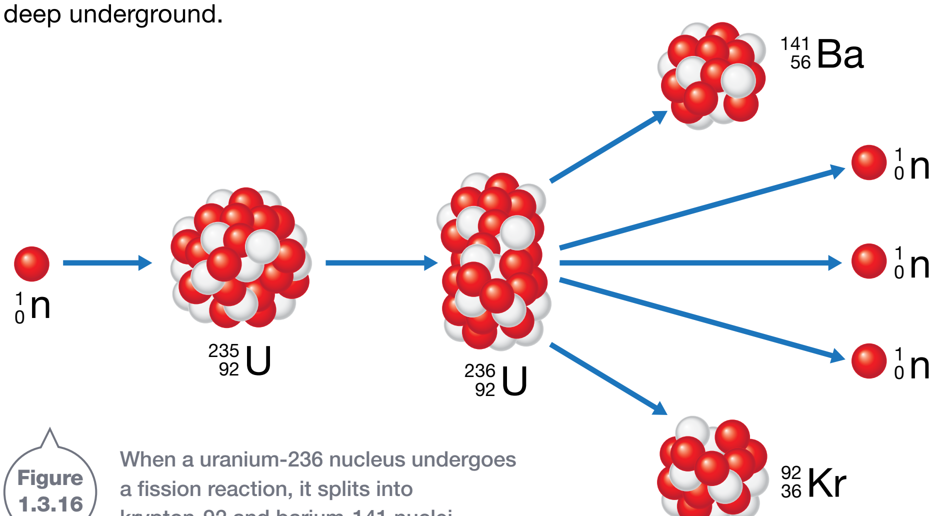



Figure 1.3.16 When a uranium-236 nucleus undergoes a fission reaction, it splits into krypton-92 and barium-141 nuclei.

More disturbing is the use of fission reactions in nuclear weapons. The extreme explosive power of the nuclear reaction and the associated radiation is enough to flatten entire cities. This power was demonstrated tragically during World War II when atomic bombs were dropped on the Japanese cities of Nagasaki and Hiroshima (Figure 1.3.17). The bomb blasts killed about 100 000 people instantly and almost the same number of people in the following 2–4 months due to radiation exposure.

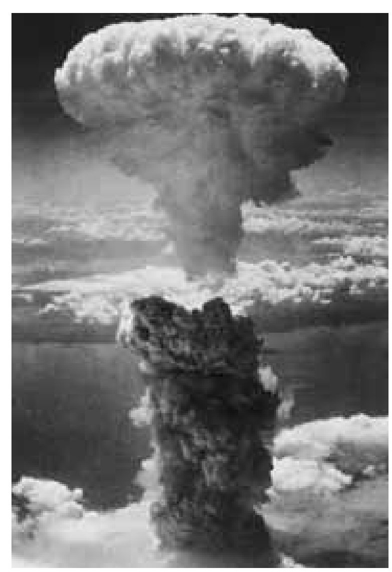


Figure 1.3.17 The extreme power of fission reactions was demonstrated when atomic bombs were detonated (exploded) over Nagasaki and Hiroshima during World War II.

## Fusion reactions

Without fusion reactions there would be no life on Earth. This is because fusion reactions power the Sun and give us warmth and light. A fusion reaction occurs when two small nuclei form a single nucleus. For example, if two hydrogen-2 nuclei collided they might form a helium-4 nucleus, as shown in Figure 1.3.18.

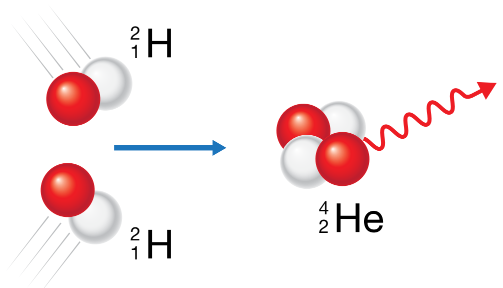



Figure 1.3.18 If two hydrogen-2 (deuterium) nuclei collide at high speed they may fuse together to form a helium-4 nucleus.

Figure 1.3.19 Fusion reactions occur at such high temperatures that scientists must hold the reaction in mid-air with strong magnetic fields that produce a 'magnetic bottle'.

However, the small nuclei strongly repel each other because they both have a positive charge. Therefore, fusion only occurs at extremely high temperatures—over 100 million degrees Celsius. There is no material on Earth that can withstand these temperatures, so scientists trying to create a fusion reactor must suspend the reaction in mid-air by using a powerful magnetic field like the one in Figure 1.3.19.

If fusion reactions could be controlled, they would provide an extremely powerful and clean source of energy. However, the power of fusion can also be used to create the most destructive weapons on Earth—hydrogen bombs. Fortunately, a hydrogen bomb has never been used in a military attack.

1.7

SciFile

### The Fukushima disaster

Japan's first-hand experience of the devastating effects of nuclear weapons has made the people of Japan understandably wary about the use of nuclear power. Their fears were realised in March 2011 when a nuclear reactor in Fukushima went into meltdown after the shock of a magnitude 9.0 earthquake and tsunami. This disaster is considered the second-worst nuclear reactor meltdown after the one in Chernobyl, Russia, in 1986. To date, only 37 injuries and 1 death from heart attack have been reported. However, the death toll is likely to increase due to cancer-related deaths in the long term.

In the picture, one-year old Yunna has her face covered to protect her from the radioactive dust sent into the air by the Fukushima meltdown.

# 1.3 Unit review

## Remembering

1 **List** three types of radiation in order from least penetrating to most penetrating.

2 **State** the units that radiation dose is measured in.

3 **Recall** the dose that is likely to cause severe radiation sickness.

4 **Recall** what happens to the atomic number and mass number of a nucleus when it undergoes:
  a alpha decay
  b beta decay.

5 **List** four uses of radiation.

6 Gamma rays are just one type of electromagnetic wave. **List** four others.

## Understanding

7 **Define** the term *radioisotope*.

8 **Describe** the nuclear processes of fission and fusion.

9 **Explain** why alpha particles, beta particles and gamma rays are classified as forms of ionising radiation.

10 Alpha particles are 20 times more efficient than beta particles or gamma rays at ionising molecules. **Explain** why they may be considered the least dangerous nuclear radiation.

11 **Define** the term *half-life*.

12 **Explain** how radiation burns and radiation sickness are caused.

## Applying

13 **Identify** the atomic symbol for the isotopes oxygen-16, oxygen-17 and oxygen-18. (*Hint*: All oxygen atoms have 8 protons.)

## Analysing

14 **Contrast** stable and unstable nuclei.

15 **Compare** the properties of alpha particles, beta particles and gamma rays.

16 **Calculate** the atomic number and mass number of the following nuclei after they undergo alpha decay.
  a $^{241}_{95}\mathrm{Am}$
  b $^{240}_{94}\mathrm{Pu}$
  c $^{210}_{84}\mathrm{Po}$

17 **Calculate** the atomic number and mass number of the following nuclei after they undergo beta decay.
  a $^{22}_{11}\mathrm{Na}$
  b $^{14}_{6}\mathrm{C}$
  c $^{137}_{55}\mathrm{Cs}$

18 **Calculate** the age of a fossil with a carbon-14 content that is:
  a half the normal amount
  b one-quarter the normal amount
  c one-eighth the normal amount
  d one-sixteenth the normal amount.

(*Hint*: Remember that the half-life of carbon-14 is 5730 years.)

## Evaluating

19 **Propose** the advantages and disadvantages of nuclear power plants and **list** them in a table.

20 **Propose** why radioisotopes that emit alpha radiation are not used for radio imaging.

## Creating

21 **Design** a pamphlet for health department workers advising them of the dangers of different types of radiation they may be exposed to in the workplace.

22 **Construct** a short story describing what you think it would be like to survive a nuclear bomb explosion and the effects of the radiation damage.

## Inquiring

1 a Research other methods of nuclear radiation detection such as film badges or cloud chambers. Use a labelled diagram to explain the workings of one method.
  b There are a large number of units for measuring nuclear radiation including gray, rem, rad, curie, becquerel and roentgen. Explain what one of these means, and give the abbreviation for the unit.

2 a The Shroud of Turin has been claimed to be the burial cloth of Jesus Christ. Explain how carbon dating has been used to date the shroud.
  b Use this evidence to make your own deduction about the age and authenticity of the shroud.

3 Investigate what is meant by the term *heavy water* and how it is used in nuclear reactors.

# 1.3 Practical activities

## 1 Half-life

### Purpose

To model radioactive decay and half-life.

### Materials

- a packet of M&Ms (or Skittles or two-sided tokens)
- a clean tray or sheet of A3 paper
- a clean jar

### Procedure

1. Copy the table from the results section into your workbook.
2. Count the total number of M&Ms in the packet and put them into the jar.
3. Shake the jar up to mix the lollies around. Pour the jar of M&Ms onto the clean tray or A3 paper.
4. Count how many M&Ms show the letter M facing upwards. Record this number in the table.
5. Place only the M&Ms showing the letter M back into the jar and dispose of the other M&Ms appropriately.
6. Repeat steps 3 to 5 until there are no M&Ms left in the jar.

### Results

| Number of repeats | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| M&Ms showing the letter M | | | | | |

1. Construct a graph of the number of M&Ms remaining (those that showed the letter M) versus the number of times the procedure was repeated.
2. Compile everyone's results into one table and plot the classroom total of M&Ms remaining with each repeat of the procedure.

### Discussion

1. **Describe** the shape of the graphs that you produced.
2. **State** the half-life of your M&M sample by finding how many throws it took for the number of M&Ms in your sample to reduce to half.
3. a **Compare** your individual results with the class results.
   b **Propose** which of these results is more reliable.
   c **Justify** your response.
4. **Discuss** how this prac models the half-life of a radioactive element.

Figure 1.3.20 M&Ms can be used to model nuclear decay.

# 1 Chapter review

## Remembering

1 **Recall** the meaning of the following terms.
 a atom
 b molecule
 c crystal lattice
 d isotopes
 e ion

2 a **List** the three subatomic particles that make up an atom.
 b **State** the charge on each.

3 **Recall** how the atomic number and mass number of an atom are calculated.

4 **State** what must happen to an atom to make it:
 a a cation
 b an anion.

5 **List** three types of ionising radiation.

6 **List** four ways in which radiation can be useful.

## Understanding

7 **Describe** the structure of an atom.

8 **Explain** Rutherford's famous experiment and how it has contributed to our current understanding of the atomic model.

9 **Describe** how cations and anions form the crystal lattices that make up ionic compounds.

10 **Describe** what happens to the ions in an ionic compound when it dissolves in water.

11 **Explain** why gamma radiation may be considered the most dangerous form of radiation, even though alpha radiation ionises more electrons for each molecule.

12 **Explain** how ionising radiation causes:
 a radiation burns and radiation sickness
 b mutations.

## Applying

13 **Identify** the name and chemical formula of the ionic compounds made from:
 a potassium cations ($K^+$) and chloride anions ($Cl^-$)
 b calcium cations ($Ca^{2+}$) and oxide anions ($O^{2-}$)
 c boron cations ($B^{3+}$) and fluoride anions ($F^-$)
 d zinc(II) cations ($Zn^{2+}$) and bromide anions ($Br^-$)
 e chromium(III) cations ($Cr^{3+}$) and oxide anions ($O^{2-}$).

## Analysing

14 You discover a new element named jellium (Je) that has a half-life of 5 days. Your sample of jellium contains only 256 atoms. **Calculate** how many jellium atoms there will be after.
 a 5 days
 b 10 days
 c 15 days
 d 20 days.

15 **Calculate** the atomic number and mass number of each of the following atoms after decay.
 a $^{238}_{92}U$ undergoes alpha decay
 b $^{14}_{6}C$ undergoes beta decay
 c $^{241}_{95}Am$ undergoes alpha decay
 d $^{22}_{11}Na$ undergoes beta decay.

## Evaluating

16 **Propose** why nuclear fusion as a power source receives more money for research than any other power source.

17 You should never try and break open a smoke detector. **Propose** reasons why.

## Creating

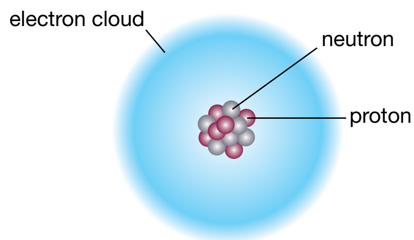
18 **Construct** electron shell diagrams for the following atoms.
 a neon (Ne) 2,8
 b magnesium (Mg) 2,8,2
 c lithium (Li) 2,1
 d boron (B) 2,3

19 **Use** the following ten terms to **construct** a visual summary of the information presented in this chapter.
atom
electron
proton
neutron
isotope
radiation
nuclear reaction
beta particle
alpha particle
gamma ray

1.8

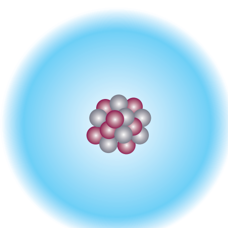
# Thinking scientifically

**Q1** Isotopes are atoms that have the same number of protons in their nucleus but a different number of neutrons. Determine which of the atoms below is an isotope of this carbon-12 atom.

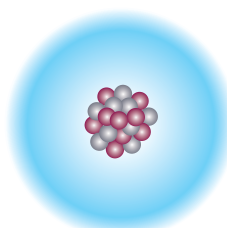



carbon atom

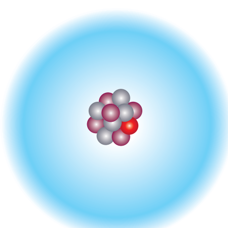
**A**



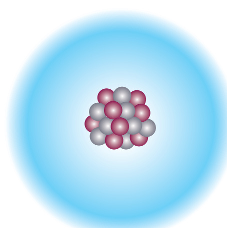
**B**



**C**



**D**



**Q2** Scientists use atomic symbols to communicate the structure of atoms. An atomic symbol consists of the chemical symbol for the element, the atomic number and the mass number. The atomic number is the number of protons. The mass number is the total number of protons and neutrons in the nucleus. Because atoms are charge neutral, the number of electrons must also equal the number of protons. Below is the atomic symbol for a nitrogen-14 atom.

Mass number → 14

Atomic number → 7

$^{14}_{7}N$ ← chemical symbol

From this information, which of the following best describes the structure of an atom with the atomic symbol $^{196}_{79}Au$?

**A** 79 protons, 196 neutrons, 79 electrons

**B** 79 protons, 196 neutrons, 196 electrons

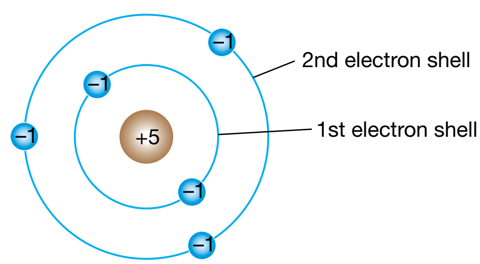
**C** 117 protons, 79 neutrons, 117 electrons

**D** 79 protons, 117 neutrons, 79 electrons

**Q3** Atoms are charge neutral because the positive charge on the nucleus is exactly balanced by the negative charge of the electrons. Ions are formed when an atom gains or loses electrons according to the following rules:

- If the outermost electron shell of the atom is mostly empty, the atom will lose its outermost electrons to become a positively charged cation.
- If the outermost electron shell of the atom is mostly full, the atom will gain electrons until the outermost electron shell is filled, becoming a negatively charged anion.

Examine the atom shown below. Given that the second electron shell can hold up to 8 electrons, determine what the charge of its ion will be.




**A** +3

**B** –2

**C** +2

**D** –3

**Q4** Every day you are exposed to small levels of radiation. You receive a dose of approximately 0.82 microsieverts from cosmic radiation and 3.83 microsieverts from radiation sources on Earth.

The best estimate for your total radiation dose each year from these sources is:

**A** 1500 microsieverts

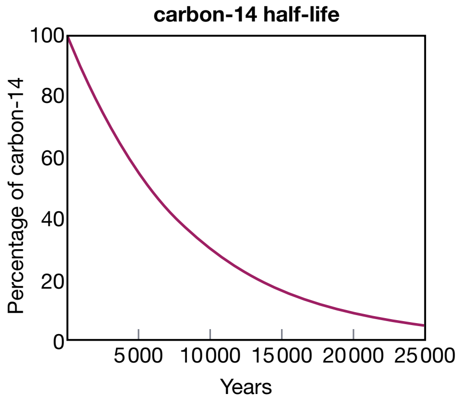
**B** 1600 microsieverts

**C** 1700 microsieverts

**D** 1800 microsieverts

**Q5** An archaeologist working in Cairo, Egypt, discovers an old artefact and takes it back to the lab for carbon dating. The lab results show that there is only 16% of the carbon-14 that would have been found in a similar artefact made today.

Using the graph below for the carbon-14 half-life, determine which is the best estimate for the age of the artefact.




**A** 5000 years
**B** 10 000 years
**C** 15 000 years
**D** 20 000 years

**Q6** A nuclear power plant worker comes into hospital after having an accident where he was exposed to high levels of radiation approximately 30 minutes before. Initially he seems fine but after an hour he starts to feel nauseated and begins vomiting. He is kept in for observation and after a few days develops diarrhoea.

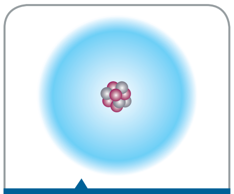
Use the table below to determine the likely dose of radiation that the worker was exposed to.

| Dose (Sv) | Symptoms |
|---|---|
| 0–0.5 | No obvious effect |
| 0.5–1.0 | Vomiting and nausea for about 1 day in 10 to 20% of people. Tiredness, but no serious disability. |
| 1.0–2.0 | Mild to moderate nausea in 50% of people with occasional vomiting, setting in within 3–6 hours after exposure, and lasting several hours to a day. |
| 2.0–5.5 | Nausea in 100% of people. Vomiting starting 0.5 to 6 hours after irradiation and lasting up to 2 days. This is followed by other symptoms of radiation sickness, e.g. loss of appetite, diarrhoea, minor bleeding. |
| 5.5–10 | Severe nausea and vomiting within 15–30 minutes, lasting up to 2 days, followed by severe symptoms of radiation sickness, e.g. loss of appetite, diarrhoea, minor bleeding. |
| 10–20 | Immediate nausea, diarrhoea and bleeding |
| > 20 | Immediate disorientation and coma. Onset is within seconds to minutes. |

**A** 0.5–1.0 Sv
**B** 1.0–2.0 Sv
**C** 2.0–5.5 Sv
**D** 5.5–10 Sv

# Glossary

## Unit 1.1



Atom

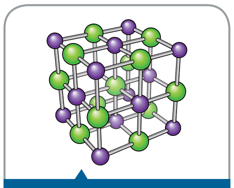
**Atom:** the fundamental building block of all materials; it consists of a cluster of protons and neutrons surrounded by a cloud of electrons

**Atomic model:** scientists' representation of an atom determined by experiment and indirect observation

**Atomic number:** the number of protons in a nucleus; the atomic number determines what type of atom it is

**Atomic symbol:** a short-hand notation for describing an atom; it consists of the chemical symbol, atomic number and mass number

**Compound:** a pure substance that is made up of two or more different types of atom chemically joined



Crystal lattice

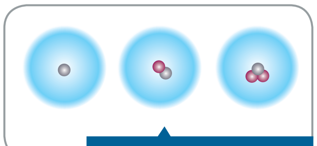
**Crystal lattice:** a grid-like structure of atoms or ions where each particle is bonded to all of its neighbouring atoms

**Electron:** a small, negatively charged particle; clouds of electrons surround the nucleus of an atom

**Electron configuration:** the number of electrons in each of the electron shells of an atom

**Electron shell:** part of the electron cloud; it is a layer that surrounds the nucleus and can only hold a certain number of electrons

**Element:** a substance made up of only one type of atom



Isotopes

**Isotopes:** atoms that have the same number of protons but a different number of neutrons in their nucleus

**Mass number:** the number of protons and neutrons in an atom

**Molecule:** a cluster of atoms that makes up an element or a compound

**Neutral:** having no overall charge

**Neutron:** a particle with no electric charge; it is found in the nucleus of an atom

**Nucleus:** a cluster of neutrons and protons at the centre of an atom

**Periodic table:** table showing all 118 known types of atoms (elements)

**Proton:** a positively charged particle in the nucleus

## Unit 1.2

**Anion:** a negatively charged ion

**Cation:** a positively charged ion

**Ion:** an atom that has lost or gained electrons and therefore has an electric charge

**Ionic bond:** a bond between a cation and an anion due to electrostatic attraction of their opposite charges

**Ionic compound:** a compound made up of cations and anions

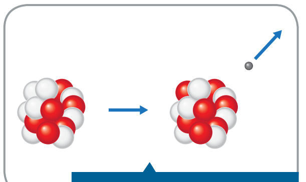
**Solubility:** how easily a substance dissolves

## Unit 1.3

**Alpha decay:** a nuclear reaction in which a nucleus ejects an alpha particle

**Alpha particle:** a particle made up of two protons and two neutrons, making it identical to a helium nucleus

**Alpha radiation:** a form of ionising radiation made up of alpha particles



Beta decay

**Beta decay:** a form of nuclear reaction in which a beta particle is ejected from the nucleus

**Beta particle:** a small, negatively charged particle that can be ejected from a nucleus during a nuclear reaction; it is identical to an electron

**Beta radiation:** nuclear radiation that is made up of beta particles

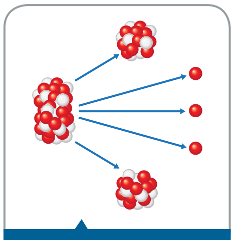
Carbon dating

**Carbon dating:** a method for judging the age of fossils by analysing the amount of carbon-14 in the fossil

**Cosmic radiation:** radiation that comes to Earth from distant stars

**Dose (radiation):** the amount of radiation absorbed over a period of time

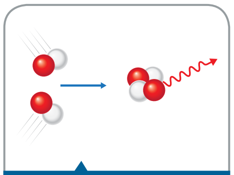
**Electromagnetic radiation:** radiation that travels through a vacuum as waves rather than particles



Fission

**Fission:** a nuclear reaction in which a very large nucleus splits into two smaller nuclei of similar mass number

**Fusion:** a nuclear reaction in which two small nuclei come together to form one larger nucleus



Fusion

**Gamma decay:** nuclear decay that involves the release of gamma rays

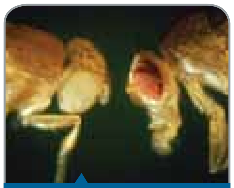
**Gamma radiation:** a form of ionising radiation made up of gamma rays

**Gamma ray:** a very high-energy electromagnetic wave that is produced when the protons and neutrons in a nucleus rearrange

**Half-life:** the time it takes for half a sample of atoms to decay

**Ionising radiation:** any form of radiation that has the ability to remove electrons from atoms and molecules

**Mutation:** a change in the DNA of a cell that causes it to change how it works and reproduces



Mutation

**Nuclear decay:** when a nucleus undergoes a nuclear reaction and emits radiation

**Nuclear radiation:** rays or particles that are emitted by a nucleus during a nuclear reaction

**Nuclear reaction:** a process that causes a nucleus to change, including alpha decay, beta decay, fission and fusion

**Radiation burns:** redness and blistering on the surface of the skin or other organs caused by intense exposure to ionising radiation

Radiation burns

**Radiation sickness:** a condition that results from a large dose of ionising radiation, causing significant cell death; symptoms include nausea, vomiting, fever, hair loss and diarrhoea

**Radioactive:** emitting radiation

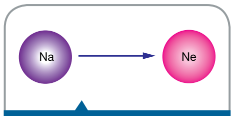
**Radioisotope:** an isotope with a nucleus that may undergo a nuclear reaction

**Sievert:** a unit for measuring a dose of radiation

**Stable nuclei:** nuclei that will never undergo a nuclear reaction

**Terrestrial radiation:** radiation that originates from radioisotopes in the ground and the atmosphere

**Transmutation:** a nuclear reaction process that converts one type of atom into a different type of atom




Transmutation

**Unstable nuclei:** nuclei that may undergo a nuclear reaction at any time

# Important materials

# 2

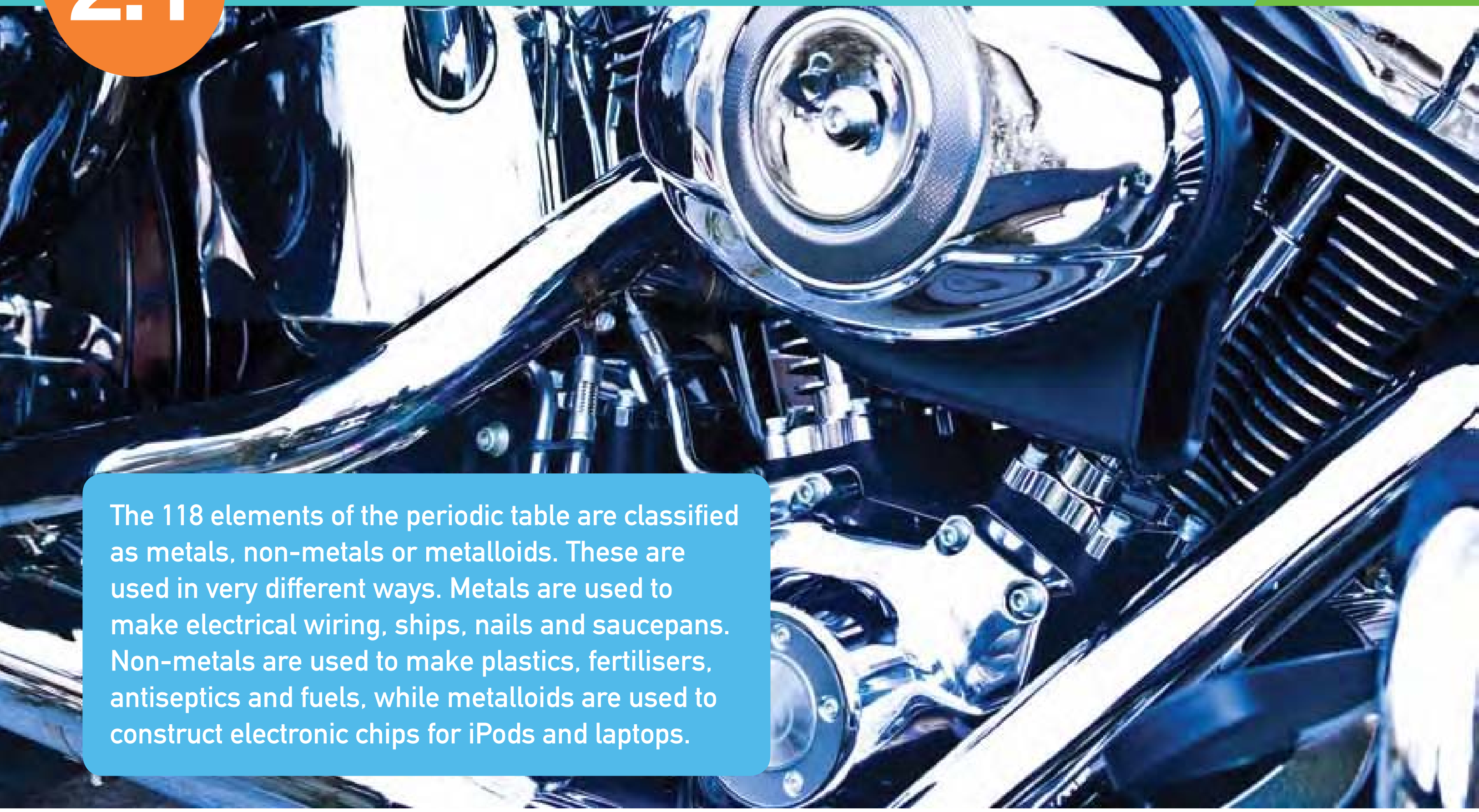

## HAVE YOU EVER WONDERED …

- why body piercings are usually made of stainless steel?
- if drugs can search for cancer and then destroy it?
- what the difference is between an acid and a base?
- what pH measures?

**After completing this chapter students should be able to:**

- describe the properties of different elements in the periodic table
- explain how properties of metals and non-metals are related to their uses
- outline the use of nanotechnology in medicine, such as the delivery of pharmaceuticals
- describe the properties of acids and bases.

# 2.1 Metals, non-metals and metalloids



The 118 elements of the periodic table are classified as metals, non-metals or metalloids. These are used in very different ways. Metals are used to make electrical wiring, ships, nails and saucepans. Non-metals are used to make plastics, fertilisers, antiseptics and fuels, while metalloids are used to construct electronic chips for iPods and laptops.

**KEY**

- Non-metals
- Metals
- Metalloids

atomic number — 13
symbol — **Al**
name — aluminium

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 **H** hydrogen | | | | | | | | | | | | | | | | | 2 **He** helium |
| 3 **Li** lithium | 4 **Be** beryllium | | | | | | | | | | | 5 **B** boron | 6 **C** carbon | 7 **N** nitrogen | 8 **O** oxygen | 9 **F** fluorine | 10 **Ne** neon |
| 11 **Na** sodium | 12 **Mg** magnesium | | | | | | | | | | | 13 **Al** aluminium | 14 **Si** silicon | 15 **P** phosphorus | 16 **S** sulfur | 17 **Cl** chlorine | 18 **Ar** argon |
| 19 **K** potassium | 20 **Ca** calcium | 21 **Sc** scandium | 22 **Ti** titanium | 23 **V** vanadium | 24 **Cr** chromium | 25 **Mn** manganese | 26 **Fe** iron | 27 **Co** cobalt | 28 **Ni** nickel | 29 **Cu** copper | 30 **Zn** zinc | 31 **Ga** gallium | 32 **Ge** germanium | 33 **As** arsenic | 34 **Se** selenium | 35 **Br** bromine | 36 **Kr** krypton |
| 37 **Rb** rubidium | 38 **Sr** strontium | 39 **Y** yttrium | 40 **Zr** zirconium | 41 **Nb** niobium | 42 **Mo** molybdenum | 43 **Tc** technetium | 44 **Ru** ruthenium | 45 **Rh** rhodium | 46 **Pd** palladium | 47 **Ag** silver | 48 **Cd** cadmium | 49 **In** indium | 50 **Sn** tin | 51 **Sb** antimony | 52 **Te** tellurium | 53 **I** iodine | 54 **Xe** xenon |
| 55 **Cs** caesium | 56 **Ba** barium | 57–71 lanthanoids | 72 **Hf** hafnium | 73 **Ta** tantalum | 74 **W** tungsten | 75 **Re** rhenium | 76 **Os** osmium | 77 **Ir** iridium | 78 **Pt** platinum | 79 **Au** gold | 80 **Hg** mercury | 81 **Tl** thallium | 182 **Pb** lead | 83 **Bi** bismuth | 84 **Po** polonium | 85 **At** astatine | 86 **Rn** radon |
| 87 **Fr** franchium | 88 **Ra** radium | 89–103 actinoids | 104 **Rf** rutherfordium | 105 **Db** dubnium | 106 **Sg** seaborgium | 107 **Bh** bohrium | 108 **Hs** hassium | 109 **Mt** meitnerium | 110 **Ds** darmstadium | 111 **Rg** roentgenium | 112 **Cn** copernicium | 113 **Uut** ununtrium | 114 **Uuq** ununquadium | 115 **Uup** ununpentium | 116 **Uuh** ununhexium | 117 **Uus** ununseptium | 118 **Uuo** ununoctium |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lanthanides | 57 **La** lanthanum | 58 **Ce** cerium | 59 **Pr** praseodymium | 60 **Nd** neodymium | 61 **Pm** promethium | 62 **Sm** samarium | 63 **Eu** europium | 64 **Gd** gadolinium | 65 **Tb** trebium | 66 **Dy** dysprosium | 67 **Ho** holmium | 68 **Er** erbium | 69 **Tm** thulium | 70 **Yb** ytterbium | 71 **Lu** lutetium |
| Actinides | 89 **Ac** actinium | 90 **Th** thorium | 91 **Pa** protactinium | 92 **U** uranium | 93 **Np** neptunium | 94 **Pu** plutonium | 95 **Am** americum | 96 **Cm** curium | 97 **Bk** berkelium | 98 **Cf** californium | 99 **Es** einsteinium | 100 **Fm** fremium | 101 **Md** mendelevium | 102 **No** nobelium | 103 **Lr** lawrencium |

**Figure 2.1.1** The periodic table displays all 118 known elements. There are roughly four times as many metals as there are non-metals and metalloids in the table, but in the universe the number of non-metallic atoms is far greater than the number of metallic atoms. This is because stars are made mainly of hydrogen and helium.

# Elements and the periodic table

Elements are the building blocks from which everything else is made. As the **periodic table** in Figure 2.1.1 shows, elements are classified according to their properties as being metal, non-metal or metalloid.

# Metals

Metals are **lustrous** (they shine when polished), **malleable** (they can be bent into new shapes without breaking) and **ductile** (they can be stretched into wires). These are just three of the physical properties that have made metals invaluable to humans throughout history. They form the basis of much of our technology and art, from horseshoes, swords, electrical wiring and the frames of skyscrapers to jewellery, statues and the gold leaf on paintings.

Figure 2.1.2 outlines the physical properties shared by the metallic elements.

**Metals are dense.** Almost all metals are denser than water and so will sink when dropped into it. The only exceptions are lithium (Li), sodium (Na) and potassium (K). These float on water.

**Metals are thermal conductors.** They pass heat easily along and through them.

**Metals are electrical conductors.** They pass electricity along and through them.

**Metals are lustrous.** They shine when polished or freshly cut.

**Metals are malleable.** They can be hammered and squashed to form new shapes.

**Metals are ductile.** They can be stretched and drawn into long thin wires.

**Metals are solid at room temperature.** Mercury (Hg) is an exception because it is a liquid.

Figure 2.1.2 The physical properties of metals

Table 2.1.1 Pure metals and their uses

| Pure metal | Element symbol | Uses | Properties that make it particularly suited to its use |
|---|---|---|---|
| Aluminium | Al | Overhead electricity cables, saucepans and cans, aluminium foil | Excellent conductor of heat and electricity, extremely light, non-toxic |
| Copper | Cu | Electrical wiring | Excellent electrical conductor, easily stretched into wires |
| Lead | Pb | Flashing around windows and roofs to stop water entry | Very soft and easily bent, resists corrosion |
| Mercury | Hg | Clinical thermometers | Liquid at room temperature, expands rapidly when heated, leaves tubes clean once it retreats, leaving no traces |
| Sodium | Na | Nuclear reactor coolant | Conducts heat well, melts at 98°C, allowing molten sodium to flow along pipes in the reactor. |
| Tin | Sn | Coating for steel cans used for storing food | Stops steel from rusting, doesn't react with food, non-toxic |
| Zinc | Zn | Coating for iron and steel (galvanised iron) | Is more reactive than iron and so protects it from rusting |

## Pure metals

Most metals cannot be used as pure elements because they have properties that make them impractical. For example, most pure metals are too soft to be made into anything useful. Table 2.1.1 shows metals that are often used in their pure form.

## Alloys

Most of the metals around you are not pure elements but are alloys. An **alloy** is a metal (known as the **base metal**) combined with small amounts of another element. The properties of the new alloy are usually an improvement over those of the base metal. For example, **steel** is much stronger and harder than its iron base metal, allowing it to be used in everything from paperclips, staples, nails and screws to cars, ship hulls and the frames of bridges and skyscrapers. Steel is an alloy of iron with small amounts of carbon added to it. Different amounts of carbon produce different alloys.

- Wrought iron contains almost no carbon and is the closest alloy to pure iron.
- Mild steel has only 0.5% carbon.
- Hard steel or tool steel has about 1% carbon.
- Cast iron has between 2.4% and 4.5% carbon. Cast iron is strong but **brittle**, shattering easily if hit or dropped.

Steel can be further improved by adding chromium and nickel to it. This addition produces rust-resistant **stainless steel**. Stainless steel is used in hot, wet and salty environments that would cause rapid rusting of other types of steel. This is why stainless steel is used in kitchens, on ships, for surgical instruments and for jewellery for body piercings like that in Figure 2.1.3.

Figure 2.1.3 High-grade stainless steel doesn't rust and so is ideal for body piercings.

Pure gold is so soft and fragile that any jewellery made from it would soon break. For this reason, silver and/or copper are added to it to create a stronger alloy. The **carat** scale measures the amount of pure gold in jewellery, with pure gold rated as 24 carat. Jewellery is often 18 carat, meaning that it is 18/24 (three-quarters or 75%) gold.

Other alloys are shown in Table 2.1.2.

SciFile

**Gold isn't always gold!**

Australian 'gold' $1 and $2 coins contain 92% copper, 6% aluminium and 2% nickel (and no gold). The 'silver' coins are 25% nickel and 75% copper. In contrast, the first circular 50 cent coins of 1966 were 80% silver! Eventually, this made them far more valuable as metal than as a coin!

Table 2.1.2 Alloys and their uses

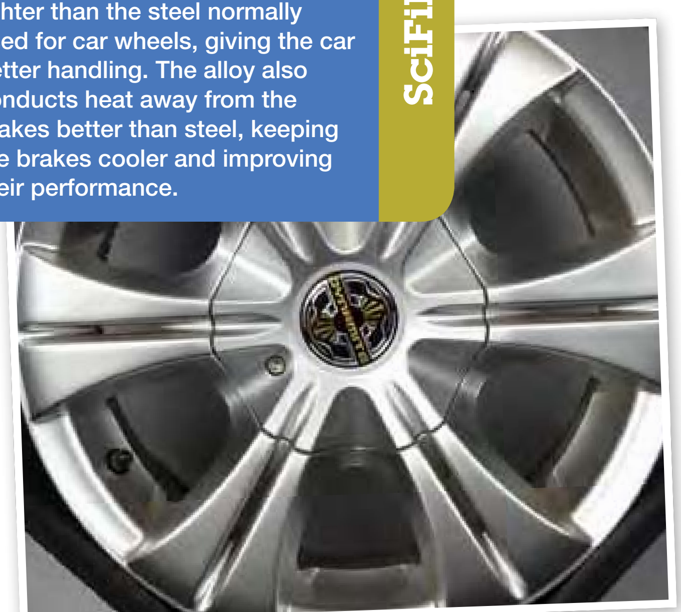
| Alloy | Composition | Uses | Advantages |
|---|---|---|---|
| Brass | 70% Cu, 30% Zn | Hinges, door handles, fittings on boats and ships, musical instruments, e.g. trumpets and trombones | • Good looking<br>• Doesn't corrode much<br>• Stronger than its base metal (copper) |
| Bronze | 95% Cu, 5% Sn | Statues, ornaments, bells | • Good looking<br>• Doesn't corrode easily<br>• Sonorous (makes a good ringing sound when struck)<br>• Harder than brass<br>• Stronger than its base metal (copper) |
| Duralumin | 96% Al, 4% Cu, traces of Mg and Mn | Aircraft frames | • Very light<br>• Stronger than its base metal (aluminium) |
| Solder | 60 to 70% Sn<br>30 to 40% Pb | Joining metals together, electrical connections,<br>low-friction bearings | • Easy to melt<br>• Easy to use |
| Cupronickel | 75% Cu, 25% Ni | 'Silver' coins (5, 10, 20 and 50 cents) | • Hard wearing<br>• Looks like silver |
| EPNS (electroplated nickel silver) | 46 to 63% Cu<br>18 to 36% Zn<br>6 to 30% Ni | Plated onto cutlery, plates and bowls | • Looks like silver<br>• Cheaper than silver<br>• Resists corrosion |
| Dental amalgam | 43 to 54% Hg<br>20 to 35% Ag<br>10% Cu<br>2% Zn<br>traces of Sn | Tooth fillings | • Hardens slowly after being mixed |

2.1
2.2
p45

**Mag wheels**

Mag wheels (alloy wheels) are made from an alloy of magnesium and aluminium. This alloy is much lighter than the steel normally used for car wheels, giving the car better handling. The alloy also conducts heat away from the brakes better than steel, keeping the brakes cooler and improving their performance.

SciFile



INQUIRY science 4 fun

## Rust away!

Can you get steel to rust in one day?

Yes

### Collect this …

- steel wool (plain, with no soap)
- vinegar
- liquid bleach
- screw-top glass jar

### Do this …

1. Put a lump of steel wool in the bottom of the screw-top jar.
2. Pour in enough water to cover the steel wool.
3. Add a little vinegar and a little bleach.
4. Screw on the top of the jar and check what happens to the steel wool over the next day.

### Record this …

**Describe** what happened.

**Explain** why you think this happened.

# Non-metals

Most non-metals are found naturally as gases in the air. A few are solids found in the Earth's crust, such as the sulfur found around volcanoes. The physical properties of non-metals are very different from those of metals. You can see these properties in Figure 2.1.4.

**Non-metals are poor conductors of heat and electricity**. They are thermal and electrical insulators.

**Non-metals have relatively low melting and boiling points**. Bromine is a liquid at normal room temperature. The other non-metals are gases or easily melted solids.

**Non-metals are brittle**. Solid non-metals tend to crumble into powders.

**Non-metals are dull**. They have little or no shine.

Figure 2.1.4 The physical properties of non-metals

**Carbon wheels!**

In 2010, Deakin University in Geelong (Victoria) and research firm CFusion released the world's first car wheel constructed from a *single* carbon fibre. Being incredibly light yet strong, the wheel promises to dramatically enhance car performance. It is to be used in one of the world's fastest cars, the Shelby Ultimate Aero.

SciFile

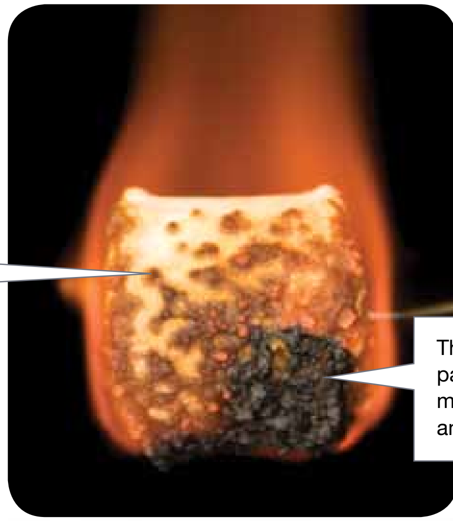
## Carbon

Carbon is an unusual element because its atoms combine with other carbon atoms and with atoms of other elements (usually hydrogen and oxygen) to form lattices, long chains and rings. Over 90% of all known compounds contain carbon, some of which are essential to life on Earth. Carbon exists in molecules in every living thing and anything that was once part of a living thing.

Pure carbon exists in several different forms, called **allotropes**. Three common allotropes are:

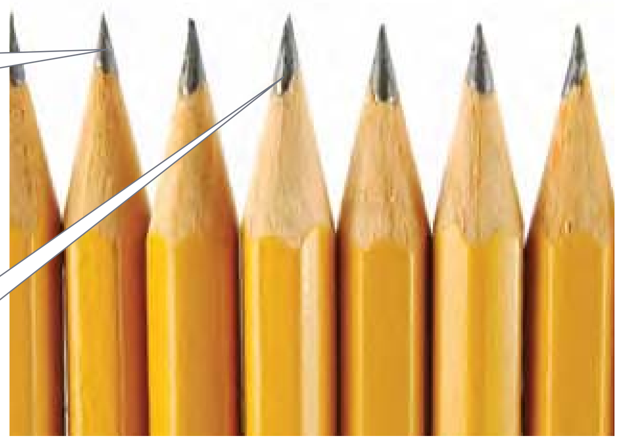
- amorphous carbon
- diamond
- graphite.

These are shown in Figure 2.1.5.



**Amorphous carbon:** black powder and burnt bits you find on burnt toast, after bushfires, in charcoal and in coal.

The black, burnt part of this marshmallow is amorphous carbon.



**Graphite:** a soft, slippery solid that conducts electricity. It is an excellent lubricant and forms the electrodes in many batteries and the connection brushes in electric motors.

The grey 'lead' in pencils is a graphite/clay mix.

**Diamond:** the hardest known natural substance. Only 20% of diamonds are gem-grade. The rest are used to cut glass, metal and masonry or are crushed to make abrasives.

Dental drills often have diamond tips. This is a scanning electron microscope (SEM) image of a diamond tip.

Figure 2.1.5 Some of the forms in which carbon exists

2 p46

2.3

## Metalloids

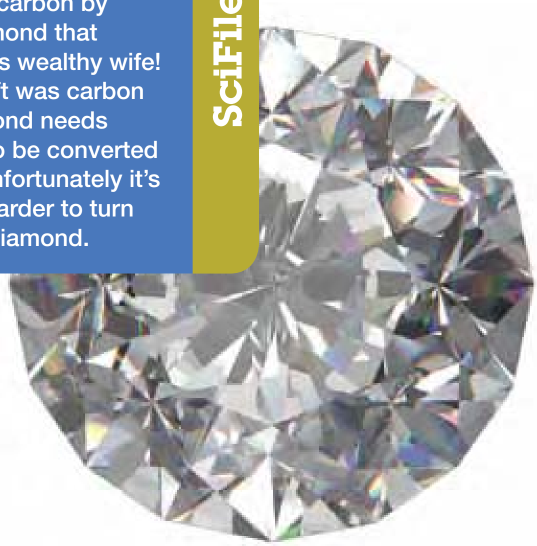
**Metalloids** (sometimes called semi-metals) act like non-metals in most ways. However, they do have some properties that are more like those of metals. Most importantly metalloids are semi-conductors, meaning that they can conduct electricity under certain conditions. This ability has made silicon and germanium ideal materials from which to build electronic components like the one shown in Figure 2.1.6. These components are used in devices such as laptops, LED TVs and iPads.

Figure 2.1.6 This electronic microprocessor chip is constructed using the metalloid silicon.

### SciFile

**Diamond destruction!**

The English scientist Sir Humphry Davy (1778–1829) demonstrated that diamond was a form of carbon by burning a diamond that belonged to his wealthy wife! All that was left was carbon dioxide. Diamond needs about 800°C to be converted to graphite. Unfortunately it's much, much harder to turn graphite into diamond.



2.1

# Unit review

## Remembering

1 **List** the names and symbols of three metals, three non-metals and three metalloids.

2 **List** the uses for:
- a graphite
- b silicon.

3 **Name** the only metal that is a liquid at normal room temperature.

4 **List** the different types of steel, from the lowest carbon content to the highest.

5 For stainless steel, **name** the:
- a base metal
- b added metals that give it rust resistance.

## Understanding

6 **Explain** why most metals sink in water.

7 **Define** the following terms:
- a lustrous
- b malleable
- c brittle.

8 **Explain** why gold is rarely used in its pure form.

9 **Explain** why the slipperiness of graphite makes it ideal for use in grey-lead pencils.

10 **Describe** how you can show that diamond and graphite are made from the same element.

## Applying

11 **Identify** two physical properties that make metals the ideal material from which to construct electrical wires.

12 **Identify** the metal common to both the alloys brass and bronze.

13 **Calculate** the fraction and percentage of pure gold in:
- a a 12-carat gold ring
- b a 9-carat gold nose stud
- c a 22-carat gold chain.

14 Wood, paper and food scraps all burn, leaving charcoal and ash behind. This suggests that they all have the same basic element in them. **Identify** what that element is.

## Analysing

15 **Compare** the number of elements that are metallic, non-metallic and metalloids.

16 **Classify** the following properties as normally belonging to metals or non-metals:
- a ductile
- b normally gas or liquid
- c dense
- d malleable
- e brittle
- f lustrous
- g dull
- h most are solid
- i thermal and electrical insulators
- j excellent thermal and electrical conductors

17 **Compare** three allotropes of carbon by listing their similarities and differences.

## Evaluating

18 Cans that contain soup, dog food or vegetables are made predominantly of steel, yet are often called tins. **Propose** a reason why.

19 Graphite is carbon (a non-metal) but it conducts electricity like a metal. **Use** this information to **propose** a reason why carbon could be classified as a metalloid instead of a non-metal.

20 **Propose** what would be the base metal in a ferrous alloy. (Use the element symbols for metals to help you.)

## Inquiring

1 Research why roof decking is corrugated or 'ribbed' and how Colorbond® roofing differs from other metal roofing materials.

2 Some people are now having the amalgam fillings in their teeth replaced with other materials. Research why.

3 Research the important non-metals chlorine, nitrogen and hydrogen. Find:
- a their melting point and boiling point
- b their state at normal room temperature
- c where they are found naturally
- d what they are used for.

4 Research what a buckyball and a nanotube are. Find what element forms their structure and find their properties and uses.

5 Design an experiment to test whether graphite or wood is a better conductor of heat and electricity. You could use 'lead' pencils in your experiment.

# 2.1 Practical activities

## 1 Making steel stronger

Heating changes the properties of steel because it changes the size of its crystals.

### Purpose

To determine which treatment makes steel tougher.

### Materials

- four steel hairpins
- steel wool
- Bunsen burner, bench mat and matches
- wooden peg
- beaker, tub or sink filled with cold water
- pliers (optional)

### Procedure

1. Copy the table from the results section into your workbook.
2. Count the number of bends it takes to snap a hairpin. One bend is out and in again. Enter the number in your table.
3. Hold another hairpin with the peg and heat the bend of the pin in a blue Bunsen burner flame until it is red hot (see Figure 2.1.7). Allow it to cool on the bench mat. This process is known as normalising or **annealing**.

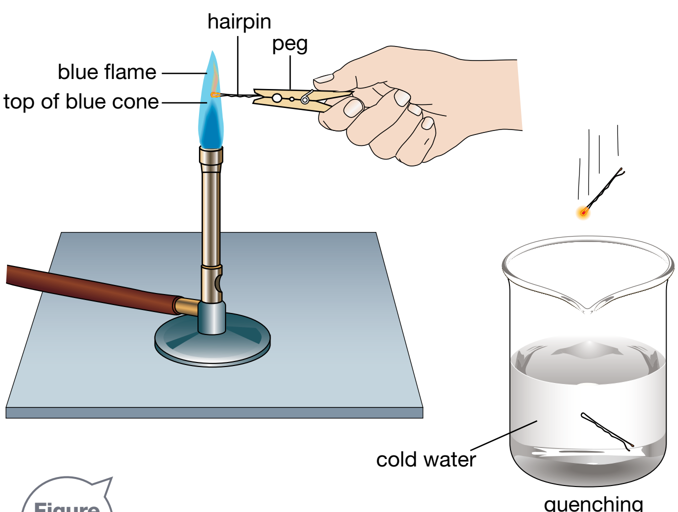



Figure 2.1.7

4. Heat another hairpin in the same way, then cool it rapidly by dropping it into a beaker of water. This process is known as **quenching**.
5. Repeat step 4 with the remaining hairpin, then polish the bend with steel wool. Re-heat the bend of the pin, removing it occasionally to check whether the bend has gone blue. Once it has, remove the pin from the flame and allow it to cool on the mat. This process is known as **tempering**.
6. Bend each of the pins as before, counting the bends until they break. Record your counts in the results table.

### Results

Use a table like this to record your observations.

| Treatment | Number of bends needed to break pin | Did the treatment make the pin tougher? |
|---|---|---|
| No treatment | | |
| Normalising/ annealing | | |
| Quenching | | |
| Tempering | | |

### Discussion

1. **Outline** the processes of annealing, quenching and tempering.
2. **State** which treatment caused your hairpin to become:
   a. more brittle (easier to snap)
   b. more malleable (more 'bendy' and less likely to snap).
3. Fast cooling produces small crystals; slow cooling makes bigger ones. **Predict** which of the treatments produced the biggest crystals.
4. **Propose** reasons why bigger crystals make steel tougher than small crystals.
5. Blacksmiths repeatedly heat, hammer and cool (quench) steel in the process of making horseshoes. **Propose** a reason why.

## 2 Making oxygen

### Purpose

To prepare and test oxygen gas.

### Materials

- 1 large test-tube, rubber stopper with opening and glass tube to fit
- hosing to fit glass tube
- 2 test-tubes with stoppers
- test-tube rack
- retort stand, bosshead and clamp
- large container (such as an ice-cream container)
- 10 mL measuring cylinder
- hydrogen peroxide solution
- manganese(IV) oxide pellets
- wooden splint
- access to electronic scales

**SAFETY**

Hydrogen peroxide burns. Wear safety glasses, a lab coat or apron, and rubber gloves.

### Procedure

**Part A: Preparation of oxygen**

1. Use the electronic scale to measure out approximately 1 g of manganese(IV) oxide pellets.
2. Use the measuring cylinder to carefully measure out 5 mL of hydrogen peroxide.
3. Set up the equipment as shown in Figure 2.1.8.

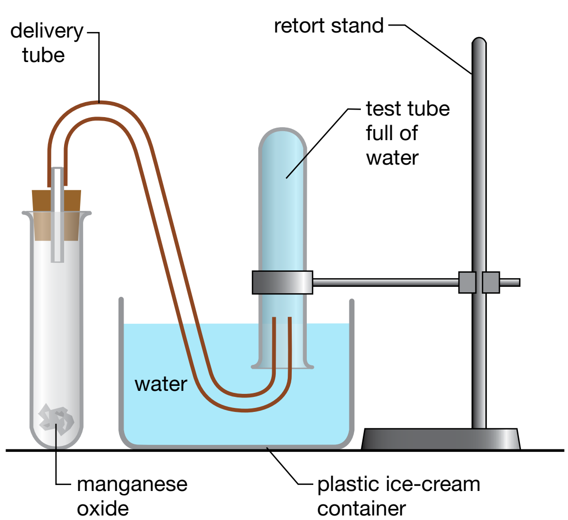



Figure 2.1.8

4. Fill both the two smaller test-tubes with water. Put your thumb over the end on one, upend it and clamp as shown. Put the other one in the test-tube rack for later on.
5. Remove the rubber stopper and drop the manganese(IV) oxide pellets into the large test-tube.
6. Add the hydrogen peroxide and replace the rubber stopper.
7. The inverted test-tube should fill with oxygen gas. Remove the test-tube when full of gas, stopper it and place it in the rack.
8. Fill the other test-tube with oxygen and store it in the rack.
9. The reaction in the large test-tube can be stopped by carefully adding water to it.

**Part B: Testing oxygen**

10. Use one tube of collected gas to make as many observations as you can about oxygen. For example, waft the gas towards you and attempt to smell it.
11. Light the wooden splint, allow it to burn for a few seconds and then blow it out. Insert the glowing end of the splint into the second test-tube of oxygen and record what happens.

### Results

1. Construct a table to record your observations.
2. Record the state, colour and smell of oxygen gas and what it did to the glowing splint.

### Discussion

1. **Use** your observations to **propose** why fanning a fire encourages it to burn.
2. **Propose** a reason why the burning splint doesn't burst back into flame when in air, despite air having oxygen in it.

# 2.2 Nano-materials

In recent years, a new branch of science has emerged: nanotechnology. Nanotechnology has led to the development of amazing new materials, such as paint and window glass that clean themselves, fabrics that kill bacteria and resist stains, alloys that can keep clogged arteries open and molecules that can help destroy cancer cells.

## What is nanotechnology?

**Nanotechnology** is the study of how to produce and control incredibly tiny structures. These structures are known as **nanoparticles** and are so small that they cannot be seen with a normal light microscope. However, they are big enough to be seen using a scanning tunnelling microscope (STM) or an atomic force microscope. The size of these structures is measured using a unit called the **nanometre** (unit symbol nm).

A nanometre is one-billionth of a metre. This makes a nanometre about one-hundred-thousandth the width of a human hair! Although tiny, a nanometre is still large compared with atoms: about 10 atoms could fit across it. The structures that nanotechnology produces are smaller than 100 nanometres in size. Figure 2.2.1 shows how small these structures are.

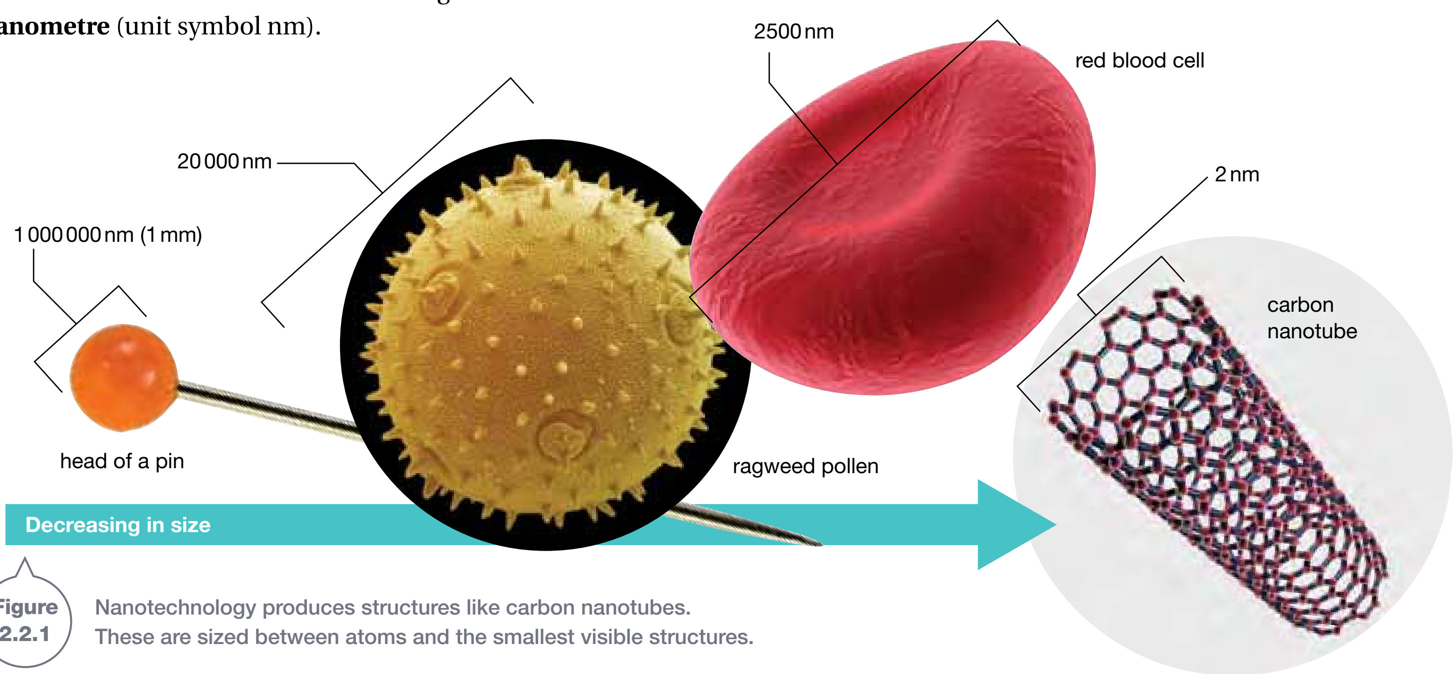



**Figure 2.2.1** Nanotechnology produces structures like carbon nanotubes. These are sized between atoms and the smallest visible structures.

INQUIRY science 4 fun

## Observing water

How well does water stick to surfaces?

### Collect this ...

- eye dropper or pencil
- a selection of different surfaces (such as aluminium foil, plastic wrap, paper, raw timber, bark, different plant leaves)
- water

### Do this ...

1. Place each of the surfaces horizontally on a table or bench.
2. Fill the eye dropper with water or dip the pencil into water. Use it to carefully place a drop of water on each surface.
3. View the water drop on each surface from its side and draw what it looks like.

### Record this ...

**Describe** what you observed.

**Explain** why some materials might encourage drops to form, while others do not.

# Self-cleaning paint

The lotus plant is a like a water-lily in that it grows with its leaves floating on water. The surface of these leaves repels water. The water drops do not wet the surface but just roll off. In 1974, Wilhelm Barthlott, a German botany professor, became interested in why. His research led to the manufacture of the world's first self-cleaning paint, called Lotusan®.

Barthlott studied lotus leaves under a scanning electron microscope (SEM) and found that the leaf surface was very rough, not smooth as expected. Figure 2.2.2 shows how rough it is. It was a combination of the roughness of the surface and the material from which it was made that prevented the water sticking to the surface.

A surface is classified as **hydrophobic** if it does not allow water to stick to it. Hydrophobic is commonly referred to as 'water-hating'. The opposite is **hydrophilic** ('water-loving'). The roughness of the lotus leaf seemed to make the surface 'super-hydrophobic', much more hydrophobic than most other known surfaces. On super-hydrophobic surfaces, water forms nearly spherical drops. You can see this in Figure 2.2.3. The angle a drop makes to its surface is known as the **contact angle**. For super-hydrophobic surfaces the contact angle is almost 180°. On less hydrophobic surfaces,

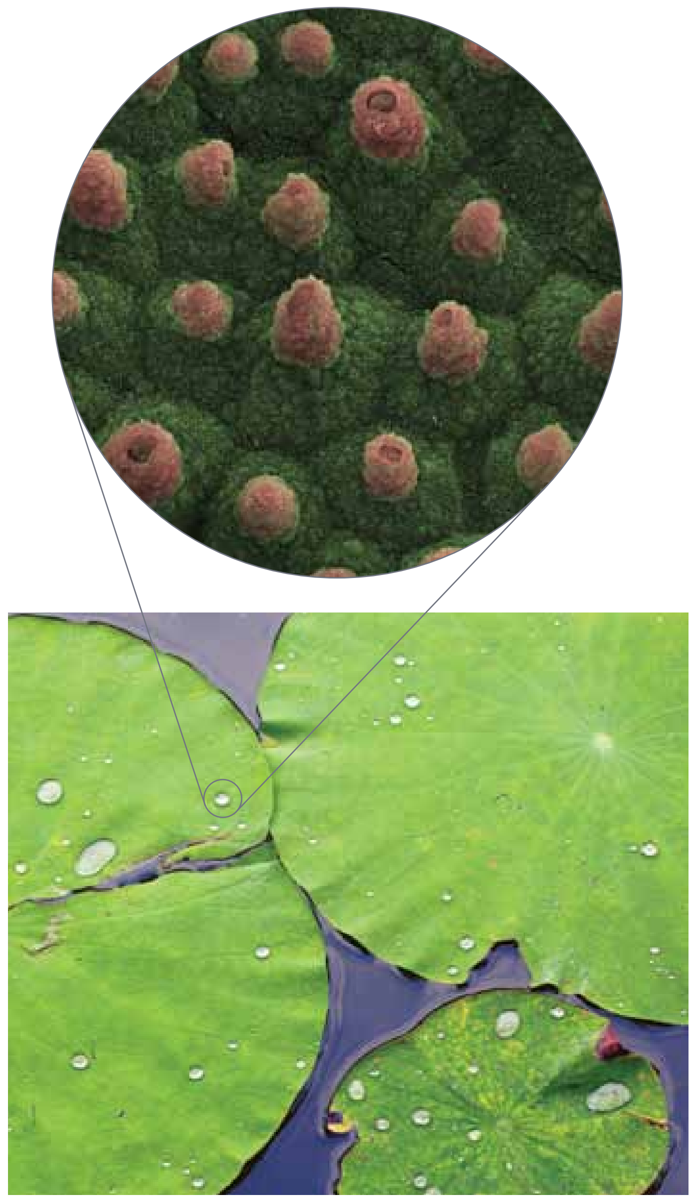


Figure 2.2.2 Lotus leaves are water-repellent. Water just forms beads and rolls off. Although the leaf looks smooth, an SEM view of it (top of picture) shows its surface to be very rough.

the drop is spherical but with a flattened base and a smaller contact angle. On hydrophilic surfaces, the drop is flattened, with an even smaller contact angle.

As Figure 2.2.4 shows, the spherical nature of water drops allows them to pick up and carry away dirt as the drops roll across a rough surface. Less spherical drops on a smoother surface pick up the dirt but then re-deposit it back onto the surface.

Lotusan is a self-cleaning paint that mimics the rough surface of the lotus leaf. Water on it forms near-spherical drops which then roll across the surface, picking up and washing away dirt as they go.

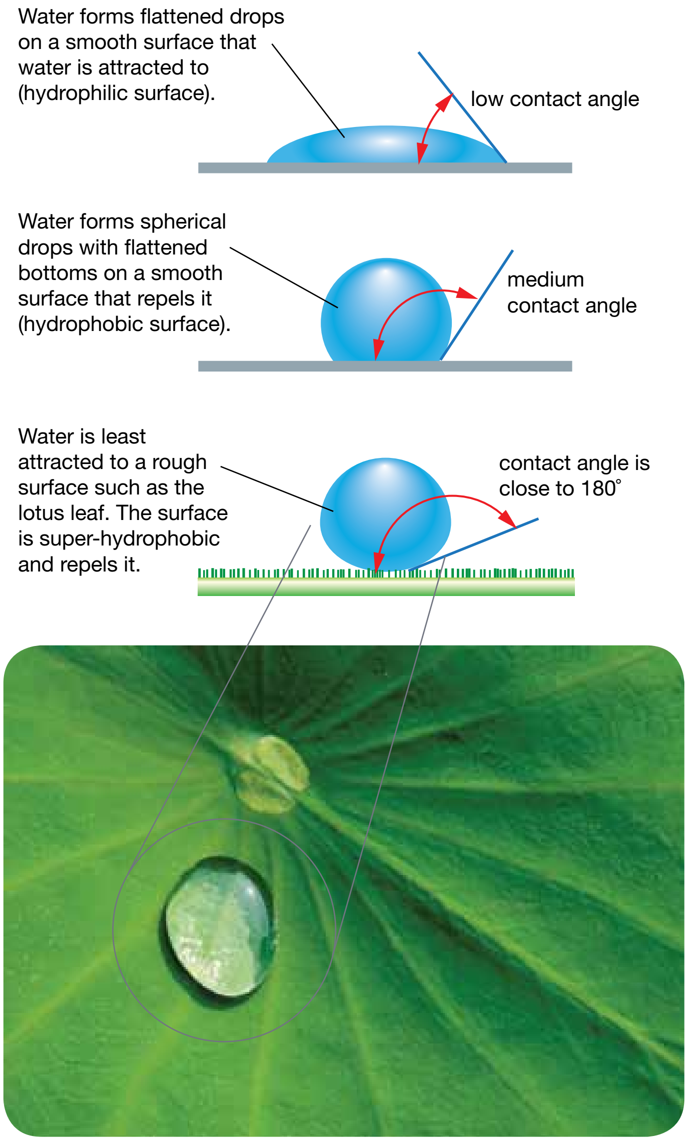



**Figure 2.2.3** The shape of a water droplet depends on whether it is attracted to or repelled by the surface it is on.

# Self-cleaning glass

The British company Pilkington has developed a self-cleaning glass that it calls Activ™ glass. To make the glass, Pilkington has used the opposite approach to the one used to make the self-cleaning paint. It has made the surface hydrophilic, or more attractive to water.

The scientists at Pilkington discovered the self-cleaning properties when they coated glass in titanium dioxide. In sunlight the titanium dioxide becomes electrically charged (called a **photocatalytic** effect). These electric charges destroy materials found in grease and fingerprints and change them into water-soluble substances. This makes the glass surface hydrophilic. Water spreads across the glass evenly, disolving dirt and helping to wash the glass clean. Figure 2.2.5 shows how this happens.

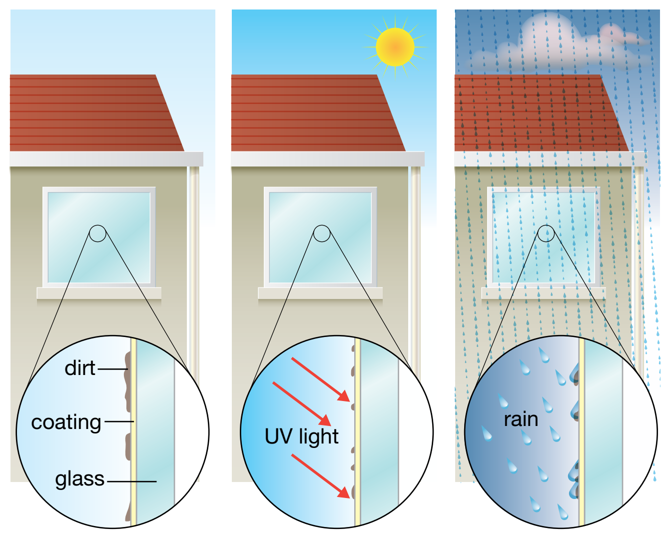



**Figure 2.2.5** Activ™ glass is a self-cleaning glass that uses a photocatalytic effect to allow water to evenly wet the surface and then run off.

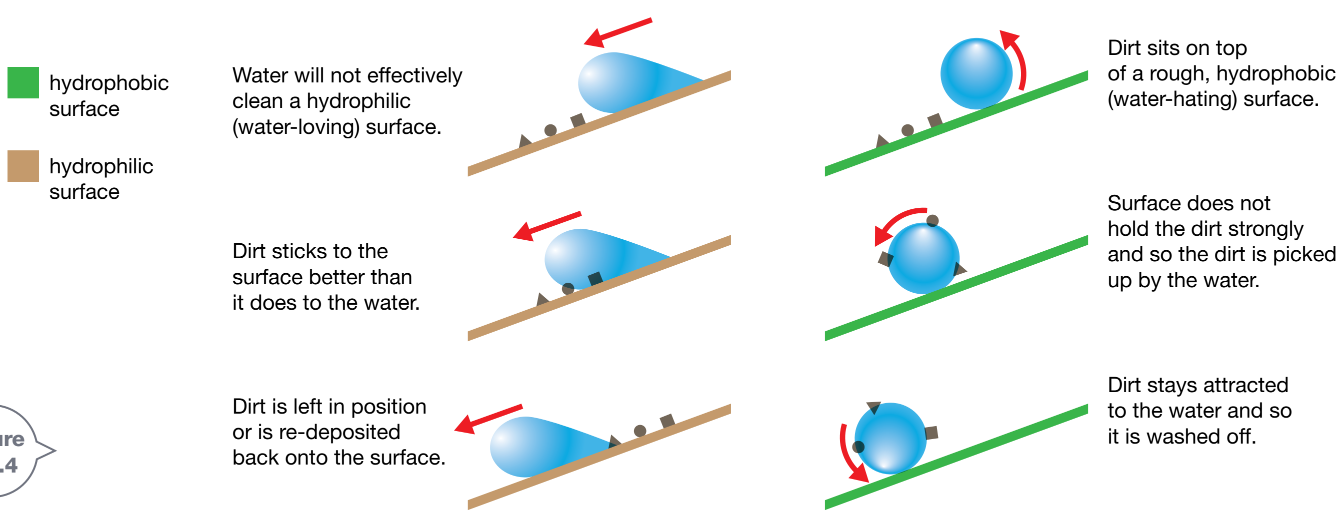



**Figure 2.2.4** Water can wash dirt off rough surfaces like the lotus leaf.

# Nanofabrics

Self-cleaning fabrics are coated in nanoparticles that produce a rough surface of super-hydrophobic, water-repelling material.

Nano-Tex® is one type of self-cleaning fabric that uses nanoparticles that take the form of whiskers. These whiskers cause water to wash dirt off the surface in the same way that it does on a lotus leaf. The whiskers also make the fabric stain resistant. Figure 2.2.6 shows how small these whiskers are.

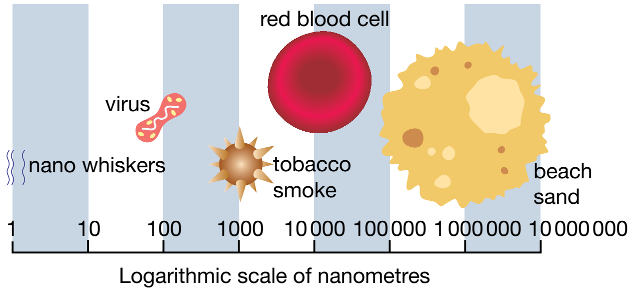



Figure 2.2.6 Nano-Tex® fabric uses tiny 'whiskers' of fabric to make the surface rough, like that of a lotus leaf. Nano-Tex treatment particles are one million times smaller than a grain of sand.

Another substance used in self-cleaning fabrics is zinc oxide. Zinc oxide is resistant to ultraviolet (UV) light and so it protects the fabric from sunlight. Zinc oxide also has a photocatalytic effect, like the titanium dioxide used in self-cleaning glass. This effect kills bacteria, keeping the material hygienic. The photocatalytic effect also breaks down dirt, allowing it to be washed off by water.

# Shape memory alloys

**Shape memory alloys (SMAs)** are metal alloys that change shape as the temperature changes. An example is shown in Figure 2.2.7. Shape memory alloys are said to retain a 'memory' of the shape they were given when cold. If you bend them into a new shape, they return to their original shape when they are heated. The first SMA discovered was an alloy of nickel and titanium, called **Nitinol**.

Nitinol can be made with different properties by mixing different amounts of nickel and titanium. In this way, it can be made to remember its shape at different temperatures.

Nitinol and other shape memory alloys are being used in human surgery for a variety of purposes. For example, Nitinol is used to construct devices called stents. A **stent** is a small tube that is inserted into an artery clogged with fatty cholesterol. The stent is crushed to make it easier to insert into the artery. Once the stent is in place, the body warms it up. When the stent reaches the core body temperature of

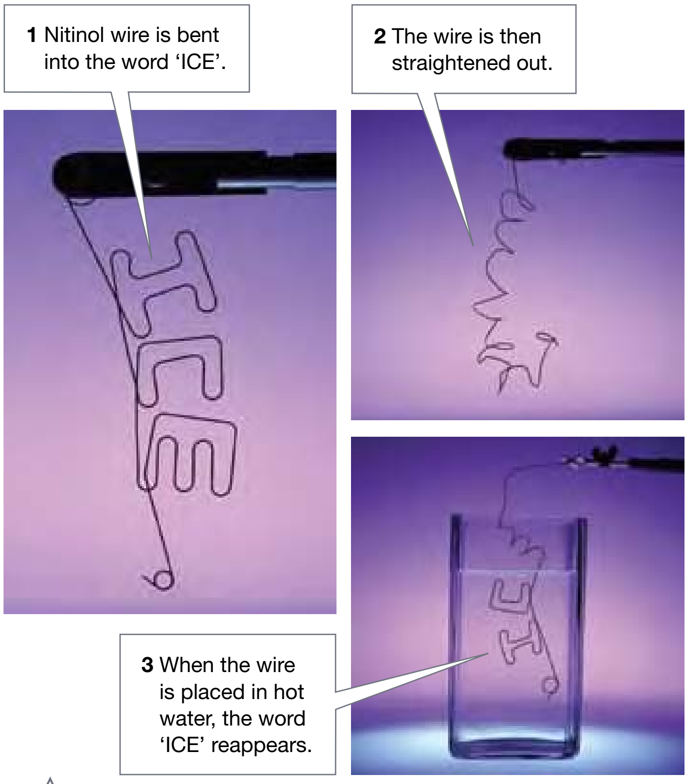



Figure 2.2.7 Nitinol is a shape memory alloy. When reheated, it 'remembers' its original shape.

37°C, it returns to its original tubular shape. The stent pushes on the artery walls, opening them and allowing blood to flow freely once again. The effectiveness of stents is shown in Figure 2.2.8. Stents are now commonly made from Nitinol.

Nitinol crystals take on three different structures depending on whether the metal is warm or cold and whether forces are being applied to it. The alloy changes shape because the metal atoms rearrange into the different crystal structures as the temperature changes. You can see this in Figure 2.2.9.

A cold wire has the twinned martensite crystal structure. Twisting the wire into a new shape changes the crystal structure into the deformed martensite shape. Heating the wire causes the crystal structure to adopt the austenite shape, and the wire returns to the shape it had before it was deformed.

To set the wire in a particular shape, you bend it into the shape you want, clamp it tightly, then heat it enough (over about 120°C) to rearrange the crystal structure to the austenite phase. You keep the wire clamped until it cools. When the wire cools, its crystal structure re-forms into the twinned martensite shape, but the wire stays the shape it was because it has been held in that shape. If you change the wire's shape again and heat it, the wire returns to the shape in which it had been set previously.

1 p55
2.4

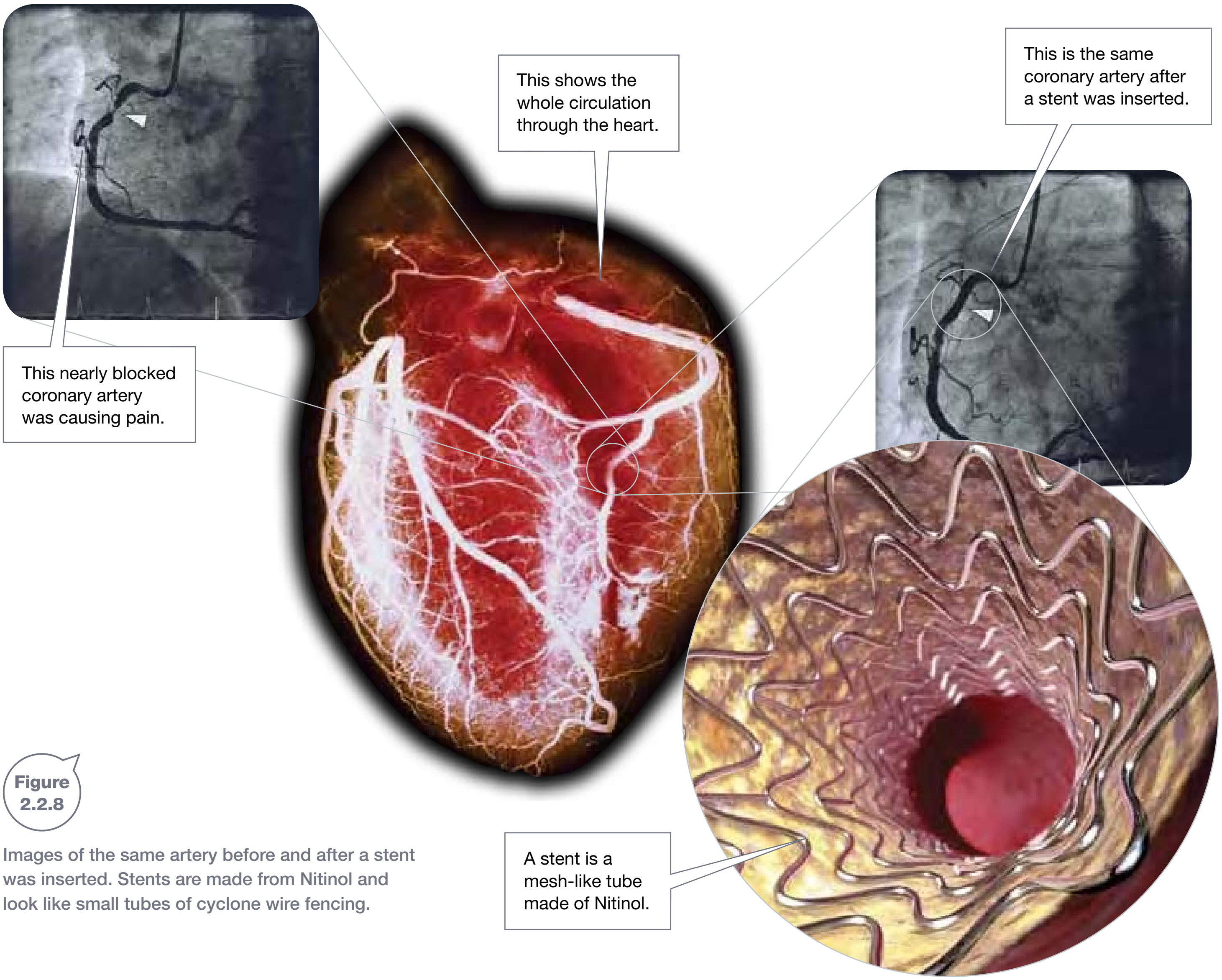



Figure 2.2.8

Images of the same artery before and after a stent was inserted. Stents are made from Nitinol and look like small tubes of cyclone wire fencing.

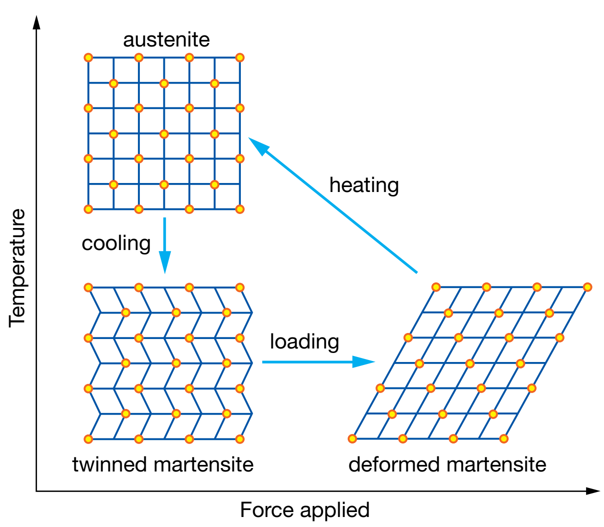



Figure 2.2.9

The crystal structure of Nitinol changes with temperature and how much force is being applied to it. Three shapes exist: austenite, twinned martensite and deformed martensite.

# The future of nanotechnology

## Carbon nanotubes

An exciting area of current nanotechnology research is **carbon nanotubes**. A carbon nanotube is a nano-sized cylinder of carbon atoms. Carbon atoms can join up to each other to form flat sheets of hexagons. These sheets can be rolled into tubes, like the one in Figure 2.2.10 on page 52. The properties of carbon nanotubes depend on how you roll the sheet. Rolling the sheet at different angles makes tubes with different properties and uses.

Carbon nanotubes are hundreds of times stronger than steel and are much lighter. For this reason they are being tried in the structures of cars, aircraft and buildings. Carbon nanotubes are also being researched for possible use in electronic devices such as semiconductors and microprocessors.

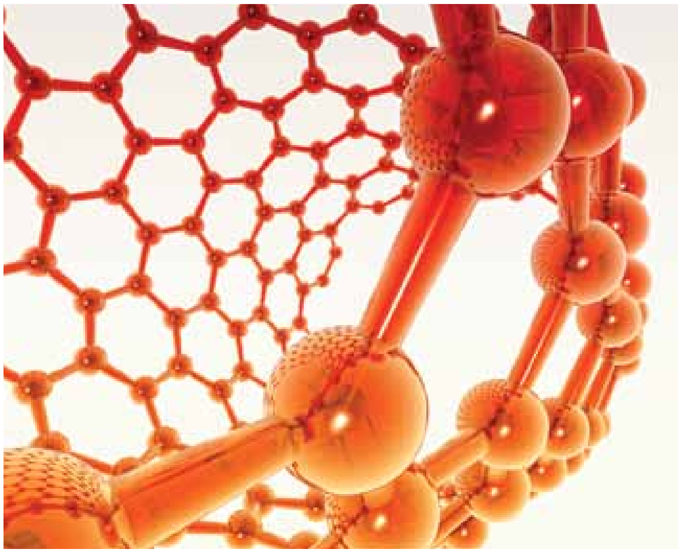


Figure 2.2.10 A model of a carbon nanotube. Carbon atoms are arranged in hexagonal units all joined together.

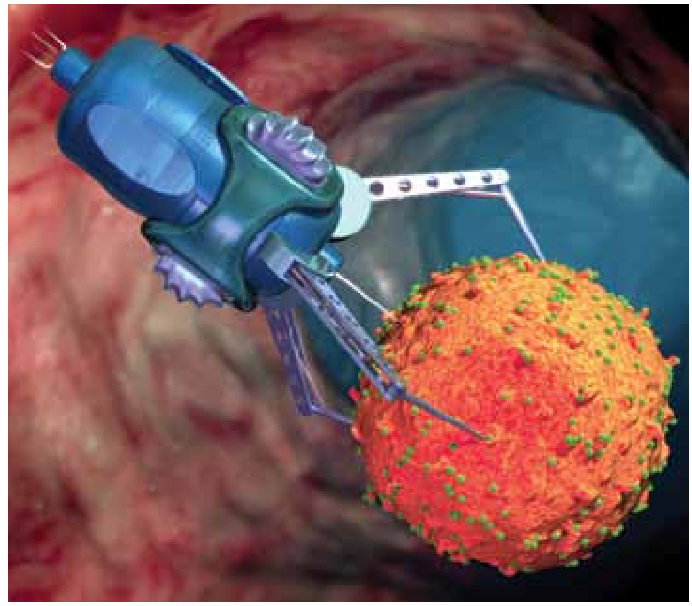


Figure 2.2.11 An artist's impression of a nanorobot targetting a particular cell

**SciFile**

**Power tennis**

A tennis racquet has been made with carbon nanotubes in the frame. It is as light as current carbon fibre racquets but is five times more rigid. Being flex resistant, these racquets are significantly more powerful than normal ones.

## Nanorobots

Nanotechnology may have its biggest impact on the medical industry. Scientists have predicted a future where patients might drink medicines, take capsules or receive injections that contain nanorobots. Nanorobots (or nanobots) are tiny devices that can get inside blood vessels and tissues to carry out a specific task, such as destroying cancer cells. Nanorobots (like the one in Figure 2.2.11) might also be able to perform surgery that is too complex and difficult for a human surgeon to do.

A major challenge is how to assemble such small robotic devices. Research has shown that it is possible to make molecular machines. One early success was to copy a protein 'motor' found both in cell membranes of bacteria and in the mitochondria of all other organisms. This protein acts like a tiny motor in that it spins around to move protons in or out of cells or mitochondria as part of energy production.

Scientists found that they could construct a nano-motor by:

- extracting the protein from the bacteria
- chemically sticking individual protein molecules to a block of silicon
- chemically attaching a tiny nickel rod to each protein.

Respiration is the chemical reaction that releases energy for the cells in your body to use. A vital part of this reaction is a molecule called ATP, which acts as an energy source for the reaction. If ATP is added to the nano-motor, then the proteins spin around like a fan. This simple motor is shown in Figure 2.2.12.

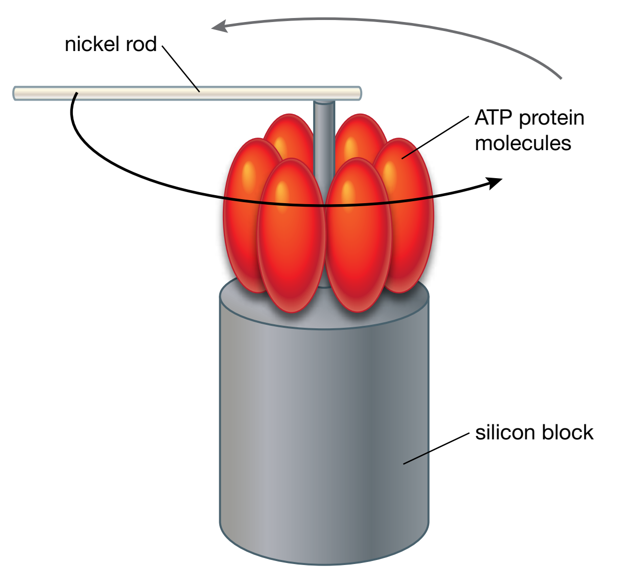



Figure 2.2.12 An artist's impression of a simple nanorobot made from the protein ATP-ase with a 750 nm nickel rod stuck to it. The nickel rod rotates like a fan.

# SCIENCE AS A HUMAN ENDEAVOUR

## Use and influence of science

### Nanomedicine

Figure 2.2.13 Chemotherapy kills healthy cells as well as cancerous ones. This makes the patient feel ill and often causes their hair to fall out.

**Pharmaceuticals (medical drugs) attempt to ease or kill whatever is causing a person to be ill. Nanopharmaceuticals promise to remove many of the problems experienced with conventional drugs.**

Antibiotics kill certain bacterial infections, ranging from ear infections to gangrene and stomach ulcers to sexually transmitted infections like chlamydia. Likewise, chemotherapy uses a series of poisons to kill **malignant** (rapidly growing and dangerous) cancerous cells. Unfortunately, most of these drugs do not target just the 'sick' cells but affect all the body's cells, including healthy ones. This means healthy cells are killed as well as cancerous ones, making the patient extremely ill (Figure 2.2.13).

### Nanopharmaceuticals

**Nanopharmaceuticals** are drugs that are nano-sized structures designed to deliver drugs directly to the 'sick' cells. These nanopharmaceuticals range in size from 5 nm to 300 nm and contain anything from ten or so atoms to hundreds of molecules. They can be made in different shapes such as spheres or crystals, or as needles. This allows them to target the specific surface of the 'sick' cell and leave healthy cells alone. These nano-sized drugs dissolve more easily than normal drugs, and so they are easier to prepare. Also a higher concentration of drug can be administered in a single dose.

Currently, twelve nanopharmaceuticals are approved for medical use or in human trials. One is Rexin-G®, a 100 nm wide particle that seeks out cancerous cells that have **metastasised** (spread throughout the body). These cells are usually impossible to find by medical imaging techniques and eventually cause new cancers around the body. Rexin-G® delivers a gene to the cancerous cells, destroying them while leaving healthy cells unaffected.

Cancerous tumours need a strong blood supply and cause the body to develop a mass of small blood vessels to help them grow. The drug fumagillin stops this development, but it tends to poison the patient after repeated doses. However, fumagillin can be attached to a nano-sized structure that delivers it directly to the blood vessels feeding a tumour. In this way, it can block the growth of cancerous tumours without making the patient ill.

These are two examples of what nanopharmaceuticals might do. Hormones and vaccines might also be delivered by a nanoparticle.

### Australian research

Malaria is one the world's deadliest diseases, killing up to 3 million people every year. Malaria is caused by the parasite *Plasmodium falciparum* and is passed on when an infected mosquito bites. The parasite then lives within the blood cells. Diagnosis is difficult, especially in the remote regions of Asia and central/southern Africa where malaria is common and pathology laboratories are rare. Dr Vipul Bansal is an expert in nanotechnology who lectures at RMIT University in Melbourne. In 2010, he was awarded a US$100 000 grant from the Bill and Melinda Gates Foundation to continue his research into a bandaid-like patch that would detect the presence of the malaria parasite. Infected blood cells tend to stick to the walls of blood vessels and tiny needles in his patch will test these cells for malaria. A nanochip in the patch will then analyse and record the data, which will give the result on a scanner passed over it.

# 2.2 Unit review

## Remembering

**1** **a** **State** the unit symbol for nanometre.
**b** **State** approximately how many atoms would fit side-by-side across a nanometre.

**2** **Name** a type of:
**a** self-cleaning glass
**b** self-cleaning fabric
**c** shape memory alloy
**d** nanopharmaceutical.

**3** **State** the approximate contact angle for a water drop on a lotus leaf.

**4** **State** what causes the photocatalytic effect in titanium oxide.

**5** **List** the advantages that carbon nanotubes have over steel.

## Understanding

**6** **Define** the term *nanotechnology*.

**7** **Explain** why spherical drops are better than other drops in cleaning dirt off a surface.

**9** **Outline** why self-cleaning glass washes clean.

**10** **Describe** how nanofabrics behave differently from normal fabric.

**11** **Outline** how shape memory alloys change shape as the temperature is changed.

**12** **a** **Describe** what a stent is and what it is used for.
**b** Nitinol stents are crushed before being inserted into an artery. **Explain** how they regain their shape.

**13** **Outline** how Dr Vipul Bansal's malaria-detection patch will work.

**14** **Describe** how carbon atoms are arranged in a carbon nanotube.

## Applying

**15** **Calculate** how many nanometres are in:
**a** 1 cm
**b** 1 mm
**c** 0.001 mm (1/1000th of a mm).

**16** Velcro tape uses little hooks and loops of material that hold together (see Figure 2.2.14). You can see these hooks and loops when you shine a bright light on a strip of the tape. **Use** the definition of nanotechnology to **determine** whether Velcro qualifies as a nanomaterial.

## Analysing

**17** **Contrast** the terms *hydrophobic* and *hydrophilic*.

**18** **Contrast** the methods by which scientists produced self-cleaning glass and self-cleaning paint.

## Evaluating

**19** Jesse heated a length of cold metal wire to 70°C but it did not change shape. Based on this evidence, he said that the wire could not have been Nitinol. However, the wire *was* Nitinol. **Propose** a reason why Jesse was incorrect.

**20** **Propose** the advantages of a stent being made from Nitinol instead of a normal alloy like stainless steel.

## Creating

**21** **Construct** a diagram to help you **define** the term *contact angle*.

## Inquiring

**1** **a** Design a way of comparing hairy leaves with smooth leaves to determine whether either type is hydrophobic.
**b** Show your teacher your plan and, if approved, carry out your experiment.

**2** Use the key word Rexin-G to find an animated video showing how this nanopharmaceutical works.

Figure 2.2.14 Velcro tape

# 2.2 Practical activities

## 1 Nitinol

### Purpose

To investigate properties of Nitinol, a shape memory alloy.

### Materials

- 3 lengths of mid-temperature range Nitinol wire (1 × 10 cm and 2 × 30 cm lengths)
- beaker tongs
- 6V battery or portable power pack
- 2 electrical leads with alligator clips
- switch
- Bunsen burner, gauze mat and bench mat
- 250 mL beaker
- 0–110°C thermometer

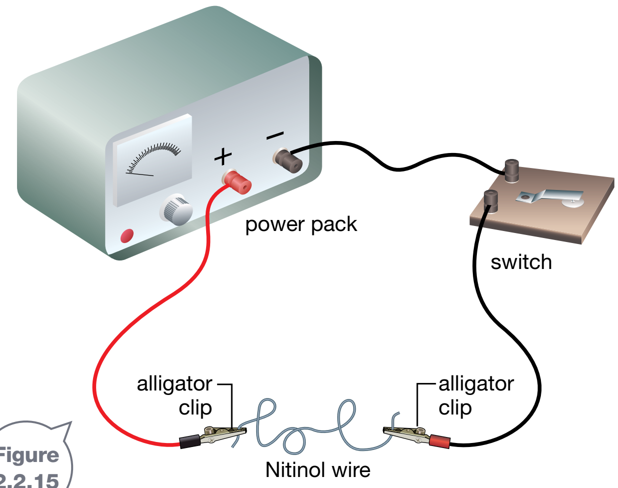


Figure 2.2.15

### Procedure

1. Bend the 10 cm length of Nitinol into any shape you choose.
2. Heat a beaker of water to 70°C.
3. Place your bent wire into the hot water and observe and record your observations.
4. Bend a 30 cm cool piece of Nitinol wire into any shape.
5. Set the power pack to 6 volts. Connect the Nitinol wire into a circuit as shown in Figure 2.2.15. Do *NOT* turn on the power yet.
6. Plug in the power pack and turn it on. Close the electrical switch for only as long as needed. Stop as soon as the Nitinol wire starts changing shape (the wire can be damaged by too much heat). Do *NOT* touch the wire, because it could be hot. Record your observations.
7. Wrap the remaining 30 cm length of Nitinol wire tightly around the end of a pair of tongs and grip it with the tongs so it cannot be moved.
8. Light the Bunsen burner, adjust the collar to half open and heat the Nitinol wrapped around the tongs for about a minute. Allow the wire to cool for several minutes and then remove it from the tongs.
9. When the wire is cool, bend it into any shape you like.
10. Reheat the beaker of water until it reaches 70°C, then drop the bent Nitinol in.

### Extension

11. Determine whether there is a critical temperature at which Nitinol behaves as a shape memory alloy. Do this by repeating steps 1 to 3 but with water heated to different temperatures.

### Results

Record your observations.

### Discussion

1. **Explain** the result seen in step 3 of the Procedure.
2. **Explain** the result seen in step 6 of the Procedure.
3. **Explain** the result from step 10 of the Procedure.

# 2.3 Acids and bases


Acids have a reputation for being extremely dangerous. But some, like those found in lemon juice and vinegar, are safe enough to eat and use in cooking. Bases also vary, from the caustic soda used to strip paint to gentler bases found in soap and disinfectant. Indicators show whether a solution is acidic or basic (alkaline). Some also measure how acidic or alkaline the solution is.

## Acids

An **acid** is a substance that releases hydrogen ions ($H^+$) into an aqueous solution (containing water). Examples are the hydrochloric acid that's in your stomach and the ethanoic acid (acetic acid) found in vinegar.

### Properties of acids

Acids share similar chemical properties. Acids:

- are corrosive. An acid burn is shown in Figure 2.3.1
- have a sour taste (think of the taste of vinegar)
- turn blue litmus paper red (shown in Figure 2.3.2)
- react with some metals, releasing hydrogen gas and leaving a salt behind
- conduct electricity
- are neutralised by bases, producing water and a salt.

**Figure 2.3.1** Acid burns can be severe, particularly if the acid is spilt into sensitive tissue such as in the eye.

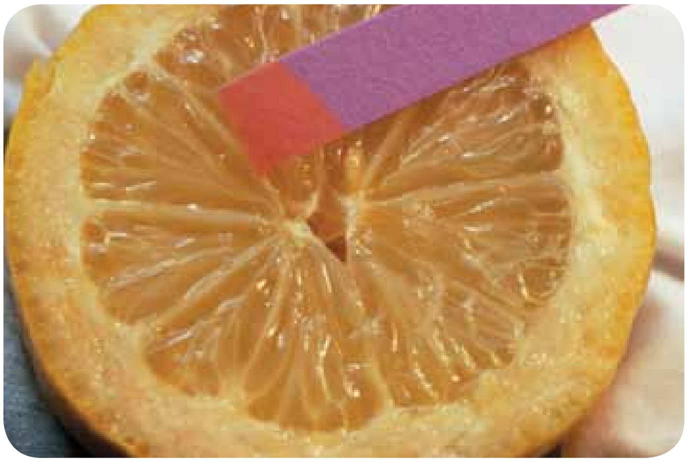


Figure 2.3.2 Acid turns blue litmus paper red.

**SciFile**

**Animal acids and bases**

A bite from a bull-ant hurts because the ant injects methanoic acid (also known as formic acid, HCOOH) into a cut made with its pincers. A bee sting also contains methanoic acid. Wasps and jellyfish inject a base. It's a different chemical but it still hurts!

## The strength of acids

Acids are molecular compounds made up of atoms from different elements. For example, a molecule of nitric acid ($HNO_3$) contains one hydrogen atom, one nitrogen atom and three oxygen atoms. Like nitric acid, all acids have hydrogen atoms in their molecules.

The acids you will work with in the laboratory (including nitric acid) are not pure substances but are solutions of acid mixed with water. When mixed with water, some of the hydrogen atoms in the acid molecule are released to form **hydrogen ions** ($H^+$).

The strength of an acid depends on how many hydrogen ions are released. An acid is a strong one if most of its molecules release hydrogen ions into solution. Nitric acid is an example of a strong acid, as are hydrochloric acid ($HCl$) and sulfuric acid ($H_2SO_4$). In contrast, an acid is weak if only a few of its molecules release hydrogen ions. An example of a weak acid is vinegar (ethanoic acid or acetic acid). Figure 2.3.3 compares a strong acid with a weak acid.

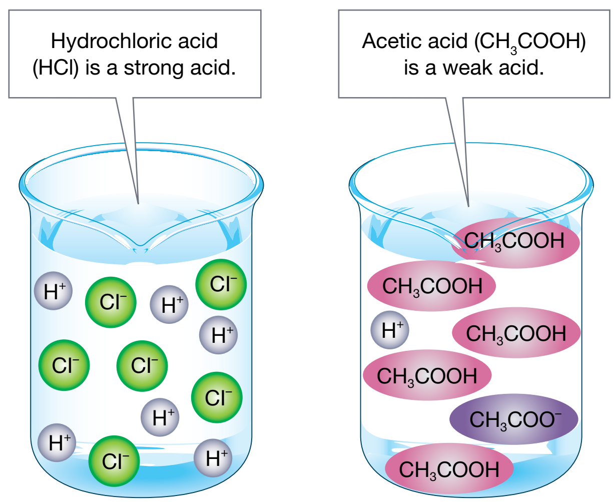



Figure 2.3.3 Strong acids like hydrochloric acid release lots of $H^+$ ions into solution. Weak acids like acetic acid (vinegar) release very few $H^+$ ions.

The number of hydrogen ions in an acid solution depends on:

- the strength of the acid. Solutions of strong acids have many more $H^+$ ions than weak acids of the same concentration. The strength of some different acids is shown in Table 2.3.1 on page 58.
- the concentration of the acid. This in turn depends on the amount of water mixed with it. If the acid solution is concentrated, there will be more hydrogen ions in the solution than in a dilute solution of the same acid.

Table 2.3.1 Examples of acids

| Strong acids | | |
|---|---|---|
| **Acid** | **Chemical formula** | **Used for/found in** |
| Hydrochloric | $HCl$ | • Cleaning mortar off bricks<br>• Your stomach (part of its gastric juices) |
| Nitric | $HNO_3$ | • Making fertilisers, dyes and explosives |
| Sulfuric | $H_2SO_4$ | • Making other chemicals, dyes, fertilisers, synthetic fibres and plastics |

| Weak acids | | |
|---|---|---|
| **Acid** | **Chemical formula** | **Use for/found in** |
| Ascorbic | $C_6H_8O_6$ | • Vitamin C |
| Acetylsalicylic | $C_9H_8O_6$ | • Making aspirin |
| Carbonic | $H_2CO_3$ | • Rain water<br>• Fizzy soft drinks and beer |
| Citric | $C_6H_8O_7$ | • Citrus fruits (such as lemons, limes, oranges)<br>• Tomatoes |
| Ethanoic (acetic) | $CH_3COOH$ | • Vinegar |
| Malic | $C_4H_6O_5$ | • Apples<br>• Most unripe fruits |
| Lactic | $C_3H_6O_3$ | • Milk, yoghurt<br>• Your muscles after heavy exercise, making them hurt |
| Tannic acid | $C_{76}H_{52}O_{46}$ | • Wood stains<br>• Tea |
| Tartaric | $C_4H_6O_6$ | • Grapes, bananas |

## Bases and alkalis

A **base** is a substance that releases **hydroxide ions** ($OH^-$). You use a weak base every time you use soap. If a base can be dissolved in water, it is also known as an **alkali**. The solution it forms is known as an **alkaline solution**. Bases such as caustic soda can burn you as badly as acids can, and so bases need to be treated with as much care as acids. All bases share similar chemical properties. Bases:

- are caustic
- have a soapy, slimy feel
- turn red litmus paper blue (shown in Figure 2.3.4)
- have a bitter taste
- conduct electricity
- are neutralised by acids, producing water and a salt.

Bases form hydroxide ions ($OH^-$) in solution. Strong bases produce lots of $OH^-$ ions, while weak bases only produce a few. The strength of different bases is shown in Table 2.3.2.

Figure 2.3.4 Alkaline solutions turn red litmus paper blue.

Table 2.3.2 Examples of bases and alkalis

| Strong bases/alkalis | | |
|---|---|---|
| **Base/alkali** | **Chemical formula** | **Used for/found in** |
| Calcium hydroxide | $Ca(OH)_2$ | • Cement, mortar and concrete<br>• Stripping hair from hides to form leather<br>• Paper production |
| Sodium hydroxide (caustic soda) | $NaOH$ | • Producing soap<br>• Paint stripper<br>• Drain and oven cleaner |
| **Weak bases/alkalis** | | |
| **Base/alkali** | **Chemical formula** | **Used for/found in** |
| Ammonia | $NH_3$ | • Household cleaners |
| Sodium hydrogen carbonate (sodium bicarbonate, bicarbonate of soda or baking soda) | $NaHCO_3$ | • Baking, to make cakes rise |
| Magnesium hydroxide (milk of magnesia) | $Mg(OH)_2$ | • Antacids |
| Sodium carbonate | $Na_2CO_3$ | • Washing powders |
| Ammonium hydroxide | $NH_4OH$ | • Household cleaners |

## pH

The concentration of hydrogen ions ($H^+$) in a solution is measured using the **pH** scale. In an acidic solution, there are more hydrogen ions than hydroxide ($OH^-$) ions. In contrast, an alkaline solution has more hydroxide ions than hydrogen ions.

Pure water is neither an acid nor a base. It's neutral, having equal numbers of hydrogen and hydroxide ions. It has a pH of 7. As Figure 2.3.5 shows, acids have a pH less than 7, while bases and alkaline solutions have a pH greater than 7.

**Blood pH**

Human blood isn't neutral like pure water but is slightly alkaline, having a pH of between 7.3 and 7.4.

**SciFile**

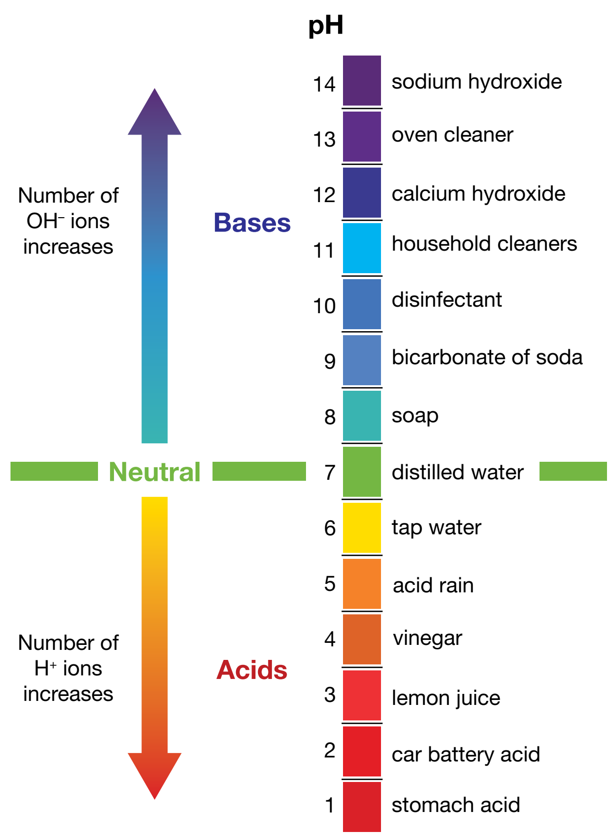



**Figure 2.3.5** Neutral solutions have a pH of 7. Acidic solutions have a pH less than 7. Alkaline solutions have a pH greater than 7.

| Indicator | Colour of indicator pH 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bromothymol blue | | | | | | | | | | | | | | |
| Litmus | | | | | | | | | | | | | | |
| Methyl orange | | | | | | | | | | | | | | |
| Phenolphthalein | | | | colourless | | | | | | | | | | |
| Universal indicator | | | | | | | | | | | | | | |

2.6
1 p62
2 p63
3 p63

**Figure 2.3.6** Different indicators have different colours, allowing pH to be determined accurately.

## Measuring pH

**Indicators** are chemicals that change colour to show whether a substance is acidic, neutral or basic. A common indicator is **litmus paper**, which turns red when dipped into acids and blue when dipped into a base. While litmus doesn't tell you what the pH of a solution is, other indicators like universal indicator do. As Figure 2.3.6 shows, different indicators change colour at different pH values.

Another way of measuring pH is to use a pH meter. One is being used in Figure 2.3.7.

INQUIRY science 4 fun

### Testing household solutions

What is the pH of different solutions around your home?

No

#### Collect this ...

- samples of various household solutions (such as fruit juices, soft drink, sour and fresh milk, tap water, salad dressing, detergent, shampoo)
- litmus paper (blue and red)
- watch-glass or white tile

#### Do this ...

1. Pour a little of each solution onto the watch-glass or white tile.
2. Touch one end of a small strip of litmus paper into the solution and then remove it.
3. Record the colour change.

#### Record this ...

**Describe** what happened.

**Explain** what this tells you about each of the samples you tested.

## Monitoring pH

The pH of swimming pools should be between 7.4 and 7.6 to ensure that bacteria and algae can't grow. The pH of a pool changes continually when:

- people swim in it
- leaves and dust drop into it
- it is topped up with new water
- sunlight breaks down the chlorine that is added to it.

For these reasons, the pH of a pool needs to be regularly measured using a pH meter or by taking a small sample and using an indicator.

**Figure 2.3.7** Pool water pH needs to be regularly monitored to ensure that the water is safe for swimmers.

Likewise, samples of river and creek water are taken regularly by environmental protection authorities to monitor pollution and the health of the water in them.

Nurseries, horticulturalists, market gardeners and home gardeners monitor the pH of the soil. Different plant types require particular pH ranges to grow well. For example, lemon trees produce more fruit when planted in an acidic soil. In contrast, fig trees produce more fruit when the soil is alkaline.

Particular care needs to be taken by anyone such as beauticians and hairdressers working with dyes, creams and lotions, because the wrong pH can burn or irritate the skin or hair. Although the pH of the materials might be known, how they react with the client's skin is not. For this reason, a small amount of chemical is usually tested on the skin and left for a short while.

# 2.3 Unit review

## Remembering

1 **Name** the acid that is in:
  a vinegar
  b milk
  c lemons.

2 **Name** the following acid and bases.
  a $CH_3COOH$
  b NaOH
  c $NH_3$

3 **List** the names and chemical formulas of two strong:
  a acids
  b bases.

4 **Name** the base that is in:
  a paint stripper
  b cement
  c baking soda.

5 **Name** the type of ion formed by:
  a acids
  b bases.

## Understanding

6 **Explain** why you have a sour taste in your mouth when you vomit.

7 **Explain** the main advantage that universal indicator has over litmus.

## Applying

8 **Use** Figure 2.3.6 on page 60 to **identify** the colour that the following indicators would be at pH 4.
  a blue litmus
  b phenolphthalein
  c universal indicator

## Analysing

9 **Compare** the number of $H^+$ ions in a solution of nitric acid with the number found in ethanoic acid (vinegar) of the same concentration.

10 Nitric acid is a strong acid but a solution of it might have exactly the same pH as a solution of vinegar, which is a weak acid.
  a **Analyse** what is happening here.
  a **Explain** why this can be.

## Evaluating

11 Heartburn has nothing to do with your heart. It's caused by gastric juices rising from the stomach into the oesophagus. **Propose** what is causing the pain of heartburn.

12 Urine has uric acid in it. **Use** this information to **propose** a reason why many gardeners encourage you to urinate near their lemon trees.

13 The pH of most public pools is measured using a pH meter, not an indicator. **Propose** reasons why.

14 Squashed ants have a distinctive smell. **Propose** what chemical the smell comes from.

15 **Propose** reasons why bricklayers commonly wear gloves when working.

## Creating

16 **Construct** a symbol (that uses no words) to be used on a sticker that would warn people that a bottle contained a concentrated solution of a strong acid like sulfuric acid.

## Inquiring

1 Find the appropriate first aid procedures to help a person who has splashed an acid or a base in their eyes or on their skin.

2 Research how to change soil that is too acidic or too alkaline for plant growth.

3 Research how knowledge of soil pH is used in agriculture.

4 Research the role of acids, bases and pH in the proper treatment of sewage.

5 Use the key words *acid base videos* to find internet videos on acids, bases and pH.

6 Use the key words *acid base games* to find interactive games on the internet. One you should try to find is the GEMS Alien Juice Bar Game.

7 Design an experiment to test the hypothesis that pikelets or scones will be better using a raising agent such as sodium hydrogen carbonate than with plain flour.

# 2.3 Practical activities

## 1 Red cabbage indicator

### Purpose

To make an indicator from red cabbage.

### Materials

- red cabbage leaves (or red flower petals such as carnation, rose or geranium)
- 250 mL beaker
- hotplate or Bunsen burner, tripod, gauze mat and bench mat
- 8 test-tubes
- test-tube rack
- dilute (0.1 M) hydrochloric acid
- dilute (0.1 M) sodium hydroxide solution
- vinegar
- salt solution
- distilled water
- soft drink
- lemon juice
- antacid tablet (such as Alka Seltzer)

### Procedure

#### Part A: Making the indicator

1. Tear up one or two red cabbage leaves, and place them in the beaker with enough water so that the cabbage is just covered.
2. Heat the beaker until the water is gently boiling. Continue to boil until the water has been strongly coloured red by the cabbage leaves.
3. Allow to cool and then filter, strain or pick out the cabbage leaves.

#### Part B: Testing the indicator

4. Place 7 test-tubes in the test-tube rack and split your cabbage water equally between them. Top them up with water so that the test-tubes are about half full.
5. Use the eyedropper to put about 1 cm of the dilute (0.1 M) hydrochloric acid solution in the first of the cabbage water test-tubes. Record what colour it turns, in a table like the one opposite.
6. In the second cabbage water tube put 1 cm of vinegar. In the third tube put distilled water, in the fourth tube put salt solution, and in the fifth tube put sodium hydroxide solution. Record the results of these tests in your table.

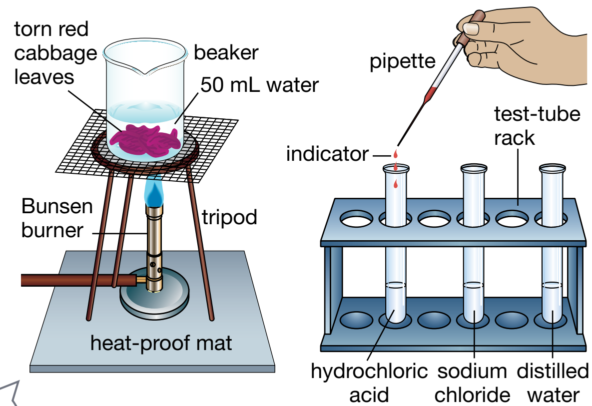



Figure 2.3.8

#### Part C: Testing unknowns

7. Add about 1 cm of lemon juice to the sixth test-tube.
8. Add about 1 cm of soft drink to the seventh test-tube.
9. Drop an antacid tablet into the eighth test-tube.

### Results

1. In your workbook, construct a table like this one.

| Test-tube/type of solution | Name of solution | Colour with red-cabbage/petal indicator |
|---|---|---|
| 1 0.1 M strong acid | Hydrochloric acid solution | |
| 2 Weak acid | Vinegar | |
| 3 Neutral | Distilled water | |
| 4 Weak base | Salt solution | |
| 5 0.1 M strong base | Sodium hydroxide solution | |
| 6 (Unknown 1) | Lemon juice | |
| 7 (Unknown 2) | Soft drink | |
| 8 (Unknown 3) | Antacid | |

2. From their colours, identify which acid or alkaline solution the lemon juice, soft drink and antacid were most similar to.

### Discussion

Not all indicators are used in a liquid form. For example, litmus paper is used more often than liquid litmus. **Design** a way to make red cabbage indicator paper and then test it.

## 2 Green eggs

### Purpose

To use indicators to turn the whites of fried eggs green.

### Materials

- red cabbage indicator from Prac 1
- small aluminium foil pie flan
- cooking oil
- 1 raw egg
- eyedropper
- hotplate or Bunsen burner, bench mat, tripod and gauze mat
- digital camera or mobile phone

### Procedure

1. Put a little oil in the aluminium foil pie flan and crack an egg into it. Try to keep the egg yolk intact.
2. Place the pie flan on the hotplate or over the Bunsen burner on a gauze mat and tripod.
3. Gently cook the egg without stirring. As SOON as the clear liquid part of the egg starts to turn white, use the eyedropper to place a few drops of red cabbage indicator into it.

### Results

Use a digital camera or photo or film function on your mobile phone to record your observations in both parts of this experiment.

### Discussion

Red cabbage indicator turns red if it comes in contact with an acid, purple in a neutral solution and green in a basic (alkaline) solution. **Identify** whether egg white (the material that surrounds the yolk) is acidic, neutral or alkaline.

## 3 pH column

### Purpose

To construct a series of coloured layers of different pH.

### Materials

- 100 mL measuring cylinder
- universal indicator
- solid sodium carbonate
- vinegar
- spatula
- long stirring rod (such as a chopstick)

### Procedure

1. Add 90 mL water and 10 mL vinegar to the 100 mL measuring cylinder.
2. Add a drop of universal indicator.
3. Use the long stirring rod or chopstick to mix well.
4. Use the spatula to add a small amount (about the size of a couple of rice grains) of solid sodium carbonate ($Na_2CO_3$).
5. Stir again, but this time *lightly*.
6. Leave the measuring cylinder in a safe place where it won't be disturbed for at least a couple of days.

### Results

1. After a day, four or five differently coloured layers should be clearly visible. Construct a diagram showing these layers.
2. Identify and label the pH of each band.

### Discussion

1. **Describe** what happens to the pH as you move towards the top of the measuring cylinder.
2. **Explain** why the lower layers would be more basic (alkaline) and the top layers more acidic.

# 2 Chapter review

## Remembering

1 Not all diamonds are good enough to be used for jewellery.
 a **State** the percentage of diamonds that are good enough.
 b **List** what other diamonds are used for.

2 **Name** the following chemicals.
 a $CH_3COOH$
 b $H_2SO_4$
 c NaOH
 d $HNO_3$

3 **State** how small a nanometre is compared to a metre.

4 **List** four examples of products resulting from nanotechnology.

5 **Name** three indicators.

6 **State** the pH of pure water.

## Understanding

7 **Describe** the advantages that alloys have over their base metals.

8 **Explain** how titanium dioxide and zinc oxide can destroy matter in dirt.

9 **Explain** how nanopharmaceuticals target 'sick' cells.

## Applying

10 **Use** a diagram to **outline** how self-cleaning paint works.

## Analysing

11 A solution was tested with different indicators. The colours they turned were:
Litmus = red
Methyl orange = yellow
Phenolphthalein = colourless
Bromothymol blue = blue
 a **Use** this information to **identify** the pH of the solution.
 b **Classify** the solution as acidic, neutral or alkaline.
 c **Predict** the colour that universal indicator would turn if it was added to the solution.

12 **Compare** hydrophobic and hydrophilic surfaces.

13 **Compare** acids with bases by listing their similarities and differences.

## Evaluating

14 Carbon has been known about for over 2000 years. **Propose** reasons why it was found much earlier than most other non-metals.

15 The 'austentite start temperature' is the temperature at which Nitinol's crystal structure changes to austentite. **Propose** a suitable austentite start temperature for a Nitinol device that can be placed into the body when cold and then allowed to warm up.

16 The 'nano whiskers' on Nano-Tex fabric result in a hydrophobic surface. **Propose** reasons why.

## Creating

17 **Construct** a diagram that shows how contact angle changes as surfaces become more hydrophobic.

18 **Use** the following ten key words to **construct** a visual summary of the information presented in this chapter.
metals
carbon
Nitinol
non-metals
hydrogen ion
acids
alloys
nanotube
diamond
nanotechnology

2.7

# Thinking scientifically

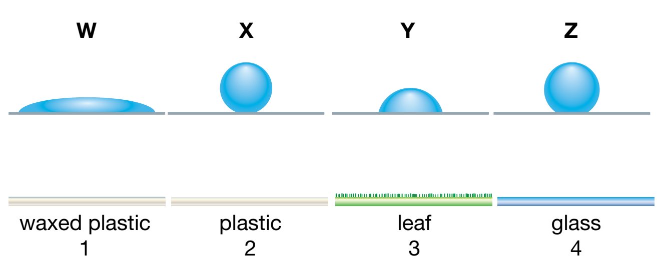
**Q1** Nitinol wire can be made with different properties depending on how much nickel and titanium are included. Other elements can also be added to change its properties.The following table shows some types of Nitinol.

| Designation of Nitinol | Minimum temperature needed for shape memory effect (°C) | Description of type |
|---|---|---|
| H | 95 | High temperature range Nitinol |
| M | 45 | Mid temperature range Nitinol |
| B | 20 | Body temperature Nitinol |
| S | 10 | Super elastic Nitinol |

Imagine you wanted to do an experiment that demonstrated the shape memory effect of Nitinol using hot water from a tap. A hot water tap is typically at a temperature of about 55°C. Which of the types of Nitinol would work and why?

**A** H, because it will stay at the martensite crystal structure in the hot water
**B** M, because it will change to martensite crystal structure in the correct temperature range
**C** H and M, because they can change to austentite crystal structure when they cool
**D** M, B and S, because they will change to the austentite crystal structure when they are placed in the water

**Q2** Studies of the behaviour of water on four different surfaces showed water droplet shapes W, X, Y and Z as shown below. There were four different surfaces (1–4).




Which of the following is the most likely correct match of water droplet shape and the surface on which it would occur?

| Possible match | Droplet shape and surface type |
|---|---|
| **A** | W4, X3, Y2, Z1 |
| **B** | W1, X3, Y2, Z4 |
| **C** | W4, X1, Y2, Z3 |
| **D** | W3, X1, Y4, Z2 |

**Q3** Acids release hydrogen ions ($H^+$) into solution.

Use this information to identify which of the following substances could NOT be an acid.

**A** HCOOH
**B** $Fe_2O_3$
**C** $H_2CO_3$
**D** $NaHSO_4$

**Q4** pH measures the concentration of hydrogen ions ($H^+$) in solution. The more concentrated the solution is with $H^+$ ions, the lower the pH is.

An acidic solution has a pH of 5. Water is then added to it. Predict what will happen to the $H^+$ concentration of the solution.

**A** It will stay the same as before.
**B** It will increase.
**C** It will decrease.
**D** It will become the same as water.

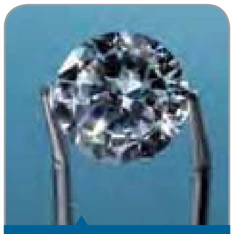
**Q5** Predict the pH of the new solution in question 4.

It will most likely be:

**A** 4
**B** 5
**C** 6
**D** 7

# Glossary

## Unit 2.1



Allotrope

**Allotropes:** different forms of carbon

**Alloy:** a mixture of a base metal and small amounts of other elements

**Annealing:** a process in which a metal is heated until red-hot, then allowed to cool naturally; also known as normalising

**Base metal:** the main metal in an alloy

**Brittle:** shatters if hit

**Carat:** a scale for measuring the purity of gold

**Ductile:** able to be stretched into wires

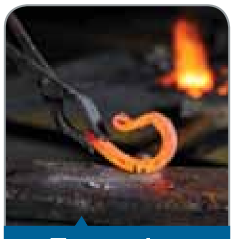
**Lustrous:** shines when polished or freshly cut

**Malleable:** able to be hammered into new shapes

**Metalloid:** an element that usually displays the properties of a non-metal but conducts electricity like a metal under certain conditions; also known as a semi-metal

**Periodic table:** a list of all the known 118 elements

**Quenching:** a process in which a heated metal is cooled rapidly by dropping it into water



Tempering

**Stainless steel:** a rustless alloy of steel that includes chromium and nickel

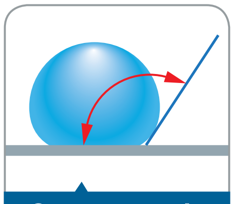
**Steel:** an alloy of iron and carbon

**Tempering:** a process in which a metal is heated, cooled rapidly (quenched) and then reheated

## Unit 2.2

**Carbon nanotube:** a nano-sized cylinder of carbon atoms

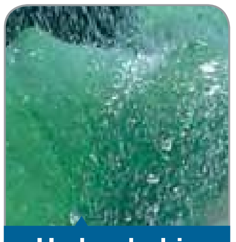
**Contact angle:** the angle that the base of a drop of water makes with the surface it is on



Contact angle

**Hydrophilic:** surfaces that attract water and allow it to stick to them; commonly referred to as 'water-loving'

**Hydrophobic:** surfaces that do not allow water to stick to them; commonly referred to as 'water-hating'



Hydrophobic

**Malignant:** rapidly growing and dangerous cancerous cells

**Metastasise:** when cancer cells spread beyond their original site into the rest of the body

**Nanometre (nm):** unit of length equal to one-billionth of a metre or one-thousandth of a millimetre; unit symbol nm

**Nanoparticle:** a particle or structure that is too small to be seen with a normal light microscope

**Nanopharmaceutical:** a medical drug that is a nanoparticle or is delivered by a nano-sized structure

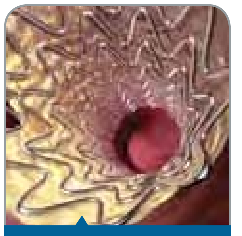
**Nanotechnology:** the study of how to produce, and control, structures at a scale below the size of visible particles but larger than atoms

Nitinol

**Nitinol:** a shape memory alloy made of nickel and titanium

**Photocatalytic:** an effect where sunlight causes materials to become electrically charged and able to react with organic matter and other particles

**Shape memory alloy (SMA):** a mixture of metals that changes shape as the temperature changes



Stent

**Stent:** a mesh sleeve that is inserted into clogged arteries to keep them open; commonly made of Nitinol

## Unit 2.3

**Acid:** a substance that releases hydrogen ions into an aqueous solution

**Alkali:** a base that dissolves in water

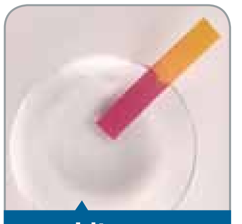
**Alkaline solution:** a solution made of a base/alkali and water

**Base:** a substance that releases hydroxide ions

**Hydrogen ion:** $H^+$, released by acids

**Hydroxide ion:** $OH^-$, formed by bases

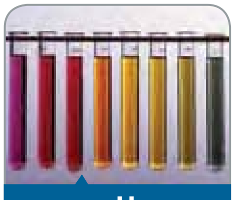
**Indicator:** a chemical that changes colour to show whether a substance is acidic, neutral or basic



Litmus

**Litmus paper:** a common indicator that turns red in the presence of an acid and blue in the presence of a base

**pH:** a scale used to measure the concentration of $H^+$ ions in a solution



pH

# Reaction types

3

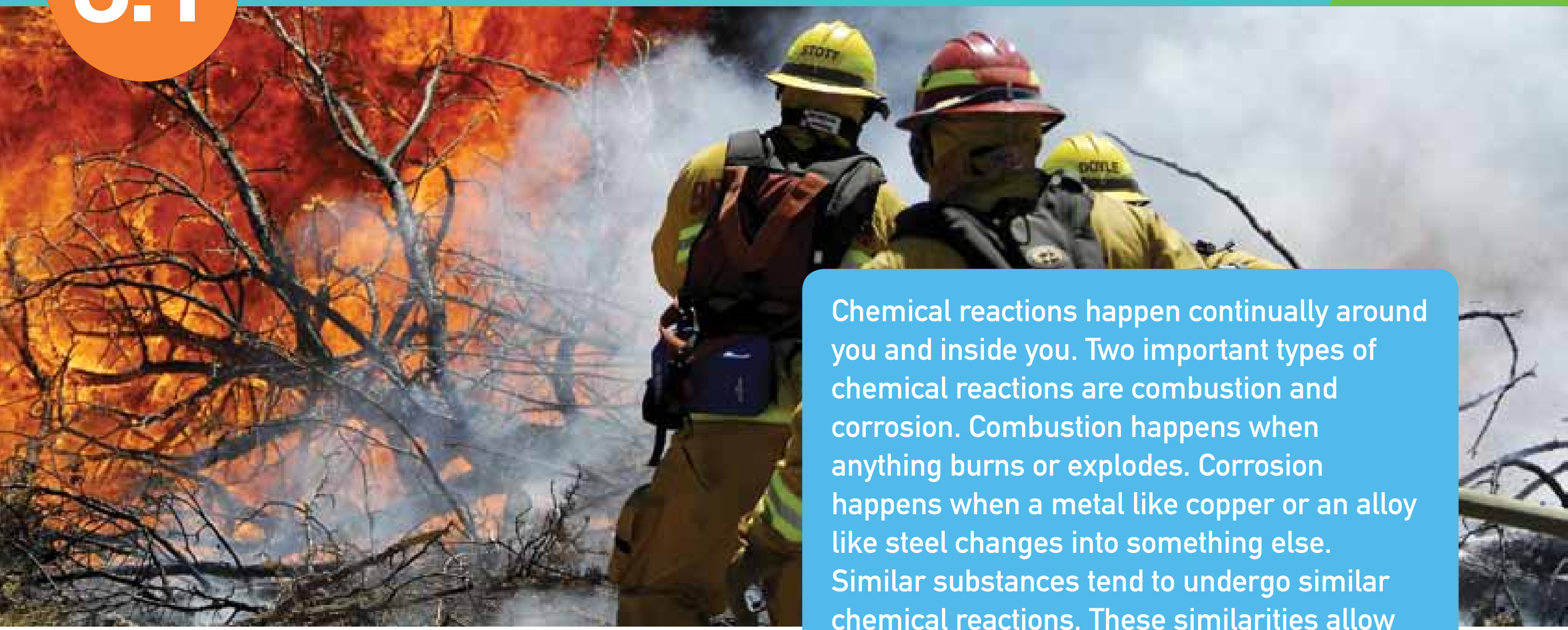
## HAVE YOU EVER WONDERED . . .

- what causes iron to rust?
- why some fires are smoky while others aren't?
- how plants can survive when they don't eat anything?
- why we breathe out carbon dioxide and not oxygen?

## After completing this chapter students should be able to:

- identify reactants and products in chemical reactions
- describe chemical reactions as a rearrangement of atoms
- describe chemical reactions using word equations
- demonstrate that mass is conserved in a chemical reaction
- classify different reactions as exothermic or endothermic
- outline the role of energy in chemical equations
- describe the role of oxygen in combustion reactions
- compare combustion with other oxidation processes
- describe how the products of combustion reactions affect the environment
- describe reactions of acids with metals, bases and carbonates
- evaluate claims relating to products such as indigestion tablets
- compare respiration and photosynthesis and their roles in biological processes.

# 3.1 Combustion and corrosion reactions



Chemical reactions happen continually around you and inside you. Two important types of chemical reactions are combustion and corrosion. Combustion happens when anything burns or explodes. Corrosion happens when a metal like copper or an alloy like steel changes into something else. Similar substances tend to undergo similar chemical reactions. These similarities allow you to predict what might happen if two chemicals are mixed. The similarities become more obvious when chemical reactions are expressed as chemical equations.

## Endothermic and exothermic reactions

Chemical equations are used to explain what happens to substances when they undergo chemical change in a chemical reaction. **Reactants** are the substances you started with before the chemical reaction. **Products** are the substances that are formed by the chemical reaction.

In some reactions, the products have more energy than the reactants. These reactions need energy to proceed and they get their energy from their surroundings. Reactions like this are known as **endothermic** reactions. An example is what happens in a chemical cold pack that you apply when you have an injury. Packets of ammonium nitrate and water are broken, allowing these substances to mix and react. As they do so, they absorb energy from their surroundings, cooling them down. The sherbet in Figure 3.1.1 acts in a similar way.

Figure 3.1.1

Sherbet leaves your tongue cold and tingling because an endothermic reaction absorbs heat from your mouth.

INQUIRY science 4 fun

### Eating sherbet

What does an endothermic reaction in your mouth feel like?

Yes

#### Collect this . . .

- ½ teaspoon citric acid
- ¼ teaspoon baking soda (bicarbonate of soda, $NaHCO_3$)
- 3 teaspoons icing sugar
- clean mixing bowl, cup or mug
- teaspoon

#### Do this . . .

1. Add all the ingredients to the small mixing bowl or mug.
2. Use the back of the teaspoon to crush any lumps and to mix everything together.
3. Keep it in a dry place until ready to eat!

#### Record this . . .

**Describe** what happened in your mouth when you ate the sherbet.

**Explain** why you think this happened.

SKILL BUILDER

## Writing chemical equations

To write a chemical equation, follow the four steps below.

### Step 1: Identify the reactants and products

As an example, consider the chemical reaction between copper and sulfur dioxide. This reaction forms copper sulfide and oxygen gas. We started with copper and sulfur dioxide, so these are the reactants. Copper sulfide and oxygen gas were produced. These are the products.

### Step 2: Write a word equation

A **word equation** is a simple written description of what is happening in the reaction. The reactants are placed on the left side of the arrow and the products on the right.

reactants → products

copper + sulfur dioxide → copper sulfide + oxygen gas

### Step 3: Write an unbalanced formula equation

The next step is to replace the names of each substance in the word equation with their element symbols or chemical formulas. This gives you an unbalanced formula equation. For the above reaction, you need to know that copper has the element symbol Cu and the chemical formula of sulfur dioxide is $SO_2$, copper sulfide is $Cu_2S$ and oxygen gas is $O_2$.

This gives you the following equation:

copper + sulfur dioxide → copper sulfide + oxygen gas

$$Cu + SO_2 \rightarrow Cu_2S + O_2$$

1 p74

3.1

3.2

### Step 4: Balance the equation

An equation is unbalanced if it has unequal numbers of atoms of a particular element on both sides of the arrow. The above equation starts with one copper atom, one sulfur atom and two oxygen atoms. However, the equation ends up with two copper atoms, one sulfur atom and two oxygen atoms. This suggests that a copper atom appeared from nowhere! That is impossible because atoms never just appear in chemical reactions. Nor do they disappear. They only change in the way they are arranged. This fundamental principle of chemistry is known as the **law of conservation of mass**. Formula equations need to be balanced, to describe accurately the rearrangement that is happening in the reaction.

A **balanced formula equation** has the same numbers of each atom on both sides of the arrow. The above reaction would be balanced if the reaction used up two atoms of copper instead of just one. This is indicated by inserting a 2 in front of the Cu, as shown here:

$$2Cu + SO_2 \rightarrow Cu_2S + O_2$$

Figure 3.1.2 shows what is happening to the atoms in this reaction.

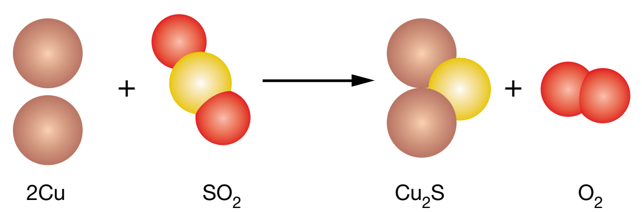



**Figure 3.1.2** Atoms can't appear from nothing and can't disappear. This is why chemical equations must be balanced.

**Photosynthesis** is the reaction that green plants use to form a sugar known as **glucose** ($C_6H_{12}O_6$). This reaction absorbs energy from sunlight (Figure 3.1.3) and so it is another example of an endothermic reaction. The photosynthesis reaction is shown below.

carbon dioxide + water → glucose + oxygen

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

**Figure 3.1.3** Without energy from the Sun, the photosynthesis reaction in these leaves would never happen and the plant would die.

## Combustion

While endothermic reactions absorb energy, **exothermic** reactions release energy. In exothermic reactions, the reactants have more energy than the products. During the reaction, the difference in these energies is released into the surroundings, usually as heat and/or light.

Combustion reactions are examples of exothermic reactions. **Combustion** occurs whenever something reacts with oxygen gas ($O_2$), burning or exploding as it does so. A bushfire is a series of combustion reactions. The chemicals in living plants and dead twigs and leaves burn in oxygen, releasing huge amounts of heat and light as they react.

Oxygen gas is always needed for combustion to occur. For this reason, combustion reactions can also be classified as a type of oxidation reaction.

Figure 3.1.4 A gas stove uses combustion to release its heat (and light).

### That's shocking!

SciFile

Explosions generate hot gases that suddenly expand at speeds of up to 8 kilometres per second! These expanding gases form blasts of wind called shockwaves, which can be as deadly as the explosion itself. A shockwave leaves a vacuum at the site of the explosion, and air flowing into this carries rubbish and debris.

## Combustion of fossil fuels

Bunsen burners, gas stoves (like the one in Figure 3.1.4), water heaters and central heating furnaces produce a hot blue flame by burning methane or ethane gas in oxygen. The reactions are:

methane gas + oxygen gas → carbon dioxide + water vapour

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

ethane + oxygen gas → carbon dioxide + water vapour

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

### Suffocating fires

SciFile

Fires consume oxygen, so there is less of it to breathe in the region of the fire! During World War II, the German city of Dresden was firebombed. Many of the 25 000 people killed in the attack are thought to have suffocated because of this lack of oxygen.

Petrol is a mixture of highly combustible chemicals called **hydrocarbons**, the most important of which is octane. Octane combusts via the chemical equation:

octane + oxygen gas → carbon dioxide + water vapour

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

## Incomplete combustion

The above combustion reactions all need oxygen fed into them. These reactions are known as **complete combustion**. If the oxygen supply is restricted, other reactions occur instead. This is known as **incomplete combustion**. Incomplete combustion is still exothermic but does not release as much heat or light energy as complete combustion does.

The reactions below show what happens to methane if oxygen is restricted.

methane + oxygen gas → carbon monoxide + water vapour

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

At the same time another reaction occurs.

methane + oxygen gas → carbon + water vapour

$$CH_4 + O_2 \rightarrow C + 2H_2O$$

Incomplete combustion reactions are 'dirty' because they produce carbon, which is left behind as soot, charcoal or smoke, like that seen in Figure 3.1.5. They also produce the poisonous gas carbon monoxide. In contrast, complete combustion reactions are 'clean'.

A Bunsen burner can show both complete and incomplete combustion. If the flow of oxygen to it is good (open airhole), then the flame is hot, clean and blue. If the air flow is restricted (closed airhole), then a cooler dirty yellow flame is produced.

Figure 3.1.5 Smoke and soot are an indication of incomplete combustion.

Figure 3.1.6 Respiration gives your body the energy it needs. The reaction needs glucose (from your food) and oxygen (breathed in). You breathe out its product, carbon dioxide.

## Pollution and climate change

Water vapour and carbon dioxide are released into the atmosphere whenever fossil fuels like gas, petrol, oil, coal, and diesel and aviation fuel are burnt. Carbon dioxide is a greenhouse gas that traps heat within the atmosphere. Over the past 150 years, humans have burned huge quantities of fossil fuels to power their cars, ships and aircraft, and to heat their homes and generate electricity. For this reason, the amount of carbon dioxide in the atmosphere has increased to levels that most scientists agree are increasing the atmosphere's average temperature. If this view is correct, it could be affecting Earth's climate.

If the combustion of these fossil fuels is incomplete, then carbon monoxide and carbon are released. Carbon adds relatively harmless but dirty soot to the atmosphere. However, carbon monoxide gas has no smell and is so poisonous that even small amounts of it can kill. Petrol also contains additives that release other poisonous chemicals when burnt. These include oxides of nitrogen and sulfur, both of which can combine with moisture in the air to form smog and acid rain.

## Other combustion reactions

A much slower and controlled combustion reaction occurs within the cells of your own body. **Aerobic respiration** combines a type of sugar called glucose from the digestion of your food with the oxygen you breathe in. This reaction releases the energy that the cells of your body need. A waste product is carbon dioxide, which you breathe out. This is what is happening in Figure 3.1.6.

glucose + oxygen gas → carbon dioxide + water vapour

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Not all combustion reactions produce carbon dioxide and water vapour. When burnt, magnesium reacts to form magnesium oxide. No other products form.

magnesium + oxygen gas → magnesium oxide

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

You can see this reaction happening in Figure 3.1.7.

Figure 3.1.7 The light released by the combustion of magnesium is so bright that it can quickly damage your eyes.

2 p75 3 p76

# Corrosion reactions

Another type of oxidation reaction is corrosion. Most metals corrode when exposed to water, air or other chemicals. **Corrosion** is the chemical reaction that breaks these metals down to form other compounds.

For example, the iron/steel body of a car slowly reacts with water and oxygen in the air and will corrode until all that's left is a pile of rust.

In a similar way, copper corrodes by reacting with gases in the air to form green **verdigris** (shown in Figure 3.1.8), a mixture of copper hydroxide and copper carbonate. The chemical equation is:

copper + water + carbon dioxide + oxygen gas → copper hydroxide + copper carbonate

$$2Cu + H_2O + CO_2 + O_2 \rightarrow Cu(OH)_2 + CuCO_3$$

Figure 3.1.8 This copper roof has corroded to form a green coating called verdigris.

Pure silver reacts with sulfur to form a black coating called **tarnish** (silver sulfide). This sulfur comes from hydrogen sulfide in air pollution or from foods such as eggs, fish, onions and pea soup.

silver + hydrogen sulfide → silver sulfide + hydrogen gas

$$2Ag + H_2S \rightarrow Ag_2S + H_2$$

Pure sodium and potassium react with just about anything. Their corrosion is very quick and often explosive because of the hydrogen gas that their reactions produce. Their chemical reactions with water are shown below.

sodium + water → sodium hydroxide + hydrogen gas

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

potassium + water → potassium hydroxide + hydrogen gas

$$2K + 2H_2O \rightarrow 2KOH + H_2$$

## Rusting

Iron and its alloy, steel, are common and relatively cheap, making them the most commonly used metals on Earth. Unfortunately, iron and most grades of steel react with air and water to form **rust**, known chemically as hydrated iron(III) oxide (chemical formula $Fe_2O_3{\cdot}H_2O$). Rust is flaky and easy to dislodge. This allows the rusting process to continue into the next layer, making the iron or steel thinner and weaker. Figure 3.1.9 shows what can happen.

Figure 3.1.9 Rust forms when iron is exposed to oxygen and water.

Although an extremely complex reaction, rusting can be summarised by the chemical equation:

iron + oxygen gas + water → hydrated iron(III) oxide

$$4Fe + 3O_2 + 2H_2O \rightarrow 2Fe_2O_3{\cdot}H_2O$$

This equation is often simplified to:

iron + oxygen gas → iron(III) oxide

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

## Corrosion of aluminium

Aluminium is very reactive. The surface metal reacts almost immediately with the air, forming a fine layer of dull grey aluminium oxide ($Al_2O_3$).

aluminium + oxygen gas → aluminium oxide

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

Unlike rust, this layer does not flake but acts instead like a tightly bound layer of paint, protecting the aluminium from further corrosion.

**Anodising** is a process that deliberately builds up a layer of aluminium oxide to protect the aluminium underneath (Figure 3.1.10).

Figure 3.1.10 These cups are made of anodised aluminium. Their surface is a layer of aluminium oxide that was deliberately built up on the surface of the metal and then coloured. This layer protects the aluminium underneath from corroding any further.

# 3.1 Unit review

## Remembering

1 **State** what substance is always required for combustion to occur.

2 **Name** the sugar made in the process of photosynthesis.

3 **Recall** the following reactions by writing the word equations for:
- a the combustion of ethane
- b the corrosion of iron.

4 **Recall** the following reactions by writing the word equation and balanced formula equation for:
- a the combustion of octane
- b the corrosion of copper.

5 **Name** the process that is often used to protect aluminium from further corrosion.

## Understanding

6 **Explain** where the energy comes from in an exothermic reaction.

7 **Explain** how a Bunsen burner can display both complete and incomplete combustion.

8 Gary's campfire was 'dying' so he fanned it with a newspaper. Flames soon appeared once more. **Explain** how his actions helped the fire build again.

9 **Explain** why the rusting of iron makes it get thinner and thinner.

## Applying

10 The combustion of butene is shown by the following word and balanced equations.

butene + oxygen gas → carbon dioxide + water

$$C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$$

**Identify**:
- a the chemical formula for butene
- b reactants for the reaction
- c products for the reaction.

11 **Identify** the missing numbers that would balance the following equations.
- a $2Ca + O_2 \longrightarrow .....CaO$
- b $C_3H_8 + 5O_2 \longrightarrow 4H_2O + ....CO_2$
- c $2Li + ....H_2O \longrightarrow ....LiOH + H_2$

## Analysing

12 **Classify** the following reactions as endothermic or exothermic.
- a A bushfire burns down a forest.
- b Photosynthesis uses energy from the Sun.
- c Aerobic respiration releases energy for use in cells.
- d Sherbet tingles in your mouth.
- e Magnesium burns in oxygen and releases light.
- f A chemical cold pack cools sore muscles.

13 **Contrast** complete and incomplete combustion.

14 **Contrast** the corrosion of iron with the corrosion of aluminium.

15 **Compare** combustion with corrosion.

## Evaluating

16 A flat sheet of paper burns quickly and with little smoke. In contrast, a tightly crumpled sheet of paper will smoulder, with few flames but a lot of smoke. **Propose** reasons why.

17 Bushfires tend to be hotter and more fierce when a strong wind is blowing. **Propose** reasons why.

## Creating

18 Benzene ($C_6H_6$) burns in oxygen gas ($O_2$) to produce carbon dioxide ($CO_2$) and water ($H_2O$).
- a **Identify** the reactants of this reaction.
- b **Identify** the products of this reaction.
- c **Construct** a word equation for the reaction.
- d **Construct** its unbalanced formula equation.
- e **Construct** its balanced equation.

## Inquiring

1 Research the products of combustion reactions (such as those in car exhausts or industrial emissions) and the effects of these products on the environment.

2 Use the key words *balancing chemical equations games* to find websites that do the balancing for you!

3 Antoine Lavoisier developed the law of conservation of mass. Research his life and achievements and construct a simple biography outlining what you found out.

4 Use the key words *chemical reaction video, corrosion video* or *combustion video* to find internet videos of different types of chemical reactions.

# 3.1 Practical activities

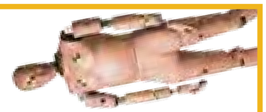
## 1 Conservation of mass

### Purpose

To demonstrate that mass is conserved in a chemical reaction.

### Materials

- 0.1 M copper sulfate solution
- 0.1 M sodium hydroxide solution
- 0.1 M sodium carbonate solution
- ammonia solution
- four 250 mL beakers
- marking pen
- electronic balance



**SAFETY**

All chemicals should be treated as toxic.

Do not taste any chemicals.

### Procedure

1. Pour copper sulfate solution into one of the beakers until it reaches the 50 mL mark. Use the marking pen to label this beaker BLUE.
2. To the other beaker add 50 mL of sodium hydroxide solution.
3. Place both beakers on the electronic balance and determine their total mass. Record this mass in a table like the one in the Results section.
4. Carefully pour the copper sulfate into the sodium hydroxide and observe what happens.
5. Place the beaker with the solutions in it and the empty beaker labelled BLUE back on the electronic balance. Once again determine their total mass. Record their mass.
6. To a clean beaker, add 50 mL of sodium carbonate. Add another 50 mL of copper sulfate to the beaker labelled BLUE. Once again, find their total mass.
7. Carefully pour the copper sulfate solution into the sodium carbonate solution. As before, find the total mass of the full and empty beakers.
8. Repeat steps 6 and 7 but this time use ammonia solution instead of sodium carbonate.

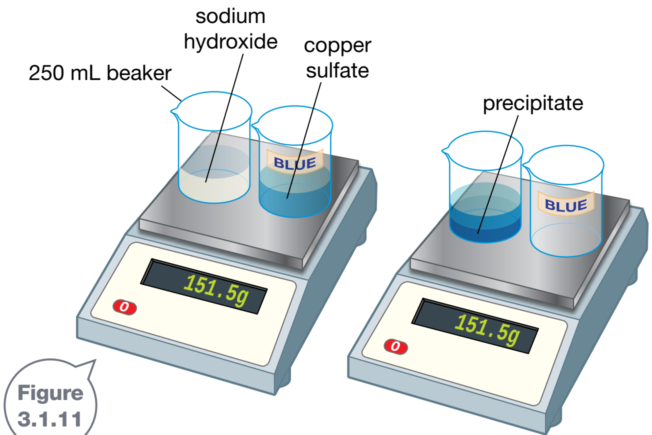



Figure 3.1.11

### Extension

9. Allow each of the mixed solutions to settle. The powdery solid that settles on the bottom of the beaker is known as a precipitate. Design a way of filtering each solution so that you can determine the mass of the precipitate formed (trapped in the filter paper) and the filtrate (the liquid that passes through the filter paper).

### Results

Record all your observations and masses in a table like the one shown here.

| | Total mass before mixing (g) | Total mass after mixing (g) | Observations |
|---|---|---|---|
| Sodium hydroxide + copper sulfate | | | |
| Sodium carbonate + copper sulfate | | | |
| Ammonia + copper sulfate | | | |

### Discussion

1. **List** evidence that chemical reactions took place once the solutions were mixed.
2. **Compare** the total masses before and after mixing.
3. **State** the law of conservation of mass.
4. **Assess** whether or not your results support this law.

## 2 Conservation of mass in combustion reactions

### Purpose
To show that combustion reactions obey the law of conservation of mass.

### Materials
- electronic balance
- clean steel wool

**Part A: Combustion in the open air**
- evaporating dish or watch-glass
- 9V battery

**Part B: Combustion in a sealed container**
- large Pyrex test-tube
- test-tube tongs
- balloon
- Bunsen burner and bench mat

**SAFETY**

Sparks will fly in Part A. Make sure they don't hit you or your clothes.

In Part B if sparks enter the balloon it could partly melt or catch fire.

### Procedure

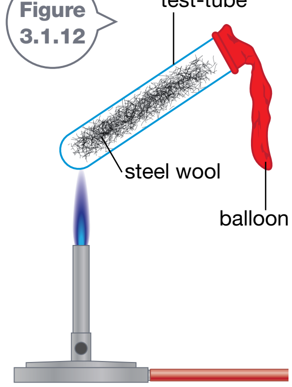
**Part A: Combustion in the open air**

1. Tease out the strands of a small piece of steel wool (about 1 gram) and place it in an evaporating dish or watch-glass.
2. Use the electronic balance to find the combined mass of both the evaporating dish/watch-glass and the steel wool. Record the total mass in a results table like the one shown in the Results section.
3. Pass an electric current through the steel wool by lowering a 9 V battery until both of its terminals touch the steel. Record your observations in the table.
4. Shift the battery around to other parts of the steel wool so that as much of the steel as possible is burnt.
5. When completed, find the mass of the evaporating dish/watch-glass and the burnt steel wool. Record the new mass in the table.

**Part B: Combustion in a sealed container**

6. Tease out a strand of steel wool (about 0.5 gram) and slide it into the test-tube.
7. Squeeze all the air out of the balloon and fit it over the opening of the test-tube, as shown in Figure 3.1.12.
8. Find the total mass of the test-tube, balloon and steel wool combined and record it in your table.

Figure 3.1.12




9. Use tongs to hold the test-tube over a blue Bunsen burner flame. Make sure that you move the test-tube back and forth in the flame and that the flame gets nowhere near the balloon. Stop heating after about 5 minutes. Record what you saw happen in the test-tube and to the balloon.
10. Allow the test-tube to cool completely. When the test-tube is cool, again find the total mass of the test-tube, steel wool and balloon.

### Results
Record all your measurements in a table like this one.

| | Total mass before (g) | Total mass after (g) | Observations |
|---|---|---|---|
| Part A | | | |
| Part B | | | |

### Discussion
1. The reactions in both Part A and Part B were combustion reactions. **State** what other substance is needed for combustion to occur.
2. The reactions in both Part A and Part B could also be classified as corrosion reactions. **Explain** why.
3. The total mass in Part A most likely increased. **Propose** where this increase in mass came from.
4. The total mass at the end of Part B was most likely the same or very similar to the total mass at the start. **Propose** reasons why.
5. **Assess** which set of results (Part A or Part B) best demonstrated the law of conservation of mass.

# 3.1 Practical activities

## 3 Cracker combustion

### Purpose

To observe how combustion releases heat energy.

### Materials

- dry biscuits (such as Clix crackers)
- large test-tube
- thermometer
- retort stand, bosshead and clamp
- bench mat
- metal tongs
- Bunsen burner
- electronic balance

**SAFETY**

An open flame can be dangerous. The room should be well ventilated.

Biscuits containing nuts should not be used in case of nut allergies.

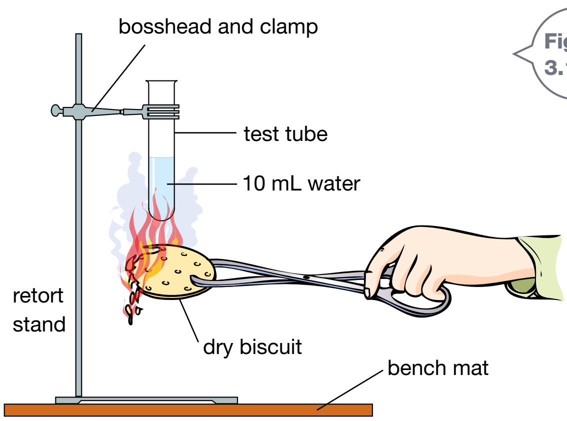



Figure 3.1.13

### Procedure

1. Set up the apparatus as shown in Figure 3.1.13.
2. Use the measuring cylinder to measure out 10 mL of water. Add it to the test-tube.
3. Measure the temperature of the water in the test-tube.
4. Measure the mass of the dry biscuit.
5. Use the tongs to hold the biscuit in a blue Bunsen burner flame. Heat the biscuit until it catches fire.
6. Quickly hold the biscuit under the test-tube. Re-light the biscuit if it goes 'out'.
7. Measure the temperature of the water again once the biscuit has changed completely into ash.

### Extension

8. Test what happens if the amount or number of biscuits is increased. For example, do two biscuits cause the temperature to rise twice as far?

### Results

1. Record all your measurements in a table like the one shown here.

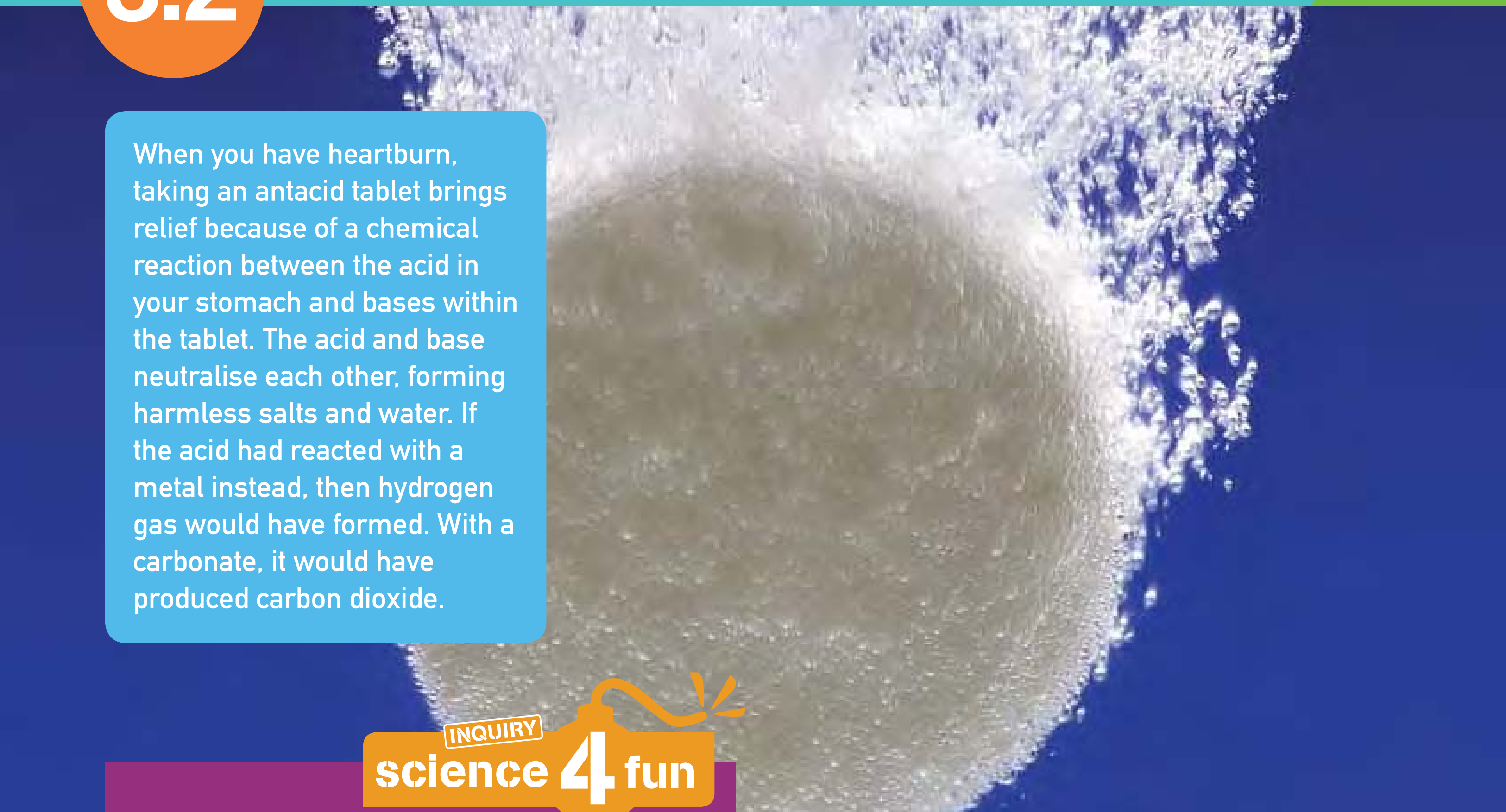
| | Number of biscuits | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Mass (g) | | | |
| Temperature before (°C) | | | |
| Temperature after (°C) | | | |
| Temperature rise (°C) | | | |
| Energy absorbed (J) = temperature rise x 42 | | | |

2. Determine how much energy was absorbed by the water, by multiplying the temperature rise by 42. (It takes 42 J of heat energy to raise the temperature of 10 mL of water by 1°C.)

### Discussion

1. a **Identify** whether the biscuit underwent complete or incomplete combustion.
   b **Justify** your answer.
2. The amount of energy absorbed by the water is less than the amount of energy released by the biscuit. **Explain** why.
3. **Construct** a conclusion for what happened when the mass or number of biscuits increased.
4. **Evaluate** your experiment to determine ways in which it could be improved.

# 3.2 Acid reactions



When you have heartburn, taking an antacid tablet brings relief because of a chemical reaction between the acid in your stomach and bases within the tablet. The acid and base neutralise each other, forming harmless salts and water. If the acid had reacted with a metal instead, then hydrogen gas would have formed. With a carbonate, it would have produced carbon dioxide.

INQUIRY science 4 fun

## Exploding bags

Can acids and bases mix together to produce an explosion?

### Collect this …

- 1 zip-lock plastic bag
- a few squares of toilet paper
- baking soda (bicarbonate of soda, $NaHCO_3$)
- vinegar
- warm water
- tablespoon
- measuring cup

### Do this …

1 Measure out a tablespoon of baking soda and wrap it up in few sheets of toilet paper. Twist the paper to hold it all in place.
2 Pour ¼ cup of vinegar and ¼ cup of warm water into the zip-lock bag.
3 Zip up the bag but leave a gap big enough for your baking soda parcel to fit through.
4 Go outside and push the parcel in. Quickly zip up the gap and place it on the ground. Stand clear!

### Record this …

**Describe** what happened.
**Explain** why you think this happened.

## Acids and metals

Acids can corrode metals, usually breaking them down into a salt and hydrogen gas. An example of this type of reaction is shown in Figure 3.2.1.

Figure 3.2.1

Iron reacts with hydrochloric acid, forming bubbles of hydrogen gas.

The general equation for the reaction between an acid and a metal is:

acid + metal ⟶ a salt + hydrogen gas

Examples are:

hydrochloric acid + magnesium ⟶ magnesium chloride + hydrogen gas

$2HCl + Mg \longrightarrow MgCl_2 + H_2$

sulfuric acid + iron ⟶ iron sulfate + hydrogen gas

$H_2SO_4 + Fe \longrightarrow FeSO_4 + H_2$

**Salt** is normally the term used for sodium chloride (NaCl). In these reactions, however, it is used in a much more general way. Here the term salt means any compound formed by a metal taking the place of the hydrogen atom in an acid. For example, potassium nitrate ($KNO_3$), magnesium sulfate ($MgSO_4$) and calcium chloride ($CaCl_2$) are all salts.

1 p83

## Neutralisation reactions

Acids and bases neutralise each other when mixed, changing each other into harmless substances such as water and a salt. **Neutralisation** reactions take the form:

acid + base ⟶ a salt + water

Examples are:

nitric acid + potassium oxide ⟶ potassium nitrate + water

$2HNO_3 + K_2O \longrightarrow 2KNO_3 + H_2O$

sulfuric acid + sodium hydroxide ⟶ sodium sulfate + water

$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$

**That feels better!**

Heartburn is caused by hydrochloric acid from your stomach rising into your oesophagus (foodpipe) and burning it. Antacid tablets contain bases (usually magnesium hydroxide and/or aluminium hydroxide) that neutralise the acid and bring quick relief.

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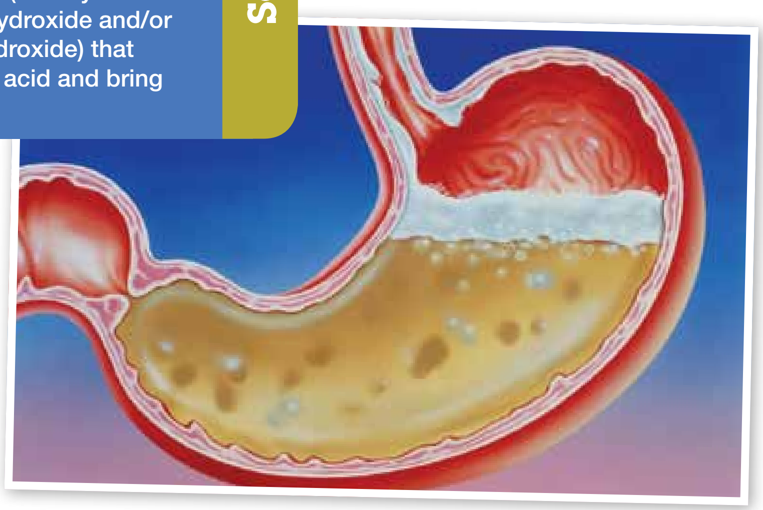


## Acids and carbonates

When the base is a carbonate, the reaction between it and an acid produces carbon dioxide as well as a salt and water. The general equation is:

acid + carbonate ⟶ a salt + water + carbon dioxide

Figure 3.2.2 shows the reaction between the calcium carbonate in chalk and hydrochloric acid. Its reaction is:

hydrochloric acid + calcium carbonate ⟶ calcium chloride + water + carbon dioxide

$2HCl + CaCO_3 \longrightarrow CaCl_2 + H_2O + CO_2$

Figure 3.2.2 Chalk contains the base calcium carbonate. Here hydrochloric acid reacts with the calcium carbonate to form bubbles of carbon dioxide.

Carbon dioxide is also produced when acids react with hydrogen carbonates. For example, vinegar (ethanoic or acetic acid) and baking soda (sodium hydrogen carbonate) mix and form a froth of carbon dioxide bubbles. You can see this in Figure 3.2.3. Its equations are:

ethanoic acid + sodium hydrogen carbonate → sodium acetate + water + carbon dioxide

$$CH_3COOH + NaHCO_3 \rightarrow NaCH_3COO + H_2O + CO_2$$

Figure 3.2.3

Bicarbonate of soda (sodium hydrogen carbonate) is a base. Vinegar contains acetic acid. When mixed, these chemicals react rapidly, neutralising each other and producing lots of bubbles of carbon dioxide.

INQUIRY science 4 fun

## Acid rain

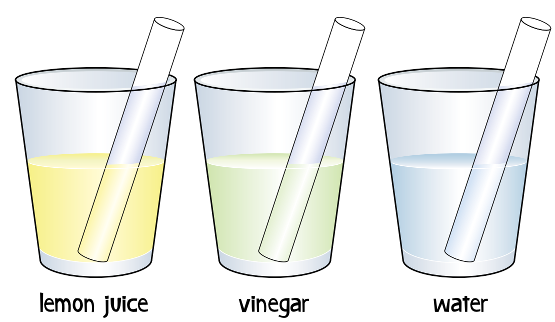
Chalk contains calcium carbonate, the same compound that is in marble. Can you use it to imitate the action of acid rain on marble?

### Collect this …

- 3 identical glasses
- 3 identical sticks or pieces of chalk
- lemon juice
- vinegar
- water

### Do this …

1. Fill the three glasses with identical amounts of lemon juice, vinegar and water.
2. Put a stick or piece of chalk in each glass, making sure each stick or piece is identical in size.
3. Leave the glasses somewhere where they won't be disturbed.
4. After three days (or more), inspect what has happened to the chalk in each glass.




### Record this …

**Describe** what happened.

**Explain** why you think this happened.

### SciFile

**Ease the pain**

The acid of a bee sting should be relieved by neutralising it with a base, like bicarbonate of soda. Likewise, the alkaline sting of a wasp should be neutralised by vinegar or even urine. Unfortunately, these usually don't work because they rarely go deep enough into the tissues inflamed by the sting.

# SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

## Acid rain

Figure 3.2.4 Acid rain has killed many forests in North America and Europe.

**Rainwater is naturally slightly acidic, with a pH between 5 and 6.**

This is because rainwater reacts with some of the carbon dioxide in the air to form carbonic acid.

water + carbon dioxide → carbonic acid

$$H_2O + CO_2 \rightarrow H_2CO_3$$

Pollution can cause rainwater to become even more acidic. The combustion of fossil fuels (particularly coal) releases carbon dioxide, sulfur dioxide ($SO_2$) and nitrogen oxides (mainly nitrogen dioxide, $NO_2$) as pollutants into the atmosphere. As a result, rainfall has more carbonic acid in it. It also has strong acids in it formed by the combination of sulfur dioxide and nitrogen dioxide with water vapour in the atmosphere. These form via a series of chemical equations that can be summarised as:

sulfur dioxide + water vapour → sulfurous acid

$$SO_2 + H_2O \rightarrow H_2SO_3$$

sulfur dioxide + water vapour + oxygen gas → sulfuric acid

$$2SO_2 + 2H_2O + O_2 \rightarrow 2H_2SO_4$$

nitrogen dioxide + water → nitrous acid + nitric acid

$$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$$

Rainwater dissolves these acids and returns them to Earth as **acid rain**. Depending on the weather, it may return instead as acid dew, fog, sleet, hail or snow. The pH of acid rain is much lower and more acidic than that of normal rain (pH 6), and has been measured as low as 3.3 (strongly acidic).

**SciFile**

### Natural acid rain

Volcanoes spew out huge quantities of sulfur and sulfur-based gases every time they erupt. Lightning produces nitrogen-based gases. These gases react with water vapour in the atmosphere and produce their own acids and acid rain. Studies of ancient ice samples from Antarctic glaciers show that some natural acid rain has always fallen.

3.4

### The effect on the environment

Although acid rain is not yet a significant concern in Australia, its effects are particularly evident in highly populated and industrialised areas such as the United States, southern Canada, Europe and China.

- Acid rain has killed forests. As Figure 3.2.4 shows, acid rain, fog and snow can kill trees. It also leaches aluminium from the soil, which then runs into rivers and lakes and percolates downwards into the groundwater. These increased aluminium levels are often enough to kill the plants, animals and fish that use or live in that water.
- Acid rain has killed fish, frogs, water snails, insects and other organisms living in lakes or around lakes. These lakes have increased acidity (decreased pH). As Figure 3.2.5 shows, pH has different effects on different animals.

- Acid rain has destroyed buildings and sculptures, like the one in Figure 3.2.6. Calcium carbonate is the major component of the marble and limestone that make up many old buildings and sculptures. Calcium carbonate is a base and so it reacts with the acids in rainfall, making the rock thinner and more likely to flake or break off. A typical reaction is shown below.

calcium carbonate + sulfuric acid → calcium sulfate + water + carbon dioxide

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2$$

Range of pH able to be tolerated

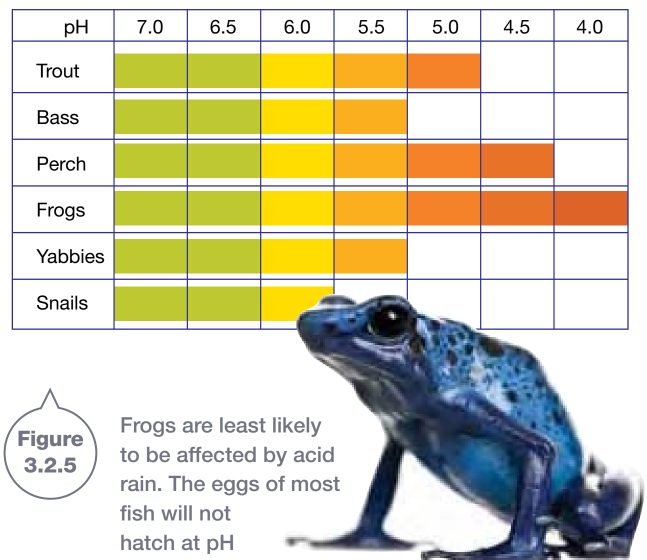



Figure 3.2.5 Frogs are least likely to be affected by acid rain. The eggs of most fish will not hatch at pH of less than 5.

Figure 3.2.6 The fine details of this marble sculpture have been destroyed because its calcium carbonate reacted with acid rain.

## Controlling acid rain

Taller chimneys (like those in Figure 3.2.7) mean that local areas are less likely to be affected by the chemicals released by them and the acid rain that forms. However, this doesn't solve the problem. It just pushes the problem onto more distant areas.

Coal-fired power plants are now fitted with 'scrubbers' that remove sulfur-based pollutants from the gases they release. In a similar way, modern cars use catalytic converters to remove nitrogen-based gases from their exhausts.

Figure 3.2.7 Pollution can cause acid rain to form. Tall chimneys minimise the damage in the area around them but increase the damage further away.

# 3.2 Unit review

## Remembering

1 **Recall** acid reactions by copying and completing the following:
- a acid + metal ⟶ ...... + ......
- b acid + carbonate ⟶ ..... + ...... + ......
- c nitric acid + potassium oxide ⟶ ..... + .....
- d ethanoic acid + sodium hydrogen carbonate ⟶ ..... + ..... + .....
- e $H_2SO_4 + Fe \longrightarrow$ ..... + .....
- f $2HCl + CaCO_3 \longrightarrow$ ..... + ..... + .....

2 **State** the pH of natural unpolluted rainwater.

3 Pollution can cause acids to form. **Recall** how this happens, by writing word equations and/or balanced formula equations.

4 **List** the two factors that cause acid rain to kill organisms in lakes.

## Understanding

5 **Explain** what causes the pain of heartburn.

6 Antacids relieve heartburn.
- a **State** the type of substance in antacids.
- b **Explain** how antacids work.

7
- a **Recall** what happens when vinegar is added to bicarbonate of soda, by writing its word equation and/or balanced formula equation.
- b **Explain** why froth forms in this reaction.

## Applying

8 The acidity of a lake increases, and animals in it die. **Use** Figure 3.2.5 on page 81 to **list** the animals in order from the most likely to die to the least likely.

## Analysing

9 **Analyse** the following word and balanced formula equation.

phosphoric acid + aluminium ⟶ aluminium phosphate + hydrogen gas

$$2H_3PO_4 + 2Al \longrightarrow 2AlPO_4 + 3H_2$$

**Identify**:
- a the reactants
- b the products
- c the chemical formula for phosphoric acid
- d the name and chemical formula of the salt produced
- e whether the reaction is an example of an acid/metal reaction, a neutralisation reaction, or an acid/carbonation reaction.

## Evaluating

10 **Propose** reasons why forests are more likely to be damaged by acid rain if they are:
- a near cities
- b on the foggy upper slopes of mountains.

11 In the Palace of Versailles near Paris (France), the marble garden statues are covered with bags in winter, as shown in Figure 3.2.8.
- a **Propose** a reason why they are covered in winter.
- b **Propose** a reason why they are not covered in summer.

12 Tall chimneys may help to minimise the effects of acid rain on a local area, but they are unlikely to be an effective solution for a whole city or a country. **Propose** reasons why.

Figure 3.2.8

## Creating

13 Calcium carbonate ($CaCO_3$) reacts with hydrochloric acid (HCl) to produce calcium chloride ($CaCl_2$), carbon dioxide ($CO_2$) and liquid water ($H_2O$). For this reaction, **construct** its:
- a word equation
- b unbalanced formula equation
- c balanced formula equation.

## Inquiring

1 Design an experiment to determine whether the reaction between vinegar or citric acid and bicarbonate of soda is endothermic or exothermic. Present your plan to your teacher and obtain approval to run your experiment.

2 Research ways of constructing a rocket using a mixture of vinegar and bicarbonate of soda.

3 Use the search terms *acid-base video* to find internet videos of different acid reactions.

# 3.2 Practical activities

## 1 Making hydrogen

### Purpose

To prepare and test hydrogen gas.

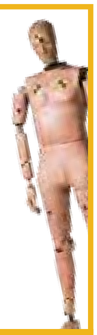
### Materials

- 5 cm strip of magnesium ribbon
- 2 M hydrochloric acid
- 1 test-tube, rubber stopper with opening and glass tube to fit
- 2 additional test-tubes
- test-tube rack
- 5 cm magnesium ribbon
- eyedropper
- wax taper

**SAFETY**

2 M HCl is a strong and concentrated acid.

Wear safety glasses, a laboratory coat or apron and rubber gloves.



### Procedure

1. Place the test-tube with the rubber stopper in the test-tube rack.
2. Roll the magnesium ribbon and drop it into the test-tube.
3. Use the eyedropper to add about 2 cm of hydrochloric acid.
4. Immediately turn another test-tube upside down and collect the hydrogen gas produced, as shown in Figure 3.2.9.
5. After about a minute, remove the upper test-tube, stopper it and stand it upside down in a test-tube rack.
6. Use the remaining test-tube to collect another sample of hydrogen gas. Stopper it and stand it upside down in a test-tube rack.
7. Stop the reaction by carefully adding water to the tube containing the acid.
8. Stand well away from the test-tube rack and light the wax taper.

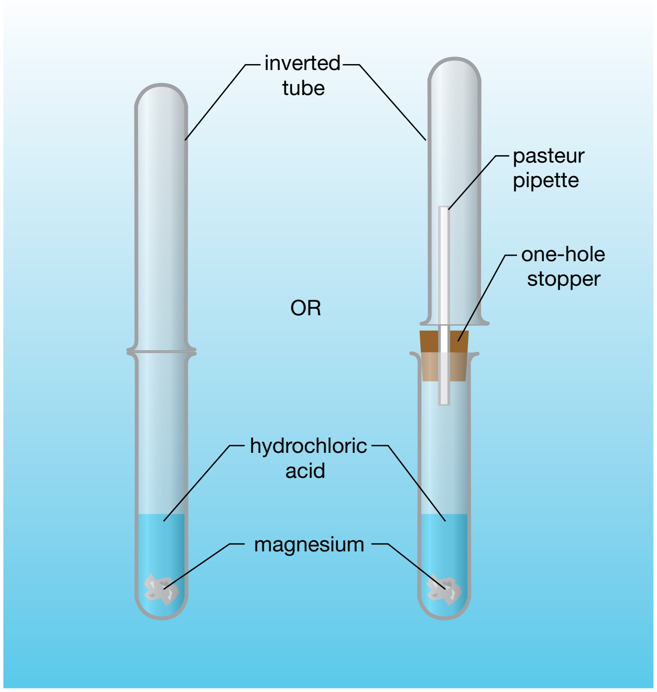



Figure 3.2.9

9. Hold the flame to the mouth of the inverted test-tube of hydrogen gas and remove the stopper.
10. Record what happens.

### Results

Record all your observations, including the smell as hydrogen was wafted towards you.

### Discussion

1. **Explain** how you knew this reaction was producing a gas.
2. **Identify** the type of reaction happening here. (Is it acid/base, acid/metal, neutralisation etc?)
3. **Construct** a word equation and a balanced formula equation for this reaction.

# 3.2 Practical activities

## 2 Evaluating antacids

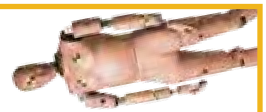
Antacids contain a base that neutralises some of the excess hydrochloric acid in your stomach.

### Purpose

To evaluate how effective different antacids are at reducing acidity.

### Materials

- 0.1 M hydrochloric acid solution
- 250 mL beaker
- liquid universal indicator or pH meter
- eye dropper
- different antacid tablets



**SAFETY**

Hydrochloric acid will burn and irritate open cuts and your eyes.

Do not taste any chemicals.

### Procedure

1. Pour about 50 mL of hydrochloric acid into the beaker.
2. Measure the pH of the solution with the pH meter or by putting a couple of drops of the universal indicator in it. Record your observations and pH in a table like the one shown in the Results section.
3. Add an antacid tablet and allow it to dissolve completely.
4. Determine the new pH of the solution with the pH meter or by using the new colour of the solution.
5. Rinse out the beaker and then repeat the experiment with another antacid tablet.

### Results

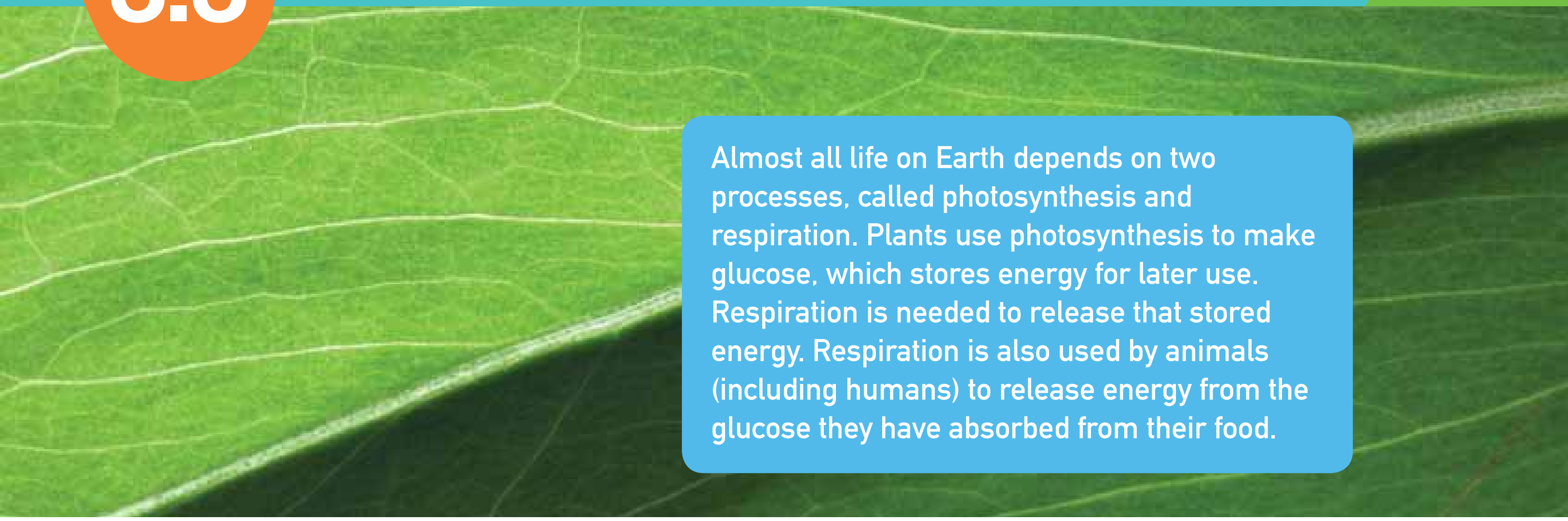
Record all your measurements in a table like the one shown here.

| | Tablet 1 | Tablet 2 | Tablet 3 |
|---|---|---|---|
| Colour of universal indicator before antacid was added | | | |
| pH of solution before antacid was added | | | |
| Colour of universal indicator after antacid was added | | | |
| pH of solution after antacid was added | | | |

### Discussion

1. **Name** the acid that is in your stomach.
2. **Explain** how this acid can cause the pain known as heartburn.
3. **Analyse** your results and determine which antacid tablet was most effective.
4. Heartburn has nothing to do with the heart. **Propose** a reason why it got this name.

# 3.3 Reactions of life



Almost all life on Earth depends on two processes, called photosynthesis and respiration. Plants use photosynthesis to make glucose, which stores energy for later use. Respiration is needed to release that stored energy. Respiration is also used by animals (including humans) to release energy from the glucose they have absorbed from their food.

## Photosynthesis

Photosynthesis is a series of chemical reactions that produce a type of sugar called glucose ($C_6H_{12}O_6$). Glucose is a molecule that stores energy that green plants absorb from sunlight. Glucose can be thought of as a plant's food.

Photosynthesis can be summarised by the following chemical equations:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose} + \text{oxygen gas}$$

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

As long as a plant has enough sunlight, carbon dioxide and water, it can manufacture all the food it needs. Photosynthesis takes place in any part of the plant that is green and exposed to sunlight. Leaves are the most exposed parts of a plant and so most photosynthesis takes place there. To maximise this exposure, most plants have flattened leaves that don't overlap. You can see this in Figure 3.3.1.

Figure 3.3.1 Leaves are arranged to catch as much sunlight as possible.

**SciFile**

### Maximising, minimising

Exposure to sunlight also dries out plants. Different leaf shapes have evolved for plants in different environments, to maximise their exposure to the sun while minimising water loss. For example, plants in hot, bright environments often have small or needle-shaped leaves. Plants near the ground in dark, wet rainforests don't get much sunlight and so have large, flat leaves to capture as much light as possible. Most rainforest plants have large leaves with deep channels in them to drain heavy rainfall.

## Leaf structure

To understand how leaves carry out photosynthesis, you need to look at the internal structure of a leaf using a scanning electron microscope (SEM). A typical image is shown in Figure 3.3.2. You can see what each part does in Figure 3.3.3.

**Figure 3.3.2** An SEM image of a slice through a leaf

## Obtaining the raw materials for photosynthesis

Photosynthesis needs carbon dioxide and water as reactants. It also needs sunlight to power its reactions (Figure 3.3.4).

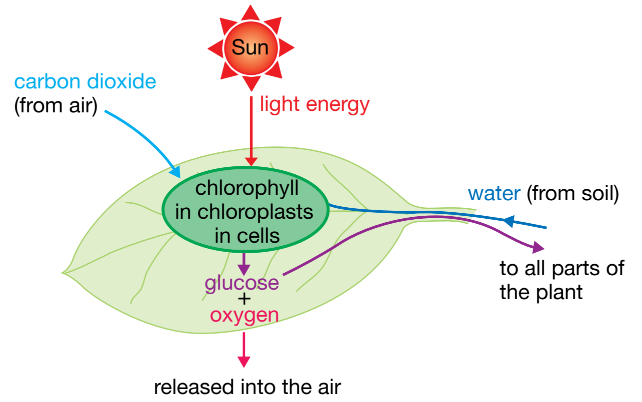



**Figure 3.3.4** All the raw materials need to be brought together in the chloroplasts before photosynthesis can take place.

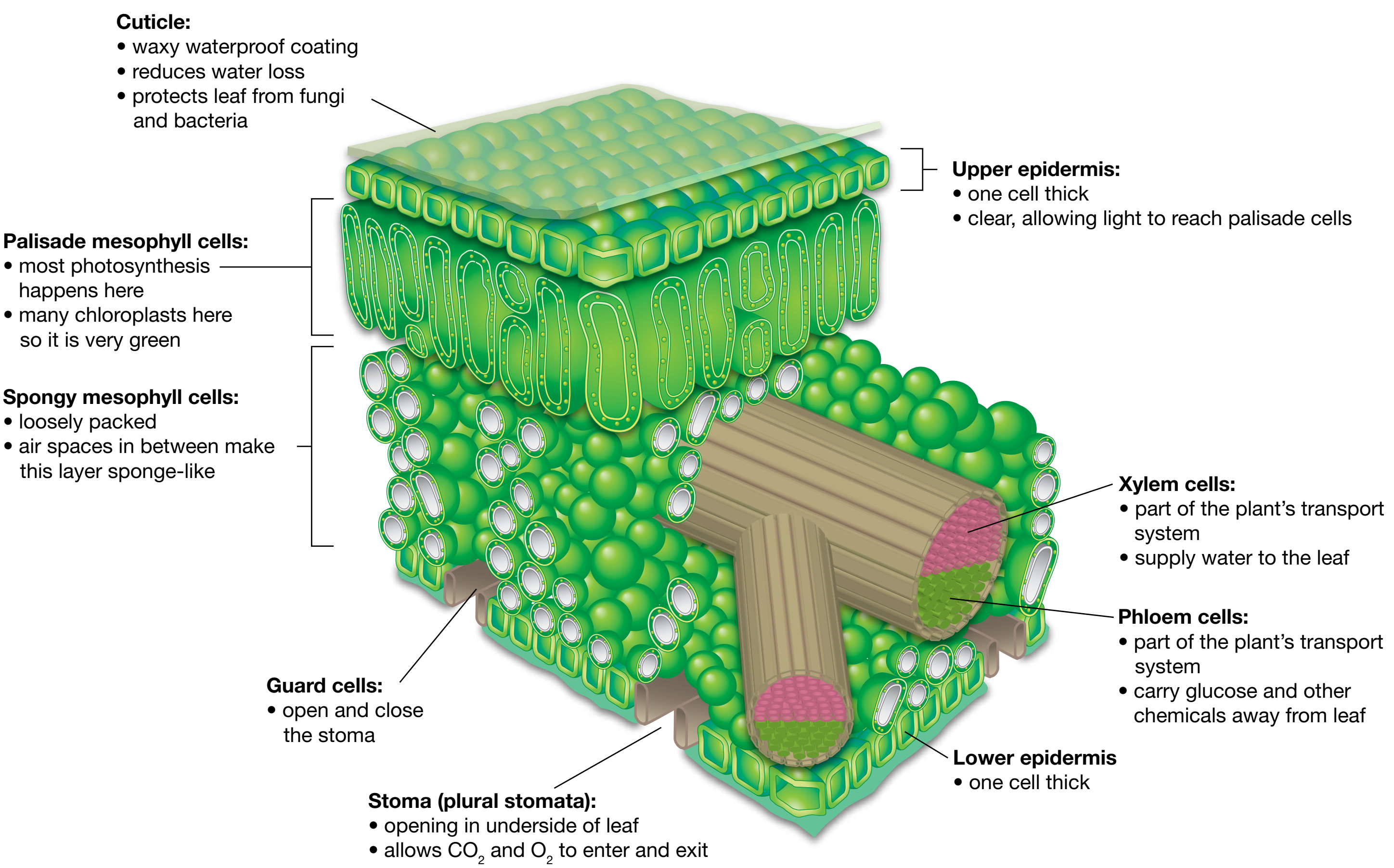



**Figure 3.3.3** The internal structure of a typical leaf

### Sunlight

Sunlight passes through the colourless cuticle and upper epidermis of the leaf into the cells of the palisade mesophyll layer. Within the chloroplasts is a green-coloured chemical called **chlorophyll**, which converts light energy from sunlight into chemical energy that the plant can use. The chloroplasts also contain **enzymes** (biological catalysts) that speed up the photosynthesis reactions happening there.

### Water

Water is carried from the roots up the veins and into the leaf. It moves from the veins into the cells of the palisade mesophyll layer and then into the chloroplasts.

### Carbon dioxide

Carbon dioxide moves by a process called **diffusion** from the air through tiny openings in the leaf called stomata (Figure 3.3.5). The concentration of carbon dioxide in the air is higher than in the leaf because photosynthesis has used it up in the leaf. Carbon dioxide continues to move by diffusion through the air spaces of the spongy mesophyll to the palisade mesophyll, where it passes into the cells and then into the chloroplasts.

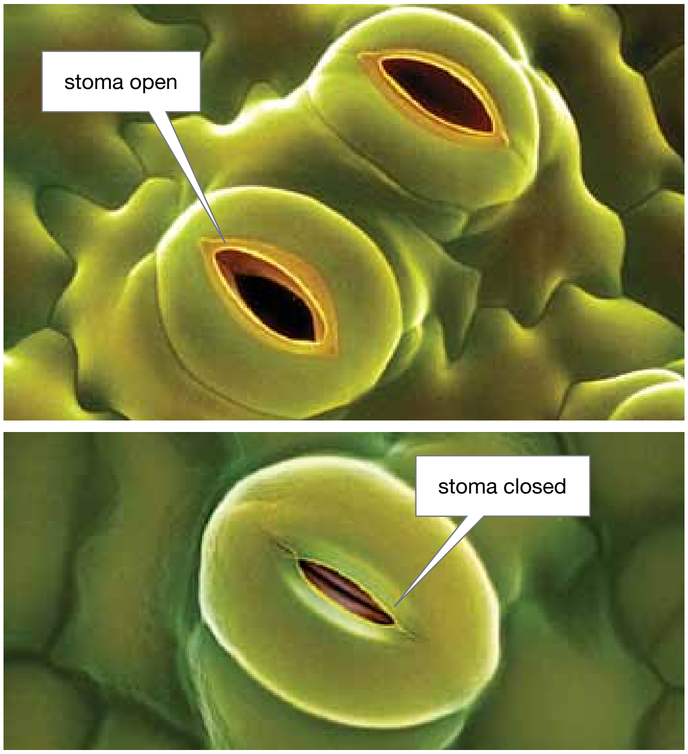



**Figure 3.3.5** These stomata provide an entry for carbon dioxide, which is needed for the plant to carry out photosynthesis. The stomata also provide an exit for the water vapour and carbon dioxide produced by respiration to leave the plant. In hot weather, the stomata close to stop dehydration through losing too much water.


**SciFile**

**No photosynthesis required!**

Sunlight can't penetrate the ocean beyond 300 metres and so photosynthesis doesn't happen there. However, at the edges of the tectonic plates are vents called 'black smokers'. Chemosynthetic bacteria collect energy and nutrients from superheated water erupting from them. These bacteria provide the basis for a food chain, and include giant tube worms, spider crabs and mussels.

## Respiration

Plant and animal cells need a constant supply of energy in order to function. They get this from a process called **respiration**, which releases energy from glucose. Plants get their glucose from photosynthesis. Animals get glucose through digestion of the food they eat.

Glucose molecules are made up of carbon, hydrogen and oxygen atoms. Energy is released when these molecules are broken into smaller ones. This energy is then available to the organism for tasks like growth, repair, movement and reproduction.

Plants use a form of respiration called aerobic respiration to release this energy. Animals also use aerobic respiration most of the time. Aerobic respiration needs a supply of oxygen as well as glucose. This is why you breathe. When exercising, the increased rate and depth of breathing removes carbon dioxide waste while supplying more oxygen to the bloodstream. This flow of gases is what is being measured in Figure 3.3.6 on page 88.

The reaction can be represented by the following chemical equation:

$$\text{glucose + oxygen gas} \longrightarrow \text{carbon dioxide + water + energy}$$

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

Aerobic respiration begins once the oxygen and glucose get to the cells. The glucose and oxygen react together in parts of the cells called mitochondria. Carbon dioxide and water are produced and energy is released. Enzymes enable this reaction to occur at a rate that meets the cell's requirements.

Figure 3.3.6 Aerobic respiration needs oxygen. Breathing provides oxygen and gets rid of the carbon dioxide produced.

- converted into cellulose for the manufacture of plant cell walls
- converted to substances used to make plant oils or proteins (the olive oil in Figure 3.3.8 was formed this way)
- converted into a more complex sugar called sucrose ($C_{12}H_{22}O_{11}$) and transported to other parts of the plant where photosynthesis cannot occur (such as the roots). Sucrose is 'normal' table sugar and is used to sweeten coffee and tea
- used in the process of making vitamins.

## Respiration in plants

Glucose is brought to the cells of a plant by the phloem. Oxygen diffuses into the plant from the atmosphere through the stomata in the green parts of stems and leaves.

The products of respiration are carbon dioxide and water. Carbon dioxide diffuses out of the mitochondria into the cytoplasm, a thick liquid sap that fills much of the rest of the cell. Some of the carbon dioxide is taken in by the chloroplasts and used in photosynthesis. The rest exits the cells and eventually exits the plant through the stomata.

Water also diffuses from the plant cell and evaporates. It exits the plant through the stomata in the form of water vapour.

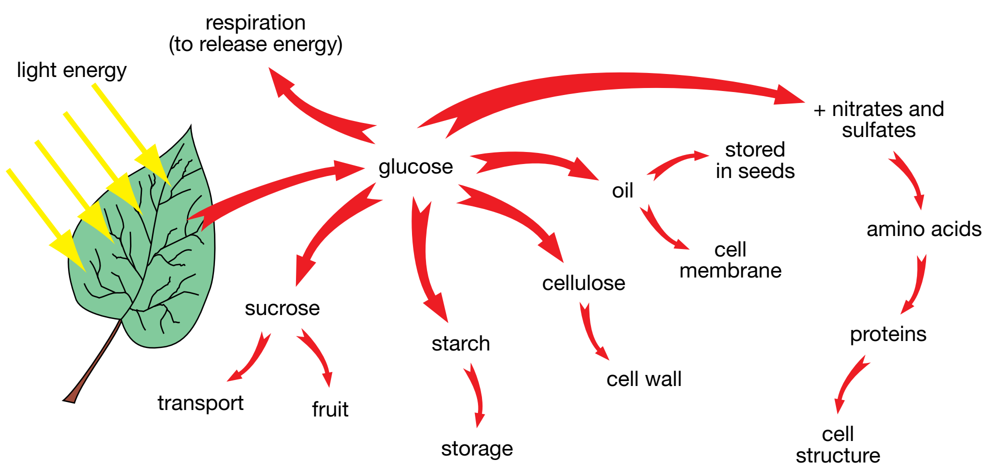



Figure 3.3.7 Glucose is not used just for respiration.

## Carbon sinks

Plant respiration releases carbon dioxide back into the atmosphere, but in smaller quantities than that used by photosynthesis. This is because the glucose produced by a plant is not used just for respiration.

As Figure 3.3.7 shows, glucose is also:

- converted to starch for short-term storage. During the night the starch may be converted back into glucose and then used as a source of energy
- stored long-term as starch in the stems or roots, like those in Figure 3.3.8

Figure 3.3.8 Potatoes and sweet potatoes are their plant's long-term store of starch. Likewise, a plant's energy can be stored as oil, some of which can be used for cooking.

By doing all this, plants store carbon that has been removed from the atmosphere by photosynthesis. Every tree, forest, field and crop can therefore be thought of as a **carbon sink**, effectively 'burying' the carbon. For this reason, some environmentalists are encouraging the preservation of existing forests and the planting of new ones to reduce carbon dioxide in the atmosphere and to reduce the effects of climate change. At present, huge areas of rainforest in South America and South-East Asia are being chopped down or burned. When they are dead, the trees cannot take in any more carbon. Rotting returns their carbon to the soil. Burning them releases much of the stored carbon back into the atmosphere as smoke, soot and carbon dioxide. Habitats for animals like the orang-utan are also destroyed.

Another important carbon sink are the diatoms that live in the ocean. **Diatoms** are single-celled organisms. Together with seaweeds, diatoms carry out 90% of all photosynthesis on Earth. When diatoms die, they drop to the bottom of the ocean, taking their carbon with them.

3 p93

## Respiration in humans

The bloodstream of animals such as humans carries glucose and oxygen to the cells. Glucose is one of the products of digestion of food. Oxygen is breathed in, then passes through narrower and narrower tubes until it diffuses through the lungs' alveoli into the blood. You can see this network of tubes in Figure 3.3.9. The blood also carries away the waste water and carbon dioxide from the cells. Some water is re-absorbed into the body. Some is removed by the kidneys to be stored in the bladder and later expelled as urine. Other water is breathed out as water vapour. Carbon dioxide diffuses from the blood into the alveoli in the lungs. It too is then breathed out.

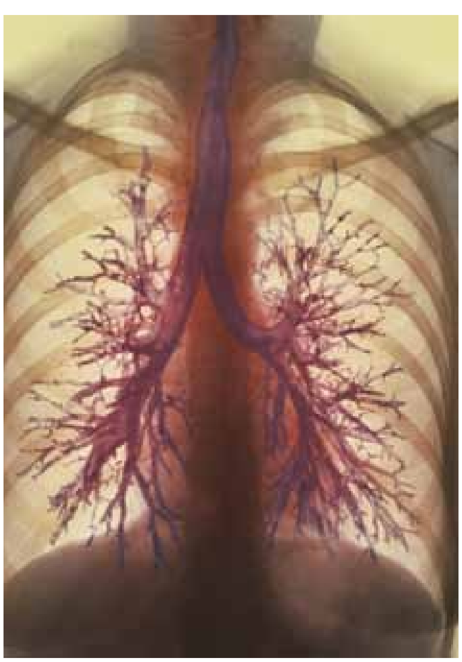


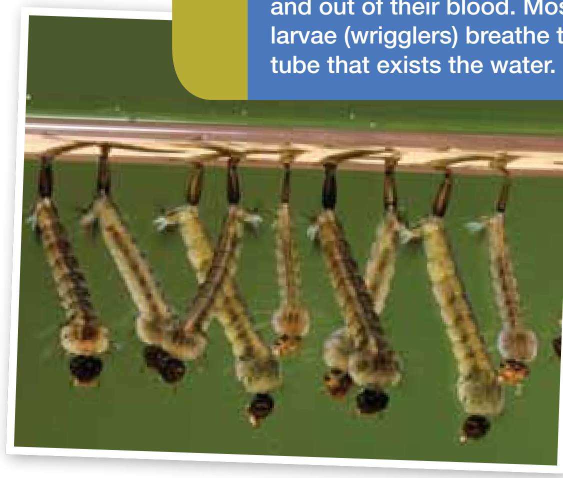
**Figure 3.3.9**

The lungs supply the bloodstream with oxygen so that aerobic respiration can occur in the cells. They also provide an exit for waste carbon dioxide and some water vapour.

**SciFile**

### How do mozzies breathe?

Mammals, birds, reptiles and amphibians such as frogs have lungs to draw in oxygen and expel carbon dioxide. Amphibians also exchange gases via their skin. Insects don't have lungs. Instead they have small tubes from the outside of their bodies feeding the gases directly into and out of their blood. Mosquito larvae (wrigglers) breathe through a tube that exists the water.



3.7

## Comparing photosynthesis and respiration

The chemical equations for photosynthesis and respiration suggest that the two processes are exact opposites of each other. For example, photosynthesis makes glucose, and respiration uses it. Both processes also use an 'energy-storage' molecule called ATP (adenosine triphosphate). However, the two processes differ. Table 3.3.1 lists the similarities and differences between photosynthesis and respiration.

**Table 3.3.1 Comparison of photosynthesis and aerobic respiration**

| Photosynthesis | Aerobic respiration |
|---|---|
| Makes glucose | Uses glucose |
| Uses carbon dioxide | Makes carbon dioxide |
| Makes oxygen gas | Uses oxygen gas |
| Uses ATP | Uses ATP |
| Has two steps: light reaction and dark reaction | — |
| Enzymes speed up the reaction | Enzymes speed up and control the reaction |
| Occurs only in the chloroplasts of cells of green plants | Occurs in the mitochondria of cells of all living things |
| Shuts down at night | Happens continuously (day and night) |

# 3.3 Unit review

## Remembering

1 **Name** the following chemicals.
   a $CO_2$
   b $O_2$
   c $C_6H_{12}O_6$

2 **Name** the green pigment found in plants.

3 **Name** the opening in the leaf that allows gases to move in and out.

## Understanding

4 **Describe** what an enzyme is.

5 **Explain** why having a large number of air spaces in the spongy mesophyll is an advantage for a plant.

6 **Explain** how aerobic respiration releases energy from glucose.

7 Sucrose (table sugar) comes from the stems of sugar cane. **Outline** how it got there.

8 Environmentalists sometimes talk about a *carbon sink*. **Explain** what this term means.

9 a **Describe** what a diatom is.
   b **Explain** why diatoms are important in an era of climate change.

## Applying

10 Equipment was set up as shown in Figure 3.3.10 to gather information about photosynthesis.

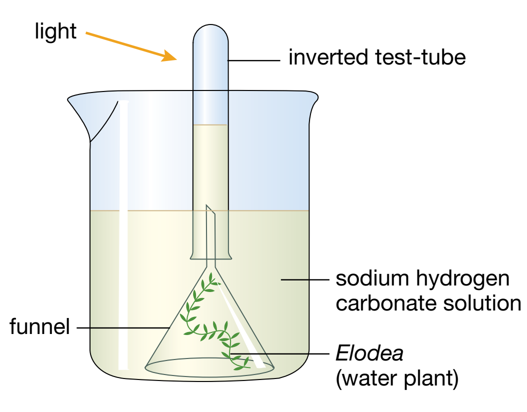



Figure 3.3.10

   a **Identify** the gas that would be collected in the test-tube.
   b **Demonstrate** how the rate of photosynthesis could be determined using this equipment.

## Analysing

11 **Contrast** the ways in which plants and animals get their glucose.

12 **Compare** photosynthesis and aerobic respiration by:
   a writing their word equations
   b writing their balanced formula equations
   c listing the ways in which they are similar
   d listing the ways in which they are different.

## Evaluating

13 The cells in the leaf epidermis are clear and colourless. **Propose** the advantages of this.

14 Climate change may lead to increased ocean temperatures. **Propose** reasons why some environmentalists are very worried about this possibility.

15 It has been suggested that humans will need to take green plants along with them if they are ever to travel far into space. **Propose** reasons why.

## Inquiring

1 Design an experiment to demonstrate that light is necessary for photosynthesis. Show your plan to your teacher. If you get their approval, carry out your experiment.

2 a Research how our understanding of photosynthesis developed.
   b Identify the main people involved in the discovery.

3 Use the key words *respiration games* to find interactive games on the internet.

4 Use the key words *respiration videos* to find clips on the internet to watch.

5 Research the life of Antoine Lavoisier and Pierre La Place and their work in proving that animals use respiration to release the energy they need from food.

6 a Research what anaerobic respiration is and when it is most likely to occur in humans.
   b List organisms that use anaerobic instead of aerobic respiration for their energy.

# 3.3 Practical activities

## 1 Looking at stomata

### Purpose

To compare the number of stomata on different leaf surfaces.

### Materials

- leaf cut from a plant
- clear nail varnish
- paintbrush or brush from a bottle of nail varnish
- forceps
- microscope
- slide and coverslip
- small container of water
- dropper

### Procedure

1 With the brush, apply a thin coat of nail varnish to a small area on the underside of the leaf.

2 Allow the varnish to dry and then use the forceps to gently peel the layer of varnish from the leaf.

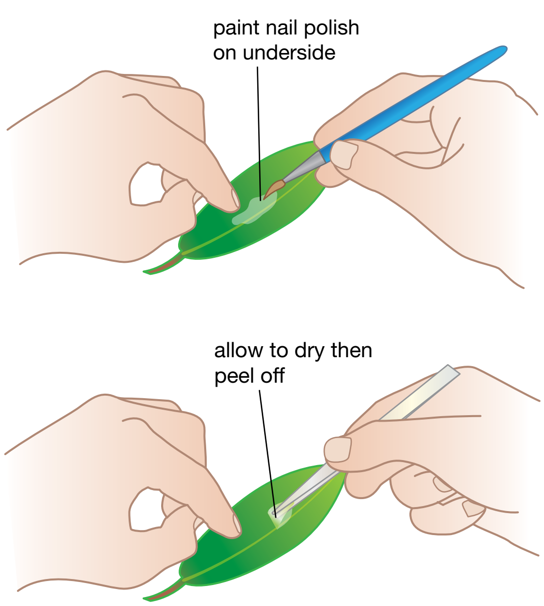



Figure 3.3.11

3 The nail varnish will have made an exact copy of the leaf surface.

4 Place the film of varnish in a drop of water on the microscope slide and place the coverslip on top, making sure that no air bubbles are trapped.

5 Examine the slide using low power on the microscope.

6 Count the number of stomata in a field of view.

7 Change the microscope to high power and focus on one stoma. Identify the guard cells.

8 Repeat steps 1 to 7 using the upper surface of the leaf.

### Results

1 Record the number of stomata you counted in one field of view for both the upper and lower surfaces.

2 Construct a diagram of the stoma and guard cells. Label the parts.

### Discussion

1 **Describe** the orientation of the leaf you studied when it was on the plant. Did it lie horizontally or hang vertically?

2 a **State** whether the stoma you drew was open or closed.

b **Justify** your answer.

3 **Compare** the number of stomata found on the two surfaces.

4 **Explain** any advantage to the plant of having the observed distribution of stomata.

5 **Predict** how the number and distribution of stomata could change if:

a leaves hung vertically rather than horizontally

b the leaves came from a plant living in a very moist environment

c the leaves floated on water, like a water lily.

## 2 Testing leaves for starch

### Purpose

To test leaves for the presence of starch.

### Materials

- 1 variegated leaf that has been in sunlight for several hours
- beaker
- hotplate
- methylated spirits
- hotplate
- test-tube
- test-tube rack
- Petri dish
- tongs
- iodine solution
- dropping pipette
- tweezers

**SAFETY**

Methylated spirits is flammable, so keep it well away from flames and the hotplate.

Wear safety glasses at all times.

### Procedure

1. Sketch the leaf, showing where there is a lot of chlorophyll (the green parts) and where there is little (the paler or cream parts). Keep this sketch for later.
2. Place around 100 mL of water in the beaker and heat on the hotplate until it boils. Drop the leaf in the water and heat it for about 30 seconds.
3. Use the tweezers to carefully remove the leaf from the water and place it in a test-tube. Keep the water in the beaker boiling.
4. Keeping well away from the hot plate, add methylated spirits to the test-tube so that the leaf is covered.
5. Place the test-tube into the beaker of boiling water and heat until the green chlorophyll is removed from the leaf.
6. Using tongs, carefully remove the test-tube from the beaker of boiling water and remove the leaf from the test-tube.
7. Place the leaf back into the beaker of boiling water for a few minutes to soften it.
8. When the leaf is soft, remove it from the water and place it in a Petri dish.
9. Add 4 drops of iodine solution to the leaf.

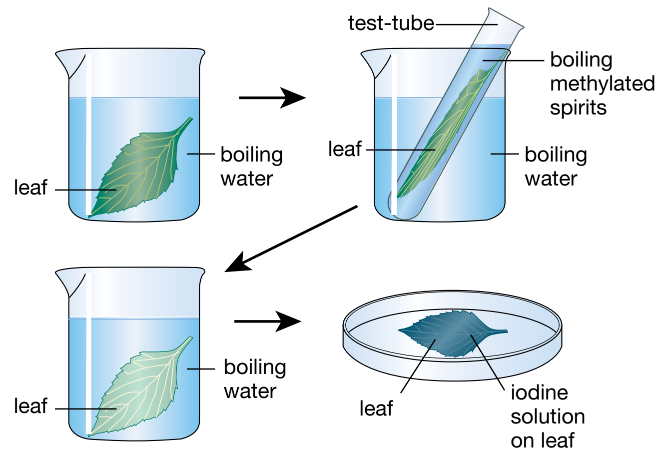



Figure 3.3.12

### Extension

10. Tape black paper or aluminium foil onto another leaf that is still attached to the plant. Cut a ‘window’ in the paper/foil to expose part of the leaf.
11. After a few days, pick the leaf and test as above for the presence of starch.

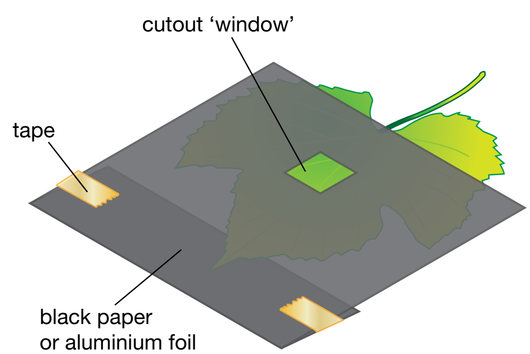



Figure 3.3.13

### Results

Sketch the leaf, showing where starch is present and where it is absent.

### Discussion

1 **Name** the substance in the leaves with which iodine reacts.

2 If you carried out the extension, **compare** the two diagrams you have made of the leaf.

3 **Explain** what the diagrams tell you about starch production in the leaf.

4 a **Predict** the results you would have obtained if you had tested a leaf picked from the plant at dawn.

b **Justify** your prediction.

5 If you carried out the extension, **construct** an annotated diagram that explains what you observed.

## 3 Respiring plants

### Purpose

To investigate respiration in plants.

### Materials

- 9 test-tubes
- 3 test-tube racks
- 9 pieces of water plant such as *Elodea*
- bromothymol blue indicator
- drinking straw
- 50 mL beaker

### Procedure

1 Two-thirds fill each test-tube and the 50 mL beaker with water. Add a few drops of bromothymol blue to give the solution an obvious blue colour.

2 Using the drinking straw, bubble exhaled air through the water in the 50 mL beaker.

3 Observe and record the colour change in the indicator.

4 Label the test-tube racks: dark, low light, bright light.

5 Add the same amount of water weed to each test-tube.

6 Place three test-tubes into each of the test-tube racks.

7 Place the test-tube racks in an appropriate place, like those suggested below:

- dark—could be placed in a cupboard
- low light—could be placed in a corner of the classroom away from the windows
- bright light—could be placed on a window sill, but make sure the water in the test-tubes does not get hot.

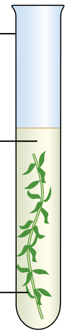



Figure 3.3.14

8 Leave the test-tubes for 24 to 48 hours.

9 Observe and record any changes in the colour of the indicator.

### Results

1 Describe what happened when you bubbled exhaled air through the water containing bromothymol blue.

2 Record your observations in a table like the one below.

| Treatment | Indicator colour | |
|---|---|---|
| | Start | After 24 hours |
| Dark | | |
| Low light | | |
| Bright light | | |

3 Bromothymol blue is an indicator that is blue in an alkaline or a neutral solution. It turns green and then yellow in an acidic solution. Carbon dioxide dissolved in water produces a weak acid.

Use this information to identify whether the solution in each test-tube was alkaline, neutral or acidic.

### Discussion

1 **Explain** the colour change that occurred when you bubbled exhaled air through the water with bromothymol blue.

2 **Describe** what happened in each of the test-tubes.

3 **Explain** why this happened.

# 3 Chapter review

## Remembering

**1** **Name** the following chemicals.
- **a** $Fe_2O_3{\cdot}H_2O$
- **b** $HCl$
- **c** $C_6H_{12}O_6$

**2** **List** two types of reactions that are classified as oxidation reactions.

**3** **Name** the poisonous gas produced by incomplete combustion.

**4** **Recall** the following reactions by writing their word equations and/or balanced formula equations.
- **a** tarnishing of silver
- **b** combustion of octane
- **c** neutralisation of potassium oxide with nitric acid
- **d** photosynthesis

**5** **Recall** the following reactions by completing their equations.
- **a** acid + base $\rightarrow$ ..... + .....
- **b** methane + oxygen $\rightarrow$ ..... + .....
- **c** $CaCO_3 + 2HCl \rightarrow$ ..... + ..... + .....
- **d** $C_6H_{12}O_6 + 6O_2 \rightarrow$ ..... + .....

**6** **List** three substances required for iron to rust.

**7** **Name** the reactant that is always needed for combustion to occur.

## Understanding

**8** Burning fossil fuels causes problems for our atmosphere. **Describe** these problems.

**9** **a** **Outline** where the raw materials for photosynthesis come from.
- **b** **Outline** how the raw materials get into the cells of the leaf.

**10** **Explain** the outcome of breathing faster and deeper when you excercise.

## Applying

**11** A small fire will be extinguished if covered by something that doesn't burn. **Use** the concept of combustion to **explain** why.

**12** **Identify** the missing number that would balance each of the following equations.
- **a** $\ldots KOH + H_2SO_4 \rightarrow K_2SO_4 + H_2O$
- **b** $2Al + \ldots HCl \rightarrow 2AlCl_3 + 3H_2$

## Analysing

**13** **Contrast** the ways in which plants and animals get the oxygen needed for aerobic respiration.

**14** **Classify** the following reactions as exothermic or endothermic.
- **a** gas burning in a Bunsen burner
- **b** vinegar and sodium carbonate suddenly get cold when mixed
- **c** photosynthesis
- **d** respiration

**15** **Analyse** the following chemical equations and balance them.
- **a** $Cu + SO_2 \longrightarrow Cu_2S + O_2$
- **b** $CH_4 + O_2 \longrightarrow CO_2 + H_2O$
- **c** $Ag + H_2S \longrightarrow Ag_2S + H_2$

## Evaluating

**16** Huge areas of rainforest in the Amazon and in Borneo are being chopped down each year.
- **a** **Propose** reasons why the forests are being destroyed.
- **b** **Propose** reasons why this destruction should be stopped.

## Creating

**17** **Construct** a word equation for the reaction:

$Ca + 2HCl \rightarrow CaCl_2 + H_2$

**18** **Construct** a table comparing photosynthesis and respiration.

**19** **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

chemical reaction
exothermic
endothermic
photosynthesis
combustion
oxidation
glucose
oxygen gas
carbon dioxide
respiration

# Thinking scientifically

**Q1** This chemical equation is unbalanced because it has different numbers of atoms of a particular element on each side of the arrow.

$Li + H_2O \rightarrow LiOH + H_2$

Identify the element/s that is/are unbalanced in this equation.

**A** Li
**B** H
**C** O
**D** Li, H and O

**Q2** Four different students attempted to balance the equation in question 1.

Identify which student (A, B, C or D) has balanced it correctly.

**A** $Li + H_2O \rightarrow LiOH + H$
**B** $Li_2 + H_4O_2 \rightarrow Li_2O_2H_2 + H_2$
**C** $Li_2 + (H_2O)_2 \rightarrow (LiOH)_2 + H_2$
**D** $2Li + 2H_2O \rightarrow 2LiOH + H_2$

**Q3** Fiona dropped a stick of chalk (containing calcium carbonate, $CaCO_3$) into hydrochloric acid (HCl). It fizzed as the reaction produced carbon dioxide gas ($CO_2$), water ($H_2O$) and calcium chloride ($CaCl_2$).

Identify the equation for this reaction.

**A** $CaCl_2 + H_2O + CO_2 \rightarrow CaCO_3 + 2HCl$
**B** $CaCO_3 + H_2O + CO_2 \rightarrow CaCl_2 + 2HCl$
**C** $CaCO_3 + 2HCl + H_2O \rightarrow CaCl_2 + CO_2$
**D** $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$

**Q4** Fiona measured the amount of carbon dioxide gas generated as the chalk dissolved in question 3. She repeated the experiment, but this time she crushed the stick of chalk into a powder. Her results are shown in the table below.

| Time (s) | Volume of $CO_2$ generated ($cm^3$) | |
|---|---|---|
| | Stick of chalk | Crushed chalk |
| 0 | 0 | 0 |
| 15 | 50 | 100 |
| 30 | 100 | 200 |
| 45 | 150 | 200 |
| 60 | 200 | 200 |
| 105 | 200 | 200 |

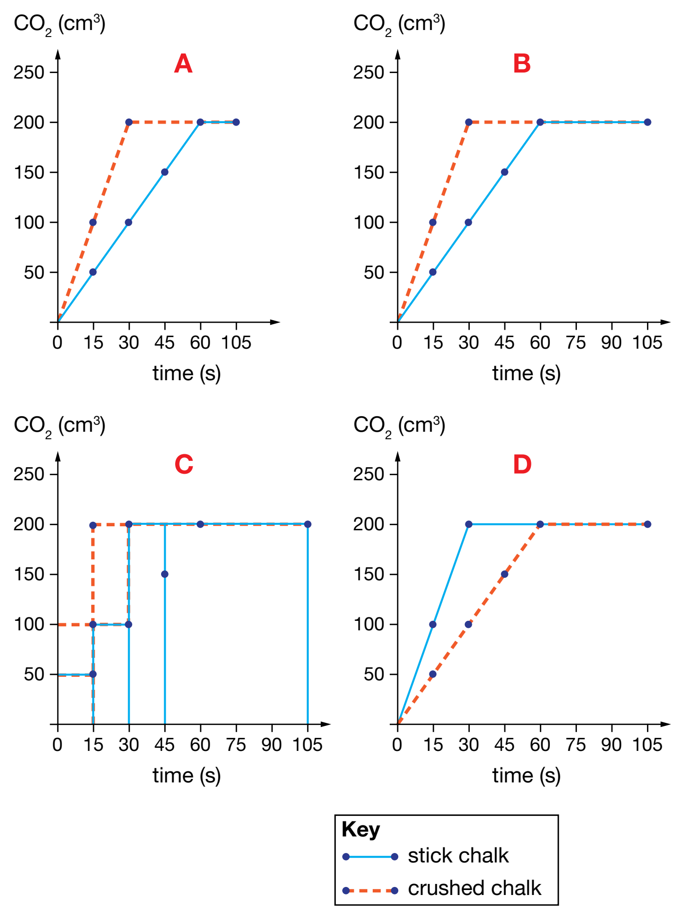
From these results, identify the best conclusion.

**A** Chalk and hydrochloric acid react together.
**B** Chalk always produces 200 $cm^3$ of carbon dioxide.
**C** Crushed chalk reacts faster than a stick of chalk.
**D** Hydrochloric acid burns.

**Q5** From the results in the table in question 4, identify the inference most likely to be correct.

**A** All the chalk had dissolved by the end of the experiment.
**B** Carbon dioxide always takes up 200 $cm^3$.
**C** Chalk always takes at least one minute to react.
**D** The formula for carbon dioxide is $CO_2$.

**Q6** Which of the following graphs best displays the results of question 4?



# Glossary

## Unit 3.1

**Aerobic respiration:** a reaction that uses oxygen to release energy stored in glucose

**Anodising:** a way of protecting aluminium from corrosion, by deliberately creating a layer of aluminium oxide over it

**Balanced formula equation:** a chemical equation that has the same numbers of each atom on both sides of the arrow

**Combustion:** a rapid reaction with oxygen that releases energy in the form of heat and/or light

Combustion

**Complete combustion:** combustion that occurs when there is plenty of oxygen. It produces carbon dioxide and water vapour.

**Corrosion:** the breakdown of metals due to their reaction with other chemicals

**Endothermic:** a chemical reaction that absorbs energy

**Exothermic:** a chemical reaction that releases energy

**Glucose:** a type of sugar produced by photosynthesis, with chemical formula $C_6H_{12}O_6$

**Hydrocarbons:** highly combustible chemicals; petrol is a mixture of hydrocarbons

**Incomplete combustion:** combustion that occurs when oxygen is limited. It produces carbon (soot, smoke) and carbon monoxide. It does not release as much heat or light as complete combustion.

Incomplete combustion

**Law of conservation of mass:** atoms are not created or destroyed in a chemical reaction. They can only be rearranged.

**Photosynthesis:** endothermic reaction that takes place in green plants. Uses energy from sunlight to combine water and carbon dioxide and produce glucose and oxygen gas.

**Products:** chemicals produced in a chemical reaction. They are written on the right-hand side of the arrow.

**Reactants:** chemicals that take part in a chemical reaction. They are written on the left-hand side of the arrow.

**Rust:** hydrated iron(III) oxide, $Fe_2O_3{\cdot}H_2O$

**Tarnish:** a black coating of silver sulfide that is produced when silver reacts with sulfur in the atmosphere; chemical formula $Ag_2S$

**Verdigris:** a green coating of copper hydroxide that is produced when copper reacts with moisture, carbon dioxide and oxygen in the atmosphere; chemical formula $Cu(OH)_2$

**Word equation:** simple written description of what is happening in a reaction

## Unit 3.2

**Acid rain:** rain that has acids such as nitric acid and sulfuric acid dissolved in it

**Neutralisation:** a reaction of an acid with a base, forming a salt and water

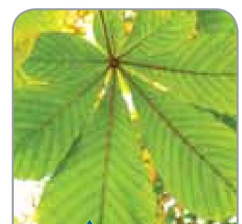
Neutralisation

**Salt:** the term commonly used for sodium chloride, but covers any compound formed by a metal taking the place of the hydrogen atom in an acid

## Unit 3.3

**Carbon sink:** a term used to describe materials that store carbon in their structures. Plants and animals can be thought of as carbon sinks.

**Chlorophyll:** a green chemical found in the chloroplasts of green plants, needed to carry out photosynthesis



Chlorophyll

**Diatoms:** single-celled organisms that live in water. They are an important store of carbon or carbon sink.

**Diffusion:** a process in which chemicals move, caused by different concentrations of the chemical

**Enzyme:** a biological catalyst that speeds up a reaction

Diatoms

**Glucose:** a simple sugar formed by photosynthesis and used in respiration; chemical formula $C_6H_{12}O_6$

**Respiration:** a chemical reaction in which glucose is broken down, releasing energy for use by the plant or animal. Carbon dioxide and water are also produced. It occurs in the mitochondria.

# Look who is using science

## PHOTOGRAPHER

**My name is Rod Ash and I am a photographer. My interest in photography first evolved when I was living and working in the Middle East and Europe. By documenting my travel adventures through photography, I developed a keen interest in the creative and practical processes involved with this art form.**

In its very basic form, photography is very much about understanding light. My diverse background in a variety of service-based industries reflected my interest in working with people, and photography was a great medium to continue this. My work is both studio and location based and allows me to travel. I love the interaction with my clients and being involved in what is often some of the most important events of their lives. I am always challenged by the science and technology associated with photography, and how I can apply this to creating an enjoyable photographic experience for my clients as well as the photographic art that reflects this experience.

## PROJECTIONIST

**My name is Ben Charter and I work as a technical supervisor at Village cinemas. I prepare films and project them onto a movie screen.**

Most of my day is spent threading film into projectors, checking that sessions start on time and that everything runs smoothly. New-release movies arrive in boxes, on three 610-metre spools. I splice cues onto the film where the credits start, and these cues trigger the cinema lights to come up. I then splice the three reels together onto one 1800-metre spool and thread this onto a platter so the film is ready to run from start to finish.

I started working in the cinema as an usher and worked my way up in the business. I have moved around and worked in five Village cinemas across Australia. I enjoy my job and, best of all, I get free tickets to any movie I'd like to see!

## RADIOGRAPHER

**My name is Brendon Hansen and I am a radiographer. I work in a hospital and capture different types of images using specialised equipment. These images include general X-rays (including mammography and dental imaging), ultrasound and CT scans.**

The image is recorded on an imaging plate, which is housed within a cassette. A CR (computed radiography) reader converts this recording into a digital image. The image is sent through a PACs (Picture Archive Communication system) to a radiologist, for analysis.

The radiologist prepares and submits a report to the patient's doctor about the information revealed in the image.

I was employed as a trainee radiographer in a hospital and attended night school to become qualified. Today, radiography is offered as a three-year full-time university course. It is a job I enjoy because I am working with and helping other people.

# 4 Heat, light and sound

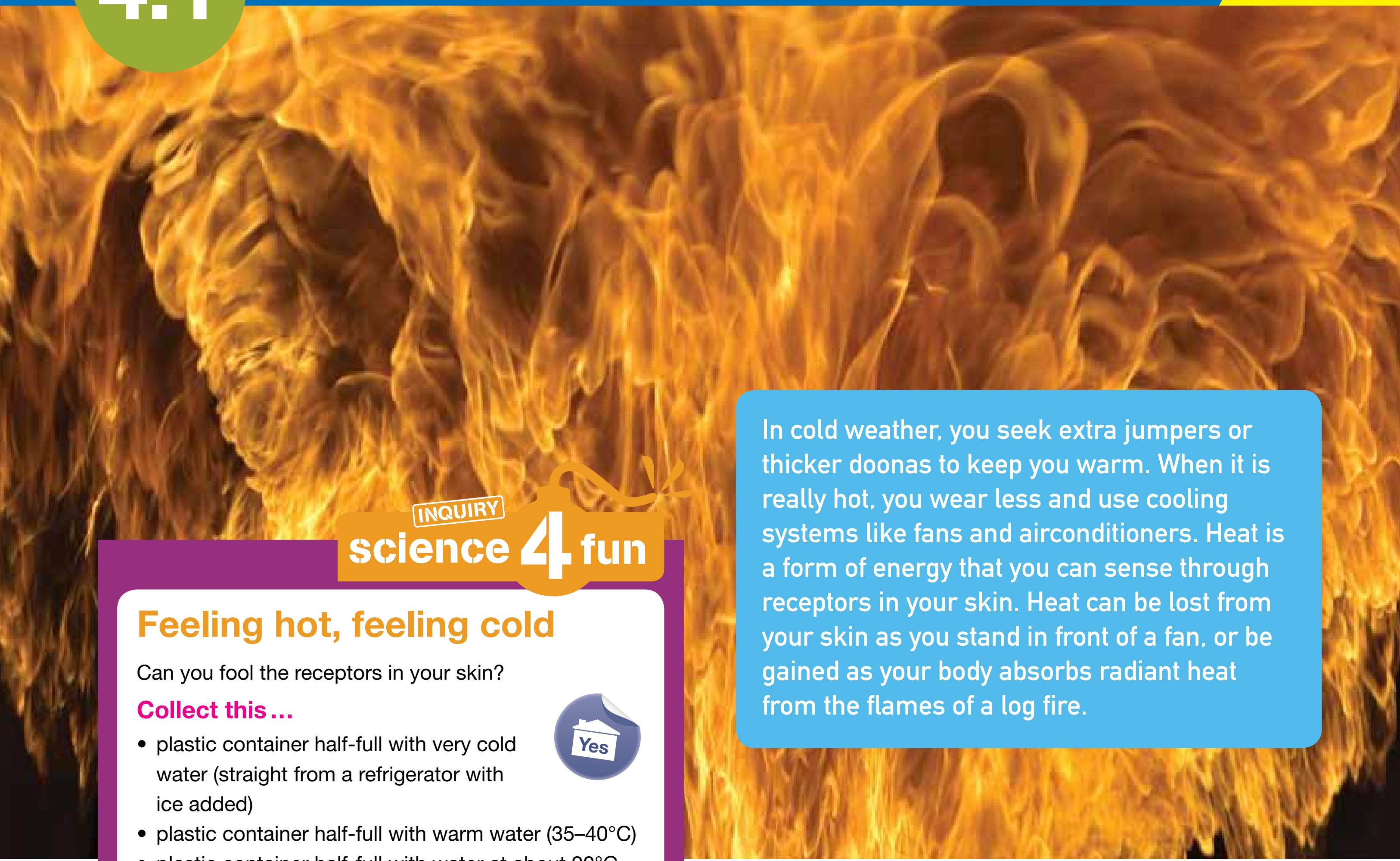
## HAVE YOU EVER WONDERED . . .

- why you can't see clearly under water?
- why a doona keeps you warmer than just a sheet?
- how 3D glasses work?
- why the sky is blue?
- how musical instruments make different sounds?
- why diamonds sparkle?

### After completing this chapter students should be able to:

- describe how different forms of energy such as heat, light and sound are transferred
- explain that the way energy is transferred depends upon the medium through which it travels
- describe situations in which energy is transferred in the form of waves, such as sound and light
- explain how your ears convert sound to electrical signals that your brain interprets as sound, and how your eyes convert light to electrical signals that your brain interprets as an image
- explain the impact of the cochlear implant and the bionic eye
- discuss how changes in frequency and amplitude of a sound wave affect the pitch and intensity heard by a listener
- recall that light is a form of energy that travels as an electromagnetic wave
- identify that light rays obey the law of reflection and that this can be used to produce an image in a mirror
- explain how refraction occurs and some of the effects that this produces
- outline how heat is transferred in terms of conduction, convection and radiation, and describe examples of each.

# 4.1 Heat



In cold weather, you seek extra jumpers or thicker doonas to keep you warm. When it is really hot, you wear less and use cooling systems like fans and airconditioners. Heat is a form of energy that you can sense through receptors in your skin. Heat can be lost from your skin as you stand in front of a fan, or be gained as your body absorbs radiant heat from the flames of a log fire.

INQUIRY science 4 fun

## Feeling hot, feeling cold

Can you fool the receptors in your skin?

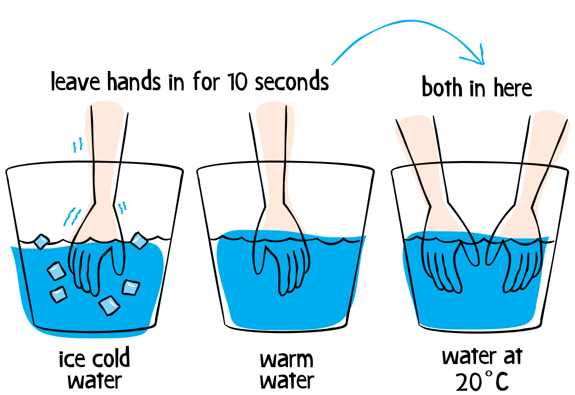
**Collect this ...**

Yes

- plastic container half-full with very cold water (straight from a refrigerator with ice added)
- plastic container half-full with warm water (35–40°C)
- plastic container half-full with water at about 20°C
- thermometer
- paper towel

**Do this ...**

1. Put one hand into the very cold water and the other hand into the very warm water and leave them there for 10 seconds.
2. Now put both hands into the water at 20°C.




**Record this ...**

**Describe** what you felt.
**Explain** why you think this happened.

## Heat

Thermometers measure temperature, but do not measure heat. Heat is a form of energy and describes the total energy of all particles within an object. Saucepans A and B in Figure 4.1.1 both contain boiling water. Although their temperatures are the same, saucepan A contains double the volume of water. Hence it has twice the heat energy of saucepan B.

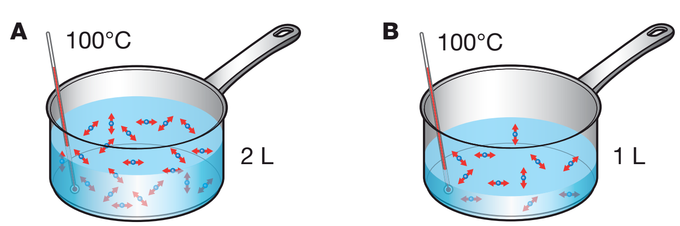



Figure 4.1.1 Saucepan A contains more heat energy because it contains more particles at the same temperature compared with saucepan B.

In Figure 4.1.2 the same amount of heat energy is supplied to two saucepans, X and Y. The saucepan with less water (X) shows the greatest temperature rise. This is because the heat energy in X is shared by fewer particles. These particles each absorb more energy and move faster. This increases the temperature of the water in X compared to Y.

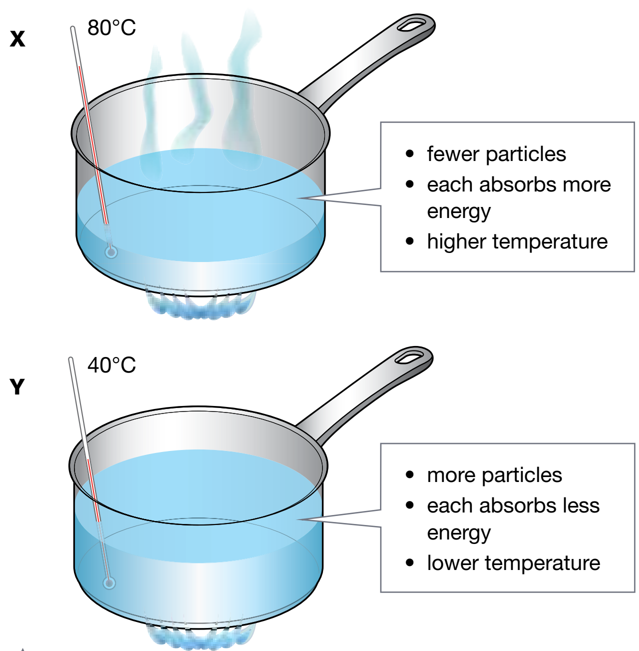



**Figure 4.1.2** With fewer particles to absorb the heat energy in saucepan X, each particle has greater kinetic energy than the particles in saucepan Y, and as a result the temperature in saucepan X is higher.

## Temperature

In everyday language, the words *heat* and *temperature* generally mean the same thing. However, for scientists, heat and temperature are very different. **Temperature** indicates how hot or how cold something is. It depends on how quickly the particles inside it are moving and is a measure of the average kinetic energy of these particles. Hotter substances have particles that are moving faster than the particles of cooler substances.

Temperature can be measured in a number of ways. Receptors in your skin give you an idea of how hot or cold something is, but these receptors can be fooled at times. A **thermometer** gives an accurate reading of temperature. A thermometer contains a liquid (alcohol or mercury) within a narrow glass tube. This liquid expands when heated and contracts when cooled. Temperature is read from a scale corresponding to the expansion and contraction of the liquid. Temperature is commonly measured in degrees Celsius (°C). The Fahrenheit (°F) and Kelvin (K) scales are also used to measure temperature.

INQUIRY science 4 fun

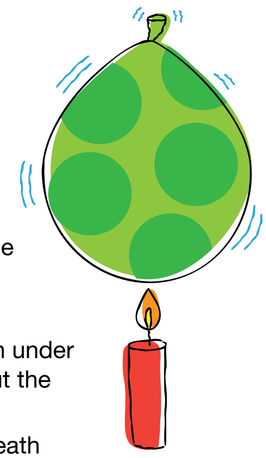
### Burning a balloon!

Can you heat water in a balloon without bursting the balloon?

No

**Collect this ...**

- two balloons
- matches
- candle

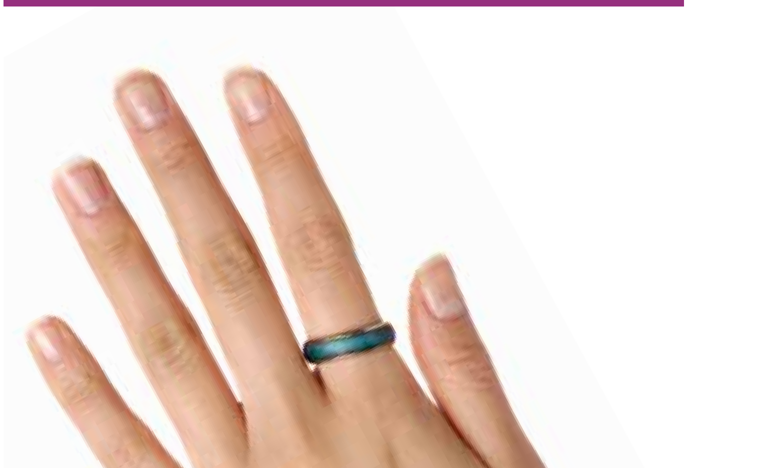


**Do this ...**

1 Blow up a balloon and tie its end.
2 Hold a lit candle below the balloon.
3 Observe what happens.
4 Now hold another balloon under a tap and fill it up to about the size of a rockmelon.
5 Place a lit candle underneath this second balloon, and again observe what happens.

**Record this ...**

**Describe** what happened.
**Explain** why you think this happened.



SciFile

**Mood rings**

Mood rings contain heat-sensitive liquid crystals. Particles in these crystals twist in different temperatures, changing colour. A green colour indicates a normal state, and a change to deep blue means you are heating up. This could indicate a happy or passionate mood change!

Figure 4.1.3 Anders Celsius

# SCIENCE AS A HUMAN ENDEAVOUR

## Nature and development of science

### Temperature scales

**In 1593 Galileo invented an early type of thermometer. He suggested that a scale to measure temperature could range from that of the coldest day of winter up to that of the hottest day of summer. This approach made sense at the time, because temperature scales were used to describe the weather and not much else.**

In 1714 a German scientist, Gabriel Fahrenheit, produced a mercury-filled thermometer. Zero on his scale was the lowest temperature he could produce from mixing salts and ice. He chose the temperature of the human body as another fixed point on his scale, which he set as 96 degrees. This scale, called the Fahrenheit scale, is still used in the United States of America today.

In 1742, the Swedish astronomer Anders Celsius proposed the Celsius scale, which is now commonly used in Australia and in most countries of the world. He named the scale 'centigrade', from the Latin meaning '100 steps'. Zero was set as the boiling point of water, with 100 degrees being the freezing point of water. After Celsius died from tuberculosis in 1744, thermometers were produced that had this scale reversed.

The British scientist William Thomson (later called Lord Kelvin) proposed a different temperature scale in 1848. He believed that zero on the scale should be the lowest temperature possible. As temperature drops, particles lose kinetic energy, until they barely move at all. This happens at –273°C, at a point known as **absolute zero**. The Kelvin scale begins at absolute zero, or 0 K. (The term *degree* is not used in the Kelvin scale, but each step in this scale is the same size as those in the Celsius scale.) The coldest place in the universe lies in deep space, where temperatures may be as low as three degrees above absolute zero. Scientists use the Kelvin scale.

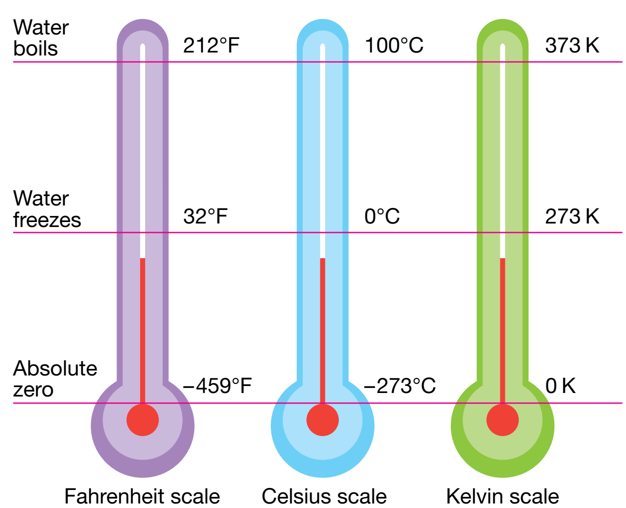



Figure 4.1.4 These three thermometers show the three scales commonly used to measure temperature. They were proposed by Gabriel Farenheit (1686–1736), Anders Celsius (1701–1744) and Lord Kelvin (1824–1907).

# Heat transfer

Heat flows from areas of higher temperature to those of lower temperature. The greater the temperature difference, the faster heat flows from one object into another. This process of heat transfer can happen in three ways:

- conduction
- convection
- radiation.

## Conduction

Hold an ice cube and your hand gets cold. This is because heat flows from your skin into the ice, lowering the temperature of your skin in the process. You know that the ice cube is absorbing this heat because it starts to melt. Heat has flowed from the higher-temperature hand into the lower-temperature ice cube. Figure 4.1.5 shows some examples of heat flow.


**Figure 4.1.5** Heat will flow from your hands into an ice block, but from a hot cup into your hands.

Hotter substances have particles that are moving at a faster rate than cooler substances. Rapid jiggling or vibration of the particles in a hot mug of soup makes the particles in a metal spoon vibrate faster too, increasing the temperature of the spoon. This vibration of particles is passed on from one particle to the particle next to it, and as this process continues along the spoon you may feel the handle getting hot. This process of heat transfer by vibrating particles is called **conduction** and is shown in Figure 4.1.6.

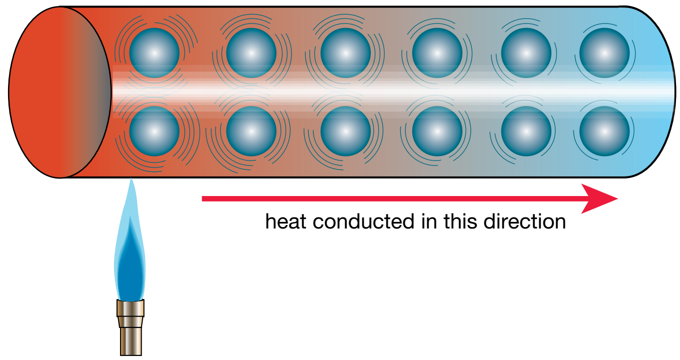



**Figure 4.1.6** Particles near the flame vibrate more quickly as they absorb heat energy. These vibrations, from particle to particle, conduct the heat along the solid.

### Conductors

Materials vary in how effectively they conduct heat. Holding a glass of ice-cold lemonade feels much colder than holding a polystyrene cup of ice-cold lemonade. Glass is a better conductor than polystyrene. As a result, heat flows from your warm hand into the cooler glass and your hand feels cold. When holding the polystyrene cup, your hand is not losing heat and so it still feels warm.

Substances that transfer heat easily are known as **conductors**. Metals, such as the saucepan shown in Figure 4.1.7, are good conductors of heat.

1 p108

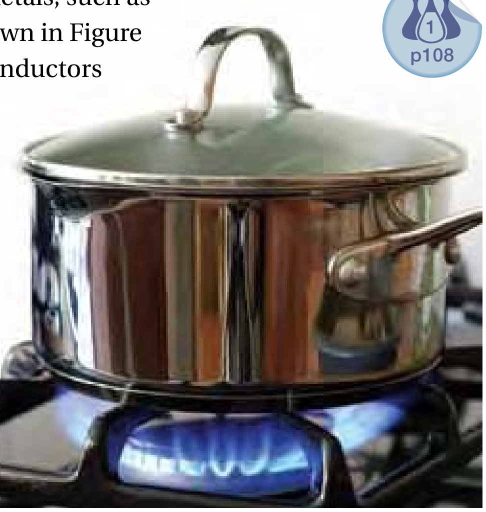


**Figure 4.1.7** Metals, particularly copper and gold, are good conductors of heat.

### Insulators

Plastic, air, cloth, wood and rubber are all very poor conductors of heat, and sometimes can block heat transfer completely. Such substances are known as **insulators**. The handles of a saucepan are usually made from insulating materials to allow us to lift them without burning our hands. An Esky uses insulating materials to keep food and drinks cool.

Gases are poor conductors of heat. Air trapped by woollen jumpers and blankets helps to insulate our bodies from losing heat. Ski parkas, doonas and sleeping bags are filled with cotton filling that also traps air and helps to protect us from the cold, as seen in Figure 4.1.8. Similarly, animals living in cold climates, such as those shown in Figure 4.1.9, have adaptations that help them stay warm.

4.1 2 p109

Figure 4.1.8 Wool fibres and the cotton filling inside a ski parka trap air and help prevent heat loss from your body.

Figure 4.1.9 These animals must stay warm in very cold conditions. Polar bears rely on body fat and a thick coat of fur for insulation, whereas penguins have layers of fat and feathers that they can fluff up to trap more air.

## Convection

As air is heated, its particles gain energy and move further apart. This hot air is less dense than cool air, and so it is pushed upwards by cooler air around it. This method of heat transfer is called **convection**, and the air flow it creates is called a convection current. Such a current is shown in Figure 4.1.10, transferring heat from an open fire. Heat is transferred by convection in liquids and gases because their particles can move around, rather than remaining fixed like those within a solid. Figure 4.1.11 shows how liquid in a saucepan is heated by convection.

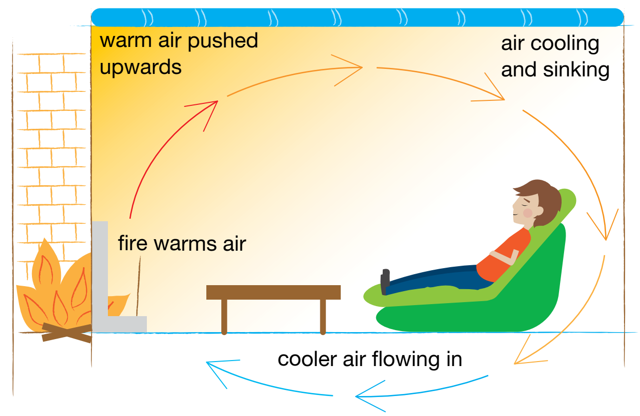



Figure 4.1.10 As air warms, it becomes less dense and is pushed up by cooler air that is sinking. These convection currents gradually spread heat from the open fire through the air in the room. A ceiling fan on winter mode would help to mix the air.

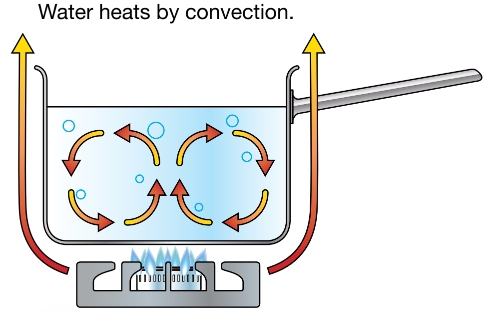
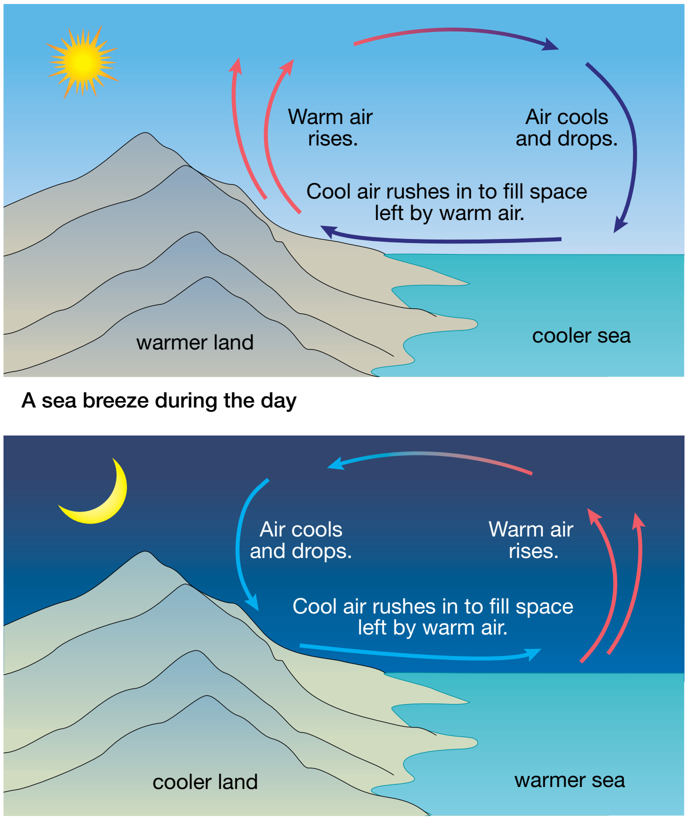



Figure 4.1.11 Particles gain heat from the hot base of the saucepan and rise to near the top of the saucepan. Cooler liquid sinks down and is then heated, and the cycle continues.

Convection explains the formation of a sea breeze during the day and a breeze towards the sea at night. This process is shown in Figure 4.1.12. Convection also circulates heat in a hot water system. This is shown in Figure 4.1.13.




A sea breeze during the day

A land breeze at night

**Figure 4.1.12** In the daytime, land heats up more quickly than the sea. Hot air is pushed upwards by cooler air that flows in towards it, producing a sea breeze. At night, the sea retains its heat for longer than the land. Warm air is pushed upwards above the sea as cool air flows from the land towards it.

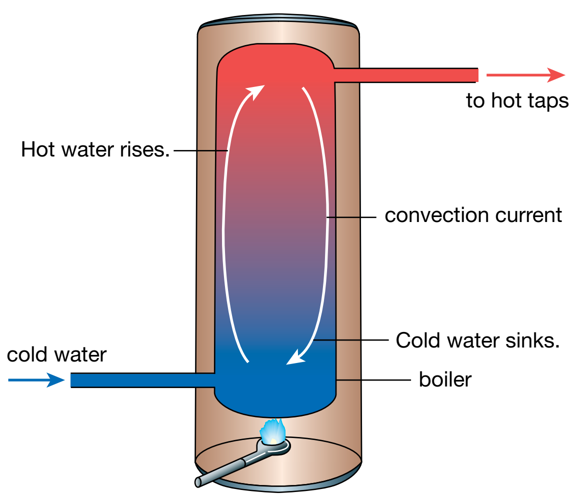



**Figure 4.1.13** Convection assists in circulation of water in a hot water system.

INQUIRY science 4 fun

## Ups and downs!

Can you see convection currents in action?

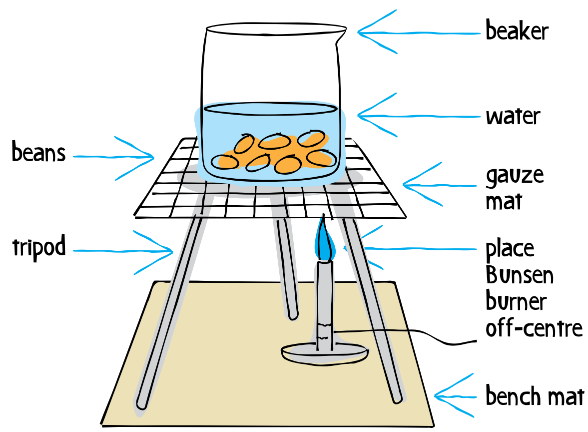
No

### Collect this …

dried beans, such as borlotti beans or chickpeas
Bunsen burner, gauze mat, tripod and bench mat
large beaker of water

### Do this …

1 Add dried beans to cover the base of the beaker.
2 Heat this carefully over a Bunsen burner.




### Record this …

**Describe** what happened.
**Explain** why you think this happened.

SciFile

### Home insulation

Heat transfer in a home occurs by conduction, convection and radiation. In winter, warm air flows out of the house, and in summer, warm air flows in. Insulation added to the ceiling and walls of a home helps to stop this transfer of heat and makes your home more energy efficient.

## Radiation

If you sit on a deck chair on a sunny balcony, you can feel the heat from the Sun on your skin. Heat has travelled through empty space between the Sun and the Earth to reach you (Figure 4.1.14). It cannot be transferred by conduction or convection on its journey because there are no particles to vibrate or flow in the vacuum of space. The Sun transfers its heat energy through a process called **radiation**.

**Figure 4.1.14** Radiation from the Sun travels through the vacuum of space to reach us. It is cooler in the shade because this radiation has been blocked.

Radiation transmits heat as invisible waves that travel at the speed of light (around 300 000 km per second). Infra-red radiation is heat energy that is transmitted this way. All objects release, or emit, some infra-red radiation.

The hotter something is, the more heat it radiates. You can feel the difference in the radiant heat produced by an oven set to a low temperature compared to a hot oven when you open the oven door. Similarly, the red-hot coals of an open fire radiate such enormous heat that you cannot sit too close to them.

When radiated heat hits a surface, it may be absorbed into it, reflected from it or transmitted through it, as shown in Figure 4.1.15. Often radiation will be partially absorbed, reflected or transmitted according to the materal and its colour.

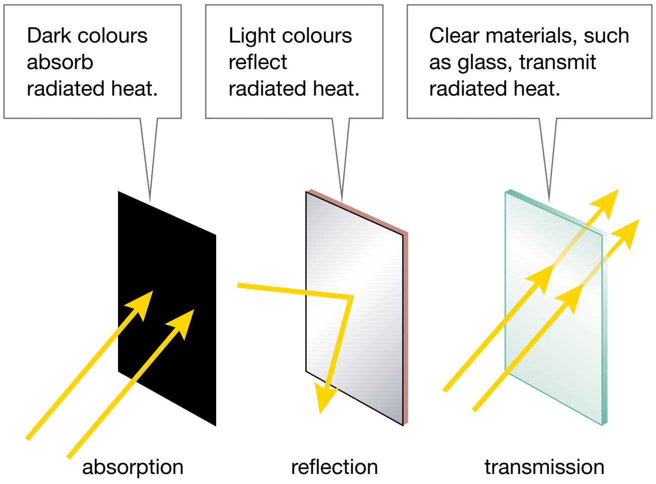



**Figure 4.1.15** When radiation hits an object, it may be absorbed, reflected or transmitted.

A dark-coloured car heats up more quickly in sunlight than a lighter-coloured car. This happens because dark-coloured objects are good absorbers of radiation, whereas lighter colours reflect much of it and don't heat up as rapidly. Darker objects also lose heat by radiation faster than lighter colours. Solar hot water systems utilise this absorption of heat energy from the Sun by using black collection panels, as shown in Figure 4.1.16.

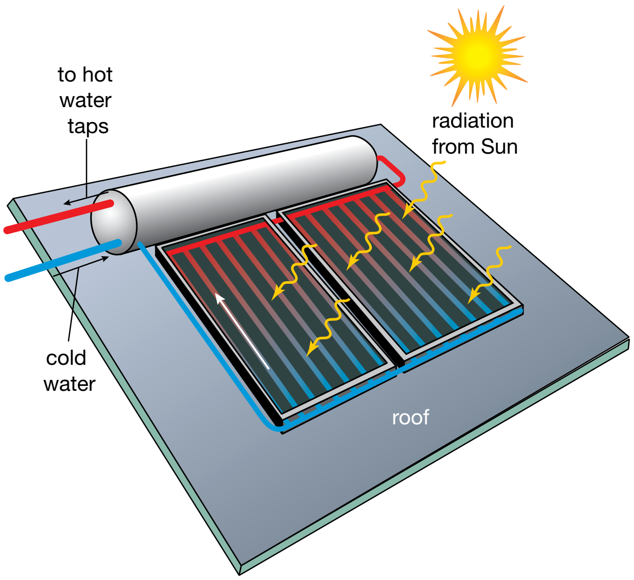



**Figure 4.1.16** Heat energy radiated by the Sun is absorbed by the cold water within the black collection panels of a solar hot water system. Some systems rely upon the natural convection of the hot water to circulate the water without the use of a pump.

4.2

3 p110

# 4.1 Unit review

## Remembering

1 **State** the temperature on the Fahrenheit, Celsius and Kelvin scales at which water freezes.

2 **Recall** how heat transfers by selecting the correct alternative in each statement below.
- a Heat always flows from an object of higher temperature to one of *lower/higher* temperature.
- b Insulators are *good/poor* conductors of heat.
- c Gases are *good/poor* conductors of heat.
- d On a warm day, a house is warmer upstairs because of *conduction/convection* currents.
- e The element of a hot water system will be located near its *top/base* and the heat is spread by convection.

3 **List** three insulators.

## Understanding

4 **Describe** how heat is conducted along a metal rod.

5 Figure 4.1.2 on page 100 shows saucepans X and Y of water being supplied with equal amounts of heat energy. **Explain** why the temperature rise in saucepan X is greater.

6 A wetsuit traps a layer of water between the wearer and the fabric of the suit.
- a **State** whether water is a good or poor conductor of heat.
- b **Explain** how this design helps to keep the wearer of the suit warm.

7 **Explain** why the vents for a ducted heating system are usually placed near the floor and not the ceiling.

8 You lose a lot of heat from your head. For most people, their hair protects them from losing too much heat from their heads.
- a **Explain** why hair is an effective insulator.
- b **Describe** a hair style that would give you excellent insulation.

## Applying

9 Heat transfer can occur by conduction, convection or radiation. **Identify** the main method of heat transfer in each situation below.
- a Your feet get hot when you are walking on sand at the beach.
- b Your back feels warm when you are sitting in the sun.
- c You boil water in an electric kettle.
- d You feel cold when you dive into a swimming pool.
- e You feel warm air as you walk into a school disco held in a hall.

## Analysing

10 **Compare** heat and temperature.

11 **Compare** the Fahrenheit, Celsius and Kelvin temperature scales.

12 Two identical bathtubs are filled to the same level with water. The particles in bathtub A move with greater speed than the particles in bathtub B. **Analyse** this situation to answer the following.
- a **State** in which bathtub the water will be at a higher temperature.
- b **State** which bathtub has more heat energy.
- c As the water cools, each bath loses heat energy. **List** three places this heat energy could go.

## Evaluating

13 Figure 4.1.17 shows the experimental set-up for a radiation experiment. The same sized black and white cardboard squares are attached to two thermometers close to an incandescent globe.

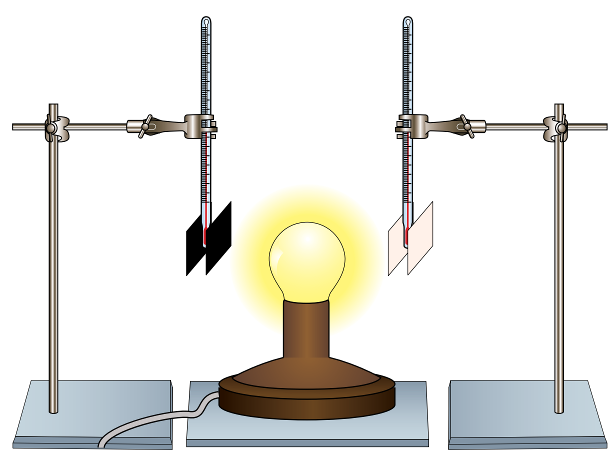


Figure 4.1.17

a **Propose** what the student performing the experiment is trying to test.
b **State** three variables that must be controlled to ensure a fair test.
c **Predict** which thermometer will show the highest reading after 5 minutes.
d **Discuss** reasons for your answer to question c.

14 **Propose** reasons why it is important for babies to wear a hat on a cool and windy day.

15 You walk barefoot on carpet in the living room of your house and your feet feel warm, yet when you walk into the bathroom and stand on the ceramic tiles your feet feel cold. The carpet and tiles are at the same temperature. **Propose** an explanation for why this is the case.

16 On a hot day, you have a choice of travelling in a red car, a white car or a black car, all of the same model. All have been parked in the sunlight for three hours.
a **Identify** which car you would choose.
b **Justify** your choice.

## Creating

17 **Design** a new type of suit that will keep you warm in cold conditions. Draw a diagram of your design, labelling what it is made from and how it keeps the heat in.

## Inquiring

1 Some animals help regulate their body temperature by heat loss through their ears. Research how animals absorb and emit heat. Prepare a multimedia presentation about the process used by three different animals.

2 Research the structure of double-glazed windows. Explain how these prevent heat loss.

3 Research how a thermos is designed to prevent heat loss. Explain how this happens, using labelled diagrams to assist your response.

4 Discover more about your body's largest organ—your skin. Create a poster with text in which you discuss either:
a different skin conditions (such as acne, warts, dermatitis, freckles and moles), or
b different forms of skin cancer, facts about each, what they look like, and how to prevent it.

5 Design and conduct an investigation into the cooling effect of a fan or an airconditioner on a warm glass of water. You could investigate how the effectiveness of the cooling device varies as the glass is positioned further away, or when the device is operated on different power settings.

6 Some manufacturers of mood rings claim that these rings can reveal a person's mood. Investigate and assess these claims.

**SciFile**

**Feeling chilly?**
Naked mole rats are the only known mammals not in control of their body temperature. Their bodies are warmed to the temperature of their burrows, about 30°C.

# 4.1 Practical activities

## 1 Comparing materials

### Purpose
To compare how well plastic, wood and metal conduct heat.

### Materials
- plastic spoon
- metal spoon
- wooden icy-pole stick
- 250 mL beaker
- small beads or similar
- butter
- very hot water (from a kettle)
- stopwatch
- ruler

**SAFETY**
Handle hot water with care.

### Procedure
1 Predict how well plastic, wood and metal conduct heat.
2 Put a dob of butter near the top of the handle of the plastic spoon.
3 Push a bead onto the dob of butter.
4 Repeat for the metal spoon and icy-pole stick. Make sure the beads are placed at equal heights and use the same amount of butter each time.
5 Carefully place the spoons and the icy-pole stick into very hot water in the beaker as shown in Figure 4.1.18.
6 Time how long each bead takes to fall off, and record your results in a table like the one shown in the Results section.

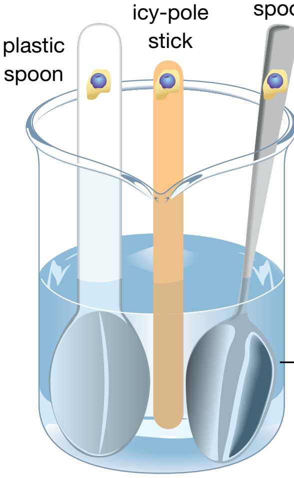



Figure 4.1.18

### Results
In your workbook, construct a table like the one shown here.

| Time taken to drop (seconds) | | |
|---|---|---|
| Bead on plastic spoon | Bead on icy-pole stick | Bead on metal spoon |
| | | |

### Discussion
1 **State** which of the materials used was the best conductor of heat and whether your prediction was correct.
2 **Assess** which material was the best insulator.
3 **Explain** why it was important that the beads were all placed at the same height in the experiment, and that the same amount of butter was used.

## 2 Testing insulators

### Purpose

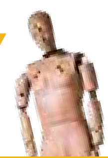
To test how effective different materials are in insulating heat.

### Materials

- empty soft drink cans
- a range of insulating materials such as: newspaper strips, cloth, cotton wool, foam, polystyrene beads, foam packing bullets, fibreglass insulation, carpet scraps
- thermometer or temperature probe
- cardboard box
- hot water
- beaker
- stopwatch or clock

**SAFETY**

Handle hot water with care.



You may use a temperature probe to gather temperature data.

### Procedure

1. Carefully measure 200 mL of hot water using a beaker, and pour this into your can.
2. Place the can inside the box.
3. Record the initial (starting) temperature of the water, and then measure and record the temperature every 2 minutes for 10 minutes. Put all your measurements in a table like that shown below.

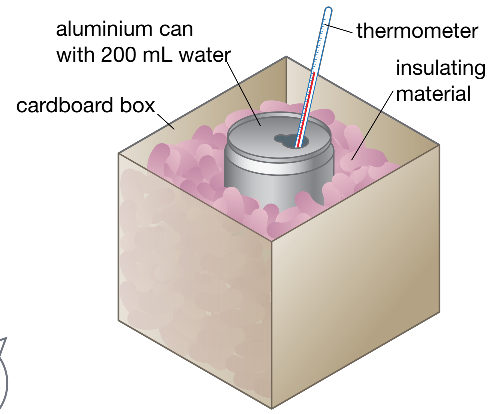



Figure 4.1.19

4. Repeat, using water at the same initial temperature and packing one of the insulating materials into the space between the can and the box, as shown in Figure 4.1.19.
5. Repeat the process, using a second insulating material.

### Results

1. In your workbook, construct a results table like the one shown below. Insert the names of two insulating materials you are going to test.
2. On the same set of axes, similar to those shown in Figure 4.1.20 on page 110, **construct** a line graph for each sample tested, to show the temperature drop over time. Alternatively, use data-logging equipment to produce a graph.

| Time (minutes) | Water temperature (°C) | | |
|---|---|---|---|
| | Can with no insulating materials (air only) | Can with insulating material A | Can with insulating material B |
| 0 | | | |
| 2 | | | |
| 4 | | | |
| 6 | | | |
| 8 | | | |
| 10 | | | |

Testing insulators continues

Testing insulators continued

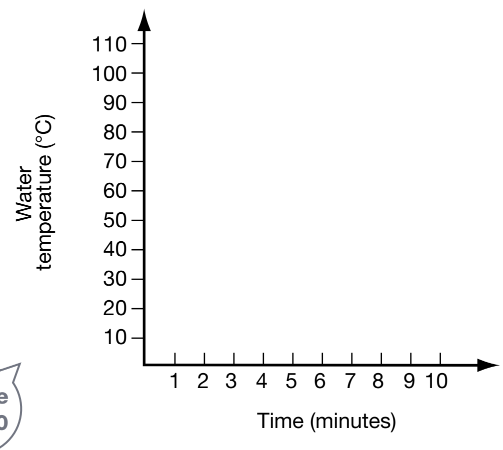



Figure 4.1.20

### Discussion

1. **Assess** which material was the best insulator.
2. **Explain** why it was important to test one can with no insulating materials.
3. **Identify** any sources of error in your experiment.
4. **Outline** any improvements that could be made to the design of the experiment.
5. **Design** another experiment that you could carry out with this equipment to test heat loss or heat gain. **Explain** which variables you would need to control.

## 3 Comparing heat radiation

### Purpose

To compare how different colours radiate heat.

### Materials

- silver, white and black aluminium cans
- thermometer or temperature probe

### Procedure

Design a prac to compare the amount of heat that is radiated over a time period from silver, white and black aluminium cans containing equivalent volumes of water at the same temperature. If available, you may wish to use a temperature probe to gather your data. With your teacher's permission, conduct your experiment.

### Results

1. Write a report on your findings.
2. Construct a line graph to display your results.

### Discussion

**Construct** a conclusion to summarise your findings.

# 4.2 Sound

Indigenous Australians developed the didgeridoo thousands of years ago. The player blows air into the didgeridoo while vibrating his lips. The didgeridoo itself makes only one note, a low rumbling sound. The unique depth of sound and tone of the didgeridoo are produced by the player changing the shape of his vocal tract by changing the position of his tongue. Musical instruments like a guitar produce sound using strings that vibrate. Other devices, such as ultrasound machines, rely on the reflection of sound waves to produce an image of the structures inside the human body.

INQUIRY science 4 fun

## Hear this!

Sound vibrates the air particles as it travels through them. What happens to a sound wave when you push air particles closer together?

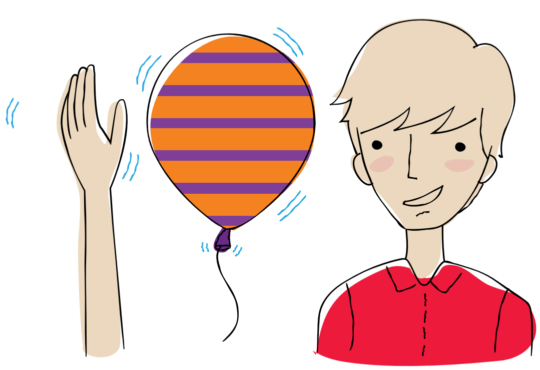
**Collect this …**

Yes

- a balloon

**Do this …**

1 Blow up the balloon and tie off the end.
2 Hold it close to one of your ears.
3 Have a partner lightly tap on the other side of the balloon.



**Record this …**

**Describe** what you could hear.

**Explain** what you think makes this happen.

## What is sound?

Sound is produced when something *vibrates*, which means to move back and forth very quickly. Table 4.2.1 on page 112 shows some common sounds and the objects that vibrate to produce them. When something vibrates, it passes the vibration into its surrounding environment, such as air. The vibration creates regions of space in which the air particles are bunched together, called **compressions**, and regions in which they are more spread out, called **rarefactions**. A **sound wave** is the movement of alternating compressions and rarefactions. This is shown in Figure 4.2.1 on page 112. These sound waves travel away from the source of a sound, in the same way that ripples of water move outwards when a stone is dropped into a pond. Because a sound wave relies upon particles that vibrate for it to be transmitted, a solid (such as a railway track), a liquid (such as water in a swimming pool) or a gas (such as air) is needed for a sound to be produced.

Table 4.2.1 Common sounds and their sources

| Sound | Vibrating source |
|---|---|
| Speech | Flaps of skin, called vocal cords |
| Drum | Drum skin |
| Piano | String inside piano—when you strike a key, the string is struck by a hammer |
| Saxophone | Reed inside the mouthpiece |
| Car stereo system | Speaker cone |
| A bell ringing | Metal casing of the bell (when struck) |

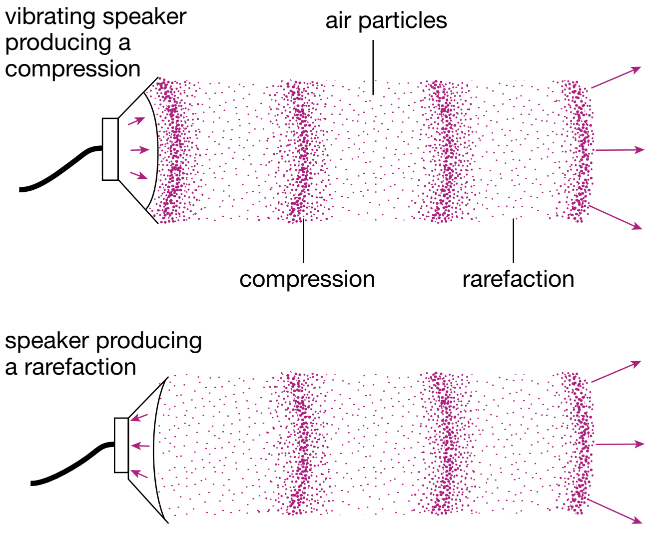



Figure 4.2.1 A vibrating speaker produces regions in which air particles are close together, called compressions, and regions in which air particles are spaced further apart, called rarefactions. The energy moves through air as a sound wave.

## Types of waves

A wave carries energy from one point to another. This can happen in a couple of ways. The energy carried by waves at the beach moves horizontally, but the particles making up the wave actually move in a vertical direction, as shown in Figure 4.2.2. This explains why a boat in the ocean bobs up and down as a wave travels to the shore. This type of wave is called a **transverse wave**.

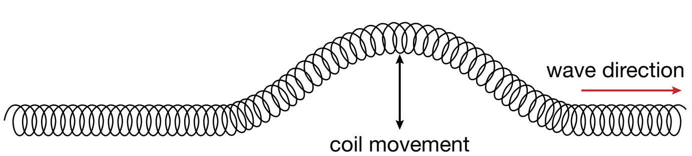



Figure 4.2.2 In a transverse wave, particles move at right angles to the direction of movement of the wave.

A sound wave differs from a transverse wave. In a sound wave, the particles that make up the wave move back and forth in the same direction that the wave is travelling. This type of wave is called a compression, or a **longitudinal wave**, and is shown in Figure 4.2.3.

1 p122

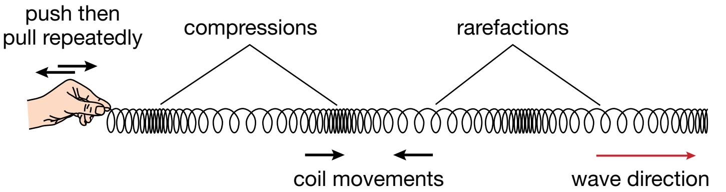



Figure 4.2.3 In a longitudinal wave, particles move in the same direction that the wave is moving.

## The speed of sound

The more closely packed the particles in a medium (a 'medium' is the surrounding environment), the faster a sound wave will travel through it. As a result, sound travels faster through solids than through liquids, and faster through liquids than through gases. Table 4.2.2 shows the speed of sound in several materials. Sound travels faster in warmer air than in cooler air, because the particles in warmer air move with greater kinetic energy.

Table 4.2.2 Speed of sound in various materials

| Material | Speed of sound (metres/second) |
|---|---|
| Air (at 0°C) | 331 |
| Air (at 18°C) | 342 |
| Water | 1440 |
| Wood | 4500 |
| Steel | 5100 |
| Glass | 5200 |

## Where does sound go?

You can usually hear when people are at home in your house from noise in the kitchen, living room or bedrooms. Sound passes through thin walls and is transmitted short distances through most materials.

Hard surfaces, such as concrete or bathroom tiles, reflect sound waves. This reflected sound is heard as an **echo**. The time difference between sending and receiving sound waves can be measured. This difference can be used to calculate the depth of objects in the sea, using a technique called sonar (**so**und **na**vigation and **r**anging), shown in Figure 4.2.4.

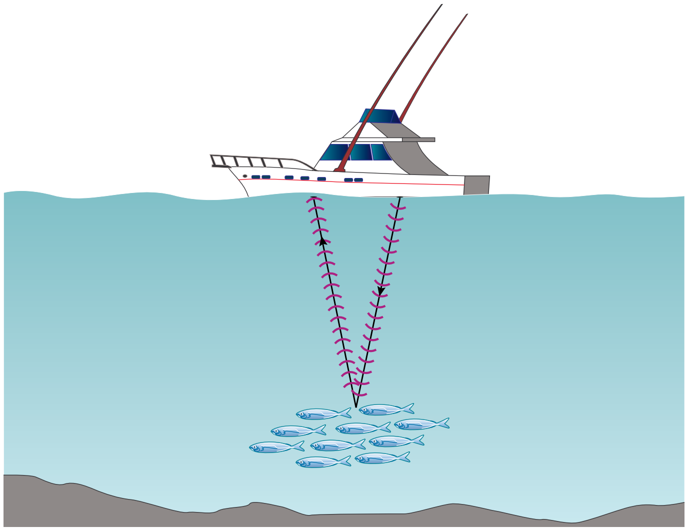


Figure 4.2.4 Sonar can be used to calculate the depth of objects in the sea, such as a school of fish.


## Sonar calculations

Sound travels at about 1500 metres/second in sea water. Sonar measures the time it takes for sound to return to the ship. This data may be used to calculate how deep the water is, or how deep a school of fish are.

To calculate depth:

1 Halve the time it takes for the sonar signal to return. This gives the time it takes for the signal to reach the bottom or the fish.

2 Multiply this by the speed of sound in sea water (i.e. × 1500).

## WORKED EXAMPLE

### Sonar calculations

#### Problem

Sound travels at a speed of about 1500 m/s in sea water.

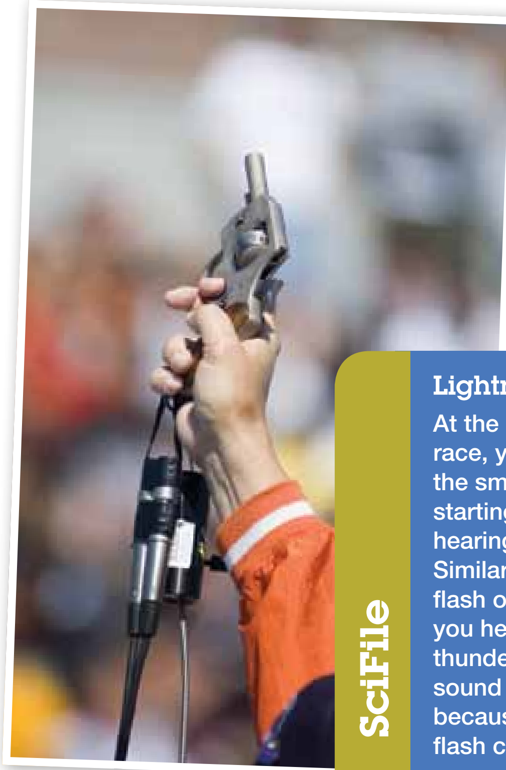
a It took 0.4 seconds for a sound pulse sent from the ship in Figure 4.2.4 to return. Calculate the depth of the fish.

b Calculate the depth of the fish, given that the sound took 1 second to return.

#### Solution

a If it took 0.4 seconds for a pulse to return, then the sound reached the fish after 0.2 seconds. The sound pulse travelled at 1500 m/s, so this means that the fish are located $0.2 \times 1500 = 300$ m below the ship.

b If the sound returned in 1 second, then it reached the fish in 0.5 second. The fish are located $0.5 \times 1500 = 750$ m below the ship.



SciFile

### Lightning speed

At the start of a running race, you may notice the smoke from the starting pistol before hearing its sound. Similarly, you see a flash of lightning before you hear the rumble of thunder. You hear the sound of thunder because the lightning flash causes the surrounding air to expand rapidly. The reason you see the lightning before hearing the thunder is that light travels much faster than sound.

SciFile

### Boom!

Fighter jets regularly travel at supersonic speeds—faster than the speed of sound. As the jet catches up to and then overtakes the sound waves it has produced, a very loud 'sonic boom' is heard. Sonic booms can smash windows and damage the hearing of humans, birds and other animals. When a sonic boom happens, moisture in the air can become so compressed that it forms a 'cloud' of ice crystals.

Soft materials like curtain fabric, carpet and cushions (Figure 4.2.5) absorb sound and convert it into heat. This reduces the reverberation, or length of time a sound is heard. Sound absorption like this is needed in concert halls, so that there is no overlap between the sounds being performed and their echoes, which would otherwise distort what you hear. Figure 4.2.6 compares how well some materials absorb sound.

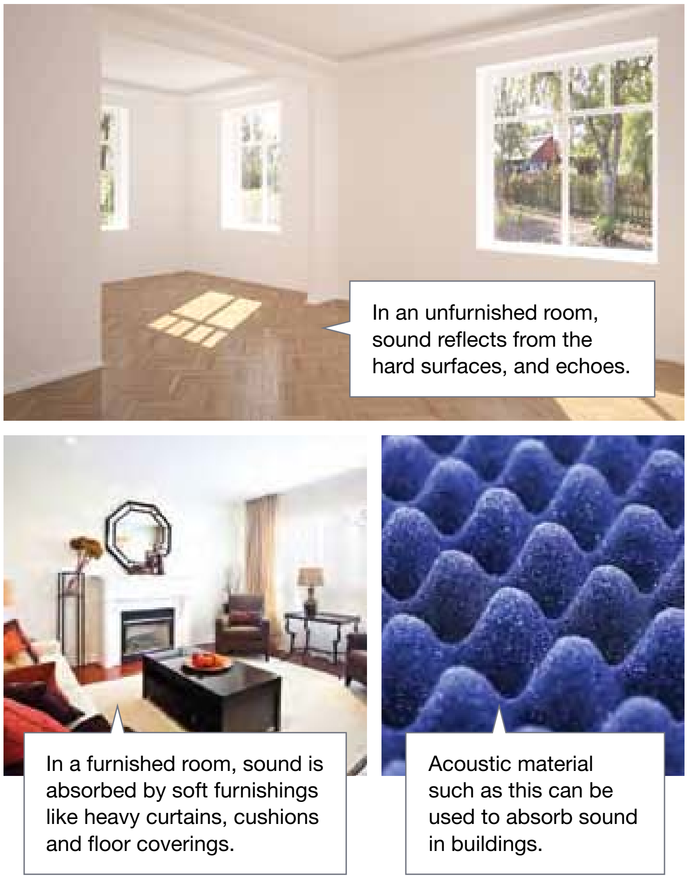



**Figure 4.2.5** Different materials will give a room different reverberation times.

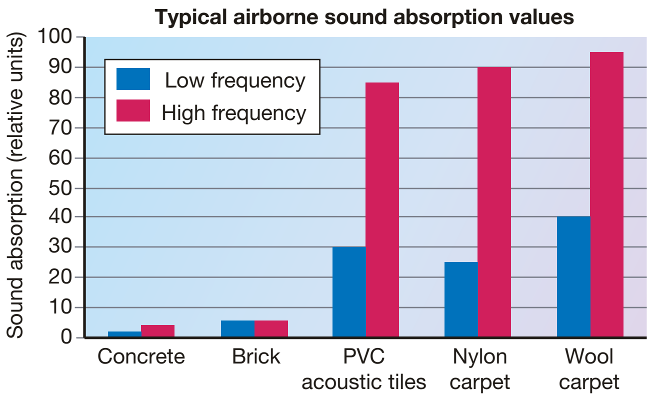



**Figure 4.2.6** This graph compares the sound absorbtion levels of different materials.

## Frequency and pitch

A dog has a low-pitched growl, whereas a bird chirps with a high-pitched sound. The different sounds can be compared by analysing their sound waves using a cathode ray oscilloscope (CRO), as shown in Figure 4.2.7. A source that vibrates rapidly produces sound of a higher pitch, or **frequency**, than one that vibrates more slowly. The number of vibrations a sound makes each second is called the frequency of a wave. Frequency is measured in **hertz** (**Hz**).The **wavelength** of a sound is the distance between successive peaks. It is measured in metres. Figure 4.2.8 shows that graphs of louder sounds have larger peaks, meaning louder sounds have greater amplitude than softer sounds. Sounds with higher frequency produce soundwaves that are shorter in wavelength with the compressions and rarefactions bunched closer together than sounds at a lower frequency, resulting in a shorter wavelength.

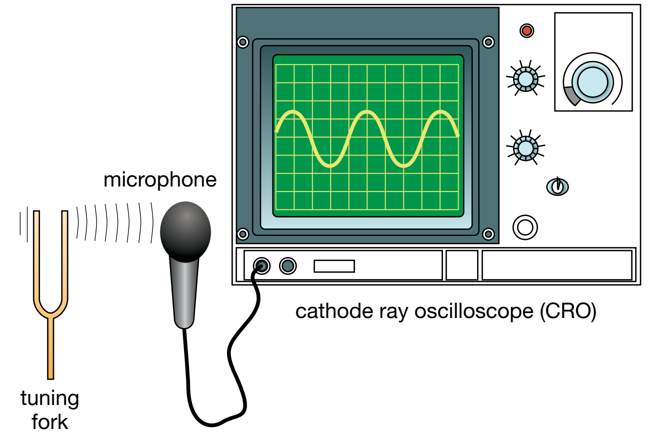



**Figure 4.2.7** A CRO converts sound waves into electrical signals that can be viewed on a screen. The trace shown on the screen is a graph that shows how the pressure of particles making up the sound wave changes as the wave travels.

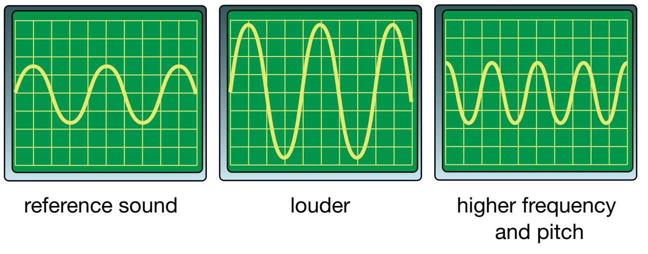



**Figure 4.2.8** A loud sound has a taller graph on a CRO than a quiet sound. Higher-frequency sound waves have a short wavelength.

2 p122

## The Doppler effect

Have you ever heard the wail of an ambulance siren rushing past? When an ambulance travels towards you, the sound waves it emits bunch up. This makes the sound of its siren higher in pitch. As the ambulance moves away, its sound waves are spread further apart and the sound is lower in pitch. Called the Doppler effect, this occurrence is named after the Austrian physicist Christian Doppler, who described it in 1842.

SciFile


INQUIRY science 4 fun

## Straw clarinets

How does changing the length of a flute or a clarinet change the sound it produces?

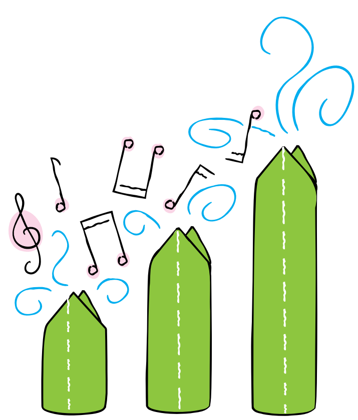
### Collect this ...

- a straw
- a pair of scissors

Yes

### Do this ...

1 Squash the end of a straw.
2 Cut the top off the straw to make a point.
3 Blow into the pointy end of the straw.
4 Try different positions until you get a buzzing sound.
5 As you are making the sound, have a partner carefully cut the other end of your straw.
6 Keep cutting, making the straw shorter and shorter.



### Record this ...

**Describe** how the sound changed as the straw got shorter.

**Explain** how you think the straw produced a sound.

Our ability to hear higher frequencies of sound reduces as we age. Young people can typically hear a range of frequencies up to 20 000 Hz, yet most people over 65 years cannot hear frequencies above 5000 Hz. Hence, mobile phone ringtones like the mosquito (16 000 Hz) cannot be heard by older adults.

Many animals, such as dogs and cats, can hear sound frequencies that are outside our human range of hearing. **Ultrasound** is the name given to sound waves with frequencies above our hearing range. Bats emit squeaks with frequencies up to 200 000 Hz, which reflect off surfaces around them and are used by the bat to avoid obstacles and to locate food. Elephants can hear a range of frequencies lower than our own hearing range. These frequencies are called **infrasound**.

Computer analysis of the way ultrasound reflects from living tissue can be used to create an image, like the one shown in Figure 4.2.9.

Figure 4.2.9 Ultrasound waves pass easily through fluids and soft tissue but are reflected from other layers within an organ or foetus. Echoes of these waves are detected and analysed by computer to create the image, such as this 3D image of a human foetus.

SciFile

**Teenager repellent!**

The Mosquito (or mosquito alarm) emits a high-frequency sound of around 17 000 Hz. This can typically be heard only by people under the age of 25. The device has been used around the world to discourage youths from hanging around outside shops or railway stations. Now, teenagers have had the last laugh—using the sound of the mosquito alarm to signal incoming text messages.

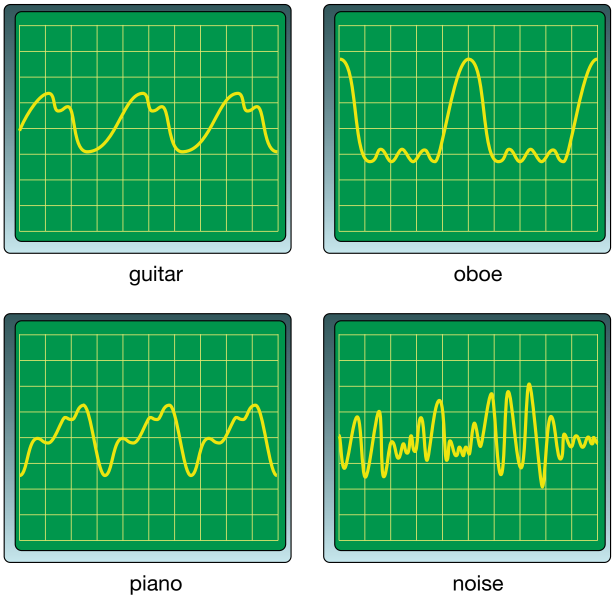




Figure 4.2.11 Musical notes played using an instrument have a smooth, repeating pattern when viewed on the CRO. Different types of instrument produce characteristic sounds. Background noise shows up as a uneven mixture of waves.

## Musical instruments

All musical instruments produce sounds by vibrations (Figure 4.2.10). They do this in different ways and produce sounds of differing characteristic qualities. These differences can be compared by playing the sound into a microphone attached to a cathode ray oscilloscope. Typical traces from some instruments are shown in Figure 4.2.11.

On a guitar, a violin and a piano, vibrations are produced by strings. Changing the length of the string alters the frequency of the sound produced. Longer strings vibrate more slowly, producing lower-pitched sound than shorter strings. When you press a string against the neck of a guitar, you shorten the effective length of that string.

Figure 4.2.10 Each of these musical instruments uses vibration to create its sound. Guitars use vibrating strings, saxophones use a reed and drums use a 'skin'.

In percussion instruments like drums, the skin stretched over the top of the drum vibrates when you hit it. In instruments like the triangle or the cymbal, the instrument itself vibrates.

In wind instruments, a column of air vibrates. When you play a flute or a recorder, the length of this vibrating column of air is increased when you cover holes along the tube, and shortened when you leave the holes open. A longer vibrating column of air produces a lower sound than a shorter vibrating air column.

## How you hear: the ear

Your ears collect sound waves, amplify their vibrations and convert these into electrical impulses. Your brain then interprets these impulses as sound. Figure 4.2.12 illustrates the parts of the ear and describes how they function.

SciFile

**Popping ears**

As an aircraft takes off, or if you go up into the hills, the air pressure outside your eardrum falls, but the air pressure inside your ear remains the same. This pushes against your eardrum. When your ears 'pop', the Eustachian tube opens and releases air through your nose and throat, which balances the air pressure on your eardrum.

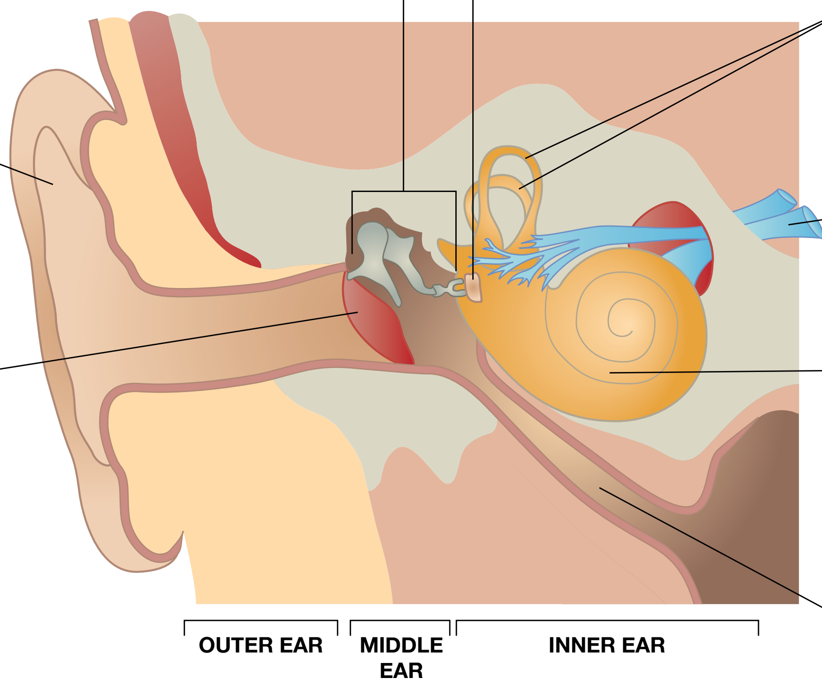



**Figure 4.2.12** These structures work together to allow vibrating air entering the ear to be interpreted by our brain as a sound.

Over 1 million Australians have a hearing disability, ranging from mild hearing loss to complete deafness. These problems can be because:

- the ear canal is blocked with wax, preventing the passage of sound waves
- the middle ear is filled with fluid
- the eardrum has been ruptured by an extremely loud noise or as the result of infection
- sensory cells of the ear have been damaged by loud noise
- a defect in the auditory nerve or the tiny hairs of the cochlea prevents sound impulses being transmitted correctly to the brain.

The cochlear implant, or bionic ear (shown in Figure 4.2.13), has helped many people with serious inner-ear damage to hear sound for the first time.

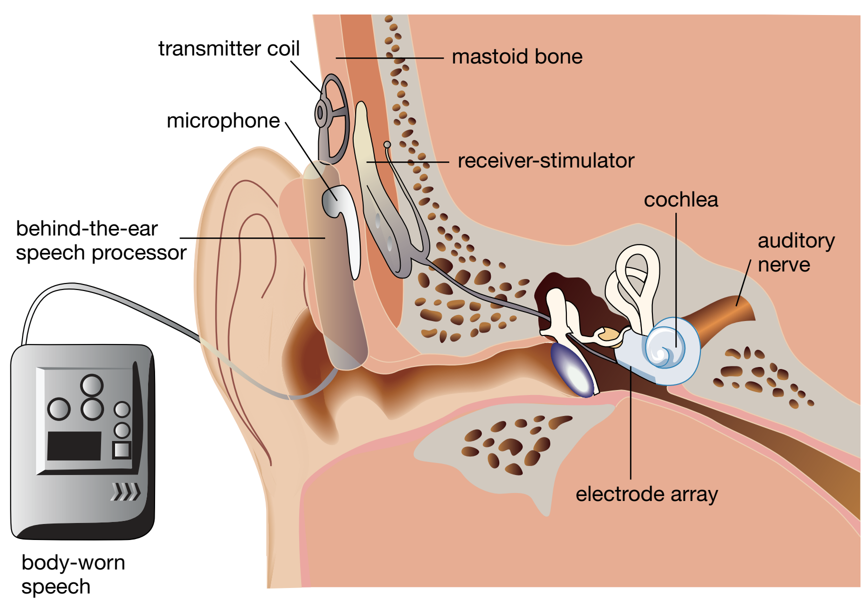



**Figure 4.2.13** The cochlear implant, or bionic ear, is an Australian invention. It was developed in the 1970s by a group of scientists led by Professor Graeme Clark. It assists people by converting sounds into electrical impulses that are sent to the brain.

# SCIENCE AS A HUMAN ENDEAVOUR

## Use and influence of science

### Workplace hearing protection

Figure 4.2.14 Some workplaces are noisier than others, like the airport where this man works.

**Delicate cells in your ears can be damaged by loud noise. They need to be protected from excessive noise in the workplace.**

Many people work in jobs that use noisy machinery (Figure 4.2.14). Loudness can be measured using a device called a sound level meter. Loudness is measured in **decibels** (unit symbol dB). The decibel scale is shown in Figure 4.2.15, alongside some common examples of similar sound levels.

Exposure to noise levels above 85 dB for long periods can permanently damage your hearing. The degree of damage depends on how loud the noise is, and how long you are exposed to it. People spend much of their day in their workplace, and so exposure to constant loud noise can have a significant effect on their hearing.

Noise destroys delicate sensory cells in the inner ear, called hair cells. These cells detect vibration and send electrical signals to the brain. Such damage can be seen in Figure 4.2.16. If affected, these cells cannot be replaced.

Repeated exposure to loud noise can also lead to **tinnitus**, a condition in which a person hears a permanent ringing in their ears. Noise-induced hearing loss (NIHL) has been recognised as a major industrial disease in Australia and around the world. It makes hearing higher-frequency sounds more difficult. In turn, this can lead to problems communicating, increased fatigue, stress and anxiety.

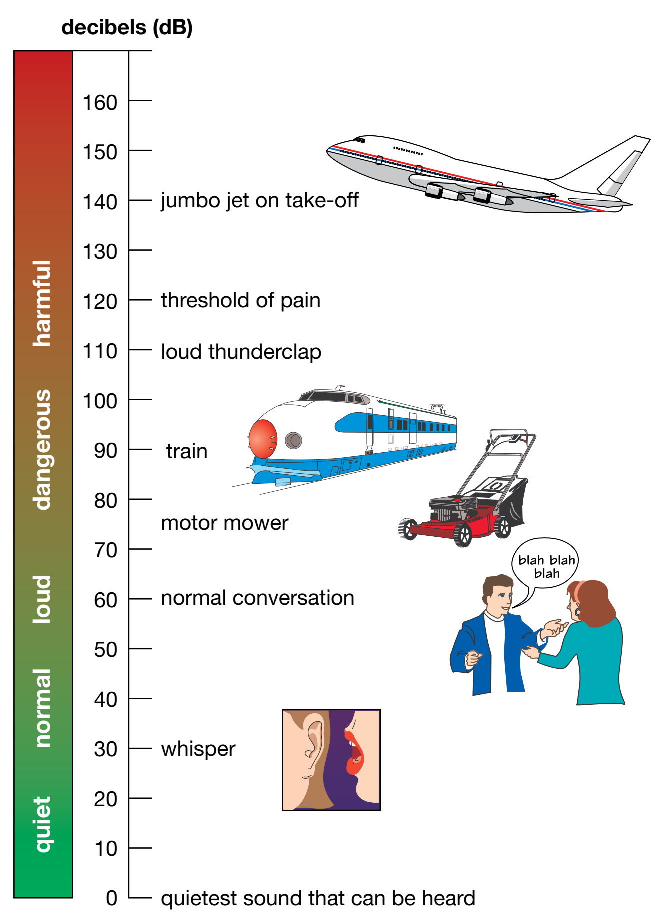



Figure 4.2.15 Sound intensity level, or loudness, is measured using the decibel scale.

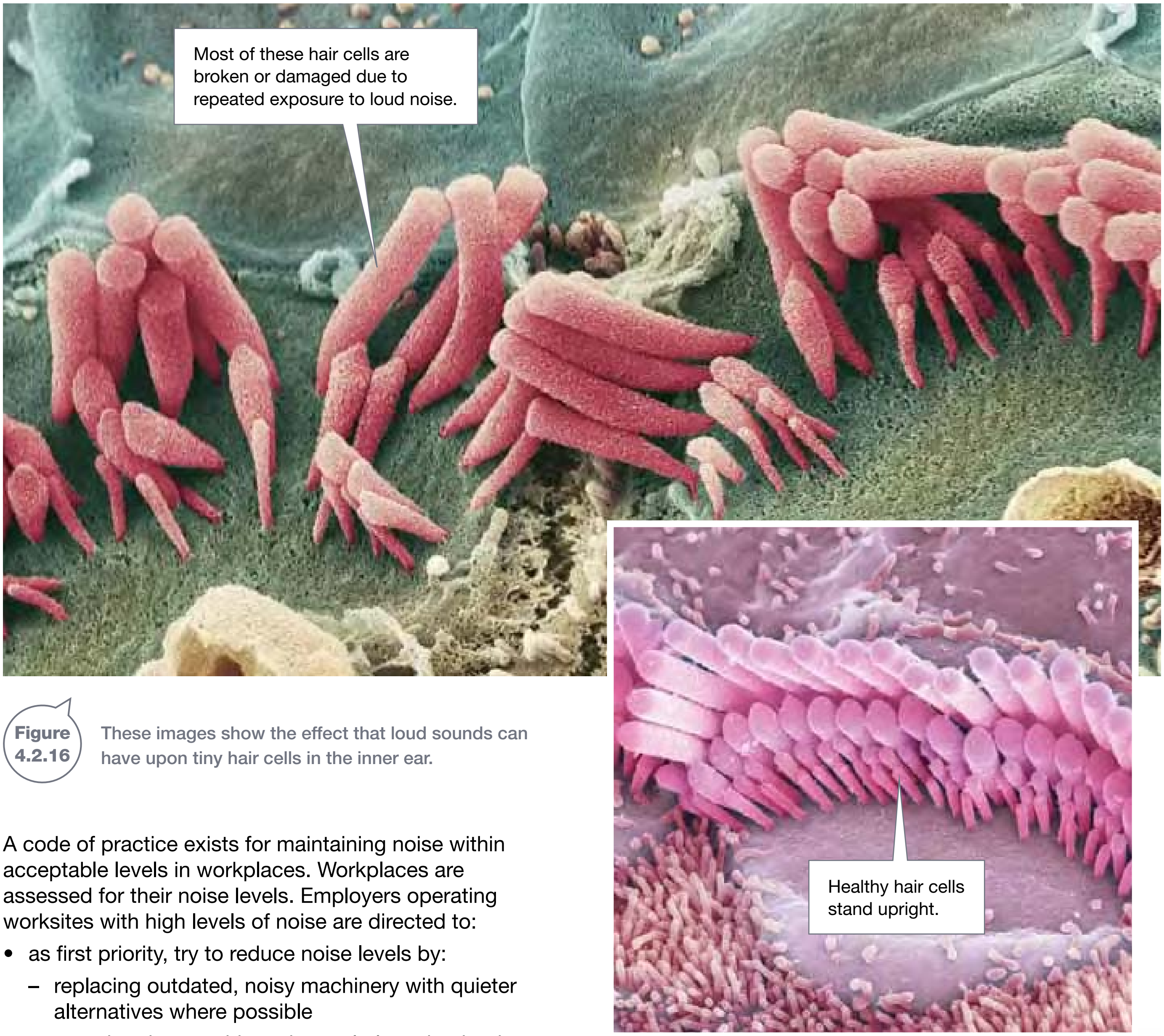



**Figure 4.2.16** These images show the effect that loud sounds can have upon tiny hair cells in the inner ear.

A code of practice exists for maintaining noise within acceptable levels in workplaces. Workplaces are assessed for their noise levels. Employers operating worksites with high levels of noise are directed to:

- as first priority, try to reduce noise levels by:
  - replacing outdated, noisy machinery with quieter alternatives where possible
  - ensuring that machinery is regularly maintained
  - reducing metal-to-metal contact in machinery by inserting materials to dampen sound
- block noise transmission by:
  - shifting noisy machinery to more remote areas of the workplace
  - fitting sound-absorbing materials to the ceiling or walls
  - using sound-absorbing curtains to screen off an area or machine
- ensure that all areas of loud noise are signposted as hearing protector areas
- ensure that workers are not exposed to sound intensity levels greater than 85 dB averaged over an 8-hour period
- ensure that affected workers wear personal hearing protectors, such as correctly fitted earmuffs or earplugs (shown in Figure 4.2.17), and that these workers undergo regular hearing tests to monitor their hearing.

**Figure 4.2.17** Earmuffs and earplugs reduce the pressure variations on ears. This helps prevent the eardrum and hair cells from being damaged by loud noises.

# 4.2 Unit review

## Remembering

1 **State** whether the following are true or false.
  - a Sound is produced by vibrations.
  - b Regions of high air pressure are called rarefactions.
  - c A sound wave can travel in a vacuum.
  - d Waves at the beach are called transverse waves.

2 **Name** the unit that is used to measure the frequency of a sound wave.

3 **List** the causes of four types of hearing loss.

## Understanding

4 **Explain** why sound travels faster through solids than through liquids.

5 Theo discovers after an audit that his printing workshop is excessively noisy and is putting his workers at risk. **Describe** three ways he could reduce the noise level.

6 Think of an example to help you **define** the term *reverberation*.

7 Refer to Figure 4.2.16 on page 119 and **explain** why Australian workers are not allowed to be exposed to noise levels above 85 dB averaged over an 8-hour working day.

8 Refer to Figure 4.2.12 on page 117 and answer the following questions about the ear.
  - a **Describe** the function of the eardrum.
  - b **Describe** the role of the ossicles.
  - c **Explain** how these electrical impulses travel to the brain.

## Applying

9 **Use** the speed of sound in water as 1500 m/s to **calculate** the following.
  - a Mia and Eve are on a fishing trip. They send an ultrasound pulse into the water below their boat and it takes 0.2 seconds to return. **Calculate** how far below the boat the fish are likely to be.
  - b Oceanographers mapping the ocean floor direct an ultrasound pulse beneath their ship. It takes 6 seconds to return to them. Given that this pulse reflected from the ocean floor, **calculate** how deep the ocean is at this point.

10 **Use** Figure 4.2.15 on page 118 to estimate the sound level intensity (in dB) of:
  - a city traffic
  - b two people arguing loudly
  - c a chip packet crinkling in a movie theatre
  - d a car backfiring.

11 Light travels 300 000 km every second. The time it takes to see a flash of lightning a few kilometres away is almost zero. Assuming you see a lightning strike as it happens, and count 6 seconds before hearing the rumble of thunder produced by the strike, **calculate** how far away you are from the storm. Assume the speed of sound is 340 m/s.

## Analysing

12 Figure 4.2.18 illustrates three traces of sounds on a cathode ray oscilloscope.

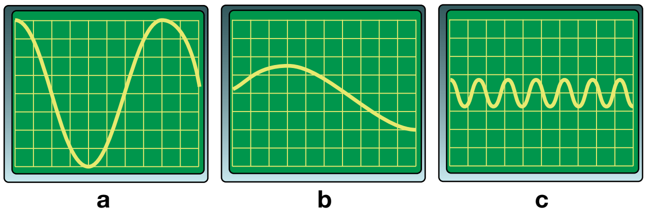



Figure 4.2.18

**Identify**:
  - a the sound with the highest frequency
  - b the sound with the lowest frequency
  - c the loudest sound.

13 **Analyse** Figure 4.2.12 on page 117 to **explain**:
  - a the shape of the pinna
  - b where vibrations are converted to electrical signals.

## Evaluating

14 **Analyse** Figure 4.2.6 on page 114 to answer the following questions.
  - a **State** which material listed best absorbs high-frequency sounds.
  - b **State** which material reflects the greatest proportion of sounds.

c **Propose** a reason why this material does not absorb much sound.

d **Explain** what happens to the sound energy absorbed by materials.

15 A blind person buying a house may make clicking noises to find out how big a room is. **Propose** how clicking could provide this information.

16 **Propose** how a speech recognition system would operate.

17 Use the information in Figure 4.2.19 to answer the questions below.

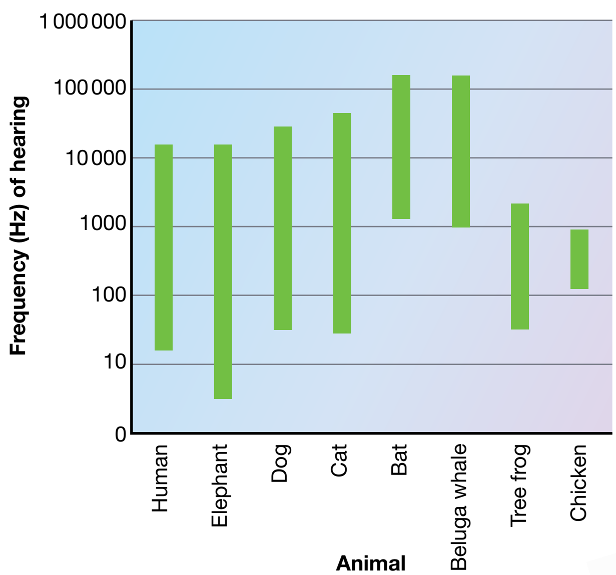



Figure 4.2.19 This chart compares the range of hearing of humans and several animals. Note that the vertical scale is a logarithmic scale, meaning each division on the scale is ten times as large as the previous division.

a From the animals shown, **identify** which can hear the highest-frequency sounds.

b **Identify** which animal or animals can hear the lowest frequency.

c The bat and the beluga whale rely on echolocation using ultrasound. **Propose** why they need to have a higher hearing range than humans.

d Dog whistles are audible to dogs but not to humans. **Propose** the frequency range of such whistles.

e **State** whether a chicken can hear any of the sounds heard by a bat.

## Inquiring

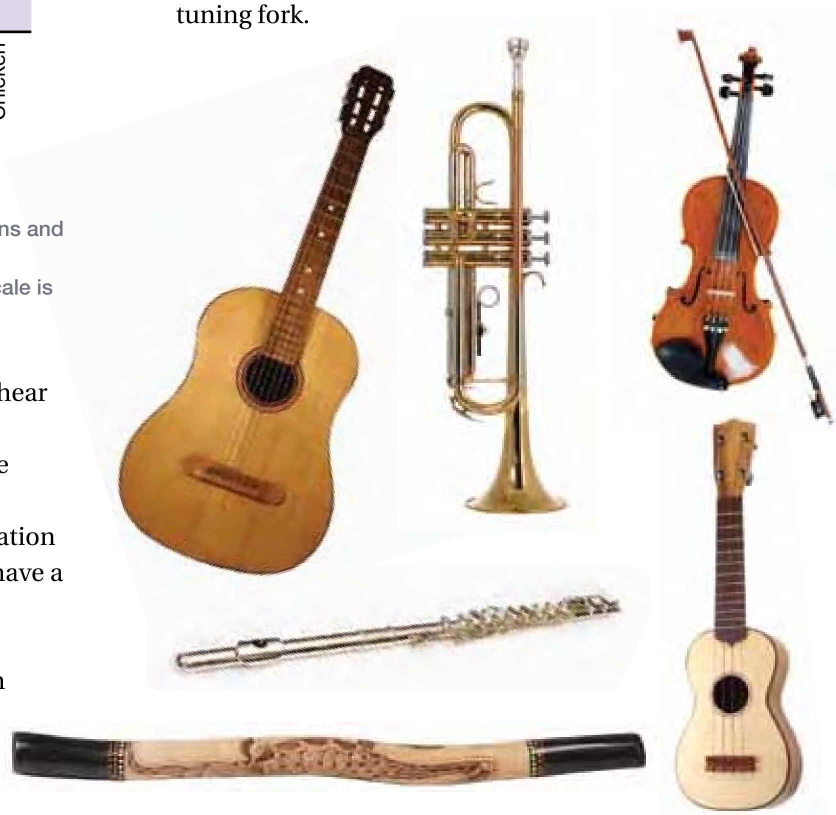
1 It is easy to listen to sounds above 105 dB when using an iPod, particularly when increasing the volume in a noisy environment. Create a brochure outlining recommendations on how to use an iPod safely without risking your hearing.

2 Some people are calling for devices such as the Mosquito alarm to be banned because it breaches human rights. Research this issue and list arguments for and against such a ban.

3 Construct an instrument capable of making sound that also allows you to change the pitch. Explain how your instrument produces these different sounds.

4 Use a sound-level meter to investigate how well various materials absorb sound.

5 Use a microphone and cathode ray oscilloscope to investigate the differences in sound made by a range of musical instruments (for example, guitar, violin, ukulele, didgeridoo, flute, trumpet, oboe) and compare these to the sound produced by a tuning fork.



# 4.2 Practical activities

## 1 Making waves

### Purpose

To use a slinky to model transverse and longitudinal waves.

### Materials

- a slinky spring

### Procedure

1. Hold one end of a slinky. A partner holds the other end.
2. Move your end of the slinky up and down at a regular speed, as shown in Figure 4.2.20a.
3. Sketch a side view of the waves you made. These are called transverse waves, and are like water waves.
4. Try to alter how you produce the waves so that they are bunched closer together, with greater frequency.
5. You and your partner hold each end still.
6. Tap one end of the spring horizontally so that a pulse travels through the spring, as shown in Figure 4.2.20b.
7. Try to draw what is happening here from a side view. This is a longitudinal wave, like a sound wave.
8. Try to alter how you produce these waves to increase their frequency.

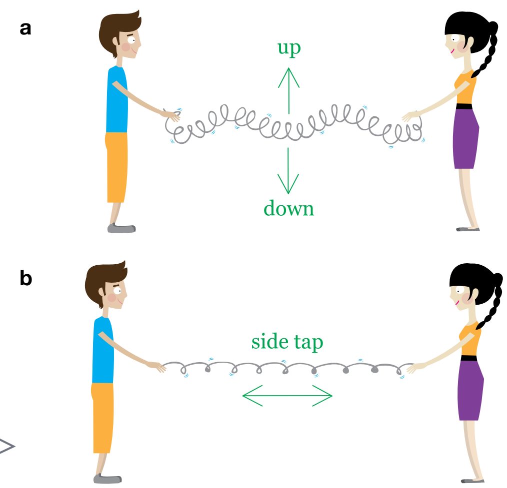



Figure 4.2.20

### Discussion

1. **Describe** how the slinky moves when:
   a. a transverse wave passes through
   b. a longitudinal wave is transmitted.
2. **Explain** how you were able to increase the frequency of:
   a. the transverse waves
   b. the longitudinal waves.
3. **State** which of the two wave types you produced is more like a sound wave.

## 2 Good vibrations

### Purpose

To investigate the differences in producing high-pitched and low-pitched sounds.

### Materials

- 5 beakers (or glasses) of the same size
- water
- a pen or a chopstick
- a ruler

### Procedure

Part A

1. Hold a ruler over the edge of a bench and flick it so it vibrates.
2. Listen to how the pitch changes as you reduce the length of ruler vibrating.

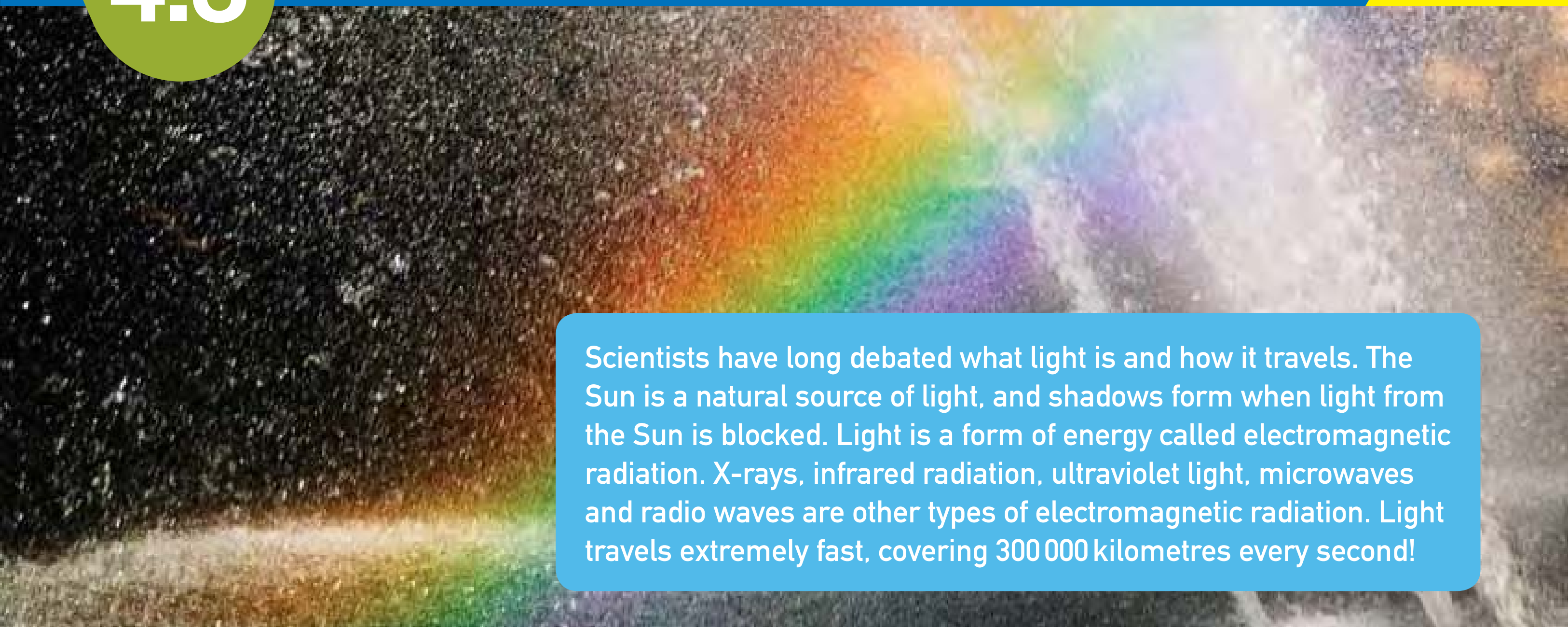
Part B

3. Line up the beakers (or glasses) on your bench.
4. Fill each beaker to a different depth with water.
5. Carefully tap the glass of each using a pen, chopstick or other object, and listen to the variation in pitch.

### Discussion

1. **State** which length of vibrating ruler made the lowest sound and which made the highest sound.
2. **Construct** a diagram that shows the difference between sound waves produced.
3. **Describe** the pitch of sound produced by the beaker with the least amount of water.
4. **Deduce** how the length of the ruler and the depth of the water in the beaker are related to the pitch of the sound they produce.
5. **Explain** whether you think the vibrations would be faster or slower when producing high-pitched sounds.

# 4.3 Light



Scientists have long debated what light is and how it travels. The Sun is a natural source of light, and shadows form when light from the Sun is blocked. Light is a form of energy called electromagnetic radiation. X-rays, infrared radiation, ultraviolet light, microwaves and radio waves are other types of electromagnetic radiation. Light travels extremely fast, covering 300 000 kilometres every second!

## Properties of light

Like infrared radiation, light is a form of energy called electromagnetic radiation. It travels as a wave, called an electromagnetic wave. This has a complex structure, shown in Figure 4.3.1. Like a sound wave, an electromagnetic wave has a specific frequency and wavelength. But unlike a sound wave, which requires a medium such as air to be transmitted, an electromagnetic wave does not. Infrared radiation and light from the Sun travel through the vacuum of empty space to reach Earth. A sound wave may travel at around 340 metres per second, whereas a light wave travels at some 300 000 km per second.

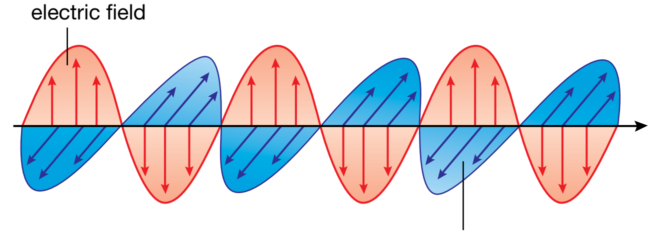


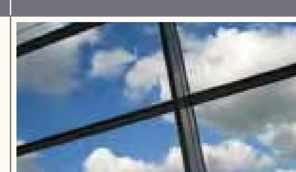
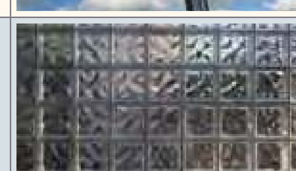
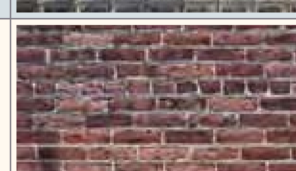

**Figure 4.3.1** Light travels as an electromagnetic wave. It consists of alternating electric and magnetic fields.

When light hits a surface, it may be:

- transmitted through it
- reflected off it, or
- absorbed into it.

Table 4.3.1 outlines examples of these three situations.

**Table 4.3.1 Transparent, translucent and opaque materials**

| Light hits a surface and: | This material is called: | Examples | |
|---|---|---|---|
| Almost all light is transmitted through the substance. A clear image can be seen through it. | **Transparent** | Clear glass, shallow water |  |
| Some light may be reflected, and light that passes through is scattered. An image seen through it is fuzzy. | **Translucent** | Tissue paper, fingernails, frosted glass |  |
| Light is either reflected from or absorbed into the substance, and no light is transmitted. No image can be seen through it. | **Opaque** | A brick, a piece of wood, a desk, a football |  |

An object that releases or emits light is said to be luminous. Most objects around you, however, do not produce their own light. They are non-luminous (such as the Moon, shown in Figure 4.3.2). You see most of the things around you because light bounces off them and then into your eyes. This process is called reflection and is shown in Figure 4.3.3.

Figure 4.3.2 Although the Moon looks bright in the night sky, it is non-luminous. It doesn't make its own light but reflects light from the Sun instead. Stars are the only objects in space that make their own light.

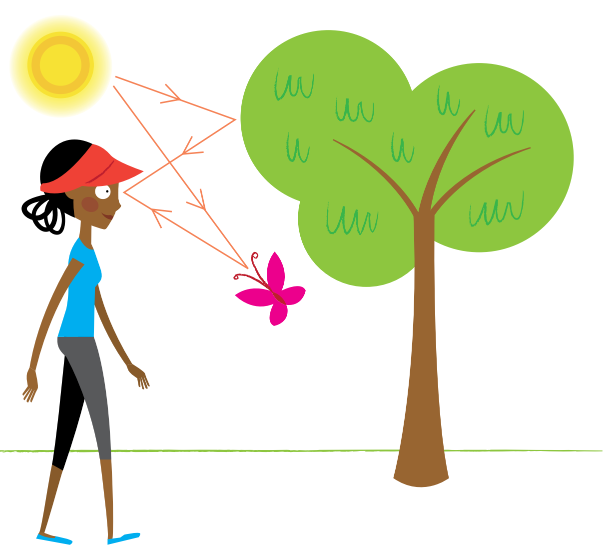


Figure 4.3.3 This girl can see the tree and the butterfly because light from the Sun is reflected from these objects and then enters her eyes.

## Diffuse and regular reflection

When light reflects off a very smooth surface such as a mirror or a window, as shown in Figure 4.3.4, it undergoes **regular reflection**. This produces a clear image, as shown in Figure 4.3.5.

Figure 4.3.4 You can see an image when light is reflected from a very smooth surface.

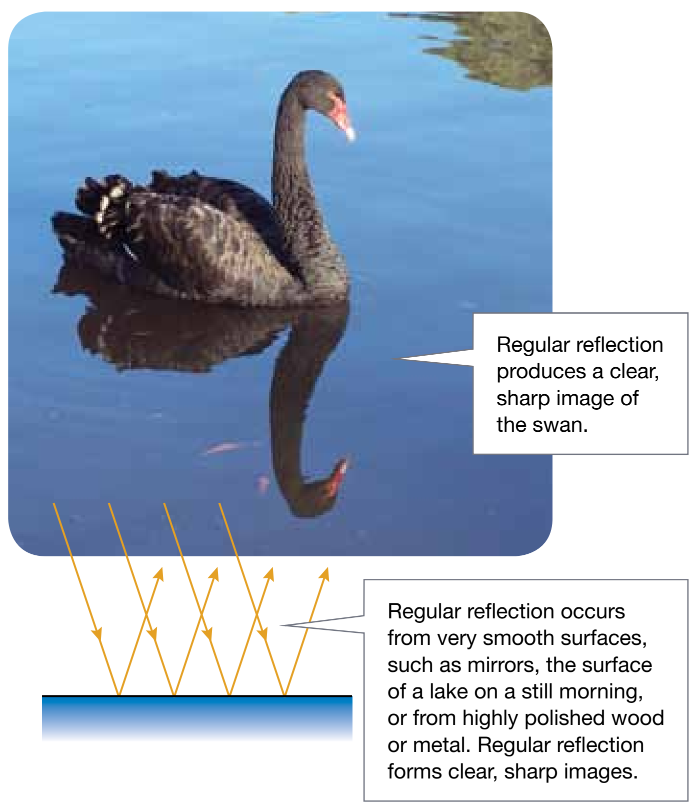



Figure 4.3.5 Regular reflection occurs from very smooth surfaces and forms clear, sharp images.

The surfaces of most objects are quite rough when viewed up close. These surfaces reflect light in many directions, and do not form an image. This is called **diffuse reflection** and is shown in Figure 4.3.6.

Figure 4.3.6 Many surfaces appear smooth but are rough compared with the surface of a mirror. Diffuse reflection occurs from these rough surfaces and no clear image is formed.

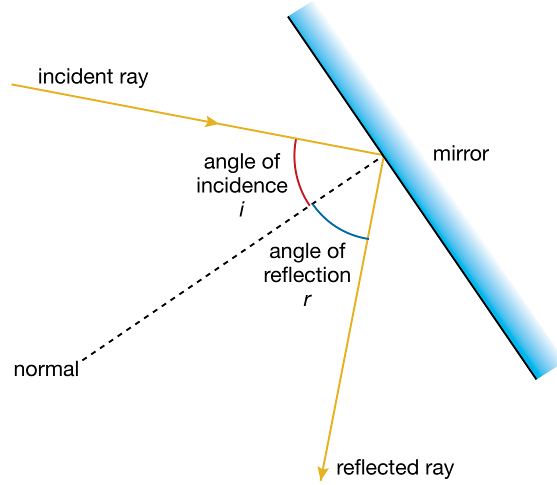



Figure 4.3.7 The Law of Reflection states that the angle of incidence of a light ray is equal to the angle of reflection.

## The Law of Reflection

If a billiard ball is hit at right angles to the cushion of the table, the ball bounces straight back along the same path. If the ball is hit at an angle to the cushion, it will bounce off the cushion at the same angle. Figure 4.3.7 shows an incoming ray, known as an **incident ray**, being reflected off a mirror in the same way that the billiard ball bounces off a cushion. This is called the **Law of Reflection**.

A dotted imaginary line, called the **normal**, is shown in Figure 4.3.7 at right angles to the surface of the mirror. This is used to measure the **angle of incidence** (shown as *i*) and the **angle of reflection** (*r*).

According to the Law of Reflection:

$$\text{angle of incidence} = \text{angle of reflection}$$

$$i = r$$

### SciFile

**Mirror on the Moon**

In 1969, Neil Armstrong and Buzz Aldrin left a device called a corner reflector on the Moon. Researchers have used the reflection of laser light from this device to accurately measure the distance from the Earth to the Moon, and have discovered that this distance increases by 4 cm each year.

p132

### INQUIRY science 4 fun

## Image finder

How far behind a mirror is an image located?

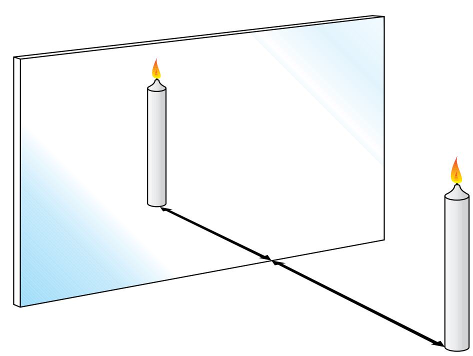
**Collect this ...**

- 2 birthday candles
- 2 dobs of Blu Tack
- sheet of glass
- sheet of paper

Yes

**Do this ...**

1. Draw a line down the middle of a sheet of paper.
2. Hold the glass so that it stands along this line.
3. Position a lit birthday candle with Blu Tack in front of the glass, as shown in the diagram.



4. Carefully look into the glass at the image formed.
5. Move an unlit candle behind the glass so that the image of the flame rests on its wick.
6. Measure the distance from each candle to the glass.

**Record this ...**

**Describe** what happened.

**Explain** why you think this happened.

# Plane mirrors

A flat mirror is also called a **plane mirror**. When you stand in front of a mirror in a fitting room when trying on clothes, your image is the same size as you. It is the same distance behind the mirror as the distance you are standing in front of it. Your image is identical to you in every way except that it is reversed sideways: your right side appears in the mirror as your left, and vice versa, as the example in Figure 4.3.8 shows. This reversal is called **lateral inversion**.

Figure 4.3.8 Although this boy is brushing his teeth with his right hand, his image appears to hold the toothbrush in the left hand. The image is laterally inverted.

## Forming an image

When a plane mirror produces an image of an object, such as a candle, it looks as though this object is really positioned inside or behind the mirror. Figure 4.3.9 shows why this happens. Light that has reflected from the candle reaches your eyes. Your brain is used to light travelling in straight lines, so it extends this light back inside the mirror to where it appears to have come from. As a result,

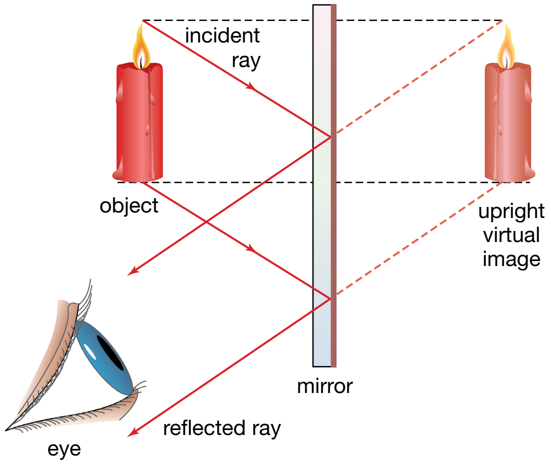



Figure 4.3.9 A plane mirror produces a virtual, upright image that is the same size as the object but reversed sideways (laterally inverted).

the candle appears to be inside the mirror. This is called a **virtual image**, because the rays of light do not really meet to produce this image.

An image seen in a plane mirror:

- is upright (normal way up)
- is the same size as the object
- is laterally inverted (reversed sideways)
- is virtual
- appears to be located as far inside the mirror as the object is in front.

4.5

# Refraction

The straw resting in the glass shown in Figure 4.3.10 appears to be bent. The straw is not bent at all. It appears this way because light was bent as it travelled out from the water in the glass to the air. This bending of light is called **refraction**.

Figure 4.3.10 This straw appears disjointed at the surface of the water in the glass and the square grid pattern on the table below it appears curved, when viewed through the water in the glass.

Light refracts when it travels from one transparent substance into another. Figure 4.3.11 shows light bending towards the normal as it enters a glass block, and bending away from the normal when it exits it.

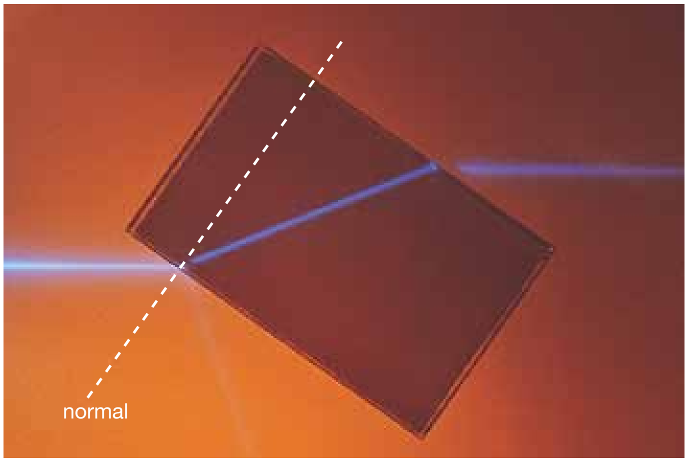



Figure 4.3.11 Light bends towards the normal when it enters this glass block and bends away from the normal when leaving. Some light is also reflected from the edges of the glass.

## Why does refraction occur?

Light travels at different speeds through different substances. The differences in its speed result in different amounts of bending, or refraction, as light passes from one substance into another. The **refractive index** is a measure of how easily light travels through a substance. Light entering the glass block from air slows down and bends towards the normal. A car that hits a flooded section of road behaves in a similar way. The first wheel entering the water slows down while the other continues at the same speed, causing the car to slow down on one side and swerve inwards, towards the normal. This is what is happening in Figure 4.3.12. As light leaves a glass block, it speeds up and bends away from the normal.

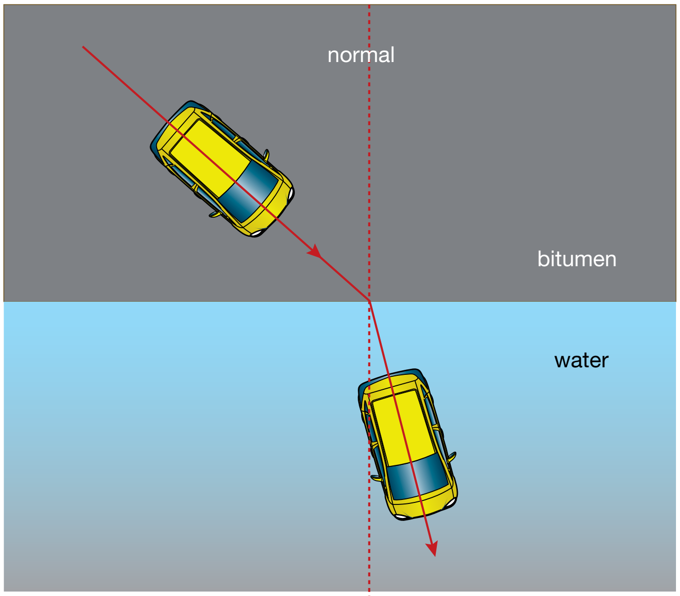



Figure 4.3.12 A car that enters a pool of water on a road will slow down and its path will bend towards a normal line.

The higher the refractive index of a substance, the more light bends when it enters the substance from air. Light travels more slowly in glass, water, diamond and Perspex than it travels through air. Table 4.3.2 shows the speed of light in a few common substances, and the refractive index of each.

**Table 4.3.2 Speeds of light in different media**

| Medium | Speed of light (km/s) | Refractive index |
|---|---|---|
| Air | 300 000 | 1.00 |
| Ice | 231 000 | 1.31 |
| Water | 226 000 | 1.33 |
| Perspex | 200 000 | 1.49 |
| Glass | 197 000 | 1.52 |
| Diamond | 124 000 | 2.42 |

The angle an incoming ray of light makes with the normal is called the angle of incidence, $i$. The angle that the refracted ray makes with the normal is called the **angle of refraction**, $r$. Figure 4.3.13 shows that light bends towards the normal when entering a substance of higher refractive index, and bends away from the normal when entering a substance of lower refractive index. Light that hits another substance head on is not bent, but continues straight through.

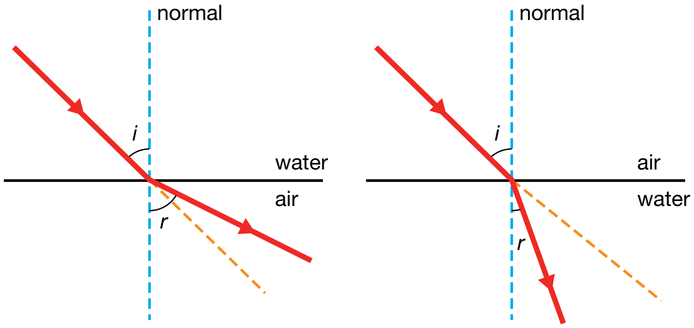



Figure 4.3.13 Light bends away from the normal when entering a substance of lower refractive index. It bends towards the normal when entering a substance of higher refractive index.

**SciFile**

### Forensic refraction

Investigators can link pieces of broken glass to a window pane smashed at a crime scene if the refractive indices of both samples of glass match. Fragments of glass from car headlights left at a hit-and-run accident can be used to identify the model of the car they came from, and eventually its driver.

INQUIRY science 4 fun

## The reappearing coin

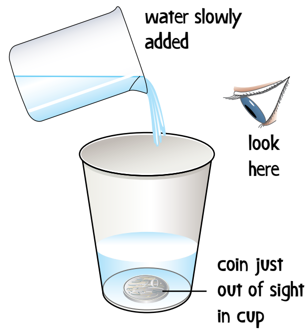
Can you make a coin appear before your eyes?

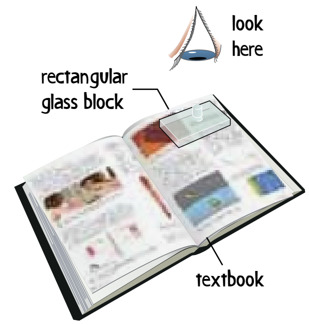
### Collect this ...

- coin
- opaque cup (one that is not see-through) or an evaporating basin
- pencil or pen
- 100 mL beaker of water
- rectangular glass block

### Do this ...

1. Put the coin in the cup.
2. Move back until the coin is just out of sight.
3. Have your partner pour water into the cup from the beaker.
4. Can you see the coin again?
5. Now place a rectangular glass block on top of this page of your textbook.
6. Study the print through the block and compare this to when the block is removed.




### Record this ...

**Describe** what happened when you viewed the coin and when you looked through the glass block.

**Explain** why you think these things happened, using diagrams to assist your response.

## Depth illusions

When someone is standing in a swimming pool, their legs look shorter than normal. Similarly, rocks on the bottom of a stream always look like they are in shallower water than they actually are. These depth illusions, like that seen in Figure 4.3.14, occur because light from an object under water is bent away from the normal when it leaves the water surface into air. When you look at this refracted light, your brain traces the light reaching your eyes back in a straight-line path. This makes the object appear to be positioned closer to the surface.

4.6

### Underwater vision

SciFile

When you are under water looking at objects without goggles or a mask, they appear blurry. Light reaching the corneas of your eyes from water doesn't bend as much as it would if it had come from air. As a result, you can't focus properly. If you wear goggles or a mask, light enters your eyes from air rather than from water. This makes everything clearer!

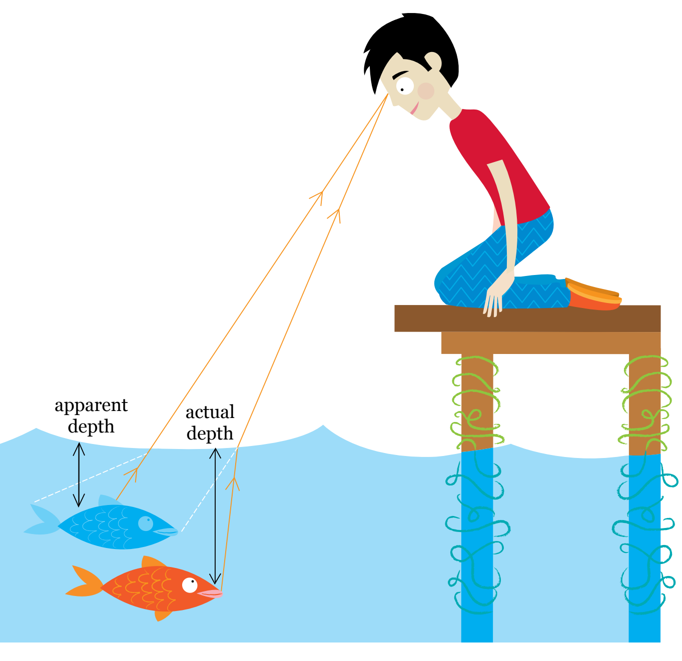



**Figure 4.3.14** Light from the fish bends away from the normal when it enters the air. Its apparent depth, or the depth it appears to be, is less than its true depth in the water. For this reason, hunters using spears to catch fish learn to aim the spear slightly below where they see the fish in the water.

# Total internal reflection

When light enters a substance of lower refractive index, such as from glass into air, it is refracted away from the normal. Figure 4.3.15 shows what happens to this ray as the angle of incidence increases. At an angle of incidence called the **critical angle**, light is refracted so far from the normal that it runs along the boundary of the two substances. For any angles of incidence greater than this, there is no refracted ray. Light is reflected from the boundary as though it was a mirror. This is called **total internal reflection**. Total internal reflection of light explains some effects of light, such as the imaginary shark seen in Figure 4.3.16. It is also the reason diamonds sparkle (see Figure 4.3.17).

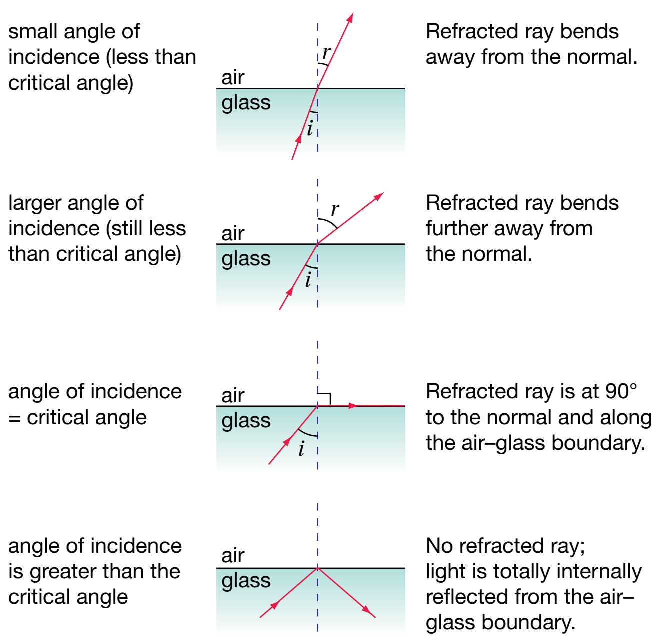



**Figure 4.3.15** What light does at the air–glass boundary depends on its angle of incidence.

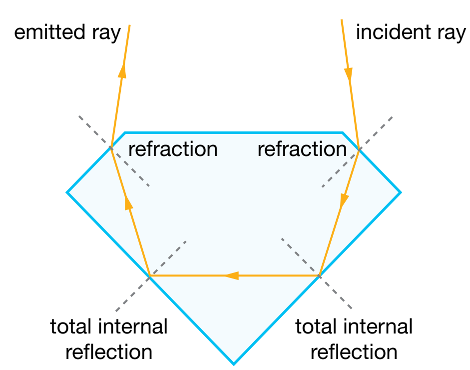

**Figure 4.3.16** Light from this shark has been totally internally reflected to produce the illusion of a shark swimming upside down above the real one.

4.7

2 p133

**Figure 4.3.17**

Diamond has a high refractive index and a low critical angle for a diamond–air boundary, of about 23°. Jewellers cut the facets of a diamond so that most light falling on the diamond will strike the back of the diamond at an angle larger than the critical angle. This means the light is reflected twice within the diamond before it emerges, making it look more brilliant.



# 4.3 Unit review

## Remembering

1 a **State** which letter in Figure 4.3.18 represents the:
   i incident ray
   ii reflected ray
   iii normal
   iv angle of incidence
   v angle of reflection.
  b **Name** the law that is demonstrated in Figure 4.3.18.

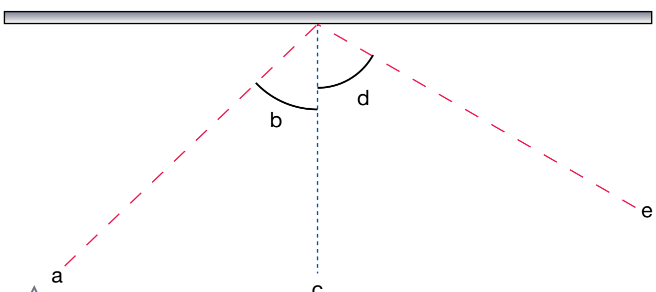



Figure 4.3.18

2 **List** five properties of an image formed by a plane mirror.

3 **State** which of the following alternatives makes each sentence true.
  a Light is refracted *away from/towards* the normal when it passes from glass into air.
  b Light travels at a higher speed through *glass/air*.
  c Total internal reflection can only occur when light passes into a substance of *lower/higher* refractive index.

## Understanding

4 **Define** the term *lateral inversion*.

5 a If you looked into the mirror shown in Figure 4.3.9 on page 126, **explain** why the image of the candle would appear to be inside the mirror.
  b **Explain** why light rays cannot originate from inside the mirror.
  c **State** the name of this type of image.

6 **Explain** why the boy shown in Figure 4.3.14 on page 128 thinks the fish is closer to the surface than it really is.

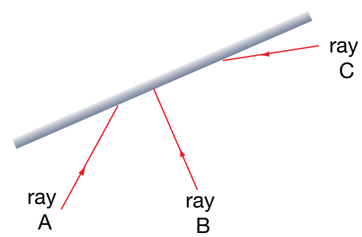
7 a **Explain** why everything looks blurry if you open your eyes under water.
  b **Describe** what you can do to make your underwater vision clear.

## Applying

8 **Identify** whether the following objects are luminous or non-luminous.
  a the star Betelgeuse
  b traffic lights
  c the planet Venus
  d fireworks
  e a glow worm
  f a bicycle reflector
  g lightning

9 Figure 4.3.19 shows three rays of light hitting a mirror. **Use** this diagram to carry out the following tasks.
  a Copy the diagram and use a ruler to draw a normal at 90° to the mirror for each of rays A, B and C.
  b Extend where each ray will be reflected in front of the mirror.
  c **Use** a protractor to **determine** which ray has the largest angle of reflection.

Figure 4.3.19




10 **Identify** in each of the following situations whether light will bend towards or away from the normal. Light travels from:
  a water to glass
  b diamond to air
  c water to Perspex
  d water to ice
  e glass to diamond
  f air to Perspex.

## Analysing

11 **Classify** the following objects as transparent, translucent or opaque.
  a a basketball
  b air
  c a pair of sheer stockings
  d shallow water
  e a piece of lightweight cotton fabric

12 **Use** a Venn diagram to **compare** light waves and sound waves.

13 a **Compare** the speeds of light in air, ice, water, glass, Perspex and diamond listed in Table 4.3.2 on page 127 with their refractive indices.
  b **Describe** how you think the refractive index of a substance affects the speed at which light travels through it.

## Evaluating

**14** **Propose** why total internal reflection never occurs when light travels into a substance of greater refractive index.

**15** If a sample of glass was found at the scene of a burglary, **propose** how this could be used as evidence in a criminal investigation.

## Creating

**16** **a** **Explain** why AMBULANCE is often painted onto the front of an ambulance with its letters laterally inverted.

**b** **Construct** a sign that says AMBULANCE, but laterally inverted.

**c** **Create** a list of ten words, written in capital letters, as they would appear in a plane mirror.

**17** Copy each diagram in Figure 4.3.20 and draw the normal to the point where light meets each boundary. **Construct** a ray on each diagram to show the likely path of each ray through each material.

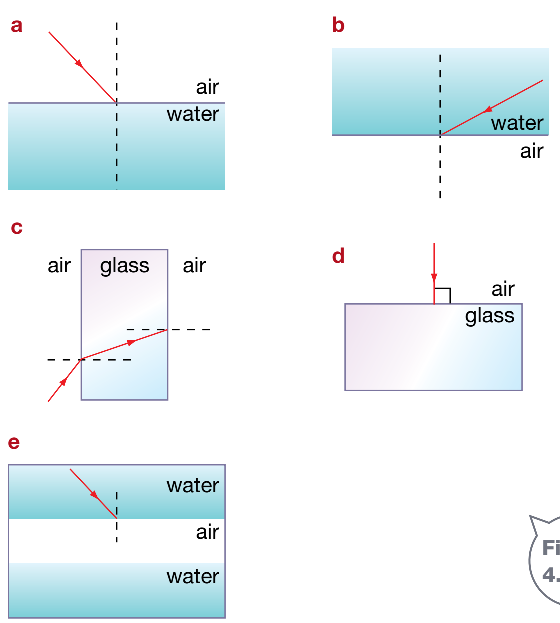



Figure 4.3.20

**18** The critical angle of light passing from water into air is 48.6°. **Construct** a diagram to demonstrate how light bends when travelling from water into air at an angle of:

**a** 60°

**b** 48.6°

**c** 25°.

## Inquiring

**1** Light has a complex structure. For many years, scientists have debated whether it travels as a particle, or as a type of wave, because it has properties of both waves and particles. Construct a timeline to show how ideas about light have changed over time.

**2** Research the phenomenon of bioluminescence, and describe how animals with this unique ability use it.

**3** Research how laser light is produced. Investigate how it is used to read a bar code on a product for purchase. Create a multimedia presentation that explains how this process works.

**4** The effect shown in Figure 4.3.21 is produced by refraction. Set up your own equipment and try to create your own refaction image using a digital camera.

Figure 4.3.21

# 4.3 Practical activities

## 1 Law of reflection

### Purpose
To verify the law of reflection.

### Materials
- light box and power supply
- sheet of white paper
- plane mirror
- ruler
- pencil
- protractor

### Procedure
1 Set up the equipment as shown in Figure 4.3.22, marking the positions of the back of the mirror and the normal line.

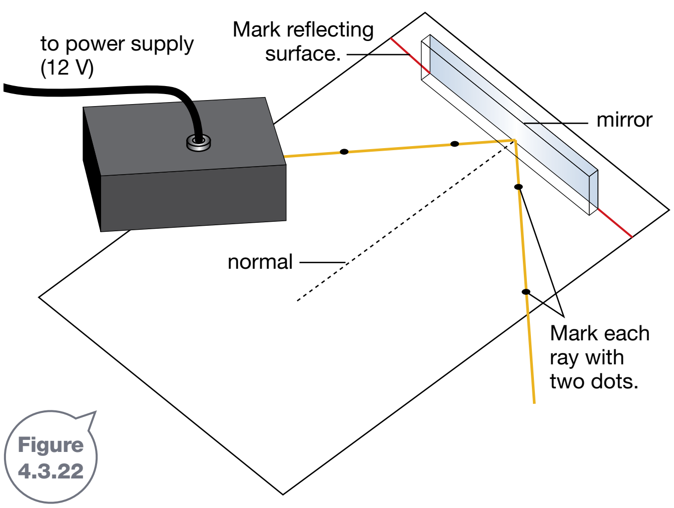



Figure 4.3.22

2 Direct a ray of light on an angle towards the centre of the mirror.

3 Mark the position of the incident and reflected rays using two dots, and then use your ruler to draw these rays on the paper. Label these 'ray 1'.

4 Repeat this process for three more rays of differing angles.

5 Direct a ray at right angles into the mirror and observe its reflection.

### Results
1 Copy the results table below into your workbook.

| Ray | Angle of incident ray | Angle of reflected ray |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |

2 Select a ray from your diagram and measure the angle that its incident ray (incoming ray) makes to the normal. Enter the angle in the table.

3 For the same ray, measure the angle that the reflected ray makes to the normal. Enter this angle in the table.

4 Complete the table for each ray tested.

### Discussion
1 **Assess** whether your results support the Law of Reflection.

2 **Describe** what happened when you directed light at right angles to the mirror.

3 **Explain** whether the Law of Reflection is still obeyed in the case in question 2, in which the angle of the incident ray is zero.

4 **List** at least three examples where you have observed the Law of Reflection in action (e.g. at the cricket when the ball bounces off the pitch).

## 2 Bending light

### Purpose

To observe and measure the refraction of light as it passes through a transparent block.

## Materials

- plastic or glass rectangular block and semicircular block
- light box and single-slit slide
- 12V power supply
- sheet of white paper
- protractor
- ruler
- pencil

### Procedure

1 Set up the equipment as shown in Figure 4.3.23. Trace around the glass block with a pencil and use a protractor to rule a normal at 90° to the surface half way along the edge.

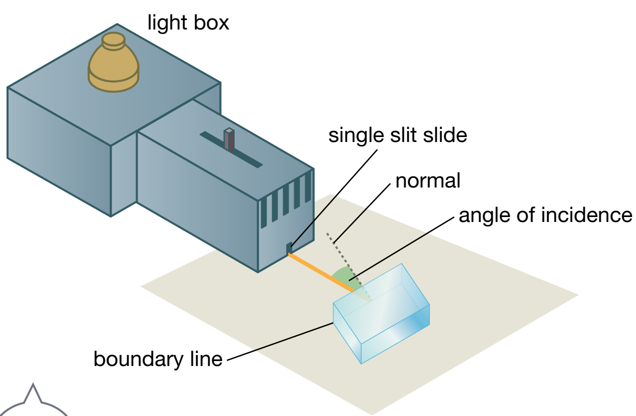



Figure 4.3.23

2 Direct a single ray of light at the centre of the block.

3 Mark a series of dots on the paper to trace the path of light incident on, refracted through and refracted out the other side of the glass block.

4 Remove the glass block and use a ruler to draw the path the light followed on the paper. Add a normal at the point where light left the glass block.

5 Make angle measurements with a protractor to complete a copy of the results table shown below.

6 Replace the rectangular glass block with the semicircular block, with its curved side facing the incoming light.

7 Move the light box in an arc to alter the angle of incidence of light at the centre of the block. Find the critical angle for the semicircular block and investigate what happens for smaller and larger angles of incidence.

### Results

Copy and complete the following table.

| | Angle of incidence | Angle of refraction |
|---|---|---|
| Light entering glass from air | | |
| Light entering air from glass | | |

### Discussion

1 **State** whether light bends towards or away from the normal when it:
  a enters the glass block
  b leaves the glass block.

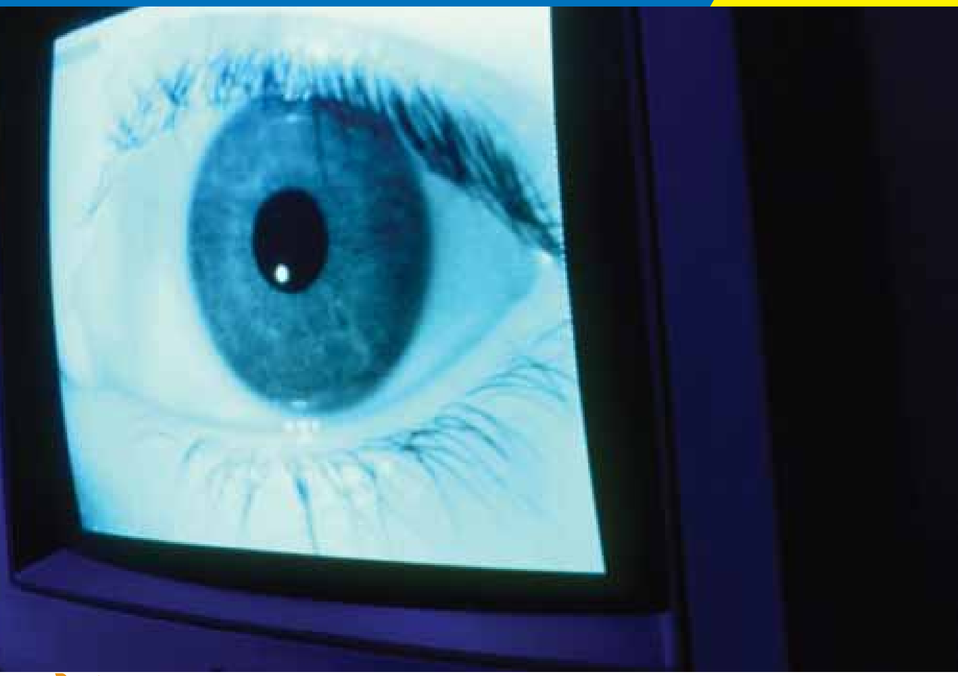
2 **Compare** the size of the angle at which light hit the glass block with the angle at which it leaves.

3 **Describe** whether all the light hitting the glass block was refracted through it, or whether some light followed a different path.

4 **State** the critical angle for the semicircular block.

5 **Describe** what you observed happening with the semicircular block when the angle of incidence was smaller or larger than the critical angle.

# 4.4 Lenses and the eye



The pattern of the iris, or coloured muscle of the eye, is as individual as a fingerprint, and is even more detailed. For a person with vision, the lenses in their eyes focus incoming light rays to a point on the back of their eyeball. The brain uses this information to produce an image. Lenses of glass or plastic are used to make a range of optical instruments such as spectacles, cameras, telescopes, data projectors and binoculars.

INQUIRY science 4 fun

## Forming an image

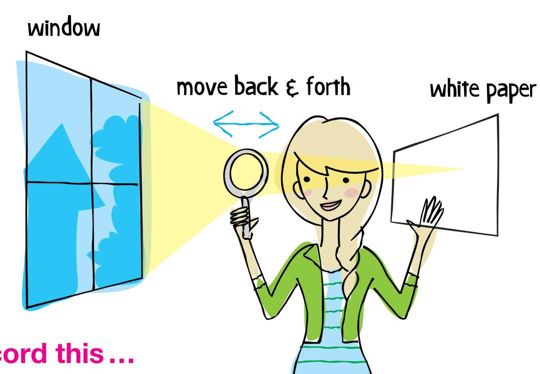
**Collect this ...**

- magnifying glass
- sheet of white paper

Yes

**Do this ...**

1 Hold the magnifying glass in front of a light source, such as sunlight through a window, a candle or a light globe.
2 Hold the sheet of paper as a screen in one hand and the lens in the other.
3 Try to focus an image on the sheet of paper by moving the lens back and forth.




**Record this ...**

**Describe** what happened.

**Explain** why you think this happened, using a diagram to assist your response.

## Convex lenses

A lens is a transparent piece of plastic or glass that is shaped to curve outwards or inwards. A lens refracts light and is used in many optical devices and in spectacles to form an image. A lens that bulges outwards is called a **convex lens**. These lenses, such as the one shown in Figure 4.4.1, cause light rays to come together, or converge. If a convex lens is held close to an object, it can be used as a magnifying glass. In this case, it produces an upright and enlarged virtual image.


Figure 4.4.1

Lenses refract light to produce different types of images. A magnifying glass is a convex lens.

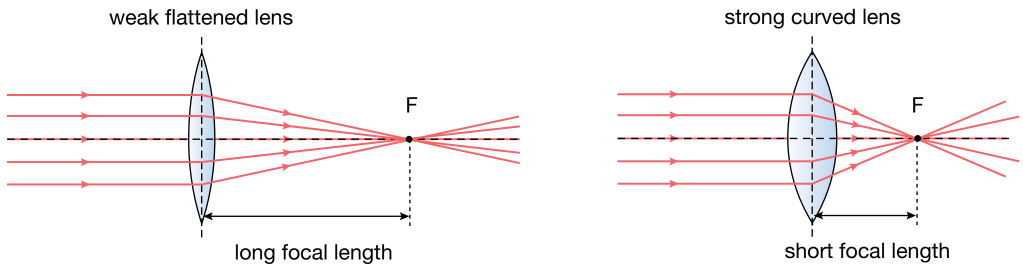



**Figure 4.4.2** Parallel rays of light are brought together at a point called the focus (F) on the other side of a convex lens. The greater the curve of the lens, the stronger the lens is and the shorter its **focal length**, or distance between the lens and the focus.

If light reaches a convex lens from a distance, the convex lens can be used to focus the light on a screen to form an image. Figure 4.4.2 shows two convex lenses of different strengths focusing light to a point called the focus of the lens (F). Light is focused to a point on a screen when you see a film at the movies. This is the type of image that is formed by the convex lenses in your eyes. This type of image is called a **real image**.

SKILL BUILDER

## Ray tracing using convex lenses

The position and nature of an image produced by a lens can be determined by drawing a ray diagram.

For images produced using a convex lens, two rays are drawn:

- *Ray 1:* Light travelling parallel to the principal axis is refracted through the principal focus of the lens. The object is shown as 'O' and focal points by a dot, as shown in Figure 4.4.3.

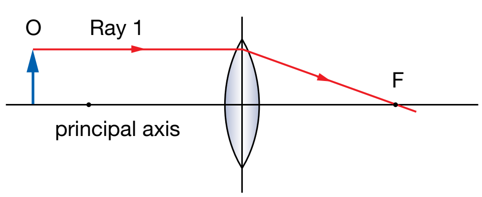



**Figure 4.4.3**

- *Ray 2:* Light travelling from the tip of the object passes straight through the centre of the lens, as shown in Figure 4.4.4.

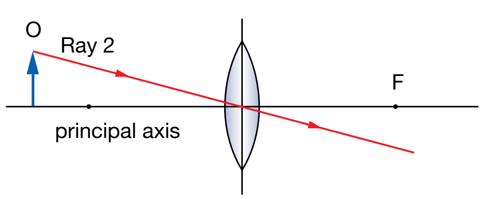



**Figure 4.4.4**

Objects placed outside the **focal length** of a convex lens always produce a real, inverted image. An example is shown in Figure 4.4.5.

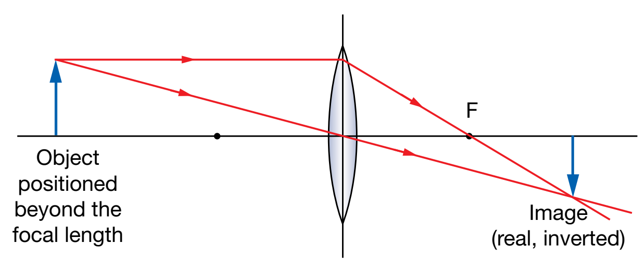



**Figure 4.4.5**

Objects positioned within the focal length of the lens always produce a virtual, upright image. In this case, to find the image we trace rays 1 and 2 back to where they appear to have come from, as shown in Figure 4.4.6.

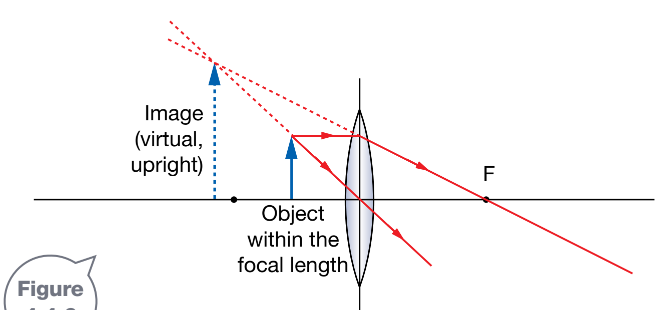



**Figure 4.4.6**

## WORKED EXAMPLE
### Images from convex lenses

Use ray tracing to identify the location and nature of the image produced by the convex lens in each situation shown below.

#### Problem 1

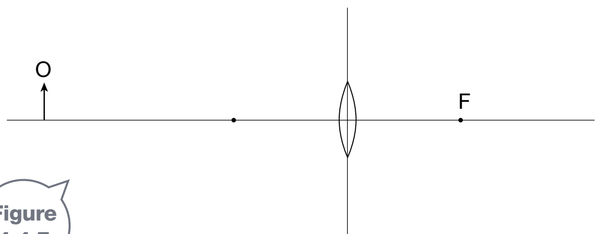



Figure 4.4.7

#### Solution 1

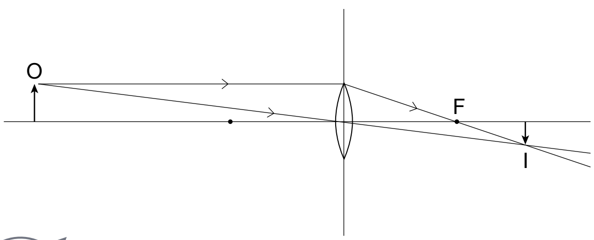



Figure 4.4.8 Image is real, inverted and smaller (diminished).

#### Problem 2

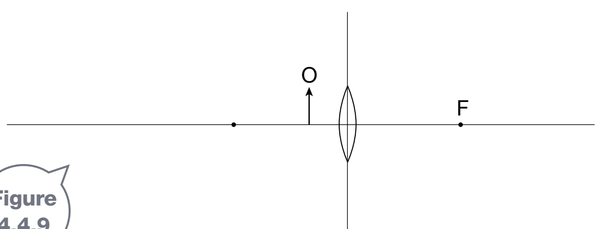



Figure 4.4.9

#### Solution 2

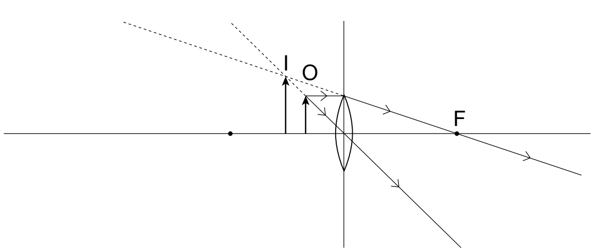



Figure 4.4.10 Image is virtual, upright and enlarged.

## Concave lenses

A lens that curves inwards is called a **concave lens**. These lenses cause light to diverge, or spread out. They spread parallel light rays as though the rays have come from a point behind the lens, as shown in Figure 4.4.11. A concave lens only produces images that are smaller, upright and virtual.

p142

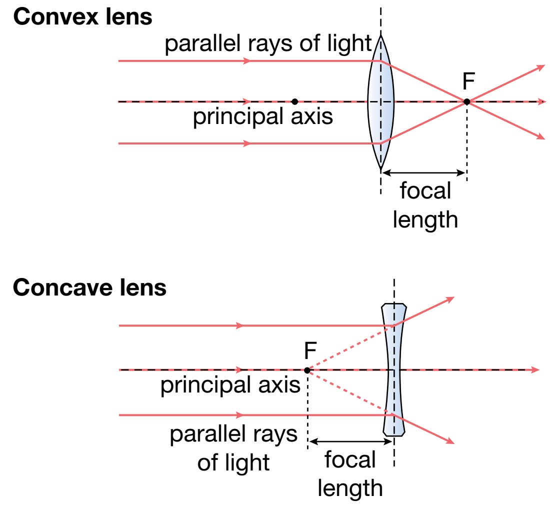



Figure 4.4.11 A concave lens causes light to diverge. To measure the focal length of a concave lens, you must trace the path of the rays leaving the lens to the single point where they appear to have come from. This point is the focus (F) of the lens.

# The eye

The most incredible optical instrument we have is our eyes. Figure 4.4.12 shows the structure of the human eye. Light that enters the eye is refracted by the **cornea** and focused by the **lens**, which is convex. Figure 4.4.13 shows how incoming light is focused to form a clear, upside-down image on the **retina**, at the back of the eye. This image is converted into a series of electrical signals, which then travel along the **optic nerve** to the brain. The brain interprets this information as an image.

**SciFile**

**Turning the world upside down**

Experiments have been conducted in which people have worn lenses that flip the world upside down. After about a week of bumping into the furniture, they reported that their brain adjusted its view and perceived this view as the right way up. When the glasses were then taken off, everything was upside down again for a while!

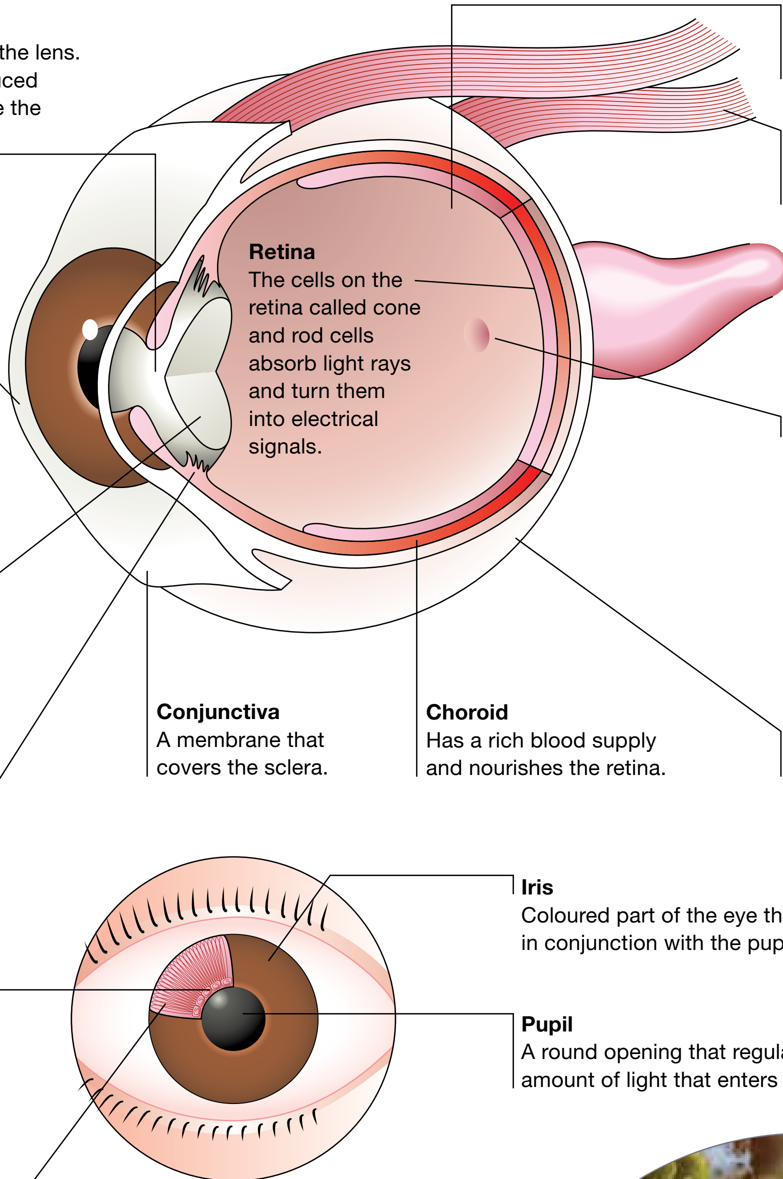
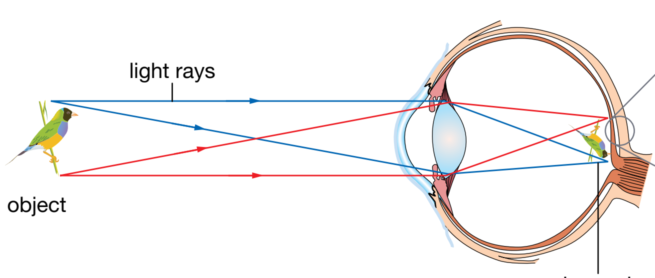



**Figure 4.4.12** These structures of the eye work together to provide vision.



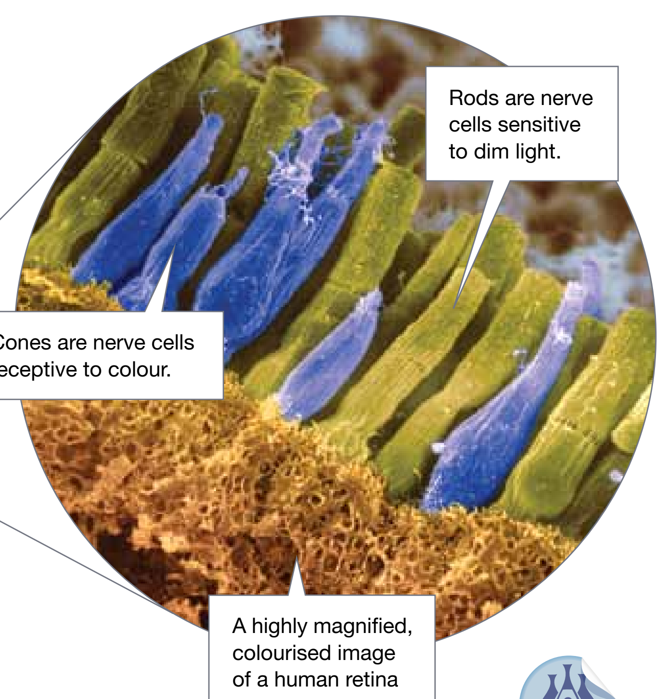




**Figure 4.4.13** The brain interprets the upside-down image formed on the retina as an upright image.

2 p142

## Vision problems

The lenses in your eyes focus on objects at different distances by changing focal length. When the muscles attached to the lens contract, the lens stretches, becoming quite flat, and able to focus on distant objects. When these muscles relax, the lens gets much fatter and bends light more, allowing close objects to become focused. This is shown in Figure 4.4.14. The ability of the lens to change shape is called **accommodation**. Unfortunately, as we age, the lenses harden, making accommodation more difficult.

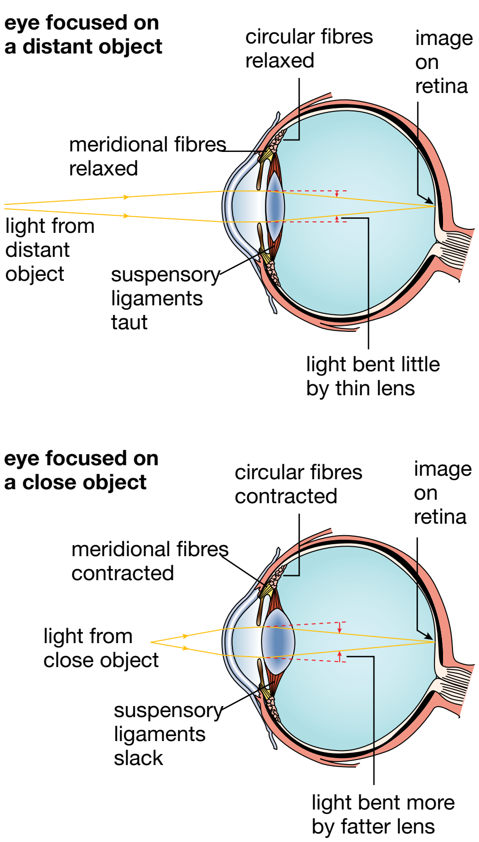



Figure 4.4.14 A 40-year-old has just one-quarter of the accommodating ability they had when younger. By age 45 almost everyone needs some form of glasses.

If light is not focused to a point at the retina, then a person will not see a clear image. This commonly leads to **short-sightedness (myopia)** or **long-sightedness (hyperopia)**.

People who are short-sighted can focus on close objects, such as a book, but distant objects, such as children in a playground, are not clear. Figure 4.4.15 shows how a concave lens is used to correct short-sightedness.

A person who is long-sighted can see distant objects clearly, but has trouble focusing on close objects. They need to use glasses when reading or doing close work. Figure 4.4.16 shows how a convex lens is used to correct long-sightedness.

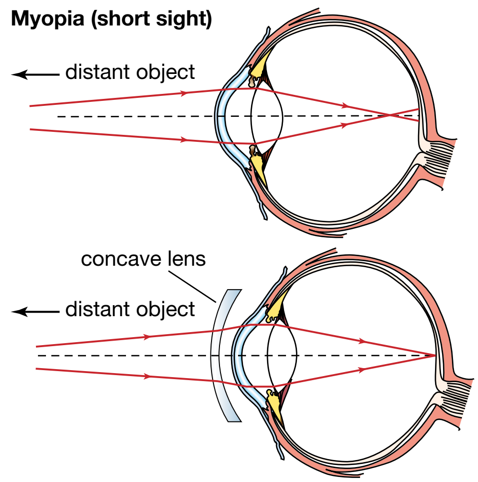



Figure 4.4.15 The eyeball is too long in a person who is short-sighted. A concave lens of appropriate strength can correct this problem.

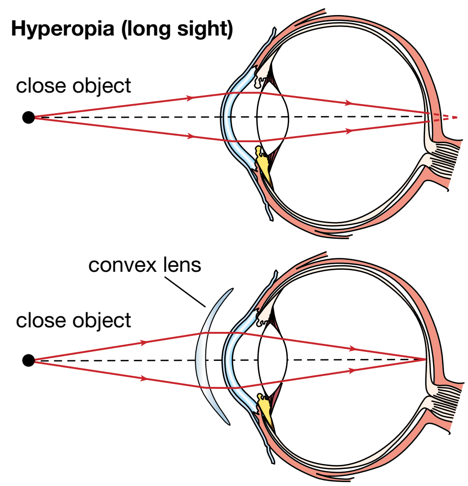



Figure 4.4.16 This person is long-sighted because their eyeball is slightly too short. A convex lens can correct this problem.

Bifocals or graded lenses may be used if a person has more than one type of vision problem. These lenses are strongest at the bottom, so a person looks down through this region to read, and looks straight through the lenses to focus on objects further away.

Some people wear contact lenses rather than glasses. These small lenses are worn directly on the cornea of the eye and are made from hard plastic, or from water-absorbing materials. Because contact lenses are in continual contact with the surface of the eye, they must be kept very clean and sterilised regularly. Another treatment for vision problems, rather than wearing glasses, is to undergo laser surgery. Such treatment reshapes the surface of a patient's cornea to alter how it focuses light.

4.8

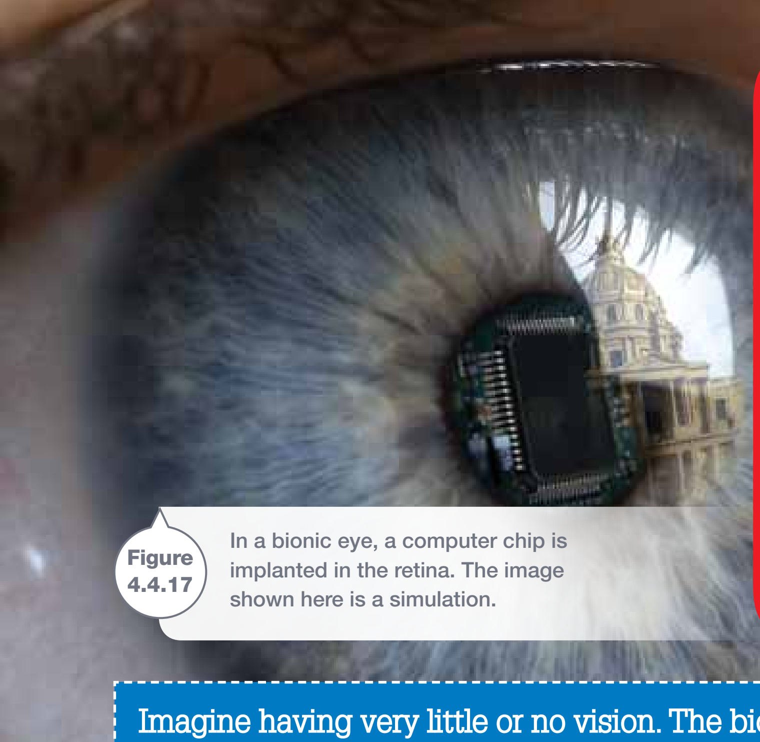


Figure 4.4.17 In a bionic eye, a computer chip is implanted in the retina. The image shown here is a simulation.

# SCIENCE AS A HUMAN ENDEAVOUR

## Use and influence of science

### The bionic eye

**Imagine having very little or no vision. The bionic eye is new technology under development that can improve vision.**

Bionic Vision Australia is developing prototypes of a bionic eye. Such a device can change the lives of people who have gone blind from eye diseases such as macular degeneration or retinitis pigmentosa. Macular degeneration is the leading form of blindness in the industrialised world. These diseases affect how the rods and cones of the retina detect light patterns. In a bionic eye, a chip containing an array of electrodes is implanted in the retina to mimic the function of the damaged cells.

The bionic eye system has a number of parts, as shown in Figure 4.4.18. Figure 4.4.19 shows the type of vision provided by early prototypes of the bionic eye. This vision is a series of light and dark regions. At the moment, patients take some time to learn how to interpret this pattern of light as vision. However, even this low-resolution image can give the person an awareness of their surroundings, and help them in moving around. The key challenge for researchers in this field is to fit more electrodes onto the chip implanted on the patient's retina. As the number of electrodes increases, enormous leaps in quality of vision will be possible.

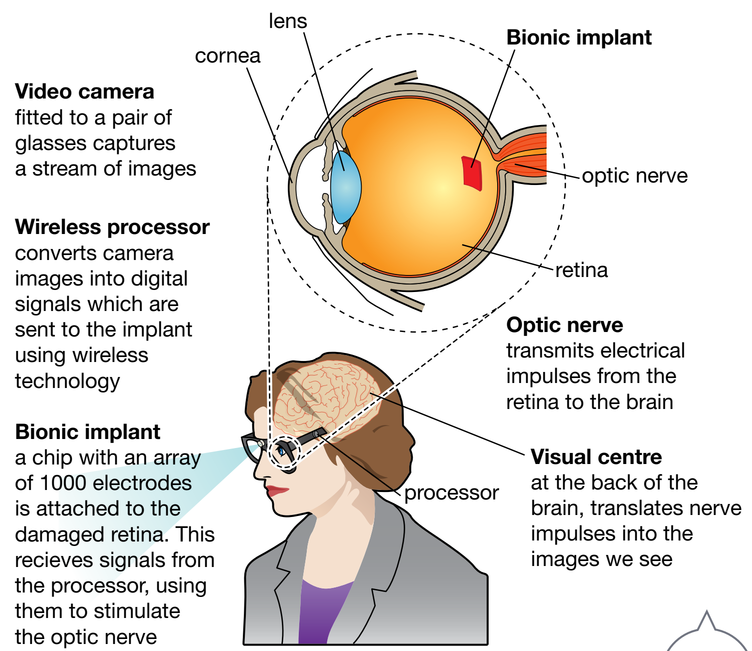



Figure 4.4.18 How a bionic eye works

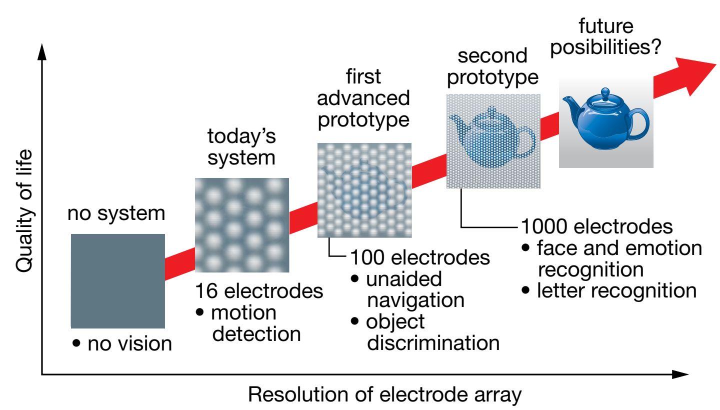



Figure 4.4.19 Prototypes of the bionic eye, and the vision they provide.

# 4.4 Unit review

## Remembering

1 **Recall** the language of lenses by matching the correct word from the list below to each of the statements that follow. (Note: Some words can be used more than once.)

focus real virtual convex concave

a In using a lens, this is the point at which distant light rays meet, or appear to meet.

b This type of image cannot be produced on a screen or a sheet of paper.

c This type of lens always produces upright, diminished, virtual images.

d A convex lens produces this type of image from a distant object.

2 **State** which of the two alternatives makes each of these statements true.

a Light entering the eye is refracted by the lens and the *cornea/retina*.

b To produce a clear image, light must be focused on the *retina/lens*.

c The image travels as a series of *light/electrical* signals along the optic nerve to the brain.

d The aqueous humour is a clear fluid that lies between the cornea and the *retina/lens*.

## Understanding

3 The following table lists the typical focal lengths for different optical devices.

| Object | Focal length (m) |
|---|---|
| Spectacles | 1 |
| Camera lens | 0.05 |
| Microscope objective lens | 0.004 |

a **State** which object uses the lens with the shortest focal length.

b **Explain** the reason that this device would require the shortest focal length.

4 Is the image formed on your retina real or virtual? **Explain** your answer.

5 **Describe** what happens to the pupils of your eyes when you are:

a in a dark cinema

b outside playing in the sun.

6 Tran is short-sighted and forgets to bring his glasses to the cinema. **Predict** whether you think he would prefer to sit near the front or the back to watch the movie.

7 **Explain** how a pair of bifocal glasses works.

8 **Describe** what happens when a person undergoes laser eye surgery.

## Evaluating

9 At a 30-year high school reunion, 29 of a class of 34 are wearing glasses. **Propose** an explanation for this, given that only five of the class wore glasses at school.

10 Su-Lin asks Joe to pass her a convex lens of focal length 25 cm from a box containing many different strength lenses. **Propose** how Joe could work out which was the lens Su-Lin wants.

11 a **State** the two major eye diseases that may be treated using the bionic eye.

b **Construct** a flowchart that explains how each component of the bionic eye functions.

c **Describe** the biggest challenge facing bionic eye researchers.

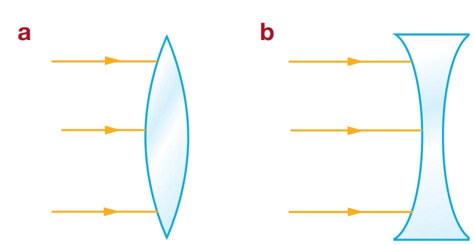
d **Propose** how having a bionic eye affects the lives of patients today.

e **Predict** the effect that this device will have when the resolution is even more detailed.

## Creating

12 Copy the lenses shown in Figure 4.4.20 and **construct** the path the light rays will take as they pass through each lens.

Figure 4.4.20



13 a Copy the diagrams in Figure 4.4.21. **Construct** a ray tracing diagram in each case.

b **Use** your diagrams to **describe** the type of image that will be formed using these convex lenses.

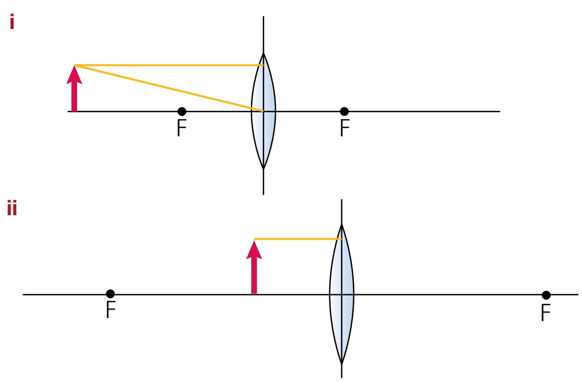



Figure 4.4.21

14 **Construct** a diagram to show the difference in the appearance of the lens in Vishwar's eyes as he looks down to read a TV guide and then looks up to watch TV.

15 **Construct** a flowchart that lists the structures and fluids light travels through on its journey from entering your eye until it reaches your retina.

## Inquiring

1 Combinations of different types of lenses are used in a range of optical instruments, such as binoculars (like the ones shown in Figure 4.4.22), data projectors, cameras, telescopes and microscopes. Research one of these instruments and then construct a labelled diagram that explains how it operates.

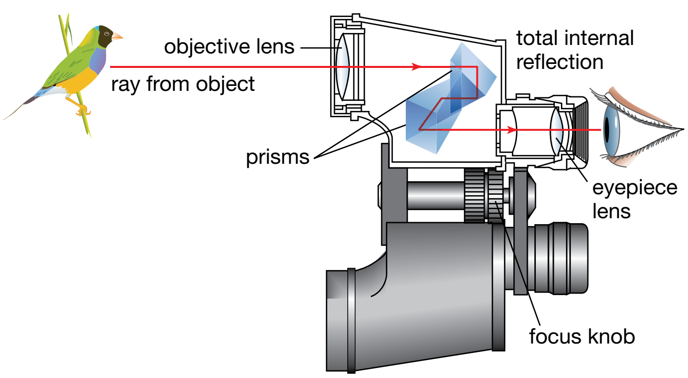



Figure 4.4.22

2 Create a booklet, poster or multimedia presentation to explain key stages in the development of photography, from the camera obscura through to digital cameras used today.

3 Explore the Bionic Vision Australia website to summarise the current progress in development of the bionic eye.

4 Find a news report on a patient who has received a bionic eye implant. Summarise how this technology has benefited them, and describe any aspects that they may have found difficult.

5 Search the internet for instructions on how to make a simple pinhole camera. Construct your camera and investigate how to get the best possible images.

# 4.4 Practical activities

## 1 Comparing curved mirrors and lenses

Mirrors can be curved and can produce real and virtual images in a similar way to a lens. A concave mirror curves inwards like a cave, whereas a convex mirror bulges outwards. A concave mirror can be used to produce a real image. Concave mirrors are used in astronomical telescopes.

### Purpose

To investigate how light is reflected and refracted from curved mirrors and lenses.

### Materials

- light box with 12V power supply
- multiple-slit slide
- set of curved mirrors and lenses of differing strengths
- pencil
- several sheets of white paper

### Procedure

1. Place a multiple-slit slide in the light box and position it on a sheet of white paper.
2. Place a concave mirror in the path of the light rays as shown in Figure 4.4.23.
3. Use a pencil to mark two dots for each incident and reflected ray on the sheet of paper.

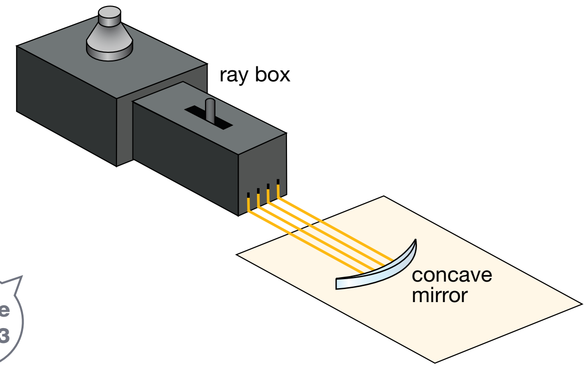



Figure 4.4.23

4. Remove the mirror and trace these rays onto the page, also showing the position of the mirror.
5. Repeat the procedure for a concave mirror of differing curvature, two convex mirrors, two concave lenses and two convex lenses, all of differing thickness. Use a new sheet of paper for each sketch.

### Discussion

1. **Describe** differences between how the concave and convex mirrors reflected light.
2. **Describe** the effect of using a more curved mirror.
3. **Compare** the way light passed through the convex and concave lenses.
4. **Describe** the effect of using a thicker convex lens compared to a thinner lens.

## 2 Finding your blind spot

There are no light-sensitive cells at the point on your retina where it joins the optic nerve. You are blind in this spot.

### Purpose

To identify your blind spot.

### Materials

your textbook

### Procedure

1. Hold this page of your textbook at arm's length.
2. Close your left eye and stare at the cross in Figure 4.4.24 with your right eye.
3. Move the book closer to your face, while still looking at the cross. Be aware of the dot while you do this.

Finding your blind spot

Figure 4.4.24

### Discussion

1. **Propose** why you don't normally notice your blind spots.
2. **Explain** what happened when the dot disappeared.
3. If you look at the dot to check that is still there while doing this test, it won't work. **Propose** why this is the case.

# Chapter review 4

## Remembering

**1** **List** the three processes of heat transfer.

**2** **Name** the only process that can transfer heat through the vacuum of space.

**3** **State** whether sound travels fastest in a solid, a liquid or a gas.

**4** **List** the parts that make up the middle ear.

**5** A beam of light hits a plane mirror at an angle of 45°. **State** the angle at which it is reflected.

## Understanding

**6** **Explain** how a sea breeze forms.

**7** **Describe** what is likely to happen to infrared radiation that hits:

- **a** a black plastic pot plant
- **b** a white shade sail over a sandpit
- **c** a glass window on a boat.

**8** Kim toasts marshmallows on an open fire. Although she can't see any flames, she can still feel heat from the fireplace. **Explain** why.

**9** **Describe** how the pitch of a violin string can be changed.

**10** **Predict** the sizes of angles *x*, *y* and *z* in Figure 4.5.1.

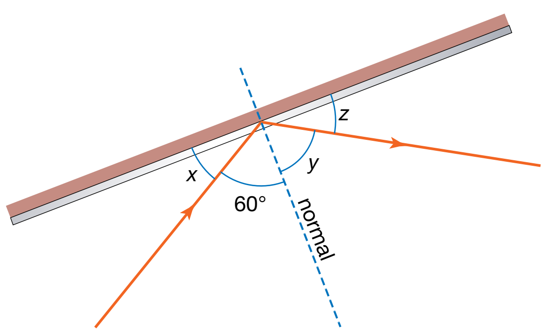



Figure 4.5.1

**11** **Explain** whether an image projected from a data projector onto a wall is real or virtual.

## Applying

**12** **Identify** what vibrates in each musical instrument below to produce a sound.

**a** a harp **b** a trumpet **c** a bongo drum

**13** A periscope is used in a submarine to allow sailors to see what is above the surface of the water. Copy Figure 4.5.2 and complete the path of a ray of light to **demonstrate** how this works.

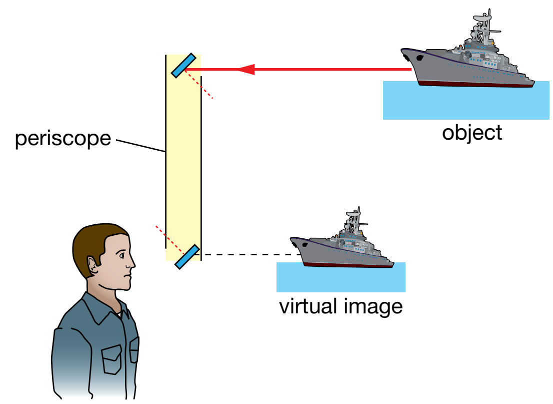



Figure 4.5.2

**14** Perspex has a greater refractive index than that of ice.

- **a** **Identify** in which material light travels faster.
- **b** If light travels from ice into Perspex, **state** whether it will bend towards or away from the normal.

**15** A light ray travels through material X and hits the boundary of the transparent material Y at an angle of 40° to the surface. It is then refracted into material Y at an angle of 35°. **Identify** whether X or Y has the greater refractive index.

## Evaluating

**16** **a** **Use** Table 4.2.2 on page 112 to calculate how far sound would travel through:

- **i** water in 5 seconds **ii** glass in 5 seconds.

**b** **Propose** why sound travels faster through glass than through water.

**17** **Propose** reasons why light travels faster in ice than in water.

## Creating

**18** A seagull circling overhead spies a fish below, as shown in Figure 4.5.3. **Construct** a diagram to show where the fish appears to be when seen by the seagull.

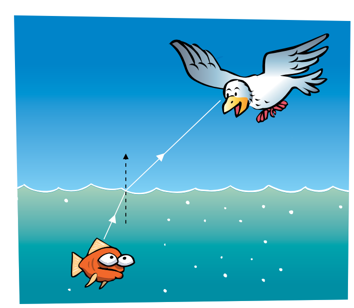


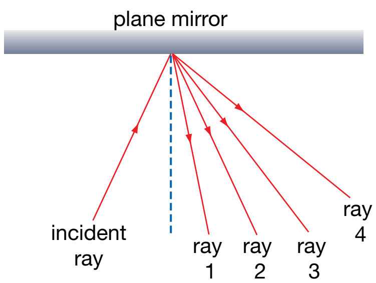
Figure 4.5.3

**19** **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter:

heat, temperature, conduction, convection, radiation, sound, frequency, wavelength, light, image

# Thinking scientifically

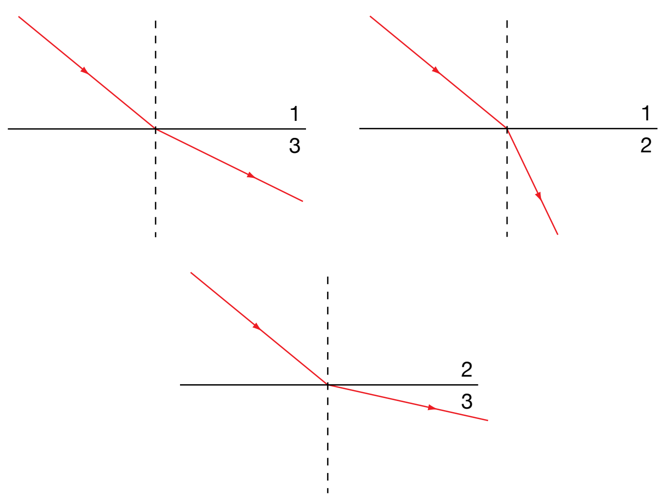
**Q1** Light reflects from a plane mirror at an angle equal to the angle at which it hits the mirror. Josh directs a ray from a light box onto a plane mirror, as shown in the diagram.




The reflected ray in Josh's experiment is:

**A** ray 1
**B** ray 2
**C** ray 3
**D** ray 4

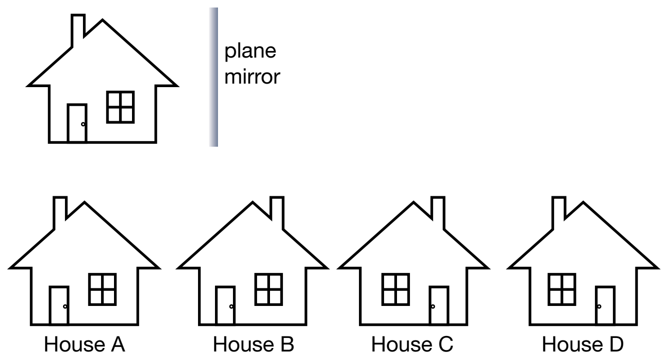
**Q2** Light refracts (bends) towards the normal when it travels from one medium into another of higher refractive index. It bends away from the normal when travelling into a substance of lower refractive index. Study the ray diagrams as light travels between materials 1, 2 and 3.




The materials listed from least to greatest refractive index are:

**A** 1, 2, 3
**B** 3, 1, 2
**C** 2, 1, 3
**D** 1, 3, 2

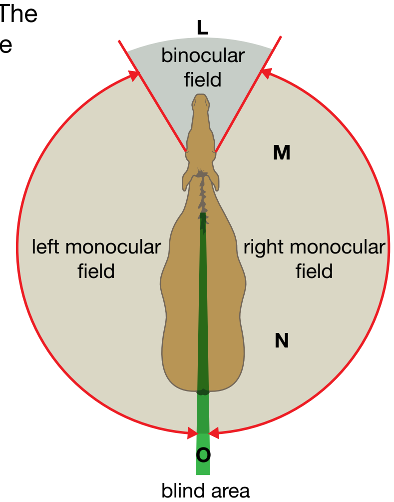
**Q3** In a plane mirror, light is laterally inverted (reflected from left to right). Select the correct image of the house as it appears when reflected through a plane mirror.




**A** House A
**B** House B
**C** House C
**D** House D

**Q4** A horse has one of the largest pairs of eyes of any animal. The horse has binocular vision and therefore a limited field of view. In this field of view, the horse can easily judge distances between objects. It also has a wide field of monocular vision to the left and right, called its left and right monocular fields. The horse cannot judge distances as effectively between objects it sees in these fields. In a small region behind the horse, it has no vision.

The diagram shows these fields of view, as seen from above the horse.




Identify which of the 1-metre tall objects, L, M, N and O, can be seen by the horse without turning its head.

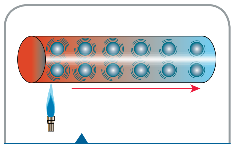
**A** only L
**B** only M and N
**C** L, M and N
**D** only L and O

# Glossary

## Unit 4.1

**Absolute zero:** the lowest possible temperature, –273°C

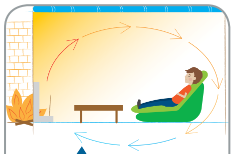
**Conduction:** a method of heat transfer in which heat is passed by vibration of particles



Conduction

**Conductor:** a substance that allows heat to flow through it

**Convection:** transfer of heat in a liquid or gas due to less dense, warmer matter rising and denser, cooler matter falling



Convection

**Insulator:** a material that does not conduct heat

**Radiation:** movement of heat in the form of electromagnetic waves, which can travel through a vacuum

**Temperature:** a measure of the average kinetic energy of particles in a substance that results in how hot or cold the substance is

**Thermometer:** an instrument used to measure temperature

## Unit 4.2

**Compression:** a region of high pressure where particles are close together

**Decibel (dB):** unit used to measure loudness

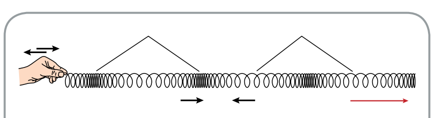
**Echo:** a sound that is reflected and heard a second time

**Frequency:** the number of waves passing a point every second

**Hertz (Hz):** the unit used to measure frequency

**Infrasound:** the sounds produced by waves of very low frequency, less than 20 Hz

**Longitudinal wave:** a wave in which the vibration is in the same direction that the wave is travelling



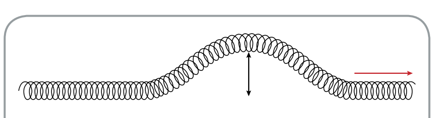
Longitudinal wave

**Rarefaction:** a region of low pressure, in which particles are far apart

**Sound wave:** regions of high and low pressure originating from a vibrating object and transmitted through a medium

**Tinnitus:** constant ringing in the ears caused by prolonged exposure to loud sounds

**Transverse wave:** a wave in which the vibration is at right angles to the direction the wave is travelling



Transverse wave

**Wavelength:** the distance from one peak of a wave to the next

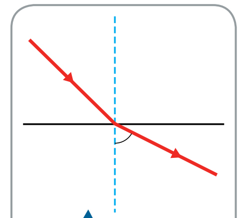
**Ultrasound:** the sounds produced by waves of greater frequency than humans can hear (greater than 20 000 Hz)

## Unit 4.3

**Angle of incidence, *i*:** the angle an incoming ray makes with the normal

**Angle of reflection, *r*:** the angle a reflected ray makes with the normal

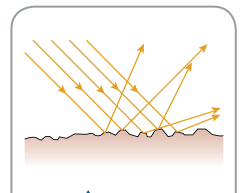
**Angle of refraction, *r*:** the angle a refracted ray makes with the normal



Angle of refraction

**Critical angle:** the angle of incidence of light that produces an angle of refraction of 90°

**Diffuse reflection:** reflection of light in many directions from an uneven surface, such as a book or a backpack

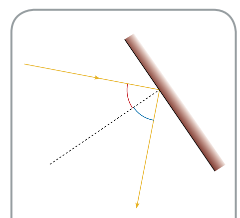


Diffuse reflection

**Incident ray:** incoming ray

**Lateral inversion:** the sideways or left-to-right reversal of an image in a plane mirror

**Law of Reflection:** the law stating that light is reflected at the same angle that it is incident, or $i = r$



Law of Reflection

**Normal:** an imaginary line that is drawn at right angles to a surface that light is incident upon

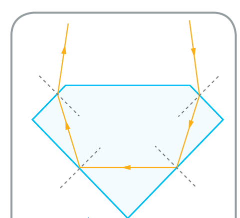
**Plane mirror:** a flat mirror

**Refraction:** the bending of light as it enters or leaves different substances

**Refractive index:** a measure of how easily light travels through a substance

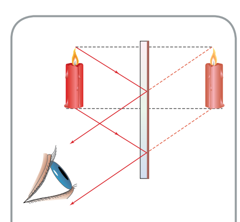
**Regular reflection:** reflection of light from a very smooth surface, such as still water or a mirror; it produces a clear image

**Total internal reflection:** when light is completely reflected from the boundary of two substances; it occurs when the angle of incidence is greater than the critical angle



Total internal reflection

**Virtual image:** a type of image formed in which the rays of light do not actually meet, but only appear to meet at a point inside the mirror



Virtual image

## Unit 4.4

**Accommodation:** the ability of the lens of the eye to change its shape to adjust its focus

**Concave lens:** a lens that curves inwards

**Convex lens:** a lens that bulges outwards

**Cornea:** a transparent covering over the iris of the eye; it bends light into the lens

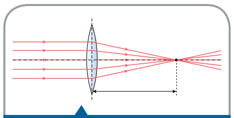
**Focal length:** the distance from a lens to its focus

**Lens:** in the eye it is a flexible structure that enables light to be focused on the retina

**Long-sightedness (hyperopia):** the inability to focus on close objects because the eyeball is too long

**Optic nerve:** a nerve that carries an electrical signal from the retina to the brain.

**Real image:** an image formed when rays of light do actually meet



Real image

**Retina:** nerve tissue at the back of the eye, consisting of cone cells and rod cells; light is converted into an electrical signal here

**Short-sightedness (myopia):** the inability to focus on distant objects because the eyeball is too short

# Electromagnetic radiation 5

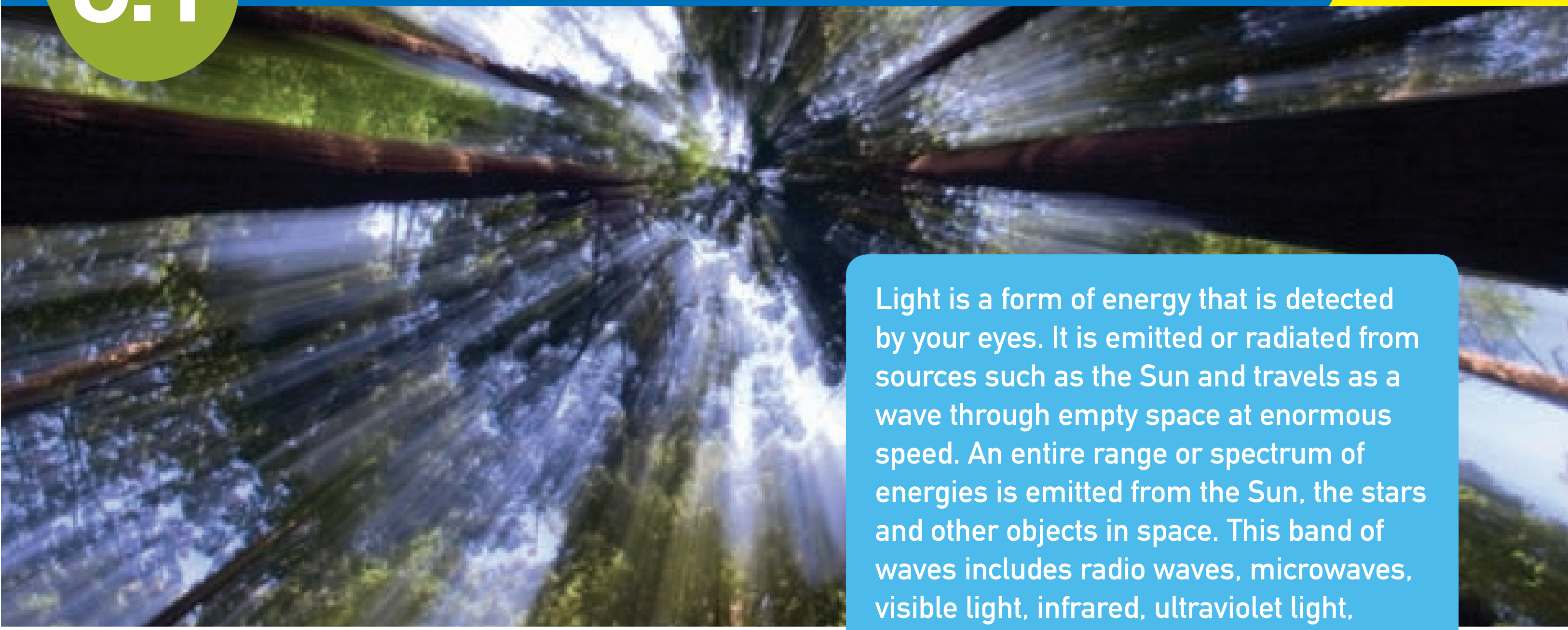
## HAVE YOU EVER WONDERED . . .

- how mobile phones work?
- how the internet works?
- how radiation is used in medicine?
- how night-vision sensors work?

### After completing this chapter students should be able to:

- recall that wave motion is a transfer of energy without matter, and that waves can be transverse or longitudinal
- describe the electromagnetic spectrum as consisting of a range of waves of differing energies that include gamma radiation, X-rays, ultraviolet (UV) light, visible light, infrared radiation, microwaves and radio waves
- compare the wavelengths and frequencies of the range of electromagnetic radiation that makes up the electromagnetic spectrum
- recall that the frequency of a light wave indicates its colour in the visible spectrum
- explain how common properties of electromagnetic radiation relate to its uses
- describe how electromagnetic radiation is used in medicine, such as in the detection and treatment of cancer
- outline how communication methods are influenced by new mobile technologies that rely upon electromagnetic radiation
- describe how technologies have been developed to meet the increasing needs of mobile communication.

# 5.1 Electromagnetic radiation



Light is a form of energy that is detected by your eyes. It is emitted or radiated from sources such as the Sun and travels as a wave through empty space at enormous speed. An entire range or spectrum of energies is emitted from the Sun, the stars and other objects in space. This band of waves includes radio waves, microwaves, visible light, infrared, ultraviolet light, X-rays and gamma rays. These all carry different amounts of energy but are all the same type of radiation, known as electromagnetic radiation.

## Wave motion

Figure 5.1.1 shows the wave motion of ripples created from a droplet of water. These ripples travel outwards from the point where the droplet hit the water. The energy of the impact travels outwards, but the actual water particles making up the wave only move up and down.

The transfer of energy without matter is called **wave motion**. There are two types of waves that can transfer energy. The particles of a **transverse wave**, such as a wave at the beach, vibrate at right angles to the direction of motion of the wave. In a **longitudinal wave**, such as a sound wave, the particles vibrate backwards and forwards in the same direction as that of the wave. Both these types of wave are shown in Figure 5.1.2.

Figure 5.1.1 A water droplet hitting a pool of water below triggers the spread of circular waves outwards from where it hit the surface.

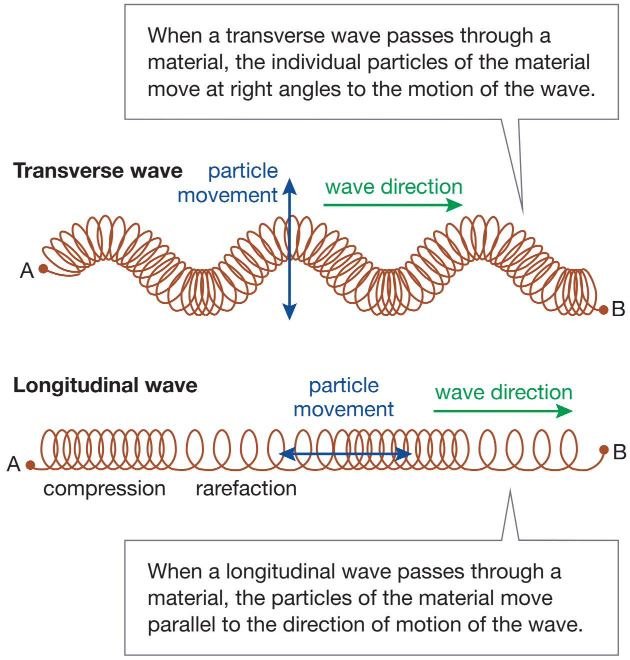



Figure 5.1.2 Transverse waves and longitudinal waves both transfer energy but in very different ways.

# Wave properties

The number of waves produced each second is called the **frequency** of the wave. This is measured in hertz (Hz), which means cycles (waves) per second. **Wavelength** is the distance between two successive waves. It is represented by the Greek symbol λ (lambda) and is measured in metres. The wavelength of some radio waves is several kilometres, whereas the wavelength of visible light is less than one thousandth of a millimetre. The amplitude of a wave is the maximum distance it extends beyond its middle position. Figures 5.1.3 and 5.1.4 show the wavelength and amplitude of transverse and longitudinal waves.

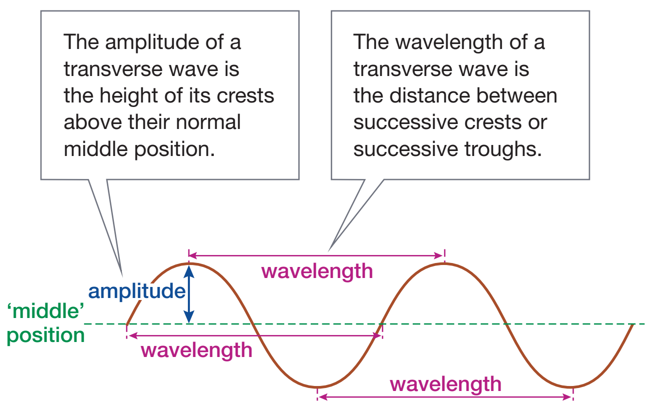



**Figure 5.1.3** The amplitude and wavelength of a transverse wave. The number of these waves passing a given point each second is the frequency of the wave.

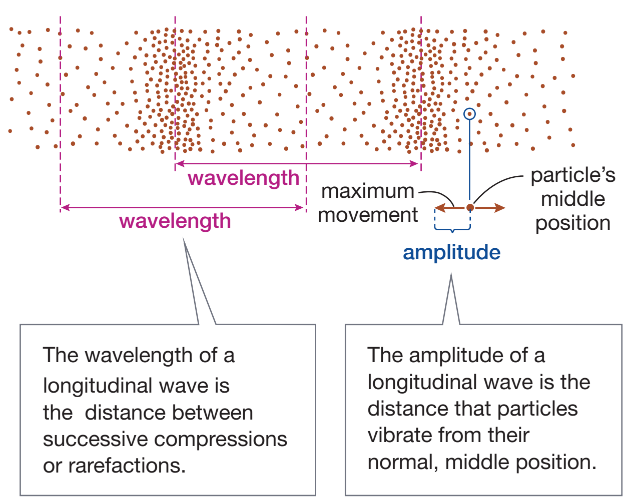



**Figure 5.1.4** The amplitude and wavelength of a longitudinal wave. Again, the number of waves passing a given point each second reveals its frequency.

## SKILL BUILDER: The wave equation

The speed, wavelength and frequency of a wave depend upon each other and are linked by a formula called the wave equation:

$$v = f\lambda$$

where: $v$ = speed of wave (m/s)
$f$ = frequency of wave (Hz)
$\lambda$ = wavelength of wave (m)

The equation can be rearranged to calculate frequency:

$$f = \frac{v}{\lambda}$$

And it can be rearranged to calculate wavelength:

$$\lambda = \frac{v}{f}$$

## WORKED EXAMPLE
### Wave equation calculations

### Problem 1

At a beach, a wave hits the shore every 10 seconds. This means they have a frequency of 1/10 Hz, or 0.1 Hz. If there is 6 m between successive waves, calculate the speed of the waves.

### Solution

$$f = 0.1\ \text{Hz}$$
$$\lambda = 6\ \text{m}$$

Using the wave equation,

$$v = f\lambda = 0.1 \times 6 = 0.6\ \text{m/s}$$

### Problem 2

The highest note produced on a typical piano has a frequency of 4100 Hz. Given that the speed of sound in air is 330 m/s, calculate the wavelength of this sound wave.

### Solution

$$\lambda = \frac{v}{f} = \frac{330}{4100} = 0.08\ \text{m}$$

This means the sound wave has a wavelength of approximately 8 cm.

## What is electromagnetic radiation?

When electric charges move, such as when electric current flows in a wire, a magnetic field is generated around the wire. Similarly, a changing magnetic field generates an electric field. This property is used to generate electricity in a typical power station.

The Scottish scientist James Clerk Maxwell (1831–1879) suggested that a changing electric field could create a changing magnetic field, which would in turn create a changing electric field. These fields would continue to generate each other. He proposed that changing magnetic fields and changing electric fields travel through space as transverse waves at right angles to each other. This is the structure of an electromagnetic wave, as shown in Figure 5.1.5.

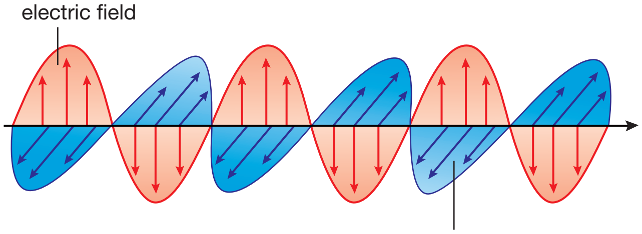



**Figure 5.1.5** Electromagnetic waves travel as two interconnected electric and magnetic fields moving as transverse waves.

Electromagnetic waves are generated naturally in our upper atmosphere and from stars, including our Sun. Visible light, microwaves and X-rays are examples of **electromagnetic radiation**. These forms of energy travel through space as **electromagnetic waves**.

5.2

## The electromagnetic spectrum

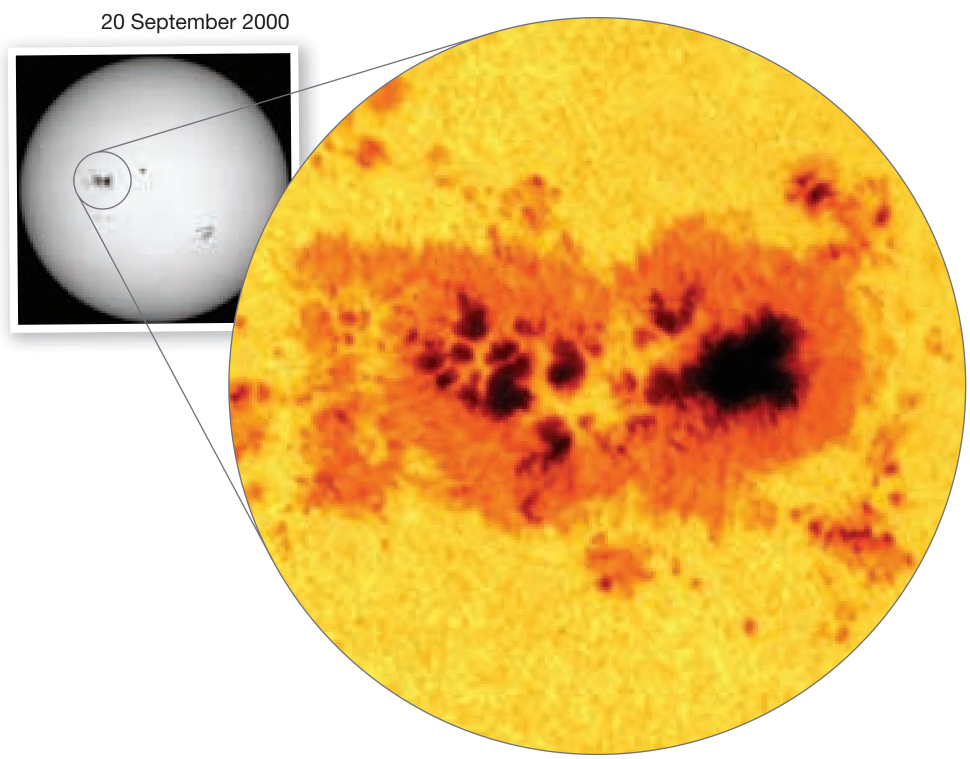
The entire range of frequencies of electromagnetic radiation that can be produced is called the **electromagnetic spectrum**. This ranges from low-energy radiation, such as radio waves, through to high-energy gamma radiation. As the energy of the radiation increases, the frequency of the electromagnetic waves increases, and the wavelength decreases. Electromagnetic waves all travel at the speed of light, which is 300 000 km/s. The electromagnetic spectrum is shown in Figure 5.1.6.

Electromagnetic waves can travel through empty space, gases, liquids and some solids. When a substance absorbs any kind of electromagnetic radiation, it also absorbs its energy. The substance may heat up or change in some way. As an example, a solar cell can convert light into an electric current.

**SciFile**

### Solar flares

Solar flares are enormous explosions that occur on the surface of the Sun. They release incredible amounts of energy across the electromagnetic spectrum, including gamma rays, X-rays, and high-speed protons and electrons. One solar flare releases approximately ten million times more energy than that of an erupting volcano. The image shows a sunspot group covering an area over twelve times that of the surface of the Earth.



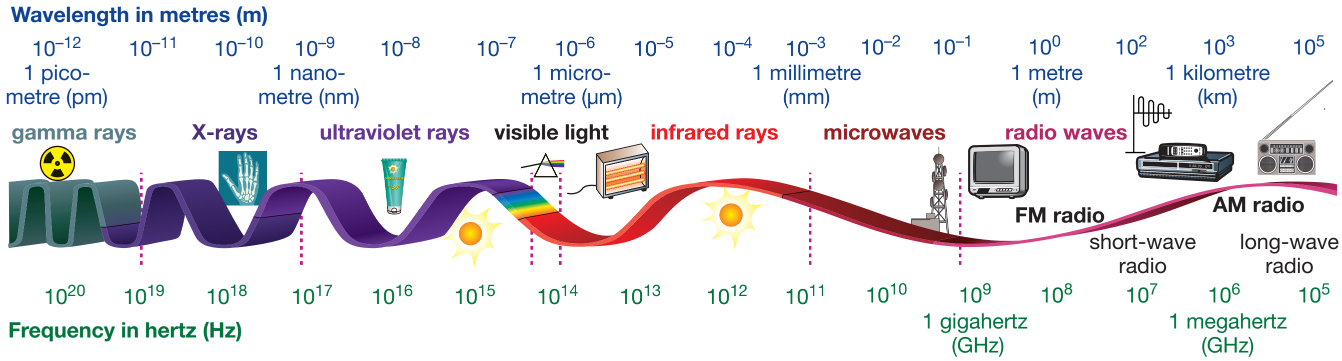



**Figure 5.1.6** The electromagnetic spectrum shows the complete range of electromagnetic waves that are possible. These waves travel at the speed of light. The shorter the wavelength and the higher the frequency, the more energy is carried by the radiation.

SKILL BUILDER

## Using scientific notation

Scientific notation is an easy way to handle very large and very small numbers. In scientific notation, numbers are written as a product of a power of ten. For example,

(a) 10 000 can be written as $1.0 \times 10^4$ (or simply $10^4$)

(b) 470 000 can be written as $4.7 \times 10^5$

(c) 21 000 000 000 000 000 000 becomes $2.1 \times 10^{19}$

The number at the top right of the 10 is called the exponent. For example, in example (c) above, 19 is the exponent. When the exponent is positive, as in the examples above, to convert the number from scientific notation to a digit, you move the decimal point this many places to the right.

For very small numbers, the exponent is negative. This indicates that to convert the number to a digit, the decimal point is moved to the left.

For example,

(a) 0.0000001 becomes $1.0 \times 10^{-7}$ (or simply $10^{-7}$)

(b) 0.0006 becomes $6.0 \times 10^{-4}$

(c) 0.0000000000000000000000098 becomes $9.8 \times 10^{-22}$

## Radio waves

Television and radio networks transmit a signal using **radio waves**. These radio waves are produced through vibrating or oscillating electrons in a transmitting aerial. Radio waves have the longest wavelengths of all types of electromagnetic radiation. This can range from a few metres to a few kilometres in length. As a result, these are the lowest-energy form of electromagnetic radiation.

Radio waves can travel large distances. They make electrons in the antenna of your television or radio vibrate, and this is converted into the sounds or images you see and hear when tuning in.

Short-wave and long-wave radio signals are also used in communications. Short-wave radio signals (wavelength about 30 m) can be transmitted long distances by beaming the waves upwards at an angle. The waves are reflected back to Earth by a layer of the atmosphere called the ionosphere, far away from where the transmitter is located.

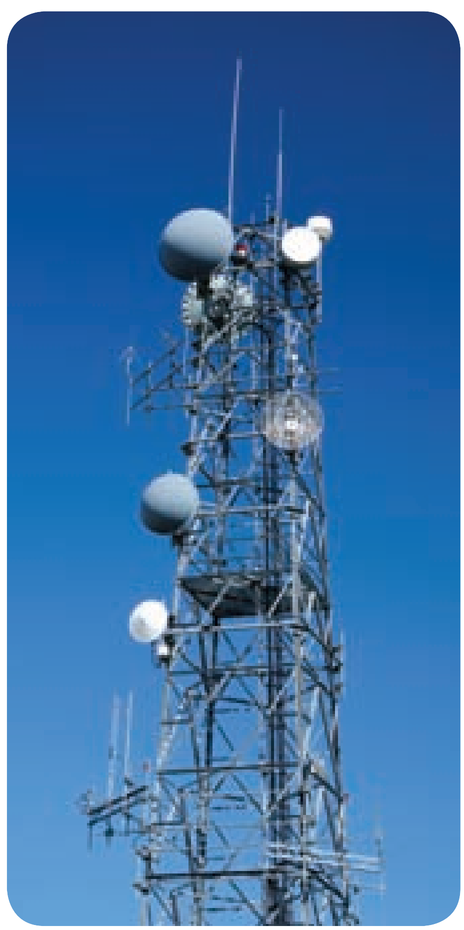


**Figure 5.1.7** Radio and television stations broadcast radio waves that are produced by electrons that are oscillating (moving back and forth).

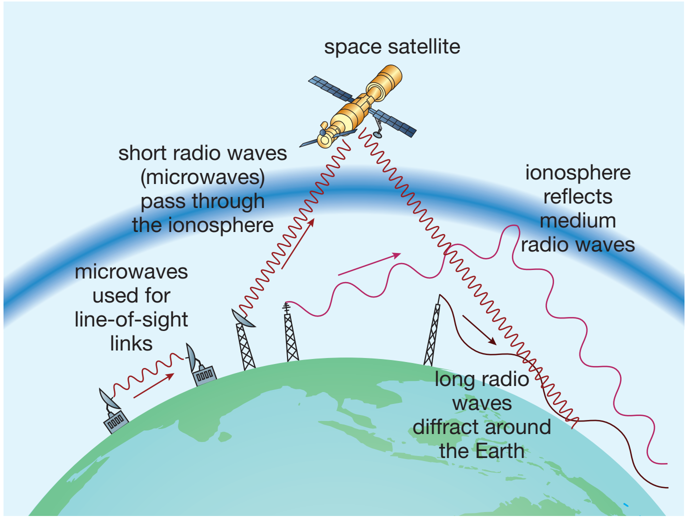



Figure 5.1.8 The wavelengths of radio waves can vary from kilometres to tens of centimetres. Long and short radio waves are useful for communication.

Long radio waves are used for communications because they bend around the Earth's surface when transmitted. These applications are shown in Figure 5.1.8.

Radio waves are also produced naturally. Objects in space, such as stars, emit radio waves.

### AM and FM radio

Each radio station broadcasts signals at a particular frequency, which you receive when you tune your radio to this frequency. AM and FM radio waves involve using a wave called a carrier wave, shown in Figure 5.1.9. The audio signal is transmitted from the microphone in the radio station, as shown in Figure 5.1.10. After being detected by the antenna of a radio, the carrier wave is subtracted from the signal, leaving only the original signal. This signal is amplified and directed to the speakers, where it is converted to sound once more.

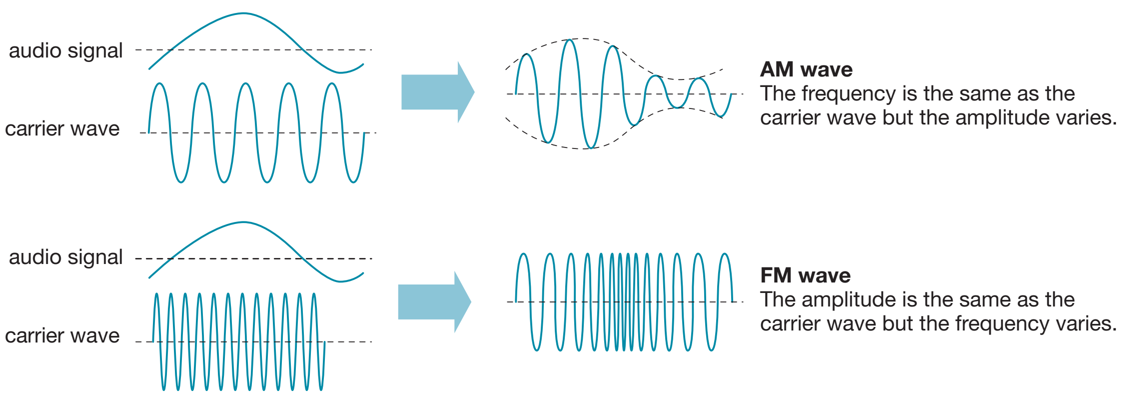



Figure 5.1.9 AM radio stations transmit waves that are amplitude modulated (in other words AM waves). In FM broadcasts, the carrier wave is frequency modulated. Each radio user, such as CB radio, the police or a radio station, operates on its own specific frequency.

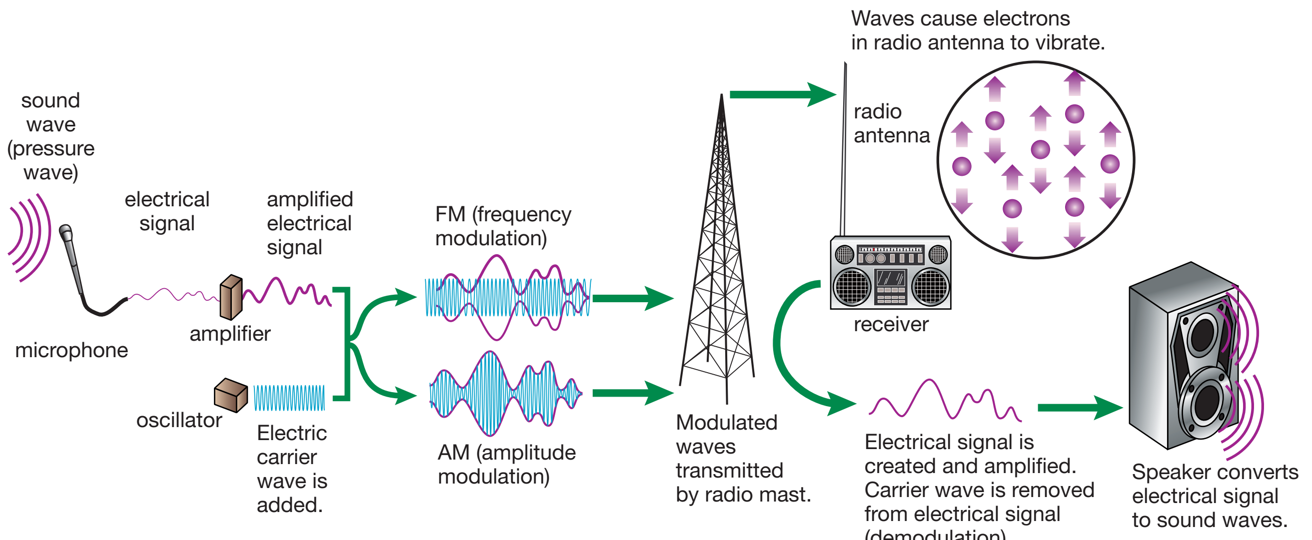



Figure 5.1.10 The steps used when broadcasting and receiving a radio signal.

An FM signal has a wavelength of around 3 metres, whereas an AM signal has wavelengths longer than 100 metres. The longer AM radio waves can bend around large obstacles like buildings, trees and hills more easily than the smaller FM waves. This bending around obstacles is called *diffraction*. AM signals travel further than FM signals, but they are of lower quality and are more likely to suffer from interference. You may have noticed this when listening to an AM radio near electrical equipment.

### Digital radio

SciFile

Digital radio is a new way of broadcasting. By transmitting multiple VHF (very high frequency) signals, filtering these for interference and then recombining the signals, digital radio delivers a cleaner, higher-quality sound that is free of crackles. Digital radio also offers a wider range of services, such as the ability to pause and rewind live broadcasts.

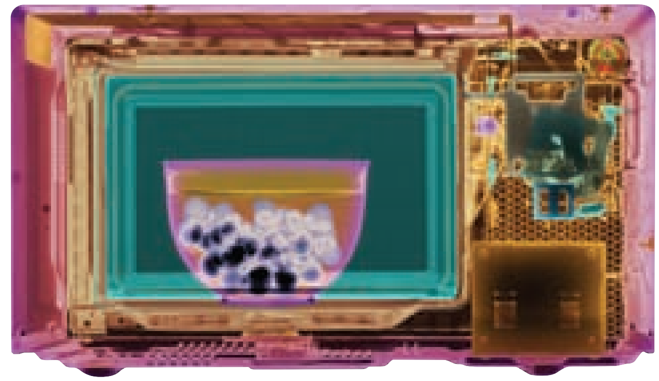



Figure 5.1.11 The wavelengths of microwaves are suitable for making particles in food vibrate, which makes the food heat up.

## Microwaves

**Microwaves** have shorter wavelengths than radio waves and are used in radar and communication systems. Shorter microwaves with wavelengths of about 0.1 mm are used in cooking. Microwaves are absorbed by water, fats and sugars in food, causing the food molecules to vibrate and heat up. Because the heating occurs inside the food without warming the surrounding air, the food cooks quickly but sometimes unevenly. Glass, paper and many plastics don't absorb microwaves, and metal reflects microwaves.

## Infrared radiation

Heat is transferred from the Sun to us as **infrared radiation**. Infrared rays are given this name not because they are red, but because they are next to red light in the visible spectrum. 'Infra' means below, and infrared radiation has a lower frequency than red light.

You cannot see this radiation, but can detect its presence as warmth on your skin. All objects with a temperature above 0 Kelvin (–273.15°C) emit infrared radiation. The hotter something is, the more infrared radiation it emits. Infrared radiation can be detected using an infrared camera, as shown in Figure 5.1.12.

5.3 p160

Figure 5.1.12 This image was created using an infrared camera. Different bands of intensities of infrared radiation are assigned a particular colour. The range of colours used to create this image are shown in the coloured bar below the couple. White corresponds to the hottest regions, while the coolest regions appear turquoise. This type of image is called a false colour image.

## Visible light

**Visible light** from the Sun helps us to make sense of our world, and is also essential for much of the life on Earth. Plants absorb light and use the energy to make the carbohydrates, fats, proteins, vitamins and other materials that humans and other animals depend on.

Visible light, or white light, consists of different colours. You can see this when you view a rainbow. Each colour has a different wavelength and frequency, as shown in Figure 5.1.13. Blue light has the shortest wavelength and the highest frequency; red light has the longest wavelength and the lowest frequency. The visible spectrum is explored in the next unit.

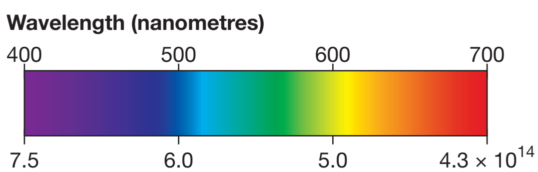



Figure 5.1.13 Visible light is a very small portion of the complete electromagnetic spectrum. It is the only band that is visible to our eyes. About 1000 waves of visible light fit into 1 mm.

## Ultraviolet light

**Ultraviolet (UV) light** is radiation with a higher frequency than violet light ('ultra' means 'beyond'). Sunlight contains UV light in addition to infrared and visible light. Your body needs some exposure to UV light to produce vitamin D. Although you cannot see UV light, it can tan or burn your skin. High exposure to UV light can cause skin cancers such as melanoma. UV light can also cause cataracts in your eyes. Approved sunglasses and sunscreens can offer us some protection from these rays.

The Bureau of Meteorology issues daily UV index forecasts like the one shown in Figure 5.1.14 to help you take precautions to protect yourself against damage from UV radiation.

Some substances fluoresce when hit by UV light, such as the rocks shown in Figure 5.1.15. This means they absorb UV light and emit visible light. White paper, teeth whiteners and some laundry powders add fluorescent particles to take advantage of this property. The particles make the paper, teeth or clothes appear brighter. UV light is also used to sterilise objects.

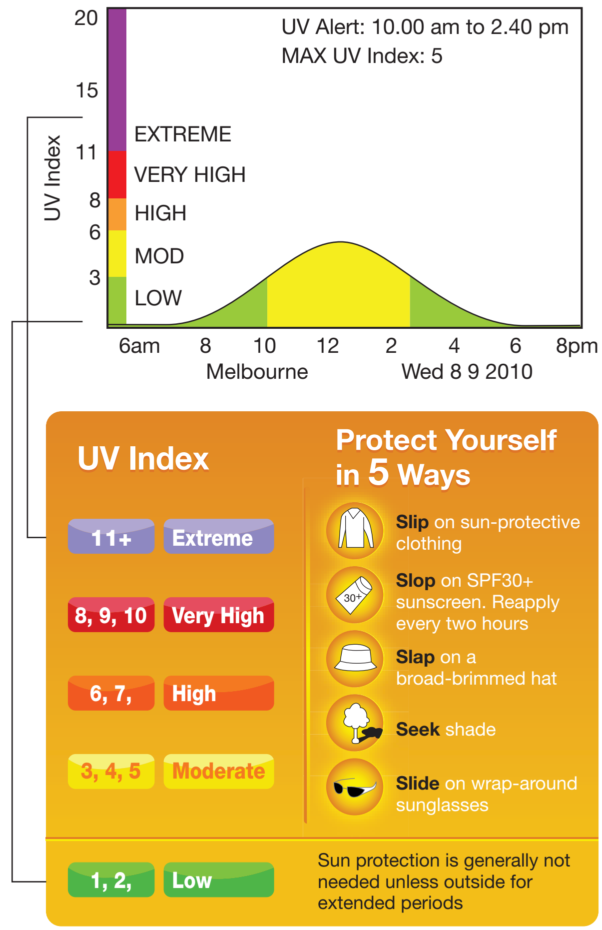



Figure 5.1.14 The Bureau of Meteorology issues daily Sunsmart UV alerts for each capital city in Australia. These alerts warn you when you need to be careful of UV exposure while outside.

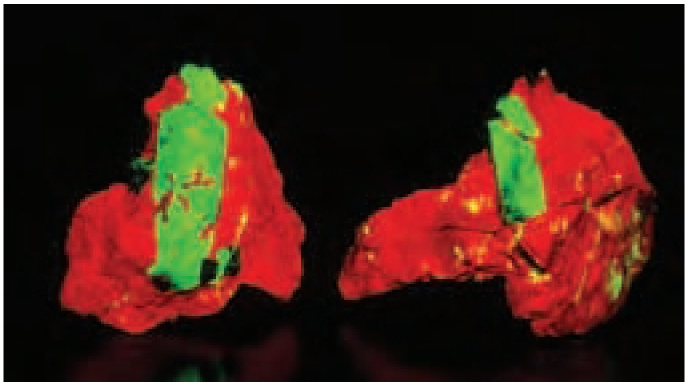


Figure 5.1.15 Many rocks including calcite, gypsum, ruby, talc, opal, quartz and fluorite are fluorescent and glow under UV light.

**SciFile**

**Skin cancer alert**

Did you know that Australia has the highest rate of skin cancer in the world? Around 1300 people die from the disease here each year.

**Glowing notes**

After a major counterfeit operation involving the circulation of fake notes in Australia in 1966, many new security features have been added to the manufacture of today's notes. If you hold any Australian bank note under a UV light, its serial numbers and a patch below its denomination (value) glow. This is because they are printed in fluorescent ink.

SciFile


2 p161

## X-rays

**X-rays** have great penetrating power and so are used to investigate the structure of objects and to find flaws in metals. This radiation has such high energy that it can damage cells and tissues, and also the genetic material inside cells. X-rays are produced when electrons hit a metal surface. This happens inside an X-ray tube. X-rays are used in radiology, to produce images of bones, like that shown in Figure 5.1.16. They are also used in radiotherapy, in which X-rays are targeted at cancer cells to kill them or stop them from multiplying.

When a patient undergoes a computed tomography (CT) scan, the X-ray sources and detectors rotate around the person. Computers then analyse the data from the CT scanner to create images of organs in the body. Luggage scanners in airports use X-ray devices to examine baggage.

Because of the high energy of X-rays, it is important that people who work with them use protective lead shields and monitor their exposure levels. This is done using a personal radiation monitoring device (PMD), such as the one shown in Figure 5.1.17. The device is worn for up to three months. The total or accumulated radiation dose is then measured. It is the employer's responsibility to ensure that this remains below a certain value, to protect the worker from possible harm.

5.4

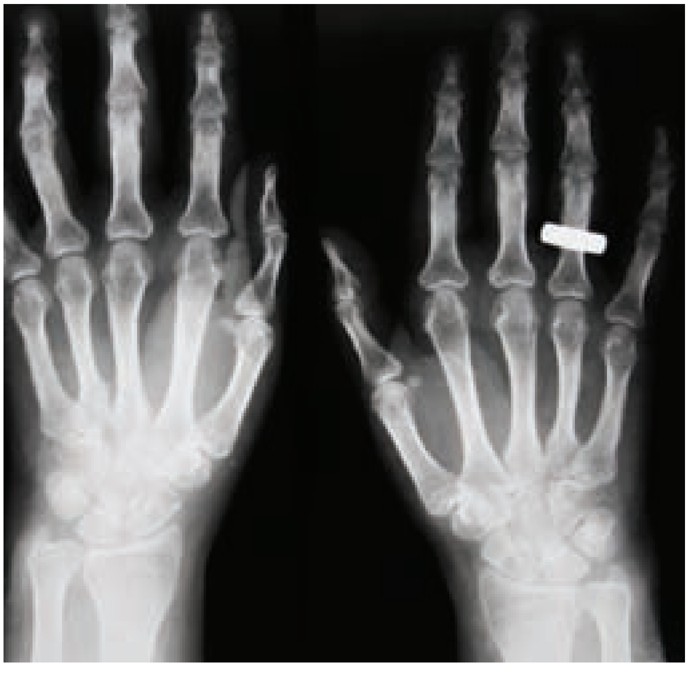


**Figure 5.1.16** X-rays can travel through human flesh, but not through bone. This makes them useful in producing images of the structures inside the body.


**Figure 5.1.17** A personal radiation monitoring device (PMD) measures a person's exposure to X-rays, gamma rays, neutrons and beta particles.

**Sharp pain!**

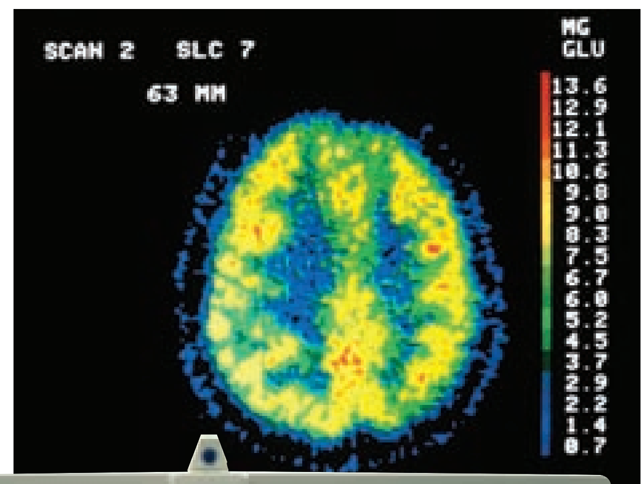
In January 2004, Patrick Lawler of Denver, USA, visited a dentist complaining of tooth pain and blurry vision. The dentist found the problem: a 10 cm nail that the construction worker had unknowingly fired through the roof of his mouth 6 days earlier! The nail was safely removed.

**SciFile**

## Gamma rays

**Gamma rays** have a wavelength of about one-hundred-billionth of a metre. Only a thick sheet of lead or a concrete wall will stop them. Gamma rays are produced in making nuclear power and nuclear bombs, and can be detected with photographic film or a machine called a Geiger counter. Due to their high energy, gamma rays can interact with matter. Gamma rays can free electrons from their atoms, which in turn ionise or remove electrons from surrounding atoms. This ability is used to target and kill cancer cells in patients undergoing radiotherapy.

Gamma rays are also useful in medical diagnosis. In the technique of positron emission tomography (PET), a patient is injected with small amounts of a short-lived radioactive material. This emits gamma rays, which are detected by a PET scanner or camera. This data is converted using computer analysis into a three-dimensional image. These scans allow doctors to study how parts of a patient are functioning, giving metabolic information. Figure 5.1.18 was produced by a PET scan in combination with a CT scan.



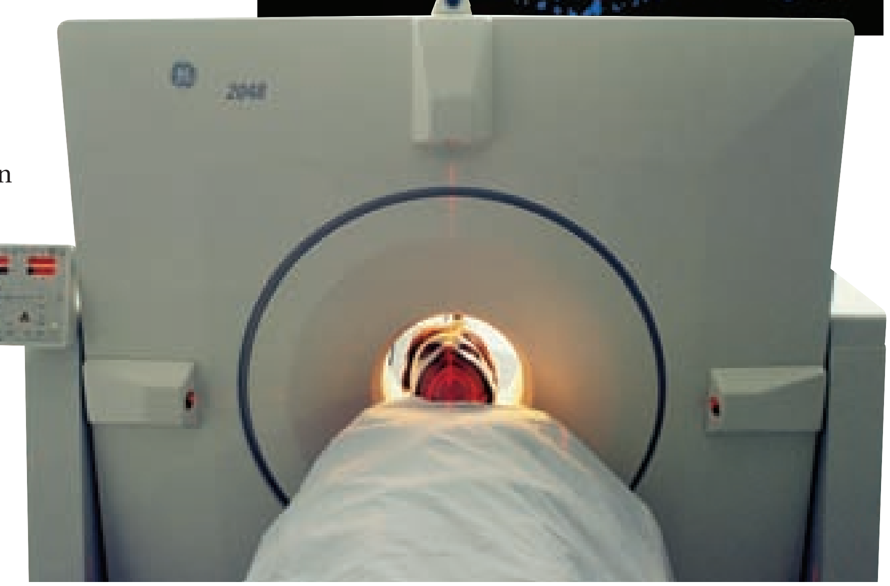



**Figure 5.1.18** PET scans allow doctors to study how parts of a patient are functioning. They are often viewed together with a CT (computed tomography) scan, which provides anatomic information regarding their body structure.

Figure 5.1.19 Wilhelm Röentgen

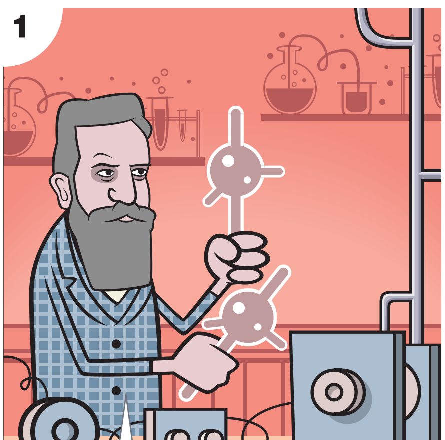
Wilhelm Röentgen was a German scientist. In 1895, he made a great discovery.

# SCIENCE AS A HUMAN ENDEAVOUR

## Nature and development of science

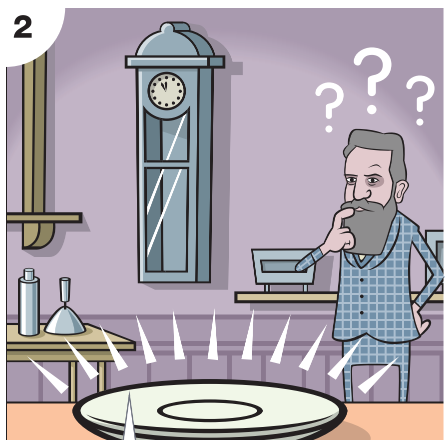
### The discovery of X-rays

1



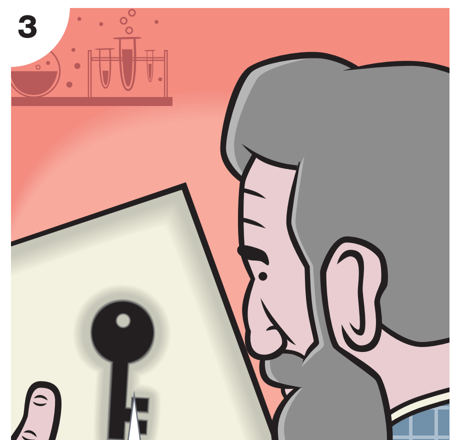
In 1895, Wilhelm Röentgen was experimenting with electrical discharges inside gas tubes. Röentgen pumped the air out of the tubes, pumped in various gases and turned on the electricity.

2



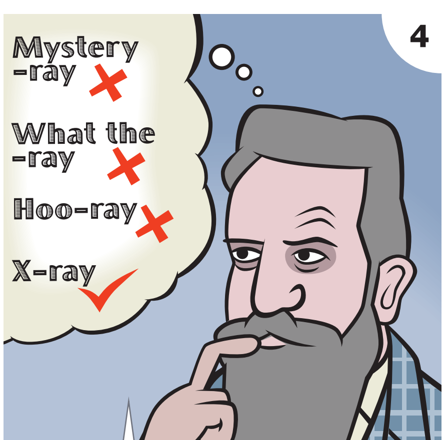
Röentgen covered the gas tube completely with heavy black cardboard. While working in darkness, he was surprised to see that a paper plate on the other side of the room was glowing. The plate was covered with a chemical called barium platinocyanide. Röentgen knew that the electrons flowing in the tube should have been stopped by the glass and cardboard shielding. He didn't know what was making the plate glow.

3



Röentgen started to investigate. He developed a photographic plate that had been left in a drawer near the tube and found the image of a key that was on top of the desk. Something was passing through glass, cardboard and wood, but was stopped by metal.

4

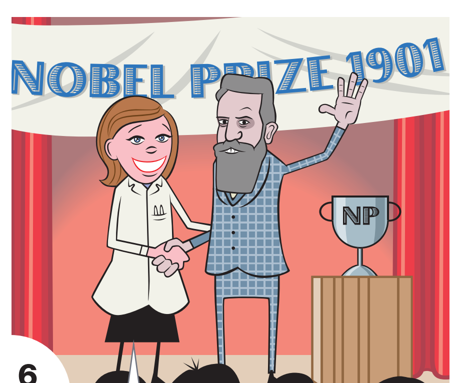



Röentgen deduced that some sort of ray must be responsible. As it was a mystery, he called it an 'X'-ray.

5

After careful experiments, Röentgen found that X-rays could pass through skin and muscle. He asked his wife to help and the earliest X-ray photographs show the bones of her hand and her wedding ring.

6




X-rays have been a vital part of modern medicine. For the first time, they allowed doctors to see inside the body. In 1901, Wilhelm Röentgen was awarded the Nobel Prize in Physics for the discovery of X-rays.

# 5.1 Unit review

## Remembering

**1** **Recall** wave motion by selecting the correct alternative in italics from each sentence below.

- **a** Wave motion is a transfer of energy *with/without* matter.
- **b** Particles of a *transverse/longitudinal* wave vibrate at right angles to the direction of motion of the wave.
- **c** The *frequency/wavelength* of a wave is the number of waves produced every second.

**2** **State** whether each statement below is true or false.

- **a** The electromagnetic spectrum ranges from low-energy gamma rays to high-energy radio waves.
- **b** As the energy of the radiation decreases, its wavelength increases.
- **c** The hotter an object, the less electromagnetic radiation it will emit.

**3** **State** which two types of field interact to produce an electromagnetic wave.

**4** **Recall** which colour in the visible spectrum has the longest wavelength.

**5** **List** three uses of X-rays.

**6** **Name** the damaging rays that are emitted in a nuclear explosion.

## Understanding

**7** **Explain** why AM radio waves travel further than FM radio waves.

**8** **Define** the term *amplitude modulated*.

**9** **Explain** why food may cook quickly but unevenly in a microwave oven.

**10** **Discuss** the meanings of the terms *infrared* and *ultraviolet* in terms of the position of these types of electromagnetic radiation in the electromagnetic spectrum.

**11** **Describe** two ways you can protect yourself from the harmful effects of solar UV radiation.

**12** **Explain** why a patient is injected with a short-lived radioactive material before having a PET scan.

## Applying

**13** **a** **Use** Figure 5.1.20 to **state** the wavelength and amplitude of:

- **i** wave A
- **ii** wave B.

**b** **Identify** which of these waves has the higher frequency.

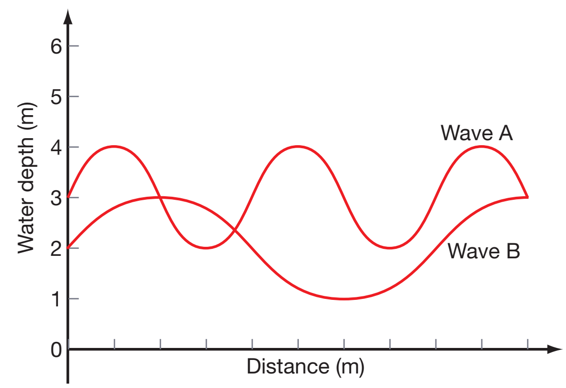



Figure 5.1.20

**14** **Apply** your understanding of scientific notation to convert the numbers below into numerals ('normal' numbers).

- **a** $2.5 \times 10^6$ m
- **b** $10^{-12}$ m
- **c** $5.7 \times 10^{14}$ Hz
- **d** $1.2 \times 10^{-9}$ m

## Analysing

**15** **Use** Figure 5.1.6 on page 151 to **classify** the following frequencies of electromagnetic radiation.

**a**
- **i** $1.0 \times 10^{14}$ Hz
- **ii** $1.0 \times 10^{22}$ Hz
- **iii** $1.0 \times 10^{10}$ Hz
- **iv** $1.0 \times 10^{6}$ Hz
- **v** $1.0 \times 10^{16}$ Hz

**b** **Identify** which of the samples above has the greatest energy.

**c** **Identify** which of the samples above has the shortest wavelength.

## Evaluating

16 Abdul is playing an A note on his piano. The note he is playing has a frequency of 440 Hz and the speed of sound in air is 330 m/s.

a **Calculate** the wavelength of the sound wave produced.

b Abdul now hits a lower note of frequency 220 Hz. **Calculate** the wavelength of this note.

c Are the wavelengths calculated above what you expected? **Justify** your answer.

17 a **State** the purpose of radiotherapy.

b **Propose** why patients undergoing radiotherapy usually suffer from unwanted side effects of the treatment.

## Creating

18 **Construct** a diagram to show a transverse wave with:

a wavelength of 2 cm and amplitude of 3 cm

b wavelength of 6 cm and amplitude of 2 cm.

## Inquiring

1 Many people have received serious burns by 'super-heating' liquids in a microwave oven. Research how this happens. Create a newspaper ad or TV commercial to warn people of such burns, and list precautions to prevent these injuries.

2 A number of techniques of medical diagnosis or treatment are possible using forms of electromagnetic radiation. Radiology, magnetic resonance imaging (MRI), radiotherapy, CT scans and PET scans are some examples. Describe how one of these processes works, and list where this technology is used.

3 Explore what part of the electromagnetic spectrum (apart from visible light) can be detected by particular organisms, such as a bee, a platypus or a snake. Investigate the capabilities of this creature and prepare a presentation that explains what is detected, and how and why this is useful.

4 Use a radio to investigate differences between the quality of reception of an AM signal and an FM signal. Compare the range of each type of signal, or how well the signal is heard inside areas such as underground carparks and around electrical appliances. Alternatively, build a mesh cage using flyscreen wire and compare the AM and FM signal of a radio inside the cage.

Figure 5.1.21

# 5.1 Practical activities

## 1 Infrared radiation

### Purpose
To discover whether silver, white and black objects radiate and absorb heat at different rates.

**SAFETY**

Be careful when pouring hot water.

If using a halogen lamp, never touch the glass bulb when the lamp is lit.

### Materials
- 3 empty identical tin cans
- white paint
- black paint
- paintbrushes
- aluminium foil
- insulating material, such as a rubber mat
- thermometer or temperature probe
- hot water, 50–55°C
- beaker
- bright halogen (or other) lamp if there is no direct sunlight

### Procedure
1. Prepare the three cans used in the experiment as follows.
   - Can A: Remove any paper from the outside to reveal the shiny surface. Use foil as a lid.
   - Can B: Paint the outside of the can with white paint. Use foil as a lid.
   - Can C: Paint the outside of the can with black paint. Use foil as a lid.
2. Punch a hole in the foil lid of each can so a thermometer or temperature probe can be inserted, as in Figure 5.1.22.
3. Copy the table in the Results section. Measure the air temperature in each can and record these values in the table.
4. Cover the top of each can with its coloured lid or foil, and place the cans on an insulating mat in direct sunlight. (If the sky is overcast, place them an equal distance away from a bright artificial light source.)
5. Insert the thermometer and measure the air temperature in the cans at 2-minute intervals over the next 20 minutes. Record these values in the results table. (Make sure the thermometer doesn't touch the bottom or sides of the can.)

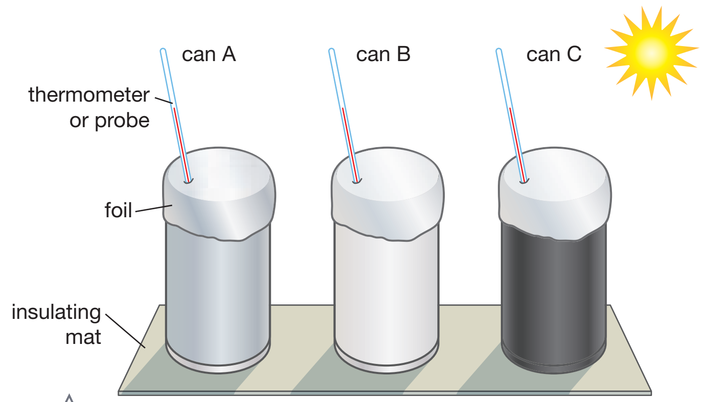



Figure 5.1.22

6. Now bring your equipment inside and record the temperature of the room you are in.
7. Carefully pour hot water (about 50°C) into the cans until they are nearly full.
8. Measure the temperature of the water in each can and record in a second table similar to the one in the results section. Record the temperatures every 2 minutes until the water in each can has cooled to room temperature. You may need to add lines to the table.

### Results
1. Copy and complete the following table for both parts of the experiment.

| Time (min) | Temperature (°C) | | |
|---|---|---|---|
| | Can A (silver) | Can B (white) | Can C (black) |
| 0 | | | |
| 2 | | | |
| 4 | | | |
| 6 | | | |
| 8 | | | |
| 10 | | | |
| 12 | | | |
| 14 | | | |
| 16 | | | |
| 18 | | | |
| 20 | | | |

2 Construct a line graph showing how the three cans absorbed heat when left outside in the sun for 20 minutes.

3 Construct another line graph showing how the water in the three cans cooled to room temperature when left inside the room.

### Discussion

1 **State** which can absorbed the most infrared radiation.

2 **Describe** how the rate of absorbing heat varied for each can.

3 **State** which can emitted its infrared radiation the fastest.

4 **Describe** how the rate of emitting heat varied for each can.

5 **Identify** any sources of error that could have affected the results of your experiment.

6 **Describe** any ways in which the quality of your results could have been improved.

## 2 UV protection

### Purpose

To design and conduct an experiment to test how effectively different materials block UV radiation.

### Materials

- UV colour-changing beads or a UV sensor
- a range of materials to test, such as: Polaroid sunglasses, cellophane of different colours, glass, transparent plastic, shadecloth, various clothing fabrics, and other items

### Procedure

Investigate how well each sample to be tested blocks UV radiation. Outline the steps of your procedure. Record your results in a data table.

### Discussion

1 **List** the different materials you tested, from most effective in blocking UV to least effective.

2 **Analyse** any sources of error in your experiment and suggest any improvements that could be made.

Figure 5.1.23 Wearing a wide-brimmed hat, sun-protective clothing and SPF 30+ sunscreen will help to protect this child's delicate skin from harmful UV rays.

# 5.2 The visible spectrum

The visible spectrum is the range of colours that combine to form white light. Visible light is just a small band of the frequencies that make up the electromagnetic spectrum. This is the band of electromagnetic radiation that our eyes can detect. The world would look very different to us if we had the UV vision of a bee, or the infrared vision of a snake.

## Colour

In 1666, the English scientist Isaac Newton passed a narrow beam of light through a glass prism. As the light exited the prism, Newton could see the colours of the rainbow, as shown in Figure 5.2.1. Newton realised that white light actually consists of all of the colours of the **visible spectrum**. He classed the colours making up this spectrum as red, orange, yellow, green, blue, indigo and violet. When all the colours shine at once, they produce white light. The splitting of white light into the colours that make it up is called **dispersion**.

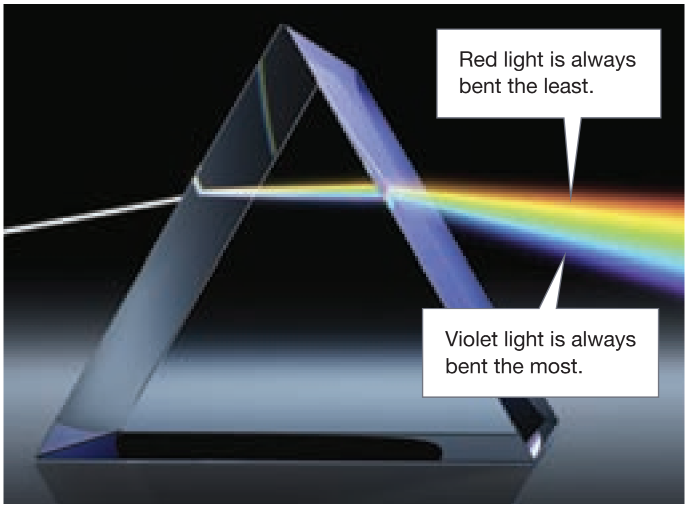



**Figure 5.2.1** When white light passes through a prism, each individual frequency of light is bent, or refracted, a slightly different amount.

**SciFile**

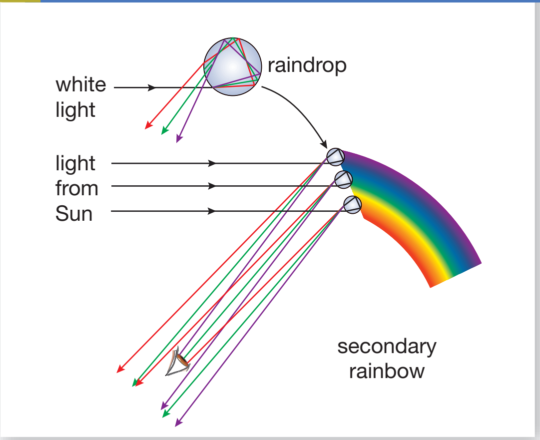
### Seven colours?

Newton believed that numbers had mystical meanings. Even though it is almost impossible to distinguish the colour indigo in the spectrum, Newton included it to give a total of seven colours. This matched the seven notes of the musical scale, the seven seas, seven days of the week and seven openings in the human head.

**SciFile**

### Rainbows

Water droplets can act like tiny prisms in the sky. Sunlight is dispersed into individual colours and is totally internally reflected back out of the water droplet. To see a rainbow, the Sun must be behind you. The rainbow you see consists of colours of light that have reflected from many individual water droplets found at many heights in the sky.

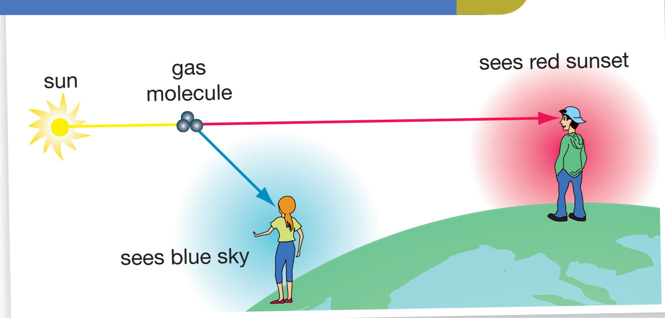


Each individual colour of light has a different wavelength and frequency. The wavelengths of visible light are extremely small, ranging from violet light with wavelengths around 400 nm, through to red light with wavelengths around 700 nm. To get an idea of how small this is, consider that 1 nm (nanometre) = $1.0 \times 10^{-9}$ m. This means that the wavelengths of visible light are less than one thousandth of a millimetre long, or about one hundredth the width of a human hair.

**SciFile**

### Blue skies and red sunsets

The colour of the sky depends on the angle at which you look at the Sun. The shorter wavelengths of blue light are more easily scattered in the atmosphere than longer wavelengths. As a result, the sky looks blue. When the Sun appears low in the sky, light travels through a thicker layer of the atmosphere than in the middle of the day. As the blue wavelengths have already scattered, you see a red sunset.




## Seeing in colour

How is it that we see one type of apple as red and another as green? Paint, or dye pigments on the surface of or within an object, determine its colour. An object viewed under white light looks red if it reflects red light towards our eyes (like the apple in Figure 5.2.2) and absorbs orange, yellow, green, blue, indigo and violet light. In reality, the red apple may reflect a little orange light as well, but this just affects the shade of red that we see. In the same way, a blue yo-yo reflects blue light (and probably a little green and violet) and absorbs all other colours of light. A white car reflects most of the light and radiant heat that hits it. In comparison, a black car reflects very little light or radiant heat. As a result, a black car will heat up more rapidly than a white car on a fine day.

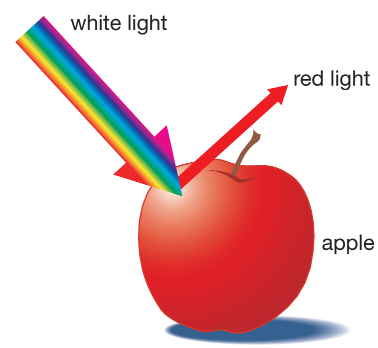



**Figure 5.2.2** A red apple reflects red light and absorbs the remaining six colours of the visible spectrum.

**INQUIRY science 4 fun**

## Blue skies

Can you create your own patch of blue sky and a red sunset?

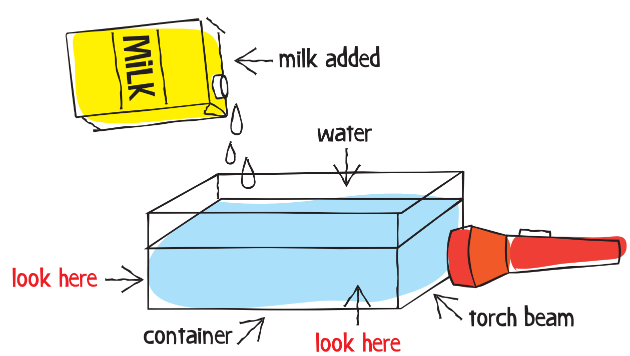
Yes

### Collect this ...

- a torch
- a transparent, rectangular container, such as a small fish tank or a plastic storage container
- about ½ cup of milk (more if using a large container)

### Do this ...

1. Three-quarters fill your container with water. This is your atmosphere.
2. Shine the torch through the water. See if you can see the beam at all.
3. Add a little milk, about 1/8th of a cup, and let it settle. Carefully look for any differences in colour of the beam, from the end close to the torch and at the far end. Look from the side and then from the end (see the diagram).
4. Gradually continue to add more milk. See how this affects the colours of the beam.

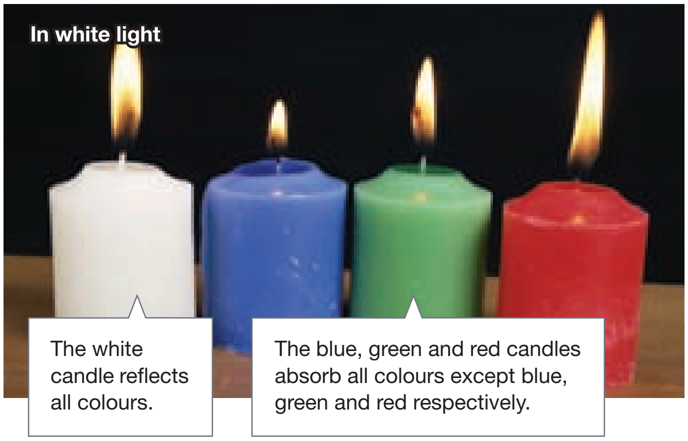



### Record this ...

**Describe** what happened.

**Explain** why you think this happened, using a diagram to assist your response.

Objects that are viewed under light of a specific colour may look quite different from when they are viewed under white light. This can be seen when comparing the four candles shown in Figure 5.2.3 viewed under white light and then red light.



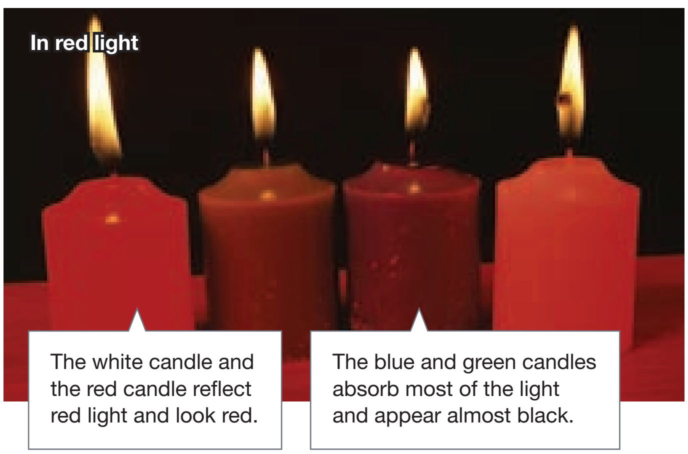




**Figure 5.2.3** Coloured candles look very different under different coloured lights.

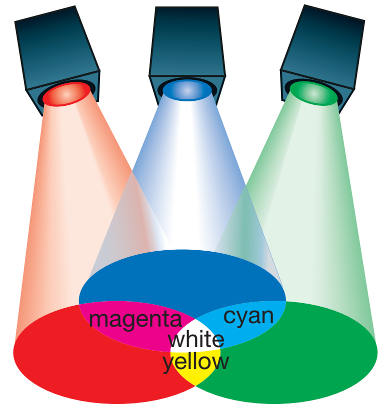



**Figure 5.2.4** Red and blue light produce magenta light, red and green light produce yellow light, and blue and green light produce cyan light. Combinations of the primary colours of light (red, green and blue), produce white light.

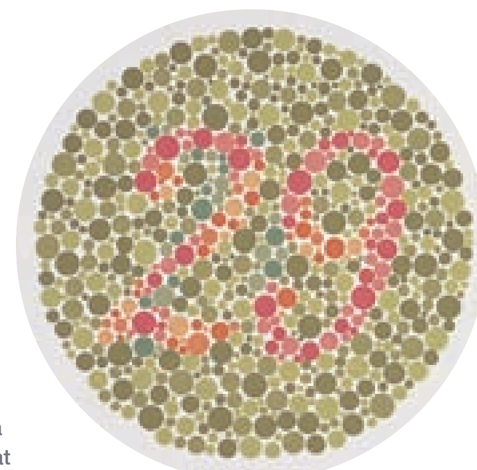


**Figure 5.2.5** A person with normal vision will see a particular number in a test like this one. What number can you see?

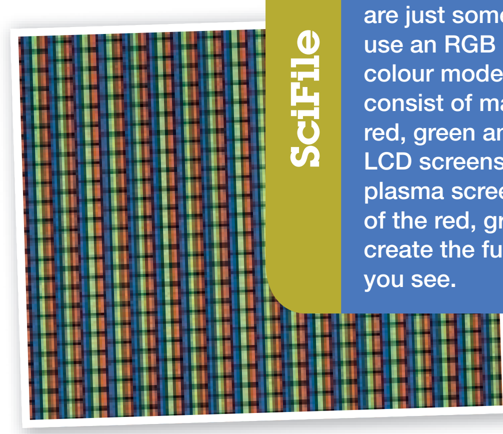
### Primary colours

White light can be produced by shining all colours together. Surprisingly, white light can also be made by using just three colours of the spectrum—red, green and blue. For this reason, these are called the **primary colours** of the spectrum. If you combine light of the primary colours in pairs, the three **secondary colours**—magenta, cyan and yellow—are produced. These combinations are shown in Figure 5.2.4.

### Colour vision

Your eyes have three types of photoreceptor cells, called cones. Each type of cone is sensitive to one of the three primary colours. Combinations of signals from these three types of cell give us our full colour view of the world. About 8 per cent of males have problems with colour vision and are said to be colour blind. This condition is rare in females.

The most common form of colour blindness is confusion between shades of red and green. An Ishihara test card, similar to that shown in Figure 5.2.5, is used to test for colour blindness.



**SciFile**

**Full colour?**

Televisions, video cameras, computers and mobile phones are just some of the devices that use an RGB (red, green, blue) colour model. Their displays consist of many tiny pixels of red, green and blue filters (for LCD screens) or phosphors (for plasma screens). Combinations of the red, green and blue light create the full colour display that you see.

## Colour filters

Just as a red apple absorbs all colours of the visible spectrum except red light, so too a red piece of cellophane absorbs all colours except red light, which passes straight through. The cellophane acts as a **colour filter**. A colour filter only allows light of its particular colour to be transmitted. Figure 5.2.6 shows the way some combinations of light are transmitted or absorbed by a filter. Coloured filters are used widely in photography and the theatre to provide a range of lighting effects. Coloured filters are also used to create 3D effects, as shown in Figure 5.2.7.

p168

## Colour printing

When all the colours of light are added together, white light is produced. However, if you were to mix together every colour of paint pigment, the final mixture would look dark and murky. As more paint pigments are added, more colours are absorbed rather than reflected. This type of colour combination is called subtractive colour mixing.

The three subtractive primary colours are cyan, magenta and yellow. Figure 5.2.8 shows how these three colours can produce all other colours. Black ink is also used in the printing process to increase the contrast of the printed image. Figure 5.2.9 on page 166 illustrates the way colour printing operates.

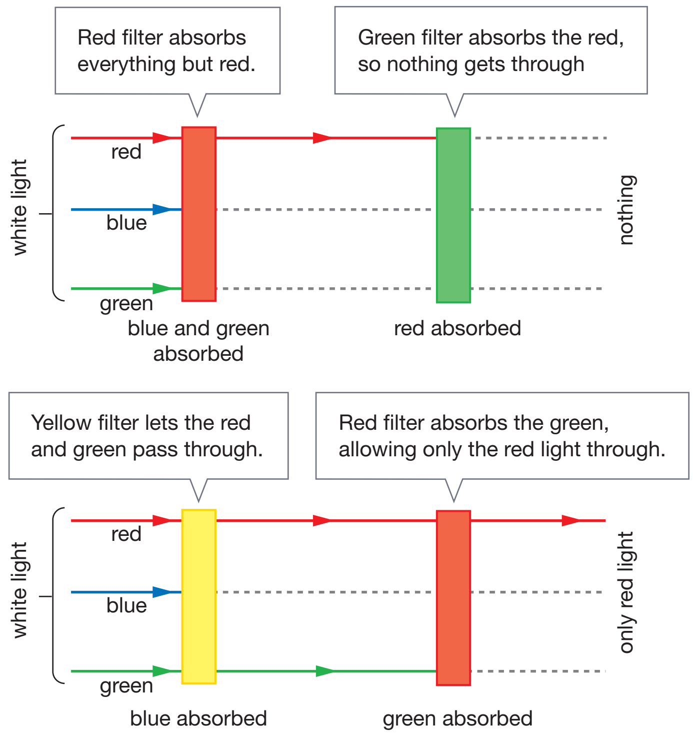



**Figure 5.2.6** Different coloured filters absorb different colours, and so they affect what you see.

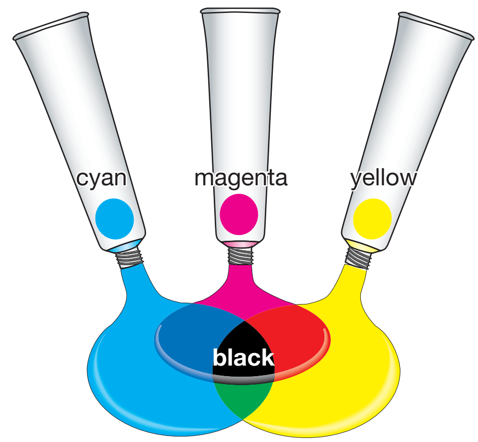



**Figure 5.2.8** Combinations of the three subtractive colours, cyan, magenta and yellow, can produce every colour of the spectrum.

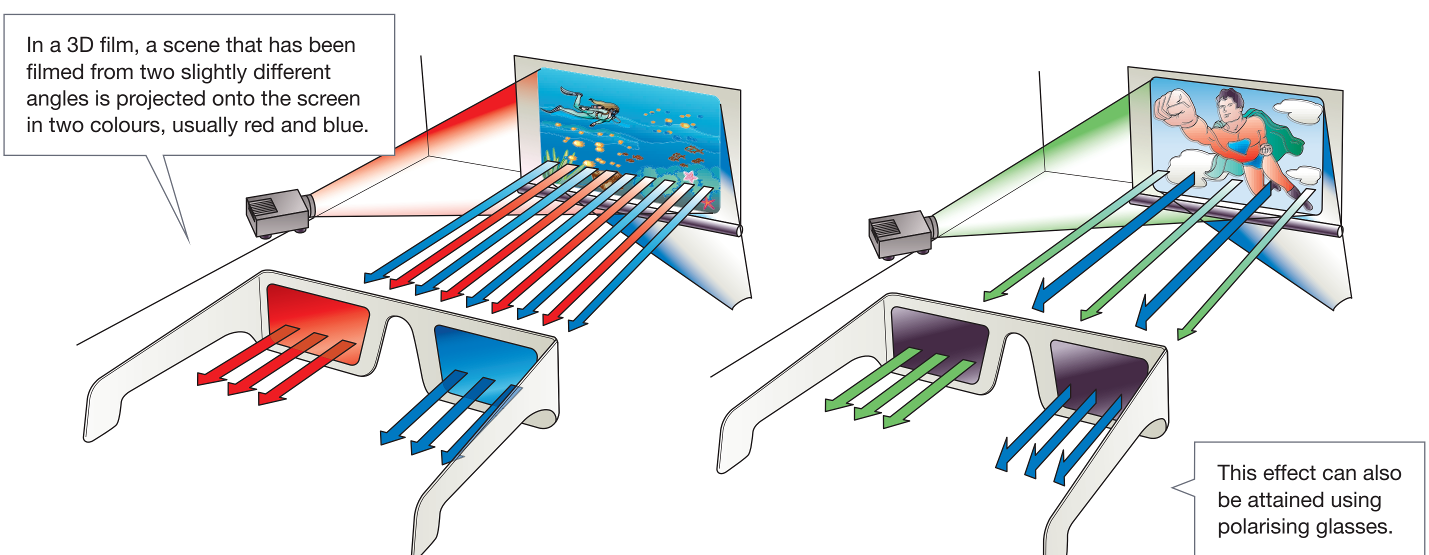



**Figure 5.2.7** When you wear 3D glasses with a red and blue filter, each eye receives a slightly different view of the movie scene. Your brain interprets this as 3D vision.

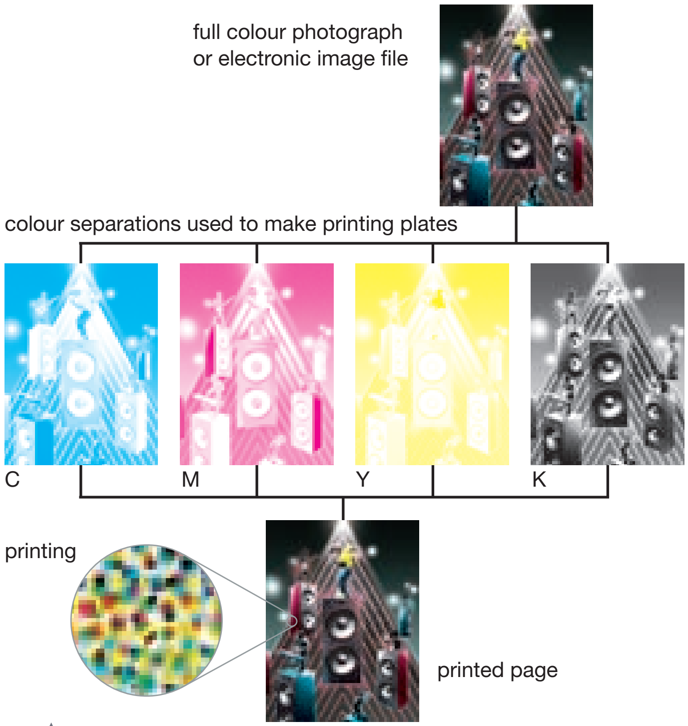



Figure 5.2.9 Colour printers produce a full spectrum of printed colour by using only four inks: cyan, yellow, magenta and black.

## Polarisation and interference of light

Light travels as an electromagnetic wave in three dimensions. If you wear a pair of Polaroid sunglasses on a sunny day, you can still see but the lenses absorb much of the light energy that hits them. This happens because light has been **polarised**. This means that only waves vibrating in a certain direction are allowed through the filter, while those vibrating in other directions are absorbed. This can be seen in Figure 5.2.10. Filters like these are used to manufacture the polarising lenses of sunglasses. They absorb much of the incoming light energy, but allow enough light through for us to still see clearly.

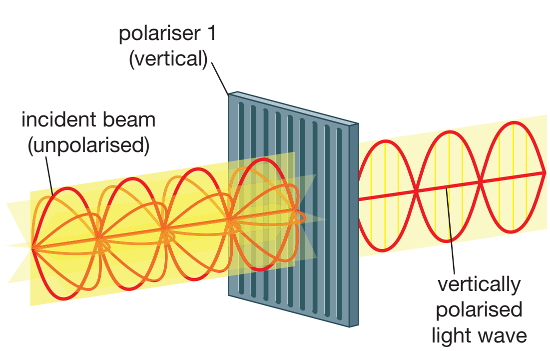



Figure 5.2.10 Electromagnetic radiation travels as a 3D wave, with electric and magnetic fields vibrating at right angles. A polariser only allows one plane of vibration to pass through it, the rest being absorbed.

You can test your sunglasses to see if they are polarised by holding another pair of polarised sunglasses in front of them. Rotate your sunglasses. If they are polarised, no light will pass through them when they are perpendicular.

Scientists believe that a pelican's eyes act as polarising filters, cutting the glare of light reflecting from calm water. When light reflects off a thin film, like a soap bubble or an oil slick (such as the one shown in Figure 5.2.11), a range of colours can be seen. In the case of a soap bubble, this happens because light reflects from both the inside surface and the outside surface of the bubble. Light reflected from the inside surface travels slightly further than light reflected from the outside surface. When the reflected light waves combine, they interfere with each other. This has the effect of adding and removing some of the frequencies of white light, creating the coloured patterns that you can see.

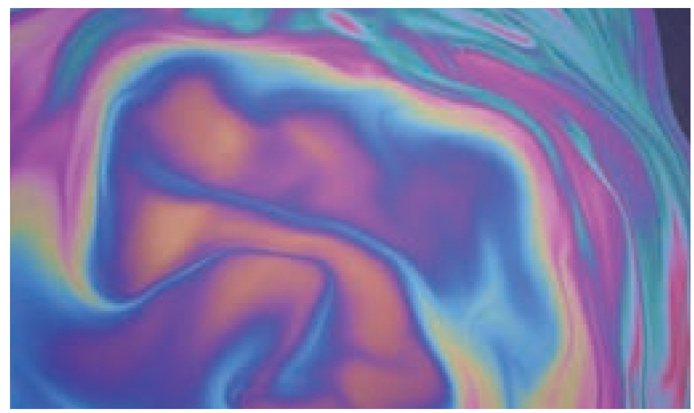


Figure 5.2.11 These colours are the result of thin film interference of light reflected from two layers of the oil slick.

**SciFile**

### Shimmering colour

Iridescence is the property of a surface when it changes colour as you view it from different sides. Sea shells, oil slicks, peacock feathers and the Morpho butterfly are iridescent. Interference of light waves reflected from the surfaces of these structures produces the iridescent colours.

5.5

2 p169

# 5.2 Unit review

## Remembering

1 a **List** all the colours of the visible spectrum.
  b **State** what is produced if all these colours are shone together.

2 **State** the colour of visible light that has the shortest wavelength.

3 **List** the three primary colours of the visible spectrum.

4 **List** the three secondary colours of the visible spectrum.

## Understanding

5 **Define** the term *dispersion*.

6 **Explain** why it is beneficial to wear white clothing when living in a very warm climate.

7 **Explain** how a pair of polarising sunglasses reduces glare.

8 **Explain** why a tricolour (three-colour) cartridge plus black ink is all that is needed in a computer printer to produce full colour prints.

## Applying

9 **Identify** the key colours reflected and absorbed when white light shines on the objects listed below.

| Object | Colours reflected | Colours absorbed |
|---|---|---|
| Red convertible | | |
| Yellow banana | | |
| Blue jeans | | |
| Black bowling ball | | |
| White dove | | |

10 a **Identify** which colour a green frog would look under yellow light.
  b **Identify** one coloured light that would make the green frog appear black.

11 For each of the three cases shown in Figure 5.2.12, **identify** the final colour (or lack of colour) that emerges.

12 Su-Lin and Sofia are dressed as shown in Figure 5.2.13, as they arrive at a night club. **Identify** what Su-Lin and Sofia's clothes look like in the nightclub's blue lighting.

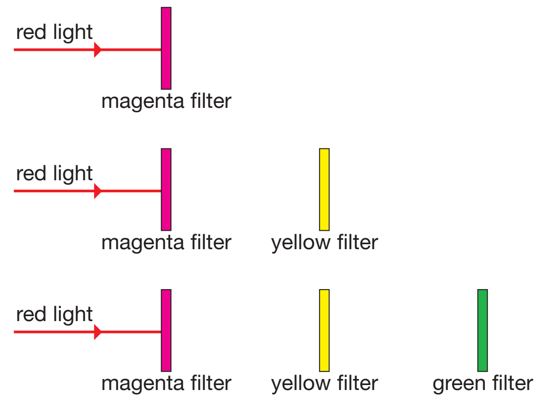



Figure 5.2.12

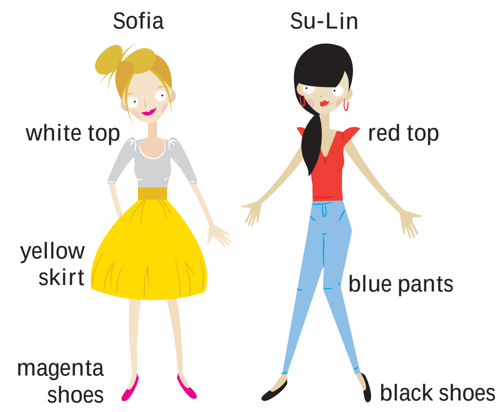



Figure 5.2.13

## Evaluating

13 **Use** two properties of light to **justify** the idea that light travels as a wave.

14 If red light was scattered more easily than blue light, **propose** what our skies would look like on a clear day.

15 The Doppler effect explains why sound waves from an approaching source sound higher in pitch than sound waves from a retreating source. You may have heard such changes in pitch when an ambulance travels past. The Doppler effect also occurs with light waves. **Propose** what colour an approaching light source and a retreating light source will appear to an observer.

## Inquiring

1 Investigate the way lighting is used inside shops to try to make items look more appealing. Compare a number of supermarket meat departments, fashion stores and cake shops, and summarise your observations.

2 Use the key word *iridescence* to list examples of this optical effect found in nature.

# 5.2 Practical activities

## 1 Combining colour

### Purpose

To investigate combinations of coloured light and to explore the behaviour of coloured filters.

### Materials

- light box
- power supply
- set of coloured filters
- set of coloured cards
- sheet of white paper

### Procedure

1. Connect the ray box to a power supply and place it on a sheet of white paper.
2. Copy Tables A and B into your workbook.
3. Place a red filter and a blue filter in the light box and adjust the mirrored flaps to combine the colours, as shown in Figure 5.2.14.
4. Change the filters as necessary to combine the light to complete Table A.
5. Now use one coloured filter at a time and shine light of this colour onto a red, blue, green, cyan, yellow and magenta piece of card. In Table B, record what each card looks like when viewed in each colour of light.

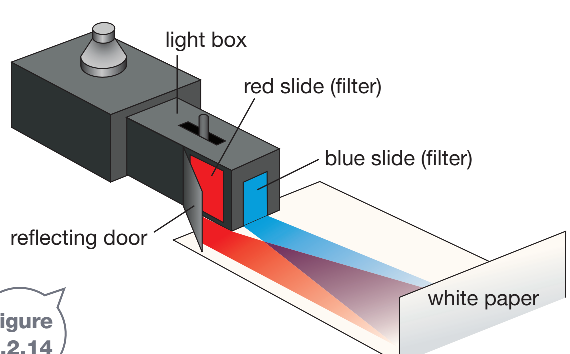



Figure 5.2.14

### Results

Use the tables below for your results.

**Table A Mixing coloured light**

| First slide | Second slide | Third slide | Colour produced |
|---|---|---|---|
| Red | Blue | | |
| Red | Green | | |
| Green | Blue | | |
| Yellow | Cyan | | |
| Yellow | Magenta | | |
| Cyan | Magenta | | |
| Red | Blue | Green | |
| Cyan | Yellow | Magenta | |

**Table B Viewing cards in different coloured light**

| Colour of slide | Colour of card | | | | | |
|---|---|---|---|---|---|---|
| | red | blue | green | cyan | yellow | magenta |
| Red | | | | | | |
| Blue | | | | | | |
| Green | | | | | | |
| Cyan | | | | | | |
| Yellow | | | | | | |
| Magenta | | | | | | |

### Discussion

1. **List** any combinations of colours that produced white light.
2. **Discuss** whether your results for Table A were as you would have predicted.
3. **Explain** the results you obtained for Table B.
4. **Propose** any ways in which this prac could be improved or extended.

## 2 Interference and iridescence

### Purpose

To investigate interference of light and iridescence.

### Materials

- light box with Polaroid filters
- power pack
- ice-cream container
- pair of Polaroid sunglasses
- pair of Real 3D movie glasses
- sticky tape
- retort stand and clamp

### Procedure

1. Set up the experiment as shown in Figure 5.2.15. Rotate the Polaroid filter and observe what happens to the reflected glare off the water as the filter rotates through 360°. Record your observations.
2. Make a pattern out of sticky tape, as shown in Figure 5.2.16. Note that the tape has been coloured in the diagram only to help you locate where the layers should go; it is not actually coloured.
3. Hold up the sticky tape pattern you made and look through it at the glare off the water (without using the filter). Rotate the tape to check that there is nothing happening.
4. Now hold up a polarising filter or a pair of polaroid sunglasses and look at the sticky tape pattern. Slowly rotate the filter or sunglasses through 360°. (Alternatively, keep the filter still and rotate the sticky tape through 360°.) Record your observations.
5. Repeat using a pair of 3D glasses, but compare the right and left lenses to see if the effects are the same. Record your observations.
6. Try changing the patterns you make with sticky tape to see how many colours you can make.

### Extension

7. Hold the sticky tape patterns in front of an LCD computer screen. Rotate the tape around while you look at it through polarising sunglasses or 3D glasses. Compare the left and right lenses in 3D glasses for colour effects in the same sticky tape pattern.

### Discussion

1. **Describe** what happened when you observed the sticky tape pattern in each step.
2. **Propose** why the colour changed in the sticky tape patterns.
3. **Explain** how a pair of polarising sunglasses works.

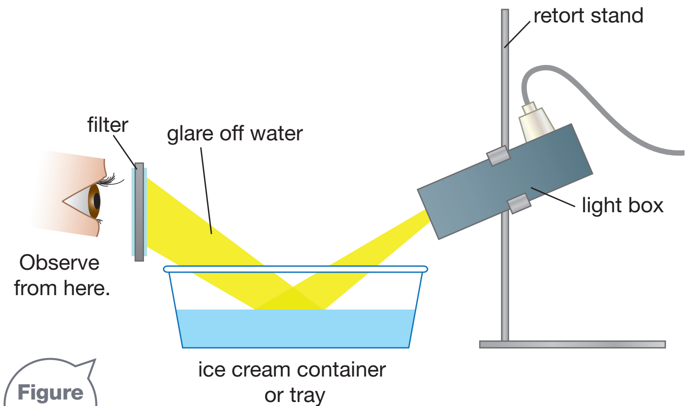



Figure 5.2.15

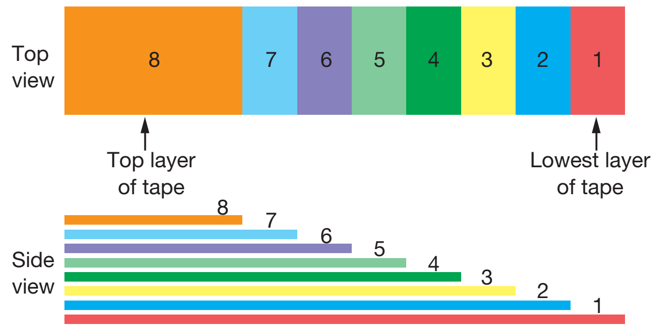



Figure 5.2.16

# 5.3 Communications and remote sensing

People can be linked to almost any part of the globe through a wireless internet network. Communications data can be sent through a range of electromagnetic radiation, such as radio waves, microwaves and pulses of visible light. Studying the way that electromagnetic radiation is reflected from and absorbed by different surfaces, such as land and water, can provide detailed information about particular locations. These remote sensing techniques are useful in weather forecasting, mapping land use and observing the effects of natural disasters.

## Modern communications networks

### Analogue or digital signals

Modern communications networks carry vast amounts of data from landline telephones, mobile phones, radio, TV and the internet. Data such as downloaded files, voice conversations and satellite images are relayed. Some mediums, such as the copper wires connected to landline phones, are designed to carry an **analogue signal**. The voltage of such a signal is determined by the speaker's voice. Analogue signals, such as that shown in Figure 5.3.1, are limited as they suffer from signal loss and interference as they travel.

Most communications systems that we use regularly, such as television, computer and iPod, rely on a **digital signal**. A modem connects a computer to a telephone line and converts the digital computer signal into an analogue signal that the phone line transmits. This process of coding the signal into a different format is called *modulation*. Our mobile phone network is digital, as is the music we listen to on CDs or DVDs. A digital signal can still be read even when interference disturbs the message.

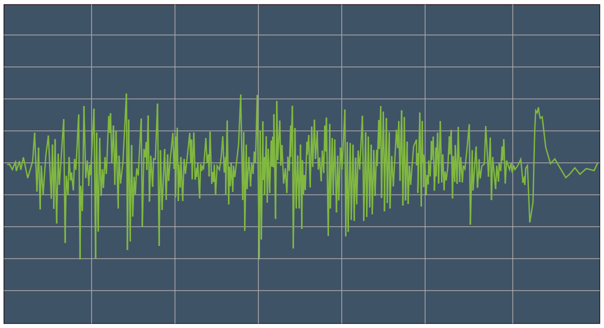


Figure 5.3.1 An analogue signal replicates the message it transmits.

Instead of relying upon a number system with ten digits, the digital system uses a **binary number system**, consisting of only two digits, 0 or 1 (or, in the case of light pulses, 'on' or 'off').

### Increasing capacity

Until relatively recently, all telephone signals were sent along copper wires. To limit signal interference, *twisted-pair* copper wires were used. These consist of a pair of insulated copper wires twisted around each other. A 600-pair copper cable can carry 600 two-way conversations.

These cables are inexpensive and do not suffer much signal loss when used over short distances. *Coaxial cable*, illustrated in Figure 5.3.2, can carry more data than twisted-pair cables. Australian cities have been linked by underground coaxial cables since the 1960s. Two cables of 50 tubes can carry 2700 two-way conversations. Such cable is used with repeaters positioned every 45 km to strengthen the signal.

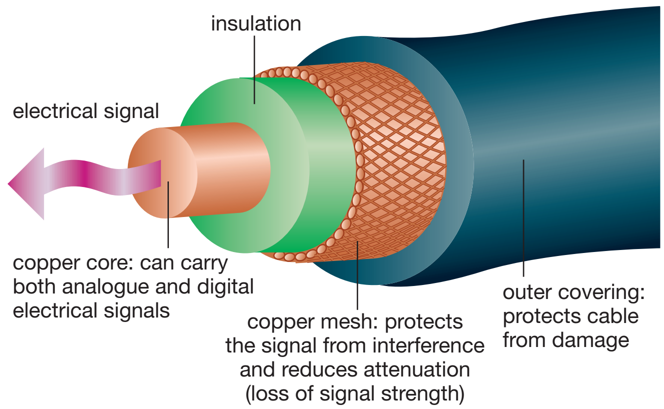



**Figure 5.3.2** The inner core of this coaxial cable transmits analogue and digital signals. The outer layers protect the signal from interference and loss of strength.

To enable the transmission of more data along a copper wire, different signals are sent along the wire at the same time. This is possible when using carrier waves of different frequencies. At the receiving end, these different frequencies are sorted back into separate signals. This is called **frequency division multiplexing (FDM)**.

Digital signals are transmitted using a technique called **time division multiplexing (TDM)**. In this process, data is broken up into smaller chunks and interwoven together, then transmitted at a single frequency as a data stream. This data stream is sorted into its components after transmission. In fact, a combination of FDM and TDM can be used to further increase the amount of data that can be carried. The amount of data that can be carried is known as the **bandwidth** of the channel.

## Channels of communication

### Optical fibre

The increasing use of computers led to even greater demand for bandwidth. In Australia from the late 1980s, a new network was laid next to the underground coaxial cable that linked cities. This network was made from **optical fibre**. Optical fibres are thin, flexible tubes made of silica glass or plastic. Each optical fibre consists of a central core of pure silica glass surrounded by a layer of less dense glass, called the cladding. This layer is coated with a plastic jacket to minimise interference. The structure of fibre optic cable is shown in Figure 5.3.3.

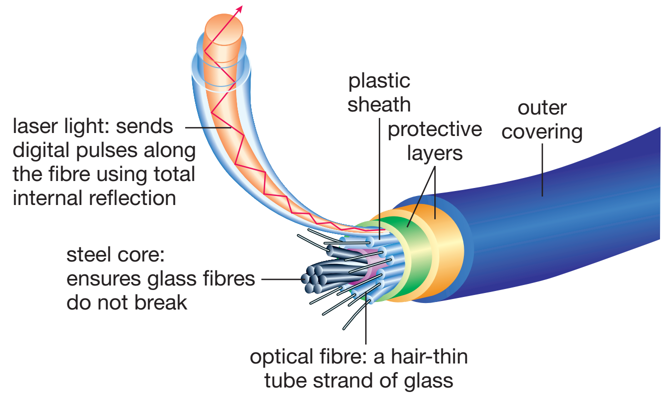



**Figure 5.3.3** A fibre optic cable is made up of many single optical fibres.

INQUIRY science 4 fun

## Bendy light

Light travels in straight lines. So can you make it turn a corner?

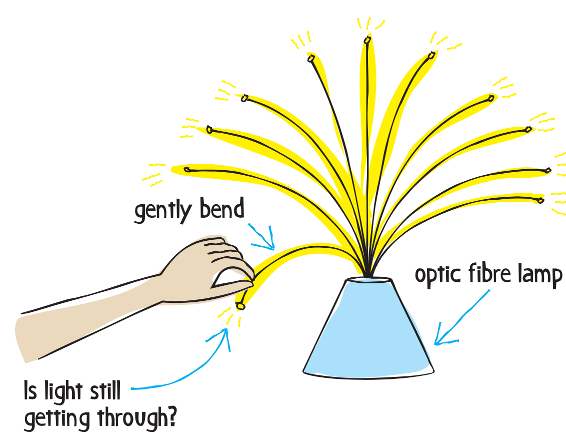
Yes

### Collect this …

- a fibre optic lamp

### Do this …

1. Turn on the lamp.
2. Carefully bend a single optical fibre, as shown in the diagram.
3. See how far you can bend the fibre but still see light coming out of its end.




### Record this …

**Describe** what happened when you bent the fibre.

**Explain** why you think this happened.

A laser produces a narrow beam of light waves that are said to be *coherent*, or in step with each other. Such coherent light is illustrated in Figure 5.3.4. Laser light (or LED light) is coded into the digital language of strings of binary numbers and is sent as a series of millions of light flashes down the optical fibre. This light is totally internally reflected as it travels along the tube. An optical receiver at the other end of the fibre converts these pulses back into a digital signal. Much higher frequency signals can be sent along a fibre optic system than can be sent through copper wires. As a result, a fibre optic system has much greater bandwidth than a copper system. A single optical fibre can carry over 30 000 telephone calls. This bandwidth can be expanded by sending signals of differing wavelength along the fibre at the same time. In addition, optical fibre is lighter and more flexible than copper cable. A signal can be transmitted around 200 km without any signal loss, and it suffers less interference than signals sent along a copper network.

1 p177

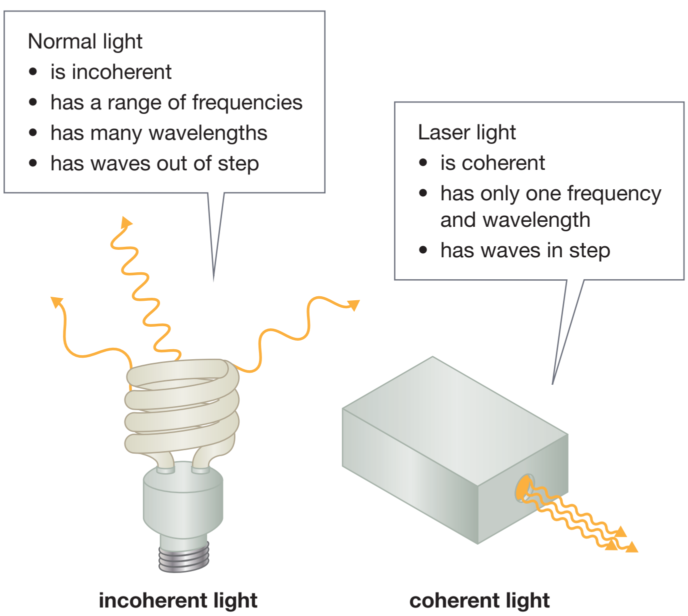



**Figure 5.3.4** Light from an ordinary light globe produces light with a range of frequencies. A laser produces light of one frequency that is coherent.

**SciFile**

**Slippery cables**

Fibre optic cables manufactured for use in Australia have a unique outer nylon jacket. This jacket protects the cabling from termites, which are unable to grip its slippery outer surface.

**Microwave links**

Microwave signals are directed in short, straight-line paths. About 2000 phone conversations can be carried using such a system, with repeater towers required every 50 km. Microwave satellite links are used for long-range mobile communications and for communications in remote areas.

## Mobile phone networks

Mobile phone networks send a digital signal of your voice through microwaves transmitted through the air. This system relies upon an interconnected series of base stations. These base stations are where antennas receive and transmit mobile phone signals. Each base station is located in the centre of a hexagonal region called a cell. Each cell uses a different frequency to transmit its signal, and no adjacent cells use the same frequency. When you dial a number, the base station in the cell that receives the strongest signal directs your call to the telephone exchange. The exchange then directs the call to the appropriate base station of the cell in which the receiving phone is held. This complex arrangement is shown in Figure 5.3.5.

**SciFile**

**What a yolk!**

Debate has raged over the question of whether mobile phone use may be linked to cancer. In 2000, a website claimed that an egg was hardboiled in 65 minutes while positioned between two operating mobile phones. Public outcry followed, with people wondering what their own phones were cooking inside their heads. The 'experiment' was later proved to be a hoax.

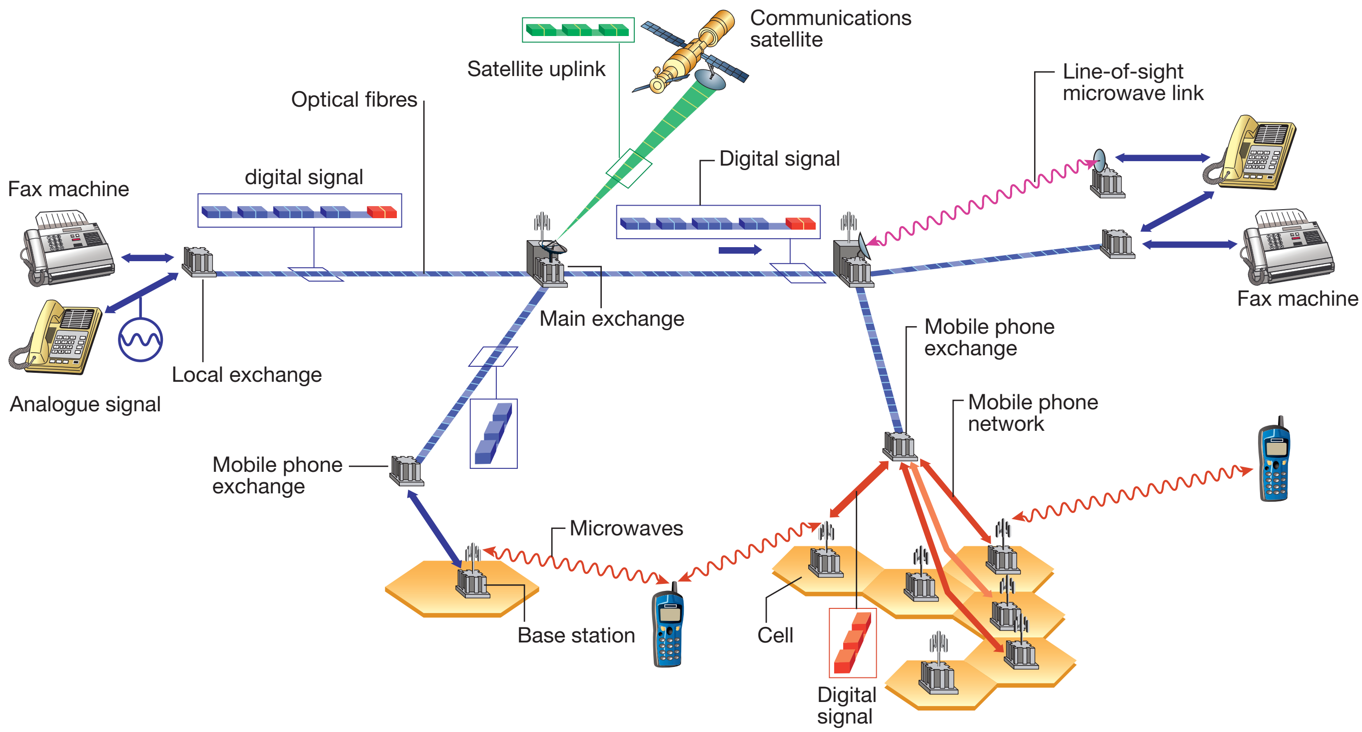



Figure 5.3.5 A modern communications network relies upon a number of channels of transmission, including copper cable, microwave links, satellite links and optical fibre. The short connections from a house to the communications network are usually made with copper wire.

## The internet

Using the internet, you can connect with people around the world in an instant. Documents that in the past would take days to reach a destination can be downloaded in minutes or seconds. A *router* is a device that manages the connection between your computer and your internet server. It is this device that is responsible for making sure your message reaches where it is meant to go.

Data to be sent as a downloaded file or email is first split into a 'packet' made up of about 1500 bytes. These packets then travel over a 'packet-switching network' in which each individual packet is directed along the best pathway for it to reach its destination. The router selects the best pathway by examining where the packet is to go and the type of network it is using. It directs the traffic in a way that eases congestion on major routes. The individual packets or snippets of the original message are reassembled when they reach their destination.

## Wireless internet networks

**Wireless internet** is a method of transmitting an internet connection using radio waves. It allows a Wi-Fi (wireless fidelity) enabled device such as a mobile phone, laptop, video game console, Bluetooth or MP3 player to connect to the internet when within range of an access point. An example is shown in Figure 5.3.6. This occurs in a similar way to mobile phones connecting to a wireless telephone network. Some businesses or places such as restaurants, coffee shops and airports offer free Wi-Fi hotspots where users can access the broadband facilities. Wi-Fi is a wireless alternative for internet access within local area networks (LANs). A Wi-Fi signal does not have a long range, only about 30 metres indoors and 100 metres outdoors. In regions further away from a wireless network that is connected to the internet, the Wi-Fi device cannot pick up a signal. In such cases, Wi-Fi is not an alternative to an internet system that operates using coaxial cable or optical fibres.

Figure 5.3.6 This WLAN (wireless local area network) card enables this laptop to link to a wireless broadband internet network.

# Gathering data about Earth

**Remote sensing** is the science of gathering, processing and analysing different types of electromagnetic radiation, such as that reflected or emitted by the Earth's surface, oceans and atmosphere. Such data is captured from a distance using a sensor called a radiometer. Some satellites, such as the Landsat satellites, incorporate multi-spectral scanners. These can detect electromagnetic radiation through a number of different bands, called *channels*. Each channel detects specific wavelengths of electromagnetic radiation, such as blue-green light, green light, red light and infrared radiation of differing energies. The radiation detected by the scanners has been naturally reflected, absorbed or emitted by the surface being studied. This detailed data can be combined to provide information about the moisture level of soils and clouds, and the mineral content of rocks. As a result, these satellites can be used to monitor land use and environmental change over time. They can also track ice and sand movement, map soil composition, or locate mineral deposits or the presence of surface water.

Particular substances reflect radiation in a characteristic way. Figure 5.3.7 shows the characteristic patterns of reflection of electromagnetic radiation for bare soil, vegetation, clear water and turbid (murky) water.

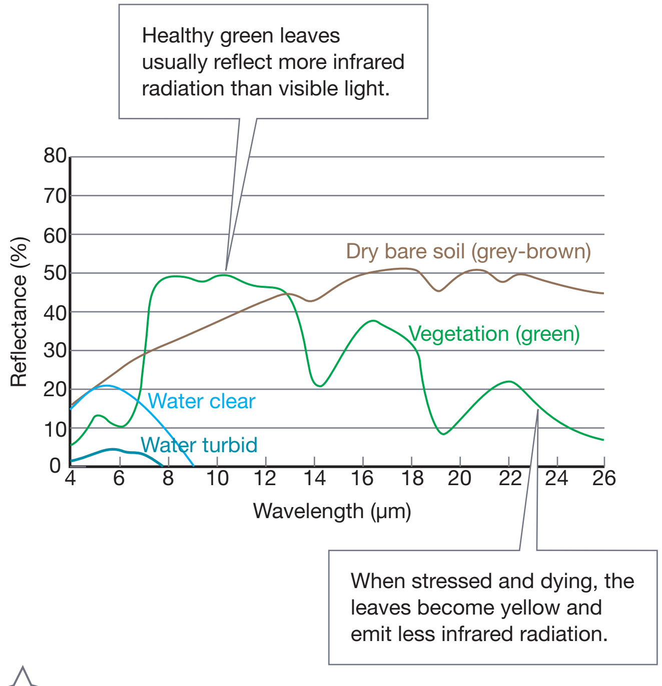



**Figure 5.3.7** Knowing the way different substances reflect radiation can be used to provide information about an unknown surface.

5.7

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## Active and passive remote sensing

Most remote-sensing techniques detect radiation that is naturally emitted or reflected from the area being studied. In these techniques, radiation such as solar radiation or infrared radiation of the Earth is analysed. Using natural reflection or emission is called **passive remote sensing**. Another form of remote sensing is called **active remote sensing**. In this case, radiation such as radio waves or microwaves is directed onto a target, and the radiation that is deflected from the target is detected and analysed. This technique is unaffected by dense cloud cover and can be done at night. It is used in urban mapping, rice mapping, flood mapping, agricultural monitoring and snow mapping. The image of Naples, Italy, shown in Figure 5.3.8 was captured using this technique. It indicates different sea surface roughness in different colours.

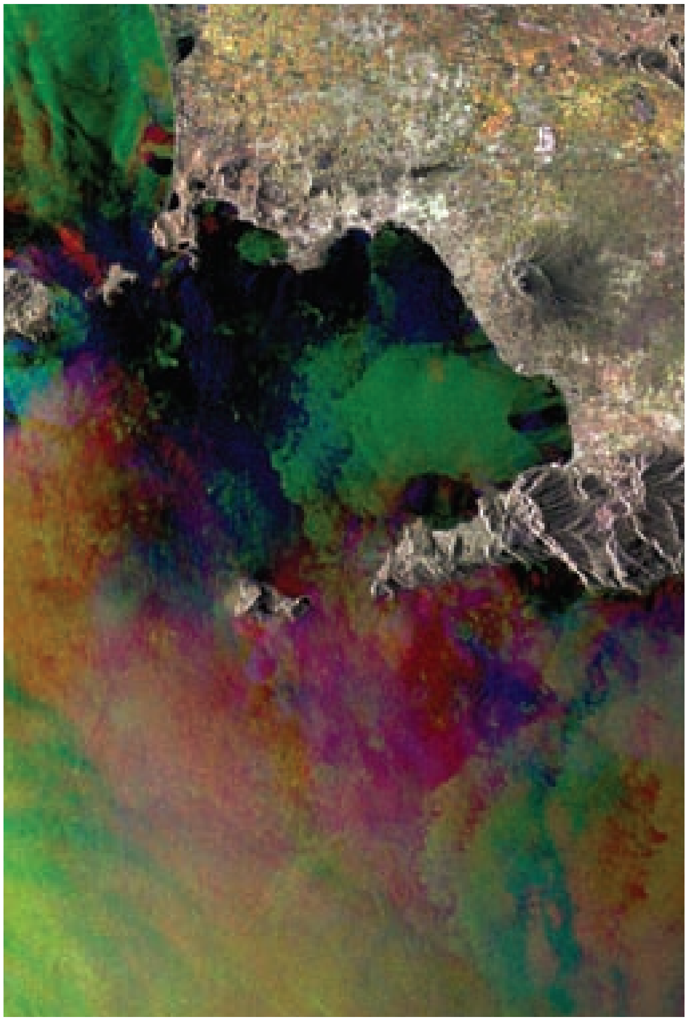


**Figure 5.3.8** This satellite image shows the seas around Naples, Italy. The different colours indicate different sea surface roughness due to winds. It was taken in 2004 using the SAR (a type of radar) on board the European ERS-2 satellite.

Figure 5.3.9 Dr John O'Sullivan

# SCIENCE AS A HUMAN ENDEAVOUR

## Use and influence of science

### Wifi helps CSIRO scientist win top gong

The technology that made wireless internet possible was developed by a team of Australian scientists.

This article appeared in *The Age* newspaper on 28 October 2009.

CRYSTAL JA

Almost two decades after pioneering high-speed wireless now used by almost a billion people each day, John O'Sullivan has won one of Australia's top science gongs.

The CSIRO scientist was awarded the prestigious Prime Minister's Prize for Science for 2009 for his WiFi technology now found in millions of laptops, printers, wireless access devices and even Nintendo's Wii.

One of Australia's most significant scientific breakthroughs, Dr O'Sullivan and his team found a way to speed up wireless networks in 1992—a problem that had previously stumped international scientists.

The idea has since generated a massive windfall for the CSIRO to the tune of $205 million and counting.

Dr O'Sullivan was given $300,000 at a gala event in Canberra on Wednesday.

Prime Minister Kevin Rudd said the award recognised Dr O'Sullivan's major contribution to astronomy as well as his groundbreaking WiFi technology.

'While looking for exploding black holes Dr O'Sullivan created a technology that cleaned up intergalactic radio waves,' Mr Rudd said.

'Then in 1992, he and his colleagues at CSIRO realised that the same technology was the key to fast reliable wireless networking in the office and home.'

'Their patented invention is now built into international standards and into computers, printers, smart phones and other devices used by hundreds of millions of people every day.'

Mr Rudd called it one of the most significant achievements in CSIRO's 83-year history and said it illustrated how scientific research can be turned into real and practical solutions.

Dr O'Sullivan and the CSIRO team beat 22 international labs to solve the 'multipath' problem—or the interference caused by reflected radio waves which slows down network speeds.

They found a way to accelerate them by splitting radio channels apart, essentially turning a one-lane road into a super highway and making wireless about five times faster.

But recognition has been a long time coming.

The CSIRO was forced to wage a long-running legal battle against big computer companies such as Microsoft for using the technology for free.

Out-of-court settlements and lucrative licensing deals have given the CSIRO one of its best performing inventions, from which it is contributing $150 million back into science research.

Dr O'Sullivan said the idea was born out of a need to 'cut the wires'.

'And to cut the wires, we needed to make it as fast as the wires,' he told AAP.

Seeing the technology in use in millions of devices around the globe, 'I can't help but feel proud,' he said.

'Even though we thought it had huge potential, I'm just blown away with how many applications there are now.'

Among the other winners, Michael Cowley took out the Science Minister's Prize for Life Scientist of the Year for breaking the link between fat and diabetes, while Amanda Barnard was named the Physical Scientist of the Year for her work in nanotechnology.

5.6

# 5.3 Unit review

## Remembering

1 **State** two disadvantages associated with analogue signals compared with using digital signals.

2 **Recall** the term that describes the amount of data a communication channel can carry.

3 **List** four common devices that may be Wi-Fi enabled.

4 **State** the indoor and outdoor range of a Wi-Fi signal.

## Understanding

5 **Describe** ways that information gathered from a Landsat satellite can be used.

6 **Describe** the function of a modem.

7 **Describe** the function of a router in an internet connection.

8 a **State** what Australian scientists at the CSIRO developed in 1992, under the leadership of Dr John O'Sullivan.

b **Describe** how this technology is used in everyday life.

9 **Outline** an advantage of using a multi-spectral scanner, compared with a single-channel radiometer.

10 a **Explain** the difference between active and passive remote sensing.

b **State** which type is used more frequently.

c **State** one advantage associated with using an active technique.

11 **Describe** what is meant by a *false-colour* image.

12 **Explain** why infrared scanners are used in search and rescue operations.

## Applying

13 Pulses of light are sent along optical fibres as a digital signal. **Identify** how the 1's and 0's of the signal are transmitted.

## Analysing

14 a **Compare** FDM and TDM.

b **Explain** the purpose of these techniques.

15 **Compare** the number of two-way conversations that can be carried by a typical twisted pair cable, a coaxial cable and a fibre optic cable.

## Evaluating

16 **Propose** why both coaxial cable and optic fibres are wrapped in an outer plastic jacket.

## Creating

17 **Design** a home of the future. In your design, label all the places in the home where you predict it will be possible to communicate with others or to access wireless internet.

## Inquiring

1 The use of radar in World War II was a great advantage to the British during the Battle of Britain in 1940. Describe how this technology was used in wartime.

2 Research the evidence concerning any link between mobile phone use and cancer. Analyse your findings and state your position on this issue.

3 Construct a timeline outlining the history of the development of one of the following technologies:
- the USB device
- iPods
- Facebook
- Twitter
- email
- the world wide web.

4 Use a NASA website to investigate the types of electromagnetic radiation gathered from three different satellites or observatories. Describe what can be discovered from this information.

5 Investigate factors that influence the reception of a mobile phone. Test your mobile in different areas of your school or neighbourhood, and in locations such as inside a metal box. Describe your findings.

# 5.3 Practical activities

## 1 Using light

### Purpose

To use glass prisms and a light source to model how light is totally internally reflected along an optic fibre.

### Materials

- light box
- power pack
- 3 glass prisms
- length of optical fibre

### Procedure

1. Connect the light box to the power source and direct a single beam of light at a glass prism.
2. Rotate the prism. Look at what happens to the incident ray as you do this.
3. Find a position in which all the light is reflected from the inside glass surface. This is called *total internal reflection*, and will only occur when rays hit the glass at an angle larger than a specific critical angle.
4. Now place a second prism in the pathway of the reflected beam and rotate it so that the beam is totally internally reflected again by the second prism.
5. Repeat this process once more, using a third prism. You should be able to make the ray of light travel in the opposite direction to its original pathway using these three prisms. Use Figure 5.3.10 as a guide.
6. Sketch the orientation of your three prisms and the reflected rays of light.
7. Curve an optical fibre into a shape that is similar to that of the light pathway that you have just drawn. Direct light along the fibre.
8. Change the shape of the fibre to see if the light can be transmitted through it.

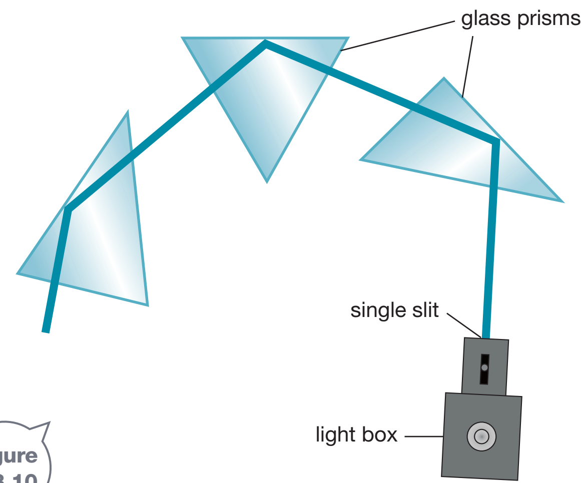



Figure 5.3.10

### Discussion

1. **Describe** what you observed happen to the ray of light as you rotated the first prism.
2. **Explain** how total internal reflection of light could be useful in communication.
3. **Construct** a diagram to show what you observed when you tried to shine light through the optical fibre.
4. **Discuss** what you found when you tried to direct the light through the fibre when bent in different directions.
5. **Identify** features of an optical fibre that make it a useful channel of communicaton usng light.

## 2 Heating the Earth and the sea

### Purpose

To investigate whether soil heats up at the same rate as water.

### Materials

- 3 identical petri dishes
- enough soil to fill two dishes
- 2 or 3 large leaves with a small amount of stem attached
- water
- incandescent desk lamp
- 3 thermometers or temperature probes
- rubber gloves

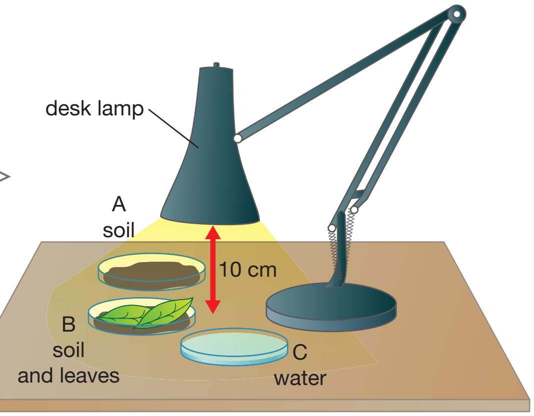
**SAFETY**

Warning:
Do not touch the hot globe.
Wear rubber gloves when handling soil.

### Procedure

1. Construct a results table similar to the one shown.
2. Turn on the desk lamp and leave it to warm up for several minutes.
3. Fill two dishes with soil.
4. Push the stems of the leaves into one of the soil samples.
5. Measure the soil temperature.
6. Using hot and cold taps, adjust these until the flowing water is approximately the same temperature as the soil.
7. Fill the third dish with water at this temperature.
8. Position the three dishes 10 cm below the light source, as shown in Figure 5.3.11. (Be careful to have the dishes equally spaced from the light source.)

Figure 5.3.11




### Results

1. Record the initial temperature of the three samples, and then the temperature of each every 5 minutes.

| Time (min) | Temperature (°C) | | |
|---|---|---|---|
| | Soil sample | Soil and vegetation | Water |
| 0 | | | |
| 5 | | | |
| 10 | | | |
| 15 | | | |
| 20 | | | |
| 25 | | | |
| 30 | | | |

2. Construct a graph showing the temperature variations of the three dishes over the 30 minutes, using a single set of axes.

### Discussion

1. **Describe** how the three samples heated up.
2. **Use** your results to **propose** whether open surfaces of land, land with vegetation or oceans would heat up more rapidly from the Sun.
3. **Propose** one improvement you could make to the design of this experiment.

# Chapter review 5

## Remembering

1 **State** the type of electromagnetic radiation that is emitted by radioactive materials.

2 **State** the approximate wavelength of an FM radio wave.

3 **State** whether AM or FM radio waves are more likely to experience static.

4 **Recall** which secondary colour is produced when red light and blue light are combined.

## Understanding

5 **Describe** two uses of microwave radiation.

6 a **List** three products that may contain fluorescent additives.
  b **Explain** why these are added to these products.

7 a **Describe** what is meant by *Wi-Fi*.
  b **List** three situations in which such technology is useful.

## Applying

8 Su-Ann sits on the beach and watches the waves roll in. She calculates that the waves are arriving every 5 seconds, a frequency of 0.2 Hz. Given that the waves have a wavelength of 2 metres, **calculate** the speed of the waves.

9 Huong and Callum are relaxing on a beach. Huong is wearing red-tinted sunglasses and Callum wears yellow-tinted ones. Emily jogs past them wearing a white T-shirt, green shorts and a magenta cap. **Identify** the apparent colours of Emily's clothes to Huong and Callum.

## Analysing

10 **Compare** a transverse wave and a longitudinal wave.

11 **Use** Figure 5.1.6 on page 151 to **classify** each of the following electromagnetic wavelengths into a type of electromagnetic radiation.
  a 2 cm
  b 3 km
  c 0.0008 m
  d 0.0000003 m

12 **Classify** the following UV Index readings as extreme, very high, high, moderate or low.
  a 2
  b 7
  c 12

13 Pigment X reflects mostly orange light with a little red and yellow, but absorbs other colours. Pigment Y reflects mostly green light, with some blue and yellow, but absorbs all other colours. You dye your favourite socks in a mixture of X and Y. **Analyse** this information to **predict** the new colour of your socks.

## Evaluating

14 **Propose** how the world would be different if optic fibres had never been invented.

15 **Propose** reasons why a mobile phone is sometimes referred to as a *cell* phone.

16 **Assess** how information such as that shown in the graph in Figure 5.3.8 on page 175 could be useful in remote sensing applications.

17 Radio waves are directed onto water droplets and the scattered radiation is detected, to reveal information about the nature of a storm. **Deduce** whether this is an active or passive technique.

## Creating

18 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

electromagnetic radiation, electromagnetic waves, electromagnetic spectrum, radio waves, microwaves, infrared radiation, visible light, ultraviolet light, X-rays, gamma rays

# Thinking scientifically

**Q1** Sheena is carrying out an experiment using three tin cans. These are identical except that one is painted black, one is painted white and one is painted light grey. Sheena's teacher tells her that dark colours are better absorbers of infrared radiation than lighter colours. The air temperature in each can is 20° at the start of the experiment. The cans are placed near a heater.

Select the likely temperature of the black, silver and white cans after an hour.

**A** black 30°, light grey 40°, white 50°
**B** black 50°, light grey 20°, white 40°
**C** black 50°, light grey 40°, white 30°
**D** black 30°, light grey 50°, white 40°

**Q2** The unit of measurement for radiation dose is the millisievert (mSv). The following table reveals the effective radiation dose involved in particular medical procedures and diagnostic tests.

| Procedure | Effective radiation dose (mSv) |
|---|---|
| CT abdomen and pelvis | 10 |
| Radiography spine | 1.5 |
| CT head | 2 |
| Bone densitometry (DEXA) | 0.001 |
| Mammography | 0.7 |

CT: computed tomography

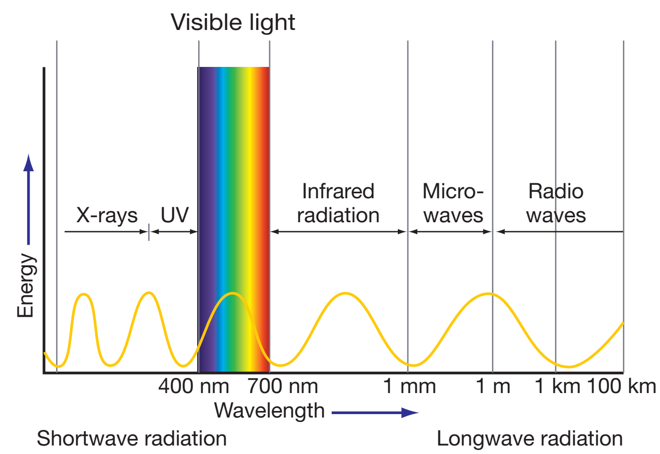
Which of the following lists the effective radiation dose absorbed by a person in order of increasing dose?

**A** bone densitometry (DEXA), CT head, CT abdomen and pelvis, radiography spine, mammography
**B** CT head, CT abdomen and pelvis, radiograph spine, mammography, bone densitometry (DEXA)
**C** bone densitometry (DEXA), mammography, radiography spine, CT head, CT abdomen and pelvis
**D** CT abdomen and pelvis, CT head, radiography spine, mammography, bone densitometry (DEXA)

**Q3** Jimmy listens at close range to a trumpet being played. If the final note of the song has a frequency of 440 Hz, calculate the number of sound waves passing Jimmy each second.

**A** 110
**B** 440
**C** 220
**D** 880

**Q4** Study this diagram, which shows the energy and wavelength of various types of electromagnetic radiation.




Identify which list ranks this radiation in order from longest to shortest wavelength.

**A** X-rays, infrared radiation, microwaves, radio waves
**B** X-rays, visible light, UV light, infrared radiation
**C** radio waves, UV light, microwaves, infrared radiation
**D** radio waves, infrared radiation, UV light, X-rays

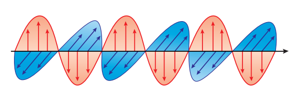
**Q5** Infrared radiation has a band of energies just below those of visible light. Given that red light has a wavelength of approximately $4.0 \times 10^{-7}$ m, predict which wavelength below would be classed as infrared radiation.

**A** $2.0 \times 10^{7}$ m
**B** $2.0 \times 10^{3}$ m
**C** $2.0 \times 10^{-9}$ m
**D** $2.0 \times 10^{-5}$ m

# Glossary

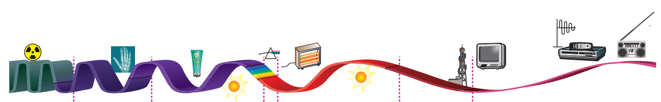
## Unit 5.1

**Electromagnetic radiation:** a range of electromagnetic waves consisting of oscillating electric and magnetic fields travelling at the speed of light



Electromagnetic radiation

**Electromagnetic spectrum:** the entire range of frequencies of electromagnetic radiation, from high-energy gamma rays to low-energy radio waves



Electromagnetic spectrum

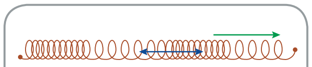
**Electromagnetic wave:** transverse electric and magnetic fields positioned at right angles to each other and travelling through empty space at the speed of light

**Frequency:** the number of waves produced per second, measured in hertz (Hz)

**Gamma rays:** extremely high-energy electromagnetic radiation emitted by radioactive materials

**Infrared radiation:** a band of the electromagnetic spectrum with energies just below that of visible light, detected by our skin as heat

**Longitudinal wave:** a wave in which its particles vibrate in the same direction as that of the wave itself

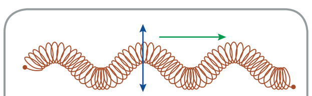


Longitudinal wave

**Microwaves:** electromagnetic radiation with wavelengths ranging from a fraction of a millimetre to tens of centimetres, used in communication and cooking

**Radio waves:** electromagnetic radiation with wavelengths ranging from hundreds of metres to tens of centimetres, used in communication

**Transverse wave:** a wave in which its particles vibrate at right angles to the direction of motion of the wave



Transverse wave

**Ultraviolet (UV) light:** a band of electromagnetic radiation with energies just above those of visible light, contained in sunlight

**Visible light:** a band of electromagnetic radiation detected by our eyes

**Wave motion:** the transfer of energy without transferring matter

**Wavelength:** the distance between successive wave crests, measured in metres

**X-rays:** high-energy electromagnetic radiation that can penetrate materials

## Unit 5.2

**Colour filter:** a transparent material that allows light of a particular colour to pass through

**Dispersion:** splitting of white light into separate colours

**Polarised:** electromagnetic radiation that is travelling in a single plane

**Primary colours of light:** red, green and blue

**Secondary colours of light:** cyan, yellow and magenta

**Visible spectrum:** the range of colours that can be seen by the eye (red, orange, yellow, green, blue, indigo and violet)

## Unit 5.3

**Active remote sensing:** detecting the reflection or emission of radiation (such as microwaves) that was directed onto a target

**Analogue signal:** a continuous signal that varies in amplitude or frequency with the information being transmitted

**Bandwidth:** the amount of data that can be transmitted through a communication channel

**Binary number system:** a number system consisting only of two digits: 0 and 1

**Digital signal:** a discrete signal consisting of a series of 'on' or 'off' pulses

**Frequency division multiplexing (FDM):** transmission of several signals along a single channel using different frequencies

**Optical fibre:** a narrow tube of glass or plastic used to transmit pulses of light.

**Passive remote sensing:** detecting the reflection or emission of naturally occurring electromagnetic radiation from a target

**Remote sensing:** a means of gathering information about an object or event without direct physical contact, e.g. using weather satellites to monitor atmospheric conditions

**Time division multiplexing (TDM):** transmission of several broken and interwoven signals along a channel using a single frequency

**Wireless internet (Wi-Fi):** a method of transmitting an internet signal using radio waves

# 6 Electrical energy

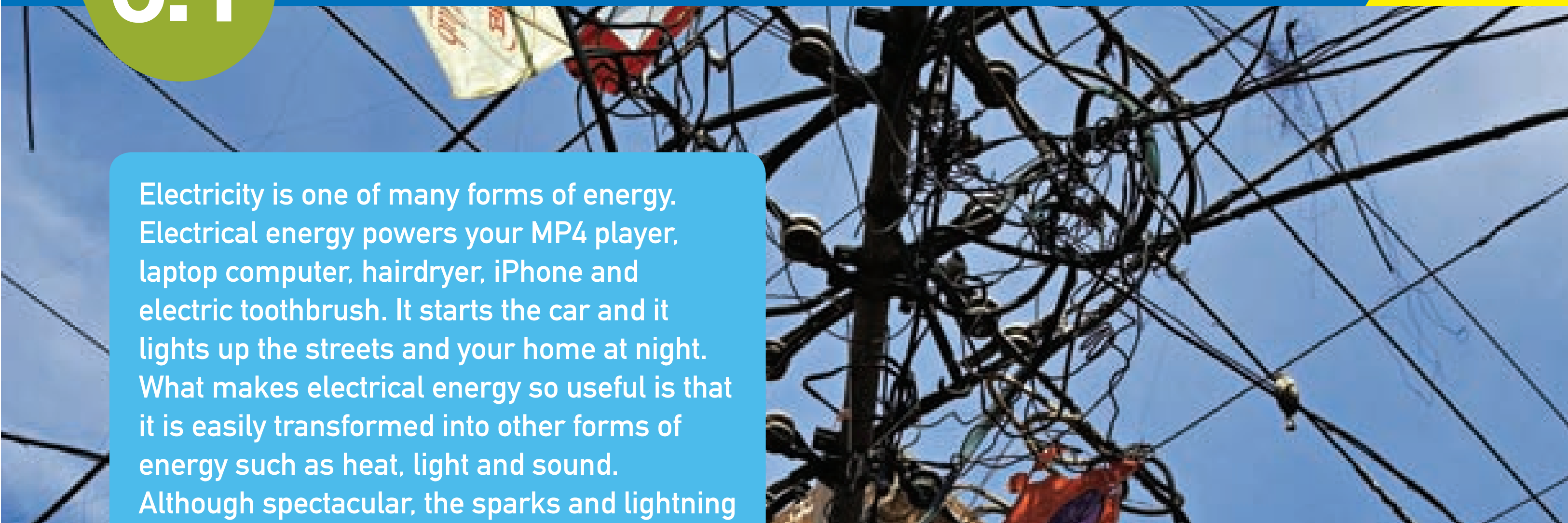
## HAVE YOU EVER WONDERED …

- why electricity is so dangerous if something goes wrong?
- how the electricity you get from a wall socket is produced?
- how electric motors work?
- what the difference between AC and DC electricity is?

### After completing this chapter students should be able to:

- describe the structure of the atom in terms of the nucleus, protons, neutrons and electrons
- describe factors that affect the transfer of energy through an electric circuit
- describe specific safety precautions with electricity
- evaluate claims relating to products such as electrical devices
- discuss the impacts of human activity from a range of different perspectives
- describe how scientific and technological advances have minimised pollution from industry
- describe how choices related to the use of fuels are influenced by environmental considerations.

# 6.1 Simple circuits



Electricity is one of many forms of energy. Electrical energy powers your MP4 player, laptop computer, hairdryer, iPhone and electric toothbrush. It starts the car and it lights up the streets and your home at night. What makes electrical energy so useful is that it is easily transformed into other forms of energy such as heat, light and sound. Although spectacular, the sparks and lightning bolts of static electricity aren't very practical. Current electricity is the form of electricity that you use every day and is the form that you get from batteries and from power points. To use current electricity, you need an electric circuit.

INQUIRY science 4 fun

## Sparks on opening!

Forces bond the particles in a solid together and energy is needed to break them. Can you see the energy released when these bonds break?

Yes

### Collect this ...

- self-stick envelope
- sugar cubes
- pliers or multi-grips

### Do this ...

1. Do this activity at night or in a very dark room. Allow your eyes time to get used to the dark before you start.
2. Seal a self-stick envelope. While in the dark, open the seal as quickly as you can (don't tear the envelope, just open its seal).
3. If you're unsure what happened, then seal the envelope and repeat.
4. While still in the dark, crush a sugar cube with pliers or multi-grips.

### Record this ...

**Describe** what happened.

**Explain** why you think this happened.

## Electric charge

Everything is made of atoms, which are themselves made of **protons**, **neutrons** and **electrons**. As Figure 6.1.1 shows, protons and neutrons are located in a small and dense core called the **nucleus**. Around the nucleus spin tiny electrons. Protons and electrons are electrically charged. Protons carry a positive charge (+) and electrons carry a negative charge (–). Neutrons carry no charge and are said to be **neutral**. Overall, the atom is neutral, because the numbers of protons and electrons are always equal. Their opposite charges balance each other out and so the atom has no overall charge.

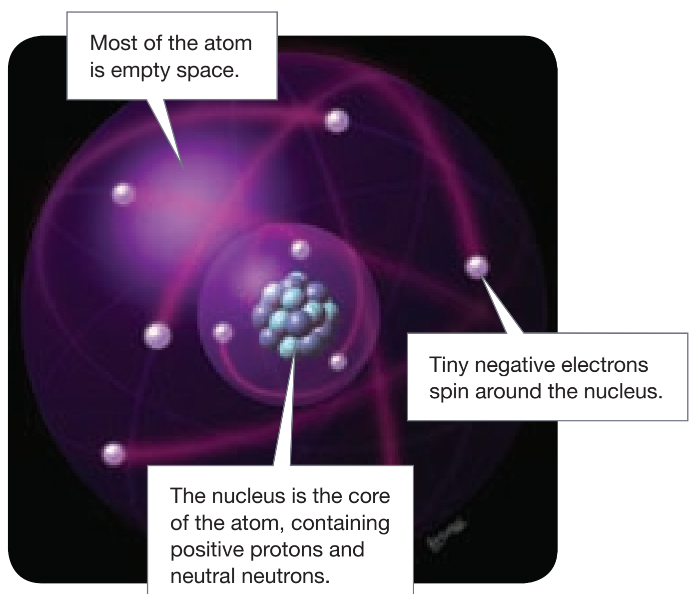



Figure 6.1.1 Atoms are neutral but contain charged particles. Charges form when there are unequal numbers of protons and electrons.

However, electrons sometimes get knocked, rubbed or pulled off an atom. This leaves the atom with more protons than electrons, giving the atom an overall positive charge. This 'charged atom' is known scientifically as an **ion**. In this case, it's a positive ion. The electrons that have been removed then attach themselves to another atom nearby. The atom to which they attach themselves will then have more electrons than protons and so will have a negative charge. A negative ion is formed.

## Static electricity

**Static electricity** is the build-up of electric charge on a surface. This build-up of charge most commonly occurs because the surface has been rubbed against another surface. Electrons have been rubbed off one surface (charging it positive) and have transferred to the other surface (charging it negative).

Static charge usually leaks away after some time into its surroundings, including the air around it. This returns the materials to their original neutral state. However, if the build-up of charge continues, the electrons may jump across a gap from the negatively charged surface back to the positively charged surface. As they jump back, the electrons release all their energy in one go. This converts the energy into the heat, light, sound and motion (kinetic energy) that you observe as a spark or lightning bolt. This is what is happening in Figure 6.1.2.

Figure 6.1.2 A lightning bolt happens when static charge builds up within the atmosphere and then jumps to Earth, a building or another cloud.

1 p188

**SciFile**

**Strike me lucky!**

A bolt of lightning:

- is about 5 cm wide
- has a temperature of around 30 000°C (hotter than the surface of the Sun)
- is the main source on Earth of plasma, the fourth state of matter
- could power a 25 watt light globe for a year!

**SciFile**

**Bright spark!**

Electrons from a 240 V power point have insufficient energy to jump the gap in a switch. However, extreme voltages cause air in the gap to break down, allowing a spark to jump across it! A 1 cm gap requires about 3000 V for it to 'spark'.

## Current electricity

The electricity you get from a battery or a power point is not static electricity. It is made up of electrons moving along a wire, like those in Figure 6.1.3. This movement of charge is called an electric **current**. These moving electrons have energy that is transformed into other forms of energy as the electrons pass through things like light globes (transforming electrical energy into light), heating elements (into heat) and motors (into movement).

If the electrons don't move, no energy is received by the light globe, heater or motor and so nothing happens. It remains 'off'.

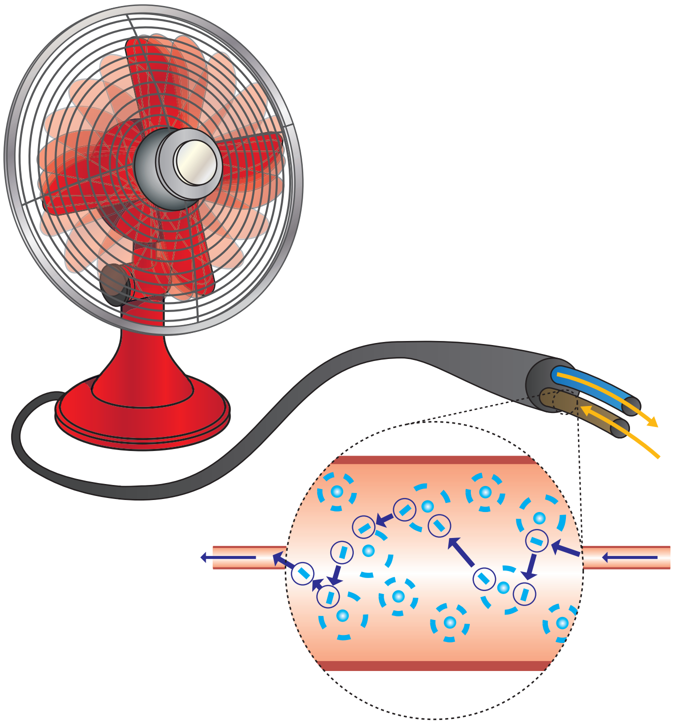


Figure 6.1.3 Electrical appliances work because electrons flow through their circuits. The energy the electrons carry is then transformed into heat, light or motion.

# Simple electric circuits

Electrons need a path to travel around so that they can deliver their energy. This path is called an **electric circuit**. As Figure 6.1.4 shows, an electric circuit needs:

- an energy source, such as a battery or a generator like the dynamo on a bike. This supplies the electrons in the wire with the energy they require to get them moving around the circuit
- an energy user, such as a light globe, heating element or motor. These devices convert the energy that electrons are delivering to them
- wires to connect everything, making the circuit complete.

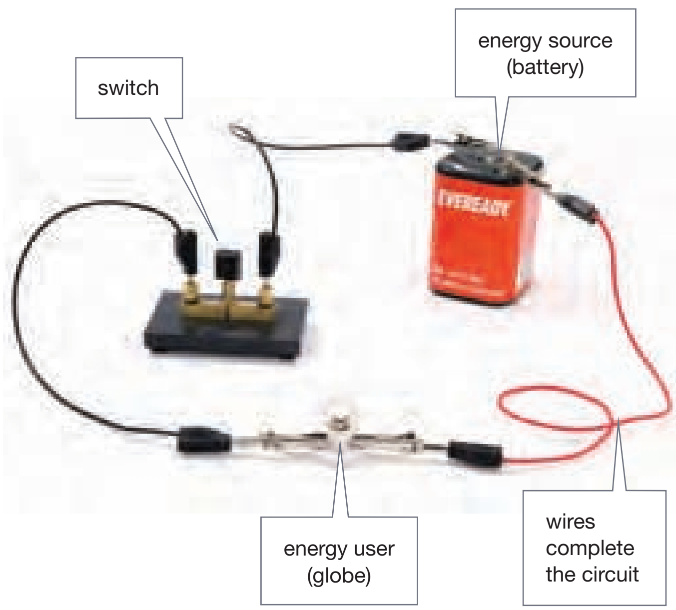



**Figure 6.1.4** A circuit needs an energy source, an energy user and wires to connect them all. The circuit usually has a switch too.

Any break in an electric circuit stops the flow of electrons and stops them from delivering their energy. Most electric circuits have switches that deliberately break the circuit, turning it on and off.

# Circuit components

The different parts of a circuit are known as its **components**. Each component is given a different symbol. This makes diagrams of circuits easier to construct and easier to understand. Some of these components are shown in Figure 6.1.5.

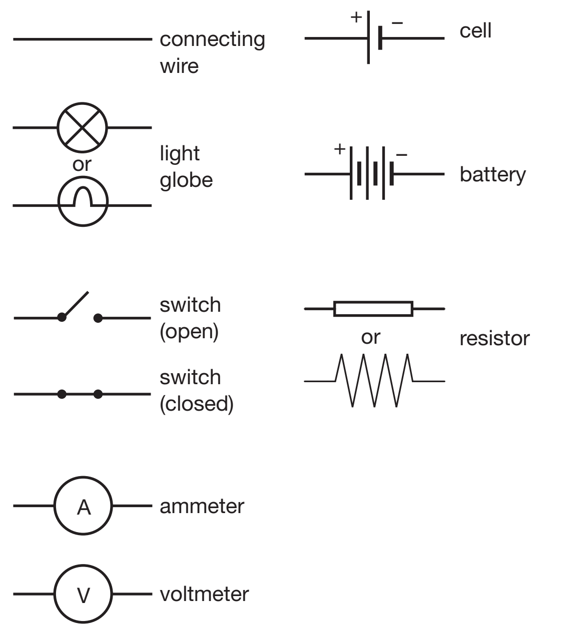



**Figure 6.1.5** These symbols are used to show the different components that are connected up to make a circuit.

## Circuit diagrams

A **circuit diagram** is a simplified and shorthand version of a real circuit. It shows how all the components in the circuit are connected.

A torch is an example of a very simple circuit. Its energy source is a battery and its globe transforms electrical energy into light. The circuit diagram for the torch is shown in Figure 6.1.6. The battery supplies the electrons with energy. As the electrons flow through the globe, they lose almost all their energy, which is transformed into light energy and some heat energy. The electrons then travel back to the battery, where their energy is replenished.

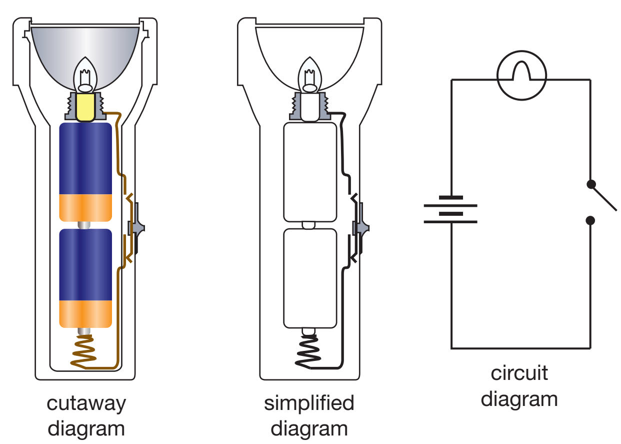



**Figure 6.1.6** A torch has a battery, a globe, wires and a switch.

# 6.1 Unit review

## Remembering

1 **State** whether the charges of the following are positive, negative or neutral.
- a an atom
- b a proton
- c a neutron
- d an electron

2 **Recall** charges by copying the following statements and completing them. To complete each statement, insert the sign = or > (is greater than) or < (is less than).
- a In an atom, the number of protons ___ the number of electrons.
- b In a positive ion, the number of protons ___ the number of electrons.
- c In a negative ion, the number of protons ___ the number of electrons.

3 **List** the forms of energy released when a spark jumps across a gap.

4 **Name** the charged particles that carry an electric current through a circuit.

5 **List** what an electric circuit needs.

6 **List** three examples of each of the following components of an electrical circuit.
- a an energy supplier
- b components that use electrical energy

7 **Recall** the symbols for the following electric components by sketching them.
- a globe
- b battery
- c single cell
- d switch

## Understanding

8 **Define** the following terms.
- a nucleus
- b neutral
- c component

9 **Calculate** whether the particles in Figure 6.1.7 would be neutral, positively charged or negatively charged.

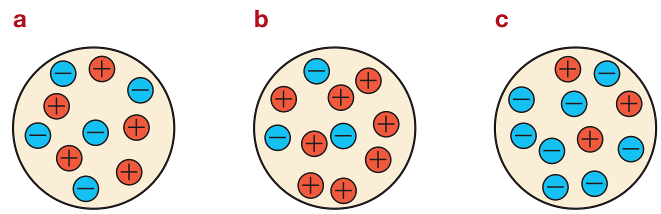



Figure 6.1.7

## Applying

10 **Identify** whether the following are displays of static electricity or current electricity in action.
- a the spinning motor of a hairdryer
- b lightning
- c a spark felt when you touch a doorknob after walking across carpet
- d the TV when it is on

## Analysing

11 **Contrast** static electricity with current electricity.

12 **Analyse** the circuits shown in Figure 6.1.8 and **identify** which globe(s) would never light up.

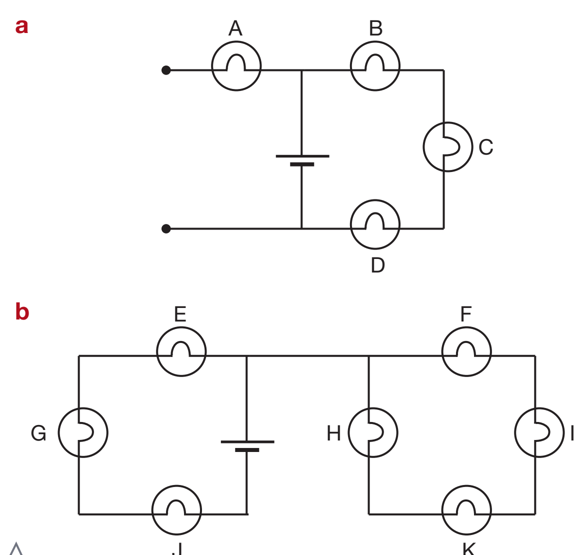



Figure 6.1.8

## Evaluating

**13** It is difficult to get all the grains of rice out of the plastic bags they come in, because some always stick to the sides. **Propose** an explanation for this observation.

## Creating

**14** **Construct** circuit diagrams for the circuits shown in Figure 6.1.9.

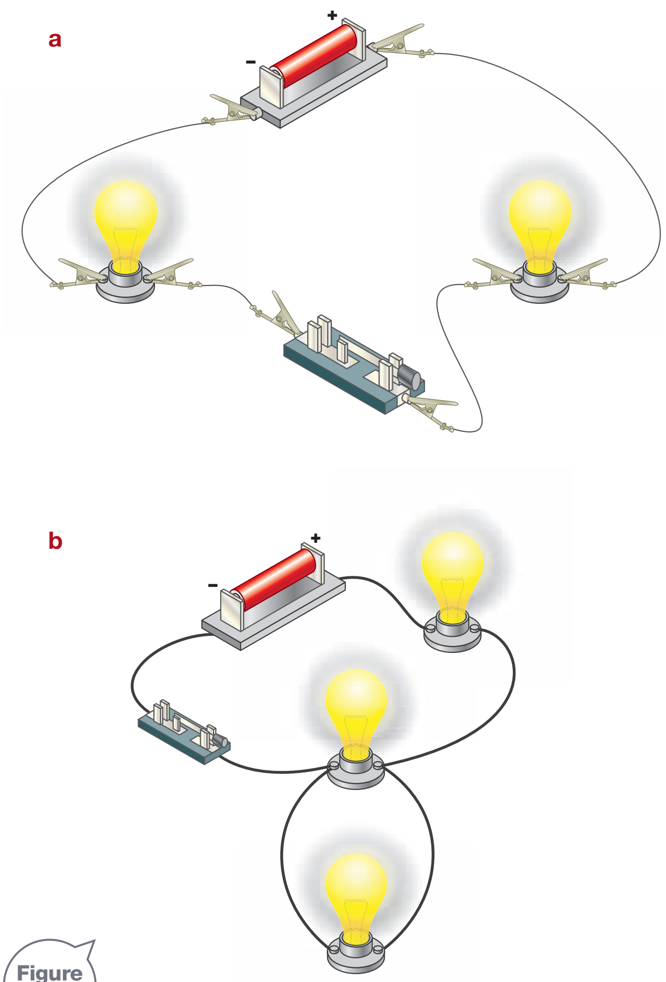



Figure 6.1.9

## Inquiring

**1** Research lightning. Find out:
- **a** how it is generated
- **b** how it discharges (releases)
- **c** its voltage
- **d** what it is most likely to strike
- **e** whether it can strike the same place twice
- **f** what you should do if you are outside when lightning is around.

**2** Investigate animals that detect their prey by using the electrical signals that come from the movement of the prey's muscles. You might investigate the platypus, sharks or manta rays.

**3** Find video clips showing amazing lightning strikes and static electricity displays.

**4** Pull apart a torch and follow its circuit from battery to globe and back again. Note that the torch might not use wires but might use the torch body, strips of metal or springs instead. Construct a labelled diagram of your torch and a circuit diagram that summarises how it works.

**5** Research the internet for instructions on how to make a super-sparker. Collect the materials required and construct one. Beware of the sparks!

**6** Static electricity makes it difficult to empty 'hundreds and thousands' from a dry plastic container. Plan an investigation to test what factors make them more 'sticky' and more difficult to remove.

# 6.1 Practical activities

## 1 Electroscopes

An electroscope detects whether an object is charged, and indicates whether it is positive or negative.

### Purpose

To construct an electroscope and use it to test the charge on different objects.

### Materials

- 3M Scotch Magic Tape® or similar
- small plastic cup such as the top from a soft drink bottle
- play dough or plasticine
- 2 plastic straws with an end that can be bent
- marking pen
- plastic comb
- various electrostatic rods (Perspex, ebonite) and cloths (wool, cotton)

### Procedure

**Part A: Testing the tape**

1 Cut two strips of sticky tape (each about 10 cm long). Record what happens when you hold the two strips of tape close to each other:
- with their sticky sides facing each other
- with the sticky side of one tape facing the non-sticky side of the other.

**Part B: Constructing your electroscope**

2 Make a base by adding play dough or plasticine to the small plastic cup. Then stick the straws in the base and bend the other end so that your set-up looks like Figure 6.1.10.

3 Cut two 10 cm lengths of tape. Stick one on your bench, leaving a little overhanging that can be used as a 'handle'. Stick the other tape on top of the first tape, once again leaving a little 'handle'. Label the tape on top with 'TOP'.

4 Rip the top tape off and stick it to the arm of one straw. Rip the bottom tape off the bench and stick it to the other straw.

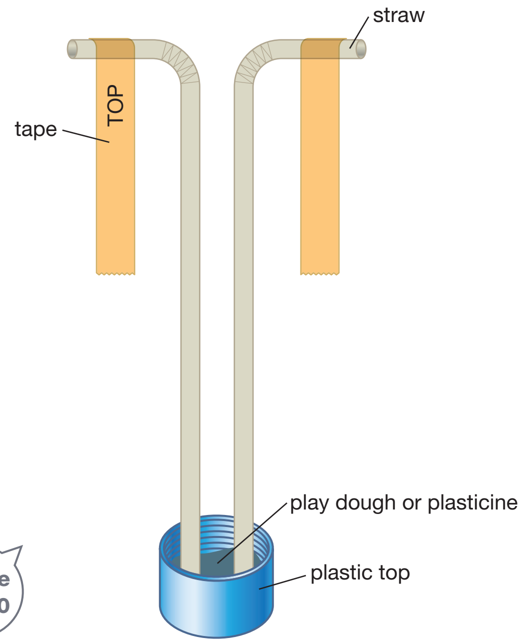



Figure 6.1.10

**Part C: Using your electroscope**

5 In your workbook, construct a table like the one shown on page 189.

6 Rub the plastic comb on your hair. Place the comb near (don't touch) the tapes and record your observations in the table.

7 Repeat step 6 with a balloon and different rods rubbed against different materials.

8 Finally, point your finger (don't touch) at each of the tapes.

### Results

1 Record what you saw when you brought the following sides of the tapes to face each other:
   - **a** sticky facing sticky
   - **b** sticky facing non-sticky.

2 Record your results to Part C in your table.

3 The charge on the comb is negative when rubbed against your hair. Use the results obtained for the comb to predict the charges of the other objects based on what they do to the electroscope.

| Object | Rubbed against | Top tape | Unmarked (bottom) tape | Object's charge (+, – or neutral) |
|---|---|---|---|---|
| Comb | Hair | Attracts | Repels | – |
| Balloon | Hair | | | |
| Perspex | | | | |
| Ebonite | | | | |
| | | | | |

### Discussion

1 **State** which arrangement of tapes (sticky side facing sticky or sticky side facing non-sticky):
   a attracted    b repelled.
2 **Use** the idea of static electricity to **explain** your results in the previous question.
3 **Propose** reasons why the tapes were charged after being ripped off:
   a the roll    b each other.
4 **Explain** why charged objects repel or attract the tapes.

## 2 How steady are you?

### Purpose

To construct a simple, fun electrical circuit.

### Materials

- 1 wire coat hanger
- wooden board
- 2 screws
- 1 empty plastic pen casing
- sticky tape
- electrical leads
- alligator clip
- globe
- switch
- battery
- access to pliers or multi-grips
- access to screwdriver

### Procedure

1 Cut a length of coat hanger wire and bend it into a twisted shape. Use screws to secure it to the wood so that the wire stands upright.
2 Cut another length of coat hanger wire and bend one end into a loop around the twisted wire. Insert the other end into the plastic body of a used pen. Secure both ends with tape.
3 Connect up the circuit as shown in Figure 6.1.11.
4 Test how steady your hand is by trying to pass the loop along the twisty wire without making the globe light up.

### Discussion

1 **Explain** why the globe only lights up when you touch the twisty wire with the loop.
2 Electrical current can pass along a coat hanger wire. **Justify** this claim.
3 Imagine you touched the loop half way along the twisty wire. **Contrast** what is happening to the electrons in each half of the twisty wire when this happens.

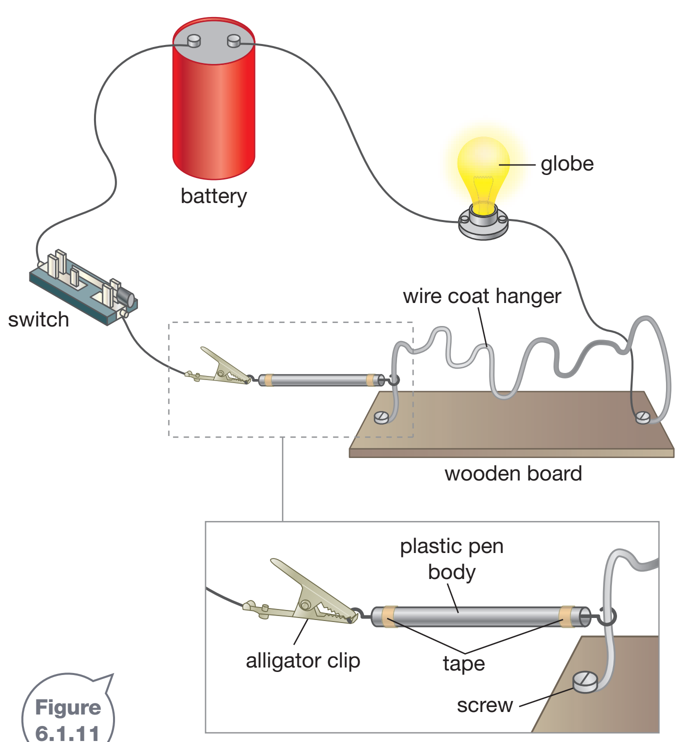
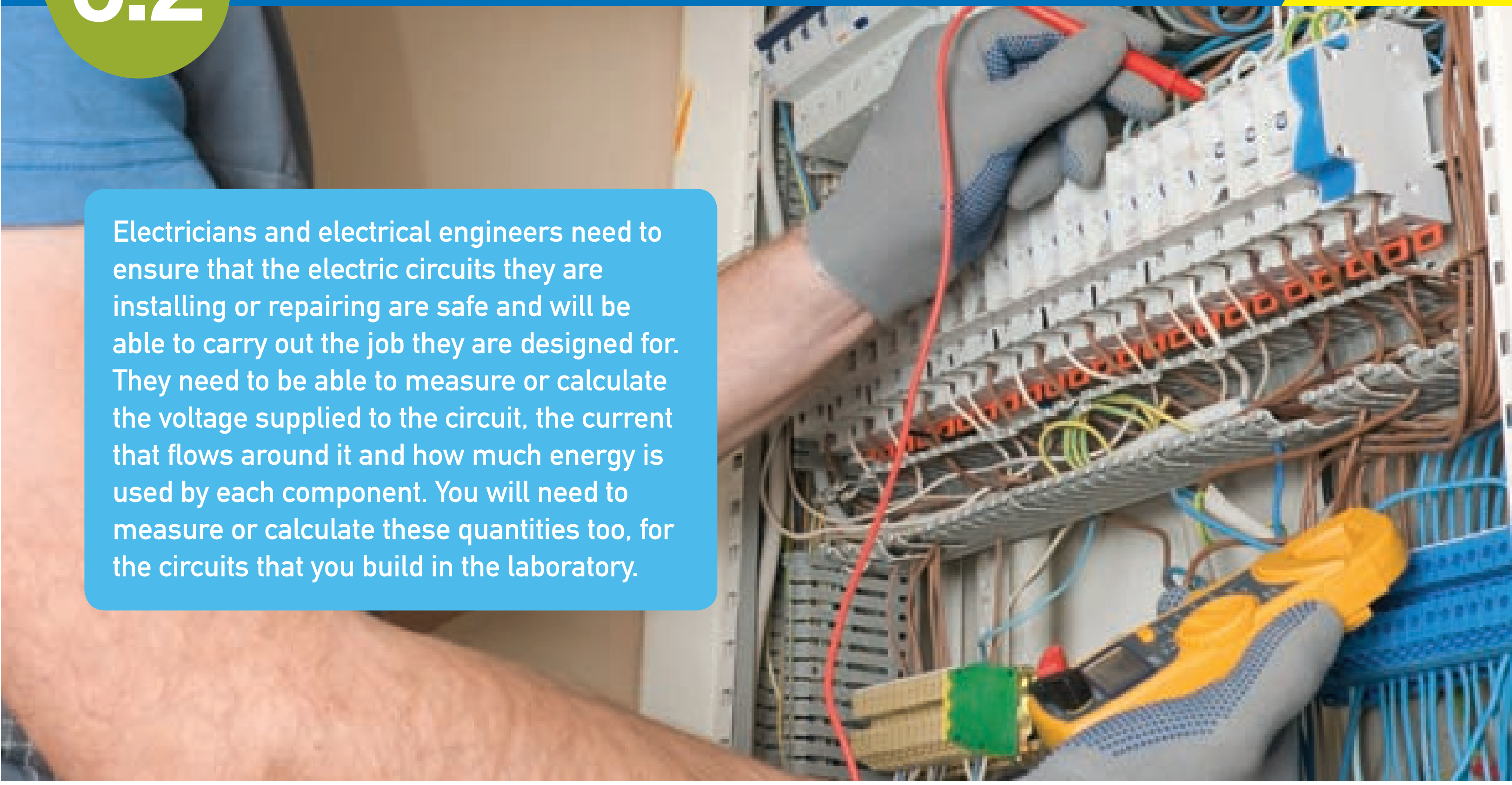



Figure 6.1.11

# 6.2 Measuring electricity



Electricians and electrical engineers need to ensure that the electric circuits they are installing or repairing are safe and will be able to carry out the job they are designed for. They need to be able to measure or calculate the voltage supplied to the circuit, the current that flows around it and how much energy is used by each component. You will need to measure or calculate these quantities too, for the circuits that you build in the laboratory.

## Current

An electric current is formed whenever charge flows from one spot to another. In an electric circuit, this flow of charge is made up of electrons moving along the wires.

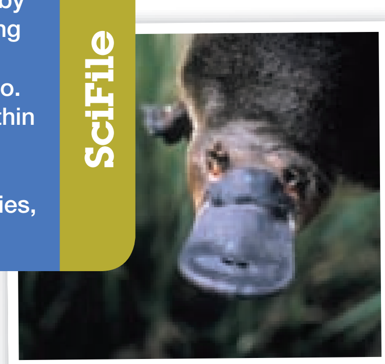
Electric current is measured using an **ammeter**. An ammeter measures the amount of charge that flows through it every second. The current is high if a lot of charge flows through it in one second, and low if only a small amount of charge flows through it.

The unit used to measure current is **ampere** (unit symbol A), which is often shortened to 'amps'.

SciFile

### Nervous about electricity?

Your muscles are activated by electrical impulses sent along your nerves. The same happens in other animals too. A platypus uses sensors within its duck-like bill to detect electric currents from the muscle movements of yabbies, fish, worms and frogs.



SKILL BUILDER

### Connecting up an ammeter

Electrons must pass through an ammeter for the charge to be detected. Therefore the ammeter needs to be in line with the rest of the circuit's components. This arrangement is known as being in **series** and is shown in Figure 6.2.1.

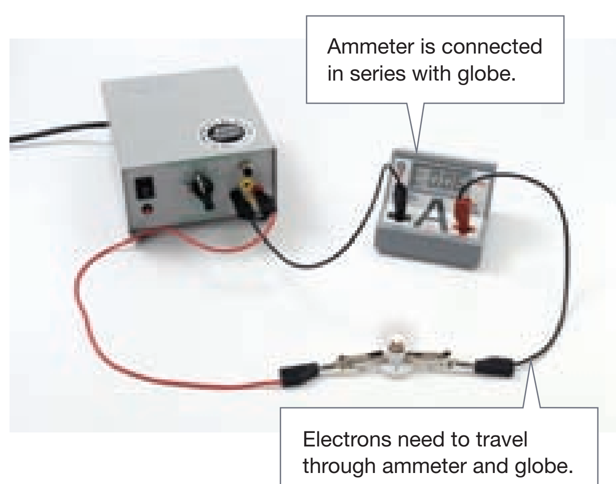



Figure 6.2.1 Ammeters measure the current that passes through them. An ammeter needs to be in line (in series) with the rest of the circuit.

# Voltage

**Voltage** is a measure of the amount of energy:

- supplied to the charges by the voltage source (the supply voltage)
- used by the charges as they pass through a component such as a light globe (the energy is transformed into heat and light).

Voltage is measured using a **voltmeter**. The voltage is high if the electrons are supplied with a lot of energy or are losing lots of energy. The voltage is low if the electrons lack energy or lose very little. If the voltage is zero, it means the battery is dead, the power point is turned off or the electrons are losing no energy in that part of the circuit.

The unit used to measure voltage is **volts** (unit symbol V).

SKILL BUILDER

## Connecting up a voltmeter

A voltmeter compares the energy of electrons before and after they pass through a component such as a light globe. For this reason, voltmeters are connected in **parallel**. This means they are not part of the circuit itself, but instead attach across the component being measured, piggy-backing it. This arrangement is shown in Figure 6.2.2.

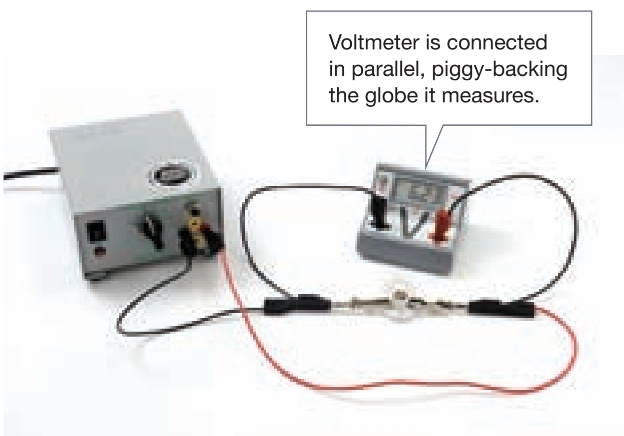



Figure 6.2.2 Voltmeters measure how much energy is used by charges as they pass through an energy converter such as a light globe. The voltmeter is connected in parallel with the component whose voltage it is measuring.

## Supply voltage

Electrons get the energy they need to move around the circuit from the circuit's energy source. Each energy source has its own voltage. Higher supply voltages give the electrons a bigger 'push' than low supply voltages.

In Australia, power points supply 240V to the electrons in any circuit plugged into them. Sometimes a **transformer** (like the one in Figure 6.2.3) is used to reduce the voltage from a power point to a more manageable voltage. For example, laptops typically only need a supply of 19V, mobile phones need 6V to recharge and digital cameras 6.5V.

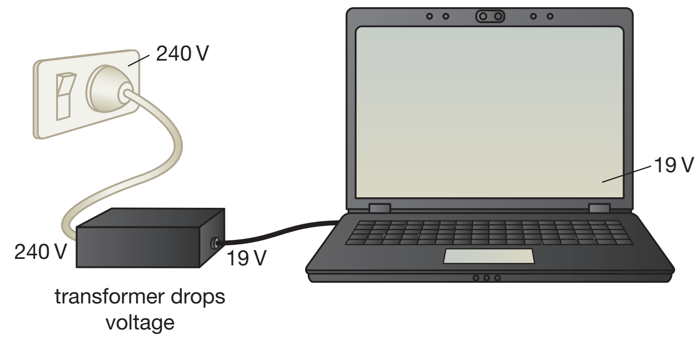



Figure 6.2.3 A step-down transformer reduces the 240 V provided by a power point to the 19 V that a laptop needs.

In the laboratory, power packs reduce the 240V from a power point to the voltages required in experiments. Most power packs can be adjusted to supply a range of voltages from 1.5V to 6V or 12V.

## Batteries

Batteries are an excellent source of portable electrical energy. Batteries are generally made of smaller cells or smaller 'mini-batteries'. Cells can be classified as:

- wet cells
- dry cells
- photovoltaic or solar cells.

A **wet cell** has two electrodes (made of a metal or some other conducting material like graphite) placed in a liquid **electrolyte** (a solution that conducts electricity). Electrons pass from one electrode to the other, passing through the circuit as they do so. Although portable, wet cells are heavy and the electrolyte (often an acid) can easily spill. The advantage of wet cells is that they can be recharged by forcing the electrons to pass 'backwards' through the circuit.

Figure 6.2.4 on page 192 shows that a car battery uses a set of six wet cells to supply its electrical energy. Each wet cell supplies roughly 2V and has two plates, one made of lead and the other made of lead oxide. The plates are placed in a solution of dilute sulfuric acid. The overall voltage supplied by a car battery is 12V.

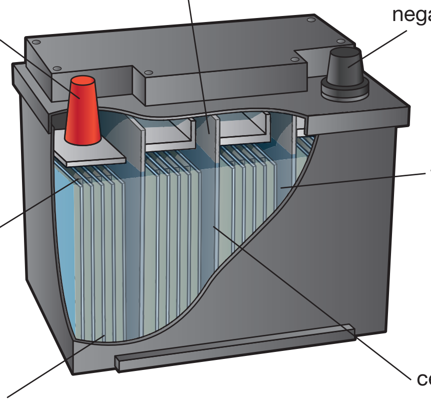



**Figure 6.2.4** A car battery is made of six wet cells. The car battery is used to start the car and run the lights and radio when the engine is off. When the engine is running, a device called an alternator reverses the current. This recharges the battery.

1 p197

The small, portable batteries used in torches, toys and remote controls are **dry cells**. Dry cells are compact because they have one electrode wrapped around another. They don't leak because they use a conducting paste instead of a liquid. A typical dry cell is shown in Figure 6.2.5.

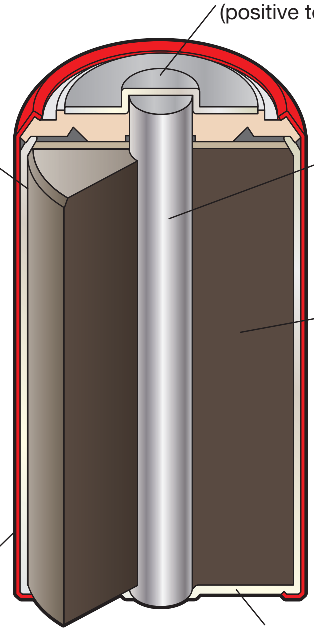



**Figure 6.2.5** Dry cell batteries are compact and don't leak.

As you can see in Figure 6.2.6, different dry cells provide different voltages. The voltage of dry cells can be further increased by placing a number of them end-to-end. For example, eight 1.5 V AA batteries arranged head to tail give the same 12 V as supplied by a car battery.


**Figure 6.2.6** Dry cell batteries come in different shapes and voltages. Higher voltages can be obtained by arranging the batteries end to end in series.

2 p198

**Photovoltaic cells** (or solar cells) convert solar energy directly into electrical energy. Energy in the sunlight knocks electrons off semiconducting silicon crystals within the cell. These electrons move away from the crystal, forming an electrical current that can be used to power appliances such as calculators, road signs and public telephones. Alternatively, the current can be used to recharge batteries for later use. For example, the solar garden light in Figure 6.2.7 uses batteries that are recharged by photovoltaic cells during the day.

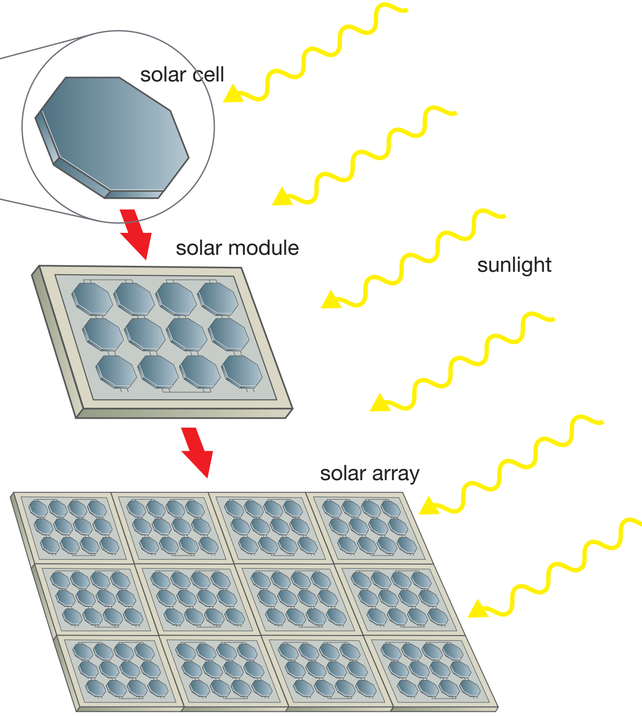
Many homes now have banks of solar panels made of many photovoltaic cells, to provide them with a source of renewable energy that releases no greenhouse gases. Any excess power generated by the panels is fed back into the electrical grid of the community and earns the household money. If insufficient power is generated at any time, the house draws electricity from the grid just like any other house.

**SciFile**

### Photovoltaic power plant

The world's largest photovoltaic power plant is to be built near Mildura (in Victoria). The plant will use arrays of mirrors to reflect sunlight (concentrating it 500 times) onto a tower of solar cells. This is very different from existing large-scale solar power plants. They use the reflected sunlight to boil water to turn turbines to make electricity.

Figure 6.2.7 Solar garden lights use sunlight to recharge their batteries during the day.




## Voltage drop

Electrons lose energy as they pass through a component such as a light globe, a heating element or a motor. This results in a voltage drop across the component. This voltage drop depends on the resistance of the component.

# Resistance

As electrons pass along the wires of an electric circuit, their path is restricted a little by the atoms that make up the wires. This restriction is known as **resistance**. Resistance measures how difficult it is for an electric current to flow through a material or a component. A high resistance means that electrons find it hard to pass through the material. A low resistance means that their trip is easy.

The energy and voltage lost by electrons as they pass through a component depends on the resistance of the materials making it up. Electrons don't bump into much as they pass through low-resistance materials, and so they lose almost no energy and almost no voltage. In contrast, high-resistance materials place obstacles in the way of the electrons. A little energy is lost every time the electrons are bumped off-course, and so overall a lot of electrical energy and voltage is lost as they pass through.

Resistance also affects the current flowing through a circuit. As the resistance of a component increases, fewer electrons get through it every second. This reduces the current flowing.

The resistance of a material depends on:

- the type of material the wire is made from. For example, metals generally have low resistance, whereas rubber has an incredibly high resistance
- the length of the wire. Doubling the length of a wire doubles the number of obstacles that the electrons must pass through. This doubles its resistance
- the thickness of the wire. It is more difficult for electrons to pass along thin wires than to pass along thick wires.

Resistance is measured using the unit **ohm**. The unit symbol for ohms is a letter from the Greek alphabet known as omega, Ω. Resistance can be measured by a multimeter, like the one in Figure 6.2.8.


Figure 6.2.8 A multimeter combines an ammeter and a voltmeter, and can also measure resistance.

## Conductors

Metals are **conductors**. This means that an electric current will pass through them. However, some metals are better conductors than others. It all depends on their resistance.

Copper is an excellent conductor. It has a very low resistance and almost no energy is lost from it. It is also relatively cheap. For these reasons, copper wires are used in most electric circuits around the home, in factories and in cars. Another excellent, low-resistance conductor is aluminium. Aluminium is more expensive than copper but is much lighter. This is why aluminium is used for high-voltage transmission lines strung between distant pylons (poles), like those in Figure 6.2.9.

Figure 6.2.9 Transmission lines need to be made of a low-resistance, light metal. Copper would be far too heavy, so aluminium is used instead.

Tungsten and nichrome alloy are metals and so they conduct electricity too, but not as well as copper or aluminium. Tungsten and nichrome have relatively high resistances and so electrons passing through them lose much of their energy and voltage. This energy is converted into heat and sometimes light. This makes them ideal to use as heating elements in electric kettles, hair dryers, electric blankets and the filaments of old-fashioned incandescent light globes like the one in Figure 6.2.10.

Figure 6.2.10 Tungsten and nichrome wires conduct electricity but have a high resistance. This old-fashioned light globe uses a tungsten filament. Its resistance converts electrical energy into light and heat.

6.3 6.4

## Insulators

Some materials have such a high resistance that they block electric current completely. These materials are said to be **insulators**. Examples are rubber, plastics, wood, glass and ceramics. Figure 6.2.11 shows how plastic is used to wrap electric wires and cables to insulate them from their surroundings. Glass and ceramics are used to insulate high-voltage power lines so that current doesn't pass into the poles that are holding them up.

Figure 6.2.11 Plastic coating is used to insulate each of the three wires in an electric cable. More plastic coating wraps all the three wires together, insulating them even further.

# 6.2 Unit review

## Remembering

**1** **Recall** the following terms by matching each term (a to c) with its correct description (i to iii).

- **a** current — **i** measures how difficult it is for charges to pass through a material
- **b** voltage — **ii** measures the flow of charge passing through the circuit
- **c** resistance — **iii** measures the energy provided to or used by charges

**2** **Recall** units and unit symbols by copying and completing the table.

| Quantity | Unit | Unit symbol |
|---|---|---|
| Current | | |
| Voltage | | |
| Resistance | | |

**3** **List** three things that resistance depends on.

**4** **List** two examples of:
- **a** an electrical conductor
- **b** an insulator.

**5** **Name** two metals that have:
- **a** low resistance
- **b** high resistance.

## Understanding

**6** **Explain** why an ammeter needs to be connected so that it is in line (in series) with the components of a circuit.

**7** **Explain** the advantages of using dry cells for a TV remote control.

**8** **Describe** what an electrolyte is and where it can be found.

**9** **Explain** what a transformer is used for.

**10** **Explain** why copper is used for the wiring around a house but aluminium is used for high-voltage transmission lines.

## Applying

**11** **Identify** whether a wet or dry cell would be best to power the following.
- **a** a laptop computer
- **b** a boat starter motor
- **c** the lights in a caravan
- **d** a bionic ear implant

**12** **Calculate** the total supply voltage of the battery arrangement shown in Figure 6.2.12.

## Analysing

**13** **Contrast** a conductor with an insulator.

**14** **Contrast** series and parallel circuits.

## Evaluating

**15** An electric current can flow when different metals touch each other.
- **a** If you place aluminium against an amalgam filling in your tooth, you will feel pain in the tooth. **Propose** reasons why.
- **b** Builders often work with different metals. For example, they use steel nails and screws, aluminium foil and copper wires. **Propose** ways in which they can keep themselves safe when working with different metals.

**16** AA and AAA batteries both supply the same voltage of 1.5V but are different sizes. **Propose** a reason why batteries come in different shapes and sizes, even when some of them supply the same voltage.

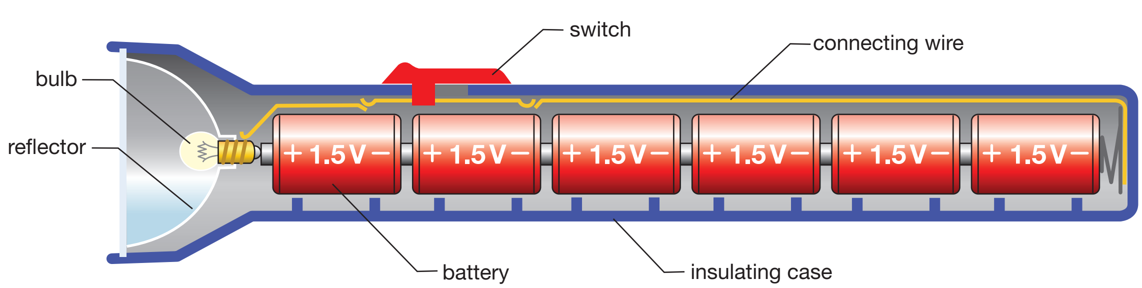



Figure 6.2.12

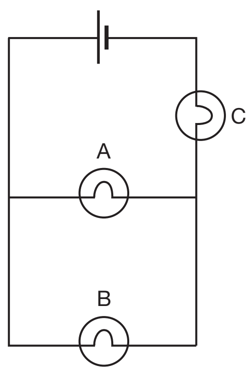
# 6.2 Unit review

## Creating

**17** **Construct** a circuit diagram like that shown in Figure 6.2.13 but add:

- **a** a switch that would turn all three globes on and off
- **b** a switch that will only turn globe B on and off
- **c** an ammeter that would measure the total current through the circuit
- **d** an ammeter that would measure the current that flows only through globe A
- **e** a voltmeter that would measure the voltage lost by charges as they pass through globe B.

Figure 6.2.13




## Inquiring

**1** Research electric eels. Find out how they generate their killer voltages and what they use it for.

**2** Open up the back of battery-powered appliances around your home and construct a table like that shown below to record details about the batteries used.

Some of the appliances you might investigate are wrist watches, cameras, smoke alarm, toys and torches.

| Appliance | Battery type | Battery voltage (V) | Number of batteries used | Total voltage (V) |
|---|---|---|---|---|
| | | | | |

**3** Figure 6.2.14 shows a superconductor. Research what a superconductor is and what it can be used for.

Figure 6.2.14 Superconductors have the ability to levitate or float in the air.

# 6.2 Practical activities

## 1 Lemon cells

### Purpose

To construct a cell and a battery using fruit.

### Materials

- lemon and/or other fruits and vegetables (such as kiwi fruit, apple, tomato, melon)
- copper nail, small sheet of copper or length of stripped copper wire
- iron nail (can be galvanised) or small sheet of iron
- milliammeter, multimeter or LED (light-emitting diode)
- connecting wires with alligator clips
- paper towel

### Procedure

1 Soften the inside of the lemon a little by squeezing it. Don't break it.

2 Insert the copper nail/sheet/wire into the lemon. Do the same with the iron nail/sheet.

3 As shown in Figure 6.2.15, connect the copper electrode to either the positive terminal of the milliammeter/multimeter or the long terminal of the LED.

4 Connect the iron electrode to the negative terminal of the milliammeter or short terminal of the LED. A current should flow immediately. Record the current flowing or describe how brightly the LED shines.

5 Remove the electrodes and pat dry with paper towelling. Repeat the experiment but with different fruits and vegetables.

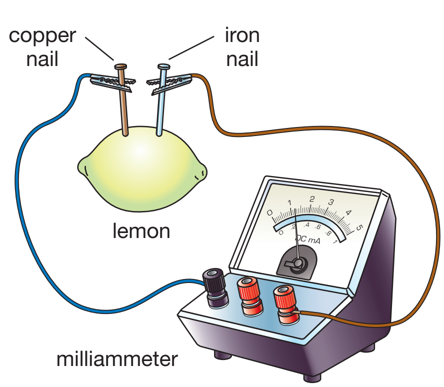



Figure 6.2.15

6 Increase the energy supplied by connecting up a series of the same types of fruit, as shown in Figure 6.2.16. Start with two pieces of fruit, then three and so on. Once again, record the current or brightness of the LED.

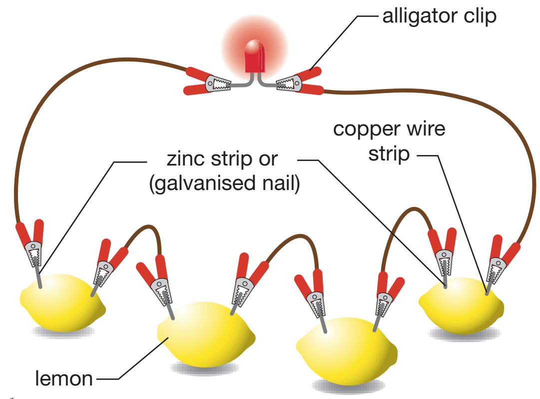



Figure 6.2.16

### Results

In your workbook, construct a table like the one below in which to record your results.

| Type of fruit | Number of pieces of fruit | Current (mA) | Brightness of LED |
|---|---|---|---|
| Lemon | 1 | | |
| Lemon | 2 | | |
| | | | |

### Discussion

1 a **Classify** these fruit batteries as wet or dry cells.
  b **Justify** your answer.

2 **Identify** the electrolyte (conducting liquid) in these fruit batteries.

3 **Propose** a reason why it was recommended that you soften the inside of the lemon a little before the experiment started.

## 2 Dry cell voltages

### Purpose

To measure the supply voltages of different batteries.

### Materials

- a selection of batteries with some charge left in them
- voltmeter or multimeter

**SAFETY**

Do not use a car battery in this activity.

### Procedure

1. In your workbook, construct a table like the one shown in the Results section.
2. Set the voltmeter or multimeter to its least-sensitive scale.
3. Attach or touch the voltmeter/multimeter terminals or probes to the terminals of each battery (for most batteries this will be their ends). Record your measurement in the results table.
4. Record the voltage printed on the battery.

### Results

Record your results in the table.

| Battery type | Voltage printed on battery (V) | Measured voltage (V) |
|---|---|---|
| AA | | |
| | | |

### Discussion

1. The supply voltage of batteries is always a little lower than the voltage printed on them. Use your results to **assess** the accuracy of this statement.
2. Batteries have a resistance (their internal resistance) and so they use up some of the supply voltage. Use this fact to **explain** your results.


Figure 6.2.17 Dry cell batteries come in a range of sizes and voltages.

# 6.3 Practical circuits

The electric circuits around your home are far more complex than the simple circuits presented so far. Your home has multiple energy users. It has many lights and power points and may have a TV, a washing machine, a computer and a dishwasher. It also has multiple switches and fuses or circuit breakers to protect the circuits—and you—if something goes wrong. The circuits in your home are parallel circuits.

## Series circuits

In a **series circuit**, all the components of the circuit are connected up one after another to form a single loop. Series circuits are the easiest of all the circuits to connect up. Figure 6.3.1 shows a typical series circuit, in which two identical light globes are connected in series.

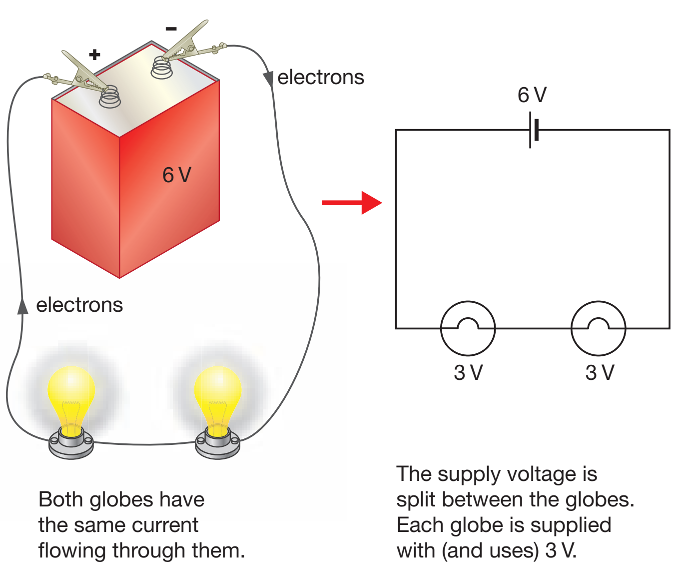



**Figure 6.3.1** This series circuit has two light globes arranged one after the other.

When the charges leave the battery, they carry a full load of energy (in this case 6V). Very little energy is lost in the wires because they have a very low resistance. This leaves 6V worth of energy to be shared equally by both globes. Each globe therefore loses 3V worth of energy. To get back to the battery, the current must pass through both globes.

Series circuits are easy to connect up but are not very practical. This is because:

- the globes cannot be controlled individually with a switch. A switch would turn them all on or all off
- current stops flowing around them if any of the globes 'blow'. This breaks the circuit and causes all the other globes to go out too, making it extremely difficult to locate which globe is the faulty one
- adding more globes to the circuit makes them glow duller than before. The supply voltage is shared by more globes, so each globe receives less voltage, and so the globe is duller than before. This effect is shown in Figure 6.3.2 on page 200.

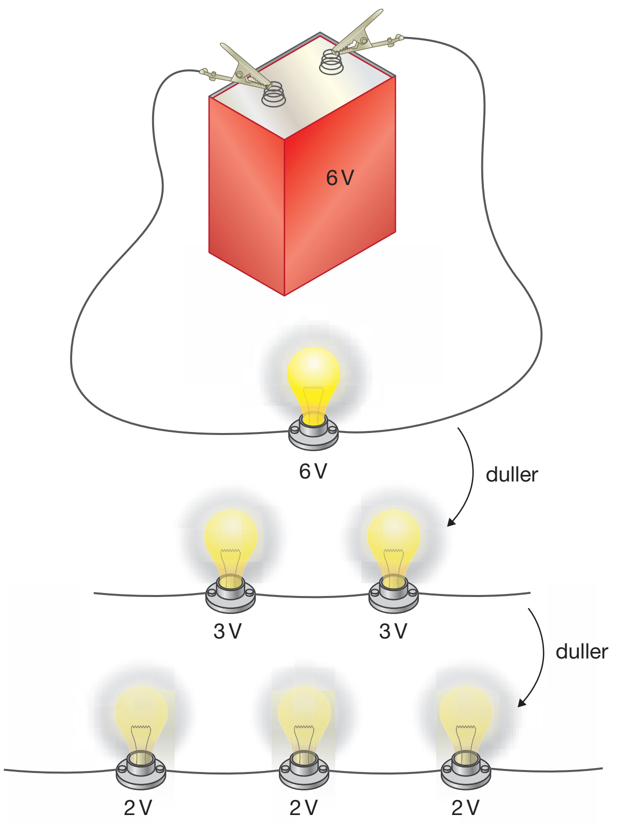



**Figure 6.3.2** Globes get duller and duller as you add more of them to a series circuit.

## Parallel circuits

A **parallel circuit** has a number of branches, each branch having its own components. A typical parallel circuit is shown in Figure 6.3.3.

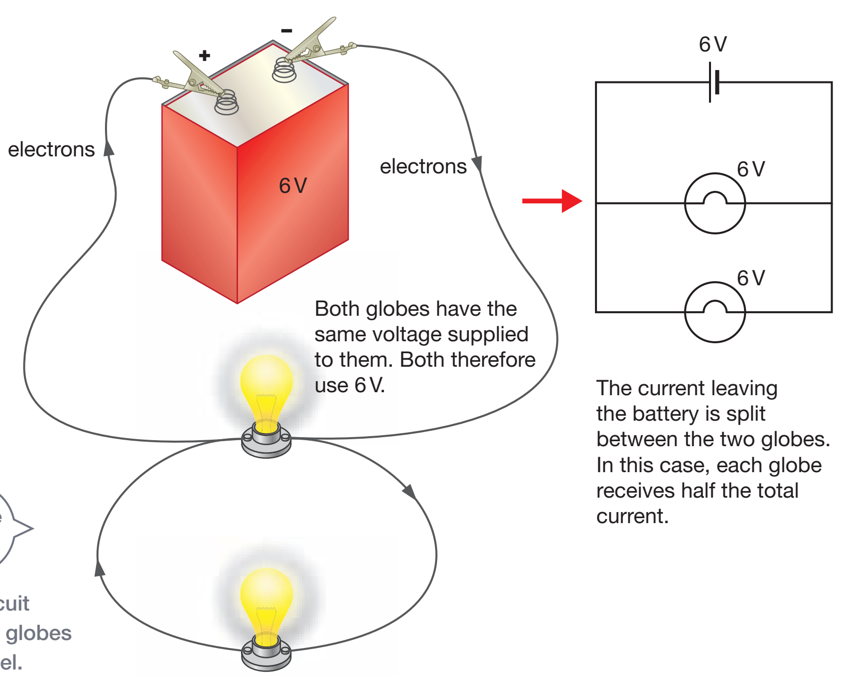



**Figure 6.3.3** This circuit has two globes in parallel.

In this parallel circuit, the current leaving the battery splits into two, with half going down each branch. An individual electron cannot pass through both globes and so loses all its energy in the one globe it passes through. Therefore, each globe receives the full 6V supplied by the battery.

Although more difficult to construct, parallel circuits have many advantages over series circuits. In parallel circuits:

- each branch can have its own switch. This allows each globe to be turned on or off independently of the others
- only one branch is affected if a globe 'blows'. All the others keep working. This also makes it easy to find the faulty globe
- adding extra globes does not affect their brightness. This is shown in Figure 6.3.4. Each branch always receives the full supply voltage, regardless of how many globes there are.

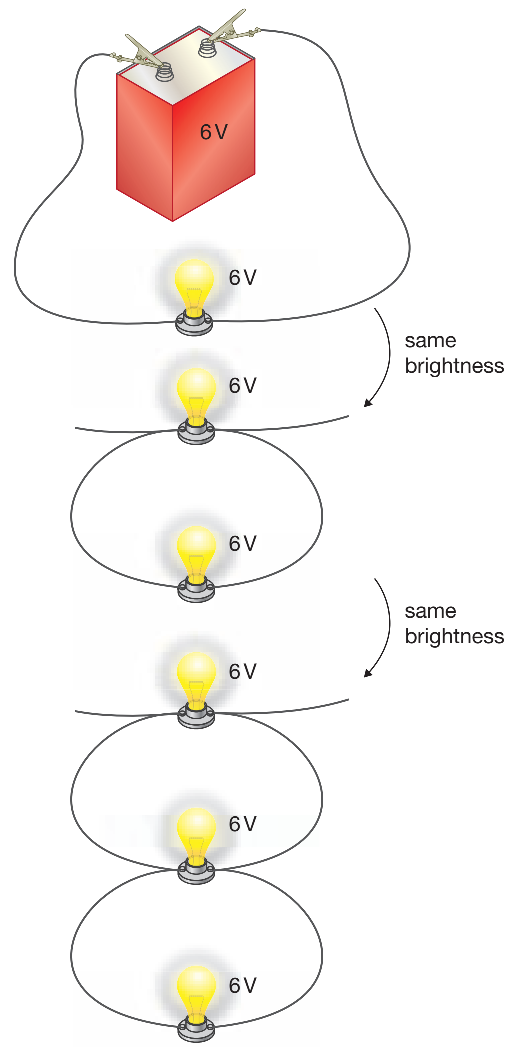



**Figure 6.3.4** There is no change in the brightness of globes in a parallel circuit when more of them are added.

In summary:

- Components in a series circuit have the same current through them but split the voltage between them.
- Components in a parallel circuit have the same voltage across them but split the current between them.

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## Combination circuits

Sometimes circuits have some of their components arranged in series and other components in parallel. Consider the circuit in Figure 6.3.5. In this circuit, two globes (B and C) are in series with each other. These two globes are in parallel with globe A.

## Household wiring

The electrical wiring in a house or an apartment is one large parallel circuit, with each light and power point located on its own branch with its own switch. Each receives the full supply voltage of 240V, allowing each to work at full power. A simplified version of a typical household circuit is shown in Figure 6.3.6.

The electrical cables supplying power points are made of three separate wires. The **active wire** (coated in brown plastic) carries current to the power point, and the **neutral wire** (blue) carries current away from it. However, 240V can be deadly if the current finds a way out of the wires and through you. This might happen if part of the circuit within an appliance breaks, allowing a wire to touch the casing or switch. You can then become part of the circuit and current will flow through you instead of down the neutral wire! The result would be an electric shock or possibly electrocution (death by electricity). To avoid this possibility, power points have a third wire, called the **earth wire** (coated in green and yellow plastic). This wire connects the power point (and any metal part of an appliance connected to it) to the earth beneath you. This provides a way for dangerous stray currents to flow out of the appliance without passing through you. The arrangement of active, neutral and earth wires within an extension lead is shown in Figure 6.3.7 on page 202.

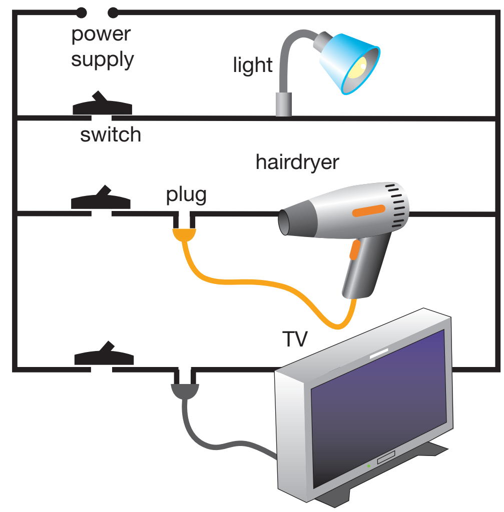



Figure 6.3.6 The circuits around your home are connected in parallel. This allows everything to be controlled independently and provides everything with 240V.

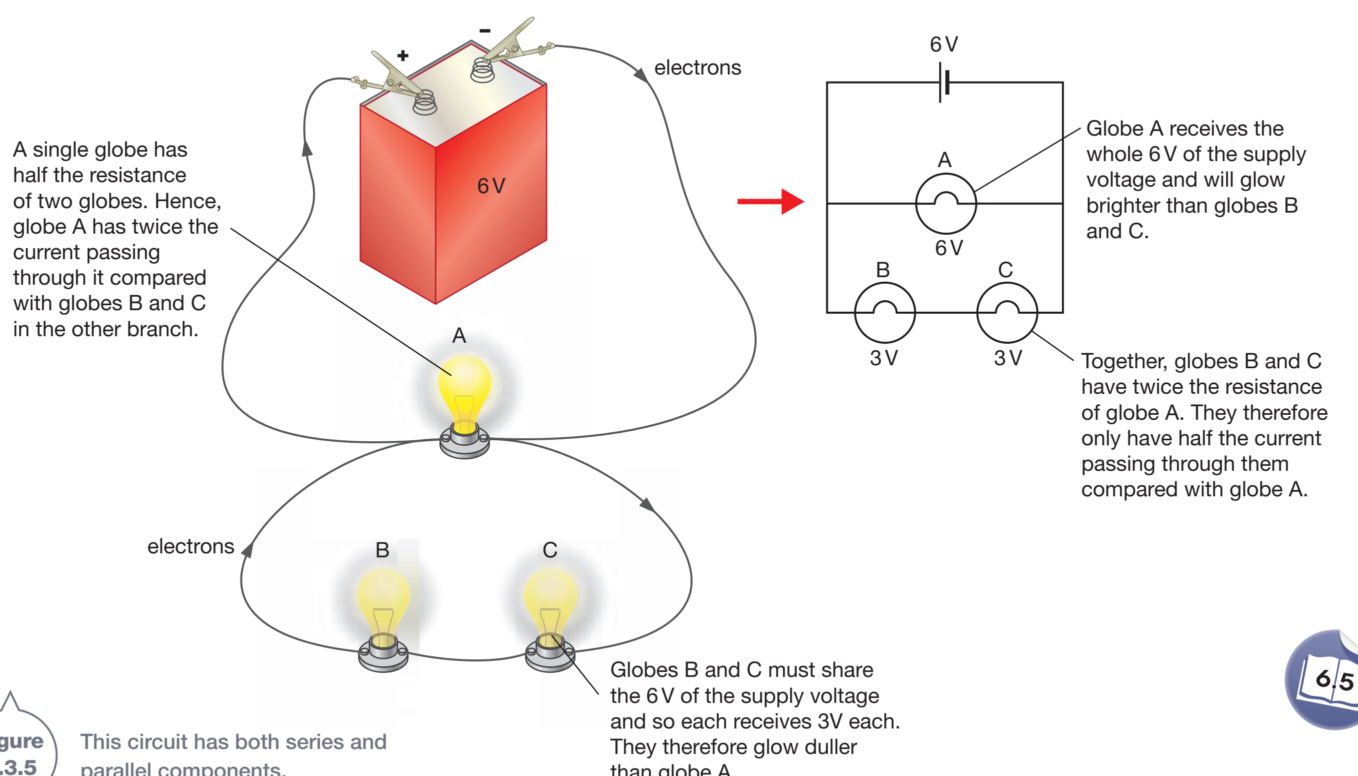



Figure 6.3.5 This circuit has both series and parallel components.

6.5

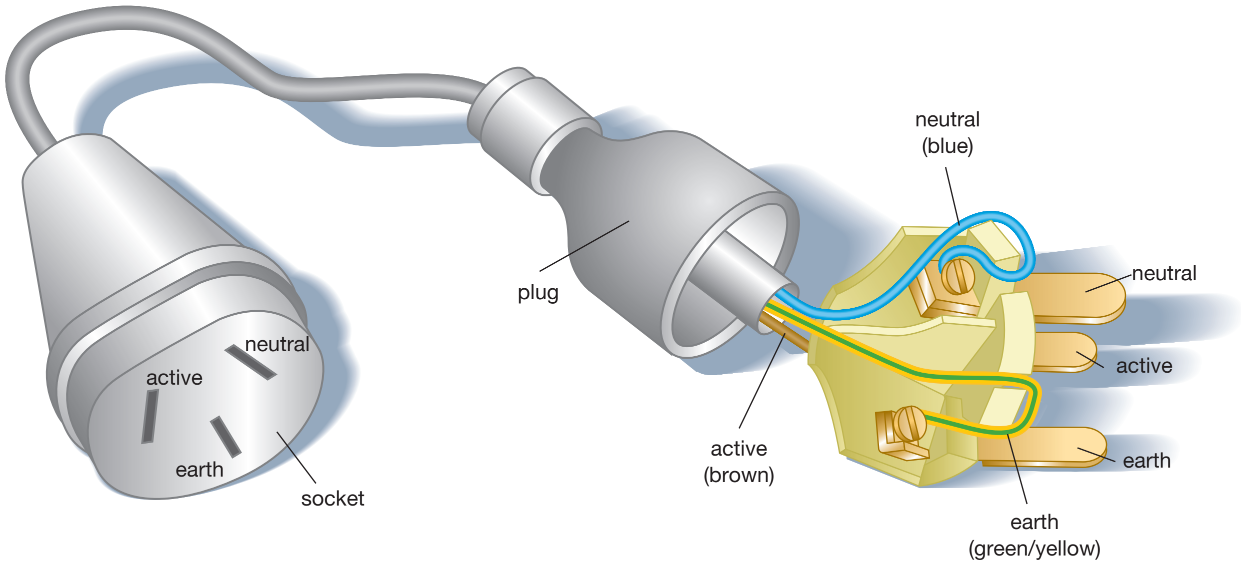



Figure 6.3.7 Power points and cables have three wires. The active and neutral wires carry the current to and from the appliance. The earth wire is included only for emergencies. Stray currents caused by faulty appliances will pass along the earth instead of through you.

**SciFile**

**Colour changes**

Old wiring may have red (active), black (neutral) and green (earth) wires. Up to 8% of electricians are red/green colour blind and cannot tell the difference between a red active wire and a green earth wire. These two wires are deadly if swapped! For the safety of everyone, the colours have been changed to brown, blue and green/yellow.


Figure 6.3.8 Old or faulty electrical wiring is the most common cause of house fires.

## Electrical safety

Most practical circuits also have a device that deliberately breaks the circuit if a faulty appliance allows an abnormally high current to flow. This current might end up passing though you or might set the house on fire. Abnormally high currents cause wires to heat up rapidly. This might melt their plastic coatings. They can then set fire to the fluff and dust trapped with the wires in the walls and roofspace. This is what happened in Figure 6.3.8.

### Fuses

A **fuse** is a wire of high resistance and low melting point. It will melt if too much current flows along it. Melting breaks the circuit and stops the current. Fuses are common in older houses, and are still used in cars and trucks and electronic devices such as music and home theatre systems. A typical car fuse box is shown in Figure 6.3.9.

2 p207

Figure 6.3.9 Cars commonly use fuses to break a circuit if something goes wrong in it. Each colour fuse will melt at a different temperature and current.

## Circuit breakers

New houses generally use circuit breakers instead of fuses. A **circuit breaker** is a switch that is activated by a higher-than-normal current. When this happens, it switches 'off', breaking the circuit. Figure 6.3.10 shows a typical household switchboard or junction box. Each circuit breaker controls a different circuit. One controls the lights while another circuit breaker controls the air conditioner. Others control the circuits of different clusters of rooms such as the family room, kitchen and bedrooms.

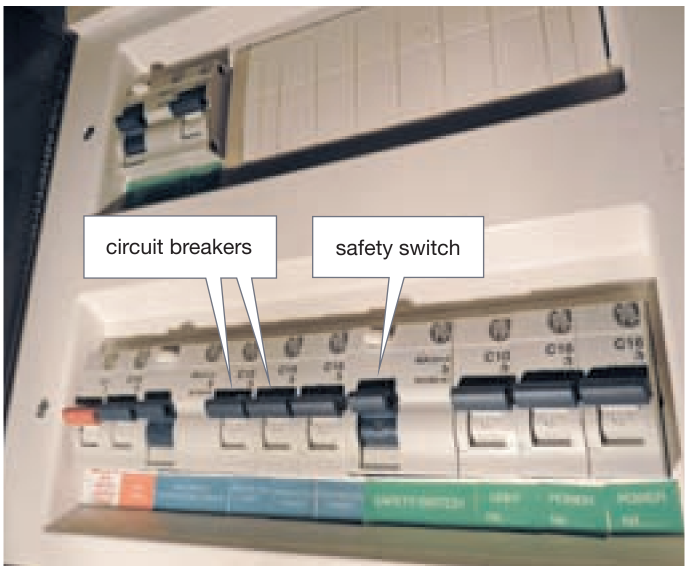



**Figure 6.3.10** You will probably find your home's switchboard near the front door. Those in most newer homes look like this one, with a set of circuit breaker switches and safety switch.

## Safety switches

Modern home switchboards also have a **safety switch** on their lighting and power circuits that monitors how much current is flowing through them. The current flowing into the house through the safety switch should be the same as the current flowing out of the house through the same safety switch. If they are different, then current is likely to be 'leaking' either into a faulty appliance or into you. When the safety switch detects a leak, it breaks the circuit within 0.03 seconds. This stops any further current from flowing. In this time, you will still receive a nasty shock but hopefully the current will be switched off fast enough to stop you being electrocuted.

Some power points around a home may also have their own safety switch, protecting you from any faulty appliances attached to it. These power points have a small blue reset/test button, as seen in Figure 6.3.11.

A safety switch is also known as a residual current device (RCD).

6.6


**Figure 6.3.11** Some power points have their own safety switch.

**SciFile**

### Strike insurance

A **surge protector** keeps your appliances from 'blowing' if there is an unexpected increase in the current through them. This mostly happens when there is a lightning strike on your home or on a powerline or transformer nearby. The surge protector breaks the current to any appliances attached to them.

INQUIRY science 4 fun

### A pain in the teeth!

What happens when aluminium is placed against the metal amalgam used in your teeth fillings?

**Collect this ...**

- aluminium foil
- your head, with a tooth that has an amalgam filling in it

Yes

**Do this ...**

1. Work your mouth so that it produces lots of saliva. Don't swallow the saliva or spit it out.
2. Cut a piece of aluminium foil and fold it so that it is small enough to pop into your mouth against a tooth. Don't make it too small, or you might accidentally swallow it.
3. Locate a filling in your teeth, preferably in one of your molars (the bigger, 'square' teeth at the back). Place the foil against the filling and bite gently onto it.

**Record this ...**

**Describe** what happened.

**Explain** why you think this happened.

# 6.3 Unit review

## Remembering

1 **List** the advantages and disadvantages of a series circuit.

2 **State** the colours of the following wires used in household wiring.
  a active
  b neutral
  c earth

3 **State** the time it takes for a safety switch (RCD) to activate.

## Understanding

4 **Describe** the advantages of a home being wired as a parallel circuit instead of as a series circuit.

5 **Define** the term *electrocution*.

6 **Describe** how electrical faults can cause house fires.

7 **Describe** how a safety switch (RCD) detects a problem in the circuit.

## Applying

8 **Use** the key below to complete the following statements. Options can be used more than once.

**Key**
A don't change
B don't light up
C shine brighter
D shine less brightly

  a If another globe is added to a series circuit, the globes _______.
  b If another globe is added to a parallel circuit, the globes _______.
  c If one globe in a series circuit 'blows', the others _______.
  d If one globe in a parallel circuit 'blows', the others _______.

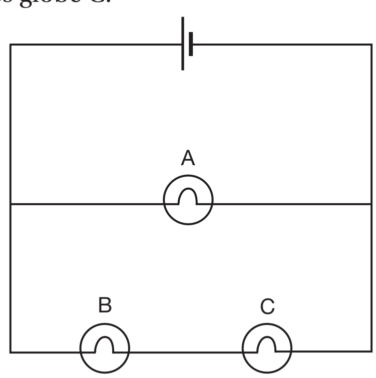
## Analysing

9 **Analyse** the circuit in Figure 6.3.12, then **use** the key below to complete the following statements. Options can be used more than once.

**Key**
A the same as
B twice
C half
D three times

  a The current through globe A is ______ the current through globe B.
  b The current through globe B is ______ the current through globe C.
  c The voltage across globe A is ______ the voltage across globe B.
  d The voltage across globe B is _____ the voltage across globe C.

Figure 6.3.12




10 **Compare** a fuse with a circuit breaker by listing their similarities and differences.

11 **Compare** a safety switch with a surge protector.

12 **Analyse** the circuit in Figure 6.3.13 to complete the table below indicating which globes would be on or off.

Note: *Closed* means that current can flow through the switch. *Open* means that current cannot flow through the switch.

| | Switch D | Switch E | Switch F | Globe G | Globe H | Globe I | Globe J |
|---|---|---|---|---|---|---|---|
| a | closed | closed | open | | | | |
| b | open | closed | closed | | | | |
| c | closed | open | closed | | | | |
| d | closed | closed | closed | | | | |

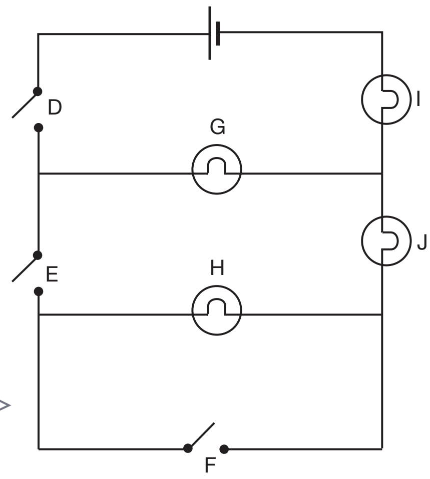



Figure 6.3.13

**13** **Predict** the order of brightness (from brightest to dullest) of the globes in Figure 6.3.14.

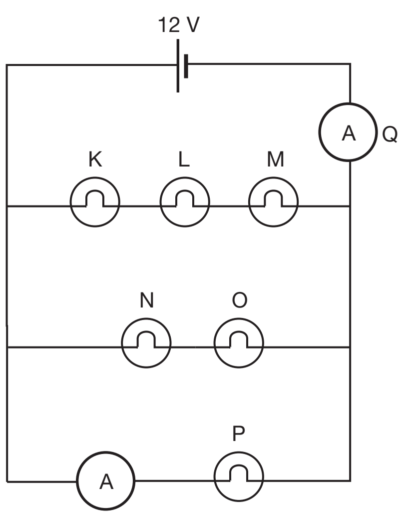



Figure 6.3.14

**14** **a** **Analyse** the circuit shown in Figure 6.3.14 to complete the following table.

| | Globe | | | | | |
|---|---|---|---|---|---|---|
| | K | L | M | N | O | P |
| Current (A) | | | | | | |
| Voltage (V) | | | | | | |

**b** **Calculate** the current through ammeter Q.

## Evaluating

**15** **Propose** what would happen if a car had all its electrical components (such as windscreen wipers, headlights, blinkers, internal light, radio) wired up in series, not parallel.

## Creating

**16** **Construct** a circuit diagram like that shown in Figure 6.3.12, but add a switch that would turn on and off:

**a** all globes in the circuit

**b** globe A only.

## Inquiring

1 Not all power points and plugs around the world are the same. Research the different types used, and present your findings as a world map with attached photos or diagrams.

2 Use the key words *electricity mania* to find interactive games in which you need to connect up household circuits.

3 Some schools have a software package called Crocodile clips which allows you to construct and test electric circuits. If your school has this package, test your skills in circuit construction.

4 Analyse the claims made in an advertisement, in a consumer report or by a salesperson about an electrical device such as a plasma, LCD or LED TV. In particular, analyse what is said about the device's power use and efficiency.

# 6.3 Practical activities

## 1 Series and parallel circuits

### Purpose

To compare series and parallel circuits.

### Materials

- three globes (preferably 6 V)
- power pack
- connecting wires
- switch
- ammeter
- voltmeter

**SAFETY**

If using a power pack of variable voltage, do not go higher than 6 V.

### Procedure

1. In your workbook, construct a table like the one in the Results section.
2. Connect up the basic circuit shown in Figure 6.3.15.

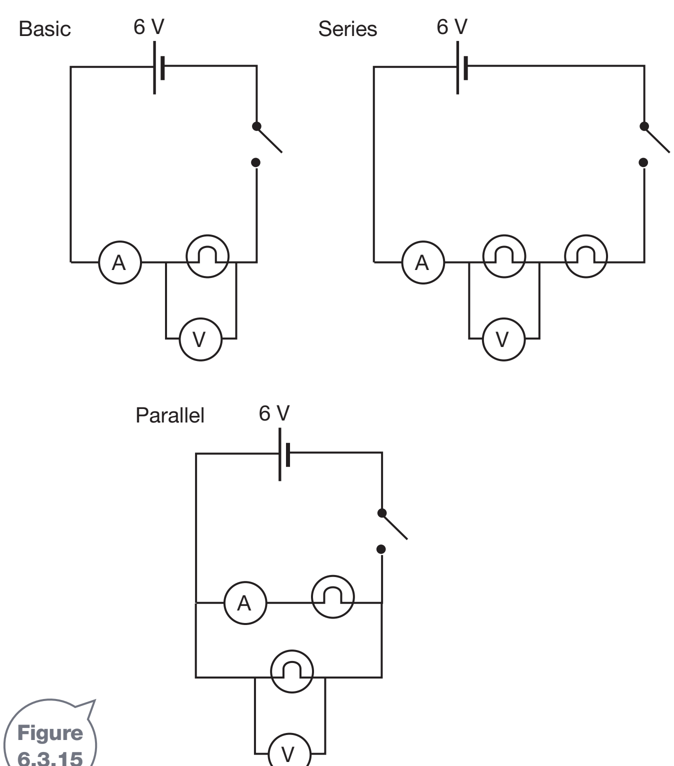



Figure 6.3.15

3. Measure the current flowing through the globe, and the voltage lost across it.
4. Add another globe to construct the series circuit shown in Figure 6.3.15.
5. Note the brightness (very bright/bright/dull/very dull) of the globes, and measure the current and voltage.
6. Remove the second globe and re-connect it so that it is in parallel (as shown in Figure 6.3.15).
7. Once again, note the brightness of the globes, and measure the current and voltage.

### Results

Record your results in the table.

| | Single globe | Globes in series | Globes in parallel |
|---|---|---|---|
| Brightness | | | |
| Current (A) | | | |
| Voltage (V) | | | |

### Discussion

1. **Describe** what happened to the current when another globe was added in series.
2. **Use** your knowledge of resistance to **explain** why this happened.
3. Adding another globe in series makes all the globes duller. **Explain** why.
4. **Explain** why adding globes in parallel makes no difference to their brightness.

## 2 Fuses

### Purpose

To construct and test a fuse.

### Materials

- 2 dry cell batteries
- cork
- steel wool
- globe
- connecting wires
- sticky tape
- screwdriver with insulating handle
- access to pliers

**SAFETY**

Do not use a nail, screw or any uninsulated metal to cause the short circuit.

Your screwdriver must have an insulating handle.

### Procedure

1. Use the pliers to strip a short section of insulation off the ends of two connecting wires.
2. Also strip off a short section of the insulation halfway down each connecting wire.
3. Construct the circuit shown in Figure 6.3.16.
4. To construct the fuse, tease out a strand of steel wool and wind it around the ends of the connecting wires.
5. A short circuit is potentially dangerous. It occurs when something happens to the circuit that gives the current a far easier path to travel along than through the energy users. It causes a massive current to flow, dangerously heating the circuit. Deliberately short circuit this circuit by touching the screwdriver as shown across the two stripped sections of the connecting wires. As you do so, watch the fuse.
6. Thicken the wad of steel wool used as a fuse, and repeat.

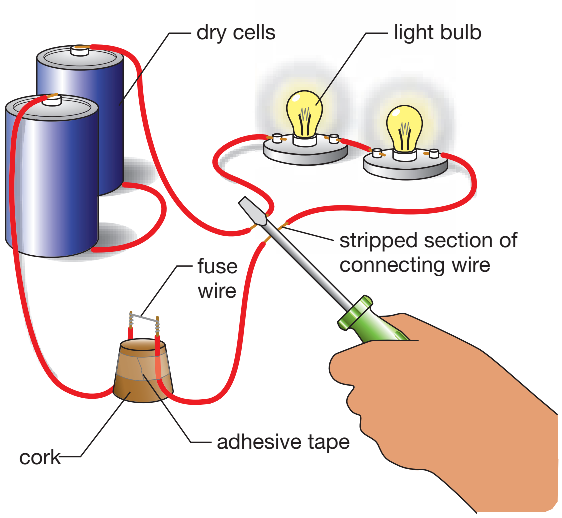



Figure 6.3.16

### Discussion

1. **Explain** the purpose of a fuse in a circuit.
2. **Describe** what the fuse did here when there was a short circuit.
3. **Describe** what happened when thicker 'fuses' were used.

# 6.4 Electromagnets, motors and generators

Batteries are a good source of portable electric power but most cannot provide the voltages required to operate kettles, washing machines and air conditioners. Even if they did, they would soon need to be replaced or re-charged. Most of the electricity used in homes and factories is generated by a power station. Electricity and magnetism are related to each other, and their relationship can be used to produce an electric current. The relationship also explains how electric motors, electromagnets and transformers work.

## Magnetism

Around a permanent magnet is an invisible force field called a **magnetic field**. This field exerts forces on:

- materials containing large quantities of iron (or cobalt or nickel). This explains why magnets can be used to separate steel nails and screws from plastic and scrap
- other magnets nearby. Each magnet has a north pole (N) and a south pole (S). What two magnets do depends on the orientation of their poles: unlike poles (N/S) attract and like poles (N/N or S/S) repel.

The direction and strength of a magnetic field is shown by its **field lines**. Field lines show the direction of the force on iron filings and compass needles. For example, the iron filings in Figure 6.4.1 have aligned (lined up) with the field lines of the bar magnet.

The needle of a compass is also a magnet and it too is attracted and repelled by the field of Earth and of nearby magnets.

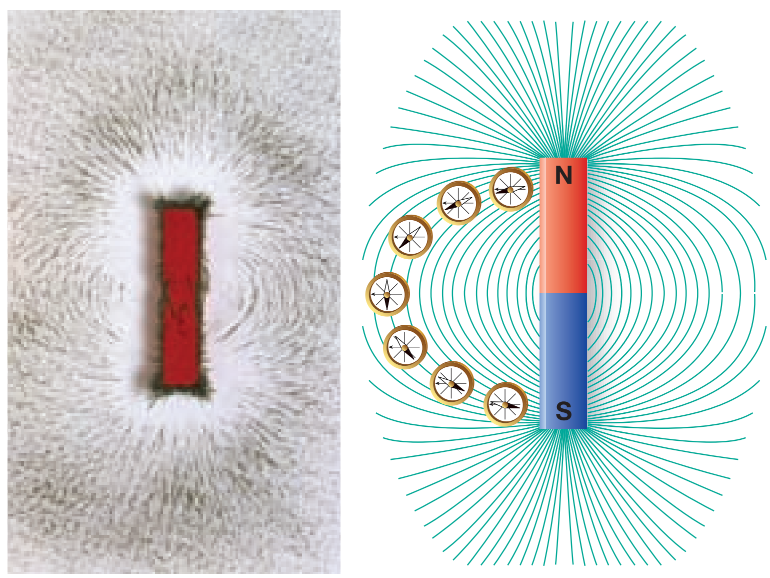



Figure 6.4.1 Iron filings clearly show the shape of a magnetic field.

## Electromagnetism

A magnetic field is also produced when an electric current flows along a wire. When compasses are placed around the wire, their needles align with the magnetic field around the wire. As Figure 6.4.2 shows, the field produced is a set of concentric circular rings. In this case, electricity has caused magnetism. The phenomenon is known as **electromagnetism**.

## Electromagnets

If a current-carrying wire is twisted around to form a loop, the magnetic field down its centre is reinforced and made stronger. If the wire is wound many times to form many coils, then the magnetic field down its core is reinforced even more. This looped current-carrying coil is known as a **solenoid**. The magnetic field it creates is shown in Figure 6.4.3. The magnetic field down the core of the solenoid is made even stronger when an iron rod is placed down it. This device is known as an **electromagnet**.

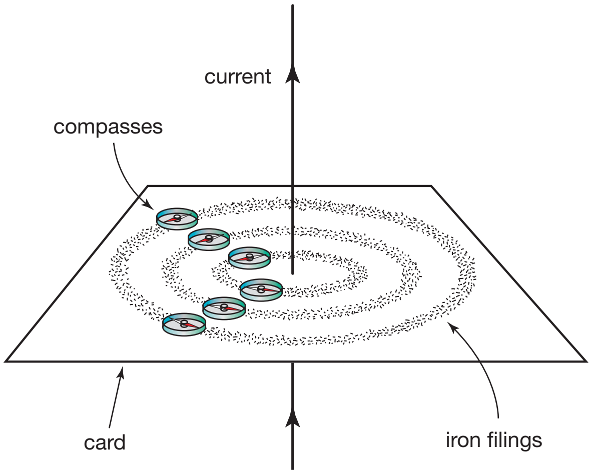



Figure 6.4.2 The magnetic field around a current-carrying wire forms concentric rings.

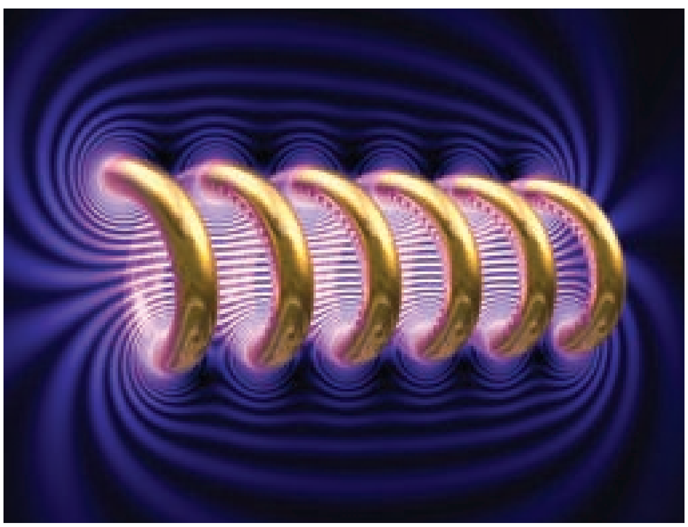


Figure 6.4.3 A solenoid has a magnetic field similar to that of a bar magnet. Insert an iron rod down the core and you get an electromagnet.

The magnetic field of an electromagnet depends on the current flowing through it. This means that an electromagnet can be controlled in ways that are not possible with a permanent magnet. Table 6.4.1 compares an electromagnet with a permanent magnet.

## Using electromagnets

Electromagnets are used in many ways. They are used to separate iron and steel metal in junkyards, in car starter motors, and to operate bells and automatic latches. If too much current flows through a house circuit, electromagnets in circuit breakers pull the switch open. This cuts the current through it.

You use electromagnets every day when you listen to your iPod or watch TV. Within every speaker, earplug or headphone is a cone that is connected to an electromagnet. As Figure 6.4.4 shows, a speaker has a permanent magnet and an electromagnet. The current fed into the electromagnet changes as the music changes its pitch and volume. The two magnets either attract or repel each other, causing the cone of the speaker to vibrate. These vibrations in turn cause the sounds you hear.

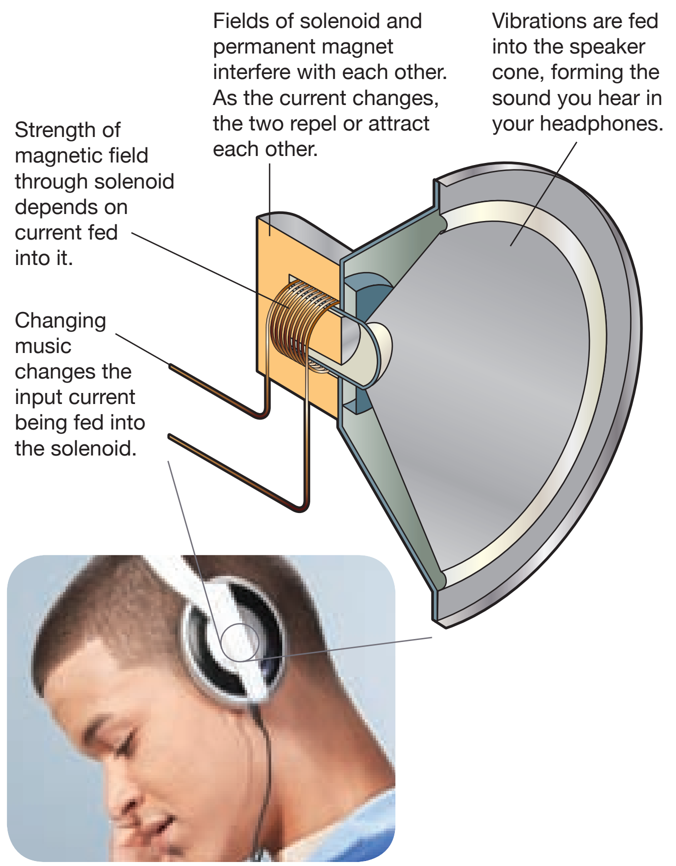



Figure 6.4.4 Speakers, headphones and earphones work because two magnetic fields attract or repel each other, causing the speaker to move.

**Table 6.4.1 An electromagnet compared with a permanent magnet**

| Properties of magnet | Electromagnet | Permanent magnet |
|---|---|---|
| Magnet on or off | ‘On’ if current flows through it<br>‘Off’ if no current flows through it | Always ‘on’ |
| Strength of the magnet | Can be altered by changing its current | Cannot be adjusted |
| Direction of the magnetic field | Can be changed by changing the direction of the current passing through it | Can only be changed by flipping the magnet end to end |

INQUIRY science 4 fun

## Pick-me-up!

**Collect this ...**

- paperclips
- C cell battery
- insulated copper wire
- access to pliers

**Do this ...**

1. Cut off 15 to 20 cm of electrical wire and use the pliers to strip the wire of its insulating plastic.
2. Wind the wire around a bolt, a large nail or a screw.
3. Hold the ends of the wire against the ends of a C battery. As you do so, try and use it to pick up a paperclip.

**Record this ...**

**Describe** what happened.

**Explain** why you think this happened.

Simple motors like this are commonly used in toys such as slot-cars because these toys don't require much speed or power. Appliances like hairdryers and power drills need stronger motors and use stronger solenoids instead of permanent magnets. As Figure 6.4.6 shows, they also use multiple planes of coils.

p219

Figure 6.4.6 Heavy-duty motors like the one in this electric fan use electromagnets instead of permanent magnets.

# Electric motors

Two magnets experience a force when placed within each other's field. Likewise, a current-carrying wire experiences a force and moves whenever it is placed in a magnetic field. In this case, electricity has caused a magnetic field that then caused movement. This too is part of the phenomenon of electromagnetism.

p218

An electric **motor** spins because of electromagnetism. A current-carrying coil is placed within the magnetic field of a permanent magnet. The two magnetic fields interact and the coil then spins because of the forces on it. This forms the basis of a simple motor, as shown in Figure 6.4.5.

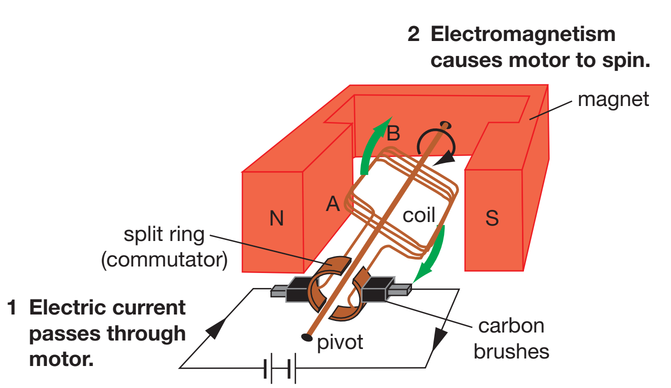



Figure 6.4.5 In an electric motor, current is passed through a coil. The magnetic field it produces interacts with the permanent magnetic field of the motor, causing the coil to spin.

# Generators

The electricity available from batteries is useful for portable devices. However, the voltages and currents are far too low for most purposes around the home and in industry. This is when a generator is needed. A **generator** uses electromagnetism to generate electricity in a similar way to how motors used electromagnetism to produce spin. A simple generator is shown in Figure 6.4.7. Table 6.4.2 compares an electric motor with a generator.

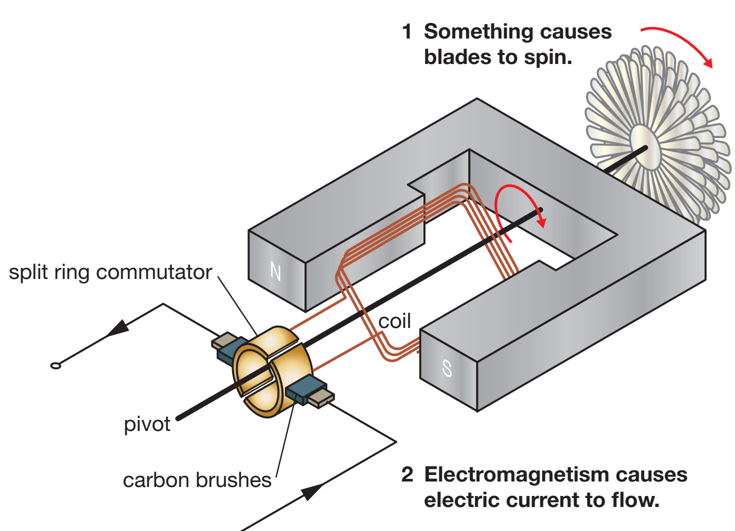



Figure 6.4.7 A simple generator shares many of the features of a simple motor. This is an example of a wind-driven generator.

Table 6.4.2 Comparing motors and generators

| | Electric motor | Generator |
|---|---|---|
| Needs | A coil | A coil |
| | A magnet | A magnet |
| | An electric current | Spinning movement |
| Produces | Spinning movement | An electric current |

INQUIRY science 4 fun

## Solenoid generators

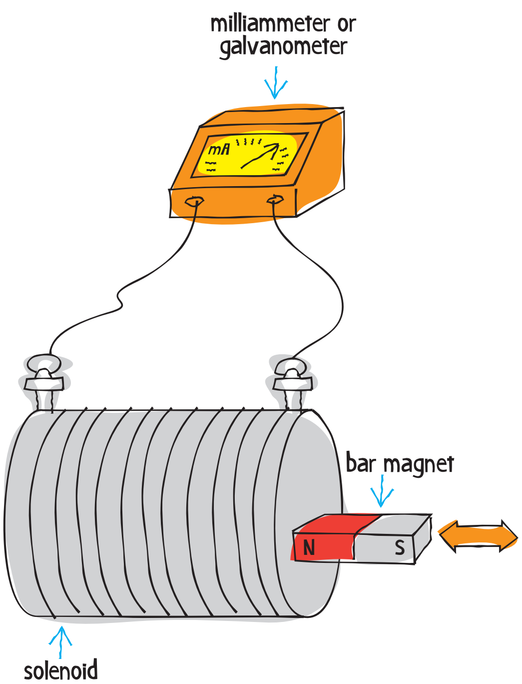
### Collect this ...

No

- solenoid or coil of wire
- milliammeter or galvanometer
- connecting leads with alligator clips
- bar magnet

### Do this ...

1 Connect the solenoid to the milliammeter/galvanometer.




2 While watching the milliammeter/galvanometer, quickly insert the bar magnet into the solenoid.

3 Leave the magnet there and then quickly remove it. Watch what happens.

4 Find out what happens when you insert the magnet more slowly, or when two magnets are used instead of one.

### Record this ...

**Describe** what happened.

**Explain** why you think this happened.

# Turbines

A simple generator produces electricity only if its coils spin. In contrast, a larger generator spins its magnet and keeps its coils fixed. Anything can be used to spin the coils or magnet. For example, many bicycles use a small generator known as a dynamo to generate current to power their headlights. The dynamo uses the front wheels of the bike to spin a magnet within a set of fixed coils.

A large-scale electricity generator is known as a **turbine**. Turbines need to be spun at high speeds, and different methods can be used to spin them. Figure 6.4.8 shows turbines being turned by the wind. More commonly, moving water or steam is used.

Figure 6.4.8 Wind turbines use a renewable resource to generate electricity.

SciFile

**SOS!**

Electricity is difficult to supply to the outback. For this reason, outback cattle stations once used bikes to power their emergency radios. One person would pedal while another person would use the radio. Solar panels and diesel and petrol generators now provide these stations with the electricity they need.

## Moving water

There are a number of ways in which water can be made to spin a turbine.

- Hydro-electricity is generated by water falling onto the blades of the turbines, spinning them like old-fashioned but very fast water wheels.
- Wave power uses the regular swells of the ocean to rock the turbines back and forth.
- Tidal power uses the massive flows of water from the twice-daily changes of the tides to spin turbines. One design is shown in Figure 6.4.9.

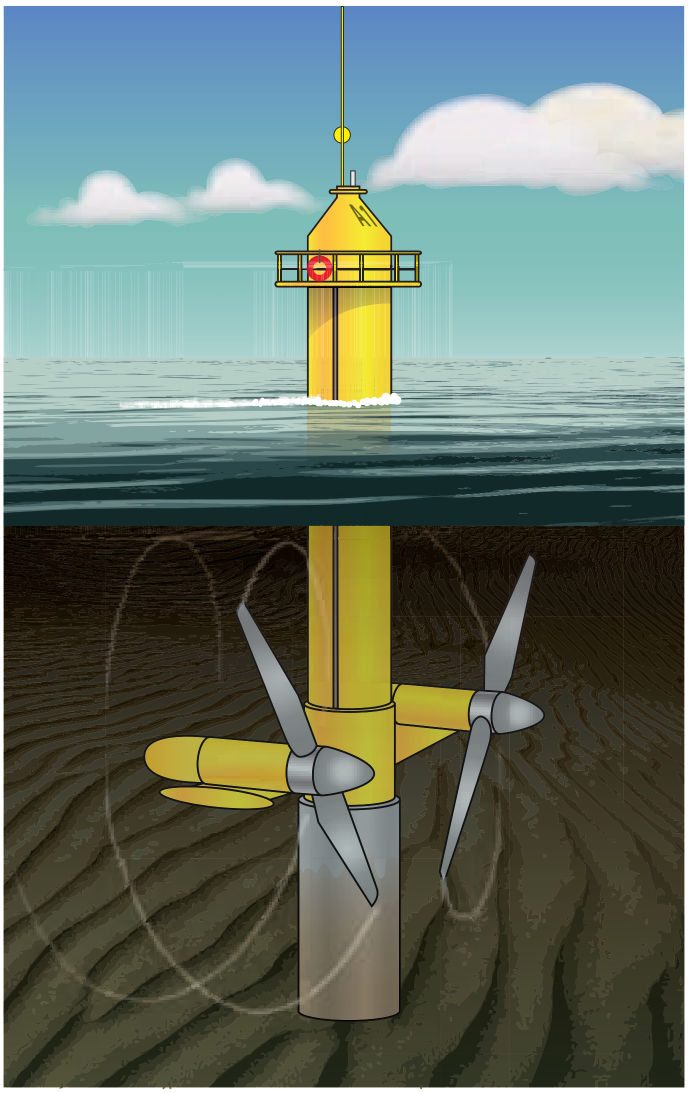


Figure 6.4.9 The tidal movement of water can spin turbines and generate electricity. This design resembles an underwater wind turbine.

**SciFile**

**That's fast!**

In Australia, AC electricity changes direction 50 times every second. This means that the turbines that make it are spinning 50 times every second!

## Steam

Most power plants around the world are basically big kettles, because they boil water and change it into high-pressure steam. This steam then spins the turbines. Afterwards, the steam is usually released via cooling towers, like those in Figure 6.4.12 on page 215. The heat required to run the 'kettle' can come from a variety of sources. It can come from:

- burning fossil fuels such as coal or gas
- burning biomass. Biomass is any biological material that comes from living or recently dead organisms. It includes wood, leftover woodchips, sugarcane waste, methane gas produced by human and animal waste, and biofuels (petrol and diesel substitutes that are 'brewed' from sugar cane, wheat, soy or corn)
- geothermal energy in which heat from deep in the Earth's crust is used to heat water that is pumped underground
- nuclear power in which a controlled nuclear reaction produces the heat necessary to generate steam
- solar power in which sunshine is reflected from mirrors onto a central furnace through which water flows.

All these methods of generating power have advantages and disadvantages. For example, burning coal is an easy and cheap way of generating steam (and therefore electricity) but it emits huge quantities of the greenhouse gas carbon dioxide ($CO_2$). In contrast, nuclear power emits almost no greenhouse gases but it produces wastes that are radioactive for many thousands of years.

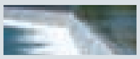
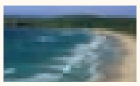
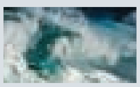
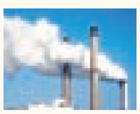
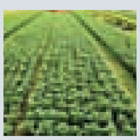
A summary of these advantages and disadvantages is shown in Table 6.4.3.

# AC/DC

AC DC is one of Australia's most famous rock bands, but AC and DC also describe electric current. Batteries and solar cells produce **direct current** (**DC**). In DC, all the electrons move in one direction and with one voltage. Turbines produce **alternating current** (**AC**). In AC, the electrons regularly change their direction and so just shuffle back and forth along the wire. The electricity you obtain from a power point is AC and it changes direction 50 times every second, at a frequency of 50 hertz or 50 Hz. The voltage also changes. Its 'average' voltage (called RMS voltage) is 240 V, but 100 times a second it climbs to 340 V and then drops to –340 V. Figure 6.4.10 shows how.

AC is produced because it can generate more power than DC, is easier to transmit and its voltages can be boosted or dropped using transformers. Table 6.4.4 on page 214 compares AC with DC.

Table 6.4.3 Comparison of different methods of turning a turbine

| | Method | Renewable? | Clean? (emitting minimal $CO_2$) | Other advantages | Other disadvantages |
|---|---|---|---|---|---|
| Uses wind | Wind  | ✓ | ✓ | • Energy is 'free'<br>• Can be located close to where power is needed | • Output changes as wind changes<br>• Turbulence from one turbine can affect nearby turbines<br>• Noisy |
| Uses water | Hydro  | ✓ | ✓ | • Quick to start up<br>• Can be used to 'top up' power supply when needed | • Valleys need to be dammed |
| | Tidal  | ✓ | ✓ | • Energy is 'free'<br>• Reliable | • Must be on the coast<br>• Needs very large tides and so can only be used in a few places |
| | Wave  | ✓ | ✓ | • Energy is 'free'<br>• Minimal environmental impact<br>• Can be located near coastal cities | • Largely experimental<br>• Output changes as waves change |
| Uses steam | Fossil fuels  | ✗ | ✗ | • Coal is abundant<br>• Coal is relatively cheap | • Power plant needs to be located near coal mines<br>• Emits huge amounts of $CO_2$<br>• Open-cut mining devastates the environment |
| | Biomass  | ✓ | ✗ | • Removes waste from the environment<br>• Can be located near where electricity is needed<br>• Individual houses, farms and factories can power themselves | • Large amounts of $CO_2$ emitted<br>• Biofuels use crops that could instead be used as food |
| | Geothermal  | ✓ | ✗ | • Energy is 'free' | • Only countries on fault lines can have large-scale plants |
| | Nuclear  | ✗ | ✓ | • Clean when operating normally<br>• Uses very little nuclear fuel | • Waste remains radioactive for many thousands of years<br>• Disastrous if something goes wrong |
| | Solar power  | ✓ | ✓ | • Energy is 'free'<br>• Can provide power to inland cities | • Needs to be in sunny areas<br>• Needs mirrors to track the Sun<br>• Takes up wide areas of flat landscape |

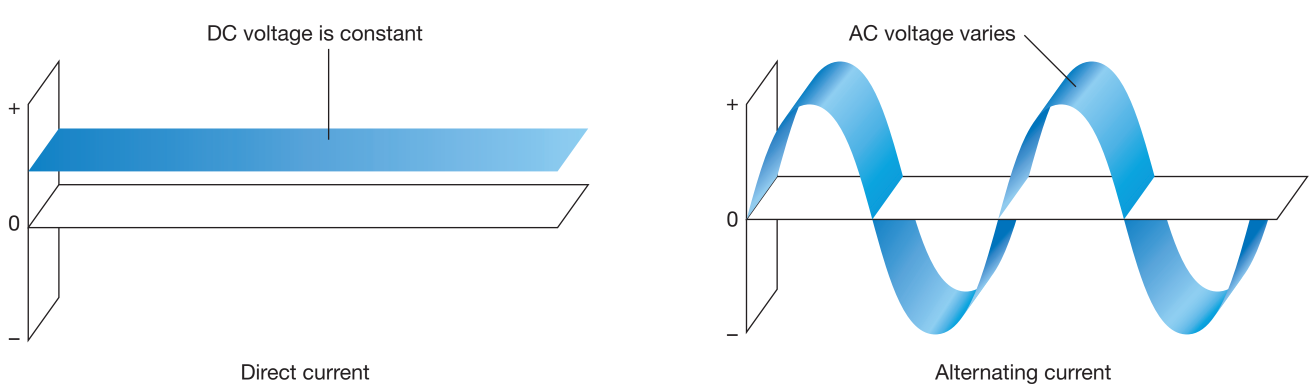



**Figure 6.4.10** DC provides a constant voltage and all its electrons move in one direction. AC provides a varying voltage and its electrons move back and forth along the wire.

Table 6.4.4 Comparing AC with DC

| | AC | DC |
|---|---|---|
| Power supplied | • Suitable for industry and household appliances | • Suitable for smaller appliances only |
| Voltage changes | • AC voltages can be boosted or dropped using transformers | • DC voltages cannot be changed<br>• They must match the voltage required by the appliance |
| AC/DC conversion | • AC to DC conversion is easy using an electronic rectifier | • DC to AC conversion is more difficult |
| Motors | • AC motors are relatively simple<br>• Power output is higher than from DC motors | • DC motors are more complex than AC motors<br>• Power output is usually low |
| Transmission losses | • Low because AC voltages can be boosted for transmission | • High because DC voltages cannot be changed for transmission |
| Storage | • AC needs to be converted to DC before it can charge/recharge batteries | • DC can charge/recharge batteries, which store the energy as chemical energy |

## Transmission of electricity

Most power plants produce AC voltages of around 20 000 V. This electricity must then be transmitted far away to the cities and towns that need it. All electrical wires have a resistance, and energy is wasted when current passes along them. One way to reduce wasted energy is to use a transformer that reduces the current and boosts the voltage until it is an incredible 220 000 to 500 000 V!

A **transformer** is a device that steps up AC voltage (increasing it) or steps down AC voltage (reducing it).

Transmission voltages are far too high for users at the other end, and so a series of transformers reduce it until it is the 240 V that is fed into your home. The final transformer is probably up a pole at the end of your street. Other transformers might even be needed inside your home to reduce the voltage even further to the levels needed for halogen light globes and electronic equipment such as computers or mobile phone rechargers.

Figure 6.4.11 shows where transformers are commonly used in the transmission lines.

6.7

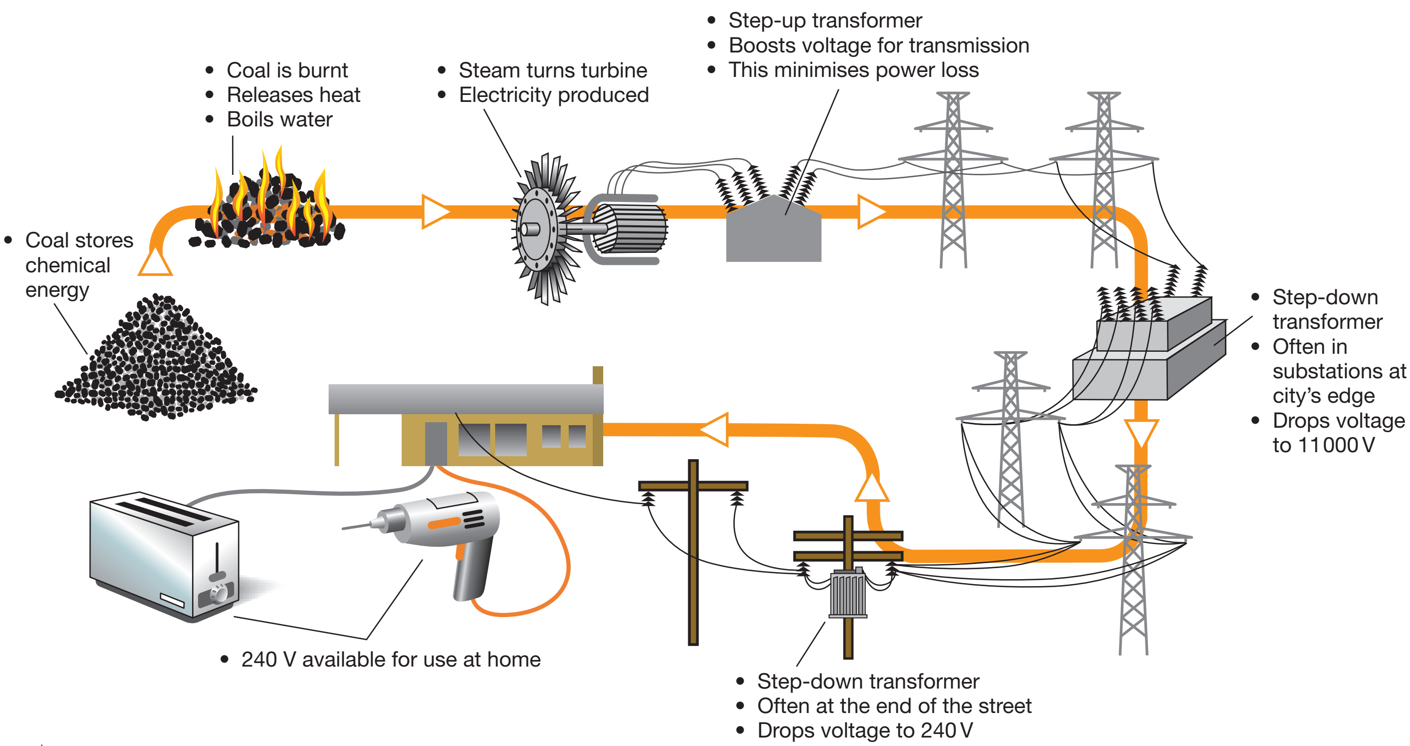



Figure 6.4.11 Transformers need to step up voltages for transmission. Another set of transformers are needed to step down the voltage to what is needed in the home.

# SCIENCE AS A HUMAN ENDEAVOUR

## Use and development of science

### Power to Australia

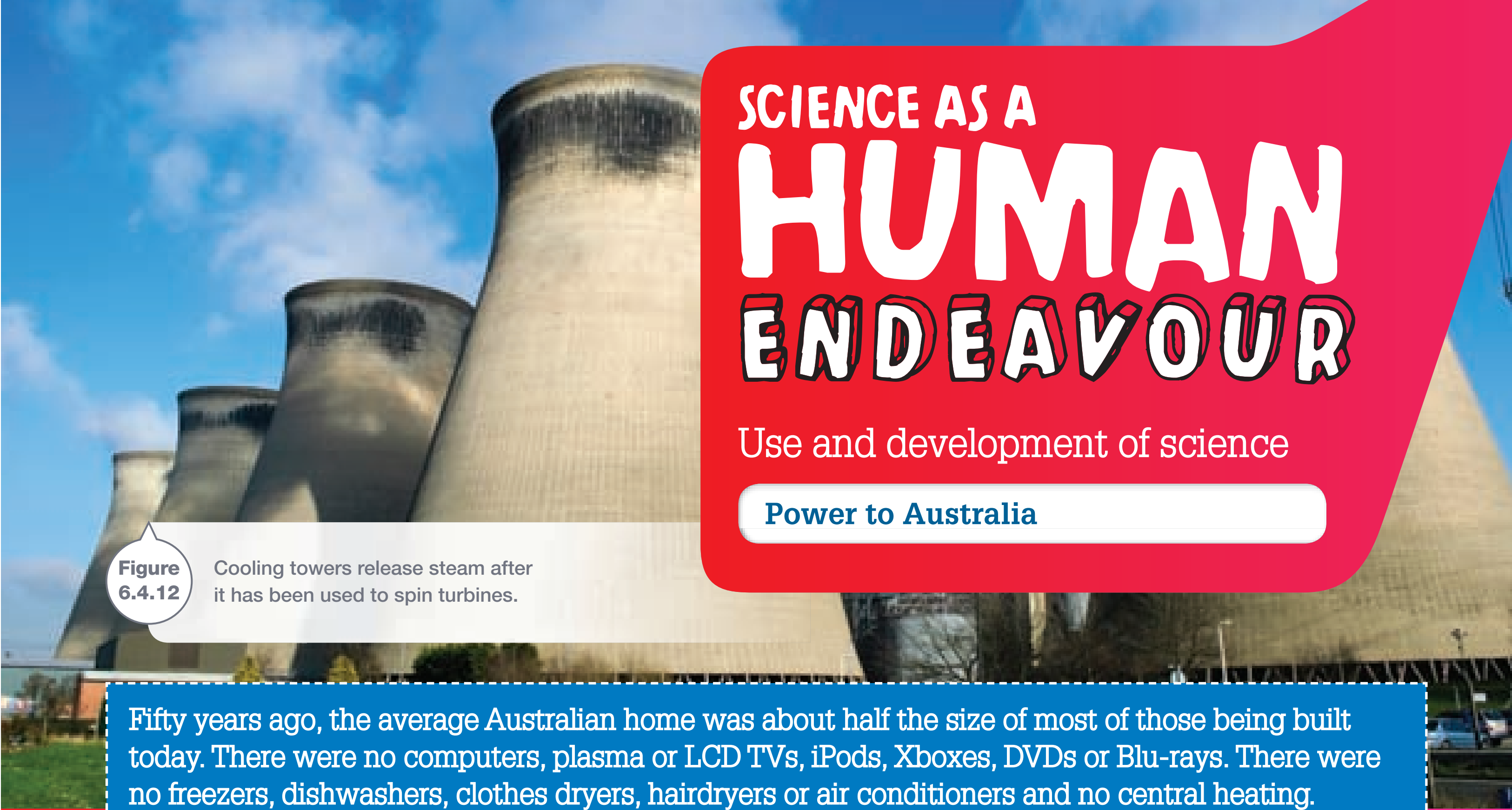


Figure 6.4.12 Cooling towers release steam after it has been used to spin turbines.

Fifty years ago, the average Australian home was about half the size of most of those being built today. There were no computers, plasma or LCD TVs, iPods, Xboxes, DVDs or Blu-rays. There were no freezers, dishwashers, clothes dryers, hairdryers or air conditioners and no central heating. All these appliances require energy (usually electricity) to run, and all contribute to the release of greenhouse gases.

Australians now produce more greenhouse gases per person than any other nation on Earth. We even release more per person than the United States! As a nation, we need to find ways of conserving energy. We also need to find better ways of generating electricity that use renewable sources and produce less (or ideally no) greenhouse gases.

**SciFile**

**McMansions**

As Table 6.4.5 shows, new houses in Australia are now the largest in the world and have rightly earned their nickname of McMansions. All these huge homes need energy to heat, cool and light. No wonder the power bills are so high!

**Table 6.4.5 Comparing the size of new houses in 2009**

| Country | Average size of a new house ($m^2$) |
|---|---|
| Australia | 215 |
| United States | 202 |
| New Zealand | 196 |
| Denmark | 137 |
| Greece | 126 |
| United Kingdom | 76 |

## Power sources

Australia has plenty of coal and gas, is not very mountainous and has few large rivers. For these reasons, nearly 80% of our electrical energy comes from coal-fired power plants. Other sources of electrical energy used in Australia are shown in Figure 6.4.13.

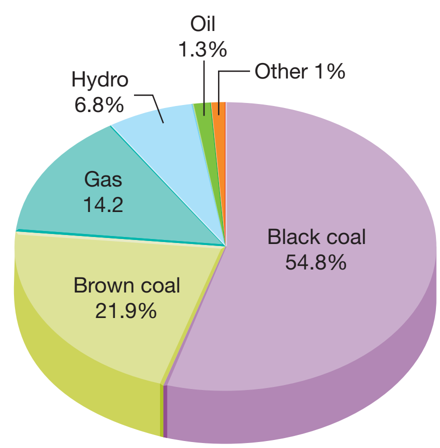



Figure 6.4.13 This pie chart shows Australia's dependence on coal for its electricity. Only Greece and Denmark rely on coal as much as we do.

## Coal-fired plants

In New South Wales and Queensland, high-quality black coal is used to generate electricity. In Western Australia and South Australia, a lesser-quality black coal is used. In Victoria, an even lesser-quality brown coal is used.

### Dirty Victoria!

SciFile

Brown coal is much wetter than black coal and needs heat to dry it before it can burn. This means that brown coal releases less energy than black coal. The whole process also produces about 1½ times more carbon dioxide than burning high-quality black coal. In Victoria, vast open-cut mines are used to get the brown coal needed by power plants. For these reasons, Victoria's coal-fired power plants are some of the most polluting in the world.

## Hydro-electricity

Australia has a limited number of hydro-electric power plants. Most plants are in the mountains of New South Wales (the Snowy Mountains), Victoria (Kiewa Valley and Dartmouth) and Tasmania (Gordon River and Devil's Gate). Others are located on major rivers that carry huge amounts of water, such as the Barron, Tully and Brisbane Rivers (Queensland) and the Ord (Western Australia). You can see a typical dam used for the generation of hydro-electricity in Figure 6.4.14.

**Figure 6.4.14** Hydro-electricity uses water falling from dams to spin turbines.

## New technologies

To reduce our dependence on coal and gas, and to reduce the amount of carbon dioxide being released, various 'green' technologies are currently being built or tested around Australia.

- *Wind farms* are becoming more common in Australia, particularly along the coast of Victoria and South Australia, where winds from the Southern Ocean are most fierce. In 2008 an estimated 42 wind farms consisting of around 650 wind turbines were already generating electricity. Many more are planned. Although wind farms provide roughly 1% of the nation's electricity needs, South Australia draws 15% of its electricity from wind farms.
- *Solar reflector generators* are currently used to generate electricity in Liddell (NSW), Whyalla (SA), Cloncurry (Qld) and the remote Indigenous communities of Hermannsberg, Yuendumu and Lajamanu (NT).
- Australia does not lie on any major fault lines (unlike New Zealand, Iceland, Japan, Philippines and Indonesia) and so large-scale *geothermal power plants* cannot be built here. However, a temperature difference always exists between the rocks deep underground and the surface. This difference allowed a small geothermal power plant to be built in Birdsville (Qld). Sites in South Australia and New South Wales are being tested to determine how suitable they might be for geothermal power production. A trial geothermal plant is being built outside Geelong (Vic). On completion, this plant will eventually provide power for 120 000 homes.
- Like most places in the world, Australia's tides are generally not large enough to be used to generate electricity. One place that has large enough tides is Broome (WA). However, the region is relatively unpopulated and there are no plans for *tidal generators* to be built there.
- Australia is ringed by sea and is constantly being battered by waves. Wave power makes sense and experimental *wave-powered generators* are being tested at Port Kembla (NSW), Douglas Point (SA) and Albany (WA).

6.8

# 6.4 Unit review

## Remembering

**1** **State** whether the following combinations of magnetic poles attract or repel.
   **a** N/N **b** S/S **c** N/S

**2** **List** the advantages an electromagnet has over a normal, permanent magnet.

**3** **State** the voltage:
   **a** available from power points in Australia
   **b** usually needed by laptops
   **c** needed to recharge mobile phones.

**4** **List** the advantages and disadvantages of electricity that is:
   **a** AC **b** DC.

**5** **List** three ways in which water can be used directly to spin turbines.

**6** Steam is commonly used to spin turbines. **List** three commonly used ways of changing water into steam.

**7** **State** where transformers are commonly used:
   **a** around the home
   **b** in transmitting electricity from the power plant to home.

## Understanding

**8** **Describe** how you can make the field lines around a magnet visible.

**9** **Explain** why toys use small permanent magnets but power drills and hairdryers use electromagnets.

**10** **Outline** how a track on an iPod becomes the music that you hear through the earphones.

**11** Below are six sentence fragments. Combine three of them to **describe** an electric motor and the other three to describe an electric generator.

An electric motor…

An electric generator…

…creates an electric current through a coil…

… passes an electric current through a coil…

…to cause it to spin.

…by spinning it.

## Applying

**12** **Identify** whether AC or DC current is used to power:
   **a** an iPod **b** a washing machine.

## Analysing

**13** **Compare** the following.
   **a** a solenoid with an electromagnet
   **b** an electric motor with a generator

**14** **Compare** a bike dynamo with a simple generator.

## Evaluating

**15** **a** **Assess** which method of power generation is best suited to providing Australia's future energy needs.
   **b** **Justify** your answer.

## Creating

**16** **Construct** a diagram that shows how power is transmitted to the city.

**17** **Construct** a Venn diagram like the one shown in Figure 6.4.15. Then **identify** which of the following terms describe a motor only, a generator only or both. Place the terms in the Venn diagram.

| | |
|---|---|
| uses a coil | uses a magnet |
| needs movement | needs electric current |
| produces movement | produces electric current |

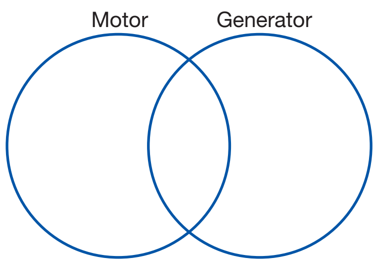



Figure 6.4.15

## Inquiring

**1** Research wind farms in your state. Find out:
   **a** where they are located
   **b** how many turbines are in each
   **c** how many more are planned for the future.

**2** Research nuclear energy as a way of generating electricity. Find the countries currently using it, and its advantages and disadvantages.

# 6.4 Practical activities

## 1 Force on a wire

### Purpose

To demonstrate electromagnetism.

### Materials

- small sheet of cardboard
- scissors
- sticky tape
- aluminium foil
- retort stand, bosshead and clamps
- wires with alligator clips
- switch
- power pack with circuit breaker/auto cutoff
- horseshoe magnet

### Procedure

1 Cut a 'picture frame' out of the cardboard and stick a single thin strip of aluminium foil across it.

2 Construct the apparatus as shown in Figure 6.4.16 and set the power pack at its lowest voltage.

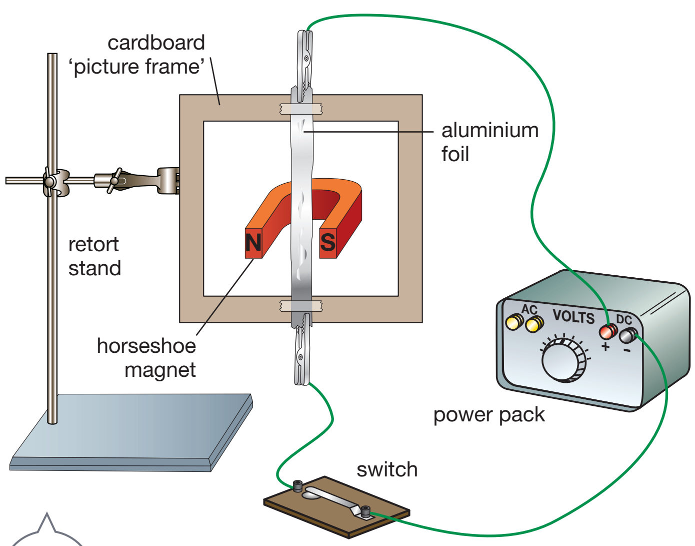



Figure 6.4.16

3 Hold the horseshoe magnet as shown and quickly close then open the switch. Record what happens, in a table like the one shown in the Results section. *Note*: The power pack might 'trip'. If it does, you will need to wait until it resets before attempting the rest of the prac.

4 Reverse the terminals on the power pack and repeat.

5 Reverse the orientation of the magnet (i.e. swap poles) and repeat.

### Results

In your workbook, construct a table similar to the one shown here, and use it to record all your observations.

| Terminals of power pack | Magnet poles | Direction aluminium strip moves (in/out/left/right) |
|---|---|---|
| As shown | As shown | |
| Reversed | As shown | |
| As shown | Reversed | |
| Reversed | Reversed | |

### Discussion

1 **Identify** what the purpose of the aluminium foil is in this experiment.

2 **Describe** what happened when:

  a the terminals of the power pack were reversed

  b the poles of the magnet were swapped.

3 **Describe** how this experiment demonstrates electromagnetism.

4 **Propose** how this experiment relates to an electric motor.

## 2 Make your own motor

### Purpose

To build a simple electric motor.

### Materials

- solid copper wire (without strands and insulating plastic)
- small piece of sandpaper
- 2 large paperclips
- 2 insulated connecting wires with alligator clips on one end
- access to pliers
- bar magnet
- plastic or paper cup
- sticky tape
- 1.5V AA battery
- rubber band

### Procedure

1. Straighten one end of both paperclips, as shown in Figure 6.4.17, and tape them to the top of the cup.

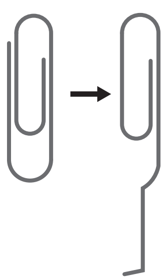



Figure 6.4.17

2. Lightly sand the ends of the copper wire. Then wind the copper around your little finger to form a coil. Leave two straight sections about 1 cm long on each side. It should look like Figure 6.4.18. Place your coil in the holder formed by the paperclips.

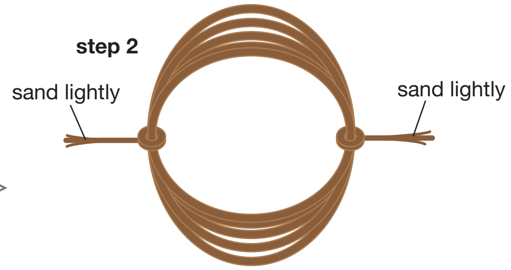



Figure 6.4.18

3. Strip about 1 cm of insulating plastic off the ends of both connecting wires as shown in Figure 6.4.19.

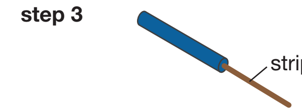



Figure 6.4.19

4. Use the rubber band to secure these stripped ends to each end of the battery. Your set-up should look like Figure 6.4.20.
5. When ready, attach the alligator clips to the paperclips. Meanwhile, hold the bar magnet close to the coil. If your motor doesn't spin:
   - try giving the coil a small flick
   - remove the coil and twist it so that the straight parts are exactly central.

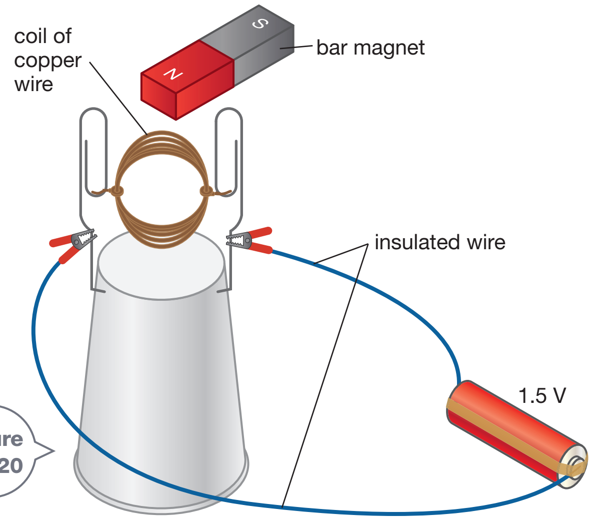



Figure 6.4.20

### Discussion

1. A motor changes the form of energy. **State** what type of energy is:
   a. provided to the motor
   b. produced by the motor.
2. **Describe** what the passage of current creates down the core of the coil.
3. The motor won't spin without a magnet nearby. **Explain** why.

# 6 Chapter review

## Remembering

1 **State** whether the following statements are true or false.
- a Energy converters have resistance.
- b A current is flowing when a spark jumps from one object to another.
- c Radiation spins the turbine in a nuclear reactor.
- d Australia has no geothermal power plants.

2 **Name** the components shown in Figure 6.5.1.

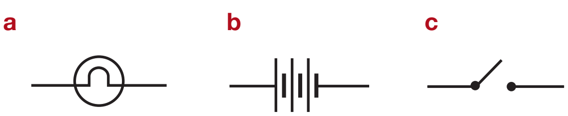



Figure 6.5.1

3 **State** what the following do if an abnormally high current passes through them.
- a fuse
- b circuit breaker

4 **State** the unit and unit symbol used to measure resistance.

5 Coal is Australia's main source of electrical energy. **List** its advantages and disadvantages.

## Understanding

6 **Define** the following terms.
- a electrolyte
- b resistance
- c solenoid

7 **Explain** why a wet cell is suitable for a car but not for an iPod.

8 **Explain** the advantages of a home having all its appliances connected in parallel rather than in series.

9 Voltage is boosted before electrical power is transmitted long distances. **Explain** why.

10 **Explain** why laptops need a transformer when plugged in.

## Applying

11 **Identify** the expected current and voltage of each of the globes in Figure 6.5.2. Enter your predictions in a table like the one provided below.

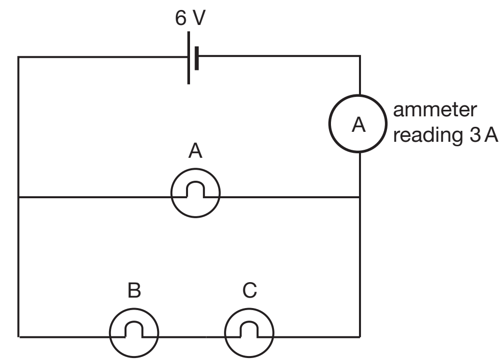



Figure 6.5.2

| | Globe A | Globe B | Globe C |
|---|---|---|---|
| Expected current (A) | | | |
| Expected voltage (V) | | | |

12 **Identify** three appliances around your home that use an electric motor.

## Analysing

13 **Contrast** the electron flow and voltage of AC electricity and DC electricity.

## Evaluating

14 **Propose** reasons why:
- a electrical wires are wrapped in insulating plastic
- b high-voltage power lines need to be insulated from the poles that hold them up.

15 a **Identify** which renewable way of generating electricity would be best for your area in Australia.
- b **Justify** your choice.

## Creating

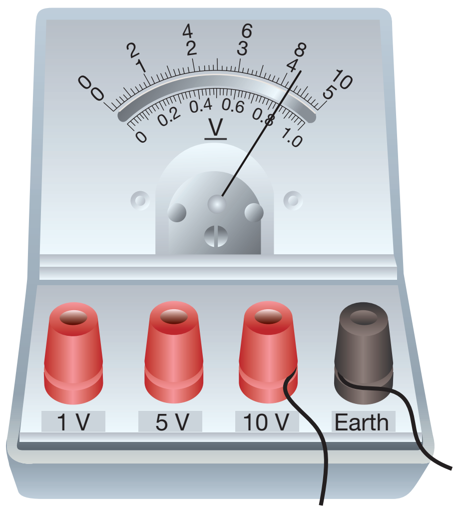
16 **Use** the following ten key words to **construct** a visual summary of the information presented in this chapter.

| | | |
|---|---|---|
| current | voltage | resistance |
| ammeter | voltmeter | magnet |
| coil | motion | motor |
| generator | | |

6.9

# Thinking scientifically

**Q1** Analogue voltmeters have a needle and a dial. Many have different terminals along their base, with each terminal measuring a different maximum voltage. This gives you the best chance of getting an accurate reading.




The voltmeter shown here was used to measure the voltage over a light globe. Its measurement is shown. State which of the following voltage readings is most likely to be correct.

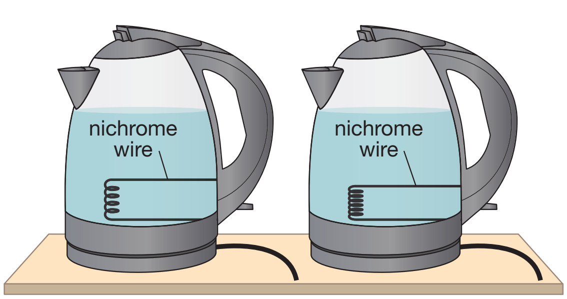
**A** 0.84 V
**B** 4.2 V
**C** 8.2 V
**D** 8.4 V

**Q2** The actual supply voltage of a 3 V battery is to be measured using the voltmeter above.

Assess which set of terminals would give the most accurate reading of this battery's voltage.

**A** 1 V and earth
**B** 5 V and earth
**C** 10 V and earth
**D** earth only

**Q3** Marge tested how long each of the electric kettles shown below took to boil water.




The kettles were almost identical. Identify what is different between them.

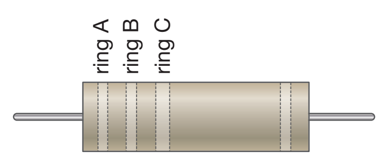
**A** the amount of water each held
**B** the voltage of the heating element
**C** the type of wire used as a resistance
**D** the resistance of each heating element

**Q4** To run a fair test on the kettles in question 3, identify which of the following Marge would have to keep constant.

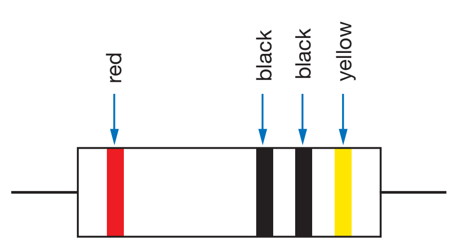
**A** the time each kettle was on for
**B** the amount of water each held
**C** the temperature of the water at the start.
**D** all of the above

**Q5** Resistors are electronic components. Their resistance is marked on them as a series of coloured bands. What each colour band means is shown in the table below.

| Colour | Ring A | Ring B | Ring C |
|---|---|---|---|
| Black | 0 | 0 | × 1 |
| Red | 2 | 2 | × 100 |
| Yellow | 4 | 4 | × 10 000 |
| Blue | 6 | 6 | × 1 000 000 |




State which of the following is the most likely resistance of the resistor shown here.



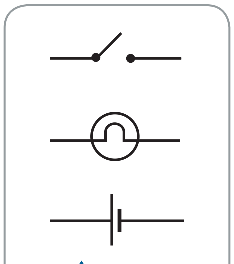

**A** 40 Ω
**B** 401 Ω
**C** 200 Ω
**D** 2004 Ω

# Glossary

## Unit 6.1

**Circuit diagram:** a simplified and shorthand version of a circuit; shows how all components in the circuit are connected

**Components:** the parts of a circuit (light globes, switches, resistors, wires, globes and batteries)



Components

**Current:** the flow of charge

**Electric circuit:** the path down which charge flows

**Electrons:** tiny negative (–) particles spinning around the nucleus of an atom

**Ion:** a charged 'atom' created when electrons are gained or lost

**Neutral:** having no charge

**Neutrons:** neutral particles found in the nuclei of most atoms

**Nucleus:** the core of an atom; it contains protons and neutrons

**Protons:** positive (+) particles found in the nuclei of all atoms

**Static electricity:** the build-up of electric charge on a surface

## Unit 6.2

**Ammeter:** an instrument that measures current

**Ampere:** the unit used to measure current; unit symbol is A

**Conductor:** material that allows a current to pass through it

**Dry cell:** a compact cell that uses a paste and not liquid for an electrolyte

Dry cell

**Electrolyte:** a conducting solution in a battery

**Insulator:** material that does not conduct electricity

**Ohm:** the unit used to measure resistance; unit symbol is Ω

**Parallel:** when components are connected in branches adjacent to one another; voltmeters are connected in parallel

**Photovoltaic cell:** a solar cell; directly converts solar energy into electrical energy

**Resistance:** a measure of how difficult it is for current to pass; measured in ohms (Ω)

**Series:** when components are connected with each other in a single line; ammeters are connected in series

**Transformer:** a device that increases or reduces voltage provided to a circuit

**Voltage:** a measure of the amount of energy provided to charges or used by them; measured in volts (V)

**Voltmeter:** an instrument that measures voltage

**Volts:** the unit used to measure voltage; unit symbol is V

**Wet cell:** a cell that uses liquid electrolyte

## Unit 6.3

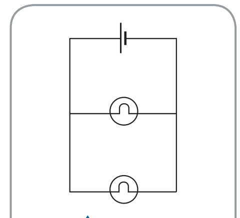
**Active wire:** a wire that carries current to a component; it is coated in brown plastic

**Circuit breaker:** a switch that turns off a circuit if too much current flows through it

**Earth wire:** a wire through which current only flows when there is a leak of current in an appliance; it is coated in yellow and green plastic

**Fuse:** a wire of high resistance; it will melt if too much current flows in the circuit

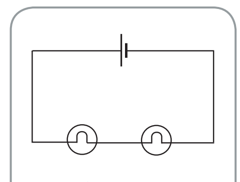
**Neutral wire:** a wire that carries current away from the component; it is coated in blue plastic



Parallel circuit

**Parallel circuit:** a circuit that has a number of branches, each with its own components

**Safety switch:** a device that turns all household circuits off if it detects a leak in current; it is also known as a residual current device (RCD)



Series circuit

**Series circuit:** a circuit with all its components arranged in a line, forming a single loop

**Surge protector:** a device that turns off power to appliances if it detects a massive and damaging increase in current

## Unit 6.4

**Alternating current (AC):** current generated by electrons changing the direction in which they move

**Direct current (DC):** current generated by electrons always moving in one direction

**Electromagnet:** a solenoid with an iron rod in its centre

**Electromagnetism:** the relationship between electricity and magnetism

Electromagnetism

**Field lines:** lines that show the direction of the force on iron filings and compass needles

**Generator:** uses electromagnetism to produce electricity; needs a spinning coil and a magnet

**Magnetic field:** an invisible force field around a magnet

**Motor:** a machine that uses electromagnetism to spin; it needs a current-carrying coil and a magnet

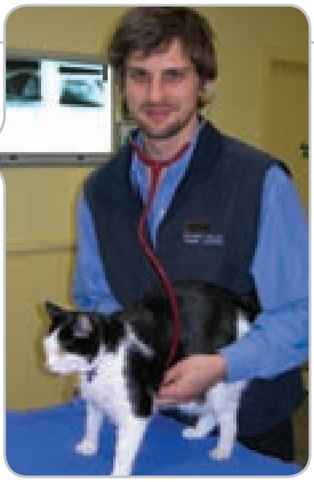
**Solenoid:** a current-carrying loop of wire

**Transformer:** a device that increases or decreases voltage

**Turbine:** a large-scale electricity generator

# Look who is using science

## VET



Hi, I am Glenn Linstead, a vet working in a private practice. My official title is veterinary surgeon. I did a five-year university degree to become a vet. I love my job, and it would be hard to imagine a better one because I have always been fascinated by animals.

I am a 'small animal' vet, which means I treat mainly pets, including dogs, cats, rabbits and birds. This job is interesting because there is a great variety of animals and conditions. I do surgery such as repairing torn ligaments in legs and removing foreign objects like balls or sticks from intestines. There are many other duties, including giving injections, stitching cuts, desexing, cleaning or extracting teeth, diagnosing illnesses, and administering cures such as drug treatments.

The thrill of curing animals and seeing the delight of their owner makes you feel great. If you like science and animals, consider being a vet. Work hard and join me in a rewarding career.

## PHYSIOTHERAPIST

I'm Kelly Sheffield, a senior physiotherapist in a hospital. I did a Bachelor of Science in Physiotherapy for 4 years at university. I gain a lot of satisfaction from my job by being able to help people and I enjoy working closely with medical staff.

The human body is an amazing machine. Learning about its complexities is very interesting. My work is extremely varied and includes areas such as working with newborn babies and children, treating women after childbirth, and treating people on ventilators in critical care units.

I rehabilitate people who have balance disorders and problems with their inner ear vestibular system. I teach exercises to patients after surgery or accidents and help people to do the things we all take for granted, such as sitting up, standing and walking. I use science every day in my job and I am very glad that I chose to be a physiotherapist.

## HORTICULTURIST

Hello, my name is Cheryl Commens, and I work as a horticulturist. Horticulture is the science of growing plants. To be able to do this effectively requires a knowledge of plant reproduction, soil chemistry and pest and disease management.

To become a horticulturist I had to study for a Diploma in Applied Science, Horticulture. I have worked in many different fields of horticulture including landscaping, retail and wholesale plant nurseries and agriculture.

Working as a horticulturist allows you to spend most of your working life outdoors. This gives you a great sense of freedom and love and respect for the environment. If you like similar things then perhaps you could consider horticulture as a career.

# 7 Body coordination

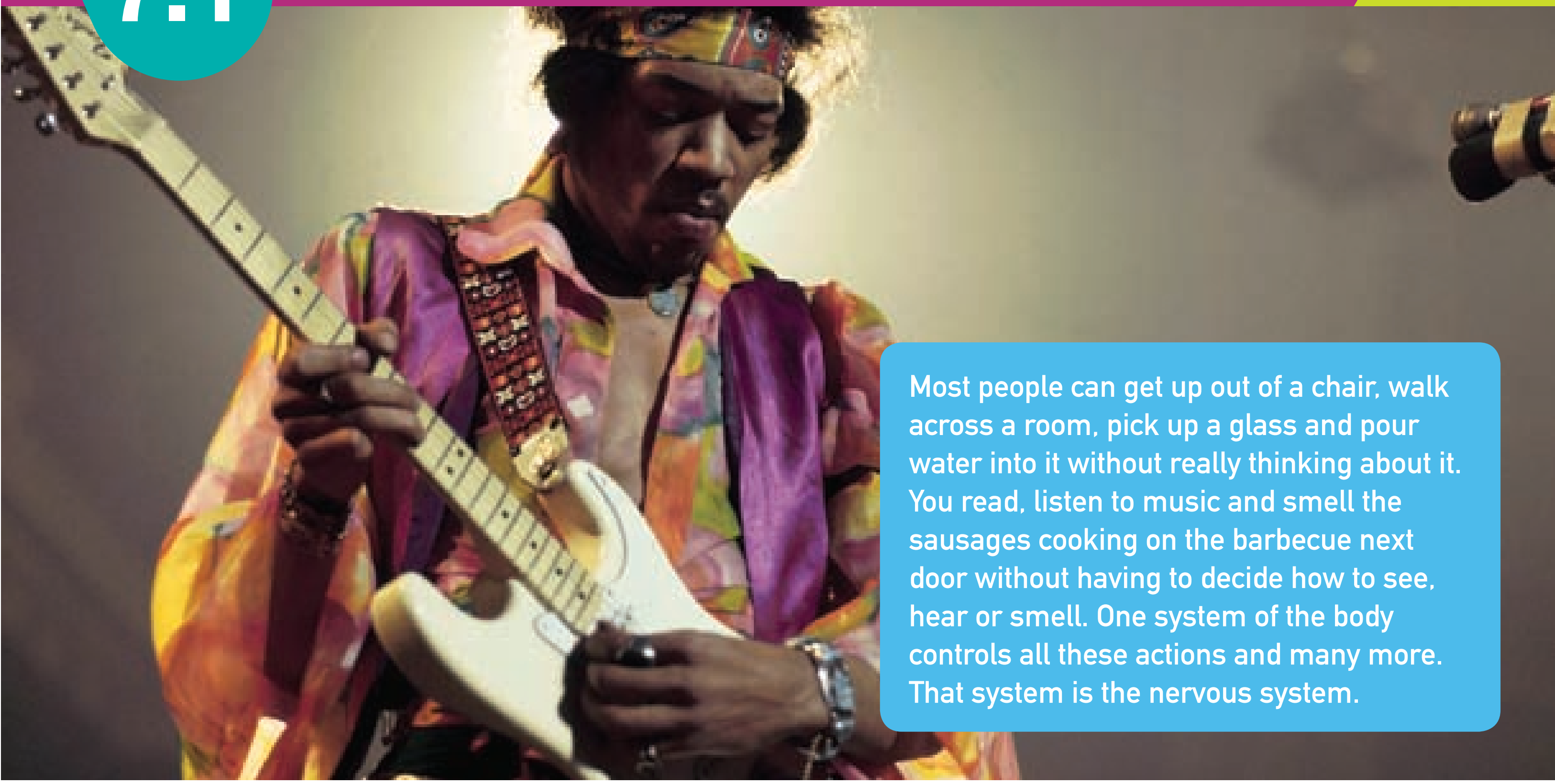
## HAVE YOU EVER WONDERED …

- what makes you shiver when cold and sweat when hot?
- why you are able to act quickly in response to sharp or hot objects?
- why you get 'butterflies' in your stomach when you are nervous or feel shaky when frightened?

### After completing this chapter students should be able to:

- explain the role of the nervous system in controlling and coordinating the functioning body
- explain the role of the endocrine system, including its role in coordinating body functioning
- discuss the interaction of the nervous and endocrine systems in coordinating the body's response to changes in the internal and external environments
- demonstrate the use of models to explain how body systems work together
- explain how all the body systems work together to provide the needs of the body and maintain an internal environment that supports the functioning cells.

# 7.1 Nervous control



Most people can get up out of a chair, walk across a room, pick up a glass and pour water into it without really thinking about it. You read, listen to music and smell the sausages cooking on the barbecue next door without having to decide how to see, hear or smell. One system of the body controls all these actions and many more. That system is the nervous system.

INQUIRY science 4 fun

## Pupils change

What changes occur in the eyes in the light and dark?

Yes

### Collect this ...

- mirror
- strip of dark cloth

### Do this ...

1. Stand in front of the mirror in a room with good light.
2. Look at your eyes—especially notice the size of the pupils.
3. Close your eyes and cover them gently with the dark cloth. Do not press on your eyes.
4. Keep your eyes closed for two minutes.
5. Remove the cloth and open your eyes. Look in the mirror immediately.
6. Observe the pupils of your eyes.

### Record this ...

**Describe** what happened.

**Explain** why this happened.

## Human nervous system

The nervous system is a communication system that controls all parts of your body. The human nervous system has two main parts, as shown in Figure 7.1.1.

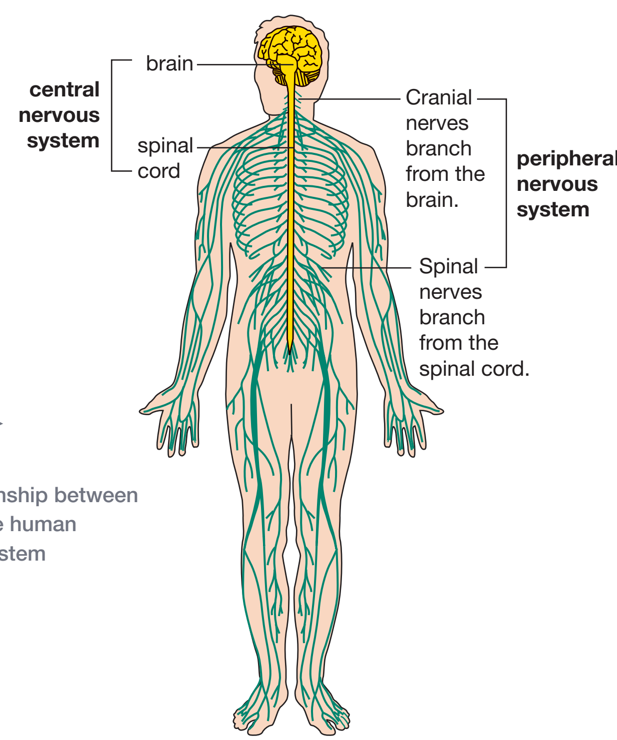



**Figure 7.1.1** The relationship between parts of the human nervous system

The two parts of the nervous system are:

- the **central nervous system** (CNS), made up of your brain and your spinal cord
- the **peripheral nervous system** (PNS), made up of the nerves that carry messages to and from the CNS and other parts of your body.

The CNS receives information from all over the body, processes that information, and then sends out messages telling the body how to respond.

## Nerve cells

The nervous system is made up of trillions of nerve cells or **neurones**. Neurones carry electrical messages, called **nerve impulses**, from one part of your body to another at very high speed. These nerve impulses can travel in only one direction.

As you can see in Figure 7.1.2, a neurone has four main parts: a cell body, dendrites, knobs and an axon. The **cell body** contains the nucleus, which is the control centre of the cell. The **dendrites** branch out from the cell body and receive messages from other nerve cells, which are then sent on to the cell body. The **axon** or nerve fibre sends nerve impulses in only one direction—away from the cell body. The knobs pass the message on to the next neurone. Two common types of neurones are:

- **motor neurones**—these carry messages from the CNS to **effectors**. Effectors are muscles or glands (tissues that secrete chemicals) that put the messages into effect
- **sensory neurones**—these carry messages from cells in the sense organs (such as your eyes, ears, tongue and skin) to the brain and spinal cord.

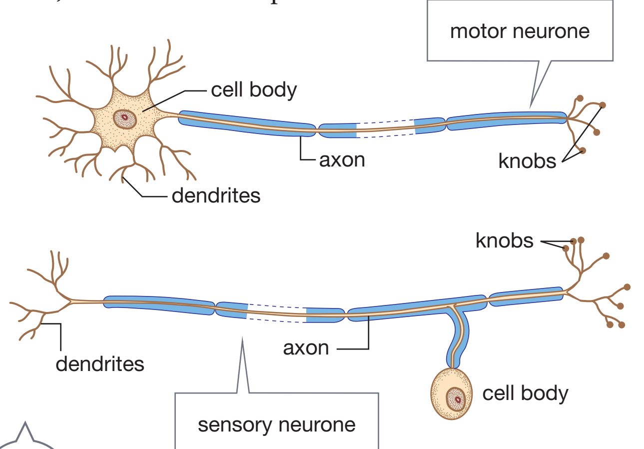



Figure 7.1.2 Two types of neurone

The messages sent along the neurone are electrical. If all the neurones in your body touched one another, stimulating one nerve ending would be like turning on one switch in your house and having all the lights and appliances come on. Your body needs to control which nerves 'fire' at a certain time.

When the nerve impulse reaches the knobs at the end of an axon, a chemical called a **neurotransmitter** is released into the space between the neurones (**synapse**). You can see this in Figure 7.1.3. The neurotransmitter carries the message from the axon of one neurone to the dendrite of the next neurone. The dendrite receives the chemical message and sends off an electrical signal.

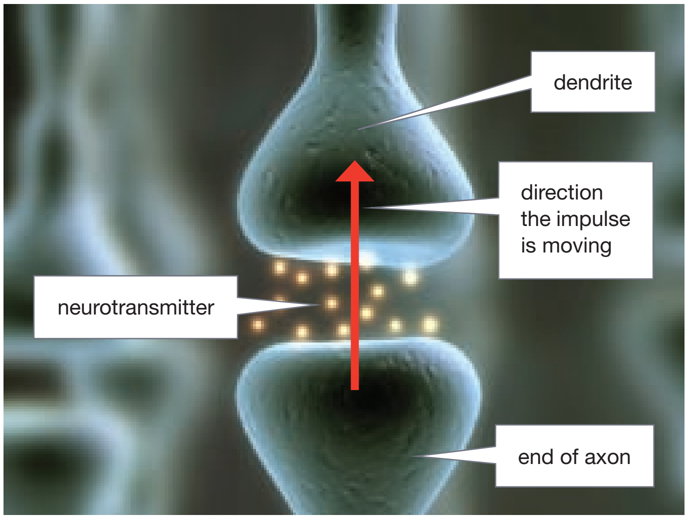



Figure 7.1.3 At the synapse, the electrical signal of the nerve is converted into a chemical signal and then back into an electrical signal again.

About 50 different neurotransmitters have been found that carry electrical impulses across these gaps. These neurotransmitters control which nerves fire and when.

In your body, the neurones are bundled together to form nerves, as shown in Figure 7.1.4. Neurones are covered with an insulating layer called a **myelin sheath**. The myelin sheath electrically insulates the neurones from each other and increases the speed of the nerve impulse.

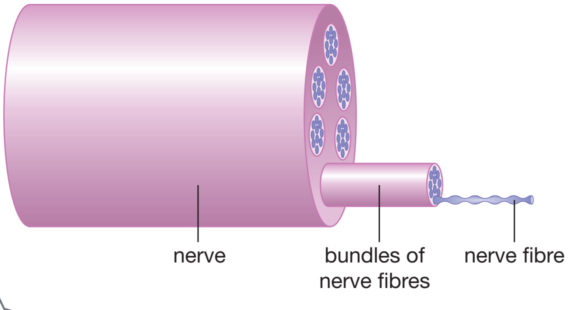



Figure 7.1.4 A nerve is made up of a large number or neurones, each of which is surrounded by a myelin sheath.

The parts of the CNS that contain neurones covered in myelin are called white matter. The parts that contain mainly cell bodies are called grey matter. The outer parts of the brain are made up mainly of grey matter.

7.1

**What a nerve!**

The longest neurone in your body extends from your big toe to the middle part of your spine and is about a metre long. A giraffe's longest nerve is at least two metres long!

SciFile

## The brain: communication centre

Humans have a very large brain for their body size, compared with other animals. The human brain contains about 100 billion neurones, and has an average volume of 1200–1400 mL.

The brain controls and regulates body functions. Without it you cannot survive. Amazing new medical imaging techniques can now look inside a living brain. MRI (magnetic resonance imaging), for example, uses strong magnetic fields to distinguish different types of body tissue (Figure 7.1.5). This is useful in diagnosing brain tumours and finding areas of brain injury. Damage to the brain is repaired slowly. Sometimes other parts of the brain take over the function of the damaged parts, but there are situations where brain damage is permanent.

### The cerebrum

When you think of what a human brain looks like, you are probably thinking of the **cerebrum**. It occupies more than 80% of the brain and contains over 10 billion neurones. Its many folds increase its surface area by three times. It is here that the higher intellectual functions of humans take place. The cerebrum controls your conscious thoughts and the intentional (voluntary) movement of every body part. It also receives sensory messages from all body parts.

The cerebrum is made up of two parts, called the right and left cerebral hemispheres. When it comes to intended actions such as walking or hitting a ball, the right hemisphere controls the left side of your body and the left hemisphere controls the right side of your body (Figure 7.1.6). Each half of the brain can work independently, but you use both cerebral hemispheres for most activities. One side usually dominates in a particular task. For example, in most people the left side has more control over language and logical thinking, such as mathematical ability. The right side is the more creative and emotional side. Musical and artistic ability depends on the right side of the brain.

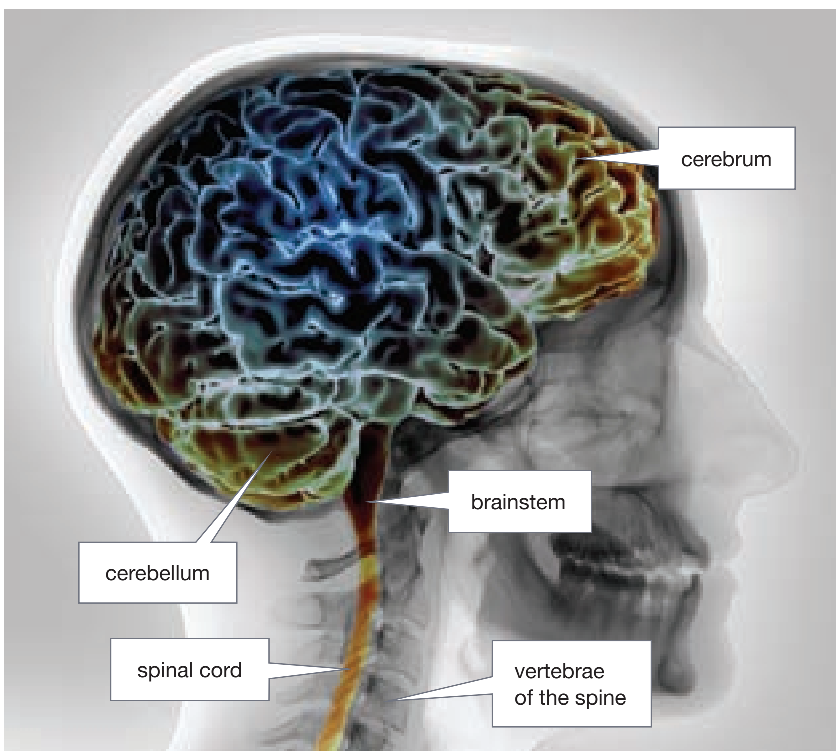



**Figure 7.1.5** Computer-enhanced X-ray showing the external structure of a human brain.

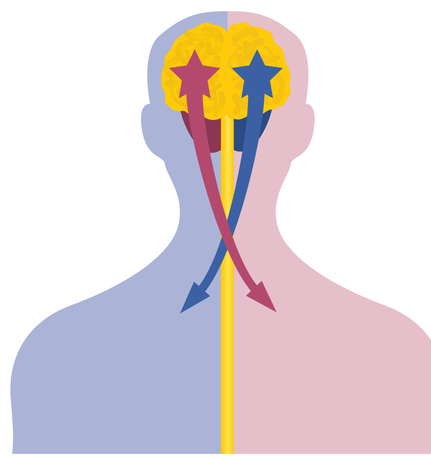


**Figure 7.1.6** The right and left sides of the brain control the opposite sides of the body.

Figure 7.1.7 uses images of the brain created using both MRI and PET (positron emission topography). Together these scans reveal the parts of the brain that are active during various activities. They show that the left-hand side of the brain is active during activities that involve language. They also show that different parts are active when listening, speaking, reading or just thinking about words.

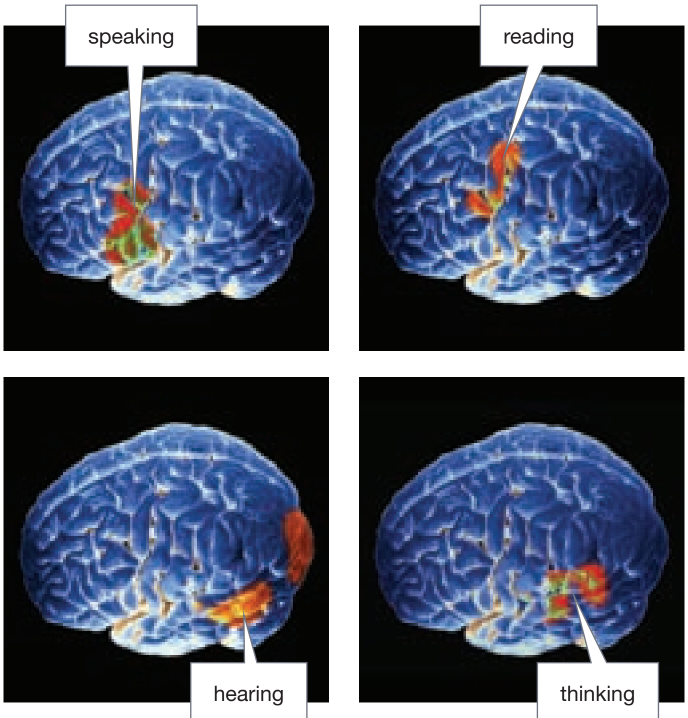



Figure 7.1.7 The red and green areas in these images show the areas of your brain that are active during various activities.

At the base of the cerebrum, where you can feel your skull curve inwards, is the **cerebellum**. Its position is shown in Figure 7.1.8. The cerebellum is responsible for coordination and balance. Without it, walking would be impossible.

The lower part of the **brain stem** or **medulla** can be seen where the spinal cord widens just after it passes into the skull. It controls the body's vital functions, such as breathing, blood pressure and heart rate. Damage to this area can be fatal.

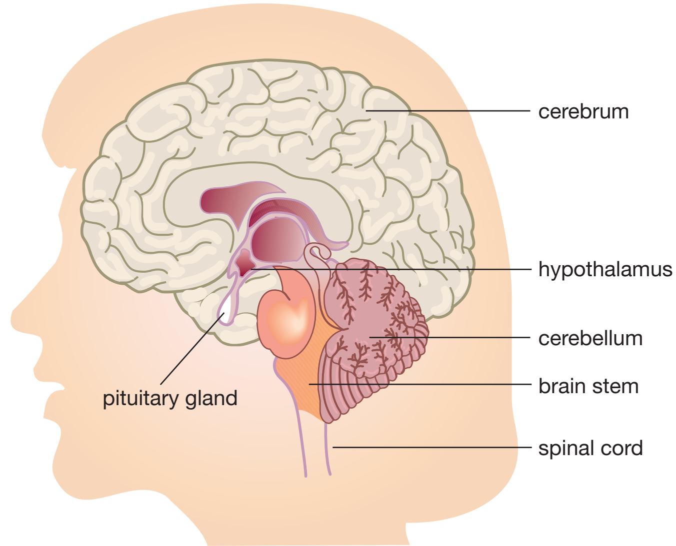



Figure 7.1.8 Vertical section through the brain

# Peripheral nervous system

The PNS has two separate parts: the somatic nervous system and the autonomic nervous system.

## Somatic nervous system

All animals including humans need information about their surroundings. The **somatic nervous system** collects this information through sensory organs such as the eyes and ears. The somatic nervous system also coordinates movement of the body.

The somatic nervous system's sensory organs are **receptors**—special organs or tissues that have nerve endings that detect changes in the environment. The changes stimulate the nerve endings to send messages to your brain. Something that you can detect using your sense organs is a **stimulus**. Stimuli in your environment include temperature, light, touch, smell and sound.

In your body there are different types of receptors. Mechanoreceptors are sensitive to stimuli such as touch. They also make you aware of muscles being stretched, for example when your bladder becomes full. Photoreceptors in the eye are sensitive to light. Thermoreceptors respond to changes in temperature. Chemoreceptors are sensitive to chemicals, such as those found in food. Chemoreceptors tell you if food is sweet or bitter.

### The sensitive skin

The skin responds to many different sensations, such as touch, pain and temperature. One of the ways that your body protects itself from the outside world is by being very sensitive to touch. Receptors in your skin alert you to a hot surface or a biting mosquito. You can see these receptors in Figure 7.1.9.

1 p235

### The sense of hearing

Sometimes receptors are grouped together to form a sense organ. An example is the receptors in the ear. The ear not only senses sound, but also helps you to keep your balance.

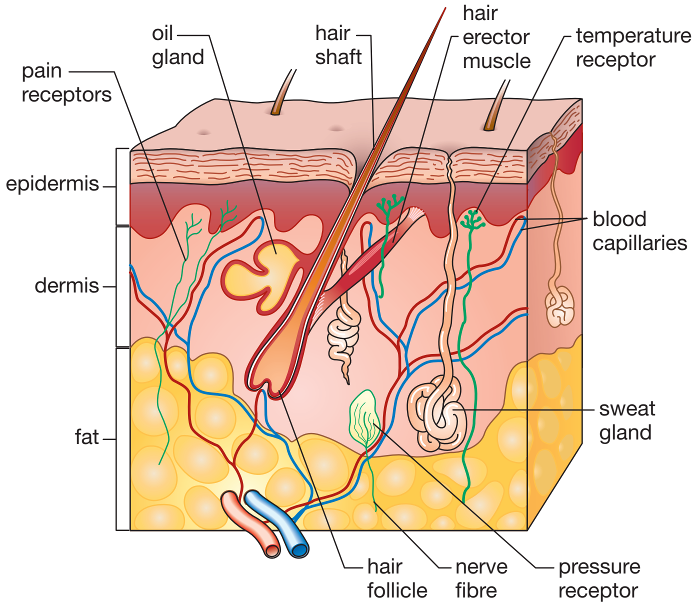



Figure 7.1.9 The skin has many receptors and provides you with a lot of information about your surroundings.

In your inner ear are fluid-filled semicircular canals. These are shown in Figure 7.1.10. If you suddenly lean in one direction, the fluid in one of the canals moves against tiny sensory hairs in the canal lining. A nerve impulse is sent to the brain, and the brain then sends messages to the muscles to help you balance.

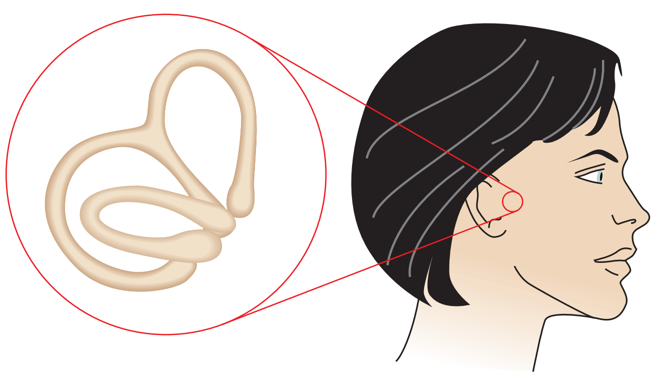


Figure 7.1.10 Nerves in the semicircular canals of the inner ear respond to gravity and help you maintain your balance.

**You spoke?**

**SciFile**

Have you ever heard girls complain that boys do not listen to them? There is a scientific basis for this. Researchers in the United Kingdom have found that male and female voices stimulate different parts of the brain and that deciphering a female voice is a more complex process.

### The sense of sight

Only about one-sixth of the eye is visible. Most of it is protected within the skull. The pupil is an opening that allows light to pass through the lens and into your eye (Figure 7.1.11). The lens bends (refracts) light to help focus the light rays onto the photoreceptors in the retina at the back of the eye. Messages are sent from the photoreceptors via the **optic nerve** to the brain for interpretation, and this is what is called vision.

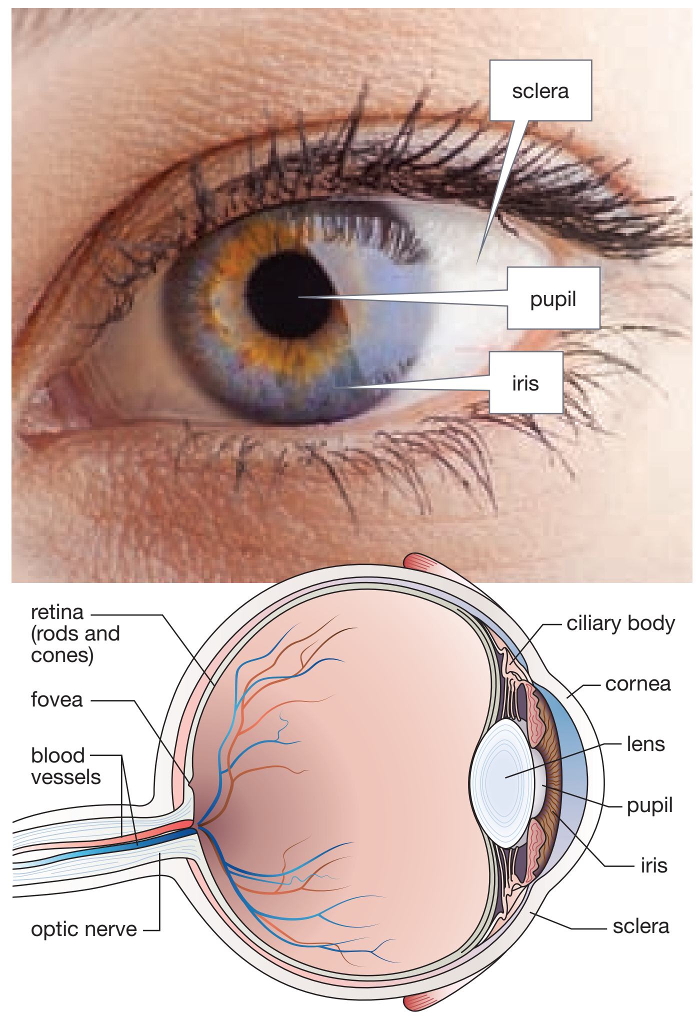



Figure 7.1.11 The structure of the human eye

In the retina there are two types of photoreceptors: rods and cones. Rods work in dim light and are responsible for night vision. Cones work in bright light and are responsible for colour vision. People with colour blindness have difficulty distinguishing between certain colours because they have fewer cones than normal.

### A sense of smell and taste

The chemoreceptors for taste and smell work together. Food never tastes as good when you cannot smell it. The receptor cells for taste are taste buds. You have about 10 000 taste buds (shown in Figure 7.1.12) scattered on the surface of your tongue.

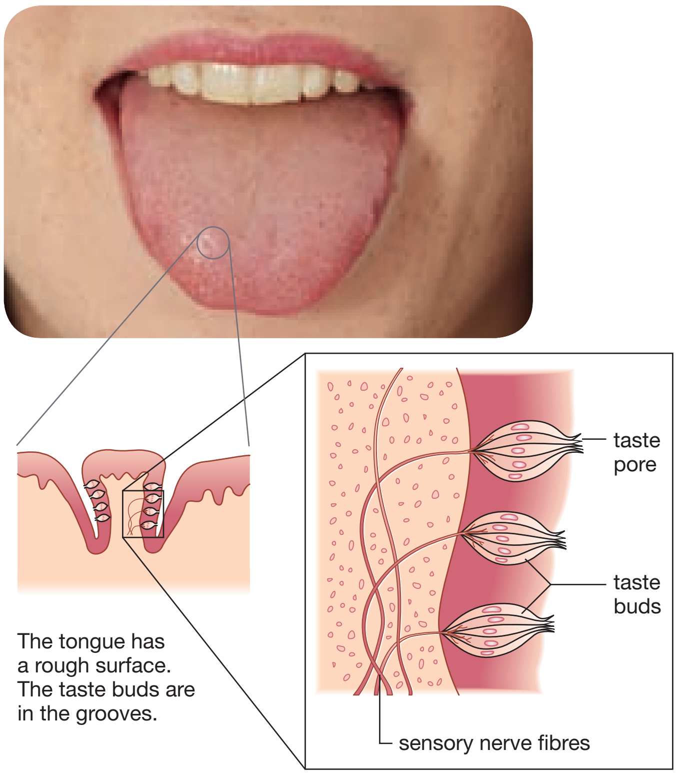



**Figure 7.1.12** Taste buds are arranged in groups to form a taste pore, through which taste receptors extend. Chemicals bind to the taste receptors and stimulate sensory nerves. Messages sent to the brain give the sensation of taste.

**Tastes good**

**SciFile**

Humans can distinguish sweet, sour, salty and bitter tastes. In 2002, umami (savoury) was added as a fifth sense. In 2010, researchers from Deakin University, Australia, discovered that humans can detect a sixth taste—fattiness.

## Autonomic nervous system

Some of the activities of your body happen without you realising it, such as the beating of your heart, the movement of food in your intestines, sweating and pupil size. These activities are controlled by the **autonomic nervous system**.

Two parts of the autonomic nervous system are the sympathetic nervous system and the parasympathetic nervous system.

The sympathetic and parasympathetic nervous systems can be thought of as opposites that complement each other. The **sympathetic nervous system** speeds up the functions of the body and makes it work more efficiently. It is the system that prepares your body for emergencies by making you more alert and preparing your body to act. The **parasympathetic nervous system** slows everything down. It is the system in control when you are resting.

To prepare your body for intense activity, the sympathetic nervous system diverts blood away from areas that will not be used in the action, such as the digestive system. It diverts the blood to areas that will be used, such as the muscles. The sympathetic nervous system:

- diverts blood flow away from the digestive tract and the skin
- stops peristalsis—the muscular action that mixes food in the intestines
- maintains blood flow to the lungs and the muscles of the skeleton—blood flow to the muscles may be increased by up to 120%
- opens the bronchioles (airways to the lungs)—this increases the amount of air able to enter the lungs, increasing the supply of oxygen to the body
- increases heart rate, thereby increasing blood flow to the muscles of the skeleton
- relaxes the muscles in the eye and dilates the pupils, allowing more light to enter the eye and improving distance vision
- increases blood flow to the heart.

**Figure 7.1.13** It is the actions of the sympathetic nervous system that cause the sensations associated with fear or stress.

The functioning of the parasympathetic nervous system:

- increases blood flow to the digestive tract
- stimulates the salivary glands and increases the rate of peristalsis, in support of digestion
- reduces the diameter of the bronchioles when there is a reduced need for oxygen
- controls the heartbeat
- contracts the muscles of the eye and reduces the diameter of the pupil to allow close vision.

Figure 7.1.14 shows how the parts of the human nervous system relate to one another.

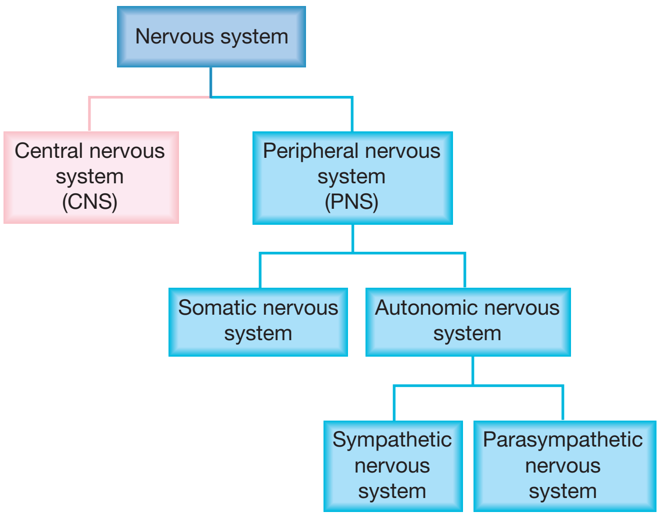



**Figure 7.1.14** The relationship between different parts of the human nervous system

## Responding to stimuli

A simple model of your nervous system is a stimulus–response model. Receptors stimulate the sensory nerves. The sensory nerves send a message to the brain. The brain works out the response that is required, then sends a message along motor nerves to the effectors—the muscles or glands that will put the response into effect. Figure 7.1.15 provides an example.

### Reflex actions: a rapid response

If you touch something hot or sharp, you automatically pull your hand away. Arm muscles that are normally under your voluntary control react very fast, without waiting for instructions from the brain. This action, called a reflex action, protects your body from danger. Consider what happens when you touch a hot object. Receptors detect the temperature of your skin. This activates a sensory neurone, which sends nerve impulses to the spinal cord.

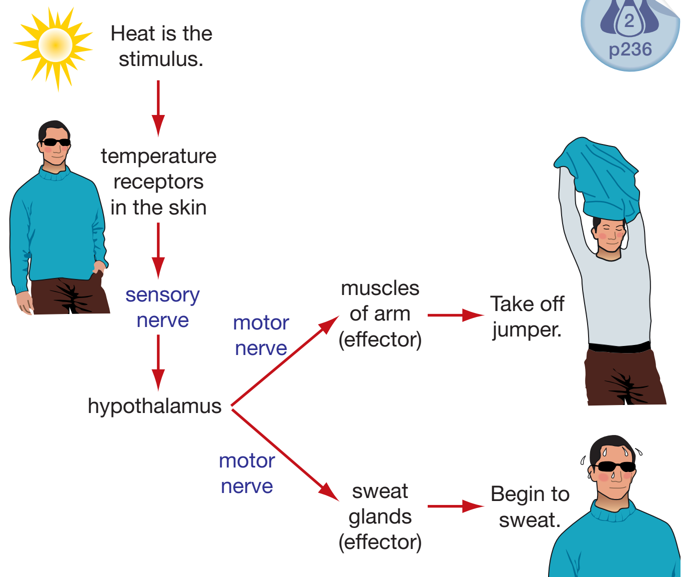



**Figure 7.1.15** This stimulus–response diagram represents your body's reaction to being too hot.

Within the spinal cord, a relay neurone passes the message directly to a motor neurone, which sends impulses to the arm muscles, which are the effectors. The arm muscles contract, lifting your hand away from the hot object. A message is sent to the brain shortly afterwards. Only then can the brain register pain. The nerve pathway operating in a reflex action is called a reflex arc. Figure 7.1.16 shows an example of a reflex arc. Most reflex actions involve only a few neurones and are therefore very rapid.

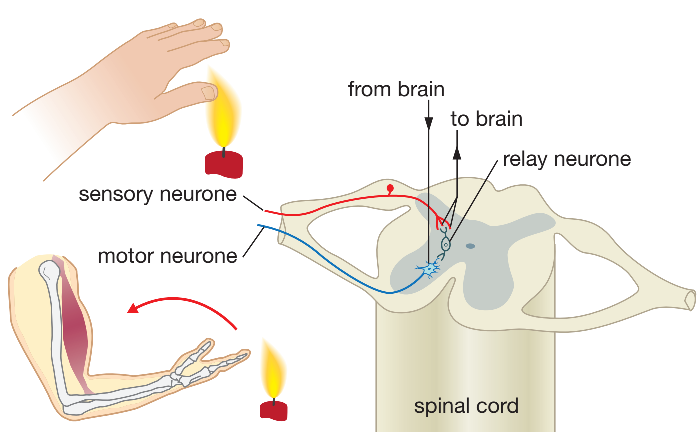



**Figure 7.1.16** The reflex arc allows you to react very rapidly to protect your body from harm.

SCIENCE AS A

# HUMAN ENDEAVOUR

Use and influence of science

## The bionic ear and eye

Figure 7.1.17 A cochlear implant

**The cochlear implant or 'bionic ear' was developed by an Australian scientist, Professor Graeme Clark.**

### The bionic ear

Professor Clark (Figure 7.1.18) was born in country New South Wales in 1935. His father was partially deaf, and this sparked Professor Clark's interest in the causes of deafness. He became a surgeon, specialising in otolaryngology, which is the study of diseases of the ear and throat. There was very little money available for his research, as most people believed it was impossible to restore hearing to the deaf.

Figure 7.1.18 Professor Graeme Clark (right) developed the cochlear implant, which allows some deaf people to hear again.

The cochlear implant (shown in Figure 7.1.17) mimics the way that the cochlea receives sounds. A microphone and a speech processor are placed behind the ear. They pick up sounds and turn them into electrical signals. These signals pass into the implant, which is placed in the skull and connected to the cochlea. The cochlea then stimulates the auditory nerve to send messages to the brain.

In 1978, Clark successfully implanted the first bionic ear into a man named Rod Saunders, who had lost his hearing in a car accident. Clark's success has been recognised worldwide.

The Australian bionic ear (shown in place in Figure 7.1.19) has now provided hearing to more than 150 000 people in more than 120 countries.

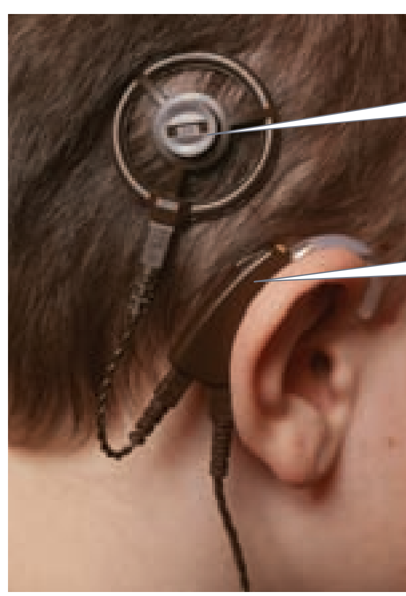



Figure 7.1.19 The bionic ear is worn behind the ear.

## The bionic eye

The bionic eye is being developed by Bionic Vision Australia researchers at the University of New South Wales.

About 1.5 million people worldwide have a disease called retinitis pigmentosa, and about one in 10 people over the age of 55 have age-related macular degeneration. Both diseases cause cells in the retina of the eye to gradually die and the person becomes vision impaired or blind.

The bionic eye is still in the experimental stage, but it is hoped that it will be able to help people with these conditions. The bionic eye is a device that consists of a camera attached to a pair of glasses. How the device works is described in Figure 7.1.20.

One version of the bionic eye is designed to enable a person to distinguish light from dark. This will help the person move around large objects such as buildings, parked cars and benches or rubbish bins on footpaths.

A second version of the bionic eye will have many more electrodes. With it, the person may be able to recognise faces and read large print (Figure 7.1.21).

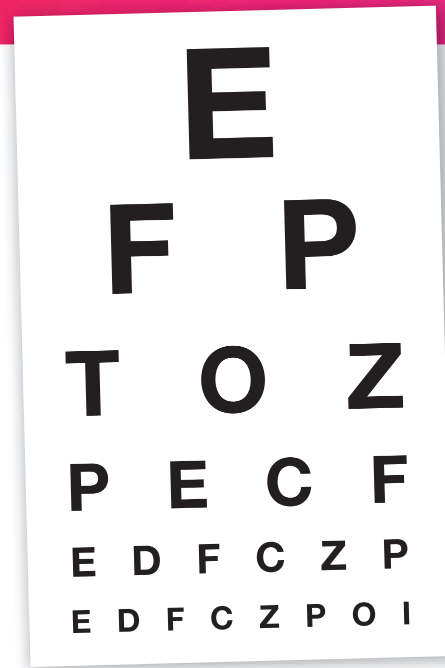



**Figure 7.1.21** It is hoped that people fitted with the second version of the bionic eye will be able to read the letters on the third line of a Snellen Chart, such as the one shown here.

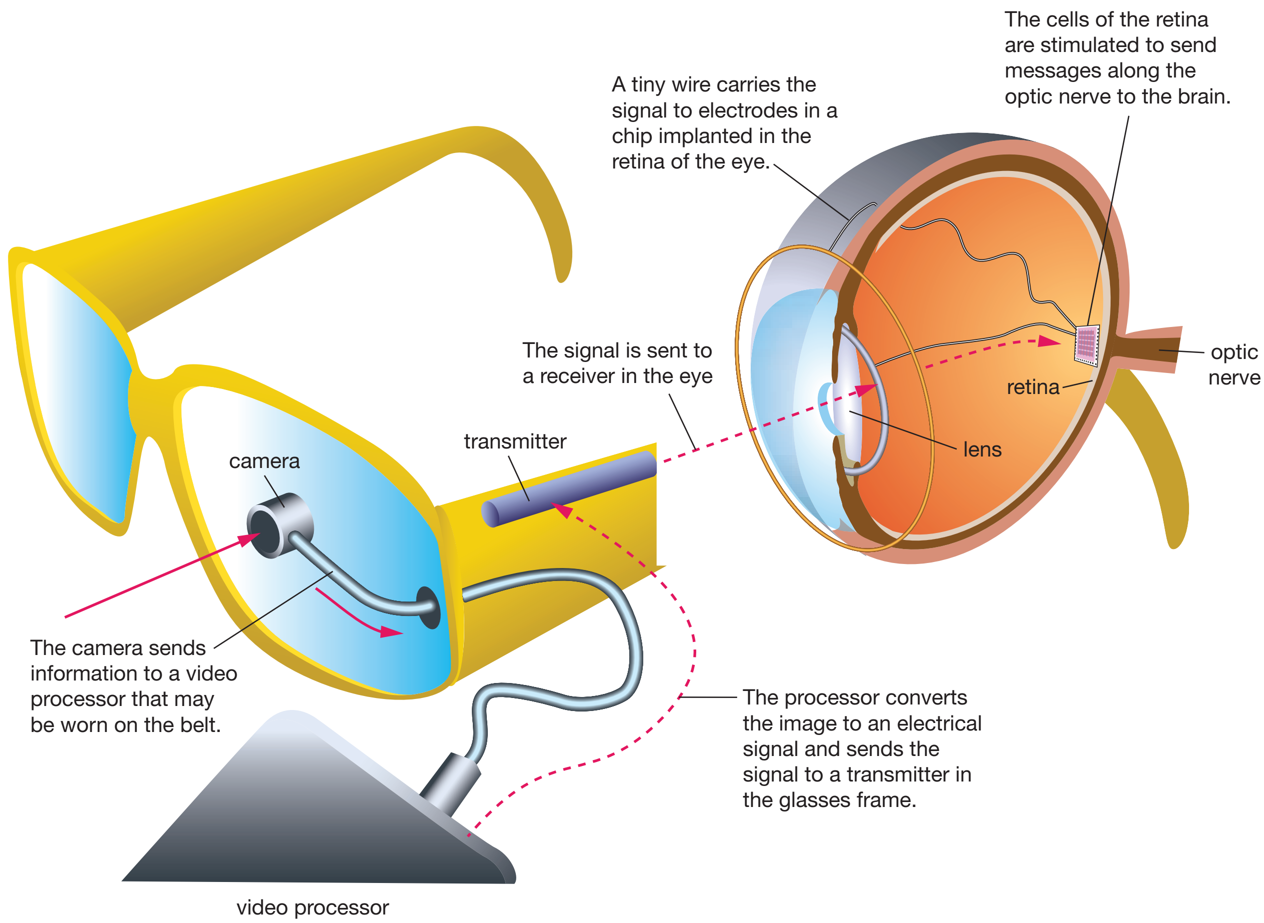



**Figure 7.1.20** How a bionic eye works

# 7.1 Unit review

## Remembering

1 **Name** the three main parts of a neurone.

2 **List** the parts of the central nervous system.

3 **Name** the layer of insulation found on nerves.

4 **List** three types of receptors found in skin.

5 **Name** two parts of the autonomic nervous system.

## Understanding

6 a **Describe** the function of dendrites.

b **Explain** how their structure suits their function.

7 **Explain** why an injury to the left side of the brain often affects the right side of the body.

8 **Describe** an example of how your brain controls an activity inside your body without your knowing about it.

9 **Describe** the function of neurotransmitters.

## Applying

10 **Use** a diagram of a reflex arc to **outline** how your foot is pulled away from a sharp object before you are aware of it.

## Analysing

11 **Contrast** the sympathetic and parasympathetic nervous systems.

12 **Compare** the roles of a sensory neurone and a motor neurone.

13 **Contrast** a stimulus and a response.

14 **Compare** the roles of receptors and effectors.

## Evaluating

15 **Propose** why severe damage to the neck region is often fatal.

16 **Propose** why many quadriplegic patients who are paralysed from the neck down can still maintain normal body functions such as breathing and digestion.

17 During a medical test called a PET scan, a sugar solution containing a radioisotope is injected into the patient. The most active brain cells use the most sugar, and so they absorb more of the radioisotope. A picture of the brain's activity is produced, based on where the radioisotope collects. **Deduce** how a PET scan could be used to determine whether a person's brain is functioning normally.

## Creating

18 a **Construct** a model of a neurone. Materials you could use include string, balloons and drinking straws.

b **Label** the parts of your model.

c **Explain** why you selected the materials you did, for each part.

19 **Construct** a model of the semicircular canals in your ears to demonstrate how they provide the information you need to keep your balance.

## Inquiring

1 Multiple sclerosis is a disease of the nervous system. Research the cause of the disease, the effect it has on the body, and current research being undertaken to find a treatment or cure.

2 Spina bifida is a birth defect that involves damage to the spine and spinal cord. Compare the spine and spinal cord of a person with spina bifida with those of a person without spina bifida. Describe the effects of these differences.

Figure 7.1.22

Child with spina bifida

# 7.1 Practical activities

## 1 Sensitivity

### Purpose

To investigate whether touch receptors are evenly distributed in the skin.

*Note*: When the subject feels two pin pricks from two pins placed 2 mm apart, two nerves have been stimulated. This means that the receptors are no more than 2 mm apart. Feeling only one pin prick indicates fewer receptors, spaced more widely.

### Materials

- cork
- three pins

**SAFETY**

The pins should just touch the surface of the skin. They should not be pressed hard enough to cause pain.

### Procedure

1. Push the two pins through a cork so that the points are 2 mm apart.
2. Push the third pin through in a position that will enable the tester to use the same cork to test the skin with only one pin. See Figure 7.1.23.

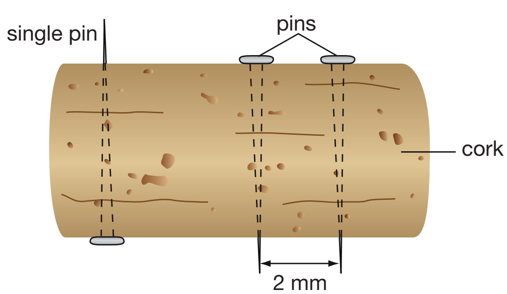



Figure 7.1.23

3. Work in pairs to test different surfaces of the body. One student is the tester. The other is the subject.
4. Holding the pins upright, the tester gently touches the skin of the subject. Test sometimes with one pin and sometimes with two.
5. Test various parts of the body, such as the:
   - back of the hand
   - palm of the hand
   - fingertips
   - upper arm
   - back of the neck.
6. When the pins touch the skin, the subject should indicate whether they can feel two points or one.
7. Test each part of the body five times, sometimes with one pin and sometimes with two pins.
8. The tester records the results, noting carefully whether one or two pins were used in the test.
9. The tester and the subject can change places and repeat the experiment.

### Results

Construct a table to record your results.

### Discussion

1. **Compare** the sensitivity of the various parts of your body. (Remember, it is only the pricks with two pins that will indicate levels of sensitivity.)
2. **Analyse** the relationship between the level of sensitivity and the function of the body part.
3. **Draw** conclusions about the distribution of touch receptors in your skin.

### Extension

Temperature receptors in the skin can detect heat gain (warmth) and heat loss (cold). Design an experiment to investigate the distribution of temperature receptors in the skin. Before you begin, determine exactly what you want to test (warm, cold or both) and how you will do this. Record you results and compare these with the distribution of skin receptors.

## 2 Reaction times

### Purpose

To calculate the reaction time for a simple task.

### Materials

- metre ruler

### Procedure

1. Work in pairs.
2. The person being tested (the subject) should sit with their elbow resting on the edge of a table.
3. The other person (the investigator) holds the ruler by the 100 cm mark so that it hangs vertically, with the 0 cm mark between the thumb and forefinger of the subject (Figure 7.1.24).

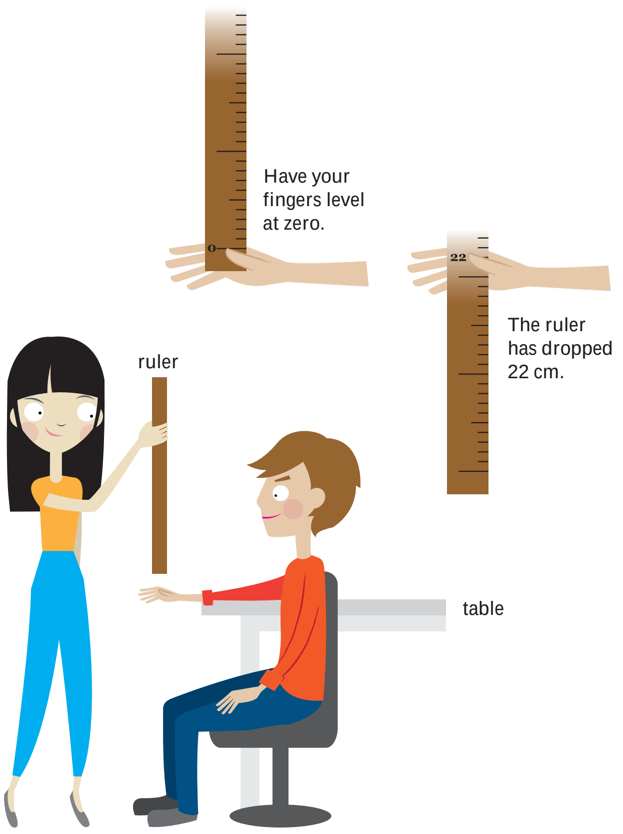



Figure 7.1.24

4. When the investigator releases the ruler, the subject tries to catch it as quickly as possible, using just their thumb and finger.
5. Record the distance the ruler has fallen, and convert it to 'time' using the graph shown in Figure 7.1.25.

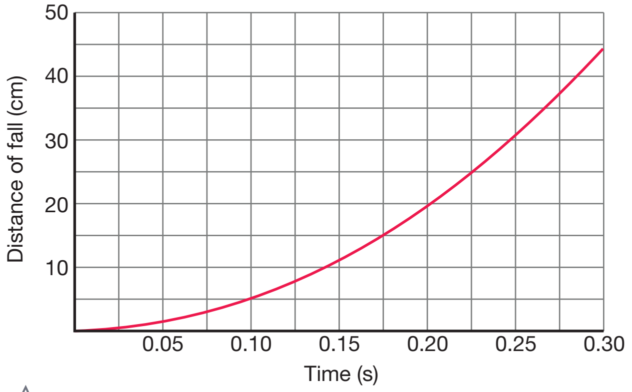



Figure 7.1.25 Graph of reflex time versus distance

6. Repeat the experiment five times to determine an average reaction time. You may wish to compare the times for left and right hands.

### Results

Enter the data into a suitable table or spreadsheet, and calculate the average reaction time.

### Discussion

1. a **Compare** your reaction time with those of other students.
   b **Propose** reasons for any differences.
2. **Interpret** your results to decide whether your reflexes improved with practice.
3. **Propose** how factors such as fatigue, alertness or distractions might affect your reaction time.
4. a **Describe** how your approach to catching the ruler changed as the experiment progressed.
   b **Propose** why these changes took place.

# 7.2 Chemical control

Your body has a second type of communications system—a system that reacts more slowly than the nervous system. In this system, chemicals are the messengers and the bloodstream is the pathway along which they travel. This system is the endocrine system and the chemicals are hormones. Hormones are responsible for the significant changes of puberty but they are also involved in less obvious ways on a daily basis throughout your life.

## Endocrine system

**Hormones** are chemical substances that act as messengers in the body. They are produced in **endocrine glands** scattered throughout the body. Together all these glands form the **endocrine system**.

The endocrine system is coordinated by the **pituitary gland**, which responds to information from the hypothalamus. The **hypothalamus** is a portion of the brain and is made of nerve tissues. You can see its location in the brain in Figure 7.2.1. It constantly checks the internal environment—that is, the conditions within the tissues, organs and systems of your body. If these conditions change, the hypothalamus responds.

The most important function of the hypothalamus is to link the nervous system and the endocrine system. It secretes hormones that act on the pituitary gland. The pituitary gland responds by either secreting other hormones or producing less of the hormones. Through its action on the pituitary gland, the hypothalamus controls important aspects of the body such as body temperature, rate of metabolism and water content.

The pituitary gland is often called the 'master gland' because it controls the activities of other endocrine glands such as the ovaries, the testes and the thyroid gland. It is about 1 cm in diameter.

**INQUIRY science 4 fun**

### I'm scared

What changes happen in your body when you are surprised or frightened?

Yes

**Do this ...**

Ask a family member or friend to give you a surprise or fright.

**Record this ...**

**Describe** the changes in your body.

**Explain** why these changes occurred.

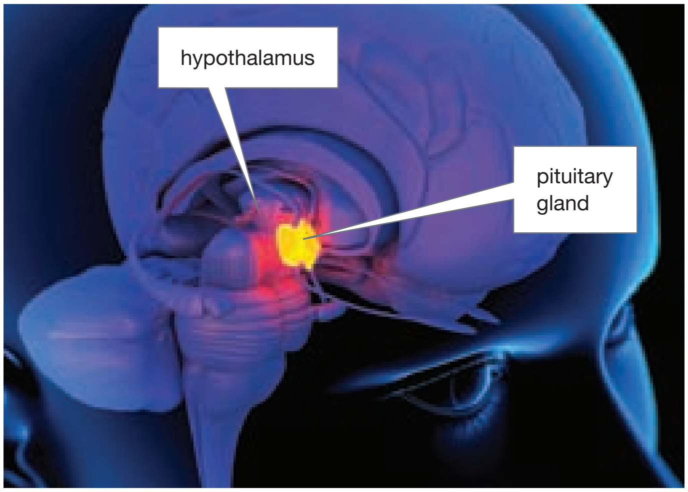



Figure 7.2.1 Two parts of the endocrine system: the hypothalamus, and the pituitary gland that attaches to it. These are located deep within the skull, where they are well protected.

Endocrine glands release their hormones directly into the bloodstream and are referred to as 'ductless' glands. The main endocrine glands of the body are shown in Figure 7.2.2.

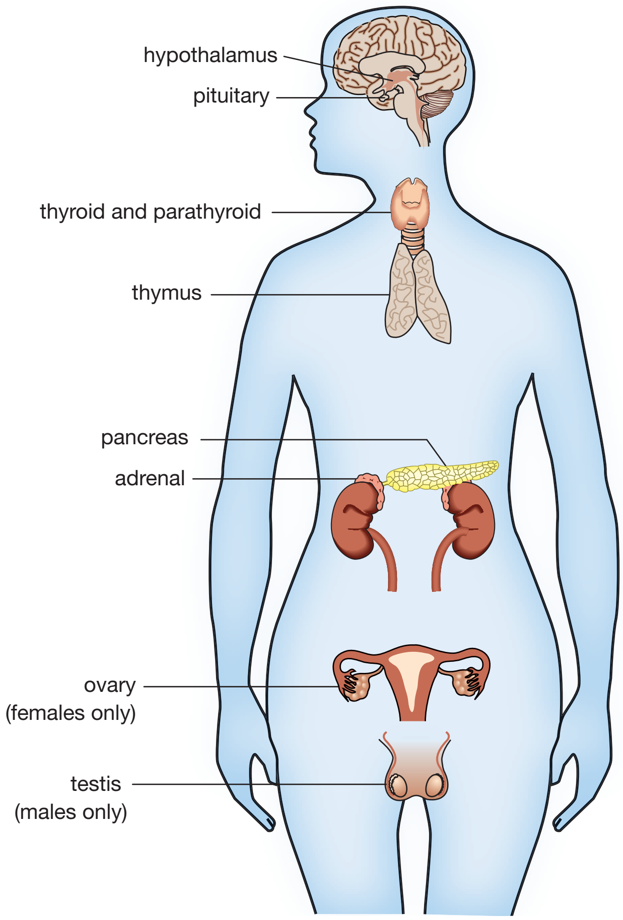



Figure 7.2.2 The main human endocrine glands

## How hormones work

Hormones are produced in very small amounts and travel through the blood, reaching all your body cells. However, they do not affect all the cells. Hormones are specific. This means that they only act on particular cells in the body. These are the **target cells**.

Different hormones have different chemical structures. This means that their shape varies. It is the shape of the hormone that makes it specific. Within cells are receptors. A hormone is only active in cells that have receptors that fit the shape of the hormone (Figure 7.2.3).

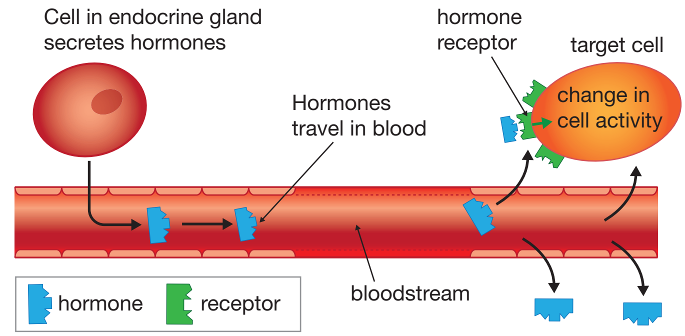



Figure 7.2.3 Hormones are only active in cells where the shape of the hormone and the shape of the receptors fit together like pieces of a jigsaw.

# Controlling the internal environment

Your body works most efficiently when the internal environment is reasonably constant. This means that factors such as temperature, water content, available energy, available oxygen and concentration of wastes in the blood are all controlled. The process of maintaining a constant internal environment is known as **homeostasis**.

Homeostasis involves receptors that are sensitive to a particular stimulus, and effectors that have an effect on the same stimulus.

To understand this, consider a reverse-cycle air conditioner like the one shown in Figure 7.2.4 as an example of a machine that maintains a constant environment. A sensor called a thermostat is set at a particular temperature range, such as 21–23°C. If the temperature of the room goes above 23°C, the air conditioner switches on and cools the room until the required temperature is reached. The sensor detects this and then the air conditioner switches off until it once more detects a rise in temperature. If the sensor detects a lower temperature than 21°C, the heating system turns on. The temperature in the room rises and the heater turns off once the set temperature range of 21–23°C is reached.

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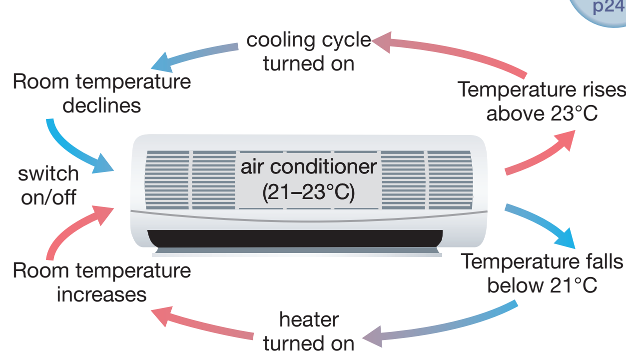



Figure 7.2.4 A reverse-cycle air conditioner maintains a preset temperature in a room by heating or cooling the air in response to temperature detectors.

# Controlling body temperature

Digestion, growth and repair, respiration and manufacture of hormones are some of the chemical reactions taking place inside your body. All these reactions together are known as your **metabolism**. The heat they produce as a by-product maintains your body temperature regardless of the temperature of your surroundings. This is illustrated in Figure 7.2.5. Because you can maintain a constant body temperature, you are said to be **endothermic**. However, if the temperature inside your body was to increase by more than a few degrees above 37°C, your metabolism would stop, and you would die. If your body temperature fell below 37°C, your metabolism would slow down.


**Figure 7.2.5**

Your body temperature stays the same regardless of the temperature of the environment. There are things you can do to help your body, such as adding clothing when it is cold, and removing clothing and using shade when it is very hot.

## Hormonal control of temperature

The hypothalamus acts on the pituitary gland to control body temperature through the action on another endocrine gland—the thyroid gland.

The hypothalamus receives information from temperature receptors in the skin and from internal structures including the hypothalamus itself.

If the hypothalamus detects a fall in body temperature, it produces a hormone that causes the pituitary gland to secrete more thyroid-stimulating hormone (TSH). TSH stimulates the thyroid to release more of the hormone thyroxine. Thyroxine travels in the blood to all cells and causes the rate of metabolism in the cells to increase. Increased metabolism generates more heat and warms the body.

Producing the hormones that cause these changes takes time, and therefore the endocrine system does not have immediate control of body temperature.

## Nervous control of temperature

Body temperature is also controlled by the nervous system and this is a more immediate response. When the hypothalamus detects a drop in temperature, it sends nerve impulses to muscle groups around vital organs such as the heart and lungs. Small shaking movements begin in these muscles. Eventually the shaking movements extend to the large muscles of the arms and legs, and you begin to shiver. Shivering increases the activity of muscle cells, producing heat and raising body temperature. This is the body's way of creating warmth by using energy.

Another aspect of nervous control is the process that reduces blood flow to your skin when you are cold. The sympathetic nervous system causes a narrowing of the blood vessels near the surface of the skin. This reduces blood flow and therefore heat flow to the skin. If the external temperature is very cold, the blood flow to the extremities (fingers, toes, nose and ears) is reduced further and you can lose feeling in them—your toes and fingers go numb.

When the hypothalamus detects a rise in body temperature, nerve messages are sent to the sweat glands and blood vessels. Blood vessels close to the skin dilate (increase in diameter) so that more blood (carrying heat) can reach the skin surface. The extra blood near the surface makes your skin more red.

The message from the hypothalamus causes the sweat glands to produce more sweat (Figure 7.2.6). Heat from your body causes the sweat (which is mostly water) to evaporate. The rate at which heat is lost by evaporation depends on the difference in temperature between the body and the surrounding air, and the relative humidity of the air.

2 p243

7.5


**Figure 7.2.6**

It takes a lot of heat to evaporate a small amount of water. This makes sweating a very effective cooling mechanism.

# Water balance

The kidneys are important organs in homeostasis. They control both salt and water balance within the body. You take in water and salts through food and drink. The body also manufactures about 350 mL of water per day as a product of cellular respiration.

You lose some water in the air you breathe out. You lose water and salts through sweat and in the faeces you produce; however, most salts and water are lost through urine. The body needs to balance its losses and gains. The kidneys are the organs that control the amount of water and salt lost. The balance between gains and losses is shown in Figure 7.2.7.

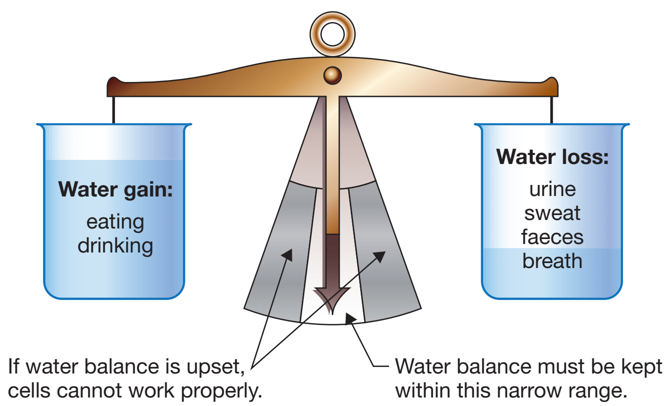



**Figure 7.2.7** Gains and losses of water by the body must be balanced. If there is too much or too little water in the body, it will not function correctly.

About a quarter of the blood from every heartbeat passes through the kidneys—about 50 litres/hour. Of this about 7 litres is processed by millions of microscopic filters within the kidney. These filters remove harmful wastes (such as urea), salts and water from the blood. The kidney returns to the blood the salts, glucose and water needed by the body. Wastes, excess salts and excess water pass from the kidneys into the bladder, where they are stored before being released from the body as urine.

If you drink a lot more water than your body requires, you produce large amounts of light-coloured, dilute urine. If your water intake is inadequate, you produce dark-coloured, concentrated urine. The amount of water in urine is controlled by **antidiuretic hormone (ADH)**. ADH causes the kidneys to reabsorb water directly from the renal tubules of the kidney. Salts and waste products are concentrated in the liquid, which will eventually become urine. ADH is secreted by the pituitary gland under the control of the hypothalamus.

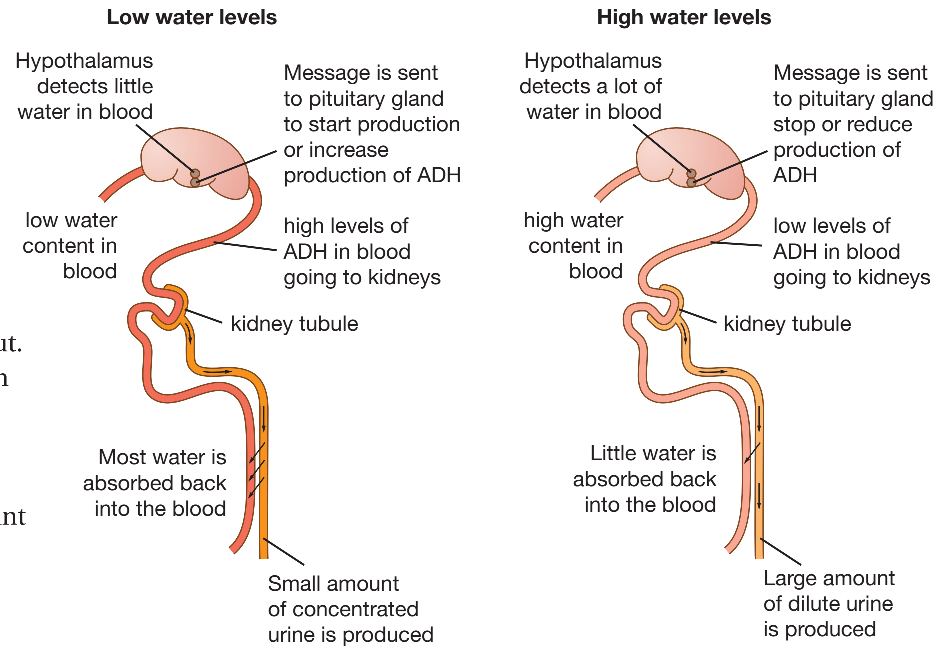



**Figure 7.2.8** The volume of urine excreted by the kidneys is controlled by antidiuretic hormone (ADH) in a negative feedback system.

The hypothalamus monitors the volume of blood passing through it and the concentration of water in the blood. Dehydration increases the production of ADH and water is retained in the body.

Figure 7.2.8 illustrates the relationship between the parts of the body involved in water balance. Figure 7.2.9 demonstrates the feedback system involved in this process.

7.7

7.8

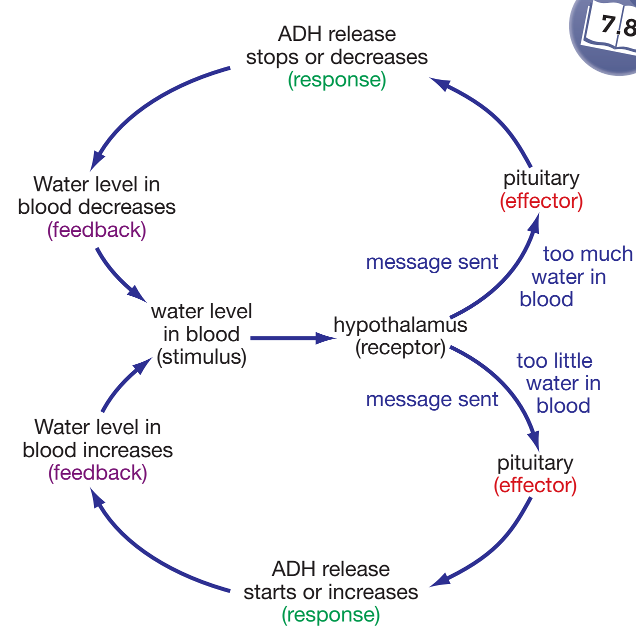



**Figure 7.2.9** Homeostasis is achieved using negative feedback systems. In this type of system the response of the system (in this example the amount of ADH produced) works to change the inputs to the system (in this case the amount of water in the blood).

## Blood sugar control

To provide energy for your body throughout the day, your cells need a continuous supply of glucose for cellular respiration. Too much glucose makes your blood thick, meaning that it can move only slowly through your blood vessels. Too little glucose makes you feel dizzy because you have insufficient energy. Glucose is carried around the body dissolved in the blood plasma. It enters the blood from the digestive tract and is absorbed by most body cells. Despite this intake and usage, glucose levels in the blood remain fairly constant at about 0.8–1 mg/mL. The steady concentration is due to the action of two hormones: insulin and glucagon (Figure 7.2.10). These hormones are made by groups of specialised cells in the pancreas, called 'islets'.

An increase in blood glucose levels after eating is detected by receptors in the pancreas. The pancreas then releases the hormone **insulin**. Insulin causes the liver and muscles to extract glucose from the bloodstream and convert it into a larger molecule called **glycogen**. The glycogen is stored in the liver and glucose levels in the blood are reduced.

When glucose is taken from the bloodstream during activity, the pancreas detects this and responds by releasing another hormone, called **glucagon**. Glucagon has the opposite effect to insulin. So, by the controlled release of the two hormones, glucose levels are kept fairly constant.

People with the disease diabetes are either not able to produce insulin or their tissues are not able to respond to it.

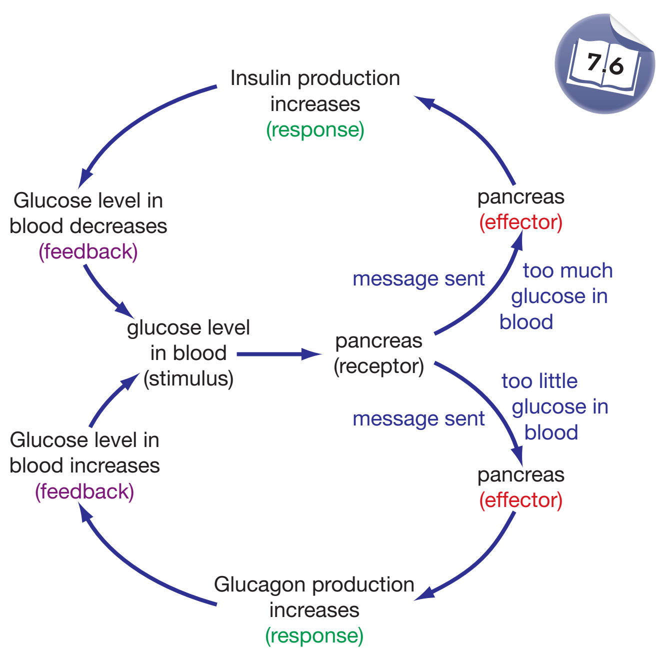



Figure 7.2.10 Control of glucose in the blood is by a negative feedback system. The body responds to increased glucose levels in the blood by producing insulin. Insulin causes glucose to be removed from the blood. When glucose levels in the blood fall, glucagon allows the glycogen in the liver to be released and glucose is returned to the blood.

## Responding to stress

If you are in a frightening or stressful situation, your nervous system registers this and sends messages to the **adrenal glands** situated on your kidneys. They produce a hormone known as **epinephrine** (commonly called **adrenalin**).

Epinephrine causes your heart rate to increase, blood vessels to contract and air passages to dilate (open up). This reaction of the body to adrenalin makes you more alert and prepares your body to act in an emergency. The response is triggered by the sympathetic nervous system.

Nearly all the body tissues are target cells for epinephrine. However, the effect of the hormone varies from tissue to tissue. The smooth muscles of the airway relax, allowing more oxygen to be taken into the body. But the smooth muscles of the blood vessels contract, increasing blood pressure.

Epinephrine inhibits insulin secretion by the pancreas. Glucose therefore remains in the blood where it can be taken up by the cells, especially muscle cells, and used to release energy.

Figure 7.2.11 Both your nervous system and your endocrine system react to stress and fear. People with large amounts of epinephrine in their bloodstream can do things they would not normally be able to do, such as leap over a fence.

Once the hormones have done their job and the frightening situation is past, the hormones break down quickly. Constant high levels of this hormone in the body can do harm.

# 7.2 Unit review

## Remembering

1 **Recall** the term used to describe the cells that respond to hormones.

2 **Name** the hormones that control glucose levels in the blood.

3 **List** three endocrine glands and the hormones they produce.

## Understanding

4 **Define** the term *homeostasis*.

5 **Describe** the relationship between:
- a hormones and the endocrine system
- b the pituitary gland and the hypothalamus
- c antidiuretic hormone and the colour of urine.

6 **Explain** why sweating is an efficient way for the body to lose heat.

7 a **Explain** why it is important that your body temperature remains constant.
- b **Describe** two involuntary reactions that keep your temperature from rising.
- c **Describe** one involuntary reaction that prevents your body temperature from falling.

## Applying

8 a **Identify** the endocrine glands labelled A, B and C in Figure 7.2.12.
- b **Identify** by its letter the gland that produces the hormone that controls the concentration of glucose in the blood.

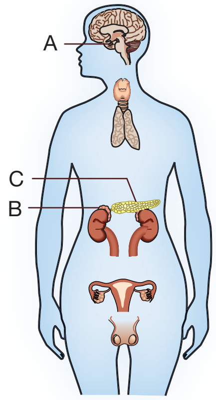



Figure 7.2.12

9 About 7 litres of blood is filtered by the kidneys in every hour. **Calculate** the number of times your blood would be filtered each day. Assume you have 5 litres of blood.

## Analysing

10 **Compare** the way that glucose levels and temperature are controlled in the body.

11 **Discuss** the need for two hormones to control glucose levels in the blood rather than just one.

## Evaluating

12 **Use** the information in the table below to **propose** differences there would be if the data came from a person who:
- a ate a lot of salty food
- b had been out in the sun for a long time
- c ate a large amount of sugar.

| Substance | Amount in blood (%) | Amount in urine (%) |
|---|---|---|
| Water | 90–93 | 95 |
| Glucose | 0.1 | 0 |
| Salts | 0.37 | 0.6 |
| Urea | 0.03 | 2 |

13 **Propose** why it is important that glucose is not excreted in urine.

14 The changes in hormones in response to an increase in body temperature are described on page 239. The changes in response to a fall in body temperature are not described. **Propose** what these changes might be. There are no different hormones involved.

## Creating

15 a **Construct** a sketch-line graph showing the expected changes in your blood glucose levels after eating some lollies.
- b **Describe** what is causing the glucose levels to change.

16 **Construct** a flow diagram showing the reaction of your body to fear.

## Inquiring

1 Find out how epinephrine is used to treat heart attack and allergic reaction.

2 Research the functions of the thyroid gland and the effects of having an overactive or underactive thyroid.

# 7.2 Practical activities

## 1 Model feedback system

### Purpose

To demonstrate a feedback system, using people.

### Materials

- blindfold
- chairs and desks to create an obstacle course, or an area of the school that includes some obstacles

**SAFETY**

Do not put the subject into any dangerous situations.

### Procedure

1. Work in pairs. One person is the controller and the other is the subject.
2. The subject is blindfolded and follows the course in response to commands provided by the controller.
3. The controller directs the subject as quickly and accurately as possible around the course using only the commands 'left' or 'right'.
4. On completing the course, the controller and the subject change position. In this second trial the controller may also use the words 'forward', 'back' and 'stop'. This represents a more sophisticated form of feedback.

### Discussion

1. **Propose** what is being controlled in this system.
2. a **Compare** a natural feedback system with this model.
   b **Identify** the part represented by the controller.
   c **Identify** the part represented by the subject.
3. **Compare** the success of the feedback system in the first trial with the second trial, when more information was provided to the subject.
4. **Assess** the model as a representation of a natural feedback system such as temperature control or level of glucose in the blood.

## 2 Changing temperature

### Purpose

To investigate the effect of exercise on body temperature.

### Materials

- electronic clinical thermometer (if available, data-logging equipment could be used for this experiment)
- area of the school where students can run

**SAFETY**

Students with health problems may not be able to take part in this experiment.

### Procedure

1. Work in pairs. One person is the subject and the other is the recorder.
2. Record the skin temperature of the subject at the start of the experiment. *Note*: Measure the skin temperature by holding the thermometer inside a bent elbow. Measure the internal temperature at the ear using an electronic clinical thermometer.
3. The subject undertakes 10 minutes of vigorous exercise, enough for them to feel hot and possibly turn red in the face.
4. Record the skin temperature and the internal temperature of the subject.
5. Observe and record any other changes resulting from the exercise.

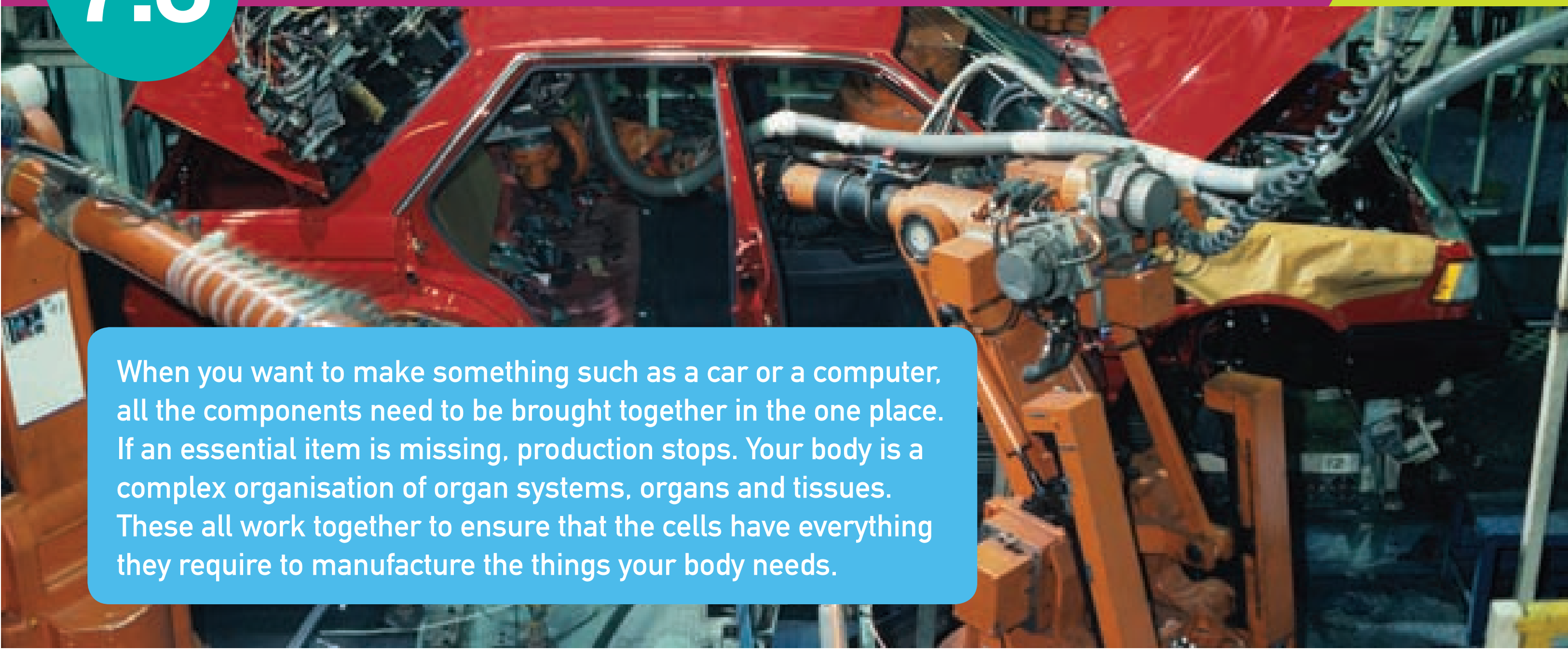
### Results

Record all measurements and observations.

### Discussion

1. **Describe** the changes to the skin temperature during the experiment.
2. **Describe** the changes to the internal body temperature during the experiment.
3. **Compare** the changes in skin temperature with the changes in internal body temperature.
4. **Describe** any other changes that were observed.
5. **Propose** ways in which these other changes could contribute to the observed changes in temperature.

# 7.3 Coordinated body systems



When you want to make something such as a car or a computer, all the components need to be brought together in the one place. If an essential item is missing, production stops. Your body is a complex organisation of organ systems, organs and tissues. These all work together to ensure that the cells have everything they require to manufacture the things your body needs.

INQUIRY science 4 fun

### It smells!

How long does it take for a scent to travel across a room?

Yes

**Collect this ...**

- spray can of perfumed deodorant or air freshener
- partner
- stopwatch or watch with a second hand

**Do this ...**

1. Close all the windows and doors in the room to reduce air movement.
2. You stand on one side of the room facing the wall with your eyes closed.
3. Your partner gives a short spray of deodorant into the air and records the time.
4. You call out as soon as you can smell the scent. Record the time.
5. Repeat the experiment using twice the amount of deodorant. However, you will have to wait until all the scent has cleared from the room before you do this.

**Record this ...**

**Describe** what happened.

**Explain** why you think it happened.

## Metabolism

Within your cells, a large number of chemical reactions take place. Collectively these reactions are known as metabolism—the chemical processes that maintain life and allow organisms to grow and reproduce, maintain their structures and respond to their environments.

The chemical reactions of metabolism are divided into two groups:

- reactions that break down organic matter—examples include respiration, which breaks down the glucose molecule to releases energy, and the breakdown of wastes into harmless substances for excretion
- reactions that build complex molecules from simpler substances—an example is the construction of new cells and cell components such as proteins and genetic material (Figure 7.3.1).

Figure 7.3.1

These plants are able to grow because their metabolism builds simple chemicals into the complex components of new cells.

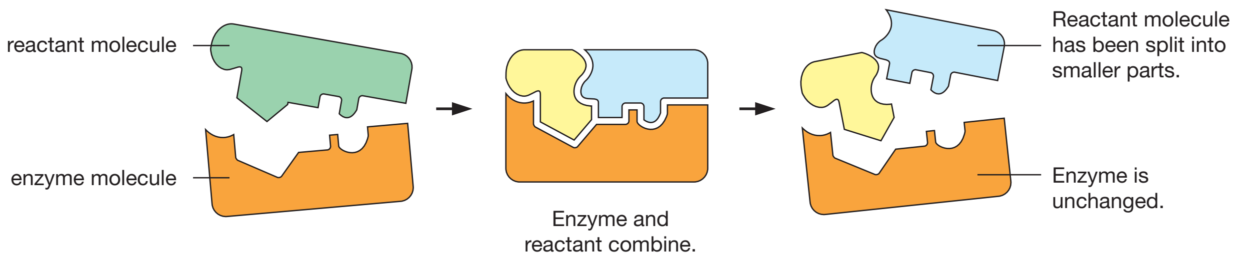



Figure 7.3.2 The 'lock-and-key' model explains the action of enzymes. In this diagram a larger molecule has been split into smaller ones. The opposite reaction can also occur with other enzymes, where smaller molecules are joined to form a larger one.

## Enzymes

All the reactions in your body are helped along by **enzymes**. These are organic **catalysts**—substances that speed up the rate of a reaction without being used up in the process. Without the help of enzymes, many reactions would occur too slowly to maintain life.

There are over 700 enzymes in the human body and each one is specific to one particular chemical reaction. Scientists have constructed a model of how enzymes work. This model is known as the 'lock-and-key' model, shown in Figure 7.3.2.

Each enzyme has a particular shape that allows it to attach to a specific molecule that is going to be changed by the chemical reaction—the **reactant molecule**. In a reaction, the enzyme and the reactant molecule (or molecules) join together and the reactant molecules are then changed in some way.

1 p252

**That's fast!**

Enzymes can increase reaction speeds by up to ten billion times. That's like taking a minute to do something that otherwise would take 18 000 years!

SciFile

# Getting nutrients

The source of many of the raw materials your body needs for metabolism is the food you eat. When you chew on an apple or a slice of bread, the nutrients it contains are needed by your body but they are not always in a form that your body can use. It is the job of the digestive system to chemically change the complex molecules in the apple and the bread into simple chemical substances your body can use.

The food you eat contains complex carbohydrates, proteins and lipids. Through the reactions of chemical digestion they are progressively broken down, so that when the food reaches the small intestine it is in the form of simple chemical substances.

Figure 7.3.3 The nutrients in the food you eat are not in a form that can be used by the body. They have to be changed chemically by the digestive system.

- Carbohydrates are broken down into glucose.
- Proteins are broken down into amino acids.
- Lipids (fats and oils) are broken down into fatty acids and glycerol.

These simple chemical substances are small enough to pass through the thin walls of the villi lining the small intestine, through the thin walls of capillaries and into the bloodstream, as shown in Figure 7.3.4.

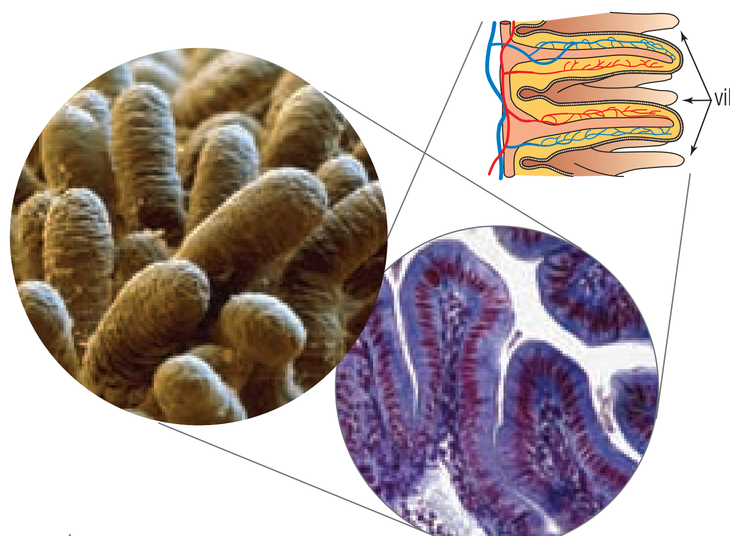



Figure 7.3.4 Villi are small projections on the wall of the small intestine. They greatly increase the surface area through which nutrients can be absorbed.

## Diffusion

The simple chemical substances produced by digestion are very small particles. They move by diffusion through the cells of the villi and capillaries. **Diffusion** is the movement of particles of a substance from an area of high concentration of that substance to an area of low concentration of that substance. In simpler terms it means that the particles move from an area where there is a lot of that type of particle to an area where there is not much at all. Diffusion takes place in liquids and gases where the particles have enough energy to move around.

Figure 7.3.5 models how diffusion works. The particles are moving around, bumping into each other on both sides (A and B). However, they are separated from one another by the barrier. Side A has a higher concentration of red particles than side B. Side B has a higher concentration of yellow particles than side A. If the barrier between the two sides is removed, then the particles can move freely. More red particles move to the right than to the left. Eventually the red particles are evenly distributed across the whole area. In the same way, more yellow particles move to the left and eventually are evenly distributed across the whole area, as shown in the lower part of Figure 7.3.5.

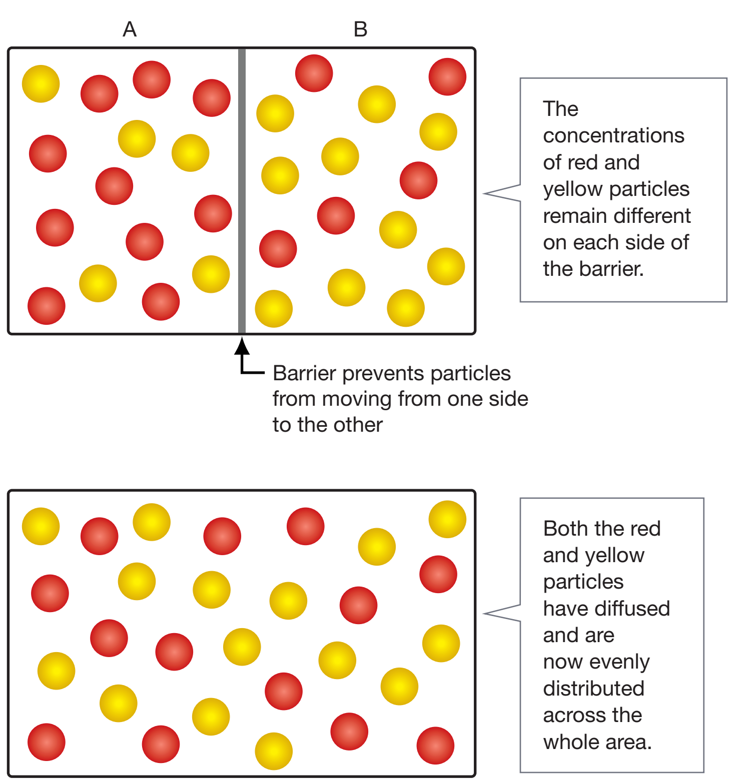



Figure 7.3.5 The process of diffusion

After eating, there are high concentrations of glucose, amino acids, fatty acids and glycerol in the small intestine. In the bloodstream there are low concentrations of these molecules. Most of the molecules move by diffusion from the small intestine into the blood capillaries in the villi.

The flow of blood in the capillaries quickly carries the digested materials away, so there is always a higher concentration in the small intestine and lower concentration in the blood, and diffusion continues.

2 p253

# Getting oxygen

The air you breathe enters your respiratory system through your nose and mouth. It passes down the trachea, bronchi and bronchioles, ending up in the alveoli. The walls of the alveoli are only one cell thick and are surrounded by blood capillaries (Figure 7.3.6). Oxygen dissolves in the moist surface of the alveoli and moves by diffusion across the short distance from the space inside an alveolus to the blood.

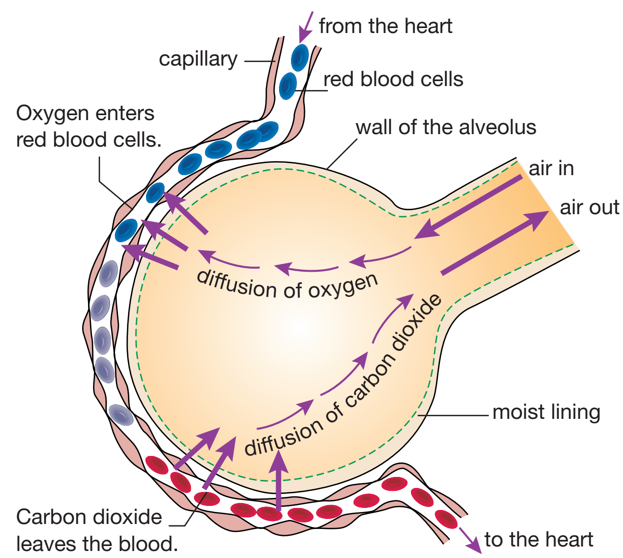



Figure 7.3.6 The walls of the alveoli are only one cell thick, and so are the walls of the blood capillaries. The ideal situation for gas exchange is where the surface of the alveolus and the blood capillary are in contact.

Once in the blood, the oxygen combines with haemoglobin in the red blood cells. The flow of blood carries the oxygen away, so the concentrations in the alveolus and the blood never become equal. In this way, oxygen continues to move into the blood.

# Circulation

The circulatory system of arteries, capillaries and veins is an efficient system that carries materials to and from every cell of your body. The heart is the pump that keeps the blood moving and without it the cells would soon be starved of the materials they need to function.

## Heartbeat

The heart is made up of cardiac muscle. Cardiac muscle naturally contracts and relaxes without any input from the nervous system. The cycle of the heartbeat is initiated by a small patch of muscle, called a pacemaker (or SA node), shown in Figure 7.3.7.

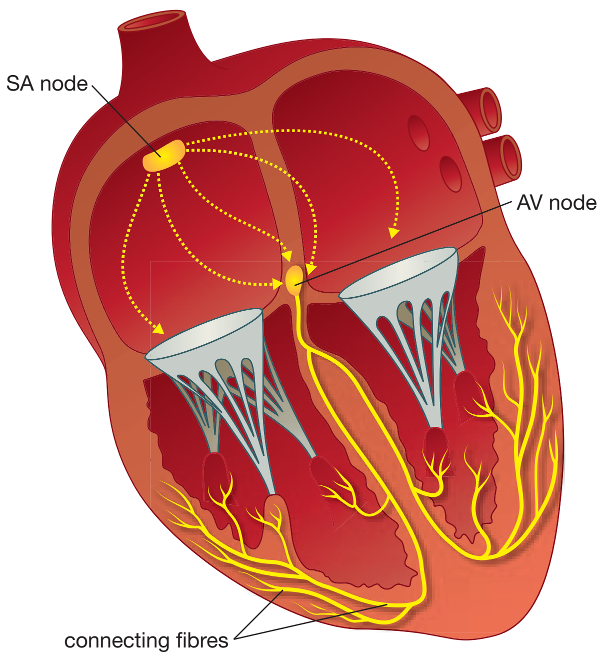



Figure 7.3.7 The heart has two specialised areas of muscle (the SA node and the AV node) that control and synchronise the heartbeat.

The rhythm of relaxation and contraction of the muscles in the pacemaker sets the rhythm for all the other cardiac muscle. The pacemaker stimulates both atria to contract simultaneously. When the stimulus reaches the tissue between the atria and the ventricles, another small patch of specialised tissue (the AV node) stimulates both ventricles to contract. An electrocardiograph of a normal heartbeat is shown in Figure 7.3.8.

If the impulses in the ventricles become disorganised because the stimulus is not picked up correctly, the muscles of the ventricle begin to twitch spasmodically. This is a condition known as ventricular fibrillation. Blood flow stops and unless the heart rhythm is restarted, death will follow swiftly.

A defibrillator is used to give the heart a jolt using electric current, in an attempt to restore the heart's natural rhythm and save the person's life. That is what is happening in Figure 7.3.9. Defibrillators are found in hospital emergency rooms, ambulances and commercial aircraft.

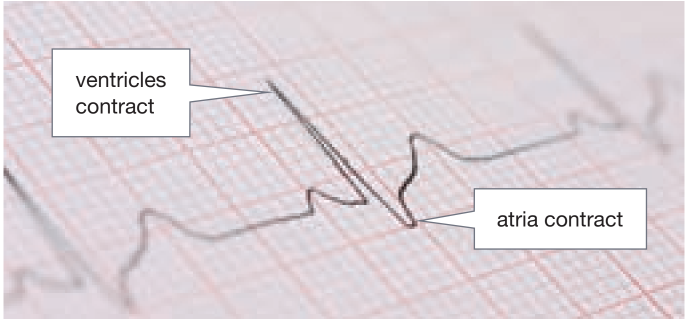



Figure 7.3.8 An electrocardiograph creates a picture of the heartbeat. The high peak is the contraction of the ventricles. The lower peak is the contraction of the atria. Then the heart rests.

Figure 7.3.9 Defibrillators are used in hospitals to restart the heart of a person who has suffered heart failure.

## Changes to heart rate

The rate at which your heart beats is changed according to the needs of your body.

Stress or fear causes nerves of the autonomic nervous system to produce noradrenalin, a hormone that affects the heart in two ways:

- It increases the rate and strength of the heartbeat, which leads to an increase in blood flow.
- It increases the strength of the contractions.

Under the effect of noradrenalin, the heart may pump up to five times as much blood per minute as normal.

Vigorous exercise, such as the cross-country race shown in Figure 7.3.10, accelerates the heartbeat in two ways.

- As cellular respiration increases, so does the carbon dioxide ($CO_2$) level in the blood. Receptors in the carotid artery (in your neck) and aorta detect the increased $CO_2$ concentration and send messages to the medulla (in the brain). Nerves of the sympathetic nervous system then stimulate the heart to beat faster.
- As muscular activity increases, more blood is pumped back to the right atrium. The atrium wall stretches to hold the extra blood. Stretch receptors in the wall of the atrium send nerve impulses to the medulla. Nerves of the sympathetic nervous system stimulate the heart to beat faster.

**Figure 7.3.10** When you exercise, receptors in your body detect changes. The sympathetic nervous system is stimulated. It sends impulses to effectors that respond in ways that meet the changed needs of your body.

When the stress or fear subsides, or you stop the vigorous exercise, the changes are detected by the receptors in the aorta and the carotid artery. The message is relayed to the medulla. This time the medulla stimulates the parasympathetic nervous system and its actions slow the heartbeat.

## In the cells

Your body is made up of billions of microscopic cells. Within the cell are smaller structures known as organelles that can only be seen using an electron microscope (Figure 7.3.11).


**Figure 7.3.11** Organelles are so small that they can only be seen clearly when magnifications of over 100 000 are used.

**Mitochondria** are the organelles in which cellular respiration takes place. Oxygen and glucose enter the cell from the blood capillaries and move through the cytoplasm to the mitochondria. Once in the mitochondria, the oxygen and glucose are used in cellular respiration. Cellular respiration is a series of chemical reactions assisted by enzymes that releases energy from glucose.

While the reactions of respiration are taking place in the mitochondria, chemical reactions to produce proteins are occurring in the **ribosomes**—another of the cell's organelles. At the ribosomes, amino acids from the digestion of proteins are reassembled into proteins your body can use. Enzymes and hormones are proteins, as are parts of cell membranes and muscle fibres.

Lysosomes are organelles that treat wastes within cells. Cells and organelles within your body are replaced continuously. Lysosomes digest dying cells, damaged organelles, and viruses or bacteria that have invaded the cell. The products of lysosome digestion move from the cell to the bloodstream.

## Removing wastes

The liver is our largest internal organ. Its position in the body is shown in Figure 7.3.12. It carries out many different functions, some of which are related to waste treatment. The liver:

- breaks down insulin and other hormones
- breaks down haemoglobin (from dead red blood cells), creating products that are added to bile and then disposed of through the digestive system
- breaks down or modifies toxic substances and most medicines—an excess of toxins, one of which is alcohol, may cause permanent damage to the liver
- converts ammonia to urea.

Apart from the end-products of the breakdown of haemoglobin, other wastes are carried from the liver to the kidneys and are excreted in the urine.

## Interdependence of body systems

The systems described in this chapter are interdependent. Each system depends on the others in a variety of ways and cannot function without them. Figure 7.3.13 shows the interrelationships between the excretory, digestive, circulatory and respiratory systems. The nervous and endocrine systems control the activities of these systems.

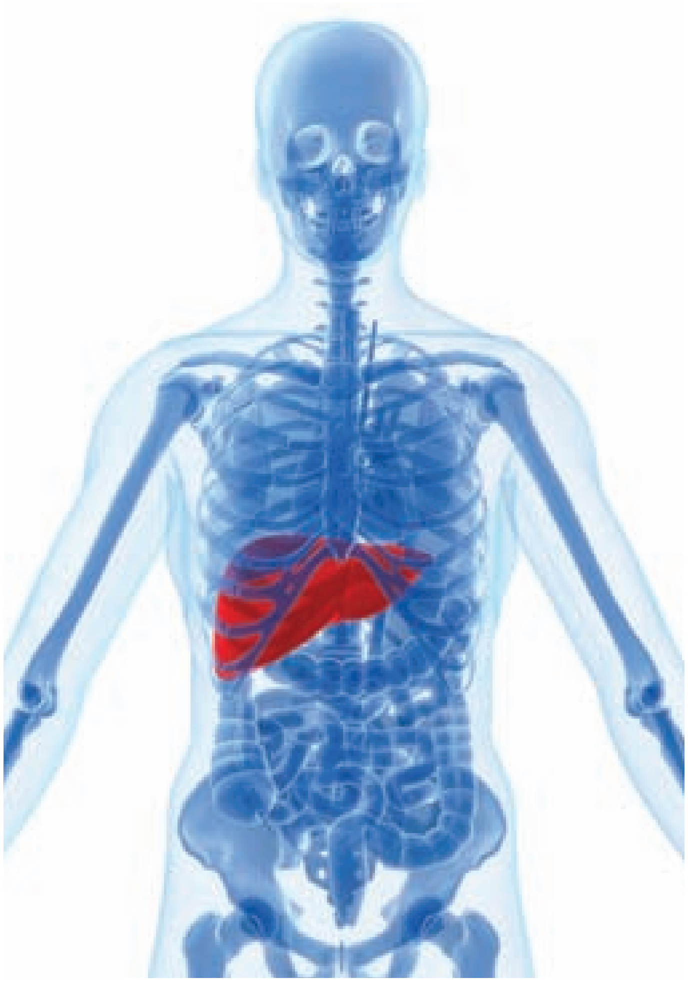


Figure 7.3.12 The liver is a very important internal organ. It has many functions, only a few of which are related to waste disposal.

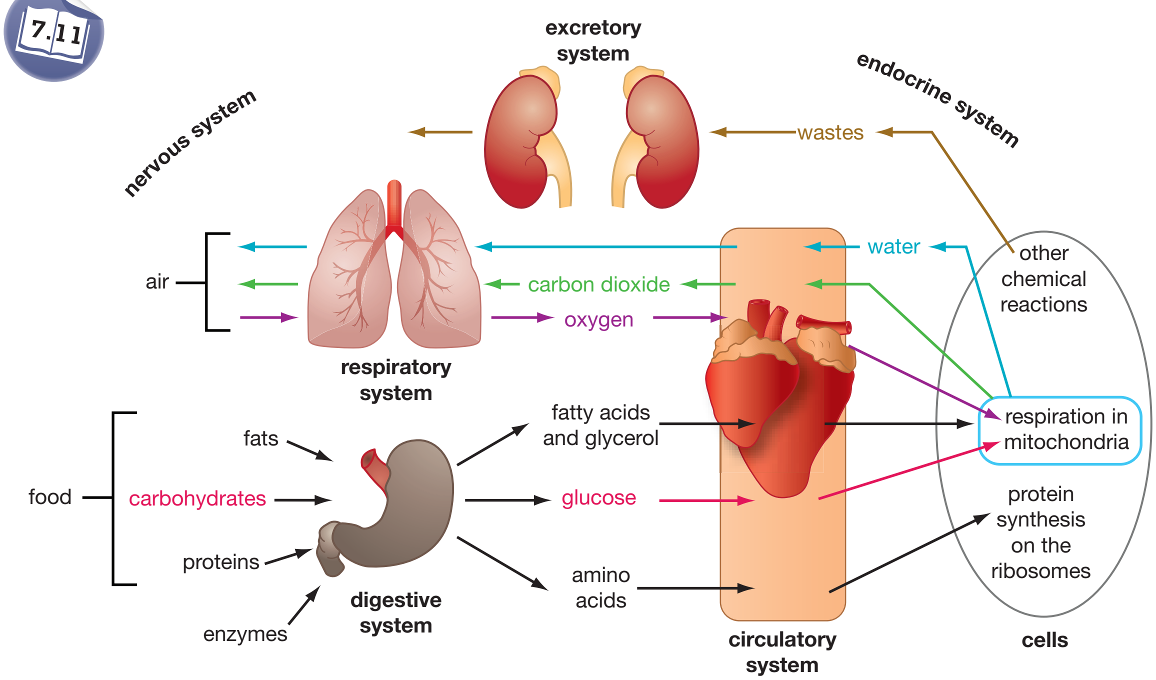



Figure 7.3.13 The interrelationships between the systems of your body

# SCIENCE AS A HUMAN ENDEAVOUR

## Use and influence of science

### Artificial pacemakers

Figure 7.3.14 Australian anaesthesiologist Dr Mark C. Lidwell invented the artificial pacemaker and went on to develop one that plugged into a light socket. It looked nothing like the modern pacemaker shown here.

**In 1899 the *British Medical Journal* reported experiments that John A McWilliam had carried out on the human heart.**

McWilliam used electrical impulses to make the heart muscle contract. By stimulating the heart at the rate of 60–70 electrical impulses per minute, he was able to keep the heart muscle contracting at 60–70 beats per minute.

This research preceded the development of artificial pacemakers—instruments used when the heart's natural pacemaker is defective. A defective natural pacemaker may cause the heart to beat too slowly, too quickly or in an irregular fashion. Any of these can cause health problems. Artificial pacemakers (Figure 7.3.14) have been developed to help control abnormal heart rhythms.

The first artificial pacemaker was invented by Australian anaesthesiologist Dr Mark C. Lidwell. He used his device to resuscitate a newborn baby at the Crown Street Women's Hospital, Sydney, in 1926. Lidwell did not patent his device and chose to remain anonymous because research of this nature was very controversial at the time. However, two years later, Lidwell worked with a physicist, Edgar H. Booth of The University of Sydney, to develop a portable artificial pacemaker that plugged into a light socket. The circuit was created by applying a pad soaked in strong salt solution to the skin and inserting a needle insulated except at its point into one of the ventricles of the heart.

Refinement of artificial pacemakers continued, but the biggest breakthrough came with the development of the silicon transistor. From that time in 1956, there was rapid development towards pacemakers that were wearable and then to ones that could be implanted in the body.

Swedish scientists pioneered the use of pacemakers in 1958, when Arne Larsson (Figure 7.3.15) was the recipient. The first device failed after only three hours. A second device lasted two days. In total Arne received 26 different pacemakers over a period of 43 years. He died in 2001 at the age of 86.

Figure 7.3.15 Arne Larsson

Modern artificial pacemakers are small devices placed in the chest or abdomen that use batteries to send electrical pulses to prompt the heart to beat at a normal rate (Figure 7.3.16). An electrode is placed next to the heart wall and small electrical charges travel through a wire to the heart.

Most pacemakers have a sensing device and send out signals to the heart only when necessary. The sensing device turns the signal on when the heartbeat is too slow. When the heart is beating normally, the sensing device turns the signal off.

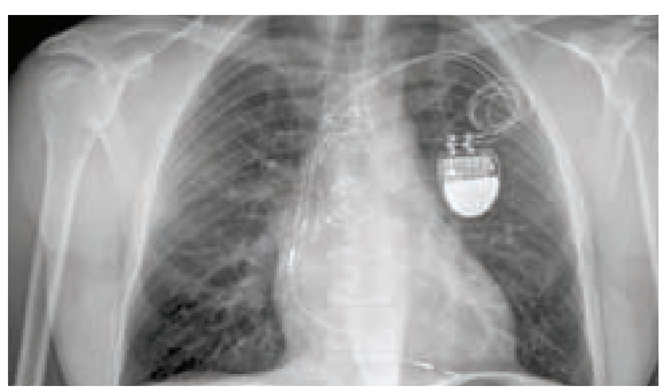


Figure 7.3.16 Modern artificial pacemakers are inserted into the body and work only when the heartbeat becomes irregular.

# 7.3 Unit review

## Remembering

1 **Name** the process by which:
  a oxygen moves from the lungs into the bloodstream
  b food is converted to molecules the body can use
  c energy is released from glucose
  d the body gets rid of wastes.

2 **Recall** the word used to describe each of the following.
  a the chemical processes that maintain life
  b organic catalysts
  c the movement of particles of a substance from an area of high concentration of that substance to an area of low concentration of that substance
  d a molecule that is going to be changed by a chemical reaction
  e the force of the blood against the walls of the arteries

3 **Recall** the information required to copy the table below into your notebook and complete it.

| Complex molecule | Simple molecule following digestion |
|---|---|
| lipid | |
| | amino acid |
| | glucose |

## Understanding

4 **Explain** why complex molecules such as proteins in your food have to be broken down into simpler chemical substances such as amino acids.

5 a **Describe** the function of the SA node and the AV node in the heart.
  b **Explain** what is happening when the heart is fibrillating.
  c **Explain** why a defibrillator is used in that circumstance.

6 **Describe** how the 'lock-and-key' model of enzyme action explains the specific nature of enzyme action.

## Applying

7 **Use** diagrams similar to those in Figure 7.3.2 on page 245 to **demonstrate** a reaction where a large molecule is split into two smaller molecules.

8 **Use** annotated diagrams to **demonstrate**:
  a how diffusion occurs
  b the roles of the circulatory system and diffusion in the movement of nutrients from the small intestine
  c the interdependence of the roles of the circulatory system, the respiratory system and diffusion in removing carbon dioxide from the body.

## Analysing

9 The chemical reactions of metabolism are divided into two groups. **Contrast** these two groups.

10 a **Analyse** the information provided in this unit to **identify** the systems involved in getting nutrients to the cells of your body.
  b **Demonstrate** how the systems work in an interdependent way to achieve this task

## Evaluating

11 In your body there are many enzymes and each is specific to a reaction.
  a **Deduce** the benefit to your body's functioning of having specific enzymes.
  b **Propose** the effect on your body if enzymes were not specific to a reaction.

12 Imagine you did not have a circulatory system and that substances such as oxygen, nutrients, hormones and wastes moved through your body by diffusion. **Propose** why it would be impossible for your body to function.

## Creating

13 **Construct** a flow diagram of the heartbeat, starting and ending with contraction of the atria.

14 **Construct** an outline of the human body, making it fill an A4 page.
  a Sketch in the parts of the body involved in making the energy in your food available to your cells.
  b Join the parts with arrows showing the direction in which substances or information is moving.
  c Label the arrow with the name of what is moving and the effect it is going to have.

## Inquiring

1 Research the work done in the body by the liver.

2 Research the life and work of Australian heart surgeon Victor Chang.

3 Find out who Mark Dorrity is and why he suffers from a condition known as rhabdomyolisis.

# 7.3 Practical activities

## 1 Enzyme activity

### Purpose

To demonstrate the action of enzymes.

### Materials

- 50 mL starch solution
- iodine
- 2 × 50 mL beakers
- stirring rod
- amylase
- Tes-Tape
- labels
- 50 mL measuring cylinder
- water bath at about 30°C

**SAFETY**

Iodine stains. Avoid contact with skin and clothes.

### Procedure

1. Label the 50 mL beakers 'enzyme' and 'no enzyme'.
2. Using Tes-Tape, test the starch solution for the presence of glucose.
3. Add a few drops of iodine to the solution until the starch is showing a distinct blue-black colour.
4. Add 20 mL of the coloured starch solution to the two 50 mL beakers. Your set-up should look like Figure 7.3.17.
5. Add amylase to the beaker labelled 'enzyme'. (Use an amount equivalent to a match head.)
6. Stir the amylase and starch solution mixture.
7. Place both beakers in the water bath.
8. Predict what you think will happen and record your prediction.
9. After about 10 minutes, note any colour change in the beakers.
10. Using the Tes-Tape, test both beakers for glucose.

### Results

1. Record any change in appearance of the beakers.
2. Record whether glucose was present in either of the beakers.

### Discussion

1. **Compare** the results you obtained with your prediction.
2. If glucose was present in either of the beakers, **explain** where the glucose came from.
3. **Account** for any colour change that occurred.
4. **Explain** why the beakers were heated to 30°C.
5. **Summarise** the results of this experiment, relating any changes to the action of amylase.

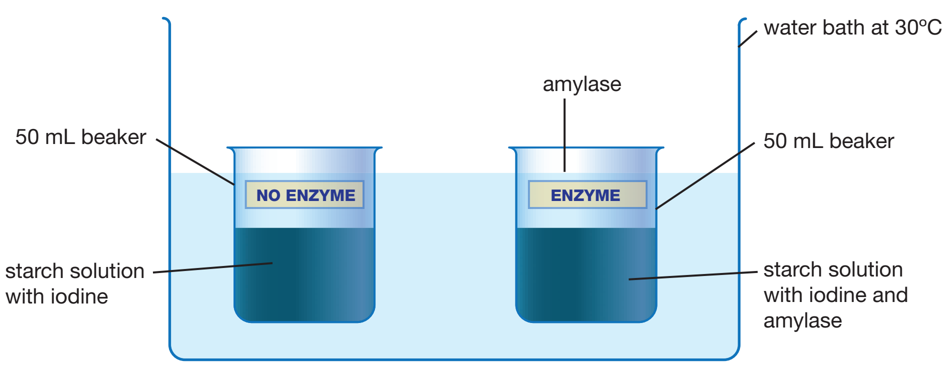



Figure 7.3.17

## 2 Diffusion

### Purpose

To demonstrate the process of diffusion in cells.

### Materials

- food colouring
- 3 pieces of dialysis tubing 15 cm long
- 3 × 500 mL beakers
- 3 × 50 mL beakers
- stirring rod
- water
- string
- 3 retort stands with clamps

### Procedure

1 Add 300 mL of water to each of the 500 mL beakers. Set them up on the bench with a retort stand behind each one (see Figure 7.3.18).

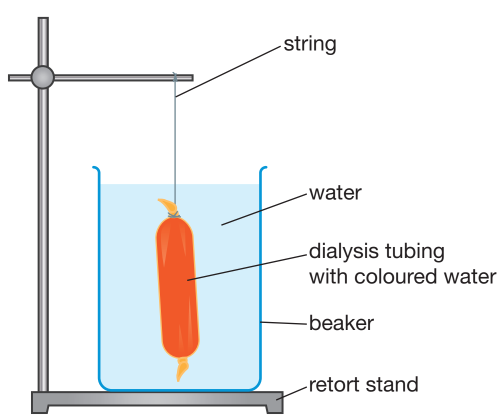



Figure 7.3.18

2 Let the water settle.

3 Add 25 mL of water to each of the 50 mL beakers. Label the beakers 1, 2 and 3.

4 Create solutions of different concentrations using the food colouring. Add 10 drops of food colouring to beaker 1, 20 drops to beaker 2 and 40 drops to beaker 3.

5 Run water from the tap over the three lengths of dialysis tubing.

6 Tie one end of each piece of tubing in a tight knot.

7 Rub the other end of the tubing to open it up.

8 Fill one piece of tubing with the coloured water from beaker 1.

9 Close the end of the tubing by tying it with string.

10 Rinse off the dialysis tube 'sausage' you have created so that there is no coloured water on the outside.

11 Using the other end of the string, tie the 'sausage' to the retort stand and suspend it over one of the large beakers.

12 Repeat steps 8 to 11, adding the other solutions to the dialysis tubing.

13 Carefully lower the dialysis tubing into the large beakers, taking care to disturb the water as little as possible.

14 Observe any changes.

### Results

Note how long it takes:

a before colour starts to 'leak' out of the dialysis tubing

b for the colour to move half way across the water in the beaker

c until all the beaker is uniformly coloured.

### Discussion

1 **Compare** the rate of movement of the coloured solutions in the three beakers.

2 **Interpret** any differences in terms of the concentration of the original solutions.

3 **Identify** the part of the model that represents the cell.

4 **Propose** an aspect of diffusion of oxygen in the lungs, or nutrients in the digestive system, that is not included in this model.

5 **Propose** a way of demonstrating diffusion of materials into cells using similar equipment.

# 7 Chapter review

## Remembering

**1** a **Name** the 'master gland' of the endocrine system.
 b **Recall** where it is situated.
 c **Recall** the organ that controls the 'master gland'.

**2** **Name** the two main parts of the human nervous system.

**3** **Name** the system that delivers materials to cells.

**4** **Recall** the word that means 'maintaining a constant internal environment'.

## Understanding

**5** **Explain** the relationship between proteins and amino acids.

**6** **Define** the term *metabolism*.

**7** **Explain** why the human body needs the following systems.
 a digestive system
 b respiratory system
 c excretory system
 d nervous system
 e endocrine system
 f circulatory system

## Applying

**8** a **Use** the example of a reverse-cycle air conditioner to **explain** the term *negative feedback*.
 b **Describe** two examples of negative feedback in the human body.
 c **Demonstrate** using diagrams how this feedback works.

**9** a **Describe** the changes that would occur in your body if you went from a warm environment to a very cold environment.
 b **Explain** why these changes take place.
 c **Identify** the systems involved in the changes and describe how the changes are brought about.

**10** a **Describe** the changes that occur in your body as you start to do some vigorous exercise.
 b **Identify** the systems that are causing the changes.
 c **Explain** how the changes are brought about.
 d **Explain** how the changes help your body maintain that level of activity.

**11** **Demonstrate** how the level of glucose in your blood is controlled.

**12** **Use** Figure 7.3.13 on page 249 to **demonstrate** that multicellular organisms rely on coordinated and interdependent internal systems

## Analysing

**13** **Compare** the nervous system and the endocrine system.

**14** a **Contrast** the roles of the sympathetic and parasympathetic nervous systems in the body.
 b **Explain** why both systems are required.

## Evaluating

**15** a **Assess** each of the statements below and decide whether they are true or false.
  i The endocrine system uses enzymes to send chemical messages around the body.
  ii Hormones are distributed to all parts of the body by the circulatory system.
  iii The digestive system can work independently of the other systems of the body.
  iv The kidneys are the only organs involved in treating wastes in your body.
 b For each statement you decided was false, **justify** your decision.

## Creating

**16** **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

| | |
|---|---|
| endocrine system | nervous system |
| metabolism | hormones |
| pituitary gland | hypothalamus |
| receptors | target cells |
| central nervous system | peripheral nervous system |

# Thinking scientifically

**Q1** Two groups of people were involved in a trial to see which activity had the greatest effect on total urine production. One group sat in the full sun on a hot day for 30 minutes. The other group exercised vigorously for 30 minutes. Neither group had anything to drink after the experiment started.

The average urine production for the group was measured at half-hourly intervals and the following results were obtained.

| Time (min) | Volume of urine produced (mL) | |
|---|---|---|
| | Group 1 | Group 2 |
| 0 | 50 | 50 |
| 30 | 53 | 50 |
| | Vigorous exercise for 30 minutes | Sat in the sun for 30 minutes |
| 60 | 60 | 30 |
| 90 | 10 | 20 |
| 120 | 8 | 20 |
| 150 | 35 | 25 |
| 180 | 40 | 23 |

Select the statement that is most likely to be true.

**A** In the time following the activity (exercise or sunbaking), the group who were sunbaking produced less urine.

**B** In the time following the activity (exercise or sunbaking), the group who were exercising produced less urine.

**C** Both groups produced the same amount of urine in total.

**D** There was a steady decline in the amount of urine produced by both groups.

**Q2** Identify the change that is *unlikely* to be occurring in the body of the young man shown here.

**A** increased levels of cellular respiration

**B** reduced heart rate

**C** constriction of blood vessels to the skin, fingers and toes

**D** shivering

**Q3** The composition of the blood and urine of four groups of students was compared, and the results are shown in the table below.

Identify the group most likely to have been involved in vigorous exercise prior to the samples being taken.

**A** Group 1

**B** Group 2

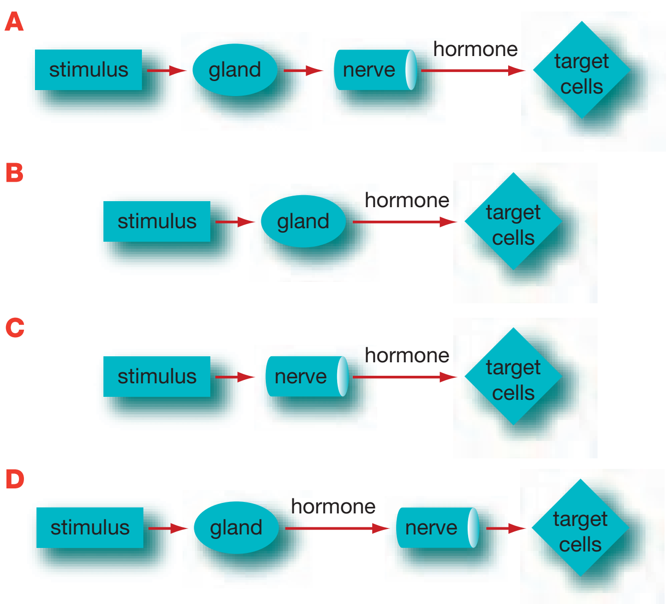
**C** Group 3

**D** Group 4

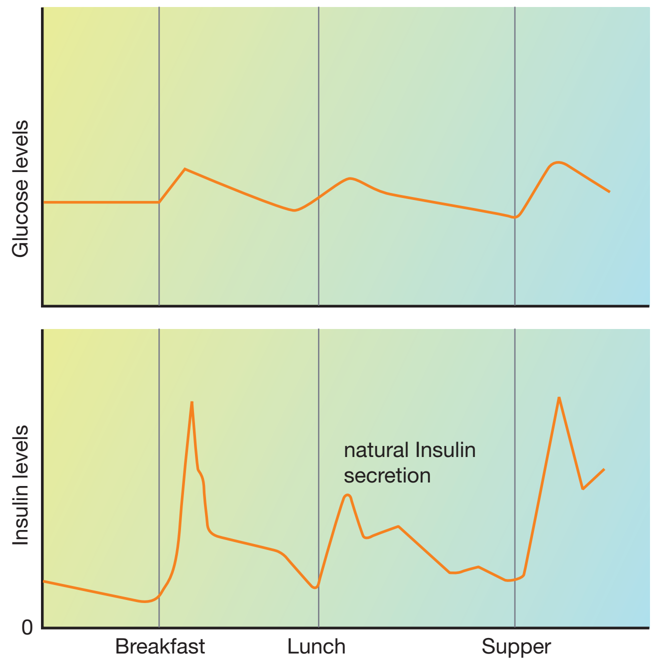
| Component | Group 1 | | Group 2 | | Group 3 | | Group 4 | |
|---|---|---|---|---|---|---|---|---|
| | Blood | Urine | Blood | Urine | Blood | Urine | Blood | Urine |
| Water (%) | 90 | 90 | 85 | 80 | 80 | 70 | 80 | 70 |
| Protein (%) | 9 | 0 | 9 | 0 | 9 | 0 | 9 | 0 |
| Glucose (%) | 0.1 | 0 | 0.09 | 0 | 0.05 | 0 | 0.09 | 0 |
| Urea (%) | 0.003 | 0.05 | 0.004 | 0.055 | 0.006 | 0.07 | 0.004 | 0.05 |
| Sodium (%) | 0.35 | 0.45 | 0.35 | 0.55 | 0.25 | 0.15 | 0.35 | 0.35 |

**Q4** After eating, levels of glucose in the blood increase. Specialised cells in the pancreas detect the high glucose levels and react by producing insulin. Insulin causes the liver and muscles to increase their uptake of glucose, removing it from the bloodstream.

Select the model that best fits control of glucose levels in the blood.



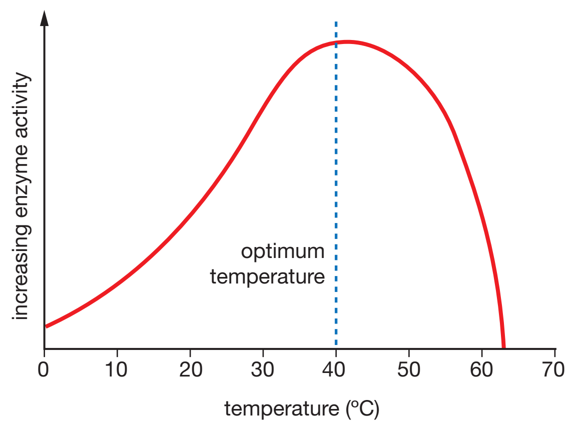

**Q5** Select the answer that best fits the data in the graphs below, which show the relationship between glucose and insulin levels in the blood.

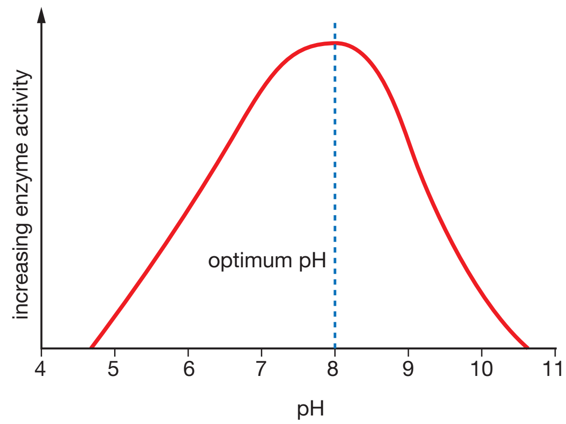



Levels of insulin are highest:

**A** when glucose levels are increasing
**B** when you are eating a meal
**C** when glucose levels are highest
**D** a short time after the peak in glucose levels.

**Q6** The following graph shows the level of activity of a human enzyme at different temperatures and pH.




The normal internal temperature of the human body is 37°C. The pH of the mouth is about 7.5, in the stomach it is about 3, and in the small intestine it is about 8.

Select the statement that best fits all the data presented.

**A** The enzyme works best at low pH and high temperature.
**B** Temperature and pH have no effect on activity of the enzyme.
**C** The enzyme would be able to function best in the small intestine.
**D** The enzyme is most likely a digestive enzyme from the stomach.

# Glossary

## Unit 7.1

**Autonomic nervous system:** the system controlling involuntary actions such as the heartbeat

**Axon:** a nerve fibre that sends nerve impulses away from the cell body

**Brain stem:** part of the brain where the spinal cord enters the skull; it controls the body's vital functions, such as breathing, blood pressure and heart rate

**Cell body:** the part of the neurone that contains the nucleus

**Central nervous system (CNS):** the brain and the spinal cord

**Cerebellum:** part of the brain that is responsible for coordination and balance

**Cerebrum:** part of the brain that controls conscious thoughts, controls the movement of every body part, and receives sensory messages from each body part

**Dendrites:** branches from the cell body that receive messages from other neurones

**Effectors:** muscles or glands that put the messages into effect

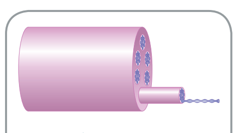
**Medulla:** the lower half of the brain stem

**Motor neurones:** nerve cells that carry messages from the CNS to effectors

**Myelin sheath:** the insulating layer that covers a neurone

**Nerve impulse:** the electrical message carried by a nerve cell

**Neurone:** a nerve cell



Myelin sheath

**Neurotransmitter:** a chemical message released at the end of an axon to be received by the next neurone's dendrites

**Optic nerve:** the nerve that carries messages to the brain from the retina at the back of the eye

**Parasympathetic nervous system:** part of the nervous system that slows the body down and controls it when it is resting

**Peripheral nervous system (PNS):** the nerves that carry messages to and from the central nervous system and other parts of the body

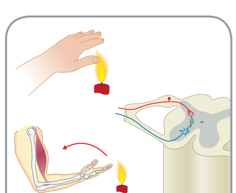
**Receptors:** special cells that detect stimuli

**Reflex actions:** quick, automatic actions that protect the body from danger; they are also known as reflexes

**Reflex arc:** the nerve pathway operating in a reflex action

**Sensory neurones:** nerve cells that carry messages from cells in the sense organs to the CNS

**Somatic nervous system:** part of the nervous system that coordinates the movement of the body and receives information from the sensory organs

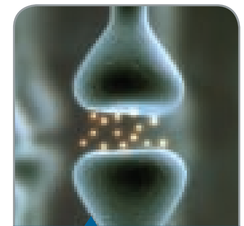


Reflex arc

**Stimulus:** any factor that stimulates a receptor and brings about a response

**Sympathetic nervous system:** part of the nervous system that speeds up the functions of the body and makes the body work more efficiently

**Synapse:** the space between two neurones



Synapse

## Unit 7.2

**Adrenal glands:** endocrine glands situated on the kidneys

**Adrenalin:** the common name for the hormone epinephrine

**Antidiuretic hormone (ADH):** a hormone that controls the amount of urine produced by the body

**Endocrine glands:** glands that produce hormones

**Endocrine system:** all the endocrine glands of the body

**Endothermic:** able to maintain a constant body temperature

**Epinephrine:** a hormone produced in the adrenal glands; it is commonly known as adrenalin

**Glycogen:** the chemical store of glucose in the liver and muscles

**Glucagon:** a hormone that has the opposite effect to insulin; it releases glucose from stores in the liver and muscles

**Homeostasis:** the process of maintaining a constant internal environment

**Hormones:** chemical substances that act as messengers in the body

**Hypothalamus:** a portion of the brain that constantly checks the internal environment of the body

**Insulin:** hormone produced in the pancreas that causes the liver and muscles to extract glucose from the bloodstream and store it in the liver and muscles

Hypothalamus

**Metabolism:** all the chemical reactions occurring in the cells

**Pituitary gland:** the endocrine gland that controls the activities of other endocrine glands; it is often called the 'master gland'

**target cells:** the cells on which a hormone acts

## Unit 7.3

**Catalyst:** a substance that speeds up the rate of a reaction without being used up in the process

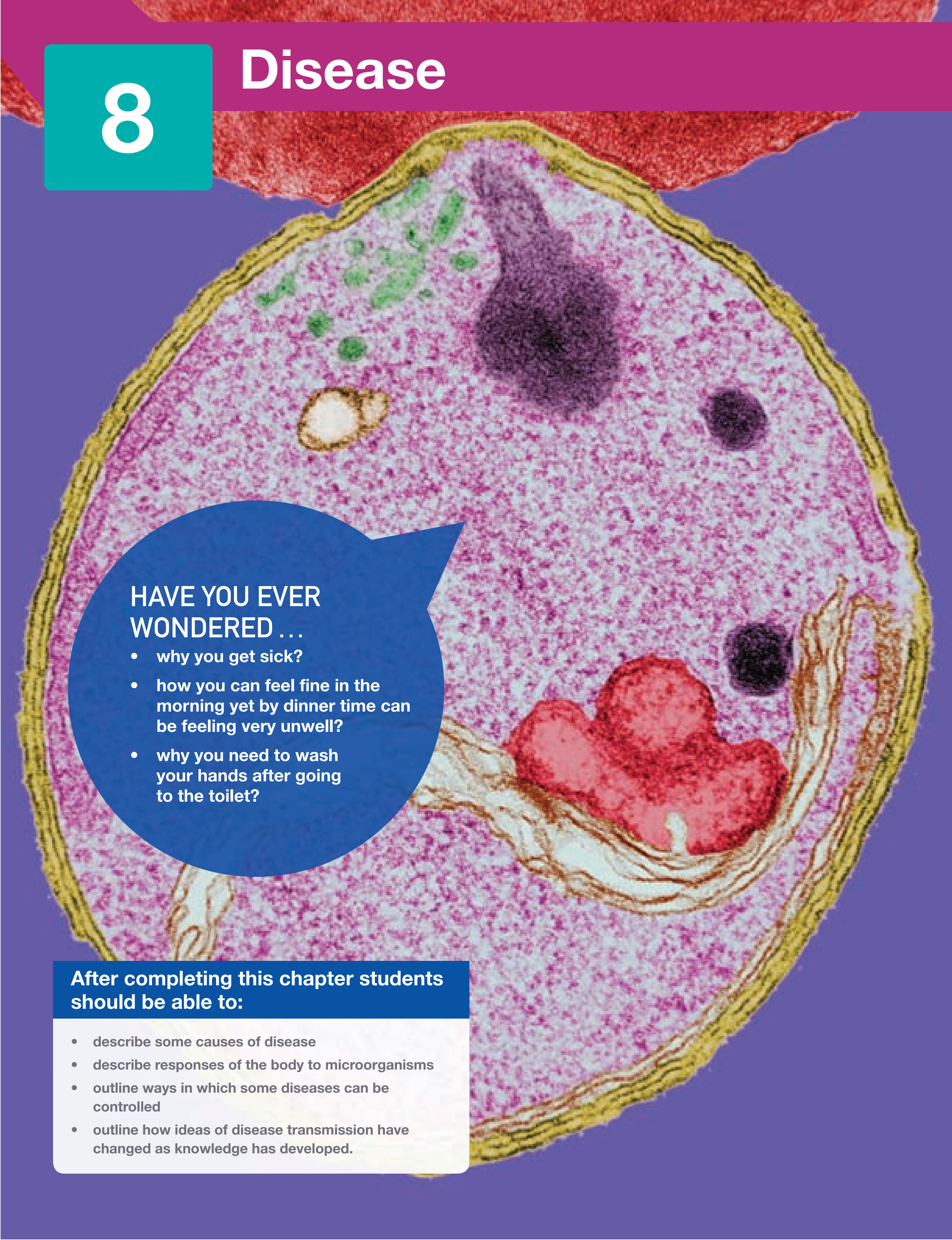
**Diffusion:** the movement of particles of a substance from an area of high concentration to an area of low concentration

**Enzyme:** an organic catalyst

**Mitochondria:** organelles where cellular respiration occurs

**Reactant molecule:** the molecule that is going to be changed by a chemical reaction

**Ribosome:** the organelle where proteins are manufactured



# 8 Disease

## HAVE YOU EVER WONDERED …

- why you get sick?
- how you can feel fine in the morning yet by dinner time can be feeling very unwell?
- why you need to wash your hands after going to the toilet?

### After completing this chapter students should be able to:

- describe some causes of disease
- describe responses of the body to microorganisms
- outline ways in which some diseases can be controlled
- outline how ideas of disease transmission have changed as knowledge has developed.

# 8.1 They make us sick!

Everyone gets sick at some time or another. When you get sick, you expect to get better quickly. Colds and upset stomachs are not usually called *diseases*. That term is normally used for more serious and long-term illnesses.

## Bacteria

A **disease** is anything that causes your body to stop working properly. One cause of disease is bacterial infection.

**Bacteria** are microscopic, unicellular (one cell) organisms. Thousands of different species of bacteria have been discovered. However, scientists are finding so many new species that they believe that most have not yet been discovered. Bacteria are an important part of the natural environment. They are decomposers, converting dead plant and animal matter and wastes into nutrients that plants use to grow. Bacteria living in the intestines of herbivores such as cows and kangaroos help with digestion. Bacteria help control insects. Humans use bacteria to make medicines and to break down pollutants such as oil and plastics. A small percentage of known bacteria cause disease. These bacteria are known as **pathogenic bacteria** or **pathogens**.

Figure 8.1.1

Bacteria in the soil are decomposers, helping to break down dead plants and animals, thus returning nutrients to the soil.

**SciFile**

**On me?**

There are more living organisms on the skin of a single human being (even a clean one) than there are human beings on the surface of the Earth!

1 p266

8.1

**INQUIRY science 4 fun**

### Is it clean?

Where in the house would you find harmful bacteria?

Yes

**Collect this ...**

- magnifying glass

**Do this ...**

1. Think about the places in the kitchen where harmful bacteria could lurk.
2. Wipe the bench surfaces over so that you think they are clean.
3. Use the magnifying glass to look at the surfaces, in corners and on ledges. You will not be able to see bacteria, but you may be able to see dust or grime that could harbour bacteria.

**Record this ...**

**Describe** what you could see.

**Explain** why the surfaces may not have been as clean as you thought.

## Bacterial diseases

Pathogenic bacteria cause hundreds of diseases, such as whooping cough, tetanus, diphtheria, impetigo (school sores), pneumococcal and meningococcal disease, and typhoid fever. These are all **infectious diseases**—they are diseases that can be spread.

Some infectious diseases are easier to spread than others. Those that are easiest to spread are described as **contagious**. Impetigo, shown in Figure 8.1.2, is a contagious disease that is more common in children than in adults. Touching someone with impetigo could result in you becoming infected, and for this reason infected children are put into **quarantine**. They are isolated from healthy people to prevent the spread of the disease. They are not allowed to attend school or day care centres until they have started treatment for the disease. Even then they can only return to school if the sores are covered with watertight dressings. Quarantine is used to prevent the spread of disease within a community, between communities and between countries.

Figure 8.1.2 If they are not treated, the oozing sores of impetigo remain infectious until they are healed. Once treatment starts, the sores should begin to heal in about three days.

Bacterial infections are treated with **antibiotics**—substances that kill or prevent the growth of bacteria. The first successful antibiotic was **penicillin**. Penicillin was not in common use until the late 1940s. Before the development of antibiotics, you would have had to depend on your own body's **immune system** to fight off infections. Even today, antibiotics don't always work.

Some people are allergic to penicillin, and not all types of bacterial infections can be treated with it. For these reasons, antibiotics other than penicillin have been developed. Penicillin and these other antibiotics have saved the lives of millions of people since they were discovered.

2 p267

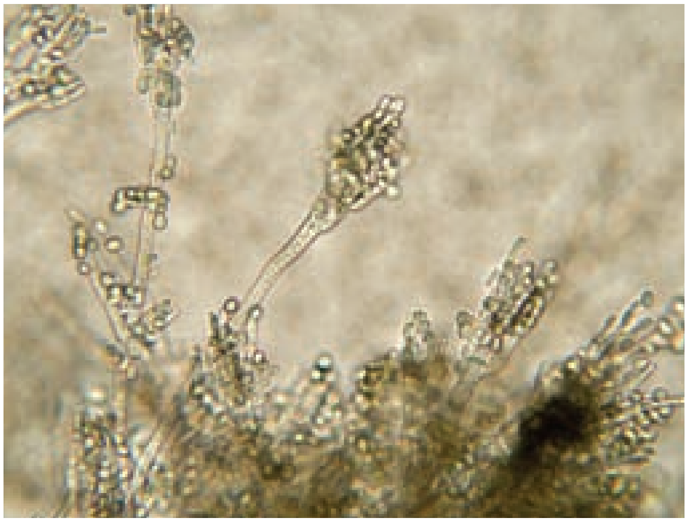


Figure 8.1.3 It was from this mould (*Penicillium*) that the first antibiotics were made.


Figure 8.1.4 People with a severe allergy to penicillin and other substances will quickly become dangerously ill if they take them. For this reason, they often wear a bracelet or medallion and carry a card with them to let emergency workers such as paramedics know of the allergy.

**SciFile**

### Accidents that work

Penicillin was discovered by accident. The Scottish scientist Alexander Fleming left some culture plates on which he was growing bacteria on a bench while he went on holiday. Mould grew among the plates. Where one particular mould grew, the bacteria didn't. Later, Howard Florey and Ernst Chain developed penicillin into a useful medicine.

# The immune system

Pathogens can enter your body in a number of ways, as shown in Table 8.1.1.

**Table 8.1.1 Methods of entry of pathogens**

| Method of entry | Examples of disease |
|---|---|
| Food and water | Food poisoning, cholera |
| Breathing in | Flu, pneumonia, tuberculosis |
| Cuts and wounds | Tetanus, blood poisoning |
| Sexual contact | Gonorrhoea, syphilis |
| Other contact | Anthrax, leprosy |

Your body has three lines of defence against disease. The first line of defence is to prevent the pathogens from entering the body.

- Skin is an effective barrier against pathogens and protects the internal organs from harmful chemicals in the environment and from sunlight.
- Fluids such as tears and saliva have mild antiseptic properties and help to wash away dust and harmful substances from openings to the body.
- Air entering through the nose is filtered by hairs in the nostrils. Other unwanted particles in the air are then trapped in the mucous lining of the trachea (windpipe). Coughing and sneezing help to get rid of these foreign particles.
- Pathogens entering the digestive system are usually killed by the acid in the stomach. Vomiting is a quick way of getting rid of something undesirable in the stomach. Diarrhoea is a rapid way of ridding the body of pathogens that have got past the stomach.

Once a pathogen enters the body tissues, the second line of defence gets started. The affected area becomes red, hot and swollen—it is inflamed. Inflammation is a response of the body to infection. Damaged cells release a chemical that causes an increased amount of blood to flow to the infected area. Within the blood are special white blood cells called **neutrophils**. You can see these in Figure 8.1.5. Neutrophils consume bacteria.

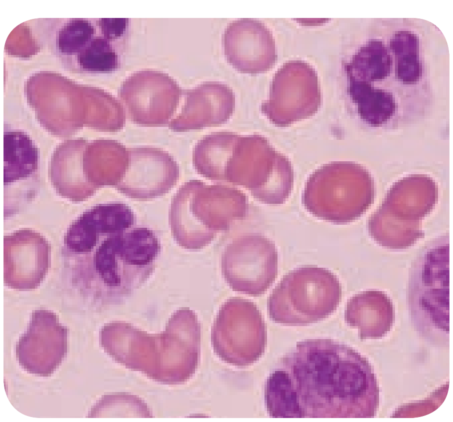


Figure 8.1.5

Neutrophils are white blood cells that have many nuclei, which you can see stained purple in some cells here. They can change shape as they hunt for and consume bacteria.

Many neutrophils are killed as a result of consuming large numbers of bacteria. Dead neutrophils form the yellow pus that collects around infected wounds, like the wound shown in Figure 8.1.6.

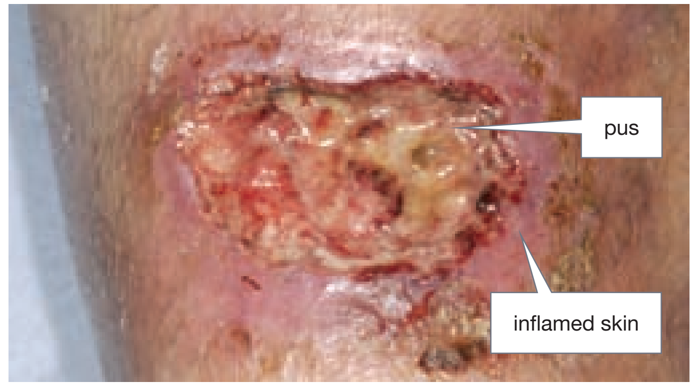



Figure 8.1.6

Once the skin is broken, the first line of defence is breached. The second line of defence can be seen at work here. The skin is inflamed and the yellow pus indicates that neutrophils have been at work.

If the pathogens are still active, the third and last line of defence is activated. The last line of defence is the lymphatic system. The lymphatic system is a series of vessels and capillaries that carry fluid from around your cells back to your heart. In areas of the lymphatic system there are swellings or nodes (lymph nodes).

Lymph nodes contain a large number of different types of white blood cells, called lymphocytes and macrophages. The function of these white blood cells is to destroy pathogens and to help protect the body in the future.

**Macrophages** are similar to neutrophils in that they consume and destroy the pathogens. A macrophage is shown in Figure 8.1.7. **Lymphocytes** respond by making a chemical called an **antibody**. Antibodies cause pathogens to clump together, making the work of the macrophages easier, as they can destroy more of the pathogens at any one time.

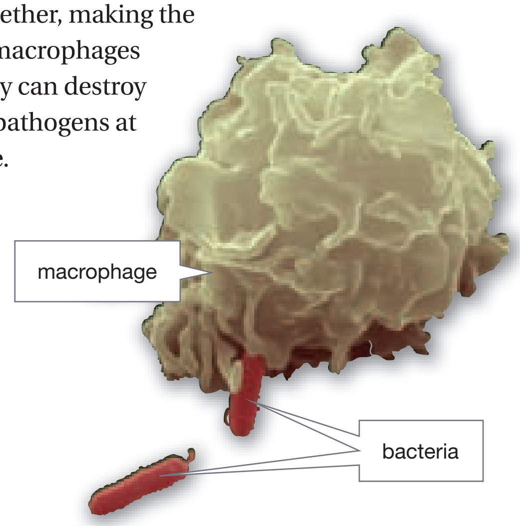



Figure 8.1.7

Macrophages are large white blood cells found in the lymph glands. This macrophage is consuming bacteria.

Each pathogen has a specific antibody that acts on it. The first time the lymphocytes meet a particular pathogen, they make antibodies that work on that pathogen. This takes some time, and meanwhile you may get sick. The next time your immune system meets the same pathogen, it is able to make the antibodies quickly and the pathogen is destroyed before it can make you unwell. You are now **immune** to that pathogen and should stay healthy if you meet it again.

When the lymphocytes and macrophages are working hard, the lymph nodes closest to the site of infection become enlarged. You can feel swollen and tender glands in places like your neck, armpits and groin.

To help you fight an infection, your body's thermostat is set higher than normal and you develop a fever. Pathogens that enter your body function best at normal body temperature. When your body temperature is higher, the pathogens are not able to function as efficiently and your immune system can fight them more easily.

The body's three lines of defence are summarised in Figure 8.1.8.

## Vaccination

Some diseases are so serious that you don't want to rely on your body developing immunity by itself. To help it out, vaccines are used. **Vaccines** are chemicals that cause your body to react as if it had met a pathogen.

A vaccine is created by taking a small amount of the poison produced by the bacterium and making it inactive, or by using dead bacteria. The inactive poison and the dead bacteria are harmless, but your immune system responds to the vaccine by making antibodies and you become immune to the pathogen.

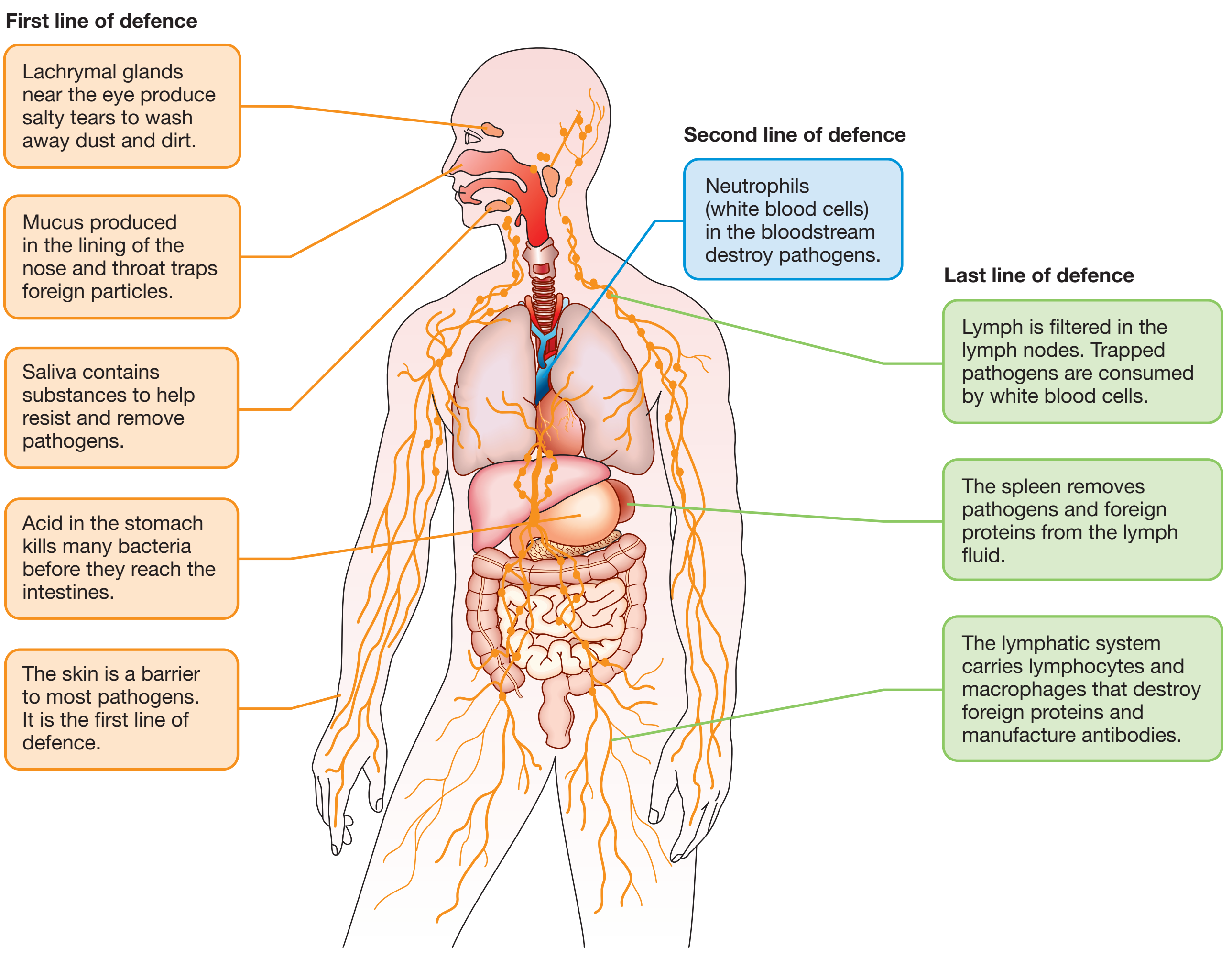



Figure 8.1.8 The function of the three lines of defence is to protect the body from pathogens.

In Australia, young children are routinely injected with vaccines against tetanus, diphtheria and whooping cough (pertussis). This process is known as being vaccinated or immunised. Other bacterial diseases for which vaccines are available include meningococcal and pneumococcal disease and typhoid fever.

### Tetanus

**Tetanus** is a bacterial infection caused by a bacterium called *Clostridium tetani*. These bacteria, shown in Figure 8.1.9, live where there is very little air—deep in the soil, or deep in the body. They can enter your body through puncture wounds, the sort you would get from standing on barbed wire or a rusty nail. As the bacteria multiply within your body, they produce a poison that causes the muscles to become stiff and to tighten suddenly (spasm). The spasms begin in the jaw, causing the jaw to lock shut. This symptom gives the disease its common name, 'lockjaw'.

The vaccine against tetanus gives you immunity for up to 10 years. After that you need a booster.

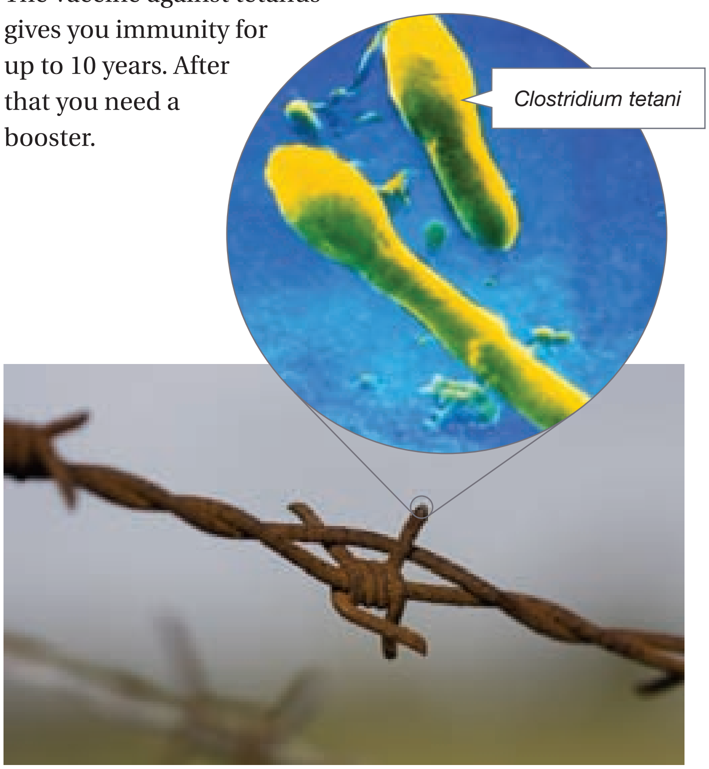



**Figure 8.1.9** Barbed wire can cause deep puncture wounds that allow *Clostridium tetani*, the bacterium that causes tetanus, to enter the body.

## Hygiene

Some diseases can be prevented by practising good hygiene. If you wake up one morning feeling sick in the stomach and then start vomiting, it is likely that you are infected with *Salmonella enteritidis*—a bacterium that causes **gastroenteritis**. This bacterium is shown in Figure 8.1.10.

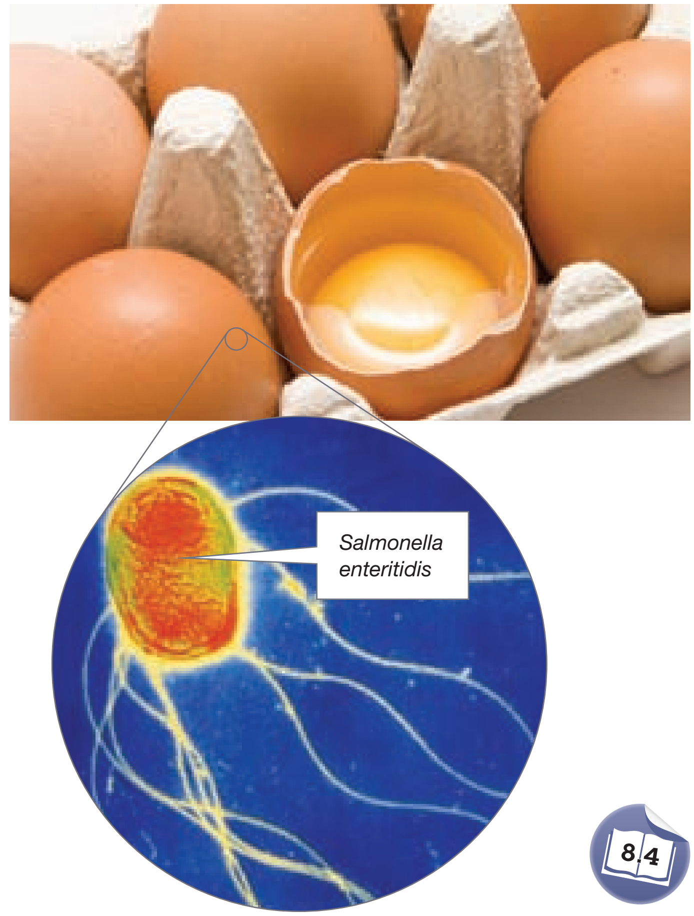



**Figure 8.1.10** *Salmonella enteritidis* is found naturally in faeces. The bacteria can be picked up when playing with animals (especially birds), or through touching dirty surfaces such as egg shells and then touching your mouth or food. *Salmonella* bacteria are responsible for over 9000 cases of gastroenteritis per year in Australia.

*Salmonella enteritidis* bacteria live naturally in the bowel of humans and other animals, especially birds. If the bacteria get into food you eat, they will multiply in your stomach, producing poisonous wastes as they do so. The poisons cause fever, headache and stomach pains. Your body tries to get rid of the poisons as quickly as possible. Vomiting gets rid of the poisons in your stomach contents, and diarrhoea gets rid of toxins produced lower down the gut. Vomiting and diarrhoea cause you to lose a lot of water, and dehydration (a lack of water in the body) may become an additional problem. So no matter how ill you feel, you must drink plenty of water.

Gastroenteritis is a disease that can be avoided if you:

- wash your hands thoroughly and frequently, after handling animals, after going to the toilet, and before handling food
- thoroughly wash all surfaces on which food is prepared
- keep foods like meat, fish and dairy products separate from one another and refrigerated.

# SCIENCE AS A HUMAN ENDEAVOUR

## Nature and development of science

### Stomach pains

Figure 8.1.11 This stomach ulcer has eaten away the lining of the stomach, leaving the tissue underneath exposed to the strong acid of the stomach. This will cause intense pain and can lead to life-threatening bleeding.

**Stomach ulcers occur when the lining of the stomach has been damaged. The stomach normally produces strong acid, and when this comes in contact with the damaged area, the result is pain.**

Ulcers in the stomach and lower in the intestines, such as the one shown in Figure 8.1.11, have been a major medical problem throughout the world. Doctors thought that stress, poor diet, alcohol, smoking or too much caffeine could all be part of the cause.

In 1979, Dr Robin Warren was working as a pathologist at the Royal Perth Hospital. Pathologists study the causes and effects of disease. Dr Warren found that an unusual bacterium was common in the stomachs of patients suffering from ulcers. Up until then, people in the medical profession were so sure that stress and diet caused ulcers that they were very sceptical about the link between a bacterium and stomach ulcers that Dr Warren had suggested. They did not believe that a bacterium could survive in the acidic environment of the stomach.

Dr Barry Marshall is a gastroenterologist—a doctor who studies diseases of the stomach and intestine. In 1981 he was looking for a research project, and decided to work with Dr Warren. They isolated this strange bacterium from the stomach and cultured (grew) it in the laboratory. It was a new species of bacterium, which they called *Helicobacter pylori* (*H. pylori*) (shown in Figure 8.1.13). The two doctors were convinced that *H. pylori* was causing ulcers, and they continued their research. The rest of the medical profession were still sceptical, and so Dr Marshall decided to test his hypothesis by infecting himself with the bacterium to see what happened.

Dr Marshall swallowed a culture of the bacterium, and a week later he began to suffer the symptoms of gastritis, the infection that comes before an ulcer develops. He then treated himself with antibiotics to destroy the bacterium, and he recovered.

The discovery of the link between *H. pylori* and ulcers has been described as possibly the most significant event in medicine in Australia in the past 20 to 30 years.

Figure 8.1.12 Dr Barry Marshall and Dr Robin Warren are two Australians who worked together to discover the cause of stomach ulcers.

8.5

Figure 8.1.13 *Helicobacter pylori* was identified as a new species of bacterium and the cause of stomach ulcers.

It was now possible to cure a disease that doctors had previously considered incurable.

Dr Robin Warren and Dr Barry Marshall have all the characteristics of outstanding scientific researchers: ability, determination when faced with scepticism and hurdles, salesmanship, and team spirit. In 2005 they were awarded a Nobel Prize for their contribution to medicine.

# 8.1 Unit review

## Remembering

1 **State** the general name for organisms that cause disease.

2 **Name** the system of the body that fights disease.

3 **Name** two common diseases caused by bacteria.

4 **State** the function of antibiotics.

5 **List** diseases that health authorities advise that all Australian children be immunised against.

6 **State** the cause of stomach ulcers.

## Understanding

7 **Define** the term *disease*.

8 **Explain** why severe cases of gastroenteritis can cause dehydration.

9 **Outline** the process used to make a vaccine.

10 **Explain** how vaccines work.

11 **Explain** what it means to be *immune* to a disease such as tetanus.

12 **Explain** why it is important that you wash your hands after playing with pets or going to the toilet.

13 **Explain** why the medical profession did not believe that the bacteria seen in the stomach could cause ulcers.

## Analysing

14 **Compare**:
  a a contagious disease and an infectious disease
  b antibiotics and vaccines.

15 **Compare** the way you become immune through natural reactions of your body and through administering a vaccine.

## Evaluating

16 Some parents think that immunisation is not necessary because the diseases it is used against are so rare in Australia.
  a **Evaluate** whether this attitude is reasonable or not.
  b What would you **recommend** if someone asked you whether or not they should be immunised against a disease?

17 Three friends went for a meal at a restaurant. Next day all were feeling very ill and were diagnosed as having gastroenteritis. **Propose** the possible causes of the illness.

## Creating

18 **Construct** series of diagrams to demonstrate how a tetanus vaccine protects you against the disease.

19 **Construct** a poster to inform people about tetanus and how it can be prevented.

## Inquiring

1 Find out more about the discovery of penicillin. Information to look for includes:
- where the research was carried out and by whom
- the timeline for the discovery
- the contribution each person made to the discovery
- other scientific research they were involved in.

2 Investigate the work of Australian scientists Fiona Wood and Marie Stoner on artificial skin.

3 In your workbook, construct a table like the one below.
  a In the table, list the diseases that you have been vaccinated or immunised against. (You may have to ask your parents to come up with this list.)
  b Research the information needed to complete the rest of the table.

| Disease | Symptoms of the disease | Prevalence in Australia | When the immunisation was developed | Age at which immunisation is given | Frequency of immunisation |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

# 8.1 Practical activities

## 1 Growing bacteria

### Purpose

To show that bacteria are common in our environment.

### Materials

- prepared agar plates
- marker pen
- zip-lock bag
- access to an incubator

**SAFETY**

Treat all bacteria as potentially dangerous.

All plates must be completely sealed with tape.

Do not open the lids of the agar plates once you have grown the bacteria. Your teacher will dispose of the plates correctly. As an added precaution, the agar plates could be sealed within a zip-lock plastic bag, as shown in Figure 8.1.14.

### Procedure

1. Take one agar plate for each group of three or four students.
2. As a group, decide where in the school you are going to expose the plates. Do not touch the plate or expose it where dangerous pathogenic organisms may exist (for example, do not expose it in toilets). Do not cough or sneeze on the plate.
3. Each group should go to a different part of the school, such as the canteen, sports oval and classrooms.
4. Go to your chosen site and open the agar plate. Wave it gently through the air for about one minute.
5. Replace the lid on the plate and seal it with tape. Mark the bottom of the plate with the name of your group and the place where the plate was exposed.
6. Place the plate top down in an incubator at 20 to 25°C and leave it overnight. If no bacterial colonies are visible, leave the plate for another 3 to 4 days.

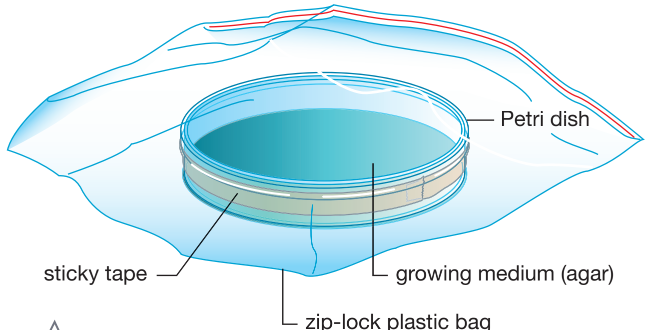



Figure 8.1.14

### Results

1. Count the number of different colonies on the plate using the following characteristics as a guide.
   - Bacterial colonies tend to be smooth and round.
   - Different bacteria may have different colours.
   - Fluffy areas like cotton wool are colonies of fungi.
2. Gather results for other groups in the class and construct a table that compares the number and variety of colonies from different parts of the school.

### Discussion

1. **Describe** the appearance of the colonies on your group's plate.
2. **Compare** the number of colonies found in the different parts of the school.
3. **Compare** the variety of colonies found in different parts of the school.
4. **Explain** the differences you identified.
5. **Discuss** the idea that one area of the school is more of a health hazard than another area.

## 2 The milk's off!

Bottled milk in the supermarket has been pasteurised. This means that most of the bacteria present in the milk have been killed. Some remain, however, and in the right conditions for growth they will multiply rapidly and cause the milk to spoil and clot. Acid produced by bacteria causes the clotting.

### Purpose

To see how quickly milk spoils in different conditions.

### Materials

- full-cream milk
- access to a refrigerator
- 3 tall heat-resistant beakers
- plastic wrap
- 3 rubber bands
- saucepan
- spoon
- electric hotplate or stove
- measuring cup
- universal indicator paper
- masking tape
- access to a marking pen

**SAFETY**

When conducting experiments with micro-organisms, treat them all as if they could cause disease.

Do not touch the milk. If you do, wash your hands thoroughly.

Do not taste or drink any of the milk.

### Procedure

1. Use the masking tape to label each beaker with one of the labels 'Cold', 'Room Temp/Control' or 'Boiled'.
2. Pour one cup of milk into the beaker labelled 'Cold'. Cover it in plastic wrap secured with a rubber band. Place this in the refrigerator.
3. Pour one cup of milk into the beaker labelled 'Room Temp/Control'. Cover it in plastic wrap secured with a rubber band. Place this in an area at room temperature where it will not be disturbed.
4. Pour one cup of milk into the saucepan and bring the milk to a simmer.
5. Stir continuously while letting the milk simmer for one minute.
6. Pour the hot milk into the beaker labelled 'Boiled'. Cover it in plastic wrap secured with a rubber band. Place this in an area at room temperature where it will not be disturbed.

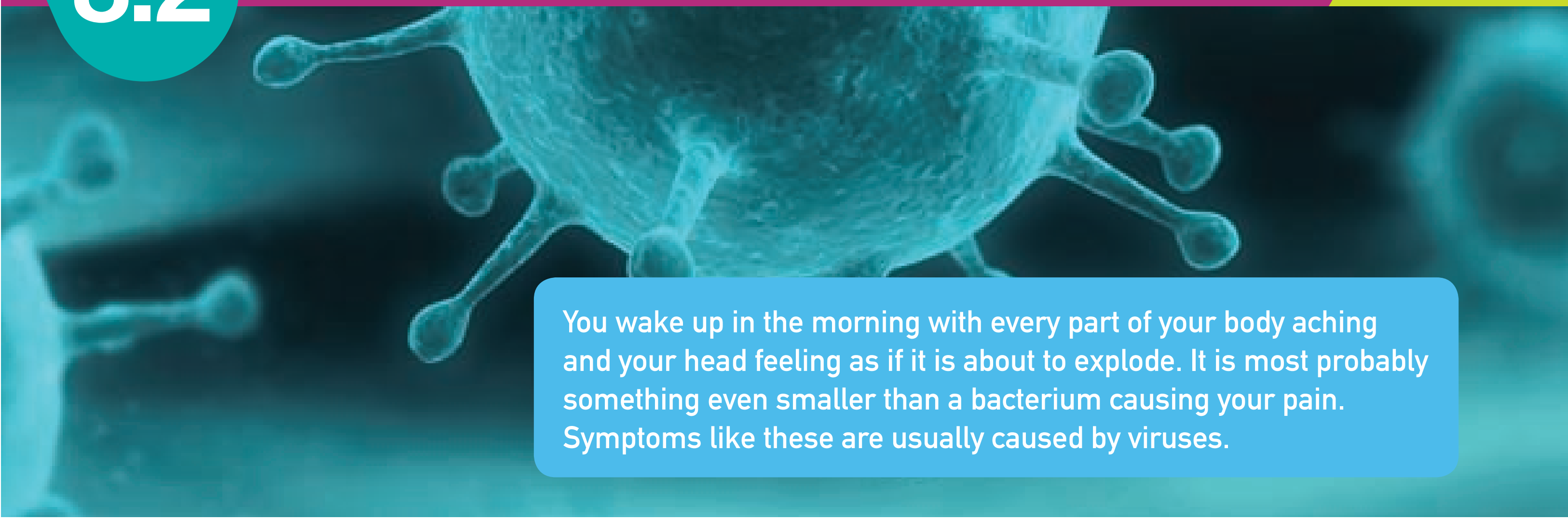
### Results

1. Record the appearance of the milk each day for 4 to 5 days. Do not remove the plastic wrap or shake the glass.
2. At the end of the experiment, when at least one of the samples of milk has separated, place an indicator strip in each beaker and note the results—acid, base or neutral—by comparing the colour of the wet strips with the chart provided with the indicator strips.

### Discussion

1. **Describe** what happened in each beaker of milk.
2. **Explain** why you think this happened.
3. **Use** your results to **explain** why milk needs to be kept refrigerated.
4. **Use** your results to **explain** why foods 'go off' faster in warm weather than in cool weather.
5. **Propose** what would have happened to unrefrigerated milk if you lived in a cooler climate.
6. From these results, **propose** recommendations on how other food products such as meat and cream should be stored.

# 8.2 Other sources of infection



You wake up in the morning with every part of your body aching and your head feeling as if it is about to explode. It is most probably something even smaller than a bacterium causing your pain. Symptoms like these are usually caused by viruses.

## Viruses

**Viruses** cause many common illnesses, such as colds and flu. They also cause measles, mumps, rubella, warts (like the one shown in Figure 8.2.1), polio, cold sores (herpes) and chickenpox.

Viruses are pathogens and are about one hundred times smaller than bacteria. They are so small that they were not seen until the invention of the electron microscope in 1931. Since then, more than 5000 types of viruses have been described in detail.

Scientists debate whether viruses are living things or not. This is because viruses can only grow and reproduce inside cells they have invaded—**host cells**. A virus uses the host cell to make thousands of copies of itself. The host cell is destroyed when it bursts open and releases new viruses that spread throughout the body, infecting and then destroying other cells.

Figure 8.2.1

Warts are abnormal growths caused by a virus that infects skin cells.

### Colds and flu

Over 200 different viruses cause colds. There can be thousands of microscopic virus particles in a droplet that is sneezed or coughed out by an infected person. If you breathe in an infected droplet, the virus has entered your body. Catching a cold is as easy as that.

Although colds are difficult to avoid, you can reduce your chances of catching one or spreading it to others.

- Cover your mouth when you cough or sneeze.
- Wash your hands frequently.
- Don't share personal items if you or the other person are ill.
- Avoid close contact with people who are coughing or sneezing or have a runny nose.
- If you are sick, stay at home so that you do not infect other people.

Figure 8.2.2

Coughing and sneezing pass viruses onto others nearby, quickly spreading the cold through a class, school and eventually your classmates' families.

**Atishoo!**
The droplets in a sneeze travel out of your mouth at over 160 kilometres per hour!

**SciFile**

8.3

The cold virus attacks the lining of the nose and throat. Extra mucus is produced, so your nose keeps running or becomes so blocked up that you feel as though you cannot breathe. Your throat gets sore and red, and you feel unwell.

You can catch flu (**influenza**) in the same way as catching a cold, by breathing in air containing virus particles, such as those in Figure 8.2.3, or by putting your hands near your mouth after touching contaminated surfaces. Flu is not the same as a cold. Both are caused by viruses, but flu develops more quickly and can be more severe. Infection with the flu virus causes a high temperature, and your whole body aches. However, your nose will not run as much as it would with a cold.

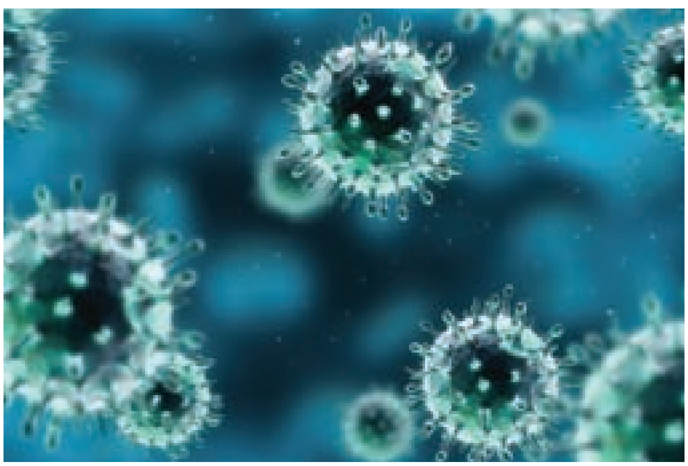


Figure 8.2.3 Viruses like these cause flu. The symptoms or indicators that you have the disease are a high temperature and aching muscles.

Antibiotics do not work against viruses. However, sometimes when you have a viral infection, bacteria invade the body and cause secondary infections. These can be treated with antibiotics. Coughing up green phlegm indicates a bacterial infection. Bronchitis and pneumonia are common secondary bacterial infections of a body weakened by fighting a virus.

Your body develops immunity to flu viruses, but you can get flu more than once because viruses are able to change quickly and new strains can appear. For each new strain of flu virus, the body has to make new antibodies, and the medical researchers have to make different vaccines. Vaccines can only be made for strains of a virus that are known.

Flu infections are usually treated as a nuisance, but they can be fatal for people with low immunity (for example, the elderly or the very young) or with other illnesses. Flu causes more than 4000 deaths in Australia each year.

## Childhood diseases

When you are born, your body has not yet had the chance to build up the antibodies you need to keep you healthy. This is why children tend to come down with lots of colds and diseases that rarely affect adults.

### Measles

**Measles** is a viral disease spread by infected people coughing and sneezing. It starts with a runny nose and sore eyes. A couple of days later a rash like the one in Figure 8.2.4 appears. In the past doctors did not worry about this common childhood illness, but now they are aware of serious side-effects. Severe cases of measles can result in permanent hearing problems or brain damage.

Figure 8.2.4 Measles rash

When European settlers first came to Australia, they brought measles with them. The Aboriginal population had no natural immunity, and measles killed a large number of them, especially children.

Measles is one of the most contagious of diseases. Since 1966, children have been routinely immunised, resulting in the disease becoming very rare in Australia.

## Chickenpox

The **chickenpox** virus causes a runny nose and a slight fever, followed by a rash of small, very itchy blisters. Scratching the blisters can lead to permanent scarring or to secondary bacterial infections of the blister.

After a person has been infected, the chickenpox virus can remain inactive in the nerve cells of their body for many years. Twenty, thirty or even forty or more years later, the virus can become active again, causing shingles—a very painful rash that can last for weeks. Figure 8.2.5 shows what the blisters of chickenpox and the rash from shingles look like.


Figure 8.2.5 Immunisation against chickenpox protects you from getting chickenpox. It also protects you from developing shingles later in life.

Routine immunisation against chickenpox did not start until 2006, so infections still occur. However, the number of infections should decline as more and more children are immunised.

# Parasitic disease

A **parasite** is an organism that lives on or in the body of another organism (the **host**) and takes nutrients from it. The host gets nothing in return and may be harmed. Some parasites can cause serious disease in humans.

## Malaria

**Malaria** is an infection caused by a unicellular parasitic organism called *Plasmodium*. Mosquitoes, such as the one shown in Figure 8.2.6, carry the *Plasmodium* from one host to another. As the mosquito pierces the skin it injects a chemical (an anticoagulant) into the hosts body to prevent the blood from clotting. The *Plasmodium* is injected along with the anticoagulant.

Malaria is one of the most widespread human diseases caused by a parasite. In the 1950s there were 250 million cases of malaria each year, with 2.5 million deaths.

Figure 8.2.6 Mosquitoes carry the *Plasmodium* (a member of the protist kingdom) from one host to another, infecting a new host as it bites them and sucks their blood.

Then the World Health Organization (WHO) coordinated efforts to control the disease. It was eradicated from many areas, including Europe, North America and Australia. In Australia, complete eradication was declared in 1981. In 1988 ‘only’ 110 million new cases were reported worldwide, but this trend has changed and now there are up to 220 million new cases of malaria each year.

Malaria has not returned to Australia, but mosquitoes capable of transmitting the disease live in northern Australia above the latitude of 19°S. About 700–800 people are hospitalised with malaria in Australia each year. These people were all infected elsewhere, mostly in Papua New Guinea.


Figure 8.2.7 Travellers to Papua New Guinea sometimes bring malaria into Australia.

Preventing infection means preventing mosquito bites in areas where the disease could return. If you live in northern Australia:

- wear protective clothing
- use insect repellent
- use a mosquito net when sleeping, if your windows are not screened
- clean up any standing water where mosquitoes could breed.

Insecticides can be used to control mosquito numbers, but they may also kill useful insects such as bees, so they are used with caution.

1 p276

**SciFile**

**Target blue**

Mosquitoes are attracted to the colour blue more than twice as much as any other colour!

## Amoebic dysentery

Most of Australia is supplied with fresh, clean water, and sewage is treated effectively. This protects you from many diseases found in other parts of the world. You only come into contact with these diseases if you travel overseas, or if some disaster at home damages the sewage system or contaminates the drinking water. One disease spread through contaminated water is amoebic dysentery. This disease causes 50 000 to 100 000 deaths per year worldwide.

**Amoebic dysentery** is caused by a single-celled organism that is most common in tropical areas. People become infected by swallowing a cyst containing the parasite in contaminated food or water. The cyst is one stage in the life cycle of the parasite.

Figure 8.2.8 There is a greater chance of contracting amoebic dysentery when there is poor (or no) sewage treatment and the water supply is contaminated.

People who contract the disease can remain infectious for years, so it is best to prevent infection in areas where amoebic dysentery occurs. When travelling in these areas, only drink boiled water or sealed, bottled water, don't have ice in your drinks and don't eat fruit or vegetables that may have been rinsed in tap water and not cooked.

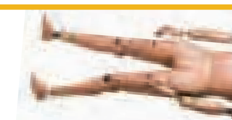
**INQUIRY science 4 fun**

### Where do spores come from?

Yes

**Collect this …**

- mushroom that is open, with dark brown gills under the cap
- sheet of white paper



**SAFETY**

Dispose of the mushroom and the paper in the bin when you are finished.

Wash your hands well after handling the mushroom.

**Do this …**

1 Place the mushroom on the sheet of paper with the gills facing down.
2 Leave it in an area where it will not be disturbed for two days.
3 Without moving the paper, lift the mushroom carefully off the sheet of paper. There should be a deposit of black spores on the paper.

**Record this …**

**Describe** the pattern on the paper. You could draw a picture or take a photograph.

**Explain** where the spores came from and what would normally happen to them.

## Fungi

Fungi such as mushrooms are useful as a source of food. Others are decomposer organisms in the environment. Some fungi cause disease. Very few of the diseases they cause are life-threatening. Most are simply a nuisance.

Fungi disperse using **spores**, which are made of a single cell with a tough skin. Fungal spores are everywhere.

A cloud of spores can be seen leaving the puffball fungus in Figure 8.2.9. The spores just need to find a warm, moist environment and they will start to grow. The warmest, most sweat-prone parts of the human body are the feet and the groin. It is there that pathogenic fungi such as tinea and thrush are most likely to grow.

Figure 8.2.9 This large puffball fungus does not cause disease. However, like all fungi, it releases spores that are light and easily blown about in the wind.

Fungal infections are contagious. They can be passed from one person to another through skin-to-skin contact, the sharing of towels, or walking on floors that an infected person has walked on.

2 p276

## Tinea

**Tinea** is a fungus that can grow on the skin, hair or nails. It grows out from a centre, producing a red, inflamed ring of skin, as shown in Figure 8.2.10. Tinea infection is often called ringworm, but no worms are involved. The tinea fungus feeds on dead skin cells. When it runs out of dead cells it will attack the living cells, causing the skin to become red and itchy. If not treated, the skin will crack and bleed. Figure 8.2.11 shows an example. The infection can be treated with a **fungicide**—a chemical that kills fungi.

Figure 8.2.10 Tinea infection is often called ringworm because of the shape of the inflamed area.

Figure 8.2.11 Tinea infection between the toes

## Thrush

**Thrush** infection is caused by fungus that is normally found in your body. Sometimes it grows out of control, causing problems. Thrush is not serious, but is very itchy and uncomfortable. It can be found as white patches on the tongue (as you can see in Figure 8.2.12) or inside the cheek, causes nappy rash in babies, and may infect the vagina.

Thrush sometimes develops when you are taking antibiotics because the bacteria that naturally control fungi have been destroyed by the antibiotics.

Figure 8.2.12 An oral thrush infection causes the tongue to be white.


Figure 8.2.13 The ideas of Galen, Avicena and Hippocrates influenced ideas about medicine in the Middle Ages.

# SCIENCE AS A HUMAN ENDEAVOUR

## Nature and development of science

### Medieval medicine

Hippocrates (460–377 BCE) and Galen (129–199 or 217 CE) are two very ancient and influential scientists. Galen defined disease as 'impairment of bodily activities'. Hippocrates believed that characteristics of the environment such as weather and drinking water caused disease. Although these ideas reflect some of what is believed today, ideas about disease have changed many times between then and now.

The Middle Ages (also known as medieval times) were the time from 500 to 1350 CE. The first 500 years was a time when the Roman Catholic Church dominated medicine and promoted the idea that illness was the result of sinful behaviour. The Black Death, which killed between one-third and half of the population of Europe in the mid-fourteenth century, was commonly believed to be a punishment from God.

By the eleventh century, Europe had become more settled. The ideas of Galen, Hippocrates and others were revisited. The Church established many centres of learning.

Hippocrates put forward an idea that four humours controlled the health of individuals. This idea was reinstated in the thirteenth century. The humours phlegm, blood, yellow bile and black bile were balanced in a healthy person and unbalanced where there was disease. Diagrams such as Figure 8.2.14 depicted the humours and their associations with the seasons, universal elements and certain qualities. These associations are listed in Table 8.2.1.

**Table 8.2.1 The humours**

| Humour | Season | Universal element | Qualities |
|---|---|---|---|
| Yellow bile (coleric) | Summer | Fire | Hot and dry |
| Black bile (melanc) | Autumn | Earth | Cold and dry |
| Phlegm (flegmat) | Winter | Water | Cold and moist |
| Blood (sangvin) | Spring | Air | Hot and moist |

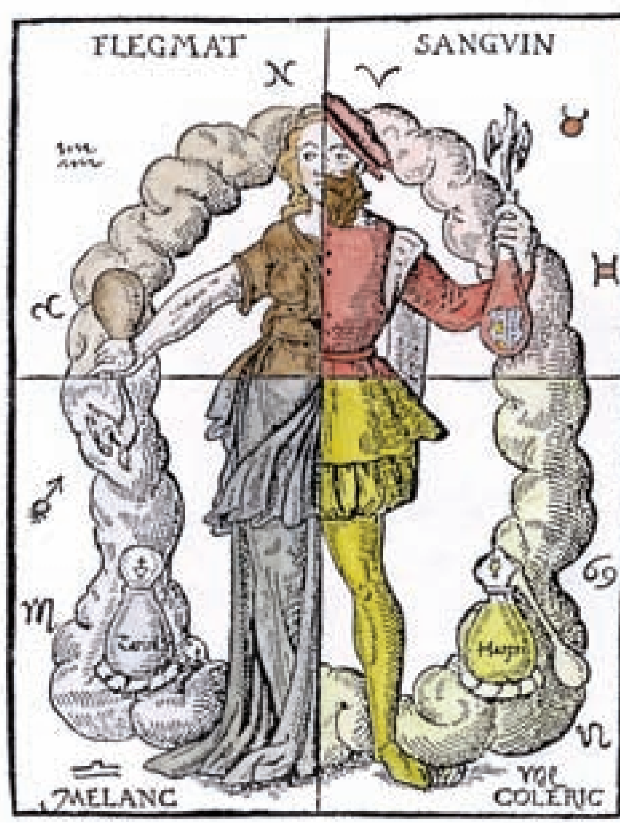



Figure 8.2.14 Each humour was associated with a particular temperament. Blood was connected with fun, yellow bile with ambition, phlegm with a calm disposition, and black bile with melancholia.

Fever was described as a hot, dry disease caused by too much yellow bile. More of the opposite humour (phlegm) was required, to cure the problem. The patient was ordered to take cold baths.

Herbal drugs were used if the treatment failed. The vomiting and diarrhoea the herbs often caused were a sign that the imbalance of the humours had passed out of the body.

Medieval doctors believed that bad smells caused disease. Getting rid of the smell would reduce the threat of disease (Figure 8.2.15). Some town authorities tried to clear the streets of rubbish and sewage even though the link between waste and disease wasn't fully understood. However, industries that produced foul smells, such as butchery, dyeing and tanning, were located side by side with homes.

**Figure 8.2.15** During the plague, doctors wore a beaked mask. The beak was filled with aromatic herbs and spices to overpower foul smells that were thought to cause disease.

Aristotle (384–322 BCE) believed that living things could generate spontaneously from non-living things. Snakes and crocodiles were thought to form from the mud of the river Nile in Egypt. Rats and mice 'appeared' from old rags, and maggots spontaneously generated from rotting meat (Figure 8.2.16). This idea was not disproved until Louis Pasteur completed his experiments in 1859.

Building on the work of earlier scientists such as Francesco Redi (1626–1697), Louis Pasteur provided enough evidence to convince scientists in Europe that there was a link between germs (bacteria) and disease.

**Figure 8.2.16** Until the nineteenth century, scientists believed that some animals arose spontaneously. They even wrote recipe books for making animals! The theory was finally discredited in 1859, when Louis Pasteur proved it wrong.

8.6 8.7

# 8.2 Unit review

## Remembering

1 **Name** two diseases caused by viruses.

2 **Name** the type of organism that causes malaria.

## Understanding

3 **Describe** the relationship between spores and fungi.

4 **Explain** the role (function) of the host cell in a viral infection.

5 **Outline** how malaria is spread.

6 **Explain** how the virus that causes colds is spread.

7 a **Explain** why taking antibiotics for a viral infection is usually a waste of time.

b **Describe** a situation where it is appropriate for a doctor to prescribe antibiotics for someone with a viral infection.

8 **Explain** why measles caused so many deaths when it was first introduced to the Australian Aboriginal population.

## Applying

9 **Use** diagrams to **demonstrate** how walking barefoot can spread tinea.

## Analysing

10 **Compare** bacteria and viruses.

11 **Contrast** colds and flu.

## Evaluating

12 The mosquito is rated by many as the most dangerous animal on Earth. **Justify** why the mosquito is often considered more dangerous than crocodiles, sharks or lions.

13 Jan and Kai were arguing. Jan said that mosquitoes cause malaria. Kai said that was not a true statement.

a **Evaluate** the statement and decide who is more accurate.

b **Justify** your answer.

14 **Propose** reasons why someone got the flu even though they were vaccinated against it.

15 A family in northern Queensland know that dengue fever is carried by mosquitoes and that there are cases of it their area. **Propose** ways they could protect themselves from the disease.

## Creating

16 **Construct** the scenario (story) for a 30-second television advertisement that makes people aware of how viral or fungal infections are spread, and ways they can prevent the spread.

## Inquiring

1 Investigate the effect of electromagnetic radiation (EMR) on humans and how EMR is used in medicine.

2 Professor Ian Frazer was named Australian of the Year in 2006. Research the reason why he received this award and the benefit to society of his medical research.

3 Gather information about viral diseases such as dengue fever, ebola, Murray Valley encephalitis, Ross River fever, rubella, poliomyelitis and AIDS.

4 A flooring company has developed a new flooring material. They have advertised that it is ideal to use in gyms and in areas surrounding swimming pools because it cannot spread tinea. Design an investigation to test their claim.

5 When people cannot easily wash their hands before eating, they are encouraged to use alcohol-based hand washes. Design an investigation that tests the effectiveness of these products as a means of controlling disease.

# 8.2 Practical activities

## 1 Carried by mosquitoes

This could be a group activity.

### Purpose

To gather information about diseases carried by mosquitoes.

### Materials

- access to the internet and other research materials

### Procedure

Use the internet to find the names of diseases carried by mosquitoes. For these diseases, gather information about:

- symptoms of the disease
- possible treatments and expected outcomes
- number of cases each year
- distribution throughout the world
- any control or eradication programs.

### Results

Create a presentation of your research. This can be in the form of a poster, illustrated talk or PowerPoint presentation.

### Discussion

1. **Describe** the most interesting thing you learned about the disease you studied.
2. **Outline** the advice you would give to people who may be travelling to where that disease is found.
3. After seeing the presentations from other members of your class, **evaluate** your presentation.
   a. What do you think you did well?
   b. How could your presentation be improved?
   c. What positive comments did you receive about your presentation?
   d. If you worked as a group to complete this task, did you work well in the group? Explain.

## 2 Growing fungi

### Purpose

To investigate what causes fruit to rot and to find out if all fruits rot in the same way.

### Materials

- paper towel
- marker pen
- a selection of fruit including:
  - 2 apples
  - 2 pieces of soft fruit such as a strawberry
  - 2 lemons
- 2 plastic boxes such as take-away containers

**SAFETY**

Dispose of all the fruit used in this investigation according to your teacher's instructions.

Wash your hands thoroughly after handling the fruit.

### Procedure

1. Read through all the steps of this procedure before you do anything.
2. Use the marker pen to label the two containers—one with 'Cut fruit', and the other with 'Whole fruit'.
3. Wash all the fruit carefully and pat it dry with the paper towel. Do not bruise the fruit.
4. Place one apple, one of the soft fruits and one lemon into the plastic container labelled 'whole fruit'.
5. Using a clean, sharp knife, make a cut in the skin of the other apple. Wash the knife and then make a cut in the lemon. Be sure to cut through the skin into the segments. Wash the knife and then cut the soft fruit.
6. Place the cut fruit into the container labelled 'cut fruit' cut side up.
7. Leave the fruit in a well-ventilated area for 3 to 5 days.

### Results

1. Write what you predict will happen to the fruit in the two different treatments.
2. Each day, observe the fruit and record any changes in its appearance. You could use photographs to support your notes.

### Discussion

1. **Compare** the changes in the 'whole fruit' with the changes in the 'cut fruit'.
2. **Suggest** what could have caused the changes.
3. **Compare** the changes in the apple and the lemon.
4. **Compare** the changes in the apple and the soft fruit.
5. **Explain** what caused the changes in the fruit.
6. **Explain** why the changes were not the same for all the fruit.

# Chapter review 8

## Remembering

1 **Name** two different types of pathogens.

2 **Recall** the names of two diseases caused by single-celled organisms other than bacteria.

3 **State** the cause of tinea and thrush.

## Understanding

4 **Explain** how washing your hands can protect you from disease.

5 **Outline** ways a viral disease may be transmitted from an infected person to a healthy one.

6 **Explain** the term *contagious*, using one contagious and one non-contagious disease in your explanation.

7 **Explain** how vaccination is able to control the spread of contagious diseases.

8 The skin, gastric juices and mucous membranes are sometimes called the body's first line of defence. **Explain** why this is an appropriate description.

9 **Describe** the role of white blood cells in the immune system.

10 **Explain** the relationship between chickenpox and shingles.

## Applying

11 **Demonstrate** how the following behaviours would protect you from disease.

  a Protect yourself from amoebic dysentery by eating fruit only if it can be peeled before eating.

  b Avoid tinea infection by not sharing towels.

  c Use insect repellent to avoid malaria.

## Analysing

12 **Discuss** the possibility of amoebic dysentery occurring in Australia.

13 **Compare** a neutrophil and a macrophage.

14 **Classify** the following as things that cause disease, or things that are part of the immune system.

pathogens, macrophages, viruses, neutrophils, skin, nose hairs, gastric juices, *Plasmodium*

## Evaluating

15 **Propose** why some vaccinations against viral diseases such as polio give you lifelong immunity, whereas it is recommended that you get a flu vaccination each year.

## Creating

16 **Use** the following ten key words to **construct** a visual summary of the information presented in this chapter.

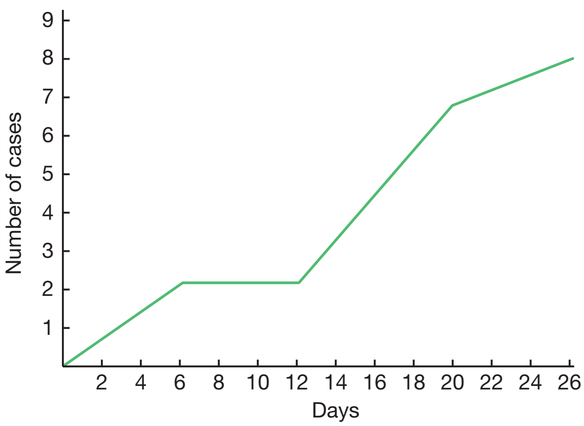
pathogen
infectious
immunity
virus
bacteria
vaccination
antibiotic
antibodies
lymphocytes
disease

8.8

# Thinking scientifically

Questions 1 and 2 refer to the following information.

There was an outbreak of flu in the area, and the local doctor was recording the number of people diagnosed each day. Below is the graph the doctor created.



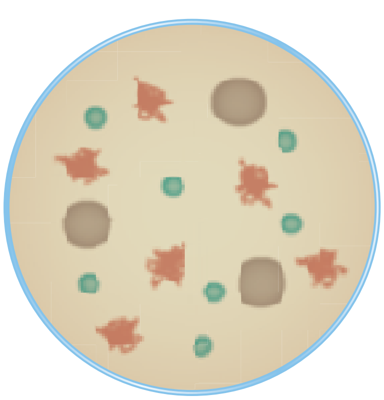

**Q1** Identify the period of time when there were no more cases of flu diagnosed.

**A** days 0 to 6
**B** days 6 to 12
**C** days 12 to 20
**D** days 20 to 26

**Q2** Identify the period of time when the number of cases increased most rapidly.

**A** days 0 to 6
**B** days 6 to 12
**C** days 12 to 20
**D** days 20 to 26

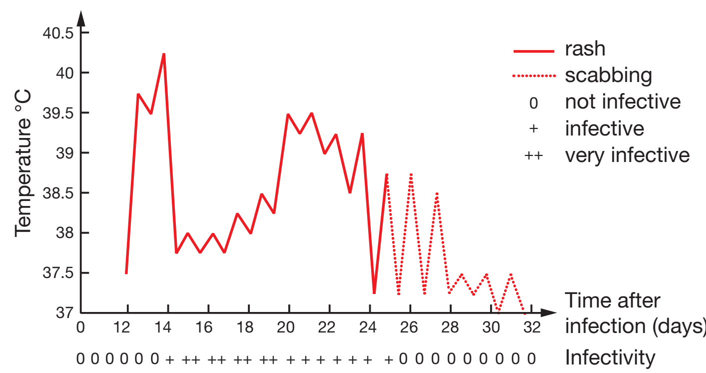
**Q3** A class of students was arguing about the number of colonies of bacteria they had on the agar plate they had exposed on the windowsill of their classroom. Below is a drawing of the plate.



How many bacterial colonies can be seen on the plate?

**A** 3
**B** 6
**C** 7
**D** 10

**Q4** Below is a graph of the temperature of a person suffering from smallpox.




Identify the statement that is consistent with the data presented.

**A** The person was most infective when their temperature was highest.
**B** Once the scabs started to form, the temperature was consistently lower than when the rash was present.
**C** The total rise in temperature from day 12 to day 14 was almost 3°C.
**D** Thirty days after infection, the temperature was consistently back to normal.

**Q5** Bacteria in the mouth can cause bad breath. The bacteria in a mouth were counted before and after using four mouthwashes. The results are given in the table below.

| Mouthwash | Bacterial count | |
|---|---|---|
| | Before | After |
| 1 | 25 | 10 |
| 2 | 80 | 25 |
| 3 | 45 | 6 |
| 4 | 60 | 15 |

Calculate which mouthwash killed the greatest percentage of bacteria.

**A** 1
**B** 2
**C** 3
**D** 4

# Glossary

## Unit 8.1

**Antibiotic:** a substance that kills bacteria or prevents the growth of bacteria

**Antibody:** a chemical made by the immune system that makes it possible for white blood cells to destroy pathogens

**Bacteria:** microscopic, single-celled organisms

**Contagious:** very easy to spread; used to describe a disease

**Disease:** anything that causes our body to stop working properly

**Immune:** able to make the antibodies to a pathogen before it can make you unwell

**Immune system:** the system in your body that fights infections

**Infectious disease:** a disease that can be spread

**Gastroenteritis:** a stomach infection caused by the bacterium *Salmonella enteritidis*

**Lymphocyte:** a white blood cell that makes antibodies and is found in the lymph nodes

**Macrophage:** a white blood cell that consumes pathogens and is found in the lymph nodes

**Neutrophil:** a type of white blood cell that consumes pathogens

**Pathogen:** an organism that causes disease

**Pathogenic bacteria:** bacteria that cause disease

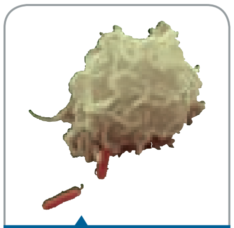
**Penicillin:** an early antibiotic

**Quarantine:** isolation to prevent the spread of a disease

**Tetanus:** a bacterial infection caused by *Clostridium tetani*

**Vaccine:** a chemical that causes your body to react as if it had encountered a pathogen

Infectious disease



Macrophage

## Unit 8.2

**Amoebic dysentery:** an infectious disease spread through contaminated water

**Chickenpox:** a viral disease; symptoms include a rash of small, itchy blisters

**Fungicide:** a chemical that kills fungi

**Host:** the organism a parasite lives in

**Host cell:** a cell that viruses have invaded

**Influenza:** a viral illness; symptoms include high temperature and body aches

**Malaria:** an infectious disease caused by *Plasmodium*; mosquitoes carry the *Plasmodium* parasite

**Measles:** a viral disease that causes a rash

**Parasite:** an organism that lives on or in the body of another organism (the host) and takes nutrients from it; the host gets nothing in return and may be harmed

**Spore:** a single cell with a tough skin that fungi use to spread

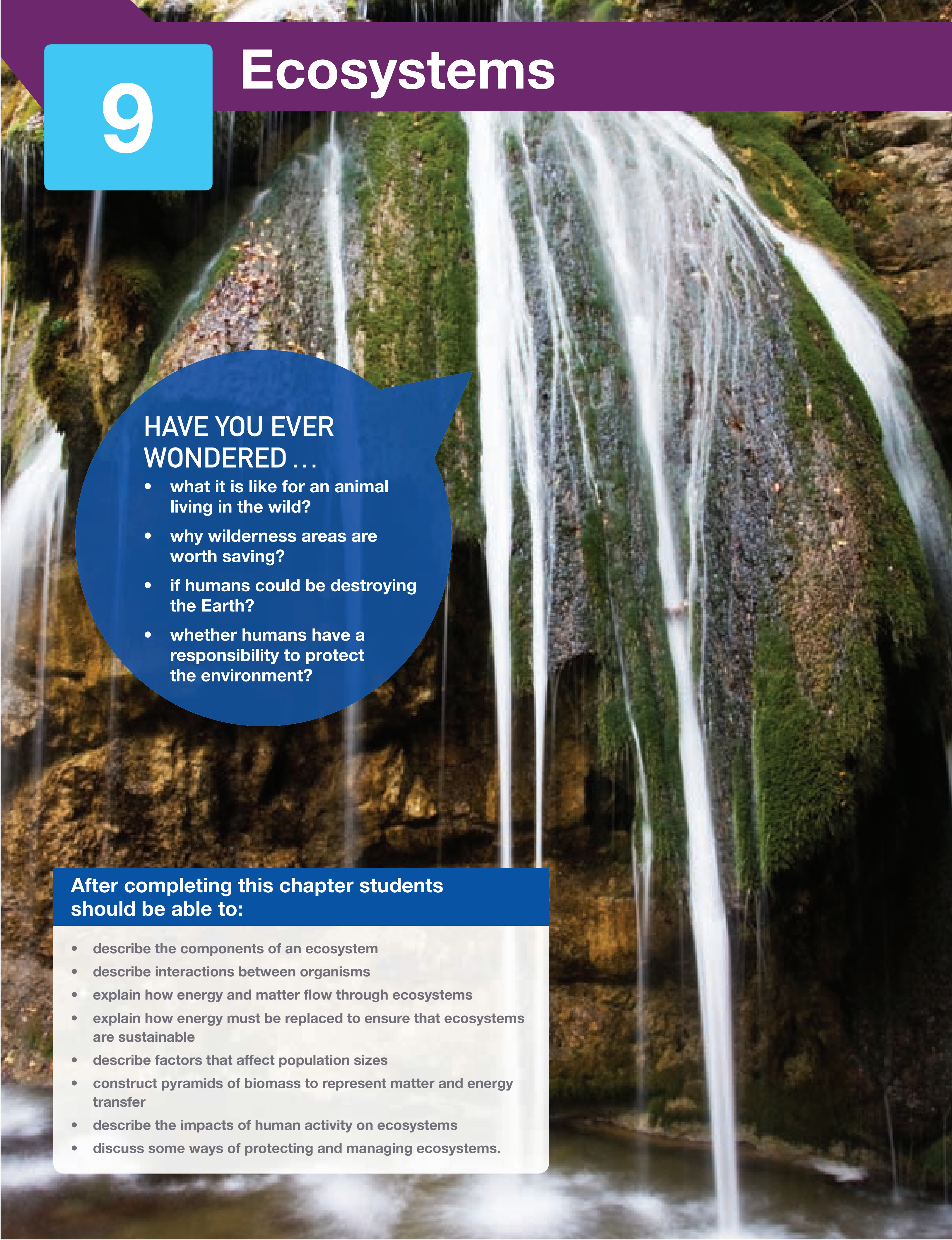
**Thrush:** a common fungal infection inside the mouth or the vagina, or causing nappy rash in babies

**Tinea:** a fungal infection in the skin, hair or nails; often called ringworm

**Virus:** a pathogen about one hundred times smaller than a bacterium

Parasite

Virus



# 9 Ecosystems

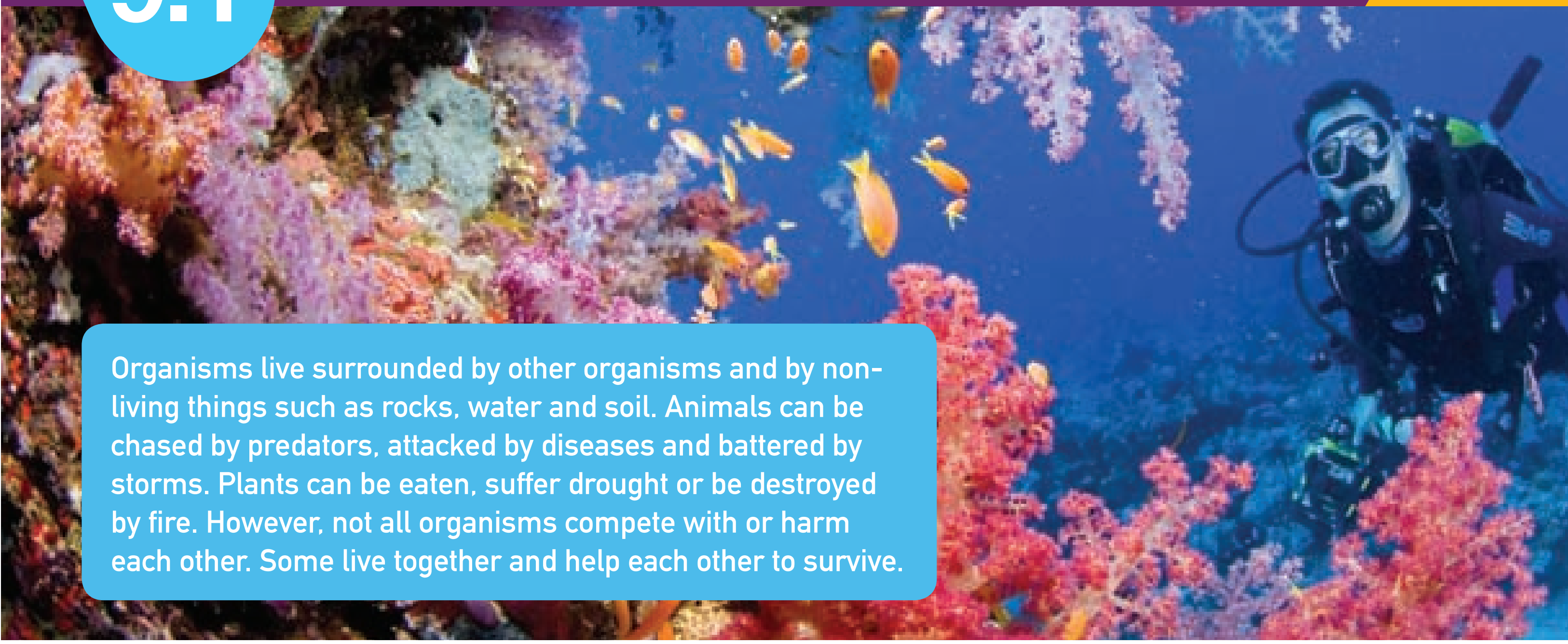
## HAVE YOU EVER WONDERED . . .

- what it is like for an animal living in the wild?
- why wilderness areas are worth saving?
- if humans could be destroying the Earth?
- whether humans have a responsibility to protect the environment?

**After completing this chapter students should be able to:**

- describe the components of an ecosystem
- describe interactions between organisms
- explain how energy and matter flow through ecosystems
- explain how energy must be replaced to ensure that ecosystems are sustainable
- describe factors that affect population sizes
- construct pyramids of biomass to represent matter and energy transfer
- describe the impacts of human activity on ecosystems
- discuss some ways of protecting and managing ecosystems.

# 9.1 Natural ecosystems



Organisms live surrounded by other organisms and by non-living things such as rocks, water and soil. Animals can be chased by predators, attacked by diseases and battered by storms. Plants can be eaten, suffer drought or be destroyed by fire. However, not all organisms compete with or harm each other. Some live together and help each other to survive.

## Interdependence

Living things depend on each other for survival. An example of this is the relationship between termites and microscopic organisms called flagellates (Figure 9.1.1). Termites feed on wood and other tough plant materials. However, they lack the digestive enzymes to digest these materials themselves.

The flagellates live inside the gut of the termites and digest the wood, and the termites absorb these digested nutrients. In return, the flagellates have a moist and stable place to live. The termites and flagellates are **interdependent**—they affect one another's survival.

1 p289

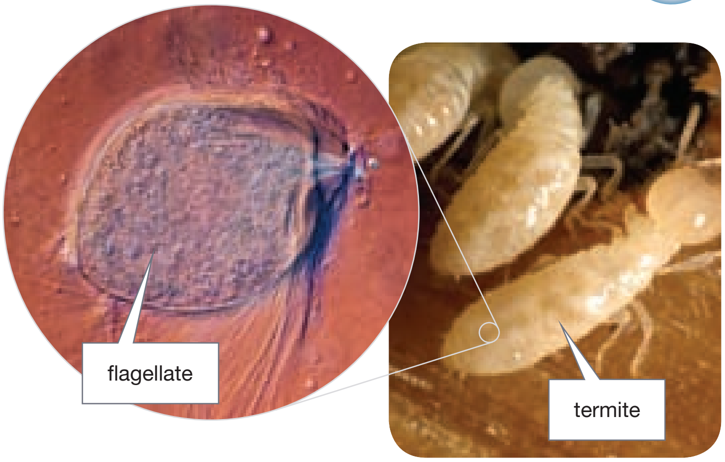



Figure 9.1.1 Flagellates live inside the gut of termites. They are interdependent.

## Ecology

Studies such as those of the termite and the flagellate belong to a sub-branch of biology called ecology. **Ecology** is the study of how organisms interact with each other and with their environment. To interact means to affect each other, in ways that may assist or harm each other. The **environment** consists of all the factors in an organism's surroundings that affect it.

A **habitat** is not the same as an environment. The habitat is simply where an organism lives. The habitat is a place, whereas an environment is a set of factors that affect survival.

## Ecosystems

To help understand how organisms live in a particular environment, ecologists use the concept of an **ecosystem**. An ecosystem is a system formed by a group of living things interacting with each other and their non-living surroundings.

Ecosystems have three main components:

- physical surroundings, such as rocks, soil and water
- living organisms
- living and non-living factors that make up the environment.

An ecosystem is a place where organisms and their physical surroundings form a balanced environment that is different from others nearby. Natural ecosystems can exist on their own. The lake ecoystem in Figure 9.1.2 on page 282 is an example.

Figure 9.1.2 A freshwater lake is an ecosystem.

Humans can create artificial ecosystems such as the aquarium shown in Figure 9.1.3. These ecosystems are usually not balanced. They need to be managed by adding food materials and removing wastes.

Figure 9.1.3 An aquarium is an artificial ecosystem because it cannot survive without human help.

## Factors influencing organisms

Organisms in an ecosystem can be affected by two main sets of factors. One set of factors is due to the actions of living organisms, while the other set is due to the non-living surroundings.

The non-living factors are called **abiotic factors**, also known as **physical factors**. These include water, air quality, the amount of light, temperature, wind, soil type, humidity of the air, tides, waves, lightning and fires.

The living factors are called **biotic factors**. Living factors in the human environment include predators such as sharks, parasites, fungi, infectious organisms, competitors (such as other humans trying to obtain food) and collaborators (such as a breeding partner). Some of these are shown in Figure 9.1.4.

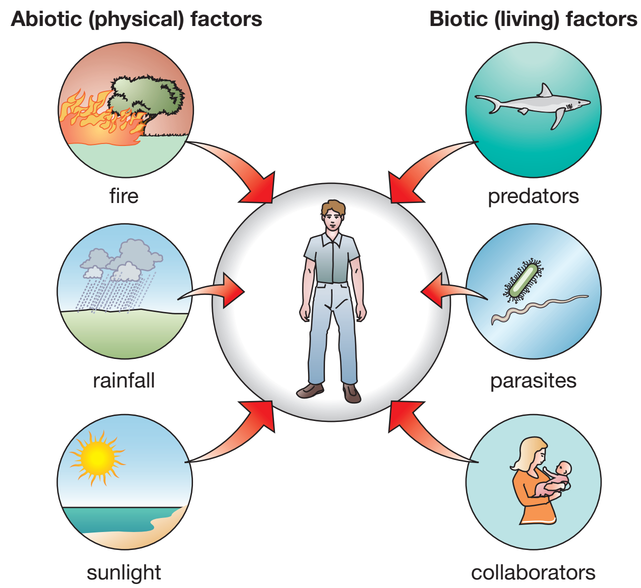



Figure 9.1.4 Abiotic and biotic factors affect all organisms.

## Abiotic factors

### Water

Water is essential for the chemical reactions in the cells of living things. All organisms require water, though not all need to drink it. Some obtain enough water in their food. For land animals, the availability of water is often the most vital factor in survival.

### Temperature

Heat affects the speed of chemical reactions in the cells. The higher the temperature, the faster these reactions take place.

The body temperature of fish, reptiles (like the one in Figure 9.1.5) and amphibians depends on the temperature of the environment. These animals can influence their body temperature in some ways, such as by lying on warm rocks in the sunlight to heat up, or hiding in a burrow if they are too hot. Biologists use the term **ectothermic** to describe these animals, rather than 'cold blooded'. This is because many of these animals are not 'cold' but have body temperatures that vary with the environment. Ectothermic means the organisms must obtain body heat from the environment rather than by generating it internally by body chemistry.

Figure 9.1.5 A reptile's body temperature depends on the temperature of the environment. Its temperature will be very low overnight and on cold mornings, and high after it has been lying in the sunlight.

Birds and mammals like humans and kangaroos are 'warm blooded', or **endothermic**. Endothermic means that the organisms have the ability to generate heat internally and control heat loss to keep their body temperature constant.

2 p289

**SciFile**

**The price of being an endotherm**

Up to 80% of food consumed by an endothermic animal goes to generating heat to maintain a constantly warm body temperature. This means an endothermic animal must find and consume many times more food than a comparable ectothermic animal.

## Fire

Some fires start because of lightning hitting trees, or because of human activity. Australian Aborigines have used fire for many thousands of years to keep the bush open and to improve the growth of plants. They knew that many Australian plants re-grow quickly after fire.

A bushfire like the one in Figure 9.1.6 can kill some plants, but it may help others. Some plants flower better after a fire and some drop their seeds. Many Australian plants will germinate after a fire due to the chemicals released in the smoke.

9.1

Figure 9.1.6 Fire can kill some organisms but help others.

**INQUIRY science 4 fun**

## Fish shapes

Why are fish shaped like they are?

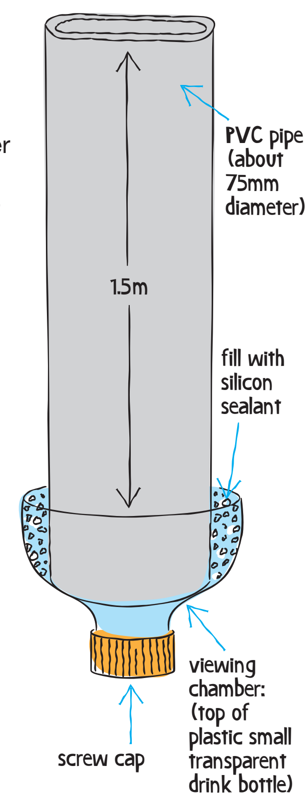
No

### Collect this …

- test container (see diagram)
- plasticine to make fish
- bucket
- timer
- water

### Do this …

1. Make the test container as shown in the diagram. It will need to be 1.5 m in height.
2. Cut five cylinders of plasticine about 2 cm wide by 2 cm long.
3. Use the plasticine to make a fish shape (with tail) and different shapes such as a sphere, cube, pyramid and rectangle. These should all be approximately the same size.
4. Fill the test container with water. Drop the shapes into the top of the container and time how long it takes each to reach the bottom.




### Record this …

**Describe** your results. Use a table.

**Explain** why fish are shaped as they are.

## Light

Light is necessary for photosynthesis. **Photosynthesis** is the process by which plants manufacture their food materials using water, carbon dioxide and light. Changes in the amount of light over the seasons trigger plant growth and flowering in many species.

## Soil type

Soils are not all the same. Some have more nutrients than others and some soils hold water better than others.

## Gas levels

Most organisms require oxygen for respiration. There is usually enough oxygen in the air for organisms, but the amount in water can change greatly. Colder water contains more oxygen than warm water does.

# Biotic factors

Organisms rarely live alone—they are surrounded by other living things including plants, animals and microorganisms. The living things in an ecosystem form a community. Different relationships exist between the organisms in a **community** and these relationships are classified by how the organisms interact.

There are many different interactions between living organisms. These interactions are biotic factors, and they play a major role in the survival of all species. Sometimes organisms assist each other, and sometimes they harm each other.

## Competition

Organisms are said to be in competition when they both try to obtain the same resource, which may only exist in limited amounts. **Competition** occurs between members of the same species (like the chicks shown in Figure 9.1.7), and between different species.

Figure 9.1.7

Baby birds compete with each other for food by trying to attract their mother's attention.

There is only a limited supply of food and resources, and so some individuals will not survive. In natural communities, competition is often fierce. There is a constant struggle for existence, and many die, especially the young, the old and the weak.

## Predation

When one organism kills and eats another, the attacker is called the predator and the one being eaten is called the prey. This feeding relationship is known as **predation**. An example is shown in Figure 9.1.8.

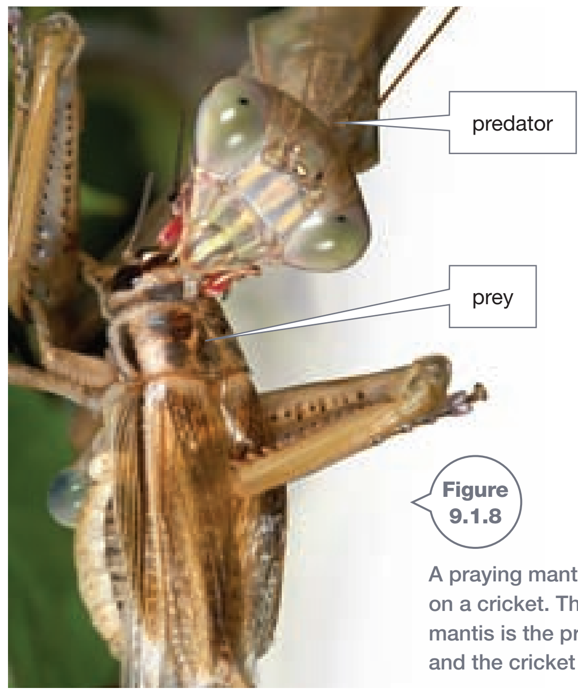



Figure 9.1.8

A praying mantis preying on a cricket. The praying mantis is the predator and the cricket is its prey.

## Mutualism

**Mutualism** is a relationship where two organisms live closely together and both benefit. The flagellates in a termite's guts are a good example. Without the flagellates, the termite would not have any food. The flagellates receive food and the correct temperature and moisture levels for survival. Both organisms depend upon each other.

The cleaner shrimp shown in Figure 9.1.9 eats parasites on the skin of the fish. Both the cleaner shrimp and the fish it cleans of parasites benefit, so this is an example of mutualism.

Pollination is another example of mutualism. Many flowering plants depend on animals (like the honeyeater bird in Figure 9.1.10) to pollinate them. Pollination is the transport of pollen (the male sex cells) to the female parts of the flower.  Pollination results in seeds. Many flowering plants are adapted to use particular animals for pollination, and without them the plants would be unable to reproduce and would eventually die out.

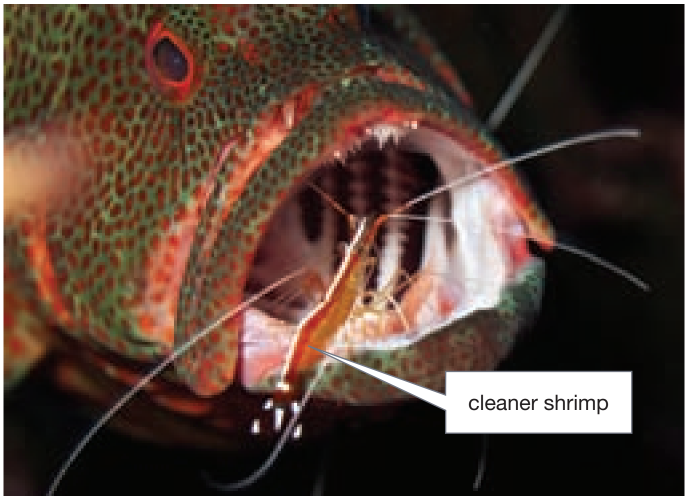



**Figure 9.1.9** Cleaner shrimp and the fish they clean are an example of mutualism.

**Figure 9.1.10** Flowering plants rely on pollinators such as this honeyeater to transfer pollen, which enables the plants to make their seeds.

## Parasitism

**Parasitism** is a relationship where one organism lives on or in another organism (the host) and feeds off it. The parasite cannot survive without the organism in which it lives. The parasite usually harms the host, but rarely kills it. An example is the caterpillar in Figure 9.1.11, which has been attacked by a wasp parasite.

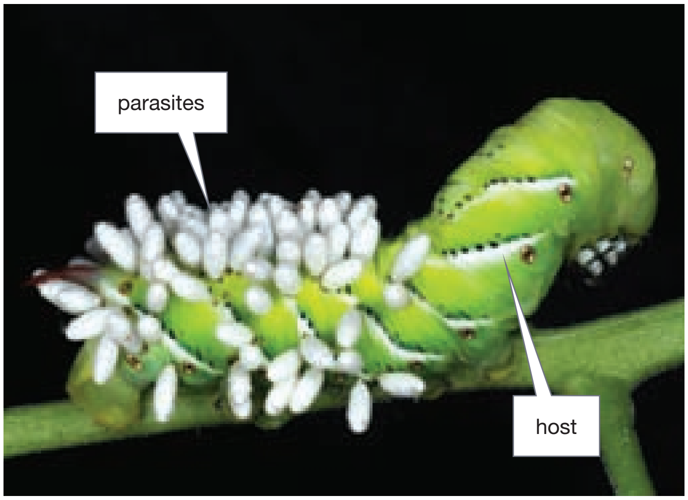



**Figure 9.1.11** A parasitic wasp has layed its eggs on this caterpillar. They will hatch and eat the caterpillar.

**SciFile**

### River blindness

River blindness is caused by a parasitic worm that lives in human eyeballs. The worm is transmitted by a bite from a type of fly called a blackfly. The worm is estimated to have made about half a million people blind.

## Commensalism

**Commensalism** is a relationship where one organism benefits and the other is unaffected. An example is the strawberry poison arrow frog. This South American frog raises its tadpoles in pools of water trapped in bromeliad plants, as shown in Figure 9.1.12. The plant is neither harmed nor receives benefit.

**Figure 9.1.12** The strawberry poison arrow frog raises its tadpoles in pools of water in the leaves of bromeliads.This is an example of commensalism.

## Defining relationships

SKILL BUILDER

Scientists sometimes reclassify relationships as more research is carried out and they learn more about them. An example is the relationship between clownfish and anemones.

Figure 9.1.13 Clownfish in a sea anemone

Anemones are related to jellyfish, and have stinging tentacles. They kill small animals and eat them. The clownfish are immune to the stings and feed on the anemone's leftover food, and receive protection from predators.

**1** Recent research has shown that some anemones grow better if clownfish live in them. So there must be a benefit to those anemones. Some species of clownfish scare away butterfly fish, which can eat anemones. Both the anemone and the clownfish benefit and so the relationship is mutualism.

**2** In aquariums, one type of clownfish catches small fish and drags them over to the anemone. The anemone stings the small fish and kills them. Both the clownfish and the anemone then feed on the dead fish. Both benefit, so once again the relationship is mutualism.

**3** It is not clear whether all clownfish and their anemones show mutualism. Some species of anemones may neither benefit nor be harmed by the clownfish. Only the clownfish is benefiting, and so the relationship is one of commensalism.

# Adaptations

Organisms are able to cope with the biotic and abiotic factors in their environment because they have special features that assist them to survive. These features are called **adaptations**. An adaptation is any feature that assists an organism to survive and reproduce in its environment.

Organisms have adaptations for every activity they engage in. Adaptations are classified as structural, behavioural or functional features of the organism.

## Structural adaptations

A structural adaptation is a body part that helps an organism to survive. For example, a bat has wings for flying. The bat's fingers are very long and form struts to support skin. You can see this in the ghost bat in Figure 9.1.14. This forms a wing, which helps the bat to survive by giving it access to a wide range of food sources. The bats can exploit foods such as flying insects, plant fruits or nectar high in trees.

Figure 9.1.14 A ghost bat's wing is a structural adaptation that allows it to fly.

SciFile

### Ghost bats

Ghost bats are not as efficient at using echolocation as many other bats. Ghost bats hunt mainly using their eyesight and hearing. They have large ears and eyes. These too are structural adaptations.

## Behavioural adaptations

A behavioural adaptation is a feature of an organism's habits, actions or way of life that helps it. For example, the spinifex hopping mouse, shown in Figure 9.1.15, only comes out at night when the air has cooled, so that it does not lose water and dehydrate. The mouse avoids the heat of the day by remaining in its burrow. A burrow is cooler and the air there is humid, with a lot of moisture in the air. This helps to slow the evaporation of moisture from the mouse.

**Figure 9.1.15** The spinifex hopping mouse hides in a burrow during the day, which helps the mouse avoid dehydration.

Dolphins use a behaviour called echolocation. When they want to know what is in the water around them, they emit clicking sounds, as shown in Figure 9.1.16. These sound waves travel through water, reflect off objects and return to the dolphin. The dolphin has the ability to receive these sound waves and form a mental image of the objects around it.

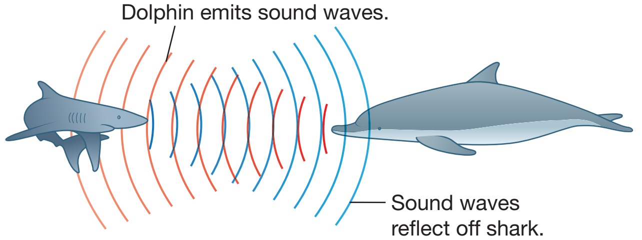



**Figure 9.1.16** Dolphins use a behaviour called echolocation to detect prey and enemies.

**SciFile**

**Sound vision**

Because sound waves can penetrate objects, scientists have concluded that dolphins can 'see' into each other. This would mean that a male dolphin may be able to tell if a female dolphin is pregnant.

The large-eared horseshoe bat (Figure 9.1.17) also echolocates its prey. It sends out high-pitched sounds through its nose, which has a structure called a noseleaf that focuses the sound into a beam. The bat moves its ears and head around to locate the returning sounds that have bounced off its prey. The bat's brain creates a 'picture' in its head of where the prey is located.

**Figure 9.1.17** The large-eared horseshoe bat hunts using echolocation.

## Functional adaptations

9.2

A functional adaptation is a feature of the way an organism's body works. When you exercise, your body automatically makes your heart beat faster so that more blood is supplied to your muscles. This is a functional adaptation, not a behavioural adaptation, because it is controlled automatically—you cannot consciously change it. Functional adaptations are sometimes called physiological adaptations. The science of physiology is concerned with how organisms function. Sports scientists study human physiology.

**Figure 9.1.18** Increasing heart rate is a functional adaptation to allow increased activity.

# 9.1 Unit review

## Remembering

1 **Name** the term that means 'a list of all the factors in an organism's surroundings that affect it'.

2 **List** the three main components of any ecosystem.

3 **List** five different physical, or abiotic, factors that affect organisms.

4 **List** five different types of relationships between organisms.

## Understanding

5 **Explain** why birds and mammals are not affected by cold weather as much as reptiles are.

6 **Explain** how fire can be useful in the Australian bushland.

7 **Define** the following terms.
- a structural adaptation
- b functional adaptation
- c behavioural adaptation

8 **Explain** why honeyeater birds are important to plants.

## Applying

9 Choose an area in your garden at home, or a favourite area of bush. Think about the changes in the physical conditions throughout the year. **Identify** all the physical factors and the changes that occur in them in a year.

10 **Demonstrate** how a eucalypt depends on both its biotic and its abiotic environment.

## Analysing

11 **Compare** a community with an ecosystem.

12 a **Discuss** five biotic factors and five abiotic factors in your environment.
b **Compare** these factors with those for a gorilla.

13 Most of the land animals found in the Arctic and Antarctica are birds or mammals. Few are reptiles or frogs. **Compare** these animals in a way that explains this observation.

## Evaluating

14 a **Classify** each of the relationships listed below.
b **Justify** your answers.
- i falcon and budgerigar
- ii tick and bobtail lizard
- iii human and pet budgerigar
- iv tinea and human
- v lion and cheetah
- vi sheep and bacteria in its gut
- vii rabbits, foxes and wedge-tailed eagles
- viii soldier ant and worker ant in a colony

15 *In Australia, it is said that termites are very important decomposers.* **Use** your knowledge of termites to **critically evaluate** this statement. (*Hint*: Is it really the termites who are the decomposers?)

## Creating

16 **Design** an alien animal. In a drawing, detail ten adaptations (of any type) that could help it survive on a planet where all of the following conditions occur.
- Gravity is ten times greater than Earth's gravity.
- The atmosphere has only 10% oxygen.
- The temperature and sunlight are three times as intense as on Earth.
- The evaporation rate is double that of Earth's hottest desert.

## Inquiring

1 Research a rainforest and sand dunes at the beach. Choose five physical factors that could affect the plants in each place and describe the differences in the factors.

2 Research the adaptations of animals such as the desert hopping mouse to drought conditions in desert regions.

3 Animals can adapt in some amazing ways to avoid being eaten. Research and describe the adaptations of five different animals that help them avoid predation.

4 Design an experiment to test the response of an animal to light. Appropriate animals to test are slaters, mealworms and millipedes.

# 9.1 Practical activities

## 1 Termite guts

### Purpose

To investigate what lives inside termite guts.

### Materials

- termite
- small watchglass
- fine forceps
- 0.6% saline solution (non-iodised salt) in dropper bottle
- petri dish
- microscope slides
- coverslips
- monocular microscope with 40× objective lens
- razor blade
- dissecting needle

**SAFETY**

Be extremely careful with the razor blade, needle and forceps.

Wash your hands carefully after the dissection.

### Procedure

1. This involves killing a termite. If you don't want to do this, ask your teacher to do it. Grasp a termite with fine forceps and drop it into the saline solution in the watchglass.
2. Using the razor blade, remove the termite's head. Hold the thorax with fine forceps and use a dissecting needle to pull out the abdomen and puncture the gut.
3. Place a drop of saline on a slide and dip the gut into it. Then put the gut back in the petri dish. Add a coverslip and observe with a light microscope. Observe first on low power, then on high power with a 40× objective.

### Results

1. Describe the organisms you see and record how many different ones there are.
2. Sketch the different flagellates you find.

### Discussion

**Propose** an explanation for the flagellates in the termite's gut.

## 2 Temperature and activity

### Purpose

To design and conduct an experiment to test the hypothesis that temperature affects the activity of animals.

### Materials

- animals such as slaters, ants, mealworms or other insects
- access to hot and cold water
- ice
- thermometer
- at least four containers such as beakers and petri dishes
- marking pens

### Procedure

1. As part of the planning process, decide which animals you will use in the activity. Remember that you must not harm the animals. To design your experiment, you must consider:
   a. what activity you will measure
   b. how to change the temperature
   c. what equipment you will need.
2. Outline how you will carry out your experiment, how you will collect your data and a list of equipment you will need. Show this to your teacher before you start experimenting.
3. Carry out your experiment and collect your data.

### Results

Present your data in a suitable way and answer the questions below.

### Discussion

1. **Describe** any pattern or patterns you found in the data.
2. **Summarise** the relationship between temperature and animal activity.
3. **Explain** the relationship between temperature and activity.

# 9.2 Sustainability

Most natural ecosystems are sustainable, meaning they maintain living conditions for the community. As long as ecosystems have a supply of matter and energy, and have a fairly large range of species, they can sustain themselves. Each organism in the ecosystem influences others and can be viewed as performing a role for the benefit of the ecosystem.

**INQUIRY science 4 fun**

## Making starch

Do plants make starch in the light?

No

### Collect this …

- leaves from plants that have been growing in the dark and in the light
- iodine solution
- labels for dark and light
- 2 petri dishes
- tripod
- hotplate
- gauze mat
- bench mat
- tweezers
- 2 test-tubes
- methylated spirits
- 100 mL beaker
- starch solution

**SAFETY**

Iodine stains hands and clothes.

Do not breathe the methylated spirits fumes.

Methylated spirits is highly flammable. Keep away from naked flames.

### Do this …

1. Boil about 50 mL of water in a 100 mL beaker. Drop the leaf from the dark into the water for 2 minutes.
2. Take it out and put it in a test-tube with 5 cm of methylated spirits. Plug the test-tube with some cotton wool. Label it ‘Dark’ at the top. Tip out the water from the beaker. (*Careful*: it is hot.)
3. Repeat steps 1 and 2 for the other leaf, but label it ‘Light’.
4. Put the test-tubes into about 70 mL of water in the beaker and boil for 5 minutes.
5. Take out the test-tubes and place the leaves in separate petri dishes. Add 10 drops of iodine solution to each leaf.
6. Put some drops of iodine solution into some starch in a test-tube.

### Record this …

**Describe** what happened.

**Explain** why you think this happened.

## Food in ecosystems

In any ecosystem, food is vital. Food contains the matter and energy required by living organisms. To understand how ecosystems function, it is important to understand the feeding relationships between organisms. Ecologists consider that each organism performs a role in the ecosystem. The organisms do not know they have a role, or that it will support the ecosystem. They are simply trying to survive. However, their interactions result in a balanced system.

### Producers

Every community must have a source of food, which is made by organisms called **producers**. Most producers are green plants such as flowering plants, conifers, moss and algae, though some are bacteria. Producers are essential for the community. Without them there would be no life, because other organisms such as animals and fungi cannot make their own food.

All the organisms that require a ready-made source of food are called **consumers**. Even humans cannot produce food without the help of plants. All the food people ‘make’ comes from plant or animal products. For example, bread comes from wheat seeds. Many animals that we eat (such as chickens and cows) are raised on plant foods. Even some animals that are carnivores (such as tuna fish) are part of a chain of other animals that started with plant eaters. All food was originally made by a producer.

Almost all producers, apart from some bacteria, make food by **photosynthesis**. This is a chemical process that takes place inside cells containing a green pigment called chlorophyll. Photosynthesis is a complicated process of many chemical reactions, but it can be summarised in a word equation as:

$$\text{carbon dioxide + water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose + oxygen}$$

For land plants, the carbon dioxide gas is absorbed from the air, and water is absorbed through the roots. When sunlight falls on the cells containing chlorophyll, the cells start making a sugar called glucose.

**Figure 9.2.1** Trees are producers. They make their food by photosynthesis.

The glucose made by photosynthesis is vital to the plant. It is used to make all the other materials that a plant needs, such as proteins, fats and vitamins. Often the sugar is turned into starch and stored in the leaves until it is needed. Many plants also store starch in seeds. This is why wheat is used to make bread and other foods. Some plants (including most grasses) do not store starch in their leaves.

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## Food chains and webs

In communities, there are sequences, or ‘chains’, of organisms feeding on each other. For example, the koala in Figure 9.2.2 feeds on eucalyptus leaves. Likewise in Figure 9.2.3, grass is eaten by the grasshopper, which may then be eaten by the frog, which in turn may be eaten by the tiger snake. A **food chain** is a sequence of organisms feeding on each other.

Organisms are classified according to their position in food chains. A herbivore (plant-eating animal) is always referred to as a **first-order consumer**. An animal feeding on the herbivore is a **second-order consumer**. In Figure 9.2.3, this is the frog. An animal feeding on a second-order consumer is a **third-order consumer**, and so on. An animal that eats another animal is also referred to as a carnivore.

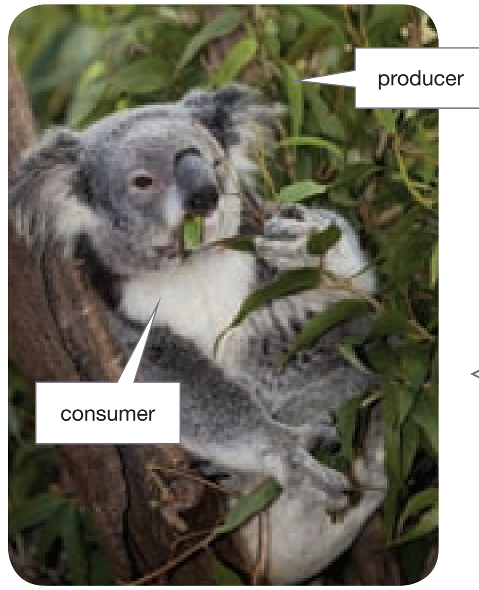


**Figure 9.2.2** Eucalypts make food materials that koalas need.

Food chains help you see that all organisms in a food chain depend on the producer.

To understand what happens to food materials in a food chain, consider Figure 9.2.3. The food materials made by the grass, such as proteins, fats and vitamins, are passed to the grasshopper when it eats the grass. The grasshopper uses these food materials to build and maintain its own body. When the grasshopper is eaten by the frog, the food materials in the grasshopper’s body are used by the frog to build and maintain its body. Similarly, when the frog is eaten by the snake, food materials pass to the snake. So the grasshopper, the frog and the snake all depend on the grass to make the food materials they need. Without grass, the snake has no food.

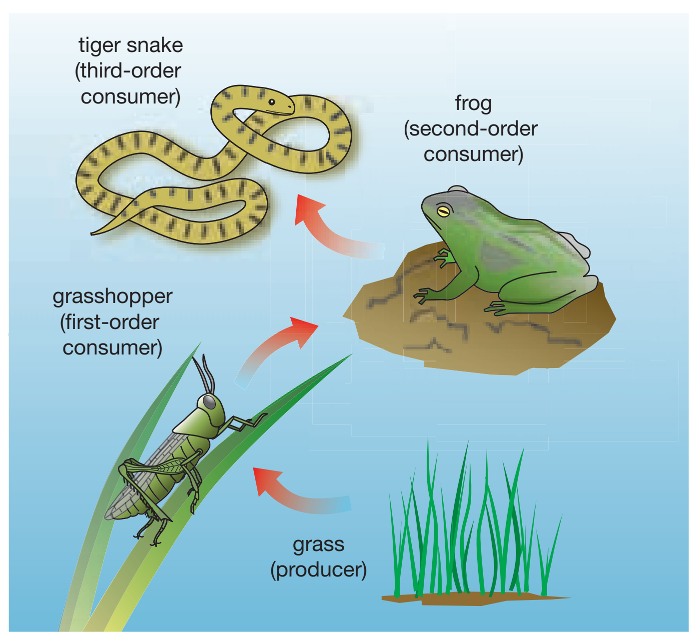


**Figure 9.2.3** A food chain shows the sequence of organisms feeding on each other.

There are many food chains in communities and they are all interconnected. All the connected food chains are known as a **food web**. Food webs are usually complex, with each organism appearing in many food chains. Figure 9.2.4 shows a small part of a food web, which demonstrates that most organisms are in several food chains. The honeyeater is in four food chains, while the bee is in three.

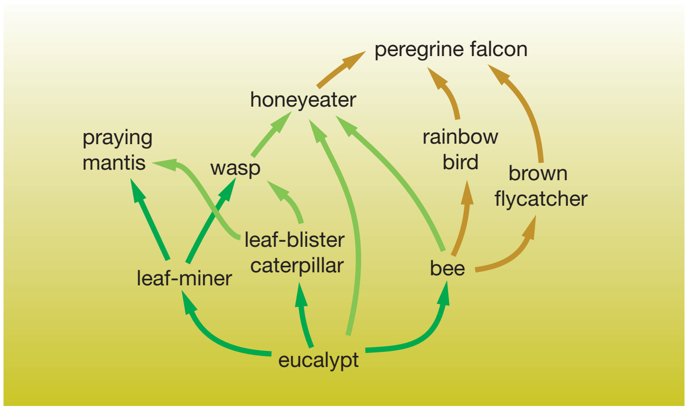


Figure 9.2.4 Part of a food web in a eucalypt woodland community

### Chemosynthesis

Some producers do not use photosynthesis to make food. They use chemosynthesis, which does not require light. These producers are bacteria that can obtain energy from chemicals from volcanic activity. Some live at the bottom of the ocean near underground volcanoes where magma erupts into the sea. This feeds a community that lives in total darkness.

SciFile

## Recycling of matter

A vitally important group of organisms in any ecosystems is the **decomposers**. These organisms are fungi (like the ones in Figure 9.2.5) and bacteria that break down dead bodies and wastes, and recycle matter for the producers to reuse. You can see this process in Figure 9.2.6. Decomposers are vital for the ecosystem to keep functioning. Without them, ecosystems would run out of resources. Decomposers allow matter to cycle in all ecosystems.

Figure 9.2.5 Fungi are important decomposers in an ecosystem.

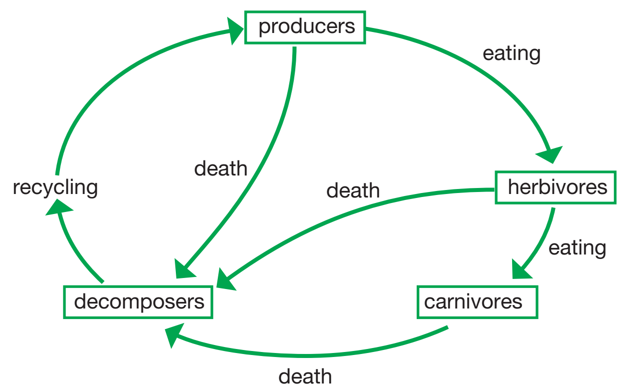


Figure 9.2.6 Decomposers recycle materials back to the physical surroundings for reuse.

## Energy flow in ecosystems

Energy does not cycle through ecosystems like matter does. Energy is said to flow continuously through the ecosystem, being lost as fast as it is gained.

To understand how energy flows through ecosystems, think about what you eat. You eat food for two reasons:

- to build new cells needed for growth and repair
- to provide energy for movement and internal processes.

In ecosystems, energy flows from one organism to another as it is eaten. The food material available to each organism is only that which is in the body cells of the organism it eats. The food materials that an organism has used up for energy are not available to the organism that eats it.

Figure 9.2.7 shows that the energy in 1000 kg of grass in an area of ground can only sustain about 100 kg of grasshoppers feeding on that grass. This is because each grasshopper uses up about 90% of the food for energy, rather than for making chemicals that form part of its body cells.

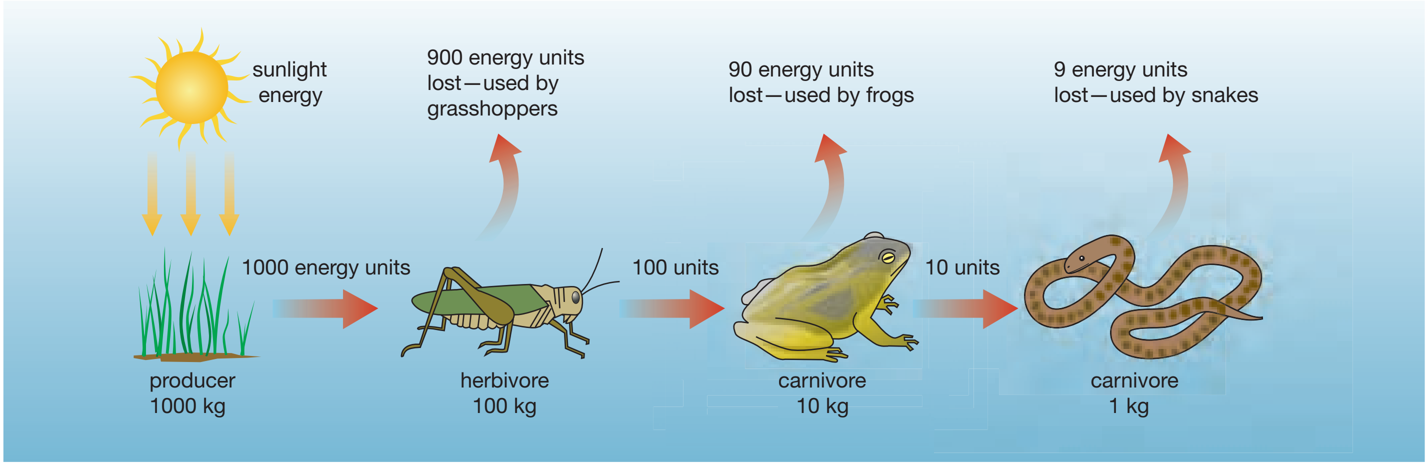


Figure 9.2.7 Energy flow through food chains results in energy losses.

The 100 kg of grasshoppers can only feed about 10 kg of frogs. The frogs use 90% of the food materials to maintain themselves and, again, only about 10% of the energy ends up in the cells of the frogs. The same losses of energy occur when the frogs are eaten by the snakes.

So, the 1000 units of energy originally in the grass ends up as only 1 unit of energy in the snakes. This food chain demonstrates that there is a great loss of energy along food chains.

The progressive loss of energy along food chains explains why the chains are short. There is little energy available to the organisms by the time it reaches the end of the chain. It also explains why there are fewer large organisms like snakes than small animals like insects. The total mass of organisms increases at each successive stage of a food chain.

## Pyramids of biomass

Ecologists construct diagrams called **pyramids of biomass**, which show the total mass of organism at each stage of a food chain. The area of each section represents the mass of organism at each stage. For the food chain in Figure 9.2.7, a pyramid of biomass would look like the one shown in Figure 9.2.8.

Pyramids of biomass are useful, because they allow ecologists to understand the total **productivity** of an area. Productivity means how well it supports life. Pyramids of biomass can be used to compare different ecosystems, and are useful in farming, fisheries, and wildlife conservation.

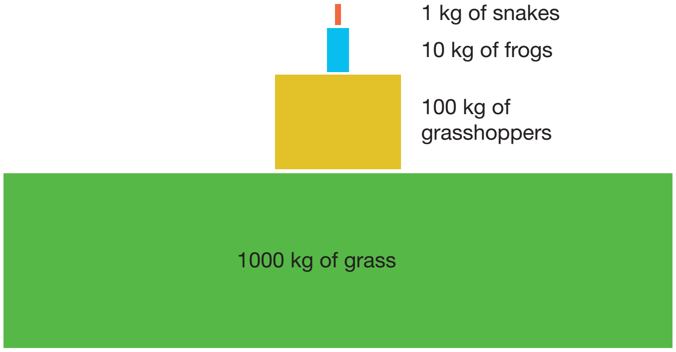


Figure 9.2.8 A pyramid of biomass shows the mass of organisms at each level in a food chain.

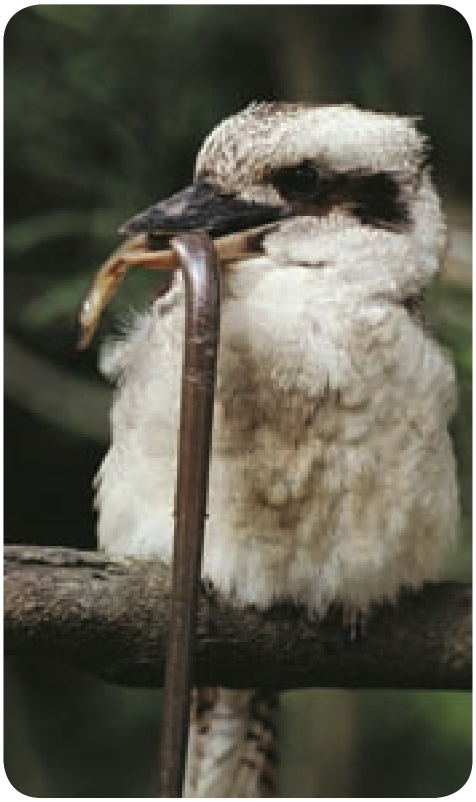

Figure 9.2.9 The kookaburras will have less total energy available in food than the snakes had. There are likely to be fewer kookaburras than snakes in the ecosystem.

9.3

# Biodiversity

**Biodiversity** refers to the range of different species in a community. High biodiversity means a large number of different species in an ecosystem. An ecosystem with many different species is less likely to be disrupted by environmental changes.

There are many reasons why biodiversity enables an ecosystem to remain stable and continue to function. Consider the invasion of an ecosystem by species from other countries, such as weeds invading an area of Australian bush (see Figure 9.2.10). It is much harder for weeds to invade a community that has many species than to invade a community with only a few species. With only a few species, it is likely that weeds could out-compete the native plants for resources. But in a community with many different native species, it is less likely that the weeds will be superior to them all.

Figure 9.2.10 When a foreign species such as this Paterson's curse invades an ecosystem, the ecosystem is more likely to resist the invasion if there are many different species in the ecosystem.

Biodiversity also helps stabilise the ecosystem when physical conditions change. Look at the food web in Figure 9.2.4 on page 292. If there is a change in the weather leading to an unusually heavy flowering of eucalypts, then there may be an increase in the number of bees. This is because more food is available and so more bees can survive. If the number of bees increases, then there is more food for honeyeaters, rainbow birds (Figure 9.2.11) and brown flycatchers. Numbers of these birds increase, and the bee population is gradually reduced again. As the bee numbers start dropping again, it becomes harder for the birds to find food. So the bird numbers decrease as the birds die or migrate away.

Figure 9.2.11 Rainbow birds are predators that eat bees and so affect the population size of bees in an ecosystem.

So the numbers of a predator and its prey tend to change as they affect each other. You can see this in Figure 9.2.12. A rise in prey numbers is followed by a rise in predator numbers. As the predator numbers increase to high levels, the prey numbers decrease. The predator numbers then decrease to very low levels, which triggers another rise in the prey. So the predators seem to control the numbers of its prey.

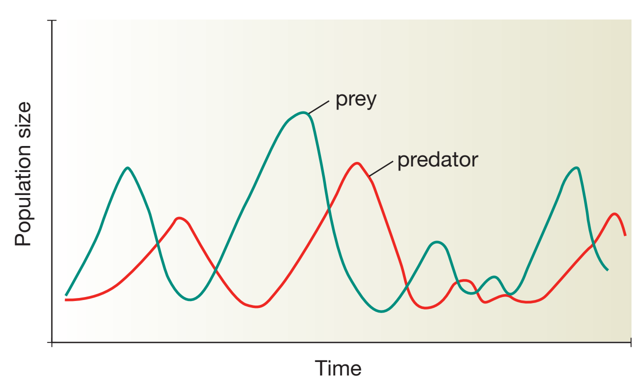


Figure 9.2.12 Predator and prey numbers affect each other.

Food webs with few species are very susceptible to changes in any one of the species. That one species may have been supporting a large part of the food web. In a food web with more species, if one source of food is lost, there will be others available.

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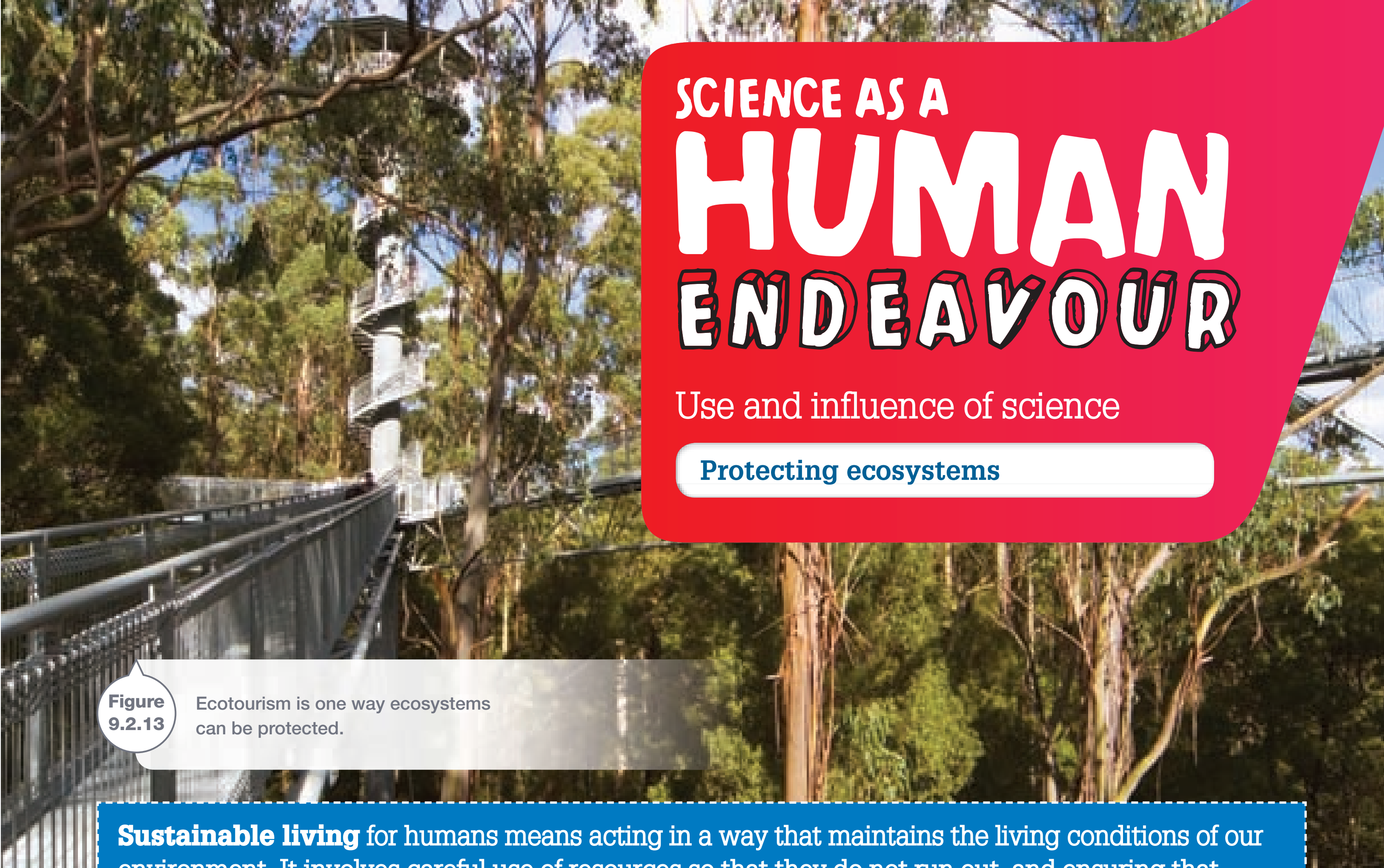


# SCIENCE AS A HUMAN ENDEAVOUR

## Use and influence of science

### Protecting ecosystems

Figure 9.2.13 Ecotourism is one way ecosystems can be protected.

**Sustainable living** for humans means acting in a way that maintains the living conditions of our environment. It involves careful use of resources so that they do not run out, and ensuring that natural ecosystems that keep us alive are not damaged by our actions.

The idea that we should protect our environment rather than just exploit it is fairly new in European and Western civilisations. In the past, few people cared or recognised that the environment was being damaged. Only recently have scientists realised that some civilisations such as Australian Aboriginals and African Bushmen had the balance right between protecting and using the environment.

One recent discovery of ecologists is that there are **keystone species** that are critical to the survival of the whole ecosystem. For example, earthworms enrich the soil and enable plants to grow, and so support all the other organisms. If earthworms were to disappear, the ecosystem would be in danger of collapsing. Research into keystone species is essential if we are to understand how to better manage ecosystems.

Another recent idea for measuring sustainable living is ecological footprint (or 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 Figure 9.2.14 shows, the area of land needed to support each Australian is about 7.5 hectares. The world average is about 2.2 hectares. Ecologists have suggested that Australians need to change how we live, to reduce our ecological footprint to about 2 hectares.

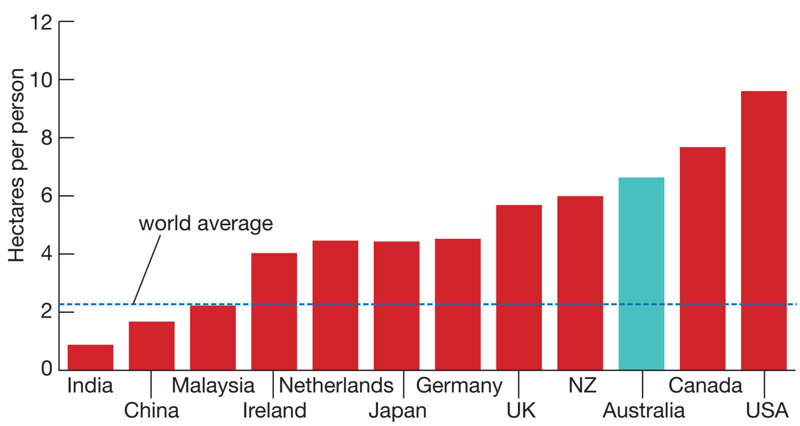



Figure 9.2.14 Australia's ecological footprint is among the highest in the world.

## Why protect ecosystems?

### Compassion

Compassion is humans feeling sympathy for other organisms. The philosophy of compassion is that all organisms have a right to live, and that humans have no right to exterminate any species. It recognises that humans are the only organism on Earth capable of understanding the possible fate of all life. Humans therefore have a responsibility to make wise decisions.

**Figure 9.2.15** This whale became stranded on a beach and was rescued by compassionate humans.

### Cultural value

Some species have a value as part of our culture. They are part of our national view of ourselves. The Australian coat of arms in Figure 9.2.16 has a kangaroo and an emu on it. Imagine how most Australians would feel if these animals were hunted to extinction. Many animals and plants are a source of wonder, interest and enjoyment and would be deeply missed.


**Figure 9.2.16** The Australian coat of arms shows some of the organisms we value as part of our culture.

### Economics

Many previous generations exploited the environment to make money but gave little thought to protecting ecosystems. The concept of the ecosystem was only conceived of in the early twentieth century. Now there is an increased awareness that money can still be made and the environment protected at the same time.

One source of income from ecosystems is tourism. People like to holiday in Australia so they can see the spectacular wildflowers, forests and animals. Australian plants and animals are world famous. This creates many jobs in the tourism industry.

Another source of income is from farming or cropping native species. Conserving commercial species, such as eucalyptus trees, prawns or kangaroos, while still cropping them, ensures that they will always be there to use.

Many useful pharmaceutical drugs have been produced from plants that were previously not used by humans. Conserving species means that new discoveries could be made as new needs arise. Also, certain animals could be possible biological control agents in the future for controlling new pests. In the future, many animals and plants may be used for cross-breeding experiments to improve the health of existing farm animals and crops.

### Survival

It is possible that humans could destroy all life if we continue to over-exploit other species. The survival of humans as a species depends on making smart decisions about the environment. For example, clearing much of the world's forests for timber could reduce the amount of oxygen in the air. If the ocean fisheries are disrupted or destroyed by over-fishing or chemical pollution, then human food resources would be seriously reduced. Clearing trees means that soils are destroyed. Some effects of clearing are soil erosion and salting of land. This alters the soil and reduces the productivity of the land, so less pasture and crops can be grown, and so less food can be produced, and people could starve.

9.4

# 9.2 Unit review

## Remembering

1 **Recall** photosynthesis by writing a word equation.

2 **Name** the term that means:
- a organisms that eat food
- b animals that only eat plants
- c animals that only eat other animals
- d organisms that break down dead bodies and wastes, and recycle material for the producers to reuse
- e animals that feed only on dead organisms.

3 **Name** the term that means:
- a the range of different species in a community
- b managing and protecting ecosystems so they continue to exist
- c species that are critical to the survival of the whole ecosystem
- d the area of land and water required to supply the resources needed for survival and to cope with the wastes produced.

4 **Name** the group of organisms that makes the food for an ecosystem.

5 **List** four arguments in favour of protecting ecosystems.

## Understanding

6 **Explain** why photosynthesis is so important to ecosystems.

7 **Explain** why decomposers are vital for a sustainable natural ecosystem.

8 **Explain** how energy enters an ecosystem, and what happens to it immediately after it enters plants.

9 **Explain** what is meant by *biodiversity* and why it is important to maintain this in an ecosystem.

10 Briefly **discuss** some ways in which protecting natural ecosystems can be worth money.

## Applying

11 **Use** the eucalypt food web in Figure 9.2.4 on page 292 to answer the following questions.
- a **Name** a herbivore.
- b **Name** two first-order consumers.
- c **Name** a carnivore.
- d **Name** two third-order consumers.
- e **List** three different food chains containing the peregrine falcon.
- f **List** three food chains, one containing three organisms, one containing four organisms and one containing five organisms.

12 **Use** Figure 9.2.4 on page 292 to **name**:
- a three animals that compete for bees as a food source
- b two animals that compete for leaf-miners as a food source.

13 **Identify** what level of consumer you are in a food chain when you eat:
- a beef
- b an apple.

14 **Use** a pyramid of biomass to **describe** energy flow for a particular food chain of your choice from Figure 9.2.4 on page 292.

15 **Use** Figure 9.2.7 on page 293 to **calculate** how much energy would be available to eagles that ate snakes.

## Analysing

16 If the amount of wattle in the food web in Figure 9.2.17 on page 298 increased, **discuss** what you think would happen to each of the following populations.
- a leaf hoppers
- b wasps
- c honeyeaters
- d beetles

17 **Contrast** the flow of matter and energy through a natural ecosystem.

## Evaluating

18 **Propose** a reason why producers are not found in caves.

19 Critically **evaluate** the view that forests are mainly useful as a source of timber.

## Creating

20 **Construct** a scientific argument that it is more efficient to feed the world's population on plants than on animals. Use your knowledge of energy flow in ecosystems as part of your argument.

# 9.2 Unit review

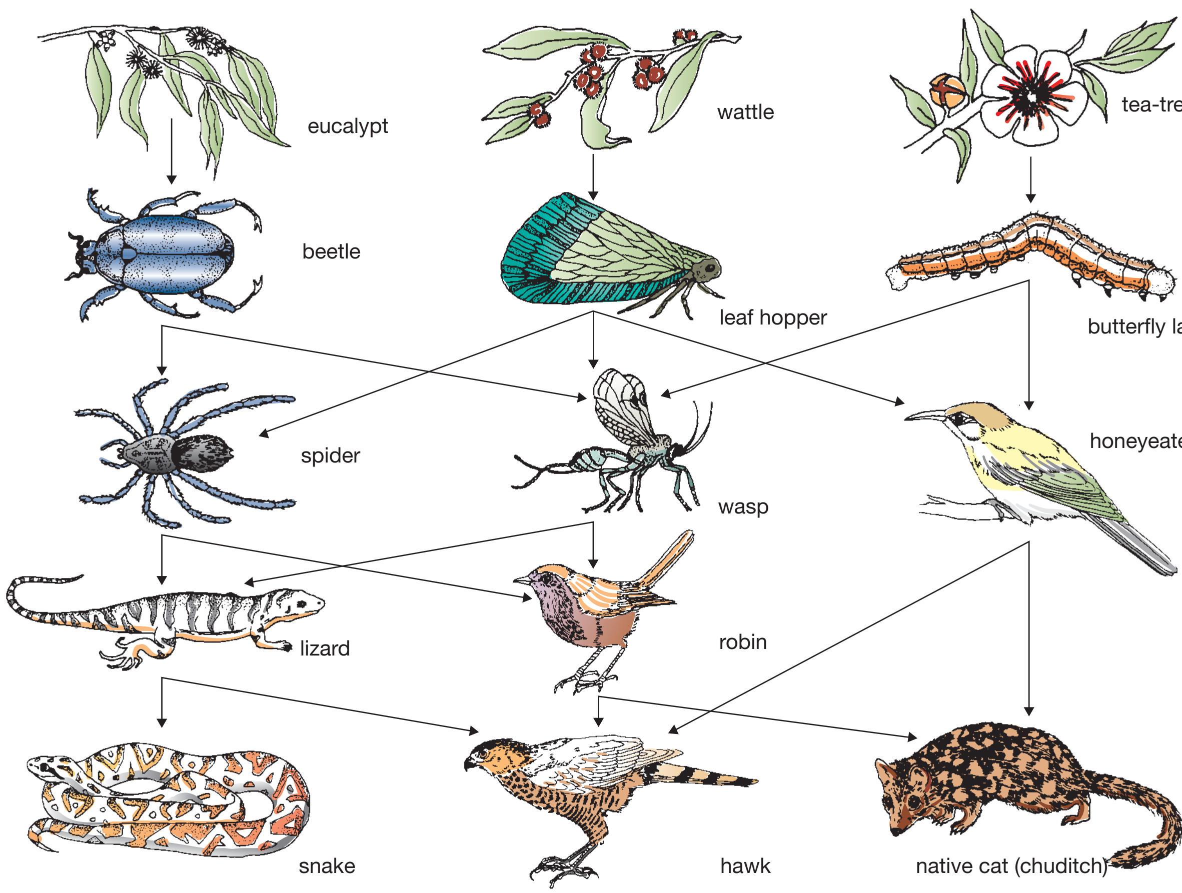



Figure 9.2.17

## Inquiring

1 Research five species, including some threatened plants and animals. For each species:
   a show on a map where it can be found, naming any national parks in the area
   b include a picture of the species
   c state the known population size
   d if it is threatened, state the main reason for its threatened status.

2 Consider the following suggestions from a pamphlet designed to help farmers protect and encourage native animals.
   - Fence off from the stock any native vegetation remaining on the farm on land that cannot be used.
   - Plant many different trees and shrubs native to the area.
   - Leave old trees standing, especially those with hollows in them.
   - Form corridors of vegetation between bushland areas on the farm and neighbouring farms.

   Discuss how each of these suggestions may help protect and encourage native animals in farming areas.

3 Research the relationship that Indigenous Australians have with the land and how their traditional land practices affected the sustainability of ecosystems.

# 9.2 Practical activities

## 1 Photosynthesis

### Purpose

To determine whether carbon dioxide and light are necessary for photosynthesis.

### Materials

- 3 × 250 mL conical flasks and stoppers to fit
- 2 small plants or shoots (e.g. clover, soursob, geranium)
- aluminium foil to cover one conical flask
- 150 mL dilute bromothymol blue solution
- straw
- lamp

**SAFETY**

Bromothymol blue is toxic if swallowed.

Wear safety glasses and avoid contact with skin.

### Procedure

1. Your teacher will blow through the bromothymol blue solution until it turns yellow. This is adding carbon dioxide to the water.
2. Label the flasks 1–3. Add 50 mL of the yellow bromothymol blue to each conical flask.
3. Add a plant to flasks 1 and 3. Stopper all flasks.
4. Wrap flask 3 in aluminium foil so that light cannot enter. Your set-up should look like Figure 9.2.18.
5. Place all three flasks in the light until the next day. If you can, put them in the sun during the day and leave them under a lamp overnight.

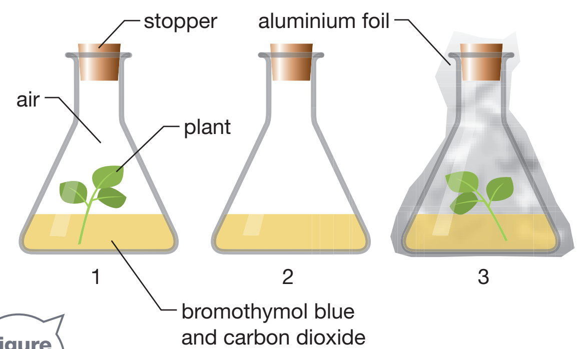



Figure 9.2.18

6. Observe the flasks the next day.

### Results

Record your results in a table.

### Discussion

1. **State** the colour of bromothymol blue when carbon dioxide is present and when it is absent.
2. **Identify** the flasks that had no carbon dioxide left at the end of the experiment.
3. **Compare** flasks 1 and 2. What do you conclude happened?
4. **Compare** flasks 1 and 3. What do these results tell you?
5. **Explain** what this experiment has shown you about photosynthesis.
6. **Explain** how this practical is relevant to understanding ecology.

## 2 Studying a leaf litter environment

### Purpose

To study the community and the physical conditions in a leaf litter environment.

### Materials

- 3 plastic bags
- margarine container
- thermometer
- 2 strips of blue cobalt chloride paper in a plastic bag, or a moisture meter
- binocular microscope
- petri dish
- fine forceps
- mounted needle
- diagram sheet of soil organisms

**SAFETY**

Do not go near long grass or possible hiding places for snakes.

Do not pick up animals with your bare hands, as some may bite or sting. Use containers to pick them up.

Studying a leaf litter environment continues

Studying a leaf litter environment continued

### Procedure

1 Take the bags, margarine container, thermometer, cobalt chloride paper and forceps to an area around the school that has a natural leaf litter cover.

2 Check the air temperature about 1 m above the soil and record it in your notes.

3 Carefully push the end of the thermometer into the leaf litter but not into the soil. Be very careful not to break the thermometer. Record the temperature in your notes. Replace the thermometer in its case.

4 Remove a piece of cobalt chloride paper with forceps and hold it in the air for 1 minute. Record the colour in your notes.

5 Place the other piece of cobalt chloride paper deep in the litter layer for 1 minute and then record its colour in your notes.

6 Quietly observe the surface of the leaf litter for a minute or so. Look for any small invertebrate animals moving near the surface. If you can catch them, put them into one of the bags. Do not try to collect vertebrates like lizards or frogs. Try not to kill any of them.

7 Scrape off some of the fresh litter from the surface and place it in the bag with the animals already collected. Try not to dig down into the lower layers of decaying leaves. Now scrape up the darker decaying litter layer into another bag. Finally, scrape up about half a cup of soil and place it into the third bag.

8 Return to the classroom and use the microscope and books to identify any animals in the three layers. Some leaf litter animals are shown in Figure 9.2.19.

### Discussion

1 **Describe** the main physical conditions of temperature, light and water in the leaf litter layer.

2 Fresh leaves fall each year, but the litter layer tends to stay the same thickness. **Explain** this observation.

3 The breakdown of the leaf litter begins with fungi, bacteria and certain animals. You probably found some animals from each of the following two groups. Choose one animal in each group and **explain** why it lives in the litter.
- Group A: springtails, millipedes, symphylids, bristle tails, earwigs, slaters, white worms, amphipods, mites
- Group B: spiders, centipedes, flatworms, pseudoscorpions, fly larvae, beetle larvae

4 **Explain** why it is necessary to have biodiversity in a leaf litter community.

5 **Explain** how this activity is relevant to our lives.

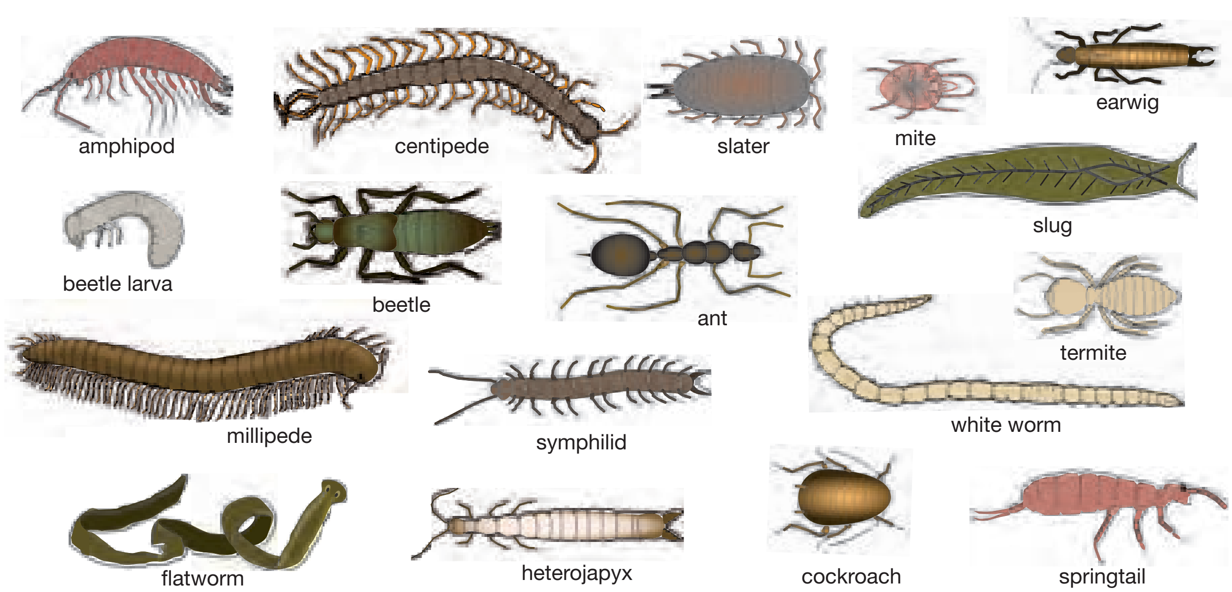



Figure 9.2.19

# 9.3 Natural and human impacts

Natural events such as fire, flood and drought can damage ecosystems, but they can also benefit ecosystems. Humans also affect ecosystems in positive and negative ways. However, it could be argued that humans are a major threat to the ecosystems of Earth. Ecologists have suggested that much of life on Earth could be destroyed unless most of us change how we live.

## Change due to natural events

Many natural events affect ecosystems. As explained in Units 9.1 and 9.2, seasonal changes affect populations through the influence of physical (abiotic) factors. Other natural events such as bushfires, drought and flooding also have a huge impact on ecosystems.

### Bushfires

Some effects of fire have already been discussed in Unit 9.1. **Bushfires** are fires that burn natural vegetation in forests, woodlands and grasslands. They can be lit by humans, but many fires are due to lightning strikes. Evidence suggests that natural fires have been affecting ecosystems in Australia for over 40 million years, while humans have probably only lived here for around 40 000 years.

Fire has a major impact on ecosystems in Australia because it promotes the germination of many plant species. After a fire, the bush regenerates through germination. Many plants are adapted to survive fires and even benefit from fire. Plants such as banksias and hakeas need fire to allow their seed cases to open and release the seeds (Figure 9.3.1). Grass trees and some orchids flower after a fire.

Figure 9.3.1 A bushfire will cause the seed cases of banksias and many other plant species to open up and drop their seeds.

Eucalypts have oils in their leaves that catch fire easily (Figure 9.3.2). Some also have 'stringy' bark that hangs down to the ground, as in Figure 9.3.3. There is a lot of plant litter that falls to the ground, such as dead leaves and bark. These may seem like strange features for a plant to have in an area where bushfires occur. However, helping a fire to spread probably provides an advantage to eucalypts. After a fire, eucalypts can quickly regenerate, whereas other plants may not. This gives eucalypts a competitive advantage in fire-prone areas.

Figure 9.3.2 Eucalyptus leaves catch fire easily because they have glands that make oils. All the light-coloured dots on the leaf are oil glands.

Figure 9.3.3 The bark on this Blue Mountains Ash is stringy and allows fire to rise up into the tree.

Eucalypts are adapted to survive fires in several ways. Having fairly thick bark keeps the growing part of the trunk and branches alive. The thick bark insulates the living cells beneath it against the heat of the fire. After a fire, new growth sprouts from the trunk and branches. All the leaves may have died, so new ones must grow to allow the plant to begin photosynthesising again. This growth is known as **epicormic growth** (see Figure 9.3.4). The new growth of shoots allows the plants to quickly produce food and gain an advantage over other plant species that may have been damaged or killed by the fire. Those species that were killed can only come back into the area by seeds from another area, and this can be a very slow process.

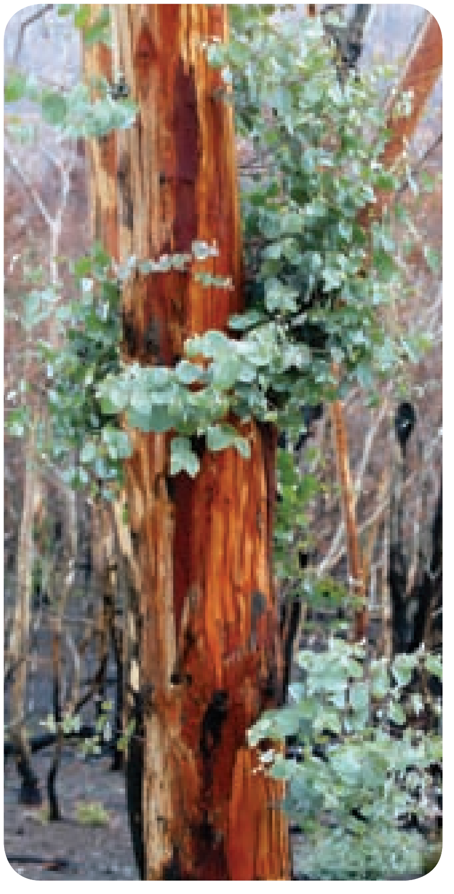


Figure 9.3.4 Epicormic growth is the sprouting of new leaves from the trunks of trees that have been burned and lost all their leaves.

Some eucalypt species have **lignotubers**. Ligontubers are swollen stems under the ground. The branches above the ground may have died in the fire, but those below ground are insulated from the heat and quickly sprout after a fire. Eucalypts that have this feature are called **mallees**. A mallee is shown in Figure 9.3.5.

The effects of fire on animals can vary. Slow-moving animals that cannot escape fires by burrowing or migrating may be killed. The dead are replaced by surrounding populations expanding back into the burnt-out area after the fire. Fire promotes the growth of fresh shoots that are highly nutritious for herbivores, which in turn benefit from the fire.


Figure 9.3.5 The top of the lignotuber, a swollen underground stem, can be seen at the base of this mallee eucalypt.

INQUIRY science 4 fun

## Plants and fire

Would some plants survive a fire better than others?

No

### Collect this …

- hand lens or magnifying glass
- digital camera or mobile phone with a camera
- large plastic bag

### Do this …

1. Find an area where there are many different plants, ranging from trees to low shrubs. (It could be at home or in the school gardens.)
2. Observe the features of at least five different plants that you think could be affected differently by a fire. Look at features such as leaf position and structure, bark thickness and structure, branch height, seed cases, dead leaves and branches, and any other features that look relevant.
3. Take a photo of each plant and try to find out its common or scientific name. If you can't name it, at least record the type of plant. If possible, collect some parts (such as the bark) of the plant that you think could affect its fire resistance.

### Record this …

**Describe** the features of each plant, in a table.

**Explain** why you think the features would be helpful or not helpful to the plant in surviving fire.

## Drought

**Drought** is an extended period of no rainfall in an area. Drought can change ecosystems by increasing the death rate and causing some species to become extinct in an area. Death of plants due to lack of water will remove a resource for animals that use the plants for food, shelter and nesting sites. The animals then either die, as has happened to the kangaroo in Figure 9.3.6, or migrate out of the area.

Figure 9.3.6 Drought is a time when many animals such as this kangaroo die from lack of food and water.

Loss of plant cover in an area can lead to erosion of soil by wind. When the rains do return, water erosion can further damage the land by washing away the soil.

Australia suffers regular droughts. The organisms that live in drought-prone areas are adapted to the conditions. However, years of drought can still cause very high death rates and threaten the long-term survival of species in these areas. There are often extended periods of drought lasting five years or more over wide areas of the country. In these times, only the strongest individuals survive and reproduce.

Some species require regular water, such as river red gums. In times of drought, the rivers do not flow and no longer flood the areas where the gums grow. Many trees die after years of drought and it is possible to lose entire ecosystems.

## Flooding

Floods are events where water temporarily covers land not normally covered by water. Heavy rains can result in rivers overflowing their banks and widespread flooding in some places. In north-eastern Australia in 2011, there were very heavy rains that led to severe flooding, especially in Queensland. Brisbane and several other cities were flooded.

The flooding also greatly affected natural ecosystems and there were high death rates among native plants and animals. Plants drown from lack of oxygen at the roots. Animals can drown or die from exposure.

In drier places, the increased rainfall leads to an 'explosion' of life. Animals and plants in such places are adapted to rapidly reproduce to take advantage of the extra food and favourable living conditions. Aquatic animals hatch from eggs that were buried in the soil and some eggs arrive carried by the wind and migrating animals, such as pelicans that fly in to nest in the area. The pelicans arrive because they can feed their young on the abundant animal life that flourishes during the flooding. One amazing place where this occurs is Lake Eyre in South Australia. Heavy rain in Queensland feeds rivers that flow into Lake Eyre, such as the Warburton River, shown in Figure 9.3.7. This flooding may happen only every ten to twenty years or more. As shown in Figure 9.3.8, the ecosystem can be extremely productive, being able to support large populations such as the pelicans.

**Figure 9.3.7** The Warburton River flows into Lake Eyre but rarely carries enough water into the lake to flood it.

**Figure 9.3.8** Exceptional rains in Eastern Australia in 2011 resulted in flooding of Lake Eyre and an explosion of life in the lake.

# Human impacts

Human impacts on ecosystems include habitat destruction, introduced species, chemical pesticides, chemical pollution and overcropping.

## Habitat destruction

**Habitat destruction** is the damage done to the factors in the environment that an organism depends on for survival. Some examples are land clearing, mining, and logging like that seen in Figure 9.3.9. These activities don't necessarily destroy habitats permanently. Ecosystems can be repaired if there is enough knowledge of the environment and resources available.

**Figure 9.3.9** Land clearing for farms has destroyed much habitat.

Animals such as the bilby, the woylie (brush-tailed bettong, shown in Figure 9.3.10), the rat kangaroo, the potoroo and the Regent honeyeater have declined in numbers as a result of agricultural development. However, some animal populations have increased because of the increased food supply. These animals include kangaroos, locusts and emus.

**Figure 9.3.10** Woylie (brush-tailed bettong) populations have declined, partly due to habitat destruction.

## Introduced species

Animals and plants brought to Australia from other countries are known as **introduced species**. Some of these animals are predators that kill native animals. Some just compete with the native species for food, and others destroy habitat.

Introduced animals that have become established in the wild are referred to as **feral animals**. In particular, domestic cats and foxes (Figure 9.3.11) have had a devastating effect on wildlife.

Figure 9.3.11 Feral cats and foxes are a great threat to native wildlife.

Animals such as rabbits, camels, donkeys, horses, goats, mice, rats and pigs have also been introduced. These can all be found running wild. They compete with native animals for food and shelter, and so fewer native animals survive.

The situation is just as bad with introduced plants. Many of these become weeds and successfully compete with native plants for the limited resources available. Examples are watsonia, blackberry, veldt grass and lantana (Figure 9.3.12). These cover large areas of native bush.

Figure 9.3.12 Lantana has become a problem weed in much of northern Australia.

## Chemical pesticides

Scientists have found that some of the first insecticides (chemicals that kills insects) developed are dangerous to more than just insects. DDT is one example of this. Research in the 1970s found that DDT was present in all the organisms in a food chain, like the one shown in Figure 9.3.13. The amount of DDT increases along the food chain. The reason more DDT was found in the clam than in the plankton was that the clam consumed a great deal of plankton. The DDT in the plankton was nearly all stored in the clam's body, and little was lost during consumption. The gull ate many clams and stored most of the DDT in its body. So the gull contained a high concentration of DDT. Poisons that build up in organisms in this way are called cumulative poisons, because they accumulate.

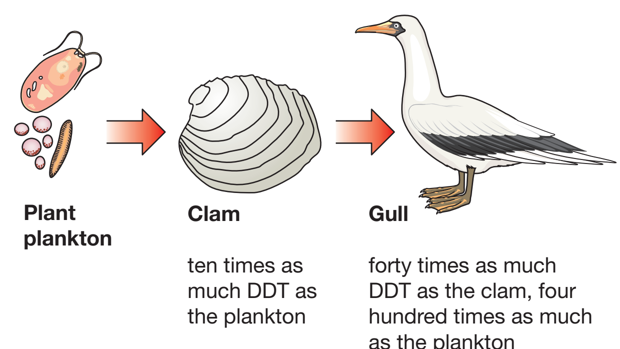



Figure 9.3.13 Food chain showing pesticide accumulation

The accumulated DDT had serious effects on some types of birds, especially those at the end of the food chain (such as peregrine falcons and eagles). DDT caused these birds to lay eggs with thin shells, which broke when the adult sat down to incubate them. So fewer young were produced, and the population decreased as adults died and were not replaced by young.

What really frightened many people was the discovery that DDT accumulated in humans, especially in breast milk. No one knew what effects it might have on human health. Research has since shown that it is linked to many diseases such as cancer, diabetes, hormonal disruption and reproductive problems. DDT use was banned in Australia in 1987. However, many poorer countries continue to use it, particularly those that have a malaria problem. In these countries, DDT levels in breast milk are extremely high.

Not all pesticides accumulate in organisms as DDT does. However, they can still cause problems if they are not used carefully. If the spray drifts away from crops, whether it is sprayed from the ground or from an aircraft (like the one in Figure 9.3.14) or if the farmer sprays at the wrong time, useful insects can also be killed.

Insects such as bees, which pollinate flowers (Figure 9.3.15), or predatory wasps that kill insect pests, can be killed.

Figure 9.3.14 Spraying insecticides on crops should be done carefully, to avoid killing useful insects.

Figure 9.3.15 Pollination of flowers can be affected when insecticides kill bees.

As the chemicals become less effective, larger and larger concentrations are needed to kill the pests. Studies have shown that the insects can now withstand much stronger sprays than when spraying began years ago. The insects have become resistant to the chemicals.

Insects become resistant to these chemicals by a process called natural selection. Natural selection will be covered in your Year 10 course.

9.6

**SciFile**

**Go organic**

Organic farming is based on the idea that many chemicals can cause problems. Organic farmers try to let pests be controlled naturally by the pests' enemies, rather than by using pesticides. The farmers also use recycled animal wastes instead of artificial fertilisers to enrich the soil. Another aim is to reduce contamination of the food by chemicals. Organically grown foods fetch high prices.

## Chemical pollution

Many scientists argue that carbon dioxide is polluting the Earth's atmosphere and causing it to get hotter. There is much debate about whether the temperature of the Earth's atmosphere is rising or not. The terms used are **global warming** and the enhanced greenhouse effect. The general opinion is that the atmosphere is warming.

Increased production of carbon dioxide gas by human activities is thought to be contributing to global warming, but natural facors are also involved.

Figure 9.3.16 Burning reactions release carbon dioxide, a gas that is considered by many scientists to be responsible for global warming through the enhanced greenhouse effect.

Carbon dioxide absorbs some of the heat radiated from the Earth, warming the atmosphere. One group of scientists argue that this effect is tiny, and not important compared with the effect of other gases such as methane and water vapour. Another group argues that it is significant.

The problem with raising the Earth's temperature is that the polar ice caps may melt, causing sea levels to rise.

If the atmosphere is warming, it could also change wind and rainfall patterns. These changes could have large-scale effects on agricultural production and could even result in the extinction of many plant and animal species. Many governments have responded to this problem by trying to limit emissions of greenhouse gases, especially carbon dioxide.

Many other chemicals pollute our environment. Oil spills from ships can cause devastation to sea ecosystems (Figure 9.3.17).

Monitoring our environment to safeguard us against dangerous chemicals is an important job for health authorities and the environmental protection agencies of government.

1 p311 2 p311

Figure 9.3.17 A volunteer helps to save a bird affected by oil from an oil spill.

## Overcropping

**Overcropping** of animal populations means killing more animals than can be replaced by the normal breeding cycle. This results in a decrease in the population. Many of the world's whale populations have declined dramatically as a result of overcropping. The population of the blue whale (shown in Figure 9.3.18) in the 1980s was only about 5 per cent of the population earlier in the century. Blue whales are now totally protected, but populations have recovered very slowly.

One of the important roles for ecologists is to find out how many animals can be removed from a population without endangering the survival of the species. Regulations control how many animals may be taken. These regulations vary for different species.

SciFile

### Minamata disease

In the 1950s, over 100 people living near Minamata Bay in Japan died or suffered nerve damage. A chemical company had released mercury wastes into the bay, and these wastes were accumulating in the food chains in the sea. People eating the local fish absorbed large doses of these mercury compounds.

Figure 9.3.18 Overcropping of whales caused a population decline. This is a blue whale, which was almost hunted to extinction in the 20th century. Numbers of blue whale are still very low.

SCIENCE AS A

# HUMAN ENDEAVOUR

## Use and influence of science

### Aboriginal people, fire and ecosystems

Figure 9.3.19 Fire is used to manage the landscape today, much like it was 50,000 years ago.

**Australia's Aboriginal people have been here for over 50 000 years. There is debate about how their use of fire to improve hunting affected the vegetation and fauna of the country. Research is continuing into the impact this may have had. Burning of the bush was viewed differently by the early Europeans and the Aboriginal people. The early Europeans seem to have been frightened of fires, whereas in some areas the Aboriginal people burned bushland regularly to improve hunting.**

Today, widespread burning is conducted by government departments to protect houses in fire-prone areas. Burning is also conducted to keep the amount of plant litter low, in order to prevent larger fires that could damage the bush as well as properties. Research indicates that keeping plant litter levels low helps in the management of hot fires.

Figure 9.3.20 A painting by Joseph Lycett showing Aboriginal people using fire to hunt in New South Wales in 1817

Figure 9.3.21 An Aboriginal park ranger at Uluru burning the land to prevent wildfires, much like his earlier ancestors did

Research into the effect of fire on native plants such as banksias has revealed that even the earliest plant fossils dating back to 40 million years ago were adapted to fire. Researchers concluded that Aboriginal people could not have affected the characteristics of these plants. However, Aboriginal land management practices may have affected where the plants grew. Most researchers agree that Aboriginal people in many areas of the country used a hunting method called '**firestick farming**'. Fires were deliberately lit at certains times of the year, to create conditions suited to plant regrowth.

The fresh growth attracted herbivorous animals to the area to feed, and made hunting easier. The fire also recycled nutrients back into the soil, which helped rejuvenate the land and made it more productive as a food source for humans. In some areas, small fires were lit to produce smoke, which frightened animals out of the undergowth and made them easier to catch.

Some recent research using satellite imaging of land being managed by the Martu people in the Western Desert has demonstrated that using a regular pattern of small fires changes the plant species that grow in grassland areas. The research showed that the vegetation in areas that had regular small burns is different from areas where lightning strikes started the fires. The main effect was that areas subjected to firestick farming had greater diversity of species. These research results support views proposed by ecologists many decades ago. Early last century, ecologists discovered that fire affects the germination of some species but not others, and that species favoured by fire become more common in areas that are burned.

Some recent evidence contradicts the idea that the use of fire by Aboriginal people had a major impact on the vegetation in forest areas. A research study headed by Dr Scott Mooney from the University of New South Wales looked at 223 sites around Australia and surrounding countries. The study compared charcoal deposits from the past 70 000 years with climate records. The study concluded that the major factor affecting fires was variations in climate between hot and cold periods. Fire activity was high between 70 000 and 28 000 years ago, then decreased between 28 000 and 18 000 years ago. It increased again after 18 000 years ago, and even more after European settlers colonised the country. This evidence seemed to indicate that climate rather than human activity was the main factor in fire history over a long period of time.

Research is continuing, and the debate about burning to control species diversity and to reduce the intensity of fires will probably continue for some time.

9.7

Figure 9.3.22 An Aboriginal man and his son using firesticks to burn off grassland in Arnhem Land, Northern Territory

# 9.3 Unit review

## Remembering

1 **List** two characteristics of eucalypts that result in fires spreading.

2 **List** some ways in which drought and floods affect ecosystems.

3 **State** three examples of habitat destruction.

4 **Name** five introduced species that have caused problems for the native animals and plants in Australia.

5 **State** an example of damage to ecosystems caused by:
  a chemical pesticides
  b chemical pollution.

6 **State** a problem caused by continual use of the same insecticides on a pest species.

## Understanding

7 **Explain** three adaptations of eucalypts that enable them to survive a fire.

8 **Explain** why eucalypts living in places where there are frequent fires could be at an advantage by having features that encourage the fire to spread.

9 **Explain** how drought could lead to damage to the soil.

10 **Explain** how overcropping can lead to the extinction of a species.

11 **Explain** how the clearing of land for farming has affected natural communities.

12 **Explain** how introduced animals (such as rabbits, foxes, cats and wild pigs) affect native animals.

13 **Explain** how the greenhouse effect may cause problems in the future.

## Applying

14 **Use** your knowledge of the effects of fire to **explain** how wattle trees may become more common in an area that is burned frequently.

15 **Demonstrate** that flooding can be an advantage in ecosystems.

16 **Use** your knowledge of food chains to **explain** how a cumulative poison such as DDT that is sprayed onto crops could kill predatory birds, such as eagles.

## Analysing

17 *Salvinia* is a plant that floats on the water surface, spreading rapidly and covering the whole surface of a lake. The weed's roots take oxygen out of the water. Any oxygen produced by photosynthesis in the leaves is released into the air, not the water.
  a **Discuss** whether this weed would cause problems for other plants in the water.
  b **Discuss** why this weed would be a problem for consumers that live in the water.

## Evaluating

18 When cropping native species such as western rock lobsters, there are laws that control:
  - what size the lobsters must be
  - the breeding condition of the lobsters.

  **Justify** how each of these laws may assist in the conservation of the rock lobster.

19 Large areas of the Amazon rainforest are being cut down. **Propose** what effect this could have on the Earth's atmosphere.

20 Australia has laws that count a strip of the seas 12 nautical miles around the Australian continent as our territory. (A nautical mile is equal to 1852 metres.) This area is called Australian Territorial Waters. Our navy intercepts any fishing vessels from overseas that come inside this limit. **Propose** why we do this.

## Creating

21 Many scientists believe that limiting human population growth is necessary to control environmental damage. **Construct** an argument for or against this statement.

## Inquiring

1 Salinity of farmland is a major environmental problem in Australia. Research why farmland is turning salty, and what is being done to try to solve the problem.

2 Survey the pesticides that you have at home. (*Warning*: many pesticides are toxic. Wash your hands if you touch them.) Check insect sprays, cockroach baits, mothballs, etc. Write down the brand names and the name of the chemical ingredients. Search the internet and the labels for information on the toxicity of these substances to humans, pets and wildlife.

# 9.3 Practical activities

## 1 Wastes

### Purpose

To investigate the effect of wastes on water communities.

### Materials

- 5 mL of each of 25%, 50%, 75% and 100% milk solutions
- dry yeast
- teaspoon
- methylene blue indicator solution in a dropper bottle
- 20 mL measuring cylinder
- 5 small test-tubes
- test-tube rack
- 100 mL beaker
- marking pen
- timer with a split button
- stirring rod

### Procedure

1. Mix half a teaspoon of yeast and 20 mL of warm water in the beaker. Leave this to stand. (Yeast is a microorganism that feeds on food materials in the milk. When it has food, it uses oxygen to grow.)
2. Mark each test-tube with a line 1 cm from the bottom and a line 3 cm from the bottom. Number the test-tubes 1–5.
3. Pour the 100% milk solution into test-tube 1 up to the 1 cm mark.
4. Repeat the process with the 75%, 50% and 25% milk solutions in test-tubes 2–4 respectively.
5. In test-tube 5 place tap water up to the 1 cm mark.
6. Add 8 drops of methylene blue to each tube and mix well. The tubes should appear blue because there is plenty of oxygen in the water. Methylene blue turns colourless when there is no oxygen.
7. Pour the yeast solution into each test-tube up to the 3 cm mark and mix each test-tube well. Do this as quickly as possible. Each tube should be done at the same time. If this is not possible, then record the time when each tube was mixed.
8. Use the split button on the timer to record how long each tube takes to lose its blue colour. Record this in a suitable table.

### Discussion

1. **Explain** what caused the colour change from blue to colourless.
2. **Describe** the relationship between milk concentration and time taken to lose the blue colour in the test-tube.
3. **Explain** what could happen in a swamp ecosystem if human food wastes got into the water and the microorganisms reacted like the yeast in this practical.

## 2 Detergents and plants

### Purpose

To design an experiment to investigate whether pollution with detergent could affect the health of water plants.

### Materials

- materials as requested by students

### Procedure

1. Researchers suspect that water plants could be damaged by detergents entering our waterways. In your group, your task is to design a way of testing whether this is true.
2. In your group, decide on aspects of your design, such as:
   a. how you will decide that plant health is damaged
   b. how you will apply the detegent and how much you will use
   c. how many plants to use and how long the experiment will last.
3. When you have done some research, draw a diagram of your set-up and show it to your teacher. Carry out your experiment if the teacher agrees.

### Results

Collect all the results in the class.

### Discussion

**Evaluate** the results of your experiment and present a report on your experiment.

# 9 Chapter review

## Remembering

1 **List** the components of an ecosystem.

2 **List** the major ways in which humans are damaging the environment.

3 a **Name** five feral animals in Australia.
b **Specify** the type of damage they do in ecosystems.

## Understanding

4 **Explain** why biodiversity is important.

5 **Explain** why all organisms in an ecosystem are interdependent.

6 **Discuss** ways of protecting and managing ecosystems.

7 **Discuss** why it is important to protect ecosystems.

8 **Explain** why termites are important in Australian ecosystems, and how they manage to perform their role.

9 **Explain** how seasonal changes in temperature, water availablity and sunlight can affect ecosystems.

## Applying

10 a **Identify** five biotic factors and five abiotic factors that affect you.
b **Explain** how they affect you.

11 **Use** your knowledge of energy in ecosystems and of pyramids of biomass to **explain** why food chains are usually fairly short, with perhaps only four levels of consumer.

12 A dingo and a wedge-tailed eagle both prey on rabbits. The dingo is infested with fleas. **Use** the following terms to **identify** the relationships between these four animals: parasitism, predation and competition.

## Analysing

13 **Compare** the effect that any two biotic and abiotic factors have on you and a plant in your garden.

14 Choose an ecosystem close to where you live.
a From your knowledge, **name** two different species of animals in the ecosystem.
b **Identify** an environmental factor that you think must affect the two species.
c **Compare** how the two species are adapted to that particular environmental factor.

15 a **Compare** the concepts of sustainability and protection of the environment (conservation).
b **Discuss** how they are interdependent.

16 The ecological footprint for Australia is about nine times greater than that for India. **Analyse** what this means for the sustainability of our lifestyles in Australia.

17 Figure 9.4.1 shows the changes in oxygen content in a lake. Assume temperature changes had minimal effect on oxygen solubility. **Interpret** the changes in oxygen content over the 24 hours.

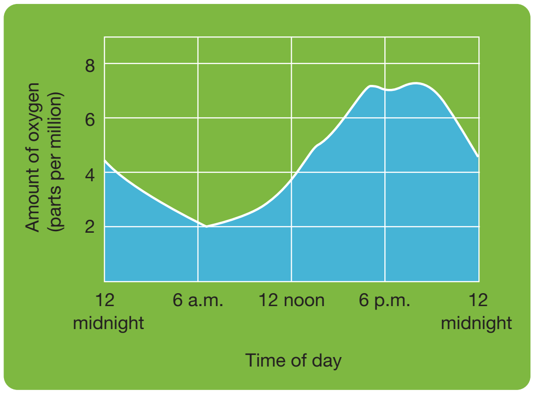



Figure 9.4.1

18 a **Compare** the ghost bat (Figure 9.1.15 on page 286) and the large-eared horseshoe bat (Figure 9.1.18 on page 287).
b **Describe** any differences you see in their heads and relate this to how efficient they probably are at echolocation.

## Evaluating

19 **Justify** the argument that photosynthesis is the most important process in ecosystems.

## Creating

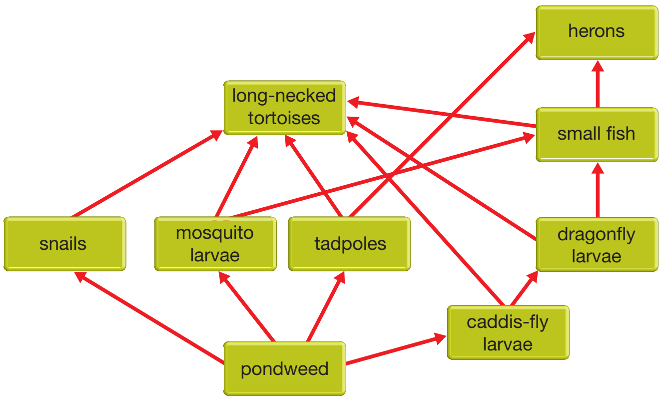
20 **Design** an experiment to test whether tomato plants or basil plants, when grown together, are affected more by competition than if they are grown apart.

21 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

| | |
|---|---|
| biotic factors | abiotic factors |
| environment | adaptations |
| structure suits function | food webs |
| biodiversity | conservation |
| human impacts | natural impacts |

# Thinking scientifically

Questions 1 to 4 are based upon the following food web.




**Q1** Identify which of the relationships in the following table is correct.

| Answer | Predation | Competition |
|---|---|---|
| **A** | Small fish and mosquito larvae | Tadpoles and dragonfly larvae |
| **B** | Snails and pondweed | Heron and small fish |
| **C** | Heron and small fish | Heron and long-necked tortoise |
| **D** | Long-necked tortoise and tadpoles | Tadpoles and small fish |

**Q2** If the lake was sprayed to control mosquitoes, identify the most likely effect.

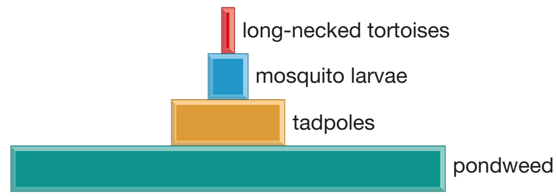
**A** The biomass of pondweed would decrease.
**B** The tadpole population would decrease.
**C** Most of the herons would migrate out of the area.
**D** The population of small fish would decrease.

**Q3** If a disease killed most of the long-necked tortoises, identify a likely short-term change in the ecosystem.

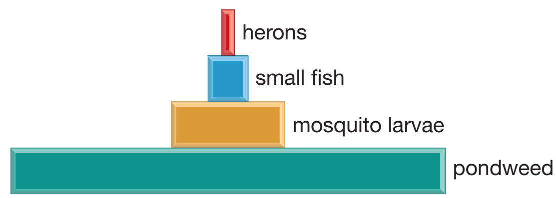
**A** rapid increase in the numbers of small fish
**B** decrease in the numbers of heron
**C** rapid increase in the biomass of pondweed
**D** no change in the biomass of caddis-fly larvae

**Q4** Identify which of the following is a correct pyramid of biomass that could be drawn for this ecosystem.

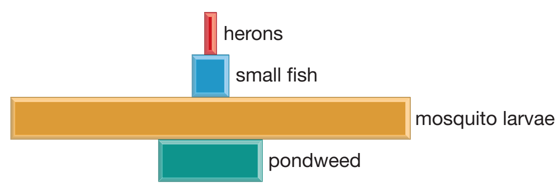
**A**



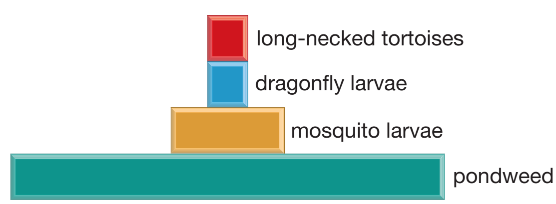

**B**




**C**




**D**



# Glossary

## Unit 9.1

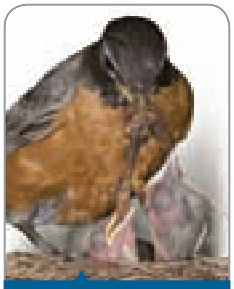
**Adaptation:** a feature that an organism has that enables it to survive

**Abiotic factor:** a non-living factor of the environment

**Biotic factor:** a living factor of the environment

**Commensalism:** relationship between two organisms, where one benefits and the other is unharmed

**Community:** all the living organisms in an ecosytem



Competition

**Competition:** relationship between organisms that are trying to use the same limited resource

**Ecology:** the study of how organisms interact with each other and with their environment

**Ecosystem:** a place where organisms and their physical surroundings form a balanced environment that is different from others nearby

**Ectothermic:** animals that obtain body heat from outside their body

**Endothermic:** animals that can generate body heat internally

**Environment:** all the factors in an organism's surroundings that affect it

**Habitat:** where an organism lives

**Interdependence:** relationship between organisms, where each affects the other's survival

Mutualism

**Mutualism:** relationship between two organisms living closely together, where each benefits the other

**Parasitism:** relationship between two organisms, where one organism lives on or in the other and feeds off it

**Photosynthesis:** the process by which plants make their food

**Physical factor:** a non-living factor (also called abiotic)

**Predation:** relationship between two organisms, where one organism kills and eats the other

## Unit 9.2

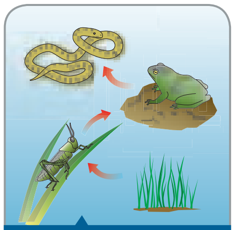
**Biodiversity:** the range of different species in a community

**Consumers:** organisms that require a ready-made source of food

**Decomposers:** organisms such as some bacteria that break down the bodies of dead organisms and animals wastes and recycle material

**Ecological footprint:** the area of land and water needed to provide resources necessary for survival

**First-order consumer:** in a food chain, the position of a herbivore



Food chain

**Food chain:** a sequence of organisms feeding on each other

**Food web:** all the linked food chains in an ecosystem

**Keystone species:** species that are critical to the survival of an entire ecosystem

**Producers:** organisms that make food for the community

**Productivity:** how well an area supports life

**Pyramid of biomass:** a diagram that shows the total mass of organisms at each stage of a food chain

**Second-order consumer:** the animal feeding on the first-order consumer

**Sustainable living:** for humans, living in a way that ensures that resources do not run out and the natural ecosystems are not damaged

**Third-order consumer:** the animal feeding on the second-order consumer

## Unit 9.3

**Bushfire:** a fire that burns natural vegetation in forests, woodland or grassland

**Chemical pollution:** chemicals escaping into the environment that can damage ecosystems

**Drought:** an extended period of no rainfall in an area, even in seasons when it normally rains

**Epicormic growth:** growth of new shoots from the stems of trees and shrubs after fires

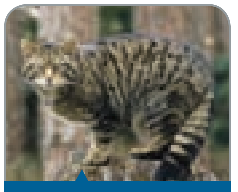
**Feral animal:** an introduced species of animal that has become established in the wild

**Firestick farming:** a hunting method used by Australian Aboriginal people, in which vegetation is burned to flush out animals and to rejuvenate the land

**Flood:** an event where water covers the land and does not soak in for a long time

**Global warming:** the increase in the temperature of the Earth's atmosphere

**Habitat destruction:** damage caused to the factors in the environment that an organism depends on for survival



Introduced species

**Introduced species:** animals and plants brought to Australia from other countries

**Lignotuber:** a swollen underground stem of eucalypts that can resist fire

**Mallee:** a type of eucalypt that has lignotubers

**Overcropping:** killing more animals than the population can replace by its normal breeding cycle

**Overpopulation:** when there are too many of a species for the ecosystem to support them and remain sustainable

# Plate tectonics

# 10

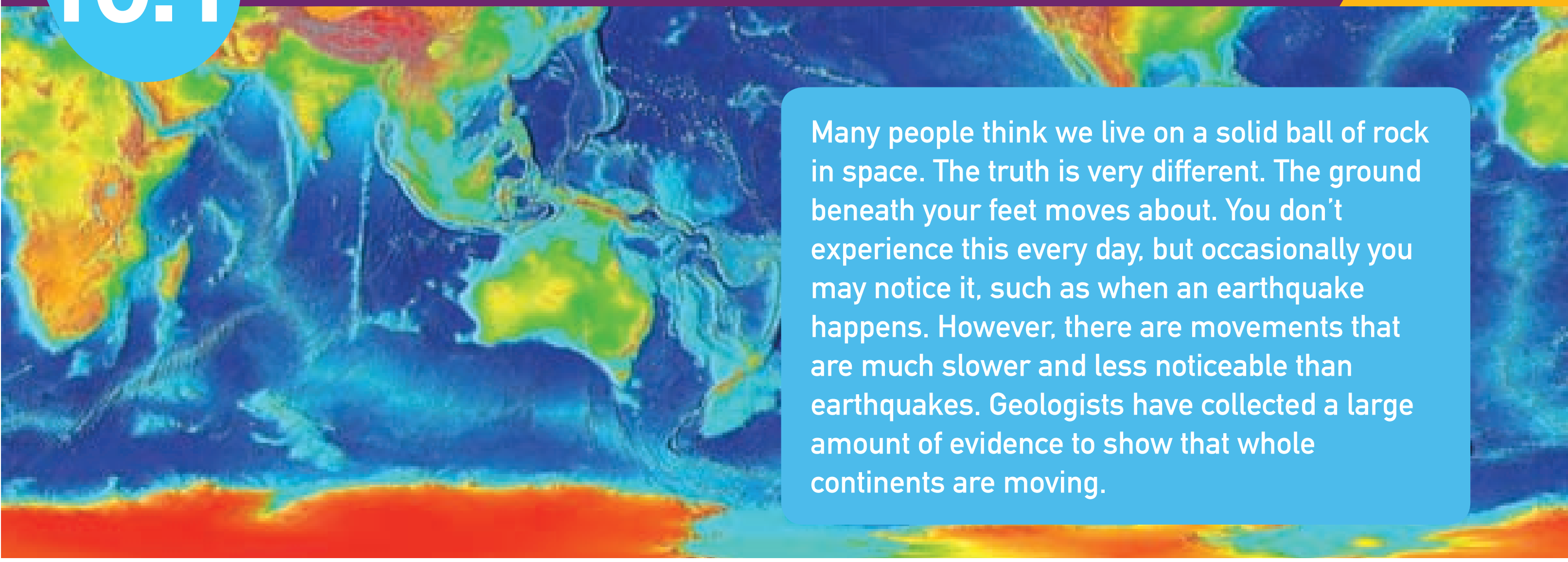
## HAVE YOU EVER WONDERED …

- why earthquakes happen?
- why volcanoes exist?
- what causes tsunamis?
- why volcanoes are found in some places and not others?
- what makes mountains form?

## After completing this chapter students should be able to:

- identify the major plates on a world map
- explain seafloor spreading
- describe how earthquakes and volcanoes are related to movement at plate boundaries
- explain the role of heat energy and convection in plate movement
- discuss and evaluate evidence that supports the theory of plate tectonics
- use plate tectonics to explain why Australia is geologically old and stable
- outline how the theory of plate tectonics developed
- describe modern technologies used in mapping plate movements
- describe how living near plate boundaries affects people's lives.

# 10.1 Moving continents



Many people think we live on a solid ball of rock in space. The truth is very different. The ground beneath your feet moves about. You don't experience this every day, but occasionally you may notice it, such as when an earthquake happens. However, there are movements that are much slower and less noticeable than earthquakes. Geologists have collected a large amount of evidence to show that whole continents are moving.

## Continental drift

A revolutionary new theory about the Earth was proposed between 1912 and 1915. Alfred Wegener, a German meteorologist and geophysicist, claimed that the continents were once connected to each other. He called the large landmass Pangaea, and concluded that the continents must somehow have separated and be drifting across the oceans. The theory was called **continental drift.** At the time, most people thought the idea could not possibly be correct.

Wegener based his conclusions on two main observations. The first observation was that the continents seemed to fit together like a jigsaw (Figure 10.1.1).


Figure 10.1.1 Africa and South America seem to fit together.

Wegener's second observation was that fossils of the same species were found on continents that were a long way apart. He could see no way the organisms could cross the oceans to reach all these places. Instead, he thought that the continents themselves had shifted. As they did so, they took the fossils with them. Wegener rearranged the continents to join them up so that the distribution of the fossils matched up across the continents. This can be seen in Figure 10.1.2.

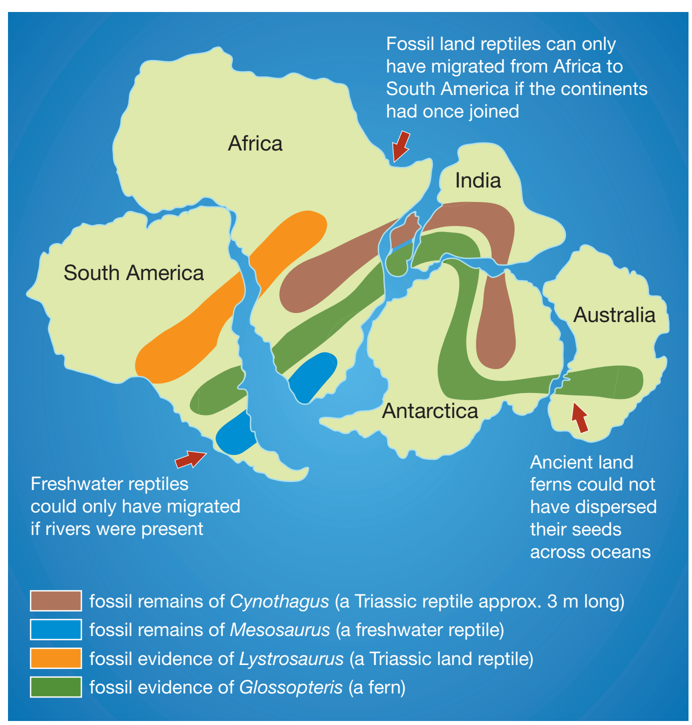



Figure 10.1.2 Fossil distribution makes sense if the continents were connected as shown here.

Few scientists believed Wegener was correct. The main reason was that there was no mechanism known by which huge continents could move. There was also no way of measuring whether the continents moved or not. Wegener died in 1930, before the discovery of new evidence that would prove him correct.

10.1

## Seafloor spreading

In 1872, scientists were surveying for an undersea cable. They did this by dropping down very long cables and measuring their length. They discovered a large mountain ridge in the middle of the Atlantic Ocean. The ridge was found to extend a long way in the South Atlantic, but the extent of the ridge was not investigated. In 1925, sonar studies by German scientists confirmed that this ridge existed and ran the length of the Atlantic Ocean.

After World War II, further studies showed that the underwater ridge continued into other oceans and right around the Earth. In 1953, the ridges were found to have a huge series of cracks (called rifts) in their centres. The system was then named the Great Global Rift system. You can see some of it in Figure 10.1.3.

In 1962, Harry Hess, an American geologist, tried to explain what was happening at the ocean ridges. He was interested because during World War II he had discovered many flat-topped mountains under the Pacific Ocean. When the Great Global Rift was discovered, he thought back to his discoveries of the undersea mountains.

Hess proposed that new rocky crust was being formed at the ocean ridges and spreading outwards. This process was later called **seafloor spreading**. Hess proposed that the crust was sinking down into the Earth in other places, called **ocean trenches**. The process of the crust sinking down is called **subduction**. You can see these processes of forming new crust and destroying it in Figure 10.1.4.

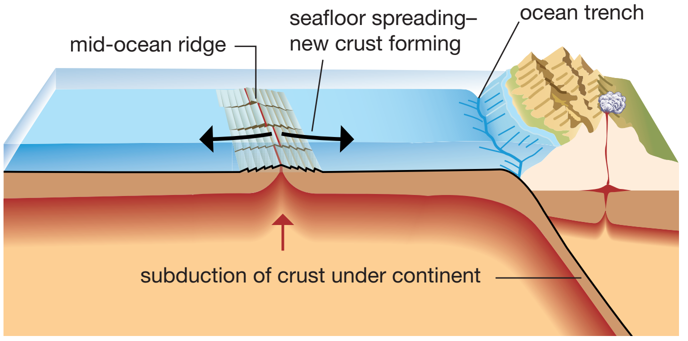



**Figure 10.1.4** Seafloor spreading and subduction are processes involved in the creation and destruction of the crust.

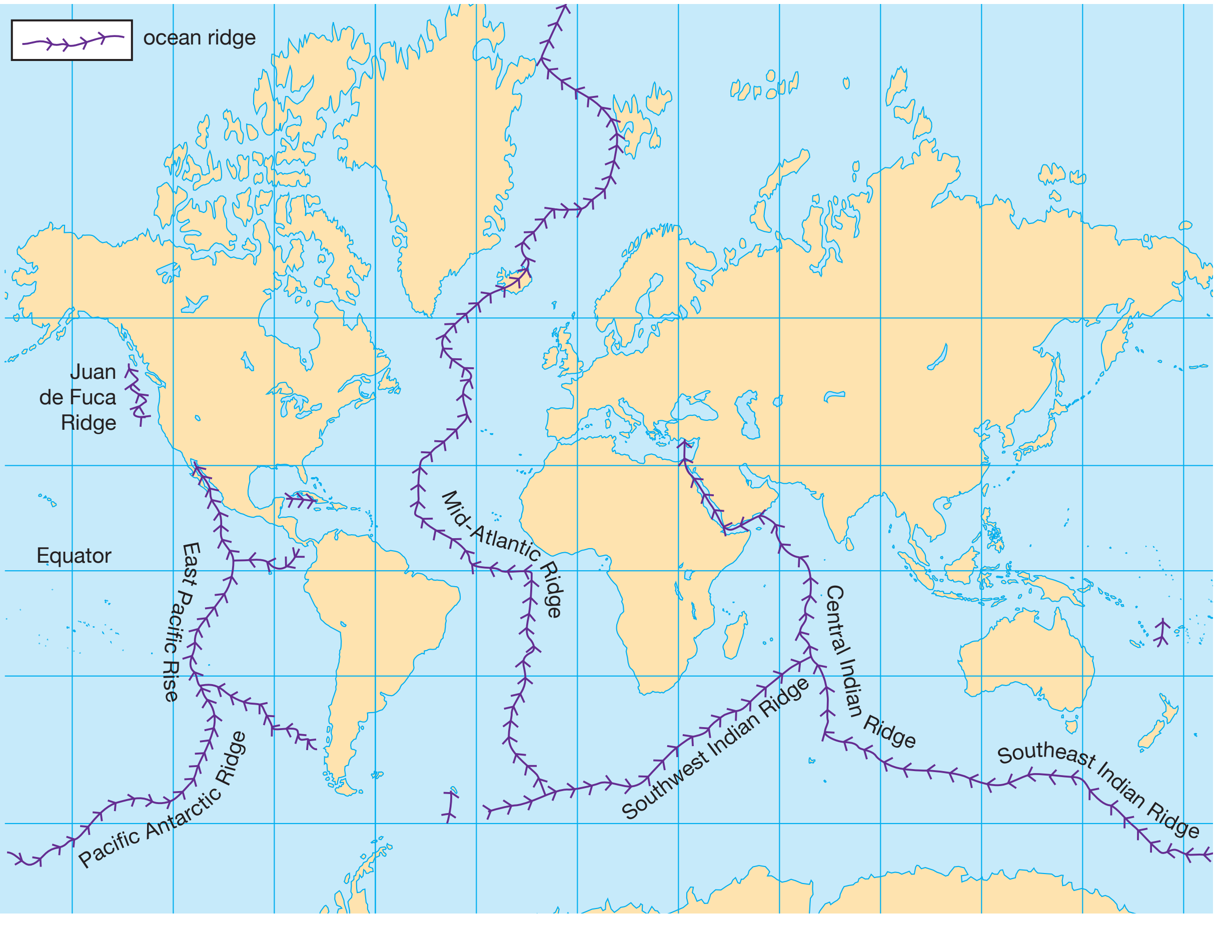



**Figure 10.1.3** The Great Global Rift system of ocean ridges.

# Magnetic striping

In the 1950s, scientists discovered that many rocks contained the iron oxide mineral called magnetite. A piece of magnetite that is suspended from a string will spin around and act as a compass. Magnetite has a north-seeking pole and a south-seeking pole, just like a compass needle.

INQUIRY science 4 fun

## Making a compass

Can you make a compass?

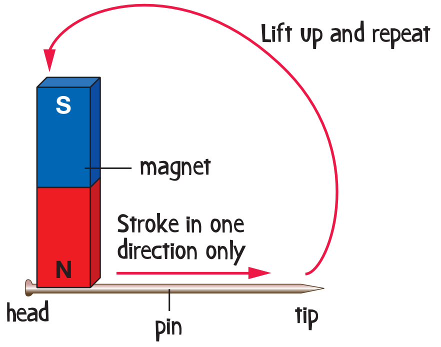
No

### Collect this ...

- small steel nail or pin
- bar magnet
- 20 cm of cotton
- compass
- sticky tape

### Do this ...

1. Place the pin on the desk and stroke it ten times from head to tip with the north-seeking pole of the bar magnet. Lift the magnet up and place it at back at the head of the pin after each stroke.
2. Tie or sticky tape the piece of cotton firmly in the middle of the pin so it hangs horizontally, and let it hang down and spin freely. Make sure you are further than 2 metres away from any metal object and the magnet.
3. Note which direction the pin tip points in. Spin it around a few times to see if it always points in the same direction. Compare the direction with a compass if you have one.
4. Repeat step 1 but use the opposite end of the magnet. Note any differences this time.




### Record this ...

**Describe** what happened.

**Explain** why you think this happened.

When molten rock solidifies, all the magnetite particles of any size line up in the magnetic field, pointing in the same direction. Therefore, the direction of the Earth's magnetic field at the time is preserved in the rock. Geologists can detect which part of the rock is the north-seeking pole. In this way any piece of rock acts like a tiny magnet.

During World War II, the US navy had discovered that there were bands of alternating strong and weak magnetism on the sea floor. They found that these bands were parallel to the mid-ocean ridges. You can see this in Figure 10.1.5. More studies by geologists confirmed this result and showed that it was due to changes in the magnetic field of the Earth over its history.

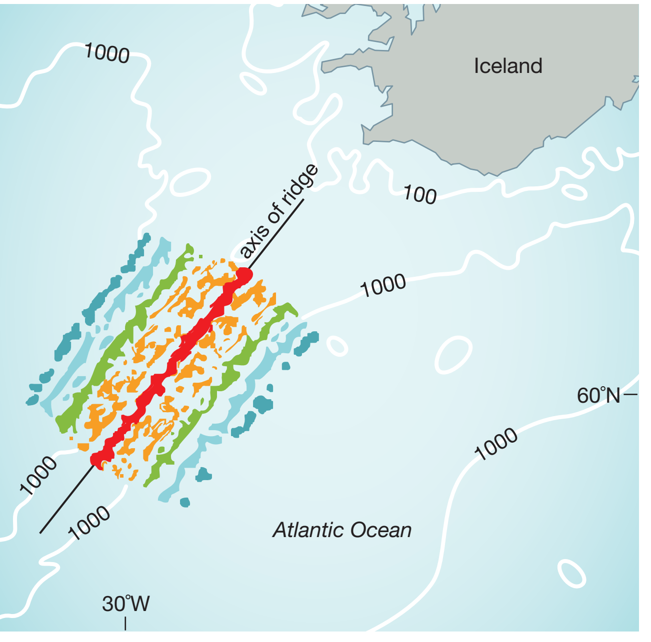



**Figure 10.1.5** The magnetism in the rocks on each side of the mid-ocean ridges is symmetrical.

Geologists found that as they went away from the ridge, the direction of north preserved in the rocks kept changing. At the start, the rocks had north pointing in the correct direction. Suddenly the direction of north changed to the opposite direction. North became south, then changed back again. This was very puzzling, because there was no way that the rocks could have spun around. The conclusion was that the Earth's magnetic field had changed every few million years.

These patterns of strips of rocks with alternating magnetism are called **magnetic striping**. The patterns on either side of the ridge were symmetrical—rocks at a particular distance from the ridge on one side always had the same magnetic direction as rocks the same distance away on the other side. At a particular distance they would both point to the current position of north, or they would both point to the current south.

At about the time that this magnetic striping was being researched, geologists began to use the term **plate tectonics** to explain Hess's theory. The cracked pieces of crust were called *plates*, *crustal plates* or *tectonic plates*.

## Support for Hess's theory

More research into magnetic striping led geologists to support Hess's theory about seafloor spreading. They concluded that there were great cracks in the crust and that magma rose up and added to each side of a crack to form new crust on the seafloor. New seafloor was being added equally on each side of the ridge.

This is why the pattern of magnetism was symmetrical—because the rocks at equal distances from the ridge on each side were formed at the same time in the past. So the direction of the Earth's magnetic field was the same in these sets of rocks on each side of the ridge. As the Earth's magnetic field changed over many millions of years, so did the magnetic direction preserved in the rocks (see Figure 10.1.6).

1 p322

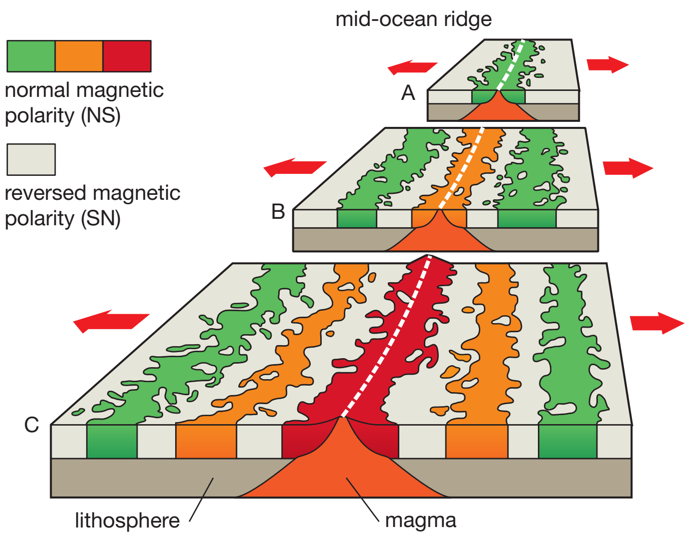



Figure 10.1.6 Magnetic striping is due to new seafloor forming on each side of a crack in the crust. The time sequence here goes from A to C.

### Age of the sea floor

More evidence supporting the seafloor spreading hypothesis came from the dating of rocks on the seafloor. The further the rocks of the seafloor were from the ridges, the older they were. This is exactly what you would expect if new rocks form near the ridge and move outwards away from it.

So the seafloor was moving, travelling away from the mid-ocean ridges. The other important fact was that the oldest seafloor rocks found were only about 200 million years old. Some of the rocks in the continents were thousands of millions of years old. So the seafloor was very young compared with the continents.

### Sediment thickness

When the sedimentary rock layers on the ocean floor were studied, it was found that the layers became thicker as you move away from the ridges. This was interpreted by geologists as showing that sediments had been falling for a longer time on the seafloor rocks furthest away from the ridges.

**SciFile**

**Glomar challenger**

Studying the thickness of sediments on the bottom of the ocean is not easy. The solution was to use a special drilling ship called the *Glomar Challenger*. This used extremely long 'drill strings'. The motor was in the ship and the drill bit cut the rock over 5 km below.

## How plates move

The picture that scientists now have of the Earth supports Wegener's original view of continental drift. Scientists have concluded that the Earth consists of several layers with different physical properties. Figure 10.1.7 shows the current view of the structure of the Earth. The upper mantle layer, called the asthenosphere, is the really important layer in plate tectonics.

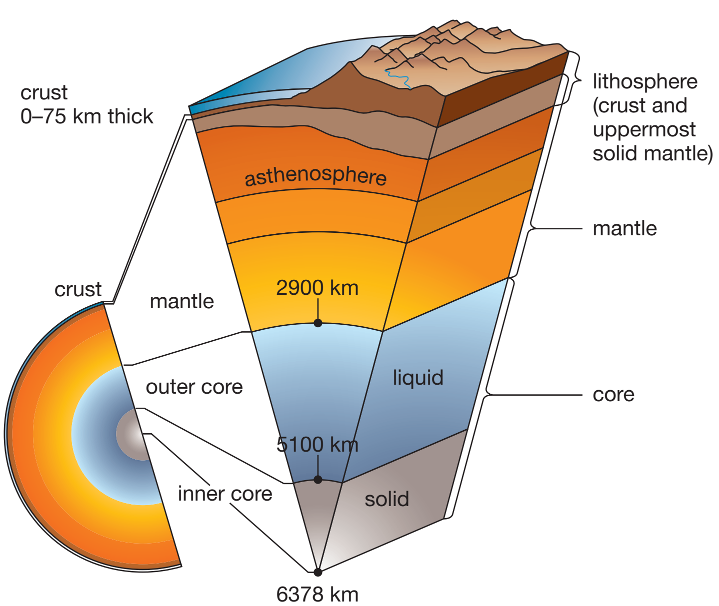



Figure 10.1.7 The Earth consists of layers. The asthenosphere is like a very thick, slow-moving liquid that allows tectonic plates to move on it.

The crust consists of many huge, cracked plates that are larger than continents. These plates ‘float’ on a layer of ‘plastic’ semi-solid rock in the upper mantle called the **asthenosphere**. Rock in the asthenosphere can flow very slowly and is very hot.

Exactly how the plates move on the asthenosphere is still being debated. There are two main theories. One is that plates are dragged along as the hot magma in the asthenosphere rises up and then flows horizontally along under the plates, creating convection currents. As the liquid rock flows, the friction between it and the tectonic plates above may be enough to move them. The other theory is that gravity pulls the new crust away from the ridge as it cools and becomes denser. Figure 10.1.8 shows the convection currents.

Then the process of seafloor spreading occurred. As new crust formed at the ridges, the continents moved along with the ocean floor as it spread away from the ridges. This is shown in Figure 10.1.9. One such rift, the Red Sea, is shown in Figure 10.1.10.

2 p323

10.2

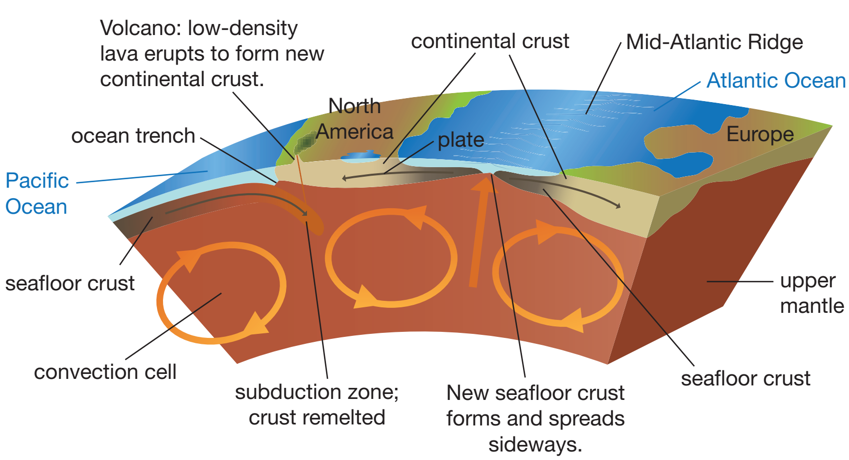



Figure 10.1.8 Convection currents may move plates by friction, but other theories also exist to explain the movement of the plates.

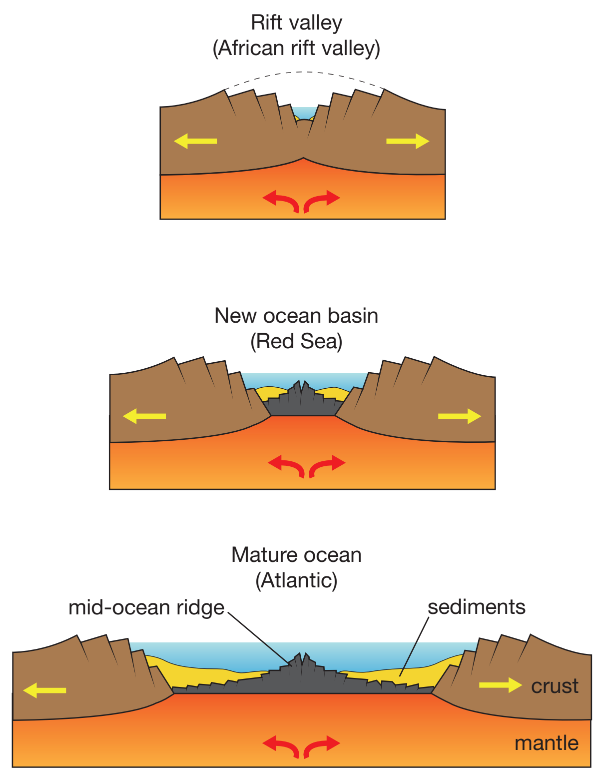



Figure 10.1.9 Continents can split apart by rifting and new ocean basins form. Seafloor spreading provided a mechanism to explain Wegener’s ideas of continents that drifted apart.

## Rifting and continental drift

Wegener’s theory of continental drift had no known mechanism by which the continents could move. Wegener had proposed that gravity and the spinning of the Earth could be involved. He thought the continents just scraped across the ocean floors.

Hess’s theory of seafloor spreading offered a much more likely mechanism for movement of the continents. He believed that the continents broke up by a process called **rifting**. The crust cracked and subsided, allowing in the oceans.

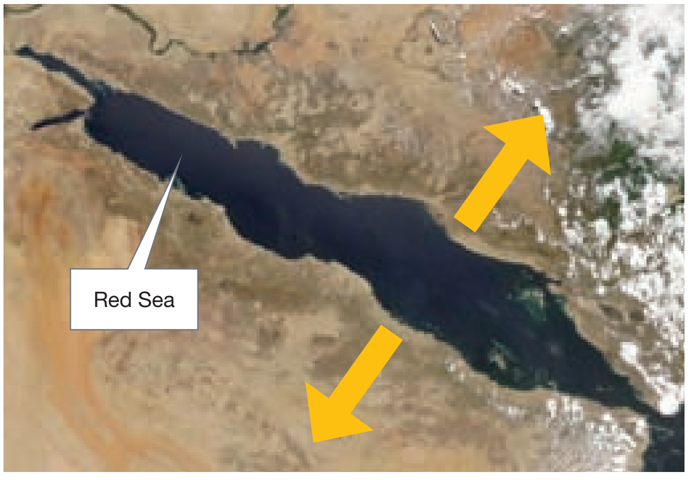



Figure 10.1.10 This satellite image shows the Red Sea, a giant water-filled rift valley at the edge of two tectonic plates.

# 10.1 Unit review

## Remembering

**1** **Name** the scientist who proposed:

- **b** continental drift
- **a** seafloor spreading.

**2** **State** the observation that led to the hypothesis of seafloor spreading.

**3** **List** the characteristics of the asthenosphere.

## Understanding

**4** **Define** the following terms.

- **a** subduction
- **b** seafloor spreading

**5** **Outline** the two main observations that led Wegener to propose the theory of continental drift.

**6** **Explain** how Wegener deduced what Pangaea looked like.

**7** **Explain** Hess's theory of seafloor spreading.

**8** **Describe** three types of evidence that supports the hypothesis of seafloor spreading.

## Applying

**9** **Use** the theory of plate tectonics to **explain** why Africa and America are older than the seafloor of the Atlantic Ocean.

**10** **Use** Figure 10.1.6 on page 319 to **explain** the process of magnetic striping.

**11** **Use** Figure 10.1.8 on page 320 to **explain** how heat and convection may be involved in the movement of crustal plates.

## Analysing

**12** **Compare** the theories of continental drift and plate tectonics.

**13** **Distinguish** between magnetic striping and magnetic field reversal.

**14** **Compare** Figures 10.1.9 and 10.1.10, and use them to **explain** how the Red Sea formed.

## Evaluating

**15** The photo at the top of page 316 shows satellite images of the Earth's topography using special sensors that detect various wavelengths of light. Geographic features are colour-coded by their height. You can see the coding in Figure 10.1.11.

Consider the topography image shown on page 316 and Figure 10.1.3 on page 317. Using these two images and Figure 10.1.11, **evaluate** whether there is any relationship between the topography and the position of the rifts.

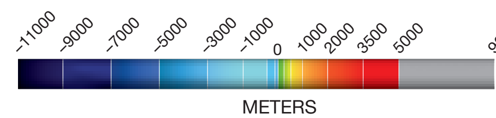



Figure 10.1.11

**16** There is an ocean trench separating Indonesia and Australia. There is an ocean ridge halfway between Australia and Antarctica. **Justify** why geologists would believe Australia is moving north.

## Creating

**17** **Construct** a table that summarises the evidence supporting the theory of plate tectonics. Have three columns in your table, with the following headings: Feature, Description, Sketch. A simple sketch of each feature alongside its description will help you remember it. Remember to include Wegener's observations.

## Inquiring

**1** Harry Hess was a geology professor before World War II. Research his US Navy career and why he became interested in continental drift.

**2** Research the following scientists and their contribution to the plate tectonics theory: Arthur Holmes, Robert Dietz and Frank Taylor.

**3** Research Alfred Wegener's theory of continental drift and how his theory compared with Antonio Pellegrini's.

Figure 10.1.12 Alfred Wegener

# 10.1 Practical activities

## 1 Magnetic striping

### Purpose

To simulate the magnetic striping patterns found in the rocks from seafloor spreading.

### Materials

- 2 plain A4 sheets of paper
- compass
- bar magnet
- red and yellow pencils
- 2 clothes pegs
- sticky tape

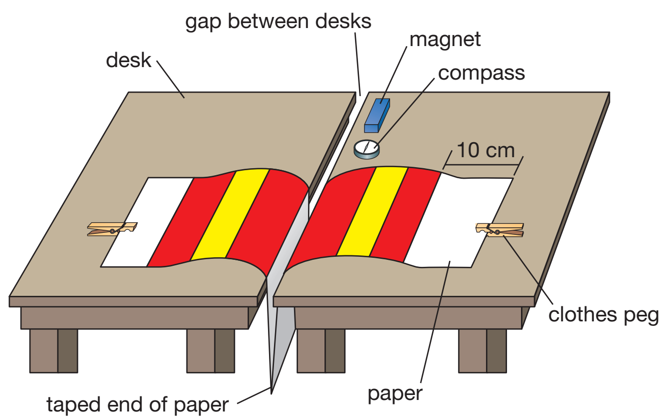



Figure 10.1.13

### Procedure

1. Tape the two A4 paper sheets together at one end so you have one long piece of paper. Rule a line across the open end of each sheet 10 cm from the end. Close the paper so the two A4 sheets are face to face with the ruled lines on the inside face of each paper.
2. Push two desks together, leaving a gap of a few millimetres.
3. Push the taped end of the paper down into the gap between the desks until you reach the ruled line. Leave 10 cm of the paper projecting above the desktop.
4. Place a compass on the desktop, next to the top edge of the paper. Place a magnet on the desk about 5 cm away from the compass. Have the north end of the magnet pointing away from the compass.
5. Gently fold the ends of the paper down, one end on each desk, and put a peg on each to weigh each end down (see Figure 10.1.13).
6. You are now ready to start your simulation. Under the desk, gently push up on the taped end of the papers until about 2 cm of paper has come out above the desk. Hold the paper still and use the red pencil to colour the 2 cm strip between the opening in the desk and the line on the paper. You should have a 2 cm red strip on each side of the opening in the desk. Your setup should look like Figure 10.1.13.
7. Spin the magnet around so that the north end is pointing at the compass.
8. Repeat step 6, but use the yellow pencil to colour in the 2 cm strip. You now should have a red strip and a yellow strip on each side of the opening in the desk.
9. Repeat steps 6–8 until you have three red lines and three yellow lines on each side of the opening in the desk. For step 7, spin the compass around so the north pole is to the top of the desk.
10. On each of your sheets, number the layers 1–6 in the order that they formed. Write on the oldest layer of rock the word ‘oldest’, and on the youngest layer, the word ‘youngest’.

### Discussion

1. In this simulation, **identify** what the:
   a. gap between the desks represents
   b. two sheets of paper represent
   c. magnet represents
   d. purpose of the compass is
   e. red colour on the paper represents
   f. yellow colour on the paper represents.
2. **State** the number and position of the layer that was the youngest on each sheet, and the layer that was the oldest on each sheet.
3. **Explain** how this simulation is useful in understanding magnetic striping along the ocean ridges.

## 2 Convection

### Purpose

To simulate the convection currents in the asthenosphere.

### Materials

- two 250 mL beakers
- potassium permanganate crystals
- tweezers
- hotplate or Bunsen burner, tripod, gauze mat and bench mat
- small coloured ice cube (water with food colouring)

**SAFETY**

Potassium permanganate stains—only handle it with tweezers.

Wear safety glasses.

### Procedure

1. Place 200 mL of water in a 250 mL beaker on the hotplate or gauze mat on the tripod.
2. Using tweezers, gently drop about five potassium permanganate crystals into the centre of the beaker. Do not move the beaker.

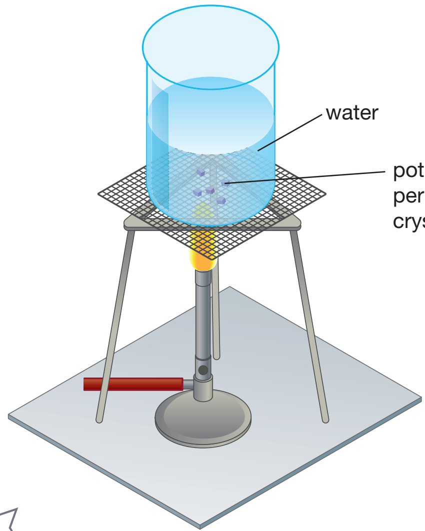



Figure 10.1.14

3. Gently heat the beaker. (If using a Bunsen burner, use with a cool flame directly below the crystals.) Carefully observe what happens to the streams of purple colour that come off the crystals. (It should happen within a minute or two.)
4. Fill the other beaker with 200 mL of tap water.
5. Use tweezers (because food colouring stains) to place a coloured ice cube into the beaker of cool water.

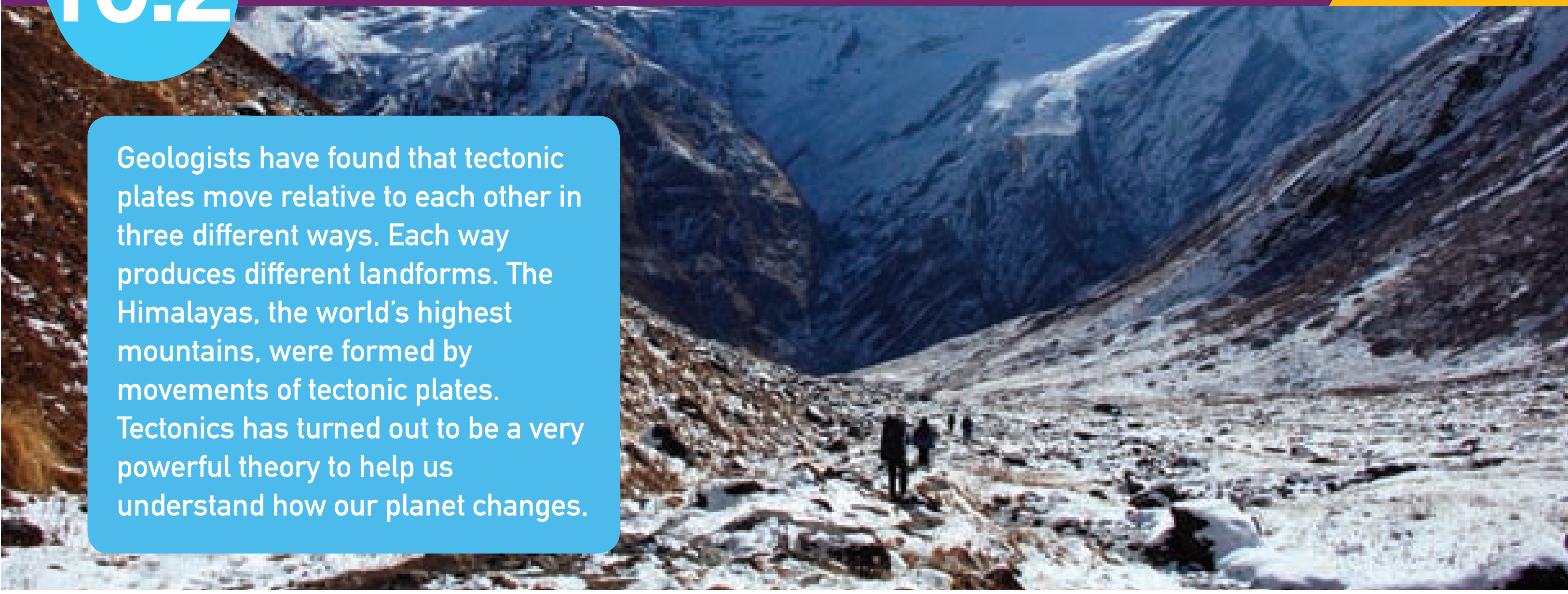
### Results

Record your observations for steps 3 and 5 as labelled sketches.

### Discussion

1. **Describe** how the stream of purple colour behaved when you heated the water.
2. **Explain** why the coloured ice cube behaved as it did.
3. **Use** the behaviour of the coloured ice cube to **propose** why the purple-coloured water sinks after reaching the surface of the beaker.
4. **Propose** a way of testing your answer to question 3 by using a bag of ice, purple crystals, a beaker and water.
5. **Explain** how this experiment helps understand what happens with magma in the asthenosphere.

# 10.2 Plate movements



Geologists have found that tectonic plates move relative to each other in three different ways. Each way produces different landforms. The Himalayas, the world's highest mountains, were formed by movements of tectonic plates. Tectonics has turned out to be a very powerful theory to help us understand how our planet changes.

## Types of crust

There are two types of crust—continental and oceanic. The **oceanic crust** is found on the ocean floor. The **continental crust** is the crust forming the continents. Oceanic crust is denser than continental crust. This is because oceanic crust has less silicon and more of the heavier elements such as iron and magnesium. Continental crust has a lot of aluminium and silicon. The densities of these types of crust are important when the plates are moving near each other.

The ocean crust is a darker colour than the continental crust and is much thinner. Oceanic crust generally lies below sea level, while the continental crust projects above sea level.

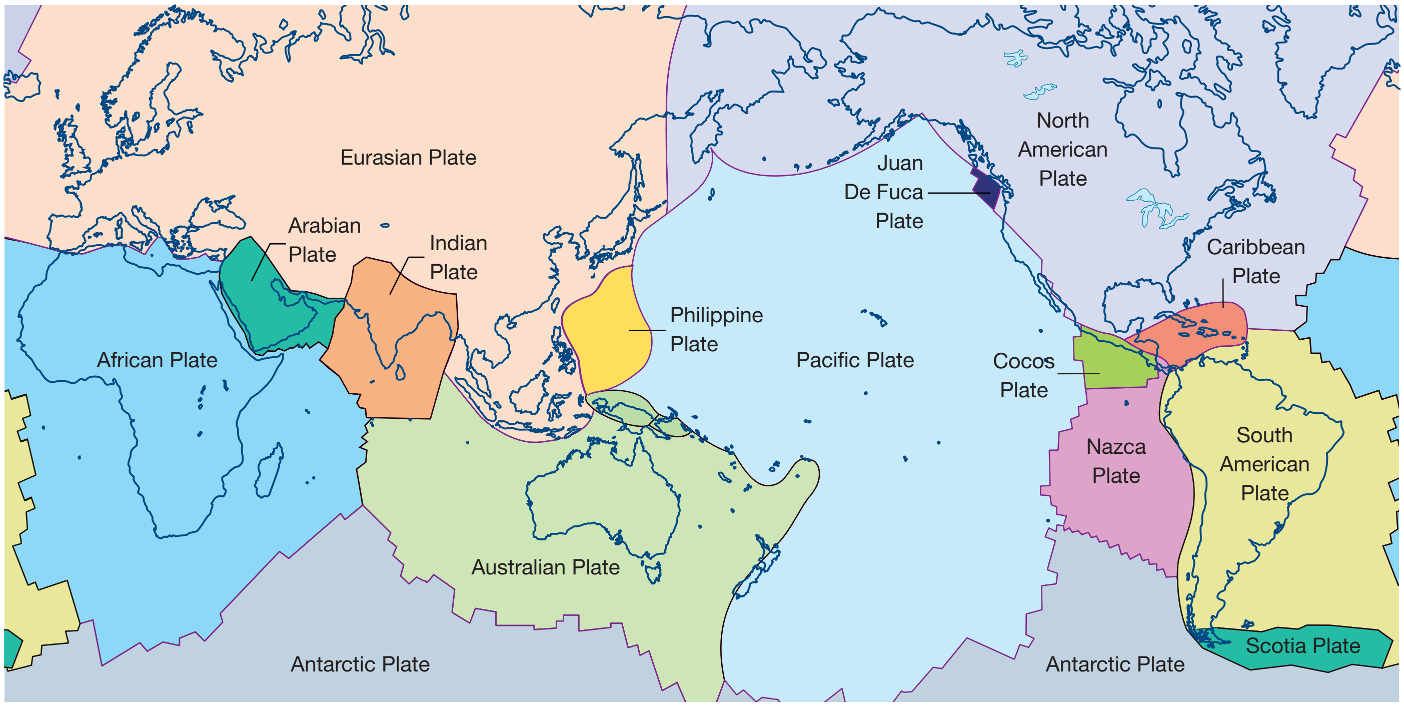



**Figure 10.2.1** There are many tectonic plates of differing sizes. This diagram shows where fifteen of the major plates are located, though many of these are split into other smaller plates.

## Where are the plates?

There are many tectonic plates of varying sizes. There are seven extremely large ones that are bigger than most continents. There are another ten or so medium-sized ones, and about 60 smaller plates. The larger plates are splitting into smaller ones in many places. The main plates can be seen in Figure 10.2.1.

## Types of plate movement

As Figure 10.2.2 shows, the tectonic plates move in three different ways at the boundaries between them.

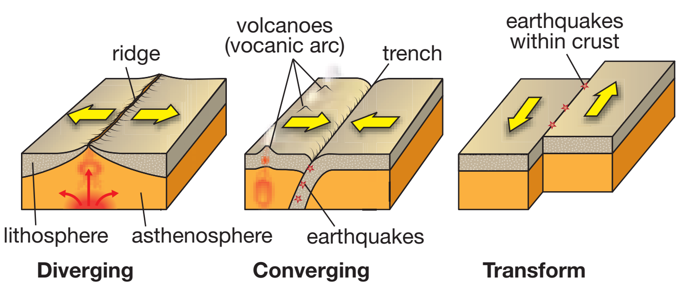



**Figure 10.2.2** The three different types of boundaries between plates. Movement is different at each boundary.

These boundaries are:

- diverging boundaries—where the plates are moving apart from each other
- converging boundaries—where the plates are colliding with each other
- transform boundaries—where the plates are sliding past each other.

You can see in Figure 10.2.3 what type of boundaries exist between the major tectonic plates.

## Diverging boundaries

**Diverging boundaries** are where the plates are moving apart from each other in opposite directions. To *diverge* means to separate. The mid-ocean ridges form a diverging boundary.

When the plates separate, there is a rift (deep crack) between them. Magma from the asthenosphere rises up into the rift and solidifies as it cools. This forms new crust, and so diverging boundaries are also known as constructive boundaries. Wherever there is an ocean ridge, there must be plates that are diverging.

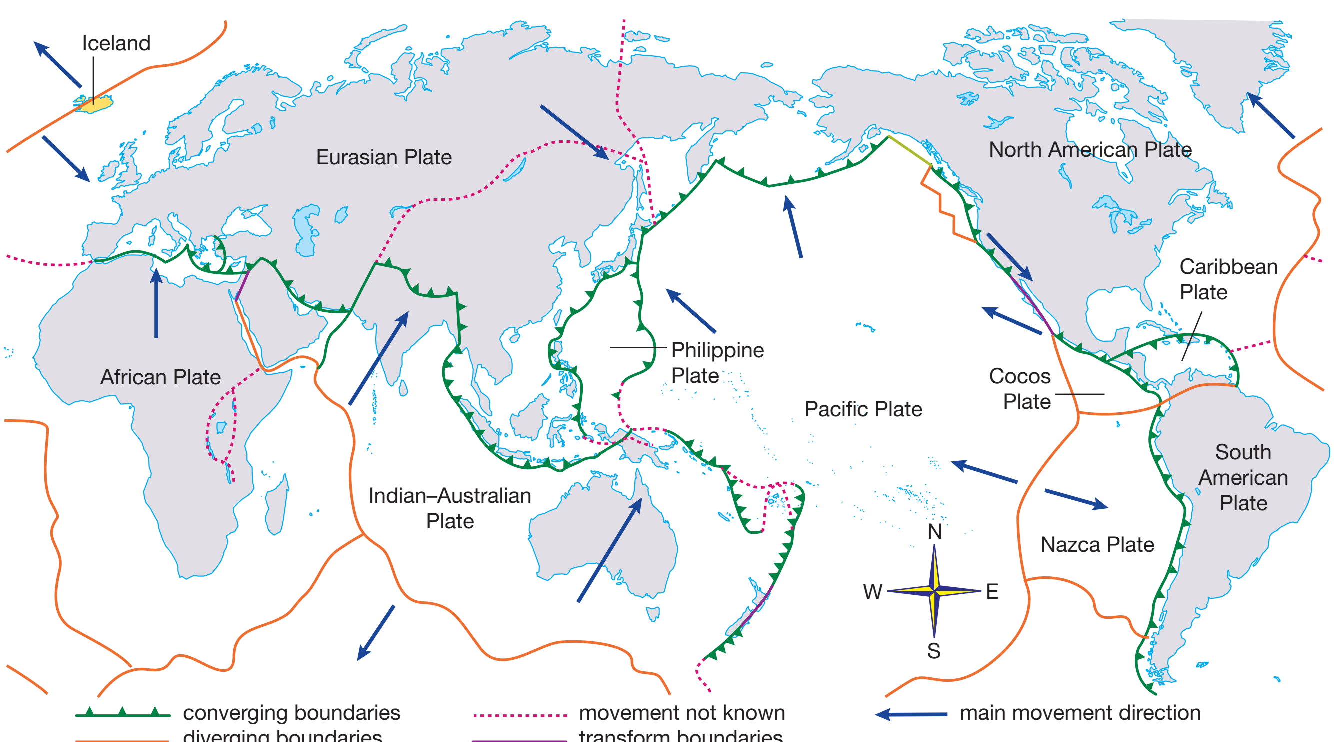



**Figure 10.2.3** The sites of the three different types of boundaries between the major plates

Diverging boundaries also occur on land. You can see the unique position of Iceland in Figure 10.2.4. The Mid-Atlantic Ridge runs right through the island of Iceland. Consequently, the island is widening as new crust is formed. Iceland has constant volcanic eruptions as the magma spews up into the rift. Measurements of the rate of widening are about 2–5 cm per year. That may not seem like much, but this spread has formed the Atlantic Ocean.


**Figure 10.2.4** Iceland is right on the Mid-Atlantic Ridge and so the island is steadily growing wider.

SKILL BUILDER

## Calculating the age of oceans

Geologists can estimate the age of geological features such as the ocean basins, rift valleys or continental islands. To do this, they use the rate of movement of tectonic plates.

For example, they can calculate the age of the Atlantic Ocean. Iceland is widening at about 2–5 cm per year. The Atlantic Ocean is about 4000 km wide between the parts of Africa and South America that appear to have been joined. So how long did it take to form the Atlantic Ocean?

First convert the distance across the ocean into centimetres.

$$4000\text{ km} = 400\,000\,000\text{ cm}$$

Now divide the rate of widening of the plates into this distance.

$$\frac{400\,000\,000}{2} = 200\,000\,000\text{ years} = 200\text{ million years}$$

So if the rate of movement of the plates has been averaging 2 cm per year, the Atlantic Ocean is 200 million years old. However, if the rate of widening is 5 cm per year, then the Atlantic Ocean is about 80 million years old.

### WORKED EXAMPLE
### Calculating the age of oceans

**Problem**

Iceland is about 250 km wide. **Calculate** how long the island may have existed.

**Solution**

$$250\text{ km} = 25\,000\,000\text{ cm}$$

$$\frac{25\,000\,000}{2} = 12.5\text{ million years}$$

Another place where diverging boundaries seem to be forming is in East Africa. A massive rift valley, called the Great Rift Valley, runs along the whole eastern part of the continent, as shown in Figure 10.2.5. At present there is no obvious crack or rift in the crust with magma welling up into it, but the land is subsiding. Geologists have proposed that in the future this could be where the next ocean will form on Earth.

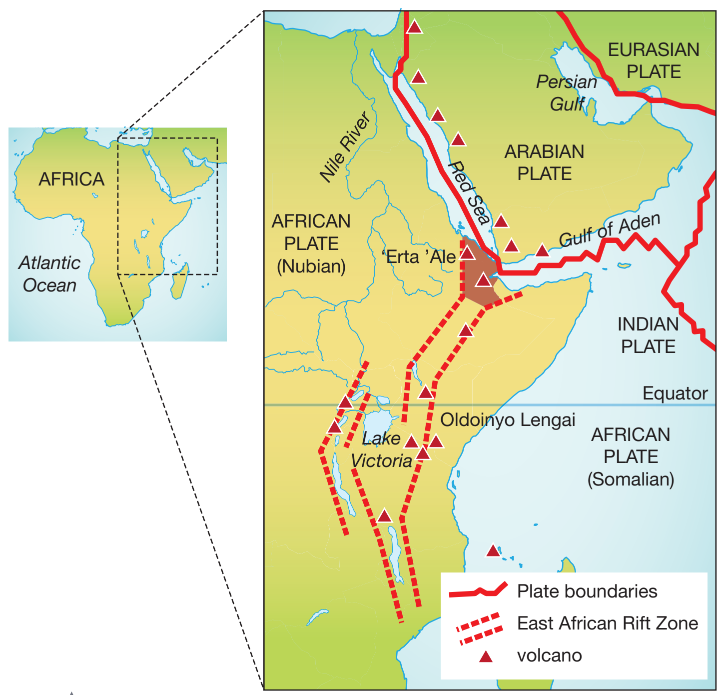



**Figure 10.2.5** The Great Rift Valley of Africa could be the site of the next ocean to form on Earth. The dashed lines show where the edges of the rifts (cracks) are. The red triangles show active, dormant and extinct volcanoes.

# Converging boundaries

**Converging boundaries** occur when two plates are colliding into each other. To *converge* means to come together. These collisions form many land features such as mountains. The features that are formed will depend on what types of crust collide. Rock is destroyed at converging boundaries, and so these boundaries are also known as destructive boundaries.

If oceanic crust is colliding with continental crust, then the denser oceanic plate sinks under the lighter continental plate. This is known as **subduction**, and can be seen in Figure 10.2.6. The continental plate becomes distorted, forming fold mountains and also volcanoes. Where the oceanic plate subducts under the continental plate, a deep ocean trench is formed. A good example is where the Nazca Plate collides with South America. The Andes Mountains have been formed along the west coast of South America, and the 8000-metre deep Peru–Chile Trench has formed.

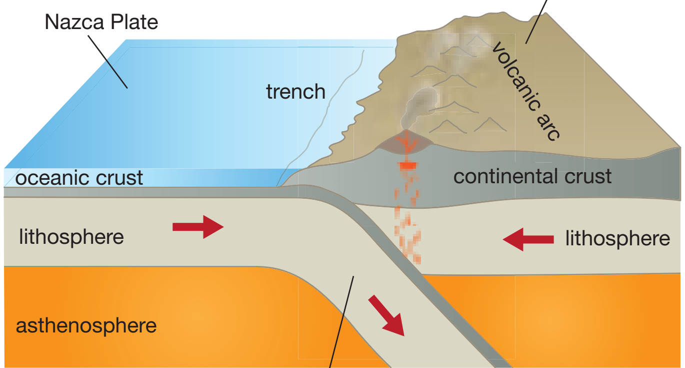



Figure 10.2.6 Subduction of an oceanic plate under a continental plate

The plate that subducts is diving down deep into the mantle, which is extremely hot. The friction of the plates colliding is also generating heat. This heat is enough to melt the crust and form magma. So crust is being destroyed as it subducts.

When two continental plates collide, both are pushed upwards because neither is denser than the other. This forms very high mountain systems. The best-known example of this is where the Indian Plate is colliding with the Eurasian Plate. This has formed the highest mountain range on Earth, the Himalayas (Figure 10.2.7). The highest mountain, Mt Everest at 8848 metres above sea level, was formed by this process.

### Into the depths

In 1960, the Mariana Trench was investigated by Donald Walsh and August Picard in a submarine called the *Trieste*. The enormous pressure cracked a window at 9000 metres on the descent and the nervous explorers spent only 20 minutes at the bottom. They saw some fish in the depths—the first time scientists knew that vertebrate organisms could live at extreme depths. They noted that the seafloor was covered in fine sediment of dead diatoms.

SciFile

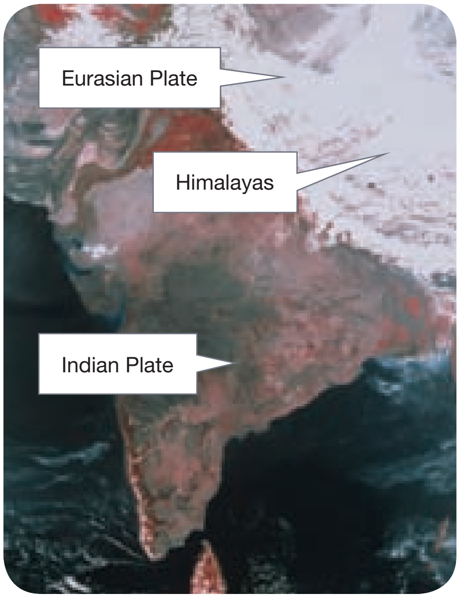



Figure 10.2.7 The Himalayas were formed by the collision of two continental plates: the Indian Plate and the Eurasian Plate.

## More evidence for tectonics

When two oceanic plates collide, one always subducts under the other. The faster-moving plate subducts. This forms a deep trench (see Figure 10.2.8). The descending plate melts and is destroyed. A chain of volcanic islands (called an **island arc**) appear as the magma formed by the subducting plate rises up to the surface. This observation of volcanic islands in the ocean was one of the mysteries that had puzzled Harry Hess before he realised that subduction must be occurring where the trenches existed. So the presence of ocean trenches and volcanic islands nearby is more evidence of plate tectonics.

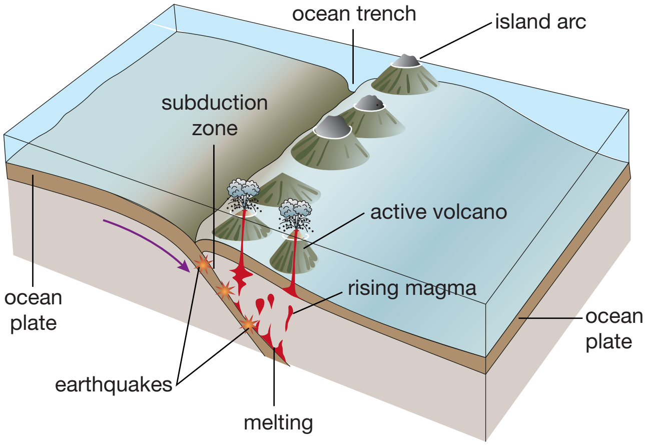



Figure 10.2.8 Oceanic plates colliding forms ocean trenches and volcanic islands. The presence of these trenches and islands supports the theory of plate tectonics.

The Mariana Trench is the deepest ocean trench as yet discovered. It occurs between two oceanic plates that are colliding. This trench occurs where the Pacific Plate meets a small plate called the Mariana Plate (part of the Philippines Plate). The trench is 10 911 metres deep. A string of volcanic islands form an island arc along the boundary.

## Transform boundaries

A **transform boundary** is where two plates are sliding parallel to each other but in opposite directions. The plates often move very slowly and then suddenly slip quickly past each other. When this happens, there is an earthquake. On land, a transform boundary usually has fold mountains along its length. There are also many cracks in the rock, called fault lines. Fold mountains and fault lines also occur under the ocean where transform boundaries exist. Fault lines usually do not form one continuous crack in the crust along the plate boundary. Instead there are many cracks parallel to each other.

One transform boundary is the San Andreas Fault in California, United States. This is where the Pacific Plate and the North American Plate move past each other. The cities of Los Angeles and San Francisco are built near the fault line. This fault has moved in the past and has caused massive earthquakes, such as in 1906, in which San Francisco was flattened.

Another transform fault runs right through New Zealand. Meeting at this fault are the Australian Plate, which is moving north-east, and the Pacific Plate, which is moving south-west. Movement of this transform boundary created the magnificent mountains of the South Island of New Zealand. You can see the transform boundary in Figure 10.2.9.

1 p332 2 p332

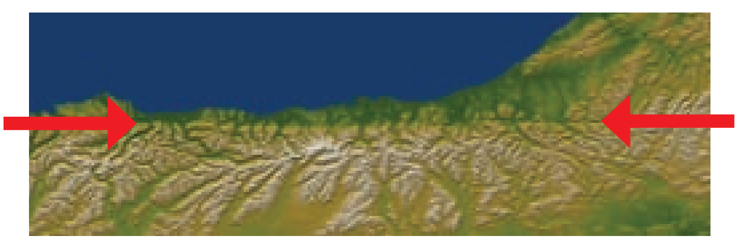


**Figure 10.2.9** This aerial view shows that the Alpine Fault of New Zealand is a transform fault. The fault line runs between the red arrows.

**Figure 10.2.10** The stunningly beautiful Milford Sound in the South Island of New Zealand sits right next to the transform fault that runs along the west coast.

## Pangaea break-up

Pangaea was the original land mass of the Earth. This gradually broke into two major landmasses: Laurasia in the north and Gondwana in the south. Australia was part of Gondwana. In the Cretaceous Period, about 65 million years ago (just as the dinosaurs were becoming extinct), Australia was separating from Gondwana. Reconstructions of how the land masses appeared in the past are shown in Figure 10.2.11.

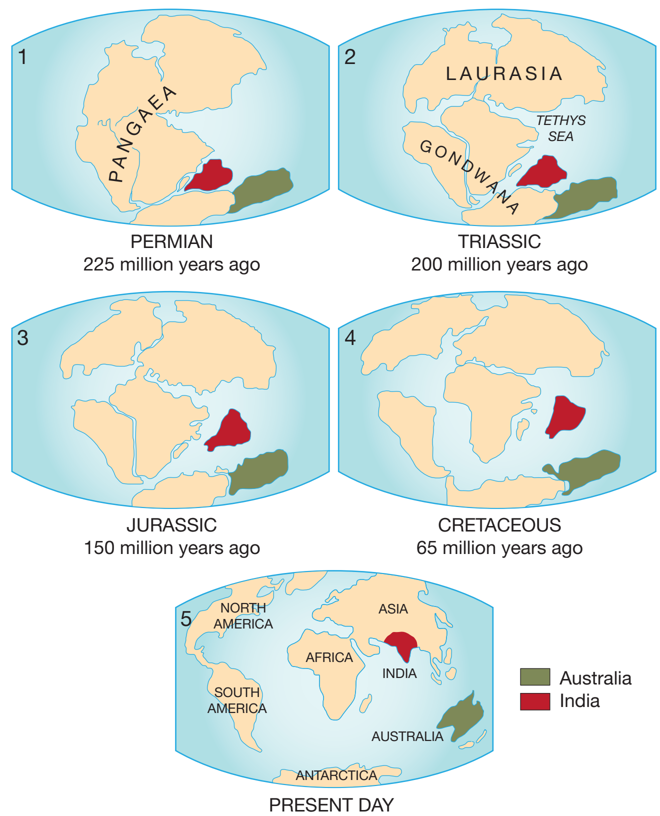



**Figure 10.2.11** Reconstruction of the break-up of Pangaea, Laurasia and Gondwana. Note the movements of Australia and India.

## Australia breaks from Antarctica

Australia's landforms and climates changed as it moved northwards on the Indian–Australian tectonic plate. About 125 million years ago, Australia was still connected to Antarctica. Almost the whole centre of Australia was covered by a sea that separated the country into four landmasses. The sea level dropped around 85 million years ago, exposing more land.

Australia slowly moved northwards, but still remained connected to Antarctica at the South Tasman Rise, a small area of land near Tasmania. About 40 million years ago, the South Tasman Rise separated, and Australia became an island continent.

## INQUIRY science 4 fun

### Plates and currents

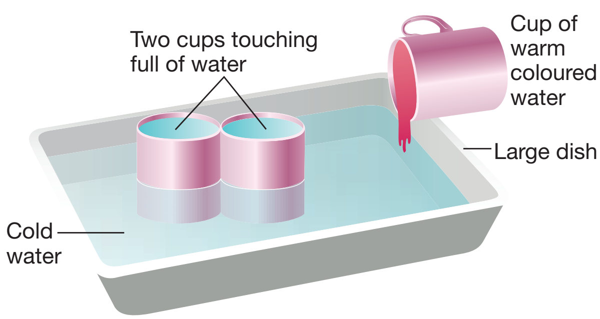
How do tectonic plates affect ocean currents?

**Collect this …**

- large dish
- three cups
- food colouring

**Do this …**

1. Set up the equipment as shown in the diagram.
2. Fill the third cup with warm tap water and add three or four drops of food colouring.
3. Very slowly (over about 30 seconds) pour the warm coloured water into one end of the large dish and watch where the colour goes.
4. Replace the water in the dish and separate the two cups in the dish so there is a gap between them about as wide as a cup.
5. Repeat step 3 and observe any difference.




**Record this …**

**Describe** what happened.

**Explain** how this is relevant to plate tectonics.

## Currents and tectonic plates

Ocean currents are affected by the movement of tectonic plates. When Australia separated from Antarctica, this allowed a new current (called the Antarctic Circumpolar Current) to form. This current was a very cold ocean current that changed the climate of southern Australia and had global influences. Antarctica steadily became colder, and southern Australia became drier as water became locked up in Antarctic ice sheets.

The warm current that flowed southwards down Australia's eastern coast was blocked by the Circumpolar Current, and southern Australia became colder and drier. However, the northern parts of Australia were becoming warmer as Australia moved into the tropics.

## Flora and fauna

Australia was isolated from all other land masses from 40 million years ago. This isolation led to the evolution of unique species of plants and animals in Australia.

Marsupials dominate Australia, with nearly 200 species. Only about 70 species of marsupial are found in the rest of the world, mostly in South America. The monotremes—the echidna and platypus—are unique to Australia.

As Australia drifted north, much of the climate gradually became drier. A large dry plain (the Nullarbor Plain) was formed. This continued the isolation of Western Australia and led to the evolution of a very high proportion of unique native plants in that state, like the ones shown in Figure 10.2.12. About 80% of its flora (plant life) is found nowhere else.

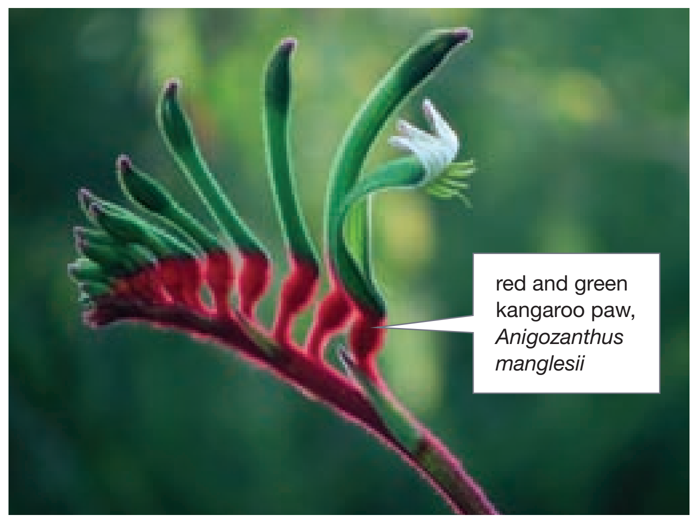




**Figure 10.2.12** The flora of Western Australia is one of the most diverse in the world, a result of its isolation due to plate tectonics and climate change.

SCIENCE AS A
# HUMAN ENDEAVOUR

## Nature and development of science

### Measuring the speed of tectonic plates

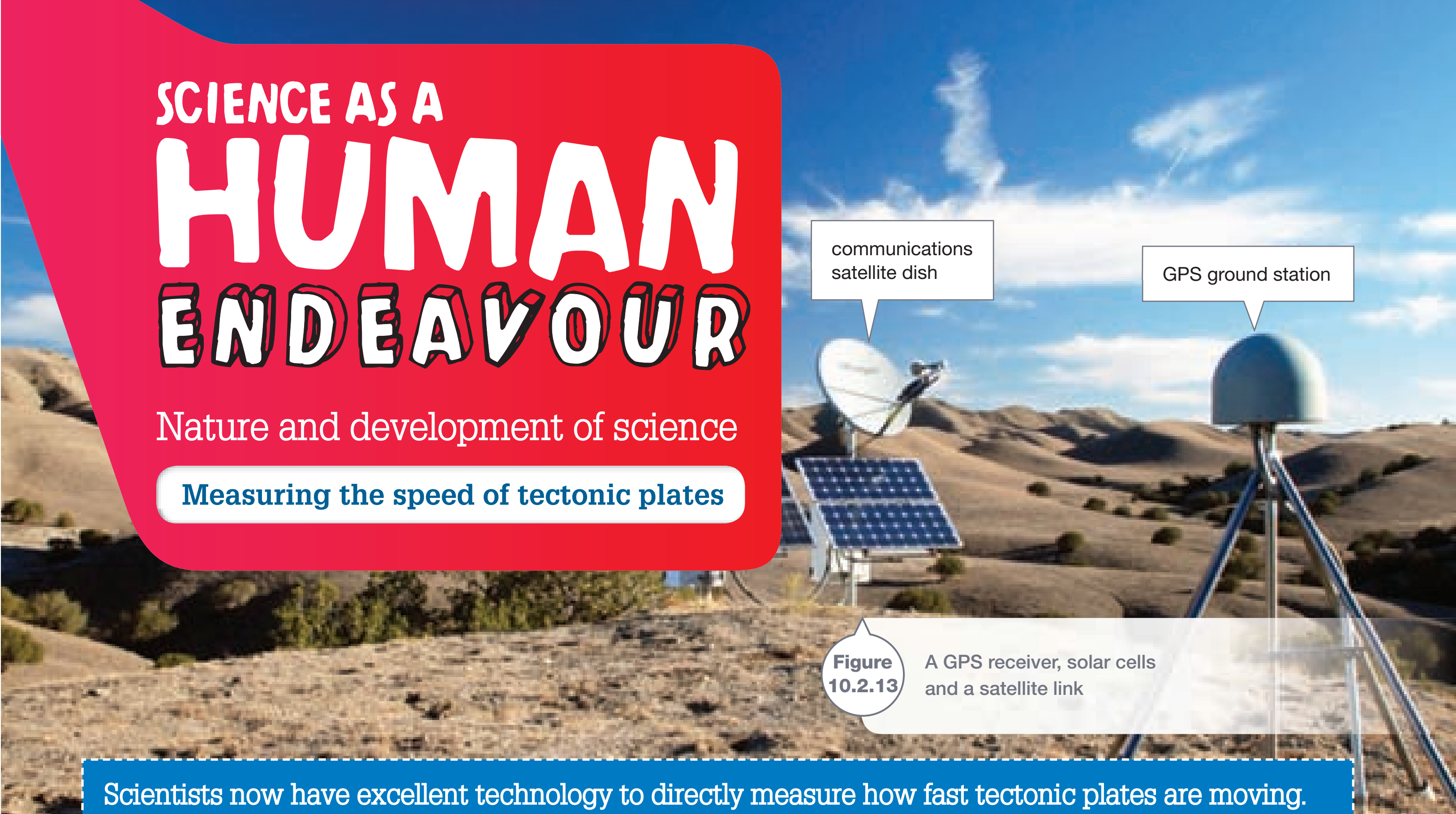



**Figure 10.2.13** A GPS receiver, solar cells and a satellite link

**Scientists now have excellent technology to directly measure how fast tectonic plates are moving. The modern geologist has several different techniques.**

The most widely used technique involves satellites and the global positioning system (GPS). A **GPS ground station** is a receiver and computer that is placed on top of a stand (like the one shown in Figure 10.2.13). The legs of the stand are fixed into the rock.

There are many GPS ground stations located on tectonic plates around the Earth. A group of 24 satellites circling the Earth sends radio signals to the GPS ground stations. If a ground station detects at least three satellites, it can work out its position on the ground. The ground station computer works out where it is. By comparing all the data from different ground stations, scientists can see how much the ground stations have moved compared with the others. The computer can determine movement sideways and also up and down (if four satellites can be detected).

The best GPS stations are accurate to a few millimetres. Measurements from these stations show that rates of plate movement vary greatly between the different plates and even between parts of the same plate. The fastest-moving plate is near Easter Island in the Pacific Ocean. This part of the Pacific Plate is moving at about 15 centimetres per year. The slowest-moving plate is the Antarctic Ridge, which is moving at only 2.5 centimetres per year.

Another instrument that helps measure the speed of tectonic plates along particular faults is a strainmeter. This is a series of markers buried into the ground in a straight line across a fault (as shown in Figure 10.2.14). If any of the markers move out of line, the distance can be measured. This results from this type of instrument show that GPS measurements are very accurate.

**Figure 10.2.14** A strainmeter, looking through the viewing window along the line of markers (the light grey coloured 'T' shapes) that runs across a fault line.

10.4

# 10.2 Unit review

## Remembering

1 **Name** the three types of plate boundary.

2 **Name** the two types of crust that form the tectonic plates.

3 **Name** one place where the following type of plate boundary occurs.
   a diverging boundary
   b converging boundary
   c transform boundary

4 **Recall** the direction in which the plates move at the:
   a diverging boundary
   b converging boundary
   c transform boundary

## Understanding

5 **Describe** the process of subduction.

6 **Describe** plate boundaries where the following may occur.
   a subduction
   b ocean trenches
   c fold mountains
   d rifting under the sea
   e island chains
   f an ocean trench next to a continental mountain range

7 **Explain** how the evolution of unique Australian flora and fauna can be explained by changed environmental conditions following the break-up of Gondwana.

## Applying

8 The Australian Plate forms a converging boundary with the Indonesian island of Java at the Java Trench. The distance between the Australian land mass and Java is about 500 km. The Australian Plate is moving at about 7 cm per year. **Calculate** how long it could be before Australia crashes into Indonesia.

## Analysing

9 **Compare** the types of movement of the tectonic plates.

10 **Compare** subduction when two ocean plates converge with subduction when an oceanic and continental plate converge.

11 **Analyse** Figure 10.2.11 on page 328 and **explain** the origin of the Himalayas.

## Evaluating

12 **Propose** what evidence could help you decide whether two plates had converged in the past to form a continent.

13 At diverging boundaries, seafloor spreading is occurring as new crust is continually created. **Propose** why the Earth's crust is not getting any bigger.

14 **Propose** why fossils of sea creatures have been found near the top of Mt Everest (8848 m above sea level).

15 The oldest known fossils in the ocean floor are about 180 million years old, yet fossils from continents have been found that are 3400 million years old. **Propose** reasons why.

16 **Propose** why Australia became drier as it moved north on the Indian–Australian tectonic plate.

## Creating

17 In the table you constructed for Question 17 in Unit 10.1, add some more evidence from Unit 10.2 that supports the theory of plate tectonics.

## Inquiring

1 Research the following physical features to identify the plates that are moving in each case, and explain how each landform was created.
   a Andes
   b Dead Sea
   c Kermadec Islands
   d Japan Trench

2 Research the Great Rift Valley of Africa and explain why geologists predict that it could be the next major ocean on Earth.

3 Research the possible impact of moving continents on ocean currents and the global climate through geological time.

4 Research the history of plate tectonic movements of Australia and explain why Australia is a particularly stable and very old continent.

5 Research the evolution of Australia's unique flora and fauna. Using examples, explain how this is due to changed environmental conditions following the break-up of Gondwana.

# 10.2 Practical activities

## 1 Paper plate tectonics

### Purpose

To build and use paper models of plate tectonics.

### Materials

- paper template. To obtain this, type into a web browser: 'Sea-floor spreading and subduction model by John C Lahr'
- cardboard
- sticky tape
- scissors
- coloured pencils

### Procedure

1. Colour in the paper templates provided.
2. Construct the model using the instructions provided. Note: You don't need a shoebox as it says in the instructions. It can be made from flat sheets of cardboard and stuck together afterwards. The measurements are in inches. 1 inch = 2.54 cm.
3. With a partner, operate the model. This represents seafloor spreading where there are also fault lines perpendicular to the rift. The seafloor is separating away from the central rift, but it is doing it in three separate strips. Your partner must gently keep holding the three paper strips below the top. You hold the two side pieces and slowly pull them apart, watching the magnetic strips as they appear.
4. Imagine what would be happening in real strips of ocean crust as their inside edges slide past each other like the paper strips.

### Discussion

1. **Describe** what the model shows about seafloor spreading.
2. **Describe** where the three transform faults are on the seafloor spreading and subduction model.
3. a **Identify** the following features of the seafloor spreading and subduction model.
   - i subduction
   - ii convection currents
   - iii volcanic islands
   - iv sea floor spreading
   - v magnetic striping

   b **Explain** your answer in each case.

## 2 Types of crust

### Purpose

To measure the density of granite and basalt, and relate this to the behaviour of oceanic and continental tectonic plates at converging boundaries.

### Materials

- displacement can
- granite and basalt (to fit in the displacement can)
- scales or triple beam balance
- 100 mL measuring cylinder
- beaker
- cotton

### Procedure

1. Measure the mass of the basalt and the granite. Record them in a table.
2. Place the granite in a displacement can and measure the volume of water displaced.
3. Place the basalt in a displacement can and measure the volume of water displaced.

### Results

Calculate the density of the basalt and the granite using:

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

*Remember*: 1 $cm^3$ = 1 mL water (at about 20°C)

### Discussion

1. **Compare** the density of basalt and granite.
2. If the oceanic crust is high in basalt and the continental crust is high in rocks like granite, **explain** why oceanic crust subducts under continental crust at a collision boundary between these two types of plate.

# 10.3 Volcanoes and earthquakes

Volcanoes are among the most awesome sights on the planet. The largest explosion in history was from a volcano. Earthquakes can also be deadly. Earthquakes and volcanoes provide evidence of the interior processes of the Earth. They provide information that supports the theory of plate tectonics.

## Volcanic eruptions

A **volcano** is a place where extremely hot material from inside the Earth erupts at the Earth's surface. This material includes:

- gas such as steam and hydrogen sulfide
- ash (fine particles of rock)
- **lava** (molten rock)
- lumps of solid volcanic rock like scoria.

Volcanoes form where there are weak spots in the Earth's crust and where extremely hot molten rock called **magma** has accumulated below the weak spots. This magma is occasionally pushed upwards under great pressure into the volcano. The effects of a volcanic eruption can be seen in Figure 10.3.1.

The magma reaches the surface, and is now known as lava. It erupts white hot at a temperature of over 1200°C. The lava changes colour as it cools, from white through yellow, orange and red, until it finally becomes a black colour as it hardens and solidifies into rock.

The type of magma that is formed will affect what the volcanic eruption is like. The eruption can be explosive when the magma:

- is viscous (flowing very slowly)
- contains a lot of water and gas.

Figure 10.3.1 Casts made of dead bodies found after an eruption near Pompeii, Italy, in 79 CE. The bodies were covered in ash that became rock. When the bodies decayed, they left a cavity in the rock. Plaster was poured in to make the cast.

This forms an explosive mix because the gas and steam bubbles grow larger as the magma rises to the surface. The bubbles grow larger because the pressure around them is dropping. This is similar to the way bubbles expand as they rise in a bottle of fizzy drink. In the magma, the expanding gas bubbles put pressure on the liquid around them. If the magma is starting to thicken and turn solid as the bubbles expand, then it can suddenly break apart explosively.

The explosions can throw out 'volcanic bombs' of rock called scoria. Scoria typically has many spaces in it where the gas bubbles have accumulated. The explosions also create a massive ash cloud. The ash cloud of a volcano (like the one in Figure 10.3.2) can rapidly rise upwards at over 200 km/h and can reach heights of 50–80 km. This is high enough to be dangerous to aircraft.

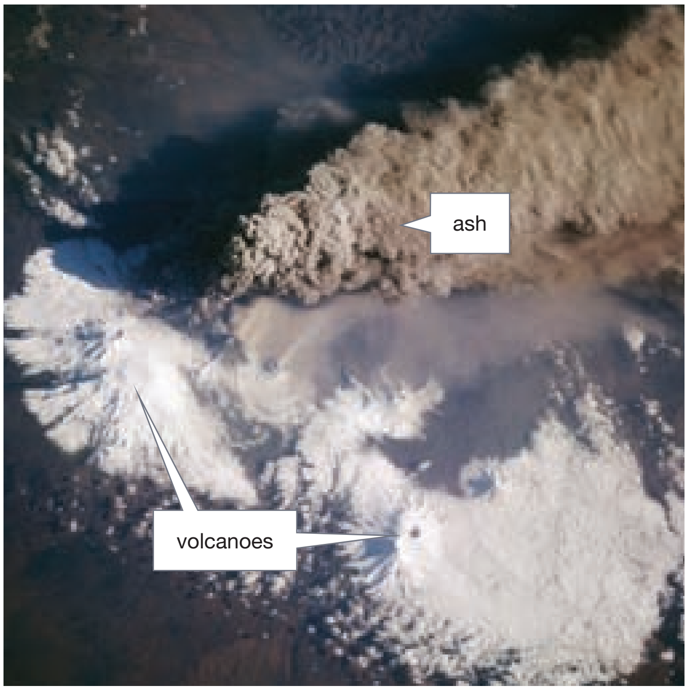



Figure 10.3.2 A volcanic ash cloud can reach up to 80 km in half an hour. The ash cloud of this volcano on the Kamchatka Peninsula, Russia, is spreading high into the atmosphere. This photo was taken from space.

Occasionally there can be a **pyroclastic flow**, where a cloud of ash, rock and gas at about 500°C rushes down the volcano like an avalanche at over 100 km/h. This will kill every living thing in its path.

**SciFile**

**Big volcano**

Mauna Loa on the island of Hawaii is the largest volcano on Earth. It is 4000 metres (4 kilometres) above sea level. But the sea floor is 5000 metres deep around the island. So the volcano is really over 9000 metres high, higher than Mt Everest.

# Where do volcanoes form?

## Volcanoes at the edges

As Figure 10.3.3 shows, most volcanoes form near the edges of tectonic plates. This is because the movement of the plates creates weaknesses in the crust and also generates a lot of heat, which can melt rock.

Diverging plate boundaries create weaknesses in the crust because the separating plates thin the crust. This lowers the pressure on the underlying hot rocks of the asthenosphere and they melt. The magma created then finds its way up through the weaknesses in the crust.


Figure 10.3.3 Most volcanoes form near the edges of the tectonic plates. This observation provides further support for the theory of plate tectonics.

Converging plates, especially where subduction occurs, create weaknesses in the crust and generate a lot of heat. If the colliding boundaries occur under the ocean, chains of volcanic islands (island arcs) can be formed at the edges of the tectonic plates (Figure 10.3.4). An example is the Lesser Sunda Islands, Indonesia (Figure 10.3.5).

1 p341

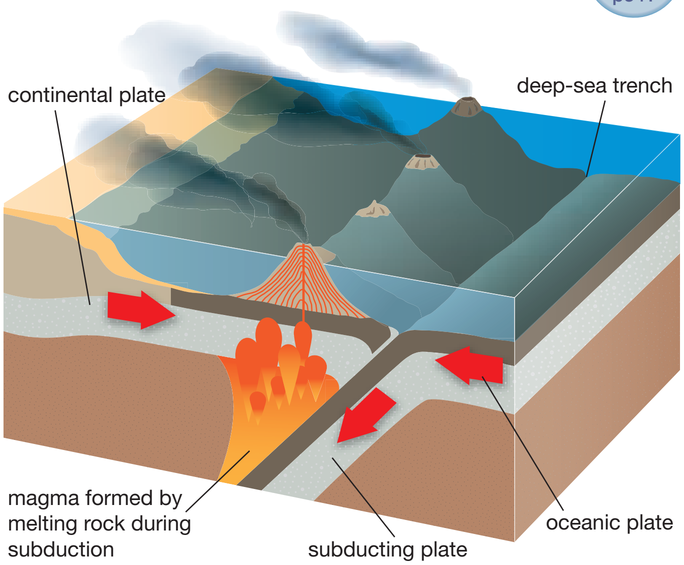



**Figure 10.3.4** Subduction results in weakness in the crust and generates of a lot of heat. A string of volcanic islands (an island arc) is evidence for colliding tectonic plates.

**Figure 10.3.5** Satellite image of the Lesser Sunda Islands, Indonesia, a chain of volcanic islands.

**SciFile**

**Krakatoa**

Krakatoa (also called Krakatau) was a volcanic island in Indonesia. In 1883, it exploded, blowing two-thirds of the island to pieces. It is the largest explosion ever witnessed by humans. A total of 21 $km^3$ of land was blown into the air. Try to imagine that! The sound was clearly heard over 5000 km away and over 36 000 people died. The photo shows the remains of Krakatoa. The bottom island and the middle island were originally joined.

## Explosive eruptions

Subduction generates heat, melting rock and forming magma. The magma rises up in huge packets through lines of weakness in the crust. It accumulates in spaces called magma chambers and is occasionally released to the surface as the pressure builds up.

There can be explosive eruptions where oceanic plates subduct under continental plates. Continental plates tend to have more silica in them than oceanic plates, and this often makes the magma formed from them quite sticky and viscous (thick). Rocks with a lot of water in them also create a lot of steam when they are heated during subduction.

## Hot spot volcanoes

While most volcanoes form near plate boundaries, some form well away from the edges of the plates. These volcanoes sit over 'hot spots' in the Earth's crust. **Hot spots** are isolated places where a lot of hot magma is being created. They can occur under oceanic or continental plates. Geologists are not sure why these hot spots exist.

In the ocean these volcanoes occur in chains of islands. In each chain there is always one island with an active volcano, while all the other islands have dormant (inactive) volcanoes. Geologists realised that the formation of these volcanoes could be explained by the theory of plate tectonics. Each island forms as it sits over the hot spot. As the plate moves, the island goes with it and so it no longer sits over the hot spot. A new part of the plate is now above the hot spot and this gradually forms a new volcano. The Hawaiian islands (shown in Figure 10.3.6 on page 336) are a good example of an island chain over a hot spot.

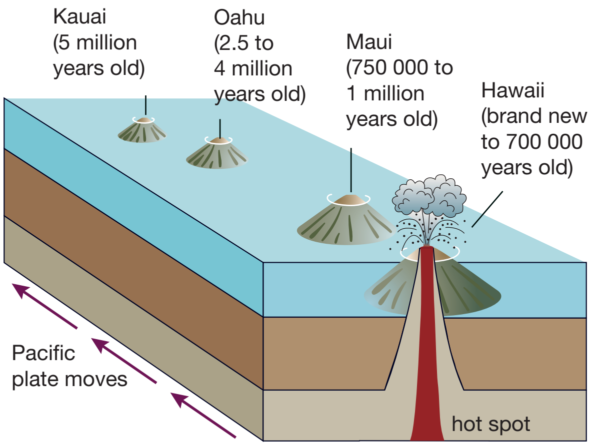



Figure 10.3.6 The Hawaiian islands have been formed by movement of the Pacific Plate over a single hot spot in the Earth's mantle.

## What causes an earthquake?

An **earthquake** is the rapid movement of the ground, usually back and forth and up and down in a wave motion. It is caused by the rapid release of energy as the tectonic plates move. Friction between the plates must be overcome before they can move. When the force is great enough, the plates suddenly move as friction can no longer hold them. This sudden movement sends out waves of energy through the rock and the water. The ground and water then shake as the waves of energy pass through them.

## Detecting earthquakes

Earthquakes are measured using an instrument called a **seismometer**. Old-style seismometers consisted of a pen on a moving drum. They used the principle of inertia. The heavy mass attached to the pen has a lot of inertia, meaning it tends to stay still. The rest of the seismometer moves with the vibrations of the Earth.

There are many designs for seismometers, and modern ones are electronic. You can see two designs in Figures 10.3.7 and 10.3.8. The trace of a seismometer is called a seismograph.

**Big quakes**

The largest earthquake ever recorded was one of magnitude 9.5 in Chile in 1960.

The world's deadliest recorded earthquake occurred in 1556 in central China. It killed an estimated 830 000 people. In 1976, another deadly earthquake struck in Tangshan, China, where more than 250 000 people were killed.

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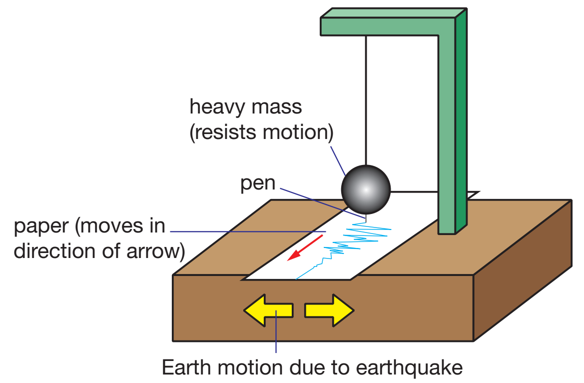


Figure 10.3.7 This design of a seismometer uses a swinging pendulum. The pen does not move much. The supporting arm and the recording paper vibrate back and forth with the ground.

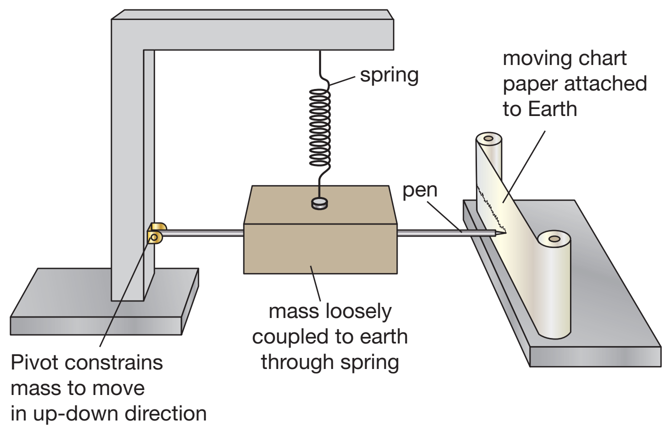


Figure 10.3.8 A vertical-mounted seismometer. The pen stays fairly still, while the recording paper and the support move up and down with the Earth.

### Seismic waves

The movement of the ground in an earthquake occurs in a shaking back-and-forth motion called a wave. These waves in the Earth caused by earthquakes are called **seismic waves**. Three main types of seismic waves can be detected (Figure 10.3.9).

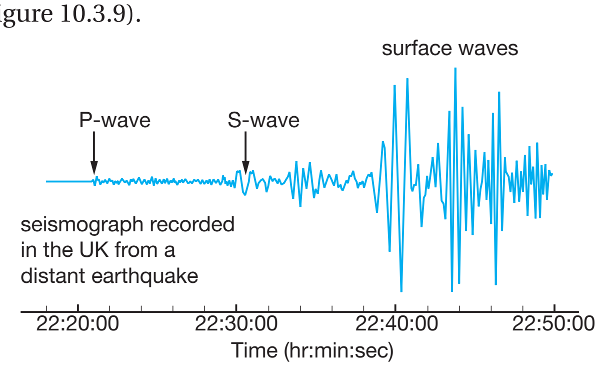


Figure 10.3.9 This seismograph shows the pen trace when S-waves, P-waves and surface waves reach the seismometer.

- **Primary waves (P-waves)** are longitudinal waves that travel fast through the Earth.
- **Secondary waves (S-waves)** are transverse waves that travel slightly slower than P-waves through the Earth.
- **Surface waves** are the slowest waves and cause the most destruction.

S-waves and P-waves travel deep under the ground and then bend upwards to reach the surface of the crust. P-waves shake the ground up and down. S-waves shake the ground sideways, back and forth.

Surface waves travel along the crust near the surface. They travel more slowly than P-waves and S-waves, but they can be much larger. They are particularly destructive if the earthquake is near the Earth's surface.

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## Where earthquakes occur

Nearly all earthquakes start at the edges of the tectonic plates. This is very obvious when you look at Figure 10.3.10. It shows that the locations of earthquakes align with the boundaries of the tectonic plates.

The strongest earthquakes occur near collision (converging) boundaries. This distribution of earthquakes provides further evidence for the theory of plate tectonics.

### Epicentres and foci

Earthquakes happen at particular places under the ground where the Earth slips, usually along a fault. The place where the quake starts is called the **focus**. This may be many hundreds of kilometres deep in the Earth. The point on the Earth's surface directly above the focus is called the **epicentre**. Buildings near the epicentre are usually the most heavily damaged.

The severity of an earthquake is calculated in several different ways. One early method, still used in some cases today, is measured on the Richter scale. This scale goes between 1 and 9. Each successive number is ten times greater than the previous number. So an earthquake measuring 5.0 is ten times more destructive than one measuring 4.0. There are two other scales commonly used as well.

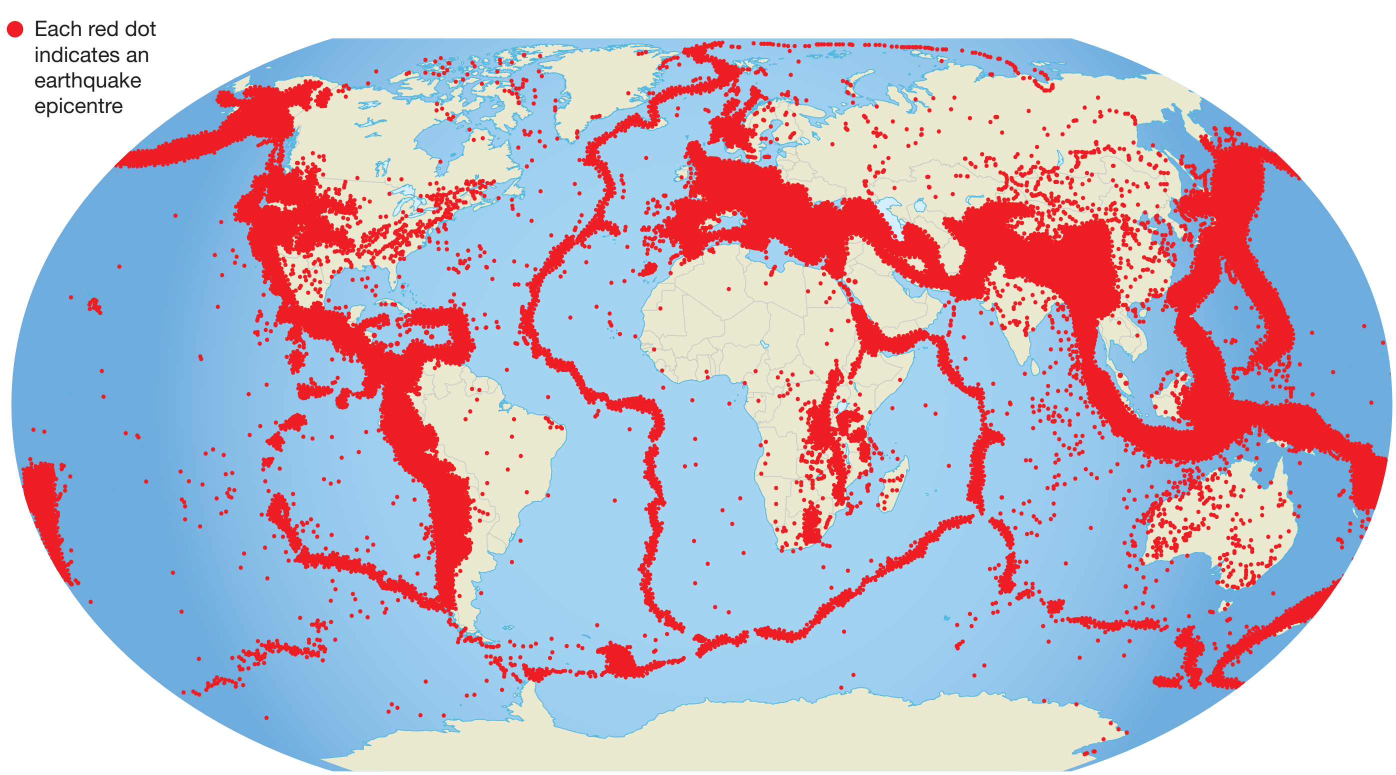


Figure 10.3.10 Earthquakes nearly all occur near the boundaries of the tectonic plates. However, some types of boundaries have more earthquakes.

# Effects of earthquakes

Earthquakes cause damage to buildings on land, and can cause landslides. However, they also cause destruction in the ocean. An earthquake under the ocean can cause a huge wave called a **tsunami**. These waves can be 100 metres high and cause massive destruction if they collide with the land near where people are living (Figures 10.3.11 and 10.3.12).

10.5

Figure 10.3.11 A tsunami hit the north-east coast of Japan on 11 March 2011, after a massive magnitude 9.0 earthquake occurred 129 km east of the town of Sendai.

Figure 10.3.12 A tsunami is a massive wave caused by an undersea earthquake. It can be devastating when it reaches land.

## Building design

It is important to design buildings to withstand earthquakes in places where earthquakes are common, such as Los Angeles (United States), Tokyo (Japan) and Christchurch (New Zealand). Engineers have found that the most effective solution is vibration control. This employs:

- dampers—structures that move in opposition to the waves and oppose their effect (Figure 10.3.13)
- base isolation—pads, springs and bearings that allow the building to suppress the waves by moving rather than vibrating with the Earth (Figure 10.3.14).

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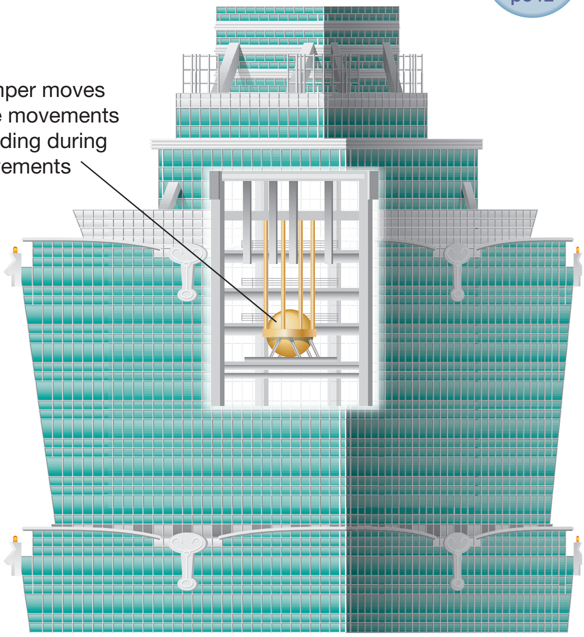



Figure 10.3.13 A damper is a structure in a building that moves and opposes the wave motion pushing on the building.

Figure 10.3.14 Base isolation involves placing structures such as these rubber bearings under a building.

Figure 10.3.15 Earthquakes cause much destruction but they also tell scientists about the structure of the Earth.

# SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

## Structure of the Earth

**Scientists cannot look directly inside the Earth. To understand its structure, they have to rely on indirect observation and data, then construct theories and models based on these. These theories and models are constantly changing as new evidence emerges.**

### Seismic waves

Seismologists use seismometers to study the Earth, and have learnt about the Earth's structure by studying earthquakes. In particular, studying how the S-waves and P-waves behave has enabled seismologists to construct the layered model of the Earth shown in Figure 10.1.7 on page 319.

Following the study of many earthquakes, seismologists used the arrival times of seismic waves at different points on the Earth's surface to draw images of the interior of the Earth. Figure 10.3.16 shows the model they constructed using this information.

Seismologists had observed that there was a 'shadow zone' where no S-waves were recorded at the surface after an earthquake. Seismologists knew from experiments that S-waves would not travel through liquids, but would travel through solids. So they proposed that there is a liquid layer around the core of the Earth. This would stop the S-waves passing through.

Seismologists also tried to explain why there was an area where few P-waves are detected. After much research studying many earthquakes, they proposed that this was due to the P-waves bending (refracting) as they passed through the liquid outer core. The waves bent down into the liquid core and this directed them away from the weak P-wave area at the surface. Further discussion and debate among seismologists led to the proposal that some P-waves bent because they had reflected off a solid inner core.

10.6

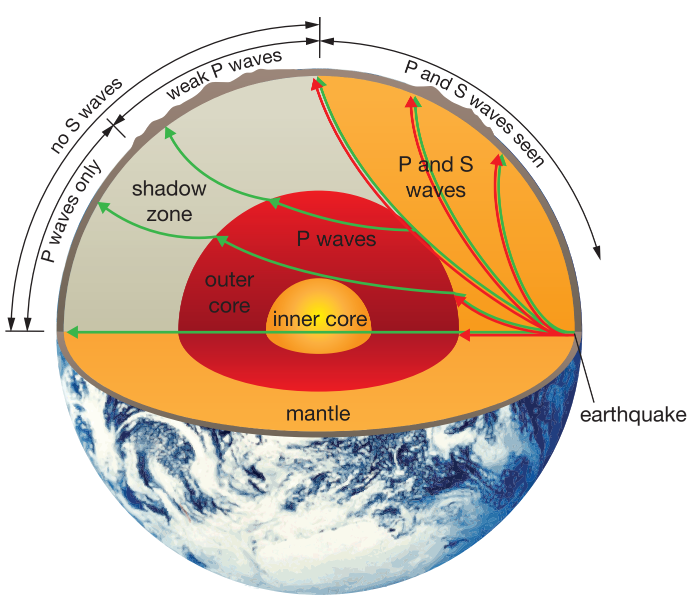



Figure 10.3.16 The behaviour of S-waves and P-waves during earthquake activity helped scientists create the layered model of the Earth's structure.

# 10.3 Unit review

## Remembering

1 **List** the colour changes in magma as it cools.

2 **List** the materials found in volcanic eruptions.

3 **Name** a tectonic process that generates heat at the boundaries of the plates.

4 **Name** the instrument used to measure earthquakes.

5 **Recall** an outcome of an earthquake under the ocean.

## Understanding

6 **Explain** why erupting magma can become explosive.

7 a **Describe** a pyroclastic flow.
 b **Explain** why it is so dangerous.

8 **Explain** how volcanoes can be dangerous to aircraft.

9 **Explain** why volcanoes are often found near the edges of converging tectonic plates.

10 **Explain** how island chains form from hot spots below the ocean crust.

11 **Define** the following terms.
 a earthquake
 b seismic wave

12 **Explain** the cause of earthquakes.

## Applying

13 The Australian Plate forms a converging boundary with the Indonesian island of Java at the Sunda Trench (also called the Java Trench). Java is one of the most volcanically active places on Earth. **Use** your knowledge of plate tectonics to **explain** the presence of these volcanoes.

14 **Use** the theory of plate tectonics to **explain** why earthquakes and volcanoes are mainly found near plate boundaries.

15 **Identify** two features of building design that prevent damage by earthquakes.

16 The distance from the Hawaiian island Kauai to the active volcano Mauna Loa is about 450 km. **Use** Figure 10.3.6 on page 336 to estimate how fast the Pacific Plate is moving (in cm/year).

## Analysing

17 **Compare** the formation of an island arc with the formation of an island chain from a hot spot.

18 **Compare** the magma produced by an oceanic plate subducting under a continental plate with that produced by an oceanic plate subducting under another oceanic plate.

19 **Compare** S-waves and P-waves.

20 **Distinguish** between the focus and the epicentre of an earthquake.

## Evaluating

21 **Propose** what evidence could help you decide whether a chain of islands was formed by a hot spot.

22 **Propose** why Japan has many active volcanoes.

23 **Use** Figure 10.3.10 on page 337 to **justify** the statement that Australia is a very geologically stable country.

## Creating

24 In the table you constructed for Question 17 in Unit 10.1, add some more evidence from Unit 10.3 that supports the theory of plate tectonics.

## Inquiring

1 Research the Reunion Hotspot and explain its possible link to the extinction of the dinosaurs.

2 Research and describe the past and possible future effects of explosive volcanoes on local and global climates.

3 Research evidence that Australia has had volcanoes in the past. List at least three different sites where there must have been volcanoes, and explain how these features were formed.

4 Research five earthquakes that have happened in the past few weeks. State where they occurred, their magnitude, any damage that occurred and some reasons why you think the earthquake happened where it did. You could start with an internet search of the US Geological Survey (USGS).

5 Research how buildings are designed to withstand earthquakes, showing examples of the use of dampers and base isolation.

# 10.3 Practical activities

## 1 Model volcanoes

### Purpose

To build a model volcano and observe its eruptions.

### Materials

- cardboard
- aluminium foil
- newspaper
- plastic tape (e.g. duct tape)
- white laboratory tray or old newspapers
- baking soda
- vinegar
- glass stirring rod
- scissors
- 100 mL beaker
- food dye
- cornflour
- Alka-Seltzer® tablets
- reaction vessel (e.g. small jar)

### Procedure

1. Fold the cardboard into a cone shape with a base diameter of about 30 cm, but leave a hole at the top large enough to hold the reaction vessel. Tape the cardboard to form the cone shape.
2. Insert the reaction vessel and tape it in securely. Seal around the edges of the cardboard with plastic tape or aluminium foil.
3. Cover the cardboard with aluminium foil to waterproof it. Tape the foil to seal it.
4. Place the volcano in a laboratory tray or on about 20 sheets of old newspaper.
5. Decide how much baking soda and vinegar to use for your first mix. Measure these out. Place the baking soda in the reaction vessel. Add a couple of drops of food dye.

   Lastly, add your measured amount of vinegar.
6. If the result was disappointing, explore different amounts of vinegar and baking soda to see if you can improve the effect. Video the experiment on your mobile phone if given permission.
7. An alternative mixture to try is a thin paste of cornflour and water (consistency of cream) and Alka-Seltzer® tablets.

### Results

Record your observations.

### Discussion

1. **Construct** a word equation for the baking soda and vinegar reaction.
2. **Compare** your model with a real volcano.

## 2 Seismometers

### Purpose

To build and test a model seismometer.

### Materials

- retort stands and clamps
- metal rod
- string
- metal weights or brick
- pen and paper
- other materials as requested

### Procedure

1. In a team, decide what your seismometer design will be like. You will have to pull the paper by hand as the pen moves over it. Construct a diagram and provide a list of necessary materials to your teacher.
2. If your teacher gives you permission, collect your equipment and build your seismometer. Test the seismometer by gently bumping the desk without moving the desk.
3. Improve on your design to make it more sensitive.
4. Observe other designs in the class and note how effective their seismographs were.

### Discussion

1. **Compare** your seismographs with those of other groups, and evaluate the effectiveness of your design.
2. **Explain** how you may be able to improve on your design.

## 3 Earthquakes and buildings

### Purpose

In this experiment you will generate your own 'earthquake' and study its effects on a small model building. You will have to design a way of testing how three variables may affect the performance of a building in earthquake areas. The three variables are:

- distribution of weight in a building
- width of the building or different sections of the building
- base isolation of the building.

### Materials

- hardcover book
- pencils
- wooden blocks, styrofoam blocks, cardboard boxes
- plasticine
- ice-cream container
- ball bearings, marbles, sand, 'hundreds and thousands'
- other materials you request

### Procedure

1. In your team, decide how you will make your 'earthquake generator', which is a way of rocking your model buildings back and forth in a wave motion. A hardcover book on pencils (like the set-up shown in Figure 10.3.17) is the simplest solution, but you will need to consider this as an experimental variable and how to control its effect.
2. Your buildings must be made in three or four sections. Use different sections (floors) about 10 cm high and base about 5 cm by 5 cm each section. You can change this if there is enough material available. You will need to make the sections from different materials such as wood or styrofoam to test variable 1.

   To test variable 2, some sections will need to be different widths.
3. To test variable 3, base isolation, you can use the ice-cream container and different materials such as ball bearings, sand, marbles and 'hundreds and thousands'. If you want to try anything else, ask your teacher.
4. Build your first model building to test one of the three variables. Place the model building on your earthquake generator and test its performance. Remember that how you operate your earthquake generator is a variable. Record your observations.
5. When you have everything working well, test the other two variables.

### Discussion

1. **Explain** how you kept the earthquake generator as a controlled variable in your three different tests.
2. **Evaluate** the importance of the three variables on building design in earthquake areas.
3. **Evaluate** the experimental procedure you used and, if necessary, **recommend** any improvements.

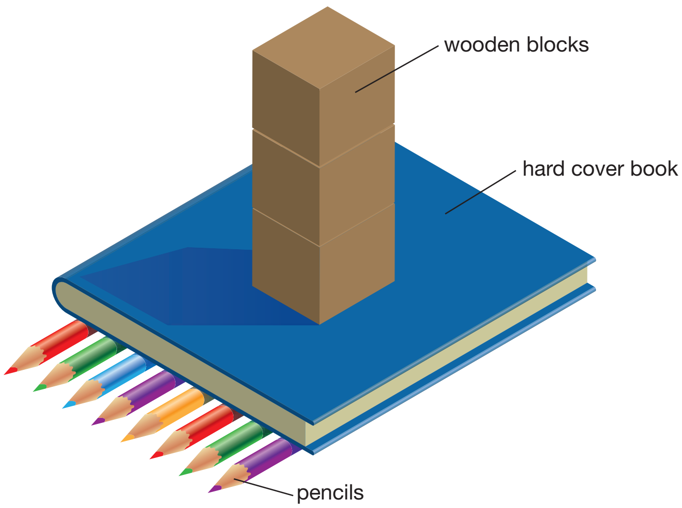



Figure 10.3.17

# Chapter review 10

## Remembering

**1** **Name** the first person to propose that the continents moved.

**2** **List** ten major tectonic plates.

**3** **List** the evidence that supports the hypothesis of seafloor spreading.

## Understanding

**4** **Define** the following terms.
- **a** lithosphere
- **b** asthenosphere

**5** **Explain** the process of seafloor spreading and subduction, and how these relate to convection.

**6** **Describe** the three types of tectonic plate movements and the effects these have on the crust.

**7** **Account** for the relationship between the places where earthquakes and volcanoes occur and where convergent and divergent tectonic plate boundaries exist.

**8** **Account** for the great age and geological stability of Australia compared with many other continents.

**9** **Discuss** some evidence that explosive volcanoes have affected the climate of the Earth in the past.

## Applying

**10** **Use** the theory of plate tectonics and the break-up of Gondwana to **explain** the evolution of Australia's unique flora and fauna.

**11** **Use** the theory of plate tectonics to **discuss** its past impact on ocean currents and the climate of the Earth.

## Analysing

**12** **Compare** the characteristics of oceanic crust and continental crust.

**13** **Compare** the effects of subduction when oceanic plates meet, with the effects when oceanic and continental plates meet.

## Evaluating

**14** **Justify** the view that mountains form because of plate tectonics.

**15** **Justify** the view that oceans form from rifting.

**16** **Critically assess** Alfred Wegener's 'continental drift' theory.

## Creating

**17** **Construct** a poster to display in your science room, adding illustrations and notes on the evidence that supports the theory of plate tectonics.

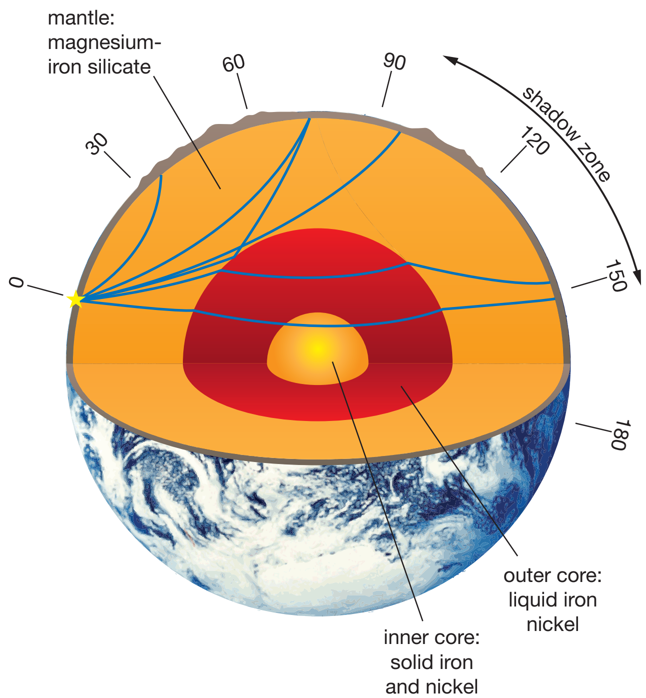
**18** **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

seafloor spreading
magnetic striping
converging boundary
diverging boundary
transform boundary
ocean trench
mountains
island arcs and chains
volcanoes
earthquakes

10.7

# Thinking scientifically

**Q1** Consider the following diagram.




This diagram is presenting evidence of:

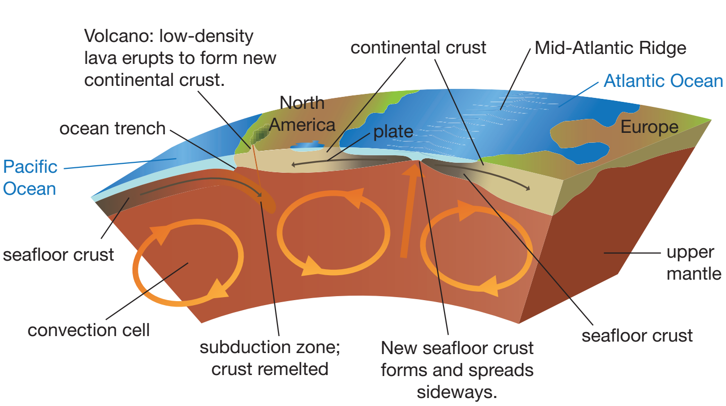
**A** volcanic activity in the crust due to tectonic plate movement

**B** the existence of earthquakes caused by subduction

**C** the interior structure of the Earth based on measurements of earthquakes

**D** how drilling has determined the chemical composition of the layers of the Earth.

Questions 2 and 3 refer to the following diagram.




**Q2** The diagram is being used to show that:

**A** the Earth is composed of layers

**B** continents are formed by seafloor spreading

**C** plate tectonics can change the Earth's climates

**D** tectonic plates move due to convection currents.

**Q3** From the diagram, you could deduce that subduction and seafloor spreading together:

**A** cause the convection currents

**B** show that the crust is recycled and therefore does not grow larger

**C** explain the formation of North America and Europe

**D** explain why volcanoes form from magma originating in the crust.

**Q4** Consider the following data on the composition of the crust.

| Mineral group | % of crust | Approximate density of mineral (weight compared with water) |
|---|---|---|
| Feldspars | 49 | 2.5–2.7 |
| Quartz | 21 | 2.6 |
| Pyroxene, olivine and others | 15 | 3–4.3 |
| Micas | 8 | 2.7–3 |
| Magnetite | 3 | 5.2 |
| Other minerals | 4 | varies greatly |

Basalt has a density of about 2.9 g/cm$^3$ whereas granite is about 2.6 g/cm$^3$. Which of the following is a likely deduction from this information?

**A** Continental crust is heavier than ocean crust.

**B** Basalt probably has more feldspars and quartz than granite has.

**C** Basalt is largely made of magnetite.

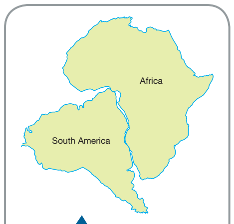
**D** There is probably more magnetite, pyroxene and olivine in basalt than in granite.

# Glossary

## Unit 10.1

**Asthenosphere:** a layer of 'plastic' semi-solid rock in the lower mantle

**Continental drift:** the separating of continents by drifting across the oceans



Continental drift

**Magnetic striping:** patterns of magnetism trapped in rocks on each side of plate boundaries

**Ocean trench:** a deep trench in the ocean floor that is much deeper than the rest of the ocean floor

**Plate tectonics:** the theory that the Earth's crust is cracked into many large pieces that move on the asthenosphere

**Rifting:** the process of continents breaking up, subsiding and allowing in the sea

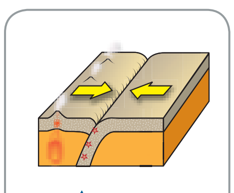
**Seafloor spreading:** the process of new crust forming at the ocean ridges and spreading outwards

**Subduction:** where the crust is sinking down into the Earth

## Unit 10.2

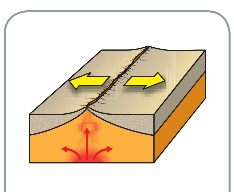
**Continental crust:** the crust that forms the continents

**Converging boundary:** where plates are colliding with each other


Converging boundary

**Diverging boundary:** where plates are moving apart from each other in opposite directions

**GPS ground station:** a receiver and computer that can detect satellite signals and calculate its position on the Earth's surface

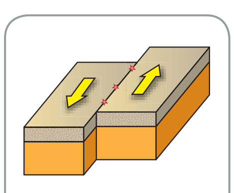

Diverging boundary

**Island arc:** a chain of islands formed at the edges of colliding tectonic plates where one plate subducts

**Oceanic crust:** the crust that forms the ocean floor

**Subduction:** when oceanic crust collides with continental crust, and the oceanic plate then sinks below the continental plate

**Transform boundary:** where plates are sliding parallel to each other but in opposite directions


Transform boundary

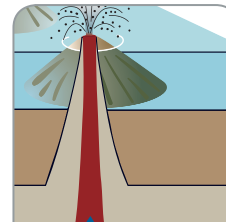
## Unit 10.3

**Earthquake:** the rapid movement of the ground, usually back and forth and up and down in a wave motion due to the movement of tectonic plates

**Epicentre:** the point on the Earth's surface directly above the focus of an earthquake

**Focus:** the place below ground where an earthquake starts

**Hot spots:** isolated places away from plate boundaries where a lot of hot magma is being created


Hot Spot

**Lava:** molten rock that has erupted onto the Earth's surface

**Magma:** molten rock below the Earth's surface

**Primary wave (P-wave):** a longitudinal seismic wave that travels fast through the Earth

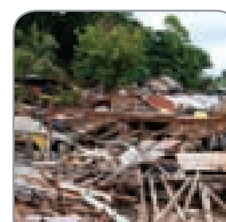
**Pyroclastic flow:** a cloud of ash, rock and gas at about 500°C that exits from a volcano like an avalanche

**Secondary wave (S-wave):** a transverse seismic wave that travels through the Earth

**Seismic wave:** the shaking, wave-like movement of the ground in an earthquake

**Seismometer:** an instrument that detects the seismic waves from an earthquake

**Surface wave:** a seismic wave that travels along the surface of the Earth in the crust


Tsunami

**Tsunami:** a huge wave in the ocean caused by an earthquake occurring on the seafloor

**Volcano:** a place where extremely hot material from inside the Earth erupts at the surface


Volcano

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