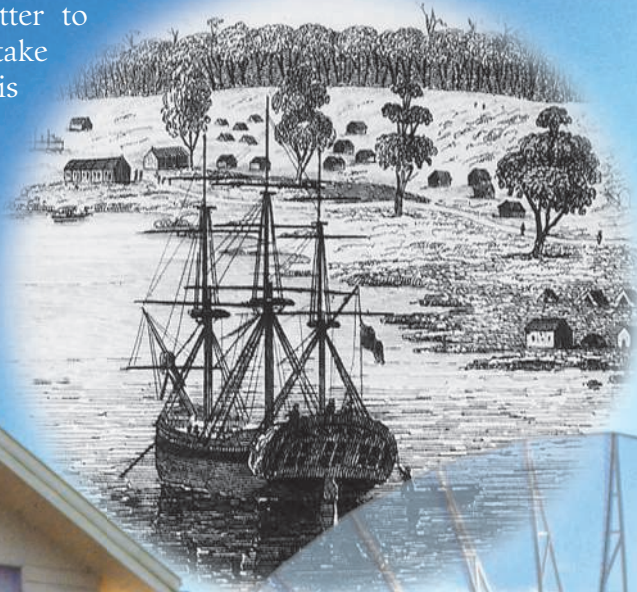


Invisible waves

5

In March 1791 Captain Arthur Phillip, Governor of New South Wales, wrote a letter to King George III in London asking to take some time off work. He received his reply over a year later — at that time it was the fastest reply in history.

How could Captain Phillip have imagined that 200 years later, he could have received a reply within seconds by telephone or email?



Think about these

What travels through air at almost one million times the speed of sound?

What do light and a Mexican wave have in common?

Microwaves can be used for heating food. What else can they do?

You can find them in living things and prisons. Where else can you find cells?

Analogue and digital — what's the difference?

Can a mobile phone kill?

What is a synchrotron and what can it do?

Key outcomes

Relate the behaviours of light, such as reflection, refraction, absorption and polarisation, to its uses in technology.

Describe the operation of a communication system and explain associated energy transfer processes.

YourQuest

A matter of communication

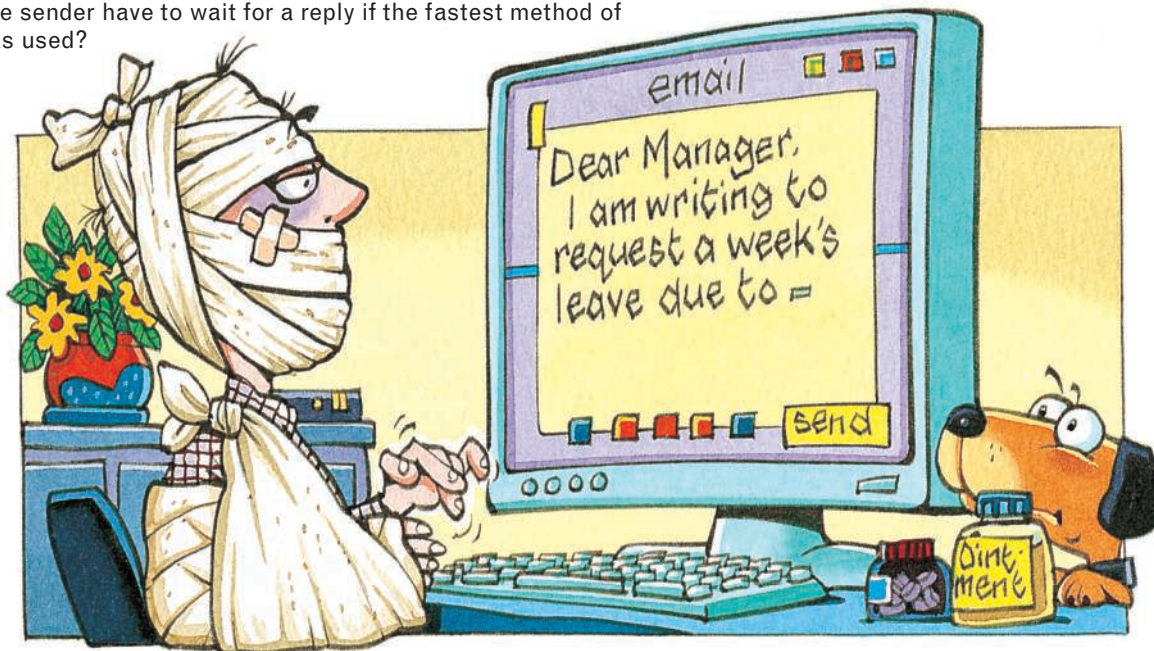
The communication between Captain Arthur Phillip and King George III that began in 1791 relied on transporting a message written on a sheet of paper. Matter, in the form of a letter, was sent from one place to another. It took 16 months for Captain Phillip to receive a response to his request for leave. That's a long time to wait if you need a holiday!

To make matters worse, the cost of each letter was the equivalent of about \$200 — and the money had to be paid by the person *receiving* the letter.

The same letter sent from Sydney to London by air mail today would take about five days to get there — and there would be another five days to wait for the reply to get back to Sydney. Just as in 1791, matter is sent from one place to another — but a lot faster. If air mail had existed in 1791, Captain Phillip would have had his answer in about 10 days.

THINK

1. What has changed since 1791 to reduce the communication time from Sydney to London and back from 16 months to 10 days?
2. What are all of the options now available for sending a request for time off work from Sydney to London?
3. Which options do not require the movement of matter from Sydney to London and back?
4. How long would the sender have to wait for a reply if the fastest method of communication was used?
5. If matter does not move from one place to another when a message is sent over a long distance, what does move?



Is this the fastest option? How does this message travel from one person to another?

Thinking about invisible waves

THINK

6. Write down as much as you know about the following types of invisible waves. Once you have finished, work with two or three others to write a group report to present to your class.
 - (a) sound
 - (b) ultrasound
 - (c) visible light
 - (d) microwaves
 - (e) infra-red
 - (f) radio waves

Making waves

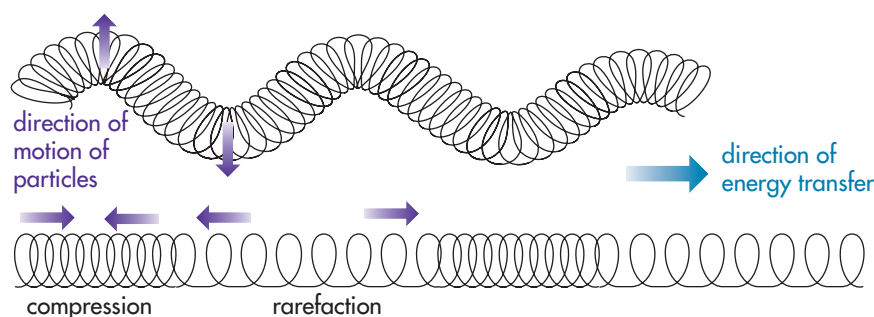
When a wave is made in a still lake by dropping a rock into it, the wave spreads out. However, the particles of water do not spread out — they just move up and down. A **wave** is able to transmit energy from one place to another without moving any matter over the same distance.

Two types of waves



Waves on water are called **transverse waves**. Transverse waves can also be made on a slinky. As shown in the diagram below, the moving particles in a transverse wave travel at right angles to the direction of energy transfer. (The word 'transverse' means 'across'.) The diagram also shows that in a **compression wave**, the moving particles move backwards and forwards in the same direction as the energy transfer. Compression waves are also known as **longitudinal waves**.

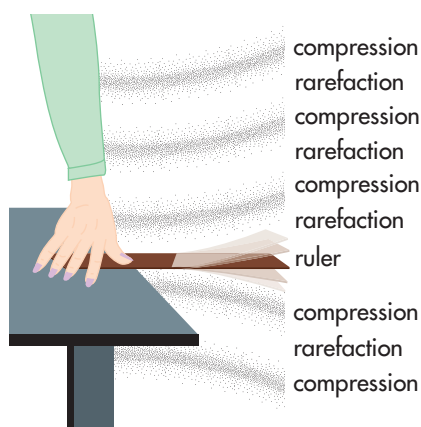
The material through which the waves travel is called the **medium** (the plural is 'media'). In the experiment on the opposite page, the media are water and the slinky respectively.



Two types of energy transfer in a slinky: a transverse wave (top) and a compression wave (bottom)

Sound waves

Sound is a compression wave. All sounds are caused by vibrations. Vibrations cause air to compress like the lower wave pattern shown in the diagram above. The diagram on the right shows how a vibrating ruler makes compression waves in air. As the ruler moves up, a **compression** is created as air particles above the ruler are pushed together. Air particles below the ruler are spread out, creating a **rarefaction**. When the ruler moves down, a rarefaction is created above the ruler, while a compression is created below it. Each vibration of the ruler creates new compressions and rarefactions to replace those that are moving through the air.



Sound is a compression wave caused by vibrations.

Some jargon to learn

The **frequency** of a vibration or wave is the number of complete vibrations or waves made in one second. The frequency of a sound wave is given by the number of compressions made in a second. The note middle C, for example, creates 256 vibrations, or compressions, every second. Frequency is measured in **hertz** (Hz), a unit named after Heinrich Hertz, the German physicist who, in 1887, was the first to detect radio waves. One hertz is equal to one vibration per second. Thus, middle C has a frequency of 256 hertz. The frequency of a sound determines its **pitch**. High-frequency vibrations produce high pitch, and low-frequency vibrations produce low pitch.

In the case of transverse waves, for example waves on water, the **wavelength** is the distance between two crests, or two troughs, or the distance between any two corresponding points on neighbouring waves. In the case of a compression wave, the wavelength is the distance between the centre of two neighbouring compressions, or two neighbouring rarefactions, as shown in the diagram opposite.

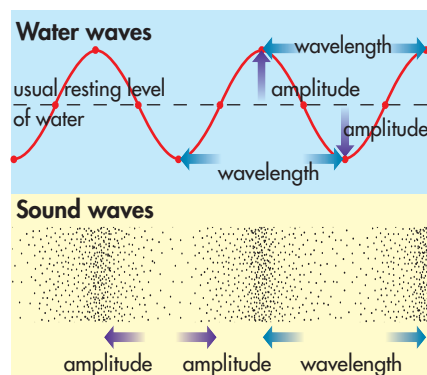
sciFacts

The human ear is capable of detecting frequencies between about 20 hertz and about 20 000 hertz. Dogs have a much greater range of hearing and can detect frequencies between 15 hertz and 50 000 hertz. Cats can hear even higher frequencies — up to 60 000 hertz.

The distance between compressions — the wavelength — of the sound of the note middle C is about 1.3 metres. The wavelength of sound made during normal speech varies between about 5 centimetres and about 2.5 metres.

As the frequency of a sound gets higher — that is, as more compressions are produced per second — the compressions become closer together. Thus, low-frequency sounds have long wavelengths and high-frequency sounds have short wavelengths.

The **amplitude** of a wave is the maximum distance that each particle moves away from its usual resting position. The amplitude of two different types of waves is also shown in the diagram below. Higher amplitudes correspond with louder sounds.



Wavelength and amplitude are useful in describing waves.

experiment



> MOVING ENERGY WITHOUT MATTER

You will need:

deep tray
small cork
eye dropper
ribbon
slinky
water

- Half fill the tray with water and place a small cork on the water's surface. Use the eye dropper to release drops of water near the cork. Observe the motion of the cork and the motion of the waves made by the drops.



A slinky can be used to find out more about waves.

1. Describe the motion of the cork.
2. Is there evidence to suggest that any water moves in the same direction as the waves?
 - Tie a ribbon around a coil near the centre of the slinky. Firmly hold one end of the slinky while your partner, holding the other end, stretches it to about the length of the room. Make a wave by rapidly flicking one end of the slinky to one side. Observe the ribbon as the wave passes.
3. Describe the motion of the ribbon as the wave moves along the slinky.
 - Make a different type of wave by pulling about ten coils of the slinky together at one end and then releasing this compressed section. Observe the ribbon as the wave passes.
4. Describe the motion of the ribbon as the wave moves along the slinky.
5. How is the motion of the ribbon different from that for the previous type of wave?
6. In each of the slinky waves produced in this experiment, energy is transferred from one end of the slinky to the other.
 - (a) Where is the ribbon after the wave has passed in each case?
 - (b) Has any particle on the slinky moved from one end to the other?

activities

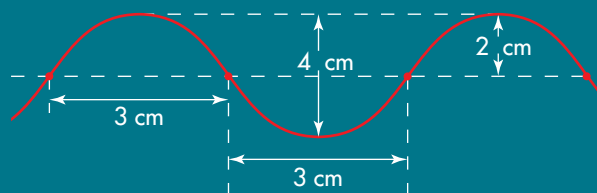
REMEMBER

- 1 What causes all sound waves?
- 2 What is the difference between a compression and a rarefaction?
- 3 What is the unit of frequency and what does it measure?
- 4 What quality of sound does the frequency determine?

THINK

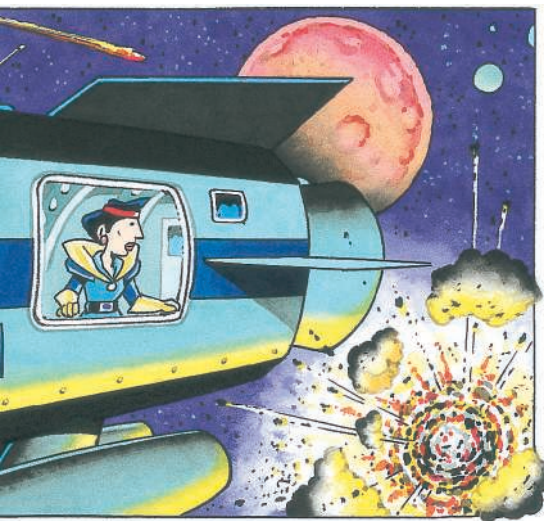
- 5 Is a Mexican wave, as seen among the crowds at some sporting events, a transverse wave or a compression wave?

- 6 What is the wavelength and amplitude of the transverse wave shown in the diagram below?



Waves on the move

Imagine that you are on a spacecraft on the way to Mars and a passing asteroid explodes. Would you hear the explosion before or after you saw it — or would you even hear it at all?



Would you hear it?

The need for particles

Because sound is transmitted as a compression wave, it can travel only through a medium that contains particles that can be forced closer together or further apart. Sound cannot be transmitted in a vacuum because there are no particles to push closer together or spread out.

As sound travels through a medium, some of its energy is absorbed by the particles in the medium and is not transmitted to neighbouring particles. Sound travels more efficiently through materials that are elastic; that is, materials in which the particles tend to come back to their original positions without losing much energy.

Speed of sound

The speed of sound in a particular medium depends on how close the particles are to each other and how easy they are to push closer together. In liquids and solids, the speed is much greater because the particles are more closely bound together. The table below shows the speed of sound in some common substances at 0°C.

The speed of sound in air is greater at higher temperatures. At sea level in dry air at 0°C, it is about 330 metres per second. At a temperature of 25°C, it is about 350 metres per second. The speed of sound in air is lower at higher altitudes. At an altitude of 10 kilometres above sea level, it is about 310 metres per second.

Speed of sound in some common substances

Substance	Speed of sound (metres per second)
carbon dioxide (at 0°C)	260
dry air (at 0°C)	330
hydrogen (at 0°C)	1300
water	1400
sea water	1500
wood	4000–5000
glass	4500–5500
steel	5000
aluminium	5000
granite	about 6000

Hear an echo?

A knowledge of the speed of sound is used in **sonar**. Sonar (**s**ound **n**avigation and **r**anging) is used on ships to map the ocean floor, detect schools of fish, and locate other underwater objects such as shipwrecks and submarines. High-frequency sound is transmitted from the ship. By measuring the time taken for the echo to return to the ship, and using the speed of sound in water, the distance to the floor of the ocean or to the underwater object can be calculated.

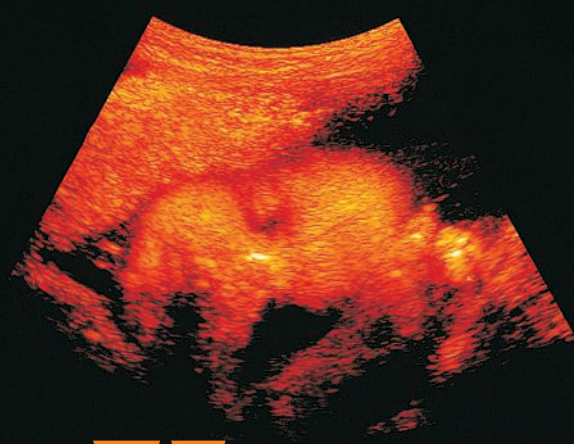
Sonar is just one example of **echolocation**. Whales, dolphins, porpoises and bats use echolocation to sense their surroundings. They each send out high-frequency sounds. The echo is detected and the animal's brain processes the information to give it a 'sound image' of its surroundings.

The power of ultrasound

Although called by a different name, echolocation is also used by engineers to locate cracks in metals; and it is used extensively in medicine. The high-frequency sound used in industry and in medicine is called **ultrasound**. Ultrasound has frequencies higher than humans can hear. Echolocation with ultrasound is used in medicine to produce images of unborn babies in the womb during pregnancy, and to search for gallstones, circulation problems and cancers. Ultrasound also has uses other than echolocation. It is used to remove some cancers,

treat an eye condition called glaucoma, shatter kidney stones and gallstones in a process called shock wave therapy, speed up the healing of muscle damage, clean surfaces, mix paint, homogenise milk and cut into glass and steel.

Ultrasound has many applications. Here, ultrasound is being used to produce an image of the face of a full-term baby in the womb.



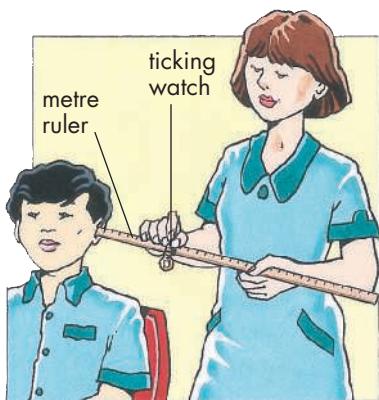
experiment

> SOUND IN DIFFERENT MEDIA

You will need:

ticking watch
metre ruler
teaspoon (or spatula)
cotton thread (or light string)

- Place a ticking watch against your ear and listen to the tick. Have your partner slowly move the watch away from your ear until you can no longer hear the ticking. Measure the distance from your ear to this point.
 - Place a metre ruler gently against the same ear and rest the watch on it against the ear. Have your partner slowly slide the watch along the ruler to a point where you can no longer hear the ticking. Measure the distance from your ear to this point.
1. What effect did the ruler have on the distance over which you could hear the sound of the ticking watch?
 - Tie about 80 cm of cotton thread to a teaspoon. Swing the teaspoon slowly so that it gently strikes the side of a bench, wall or cupboard. Listen to the sound made.
 - Place the free end of the cotton thread carefully against your ear and again gently strike the teaspoon against the same surface. Listen to the sound made.
 2. What difference does the cotton thread make to the sound heard when the spoon strikes a surface?
 3. Is sound conducted better through air or through solids?
 4. What property of the solids do you think makes the difference?



Transmitting sound

activities

REMEMBER

- 1 Why are sound waves unable to travel through a vacuum?
- 2 What is ultrasound and how is it useful?

USING DATA

The following questions refer to the data given in the table on page 114.

- 3 In general, how does the speed of sound in solids compare with that in liquids and gases?
- 4 Why do you think such a large range of speeds is given for wood and glass?
- 5 Suggest a reason why the speed of sound in most woods is generally lower than the speed of sound in steel and aluminium.
- 6 What do the data suggest about the effect of the density of a gas on the speed of sound?

THINK

- 7 Answer the question posed at the top of page 114.
- 8 Suggest why the speed of sound depends on altitude and temperature.

IMAGINE

- 9 Imagine that you are one of two astronauts walking on the moon.
 - (a) Would you be able to conduct a conversation with your partner without radios? Explain why.
 - (b) Imagine that both of your radios stopped working because you forgot to recharge the batteries. Explain how you would still be able to communicate with your partner.
- 10 Imagine that sound of different frequencies had different speeds in air. How would that affect what you heard if you were in the back row of a stadium listening to a band?
- 11 Imagine that you are standing near a steep, rocky cliff. You shout 'Hello' and one second later you hear the echo. The air temperature is about 25°C, so you estimate that the speed of sound is about 350 m/s. How far are you from the cliff?

An electromagnetic family

Isn't it great to be able to sit back in a comfortable chair and use a remote control to change the television channel or skip to your favourite scene on a DVD? When you push that remote control button, a beam of invisible **infra-red radiation** travels at 300 million metres per second towards a detector inside your television set or DVD player. The detector converts the energy of the infra-red radiation into electrical energy which, in turn, operates the controls.



A gentle push of the button sends infra-red radiation to the television set at 300 million metres per second.

Just part of the family

Infra-red radiation is just one part of the family of waves that make up the **electromagnetic spectrum**. Let's introduce the whole family, starting with the least 'energetic' members and finishing with those that are the most 'energetic'.

Radio waves include the low energy waves that are used to communicate over long distances through radio and television. They also include radar and microwaves.

Infra-red radiation, invisible to the human eye, is emitted by all objects and is sensed as heat.

The amount of infra-red radiation emitted by an object increases as its temperature increases.

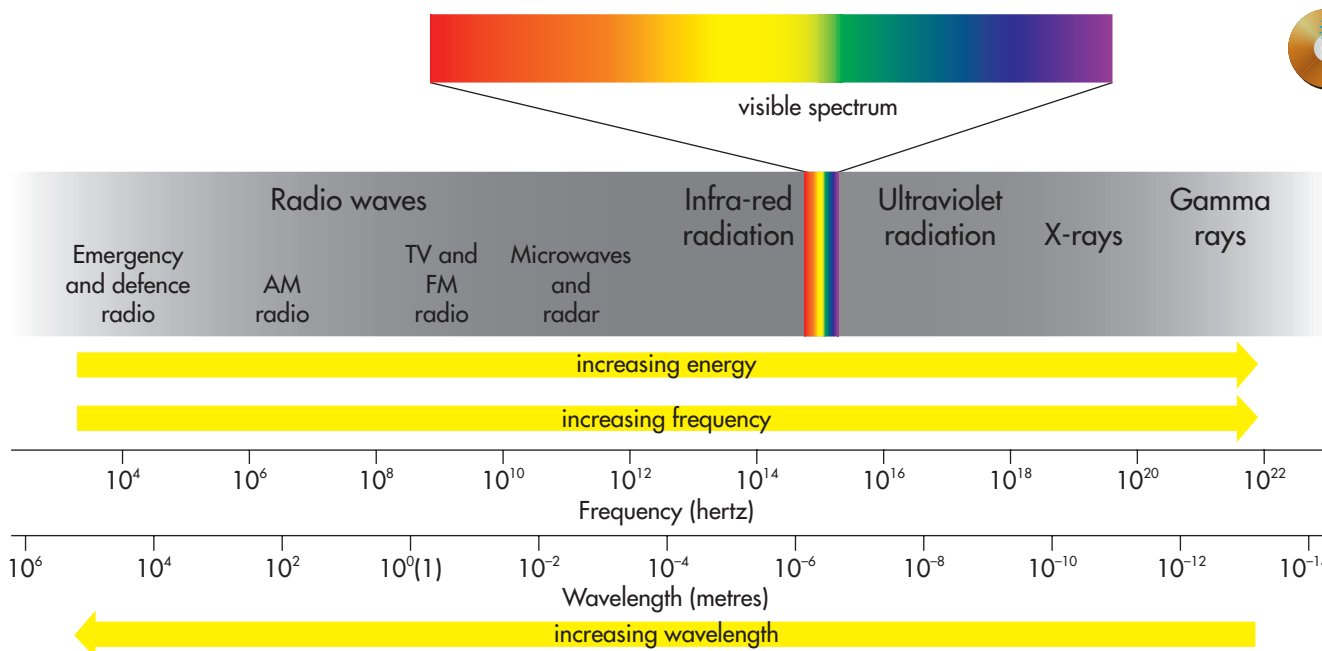
Visible light represents only a very small part of the electromagnetic spectrum. It is necessary for the sense of sight. The process of photosynthesis in green plants cannot take place without visible light.

Like infra-red radiation, **ultra-violet radiation** is invisible to the human eye. It is needed by humans to help the body produce vitamin D; however, too much

exposure to ultraviolet radiation causes sunburn.

X-rays have enough energy to pass through human flesh. They can be used to kill cancer cells, find weaknesses in metals and analyse the structure of complex chemicals. X-rays are produced when fast-moving electrons give up their energy quickly. In X-ray machines, this happens when the electrons strike a target made of tungsten.

Gamma rays have even more energy than X-rays and can cause serious damage to living cells. They

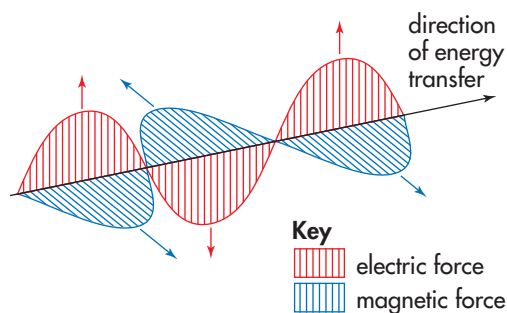


The electromagnetic spectrum

can also be used to kill cancer cells and find weaknesses in metals. Gamma rays are produced when energy is lost from the nucleus of an atom. This can happen during the radioactive decay of nuclei or as a result of nuclear reactions.

Waves without particles?

Like all waves, **electromagnetic waves** transmit energy from one place to another. All electromagnetic waves travel through air at 300 000 000 metres per second. Unlike sound waves and water waves, electromagnetic waves can travel through a vacuum. The waves consist of a repeating pattern of electric and magnetic forces. These forces are generated by changes in the speed or direction of moving electric charge. The frequency of electromagnetic waves is a measure of the number of times per second that a new electric or magnetic force is generated. The wavelength is the



A representation of part of an electromagnetic wave

distance between adjacent electric or magnetic forces. The diagram below left shows that electromagnetic waves are transverse waves. The electric and magnetic forces are at right angles (that is, across) to the direction of motion of the wave. The direction of the electric force is defined as the direction in which it would push on a positive electric charge. The direction of the magnetic force is defined as the direction in which a compass needle would point.

Polarising light

Light is polarised when it passes through a material that allows electric forces travelling in only one direction to pass through it. A polarising material known as polaroid is used in sunglasses to reduce glare caused by sunlight reflecting from water, sand, snow and clouds.

It's natural

Some electromagnetic radiation is emitted by all objects, including the sun. The higher energy waves, like ultraviolet radiation and X-rays are emitted naturally by stars. Our own sun emits ultraviolet radiation and X-rays. Gamma rays are emitted by radioactive substances and larger stars. All types of electromagnetic radiation can be produced artificially.

What's the difference?

Some of differences between sound waves and electromagnetic waves are summarised in the following table.

Sound and electromagnetic waves: some differences

Sound waves	Electromagnetic waves
compression (longitudinal) waves	transverse waves
travel through all solids, liquids and gases, but are unable to travel through a vacuum	unable to travel through some substances but travel through a vacuum
speed in air between about 330 m/s and 350 m/s, depending on temperature	speed in air about 300 000 000 m/s

REMEMBER

- Are electromagnetic waves transverse waves or longitudinal waves?
- List three properties that all electromagnetic waves have in common.
- List three differences between sound waves and electromagnetic waves.
- List the members of the electromagnetic family that have more energy than visible light.

USING DATA

- The sound of a starting pistol can be heard easily by an observer one kilometre away. From that distance, the sound of the pistol is heard some time after the smoke is seen. Calculate to the nearest second:
 - how long it takes sound to reach the observer
 - how long it takes light scattered from the smoke to reach the observer.
- The speed of sound in air at a temperature of 25°C is about 350 m/s.
 - How long would it take for sound waves to travel from Melbourne to Sydney, a straight distance of about 700 km when the air temperature is 25°C?
 - Why doesn't it take this long for the sound to reach you by telephone, television or radio?

THINK

- How do you know that electromagnetic waves are not compression waves?
- Explain why you always hear thunder after you see the lightning that caused it.

INVESTIGATE

- What happens when you look at the liquid crystal screen of a calculator through a polarising material?

We're on the air

The human desire to continually improve communications seems infinite. Since the Stone Age, humans have been finding new ways to communicate with more people over greater distances at a greater speed. After the discovery of radio waves by Heinrich Hertz in 1887, and a few years of clever work by the Italian engineer Guglielmo Marconi, it became possible to send messages over long distances at the speed of light.

Riding on a radio wave

Radio waves are emitted naturally by stars. They can also be produced artificially when electrons in a metal rod are made to vibrate rapidly. This metal rod is called a **transmitting antenna** or transmitter. These vibrations cause radio waves to travel through the air (at about 300 000 kilometres per second). The radio waves can be detected by a **receiving antenna**, which is a metal rod just like the transmitter. The radio waves cause electrons in the receiving antenna to vibrate rapidly, producing an electrical signal. The process of using radio



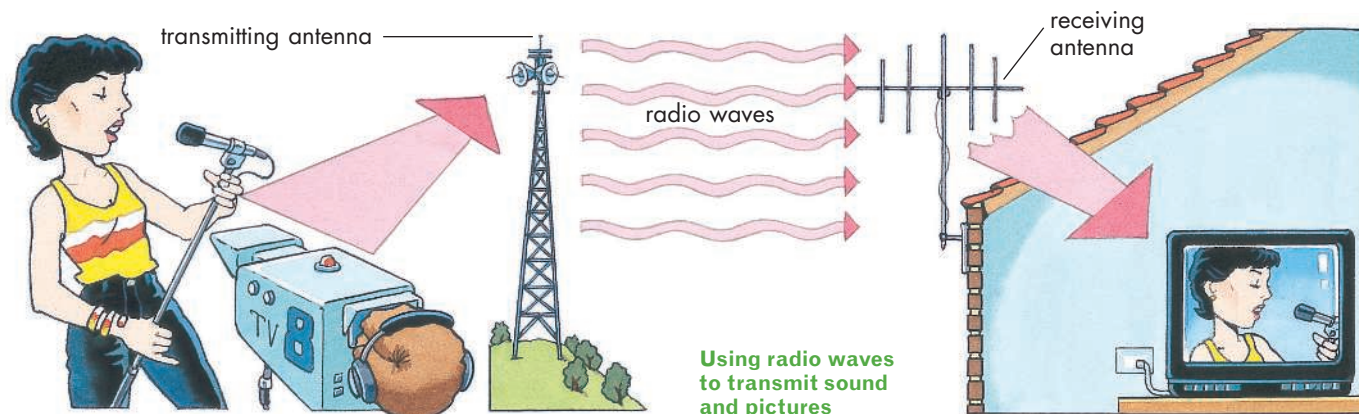
Through television and radio we can hear news from all over the world — and even from space — within seconds.

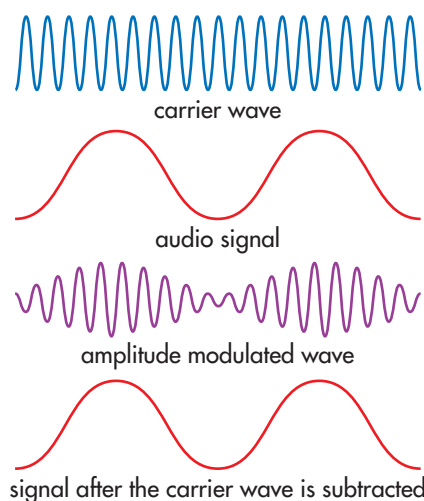
waves to transmit either sound or television pictures is shown in the diagram below.

AM radio

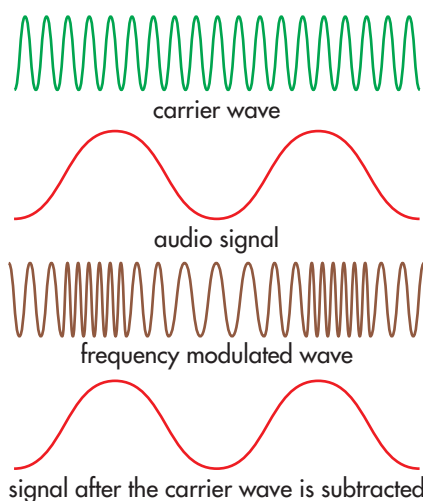
Each AM radio station has a particular frequency of radio waves on which it transmits sound signals. The sound signal must firstly be changed to an electrical signal. This electrical signal is called an **audio signal**. The waves on which messages are sent are called **carrier waves**. The audio signal is added

to the carrier wave, producing a modulated wave, as shown in the diagram on the opposite page. The receiving antenna of your radio detects the modulated wave. Your radio then 'subtracts' the carrier wave from the signal, leaving just the audio signal. The audio signal is amplified by an audio amplifier inside the radio and sent to speakers. In the speakers, the changing electric current is used to make the surrounding air vibrate to produce sound.





AM radio transmission



FM radio transmission

The carrier signals for AM radio stations have frequencies ranging from about 540 kilohertz up to about 1600 kilohertz. When you tune in your radio, you are selecting the frequency of the carrier wave that you wish to receive. For example, if you tune to ABC Local Radio Melbourne, you are selecting the carrier wave with a frequency of 774 kilohertz.

AM stands for **amplitude modulation**, and the diagram above left shows why: the audio signal changes the amplitude of the carrier wave.

FM radio

Like AM radio stations, each FM radio station has its own carrier wave frequency. However, the carrier frequencies are much greater — between 88 megahertz and 108 megahertz (1 megahertz equals 1 million hertz). The other major difference between AM and FM radio is the way that the audio signal is carried on the carrier wave. Instead of adding the audio signal to the carrier wave (which changes the amplitude of the wave), the audio signal changes the frequency of the carrier wave as shown in the diagram above right. FM stands for **frequency modulation**.

As with AM radio, when you tune in your radio to FM you are selecting the frequency of the carrier wave that you wish to receive. For example, if you tune to Triple J in Melbourne, you are selecting the carrier wave with a frequency of 107.5 megahertz.

FM radio waves are affected less by electrical interference than AM radio waves and therefore provide a higher quality transmission of sound. However, they have a shorter range than AM waves and are less able to travel around obstacles such as hills and large buildings.

Television

Television signals are transmitted on two separate carrier waves. The visual signal is added onto one carrier wave using amplitude modulation. The audio signal is carried on a separate carrier wave using frequency modulation. When you tune your television set to a particular channel, you are selecting the visual and audio carrier waves that you wish to receive. Your television set then completes the task of removing the carrier waves and translating the signals sent into a picture and sound. This is quite a complex task, as you might imagine!

activities

REMEMBER

- 1 How are radio waves produced artificially?
- 2 Sound waves cannot be directly transmitted through the air over long distances. What has to happen to them before they can be transmitted on radio waves?
- 3 What is a carrier wave?
- 4 Explain the difference between the way that AM and FM radio waves carry audio signals.
- 5 List one advantage and one disadvantage of FM radio over AM radio.
- 6 How are television signals carried by radio waves?

USING DATA

- 7 Express the frequency of the following radio stations in Hz. (A frequency of 1 Hz corresponds to one complete wave being produced each second.)

- (a) Triple M (FM), Melbourne: 105.1 MHz
- (b) 3CV (AM), Bendigo: 1071 kHz
- (c) Triple J (FM), Shepparton: 94.5 MHz
- (d) Triple J (FM), Latrobe Valley: 96.7 MHz
- (e) ABC (AM), Sale: 828 kHz

1 kHz = 1000 Hz (or 10^3 Hz)

1 MHz = 1 000 000 Hz (or 10^6 Hz)

- 8 The wavelength (λ) of a wave is related to the frequency (f) of the wave by the equation:

$$v = f\lambda \quad \text{where } v \text{ is the speed of the wave.}$$

The speed of radio waves in air is 300 000 000 m/s.

Use this equation to calculate the wavelength of the carrier waves used by radio stations Triple M, Melbourne and 3CV, Bendigo.

INVESTIGATE

- 9 Find out more about how television pictures are transmitted and reproduced on your television screen.

The digital revolution

The audio and visual signals described on pages 118 and 119 are examples of **analogue** signals. Analogue quantities are those that can have any value and can change continually over time. **Digital** quantities are those that can have only particular values and are represented by numbers.

Whereas analogue radio and television signals are carried as continuously changing amplitudes or frequencies, digital signals are carried as a series of 'on' and 'off' pulses. The signals can have only two values — 'on' or 'off'. The original audio and video (sound and vision) are sampled and converted into pulses. Audio signals are sampled about 40 000 times every second. Video signals are sampled more than 13 million times every second. The pulses are added to the carrier waves for transmission.

Out with the old, in with the new

Digital television commenced transmission in Australian capital cities in 2001. Until some time between 2010 and 2012 both digital and analogue signals will be broadcast. During that period analogue signals will be gradually phased out, firstly in major cities and then in rural areas. Once analogue transmissions cease, a

Analogue or digital — smooth or in bits

You can read the time from an analogue watch with hands that continuously rotate, or from a digital watch with LEDs (light-emitting diodes) or liquid crystals that simply turn off and on.



An analogue watch represents time as a quantity that changes smoothly.



A digital watch represents time as a quantity that changes in 'bits'.

All physical quantities like time, speed, weight and pH can be represented in analogue or digital form. Likewise, invisible waves like sound and radio waves can be transmitted in analogue or digital form.

- Analogue forms change smoothly if the quantity being measured changes smoothly.
- Digital forms display or transmit quantities as a limited series of numbers or pulses. Digital devices are usually electronic. Their displays are made from devices that can only ever be 'on' or 'off'. For example, each number display of a digital measuring device is made up of seven devices. Each of the seven devices can be either 'on' or 'off'. The arrangement of the seven devices allows all of the numbers from 0 to 9 to be displayed.



Each number in this digital display is made up of seven LEDs, each of which can be either 'on' or 'off'.

digital TV set top box can be used to convert the digital signals back to an analogue form. This means that nobody will have to replace their old analogue TV sets with digital TV sets unless they choose to.

The introduction of digital radio is also on its way. Trials of digital radio commenced in 2003.

What's the advantage?

Both analogue and digital television signals fade away as they travel through the air. Like all other waves, the energy they carry spreads out. So, as they travel over distance their intensity, or strength, decreases. As the continuous analogue becomes weaker, the background radiation and signals from other sources have a greater effect on the amplitude of the wave. It becomes distorted. The result is a fuzzy picture and poor quality sound. Because digital signals can be only 'on' or 'off' pulses, background radiation and signals from other sources cannot interfere with them — even as they become weaker. The rapidly pulsating signals are still either 'on' or 'off' until the 'on' signals have faded away to nothing.

As a result, digital television has several advantages over analogue television. It provides:

- sharper images and 'ghost free' reception
- widescreen pictures
- better quality sound
- capability of 'surround' sound
- access to the Internet and email
- capability of interactive television, allowing the viewer to see different camera views or even different programs on the same channel

- Electronic Program Guides (EPGs) which can provide 'now' and 'next' information about programs.



A digital TV set top box converts digital TV signals into a form suitable for an analogue TV set.

activities

REMEMBER

- 1 Summarise the differences between the digital and analogue signals that are added to carrier waves for television transmission.
- 2 Will you have to have a digital TV set to watch programs when analogue transmission ceases? Explain your answer.
- 3 Digital television has several advantages over analogue television.
 - (a) List five of the advantages.
 - (b) Explain why digital signals have these advantages.

THINK

- 4 Why do digital TV signals provide the capability of interactive TV whereas analogue signals do not?

- 5 If you could choose an analogue device or a digital device to measure your weight, which would you choose? State the reasons for your choice.
- 6 Write the name of an analogue device (or substance) that measures:
 - (a) time
 - (b) speed
 - (c) weight
 - (d) pH.

INVESTIGATE

- 7 Search the Internet to find out:
 - (a) what multichannelling is
 - (b) the benefits of interactive television.

It's a long, long way

Australia is covered with a network of microwave and radio repeater towers, coaxial cables, optical fibres and satellite dishes. This network allows us to transmit television and radio signals, telephone calls, facsimiles and computer data across our massive continent.

The microwave link

Television and radio signals, computer data and telephone messages can be transmitted over long distances using microwaves. Microwaves can carry many signals at the same time. However, **repeater stations** need to be used so that the signal does not fade away before it reaches its destination. Antennas on the repeater stations receive the microwave signals and send them on to the next station.

Each repeater tower needs to be within sight of the next one because microwaves, like visible light, travel in straight lines. So, the repeater towers are built on the top of hills wherever possible.



The repeater stations are towers with dish-shaped antennas.

The electric way

Coaxial cables allow sound, pictures and data to be transmitted as pulses of electric current rather than as electromagnetic waves. The signals are carried along conducting wires inside tubes. The thin wire is held in the centre of the tube by a plastic insulating disc. Most Australian coaxial cables contain four, six or twelve tubes. Smaller conductor wires in the cable are used to provide links to small towns along the length of the cable. They are also used to control the system. Coaxial cables are buried under the ground or laid on the ocean floor.

The first major coaxial cable in Australia was laid between Sydney, Melbourne and Canberra in 1962. Coaxial cables can simultaneously transmit many more telephone calls and television signals than earlier cables were able to. As with the microwave system, repeater stations need to be used along the length of the coaxial cable so that the signal does not fade away. Coaxial cable repeater stations need to be even closer together than microwave repeater stations.



A coaxial cable contains many conducting wires in up to 22 tubes. Coaxial cables can carry television signals as well as telephone calls and facsimile messages. They are designed to minimise interference from outside the cable and to prevent the many signals being carried from interfering with each other.

sciFacts

The first microwave communications system in Australia was opened in 1959. It provided a link between Melbourne and Bendigo. This link signalled the beginning of the end for the overhead telegraph wires that hung between wooden poles.

The light fantastic

The table on page 123 shows that **optical fibres** can transmit more messages at one time than coaxial cable or microwaves. Optical fibres are long, thin, transparent strands of glass. Electrical signals from a microphone, television camera, computer or facsimile machine are converted into pulses of light. These pulses are produced when an electrical signal is used to turn the light on and off millions of times per second.

Options for long-distance communication over land

Type of link	Number of two-way conversations at once
copper cable	600
coaxial cable	2 700
microwave	2 000
optical fibres	30 000

The light pulses received at the other end are converted back into electrical signals that can be fed into speakers, a television set, computer or facsimile machine. The messages can also be retransmitted as microwaves or radio waves if necessary.

The idea of using visible light to transmit messages over long distances was not feasible until the invention of the laser in 1958. The word 'laser' is an acronym, standing for **light amplification by stimulated emission of radiation**. A laser produces an intense light beam of one pure colour. As the beam travels through the optical fibre, the glass absorbs some energy. Repeaters are needed every

35 to 55 kilometres along optical fibre cables to boost the signal. The light loses energy less quickly than normal light would, because a laser beam spreads out very little.

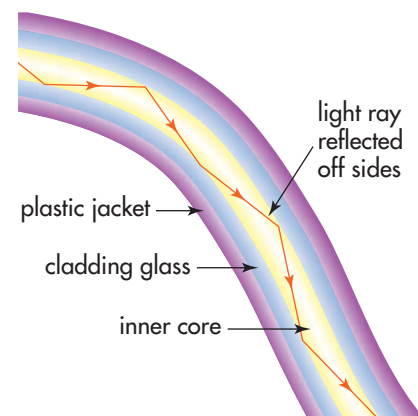
The first successful glass optical fibres were made in 1973. The advantages of optical fibres are so great that Australia already has a network of fibre cables between all capital cities. Optical fibres can be laid under the ground or under water. They are smaller, lighter, more flexible and cheaper than the electrical cables previously used for long-distance telephone, radio and television communication. Light pulses cannot be interfered with by radio waves, so there is no 'static'.



Optical fibres use total internal reflection to transmit light pulses.

Optical fibres — how they work

The glass in optical fibres is made so that light is unable to emerge from the glass. This is achieved by covering the glass with a cladding of denser glass or plastic. As light travels from the inner glass core to the denser cladding, it bends (refracts) so much that, instead of leaving the glass, it is reflected back into it. This process is called **total internal reflection**. The following diagram shows how total internal reflection occurs in an optical fibre. Even if the fibre is bent a little, the light is 'trapped' inside by total internal reflection.



Total internal reflection in an optical fibre

Satellites

Communications **satellites** allow radio waves and microwaves to be transmitted at the speed of light from continent to continent. In Australia, satellites are used to transmit radio, television and telephone signals from cities to remote areas.

Signals are transmitted to a satellite in **geostationary** orbit. The signals are then sent back to other parts of Australia, or to other satellites which, in turn, transmit the signals to other continents. The energy needed to amplify and retransmit the signals

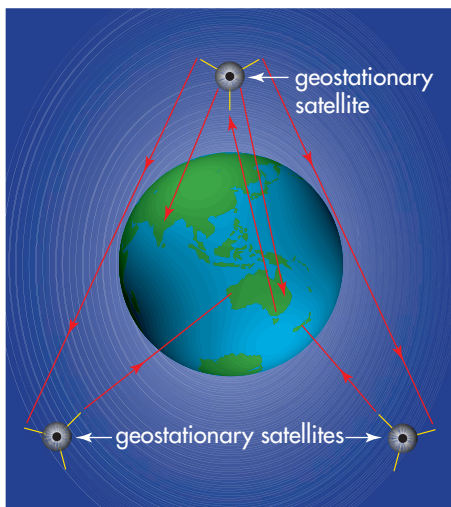
is mostly provided by the sun. Solar panels on the satellite collect solar energy, which is either used straight away or stored in batteries for later use.

A geostationary satellite is one that orbits the Earth once every 24 hours, thus remaining over the same point on Earth at all times. In order for the satellite to orbit at that rate, it must be located about 36 000 kilometres above

the equator. Tracking stations on Earth use radio signals to activate small rockets on the satellites to keep them in the correct orbit.

Dish antennas, such as the ones in the photograph below, are

aimed at a particular satellite ready to receive signals. The shape of the dish allows for the collection of a large amount of electromagnetic energy, which is focused towards the antenna.



A geostationary satellite relays radio signals to other locations in Australia, or to other continents.



These antennas receive signals that have been retransmitted by a geostationary satellite.

experiment

> TOTAL INTERNAL REFLECTION

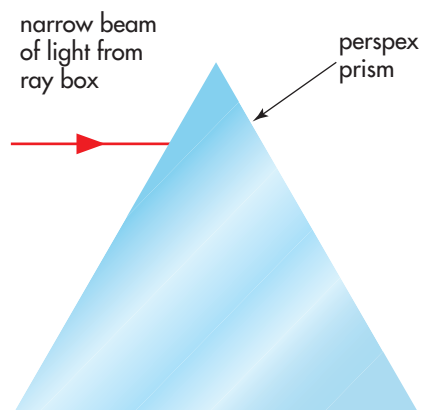
You will need:

ray box kit
power supply
perspex triangular prism
a sheet of white paper

- Connect the ray box to the power supply. Place a sheet of white paper on the workbench in front of the ray box. Use one of the black plastic slides in the ray box kit to produce a single thin beam of light which is clearly visible on the white paper.
- Place a perspex triangular prism on the sheet of paper and direct the thin beam of light towards it as shown in the diagram on the right. Observe the beam as it passes through the prism.

- Turn the prism slightly anticlockwise, closely observing the thin light beam as it travels from the perspex prism back into the air. Continue to turn the prism until the beam no longer emerges from the prism.
1. Describe what happens to the thin light beam as it passes from air into the perspex prism and back into the air.
 2. What happens to the beam of light when it no longer emerges from the prism?
 3. Draw a series of three or four diagrams showing how the path of the beam of light changed as you turned the prism.

4. Explain how the amount of light reflected changes as the prism is turned.



Observe the beam of light as it passes through the prism.

A new voice in the outback

In remote areas of Australia, the main long distance communication networks currently used are:

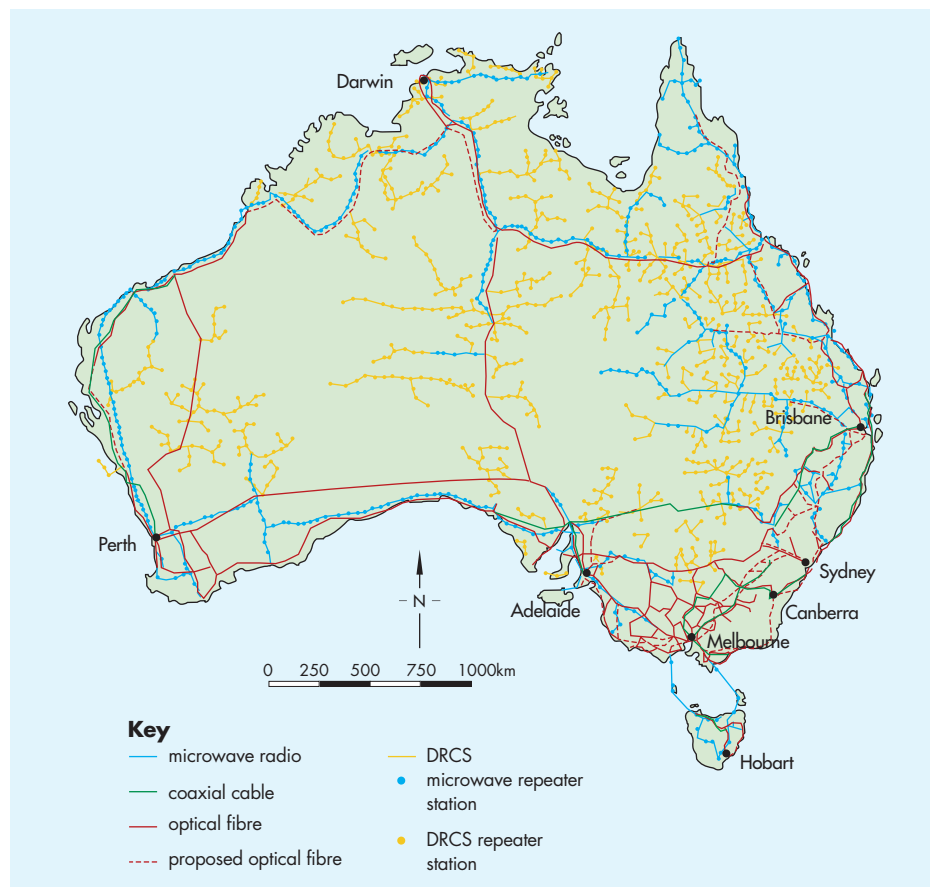
- High Capacity Radio Concentrator (HCRC)
- Digital Radio Concentrator System (DCRS)
- Code Division Multiple Access — Wireless Local Loop (CDMA-WLL)

The HCRC and DRCS systems allow people in remote areas to send or receive telephone calls using radio waves. The HCRC system consists of a central station, a remote base and a number of customer radio terminals that connect to the remote base. The signals are sent to or from solar-powered repeater stations.

All DRCS systems are now being replaced by HCRC or CDMA-WLL systems, which are faster and more reliable.



A combined HCRC/DRCS unit being installed



Australia's long-distance communication network

activities

REMEMBER

- 1 List the different types of electromagnetic waves that are used for long-distance communication across Australia.
- 2 Why are repeater stations necessary for the transmission of microwaves and other radio waves?
- 3 What is total internal reflection?
- 4 How can light be used to transmit the electrical signals from microphones, television cameras, computers or facsimile machines?
- 5 From where do communication satellites get the energy required to amplify and retransmit signals from Earth?

THINK

- 6 Why are repeater stations necessary along coaxial cables?
- 7 Refraction is the bending of light as it passes from one medium to another. What is the role of refraction in an optical fibre?
- 8 Why are microwaves and other radio waves preferred for communication in the outback rather than optical fibres or coaxial cables?
- 9 Why are communication satellites placed in geostationary orbit?
- 10 The term 'global village' has been used to describe the Earth in recent times.
 - (a) Why do you think this term has been used?
 - (b) How has the development of long-distance communication changed the lifestyles of Australians during the past 40 years?

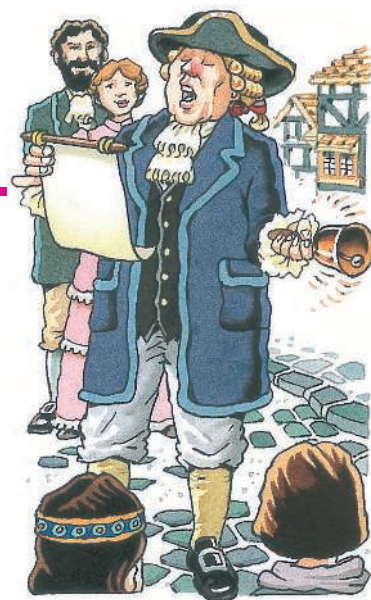
INVESTIGATE

- 11 Research and report on how outback Australians communicate with their neighbours and the rest of the world.

A step back in time

We've come a long way since the seventeenth century when one could hear the local news of the day only if the town crier walked by. Now, we receive news from all over the world — and even space — within seconds. Let's take a step back in time and see how long-distance communication began.

Morse devised a code that allowed messages to be sent simply by opening or closing a switch. Pulses of electricity operated a pen at the other end, which made dots or dashes on a strip of paper.

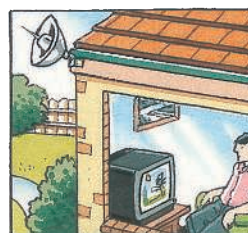
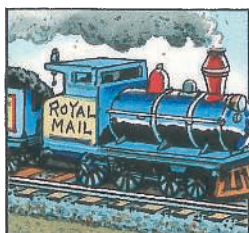
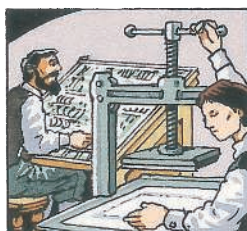
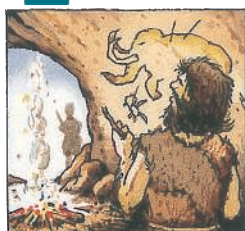


Ring, ring . . .

The invention of the telephone by Alexander Graham Bell in 1876 made it possible for the sound of a voice (instead of a coded signal) to be transmitted through telegraph wires. However, new cables were needed and many problems had to be overcome before the messages could be transmitted over more than a few kilometres. For example, it was not until 1936 that a submarine cable provided a telephone link between Tasmania and the rest of the world. At the time, it was the longest underwater cable in the world.

try This

Communication through the ages

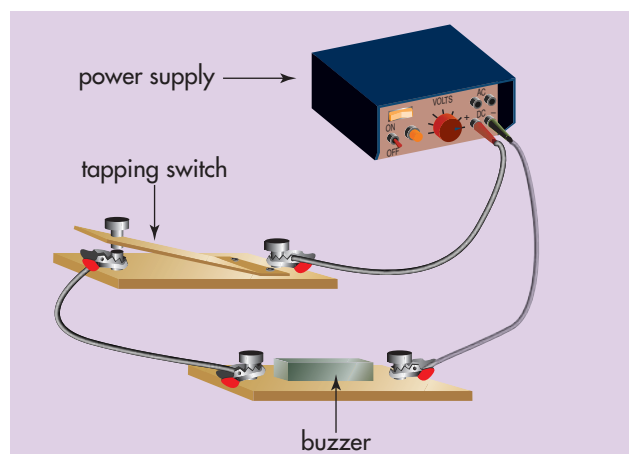


- Look at each of the sketches above. For each sketch, list:
 - the tools, or technology used to communicate
 - a likely sender of the message
 - a likely receiver of the message
 - the approximate distance over which the message can be sent
 - an estimate of the time it would take to receive the message.
- Add three sketches of your own, together with answers to (a) to (e) above.
- How can messages be sent to future generations?
- The term 'mass media' refers to methods of communication that allow a message to be sent to many people at once. How did 'the masses' receive news before radio and television?
- List the ways in which mail might have been delivered in Australia during:
 - the eighteenth century
 - the nineteenth century
 - the twentieth century.

> DOTS AND DASHES

You will need:

power supply
buzzer or light globe
tapping switch
3 connecting leads



A simple circuit for sending and receiving Morse code

- Connect the circuit shown in the diagram above. A light globe can be used instead if a buzzer is not available.
- Test your circuit to make sure that the buzzer or light globe operates only when the switch is closed.
- Write down a short message in words without letting your partner see it. Use the Morse code key and rules on the right to write your message.

- Use the tapping switch to send the message to your partner, who will write the message down in Morse code and then translate it into words.
- Switch roles and repeat the procedure. Each person will need practice, so it is best to start with messages that consist of only two or three words.

- Which letters are most easily or quickly transmitted?
- Is the code random, or is there a pattern to it? If there is a pattern, what is it?
- Which part of this communication takes the most time?

A · —	H · · · ·	O — — —	V · · · —
B — · · ·	I · ·	P · — — ·	W · — —
C — · — ·	J · — — —	Q — — — ·	X — · — —
D — · ·	K · — ·	R — · ·	Y — · — —
E ·	L · — · ·	S · · ·	Z — — · ·
F · · — ·	M — —	T —	
G — — ·	N — ·	U · · —	

1 · — — — —	5 · · · · ·	9 — — — ·
2 · · — — —	6 — · · · ·	0 — — — —
3 · · · — —	7 — — · · ·	. (Full stop) · · · · ·
4 · · · · —	8 — — — ·	, (Comma) · — · — —

Rules

- A dash lasts as long as three dots.
- A space as long as one dot is left between each pulse.
- A space as long as one dash is left between each letter of a word.
- A space as long as five dots is left between each word of a sentence.

activities

REMEMBER

- What discovery made it possible to send coded messages over long distances within seconds for the first time?
- Which invention made it possible to transmit the sound of a voice over several kilometres for the first time?

CREATE

- Create a crossword puzzle that includes some of the communication devices or methods listed below. You may wish to add some devices or methods not in the list. Provide a clue for each word.

mail	megaphone	newspaper
radio	doorbell	television
email	microphone	telegraph
the Internet	braille	telephone
fax	voice	book

- Construct a timeline to show how communication has developed through the ages. Try to extend your timeline five years beyond the present time.

THINK

- Which communication devices and methods used since the Stone Age are still used today?
- How was the news reported before newspapers, radio and television existed?
- Is Morse code a digital or analogue form of communication? Explain your answer.

IMAGINE

- Imagine that you are a time traveller. You find yourself in Baltimore in the year 1844, just in time to watch Samuel Morse send the first telegraph message to Washington DC. Write a short letter to Samuel Morse explaining to him how long-distance communication will develop up to the year 2000.

Going mobile

It does not matter whether you are playing tennis, shopping in town or relaxing at home — you can still talk to your friends on the telephone. Since the first major mobile phone service was introduced in Australia in 1987, millions of Australians have purchased mobile phones.

How mobile phones work

Domestic and business telephones are connected by cable to the network of microwave and radio links, coaxial cables and optical fibres. Mobile phones transmit signals on radio waves to a **base station**, which consists of several antennas at the top of a large tower or on top of a tall building. The base station is connected to a **switching centre**. Each switching centre is, in turn, connected to many base stations. The switching centre switches the call to other mobile phones through the **cellular system** or the fixed telephone system.

A network of cells

Mobile phones are also called **cellular phones**. That is because the base stations are set up in a network of hexagonal cells as shown in the diagram on the facing page. The cells range in size from 100 metres across to over 30 kilometres across. The base stations receive and transmit mobile phone signals from the cells that adjoin them. A mobile phone signal moves from cell to cell until it reaches its destination base station.

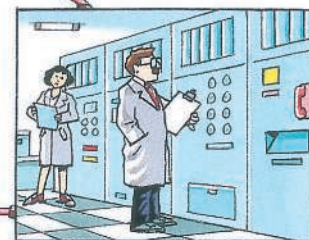


Going mobile —
a new convenience

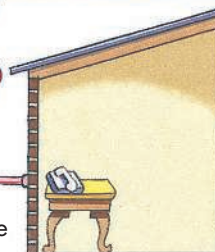


mobile switching
centre

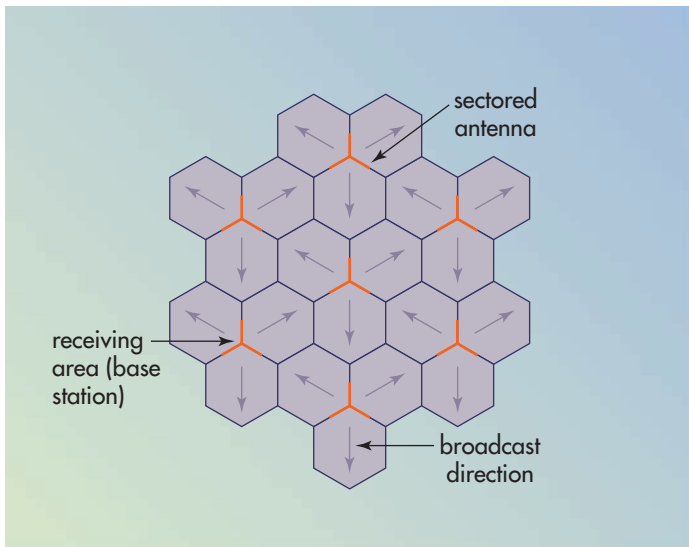
base station



fixed
telephone
system



The pathway followed by a mobile phone call



The base stations are placed at the intersection of three cells.

From analogue to digital

The first mobile phones used in Australia were operated on an analogue system. Voice messages were carried through the air in the same way that the analogue FM radio system carries sound. The voice signal changed the frequency of the carrier wave.

The analogue system was gradually phased out to be replaced by the current digital system. The analogue system ceased operating on 31 December, 1999.

The digital system carries voice signals as a series of 'on' and 'off' pulses that change the shape of the

carrier wave 8000 times every second. The digital system has several advantages over the analogue system. It provides:

- clearer and more consistent voice transmission
- less background noise and interference
- easier transmission of SMS (short message service), video, fax messages and computer data
- protection from 'eavesdropping' (by scrambling transmissions).

Four generations of phones

The cellular network currently used to transmit mobile phone signals is known as the 3G network. 3G stands for third generation. The first generation network (1G) began in the early 1980s, servicing analogue mobile phones. The second generation network (2G) was the first digital system, which began in the early 1990s. Its advantages over the first generation are described above. The current 3G network carries data much more quickly and allows web browsing and the sending and collection of email, video messaging and access to networks outside your own country.

There is even a 4G network 'on the drawing board'. It is likely to be able to carry more data than the current network and will certainly offer many more services and extra convenience for users. However, 4G is not likely to be implemented until at least 2012.

activities

REMEMBER

- 1 How are all mobile phones different from fixed telephones in the way that they transmit and receive voice messages?
- 2 Why are mobile phones also known as cellular phones?
- 3 What makes the digital system better than the analogue system for mobile phones?
- 4 What is the 3G mobile phone network and how is it different from the 1G and 2G mobile phone networks?

THINK

- 5 Use a two column table to list the advantages and disadvantages of mobile phones over fixed lines.

DISCUSS AND REPORT

- 6 About one in five primary school children now own mobile phones. What do you think about this? In a

small group, discuss the reasons for and against primary school children owning mobile phones. After the group discussion, write your own 500-word (approximately) report about your opinion on this issue.

INVESTIGATE

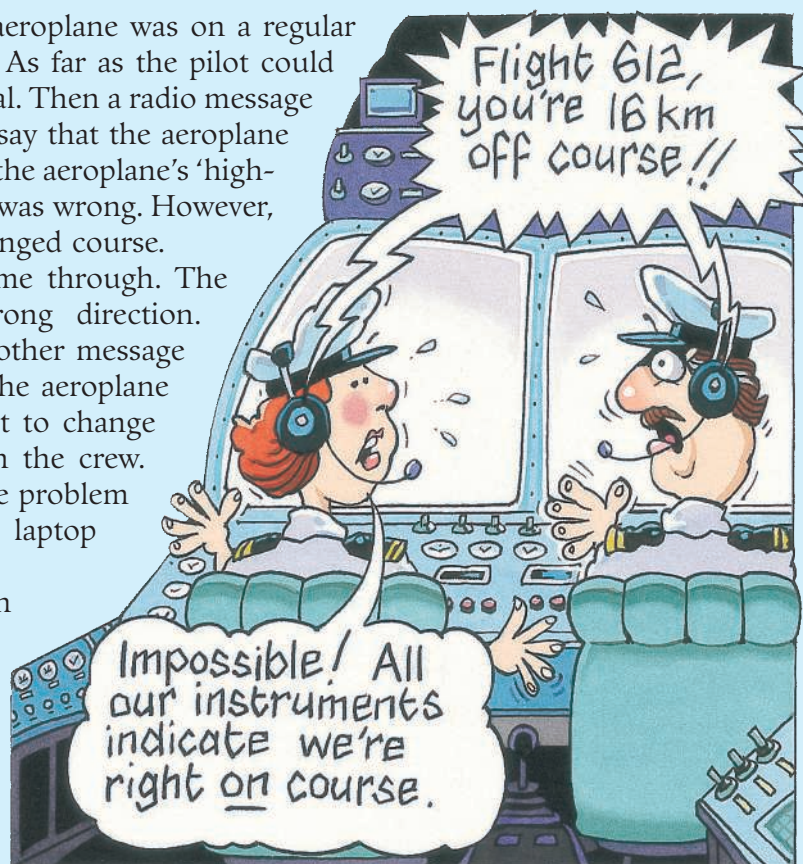
- 7 Investigate and report on the way that people in different groups use mobile phones — for example, in emergencies only, mainly for social contact or mainly for work. You could extend your survey by finding out at what age people first owned a mobile phone and what percentage of people in different age groups do not own mobile phones.
- 8 Investigate and report on the way that the use of mobile phones has changed the way that people live and work. Your report could be based on interviews conducted with relatives or friends who were at least 10 years old when mobile phones were introduced in 1987.

Electromagnetic pollution

It was April 2001 and the full passenger aeroplane was on a regular flight from Washington DC to New York. As far as the pilot could tell, it was on course. Everything was normal. Then a radio message came through from Air Traffic Control to say that the aeroplane was 16 kilometres off course. According to the aeroplane's 'high-tech' instrument panel, Air Traffic Control was wrong. However, the pilot followed the instructions and changed course.

A short time later another message came through. The aeroplane was still heading in the wrong direction. The pilot changed course again. Then another message was received from Air Traffic Control — the aeroplane was *still* off course. Another failed attempt to change course was beginning to cause tension in the crew. The passengers were totally unaware of the problem — including the one busily typing on a laptop computer.

A flight attendant noticed the open laptop and politely asked the passenger to switch it off. The aeroplane's instrument panel immediately showed that the aeroplane was, in fact, off course. The pilot was able to correct the course and the aeroplane arrived safely at its destination — although a little late.



This incident is one of hundreds that have taken place on aeroplanes. The instruments that determine an aeroplane's position rely on radio signals coming from beacons on the ground. The electromagnetic radiation coming from laptop computers, mobile phones and other electronic devices can interfere with navigational instruments.

A new form of pollution

All electrical appliances emit some electromagnetic radiation. Radio waves are emitted when electrons change their speed or direction rapidly. The amount of energy emitted by an appliance and the direction in which it travels depends on the arrangement of conducting paths inside the appliance.

The **microprocessors** used in computers and mobile phones conduct millions of pulses of electric current every second. Some commonly used household appliances, like microwave ovens, generate powerful bursts of electromagnetic radiation.

The effects of electromagnetic pollution

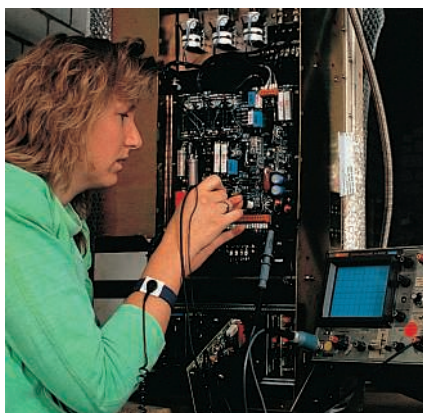
The effects of **electromagnetic pollution** are not just confined to aeroplanes. Unwanted electromagnetic radiation can interfere with the operation of many electronic devices. Some examples follow.

- Heart monitors and other hospital equipment have stopped working owing to the nearby use of mobile phones.
- Recent-model cars have stalled and failed to restart at some intersections owing to electromagnetic interference with their electronic ignition systems.
- The operation of radio telescopes has been adversely affected by the use of mobile phones and microwave ovens, and the transmissions from some satellites.
- Serious malfunctions have occurred in military helicopters as a result of interference from a nearby television station.

Tackling the problem

Some measures to try to reduce the problems caused by electromagnetic pollution are listed below.

- Aeroplane passengers and visitors to hospitals are required to turn off mobile phones.
- Some governments have introduced new regulations to force manufacturers to reduce the transmission of electromagnetic radiation by electronic appliances.
- Electronic design improvements have reduced the emission of electromagnetic radiation. Protective shields made of conducting material are being developed to protect sensitive devices.



Electronic design improvements can reduce the effects of electromagnetic pollution.

Phone masts knocking racing pigeons off track

Laura Elston, PA News, 9 February 2004

Homing pigeons are becoming increasingly lost because of mobile phone masts, racing enthusiasts said today.

Radiation waves emitted from the growing number of transmitters are believed to be interrupting the birds' homing instincts and sending them off track, the Royal Pigeon Racing Association said.

Peter Bryant, of the RPRA, said the 'unseen enemy' was sending pigeons wayward and confusing their sense of direction.

'The anecdotal evidence is that over the last two years there's been very poor returns,' he said.

Mr Bryant said the association's Stray Birds Committee was in favour of attaching a GPS tracking device to pigeons to investigate the problem.

'A pigeon weighs about a pound, but the device would be strapped on like a rucksack, so we have to wait until it's lighter.

'It's fine with eagles and albatross, but for the poor little pigeons it would hamper their return.'

Pigeons are thought to find their way home using landmarks and the Earth's magnetic field, Mr Bryant said.

He added it was impossible to estimate how many pigeons were vanishing because of the transmitters.

'During the Second World War, thousands of aircraft carried two pigeons in case the plane was downed so they could send messages,' he said.



'Now they're facing this unseen enemy in the form of mobile phone masts.'

Pigeon fancier Anne Pitkeathly, 50, from the Isle of Wight, said she had lost an increasing number of birds recently.

'When I started I was told I would lose baby birds but never the big ones,' she said.

'A lot of people think it's mobile phone masts.'

She described how one of her pigeons reacted badly after being near a mast this week.

'He was very stressed and shaking his crop, trying to be sick,' she said.

Previous research by German scientists in 1999 suggested that short wave radiation had an 'undefined negative' impact on homing pigeons.

It was found that exposed birds took longer to get home, flew at lower levels and were reluctant to go near transmitters.

Between 50 000 and 60 000 pigeons are estimated to have gone missing last year due to problems such as bird of prey attacks and poor weather, the RPRA said.

activities

REMEMBER

- 1 What do all electrical appliances have in common that makes them emit more electromagnetic radiation than other objects?
- 2 How can sensitive electronic devices be protected from electromagnetic pollution?

THINK

Read the article 'Phone masts knocking racing pigeons off track'.

- 3 The 'short wave radiation' mentioned at the end of the article refers to the radio waves and

microwaves emitted by mobile phone masts. Suggest why homing pigeons are likely to be affected by this electromagnetic radiation.

- 4 The evidence of 'poor returns over the last two years' is described as anecdotal.
 - (a) What is meant by the term 'anecdotal'?
 - (b) The pigeon racers have blamed mobile phone masts for the apparent increase in the loss of pigeons. Suggest at least one alternative explanation for the apparent increase.
- 5 Design a scientific investigation that could be used to find out

whether the homing pigeons are taking longer because of mobile phone masts or a different reason.

INVESTIGATE

- 6 Hold a portable radio near a computer. With both the radio and computer switched on, listen for any interference to the operation of the radio. How does the interference change when you:
 - (a) move the radio to different positions?
 - (b) listen to different radio stations (AM and FM)?
 - (c) switch the computer off?

Super 'scope

Imagine a microscope that is *tens of millions* of times more powerful than the best light microscopes. It already exists. It is called a **synchrotron** and it is much, much larger than any light microscope. There are now more than 50 of them throughout the world, including one being built in Australia. The Australian Synchrotron in the Melbourne suburb of Clayton is about 70 metres in diameter. The building that houses it is not much smaller than the Melbourne Cricket Ground.

Synchrotron radiation

The radiation directed at the target in a synchrotron is, like visible light, electromagnetic radiation. However, it is very different from the light used in a conventional microscope. Synchrotron radiation:

- can range from the low energy, long wavelength infra-red part of the electromagnetic spectrum up to high energy, short wavelength X-rays. The radiation can be 'tuned' to the energy and wavelength most suited for the purpose for which it is being used.
- is hundreds of thousands of times as intense as the radiation produced by conventional X-ray tubes. Intensity is a measure of the amount of power delivered to the target.
- is usually emitted in short pulses that last less than a billionth of a second
- is highly polarised (see page 117).

Together, these characteristics allow a synchrotron to produce



The Australian Synchrotron in the Melbourne suburb of Clayton

data describing objects as small as a single molecule.

Unlike a conventional microscope, you can't actually see an image. The image has to be created from the data obtained when the radiation strikes the target with the aid of computers.

How it works

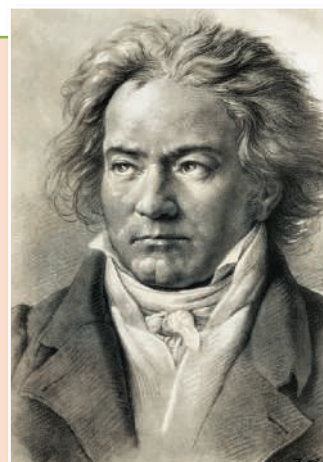
1. Electrons are fired from a heated tungsten filament with the aid

of a voltage of 90 000 volts. They reach a speed of about 159 million metres per second, 53 per cent of the speed of light.

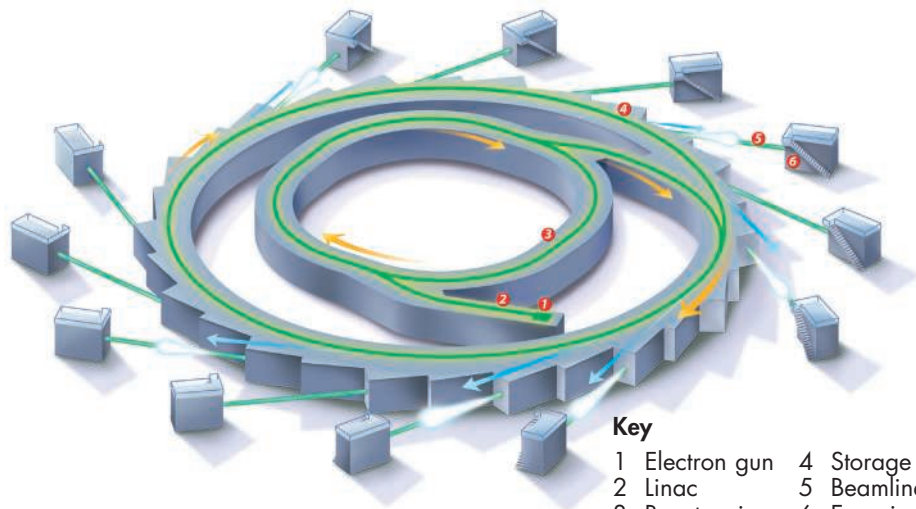
2. The **linear accelerator** (linac) uses an even higher voltage (100 million volts) to accelerate the electrons to a speed of 99.9987 per cent of the speed of light.
3. The booster ring is used to increase the energy of the electrons before they are transferred into the storage ring.

sciFacts

A synchrotron was used to help solve the mystery of the death of the German composer Ludwig von Beethoven (1770–1827). During his lifetime, Beethoven suffered from loss of hearing, cramps, fevers, chronic abdominal pain, irritability and depression. Following his death, a 15-year-old fellow musician cut off a small lock of Beethoven's hair. After many years of changing hands, the lock of hair was found in a London auction house, where it was bought by the American Beethoven Society, who allowed it to be examined at a synchrotron in Chicago. It was discovered that Beethoven's hair contained about 100 times more of the heavy metal lead than today's normal level. Beethoven's symptoms were consistent with severe lead poisoning. No-one knows where the lead came from, but it could have been from the lead that was used in serving dishes, flasks and crystal glasses during Beethoven's lifetime.



It appears that Ludwig von Beethoven, one of the world's greatest classical music composers, was killed by heavy metal poisoning.



Key

- | | |
|----------------|------------------------|
| 1 Electron gun | 4 Storage ring |
| 2 Linac | 5 Beamline |
| 3 Booster ring | 6 Experimental station |

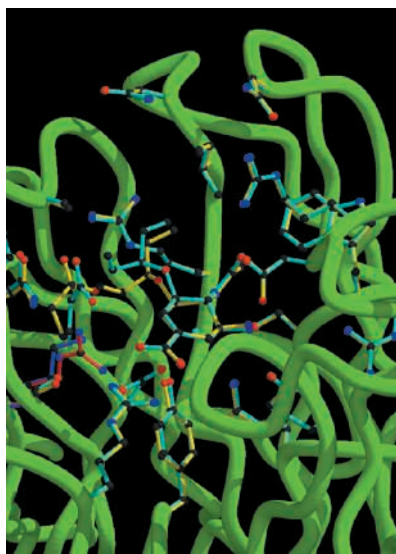
4. In the storage ring, large magnets are used to steer the electrons. As the electrons change direction, they emit electromagnetic radiation for many hours. Magnetic fields are used to replace the energy lost by the electrons during each 'lap' of the ring.
5. The synchrotron radiation is directed into a **beamline**. The beam passes through a silicon **monochromator**, which allows only the required wavelengths to pass through.
6. The experimental station contains the target object, which is rotated so that a complete, clear image is obtained.

The benefits of super 'scope

Synchrotron radiation has a wide range of applications in many areas of science and technology, including medicine, nutrition, environmental science, mining, materials, transportation, forensic science and archaeology. Some examples of the use of synchrotrons are:

- imaging proteins in the influenza virus to help develop a drug to stop it from multiplying
- the development of an artificial substance to coat the lungs of premature babies so that they can breathe more easily
- producing X-ray images of human tissue that have much more detail than conventional X-ray images. These images are being used in the fight against heart disease, breast cancer, brain tumours and many other diseases.
- the detection of weaknesses and cracks in materials used in aircraft and spacecraft
- the analysis of drill core samples in mineral exploration
- assisting in criminal investigations by more accurately identifying substances such as biological fluids, poisons, fibres and paint pigments
- identifying substances in archaeological finds such as ancient armour
- imaging molecules in chocolate to help in the production of smoother, creamier chocolate with a longer shelf life.

Images like this were used to develop the drug **Relenza™**, which is effective in the fight against all known strains of influenza, including bird flu.



activities

REMEMBER

- 1 Which parts of the electromagnetic spectrum can synchrotron radiation consist of?
- 2 Apart from having a wider range of wavelengths, how is synchrotron radiation different from visible light?
- 3 From where do the electrons used to produce synchrotron radiation come?
- 4 In the Australian Synchrotron, what is the main purpose of the:
 - (a) linear accelerator (linac)?
 - (b) booster ring?
 - (c) silicon monochromator?
- 5 What happens to electrons in the storage ring of the Australian Synchrotron?

THINK

- 6 What makes the synchrotron such a useful tool in the fight against diseases such as influenza?

CALCULATE

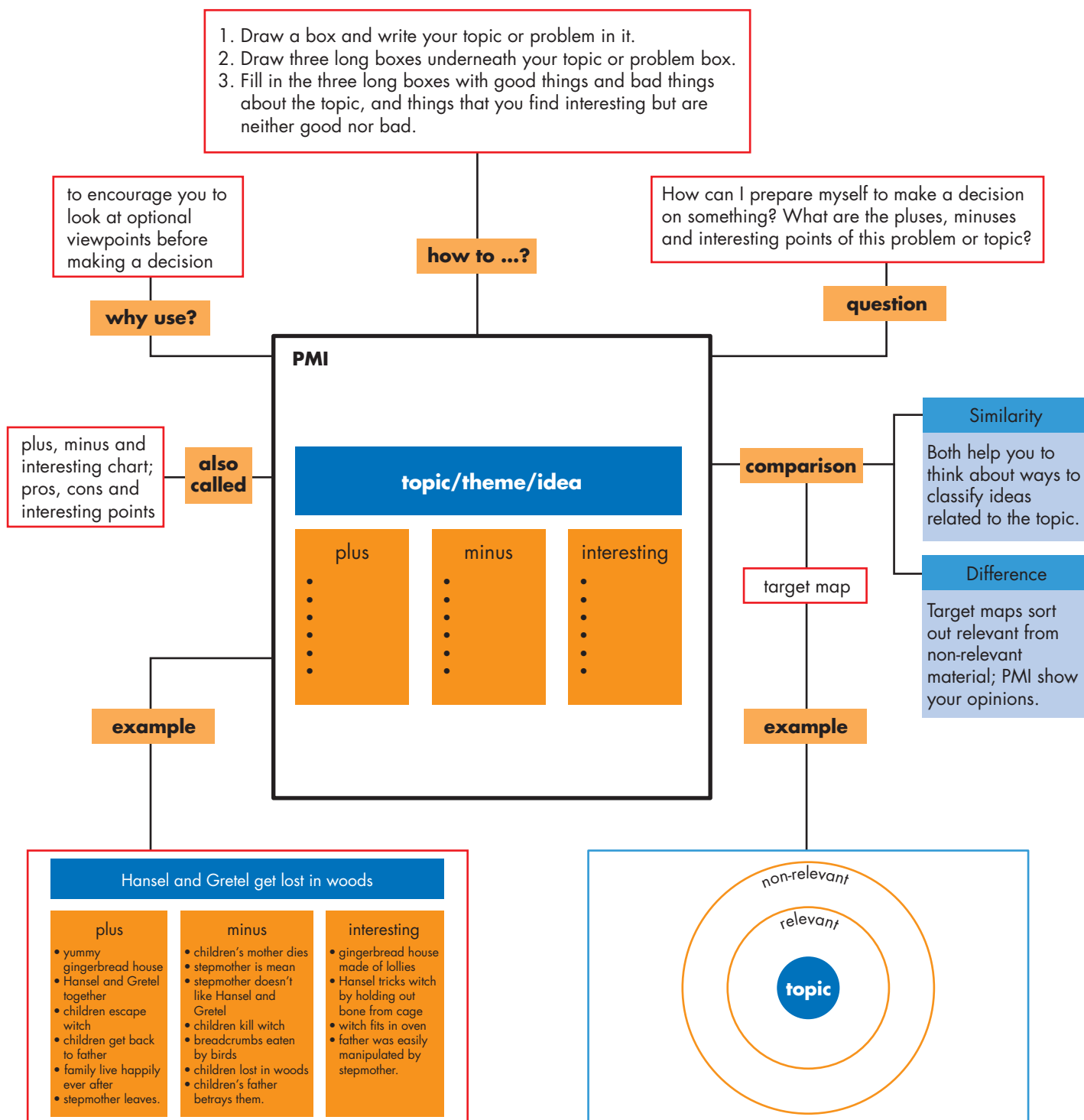
- 7 According to the US National Institute of Standards and Technology, the speed of light in a vacuum is 299 792 458 metres per second. The electrons reach a speed of 99.9987 per cent of the speed of light in the booster ring.
 - (a) Calculate this speed in metres per second.
 - (b) How much slower, in metres per second, than the speed of light are the electrons travelling?

INVESTIGATE

- 8 Use the Internet to search for case studies on the use of synchrotrons. Make a list of examples of the use of the synchrotron other than those mentioned on this page. As a starting point, visit the website for this book and click on the Australian Synchrotron weblink (see 'Weblinks', page 305).

Thinking tools:

Plus, minus, interesting and target maps



Adapted with permission from Hawker Brownlow Education © 2005 modellearning.com *Thinking Skills and EyeQ: Visual Tools for Raising Intelligence* by Ian Harris, Oliver Caviglioli and Bill Tindall

THINK AND CREATE

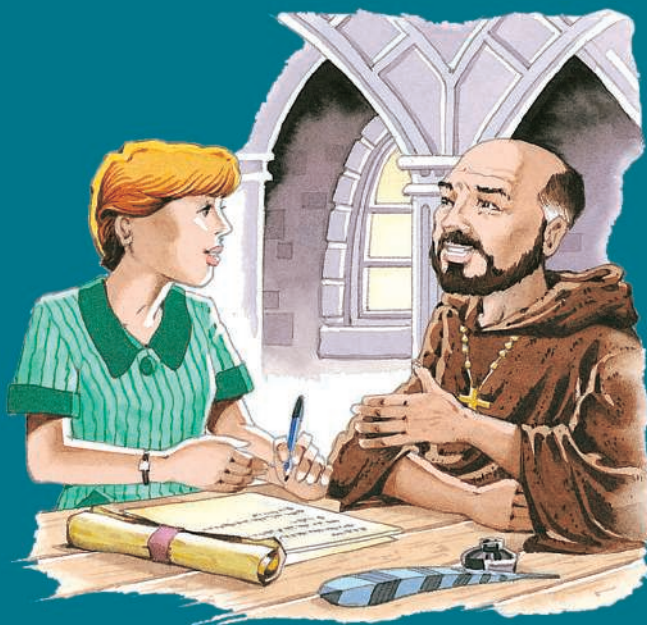
1 With a partner or in a small group, discuss the positive, negative and interesting aspects of each of the following methods of sending and receiving information. Work together to create a PMI for each of the methods to summarise your discussions.

- (a) 'snail mail'
- (b) email
- (c) phone (fixed line)
- (d) mobile phone
- (e) communication before 1788 (the year of the landing of the First Fleet in Sydney Cove).



'Snail mail' may be slow, but it has some advantages over the faster methods of sending and receiving information such as phone, email and chatting over the Internet. Creating PMIs can help you reflect on the different ways of communicating.

2 Imagine that you can travel back in time to interview someone about one of the older methods of communicating such as those illustrated on page 126. Create a PMI on your chosen method of communication, based on your imagined interview.



5 Work with a partner or in a small group to create a large target map on the topic of digital communication using both words and images. Start by brainstorming a collection of words and pictures related to both digital and analogue communication.

6 Create a timeline to illustrate the development of communication by electromagnetic radiation, beginning with the discovery of radio waves by Heinrich Hertz in 1887.

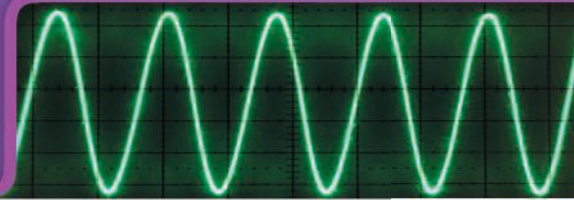
3 Use the words opposite to create a target map on the topic of electromagnetic waves.

4 Create a target map on each of the following using the words opposite and a minimum of three additional words that are relevant to the topic.

- (a) sound
- (b) synchrotrons
- (c) long-distance communication

light	longitudinal waves	
pitch	ultraviolet	infra-red
	sound waves	radio waves
300 000 km/s	rarefaction	compression
transverse waves		X-rays
	particles	
ultrasound	frequency	wavelength
gamma rays	AM radio	FM radio

Looking back

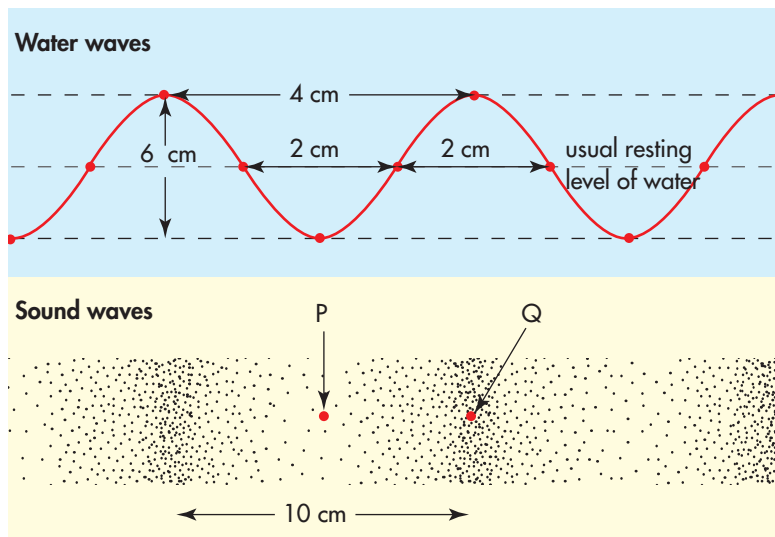


Electromagnetic waves



Electromagnetic wave type	Approximate range of wavelengths (m)	Properties
infra-red radiation		
gamma rays		
ultraviolet radiation		
light		
X-rays		
radio		

- Make a copy of the table above. However, rearrange the invisible waves in the first column so that they are listed in order of increasing frequency. Complete the table by filling in the other three columns.
- State three differences between sound waves and all of the waves listed in the above table.
- What two properties do all of the waves listed in the table have in common?
- To which type of electromagnetic waves listed in the table do microwaves belong?
- Which of the electromagnetic waves listed in the table:
 - can be produced artificially?
 - transmits the most energy?
- Which type of electromagnetic radiation is used in remote control devices like the one pictured below?
- What is the major use to society of:
 - X-rays?
 - ultraviolet radiation?
 - gamma rays?
- Explain the difference between a transverse wave and a compression wave. List two examples of each type of wave.
- The questions below refer to the water wave and sound wave shown in the following figure.



- What is the amplitude of the water wave?
- What is the wavelength of the water wave?
- What is the wavelength of the sound wave?
- Which of the points P and Q is in the centre of a rarefaction?

10. If there was no visible light coming from the sun, it is obvious that we wouldn't be able to see. But the lack of visible light would cause a much greater problem. What is that problem?
11. What is SONAR and what is it used for?
12. What is ultrasound?
13. List some of the uses of ultrasound.
14. How are ultrasound waves different from the sound waves that you can hear?
15. Explain how visible light is used to transmit sound along optical fibres. Use diagrams to illustrate your explanation.
16. Describe how digital radio signals are different from analogue radio signals.
17. What does the digital transmission of television signals have in common with the analogue transmission of television signals?
18. List some reasons why analogue television and radio are being phased out and replaced with digital television and radio.
19. Although electromagnetic radiation has many uses in society, there are also dangers associated with it.
 - (a) Why is the use of mobile phones not permitted in hospitals or during the take-off and landing of planes?
- (b) What danger does ultraviolet radiation pose to the human body and what measures should be taken to protect against it?
- (c) Find out what precautions must be taken by the operators of X-ray equipment in hospitals.

20. Throughout the history of communication, which single scientific or technical development has had the most impact in your opinion? Justify your answer.
21. Find the names of the nine communication devices or methods that are hidden in the word puzzle below. Words may be spelt across, down, diagonally or even backwards. Which of these devices or methods:
 - (a) can send messages from one country to another within seconds?
 - (b) were in common use over 100 years ago?
 - (c) can send messages to millions of others?
 - (d) is the most recently established?
 - (e) can be effective without the use of electromagnetic radiation in the transmission of information from one person to another?

N	O	I	S	I	V	E	L	E	T
I	E	R	T	N	O	Y	G	C	E
R	A	W	V	B	I	D	X	M	L
C	I	B	S	R	C	V	M	C	E
L	B	O	Q	P	E	X	U	E	P
C	M	O	I	D	A	R	I	T	H
X	A	K	O	F	H	P	C	M	O
P	I	N	T	E	R	N	E	T	N
N	L	Q	B	J	E	U	F	R	E

22. What is synchrotron radiation and how is it 'created'?
23. List some examples of how images obtained through the use of a synchrotron can benefit medical science.

