Electromagnetic radiation

5

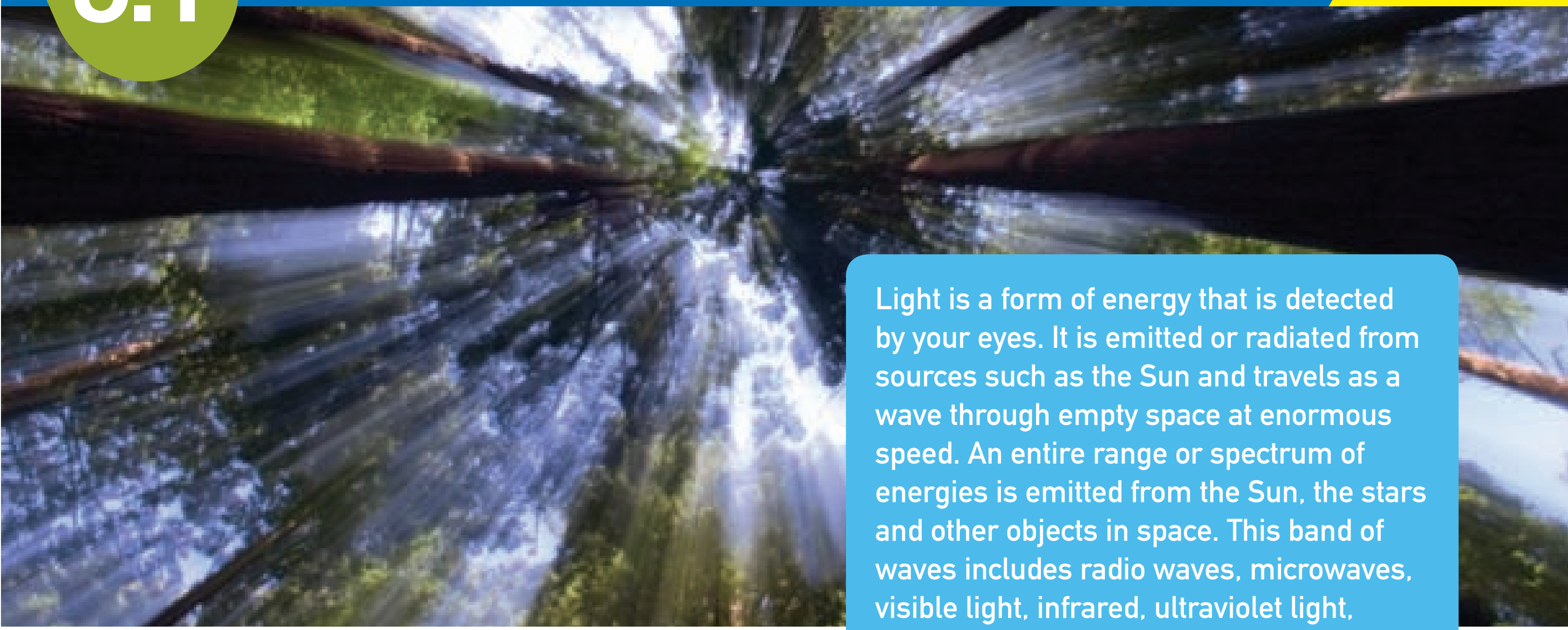
HAVE YOU EVER WONDERED . . .

- 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.

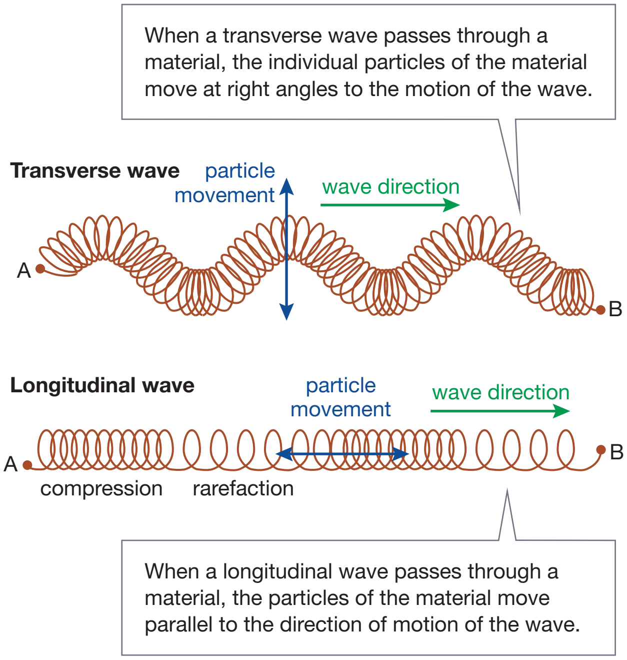


Figure 5.1.2 Transverse waves and longitudinal waves both transfer energy but in very different ways.

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.

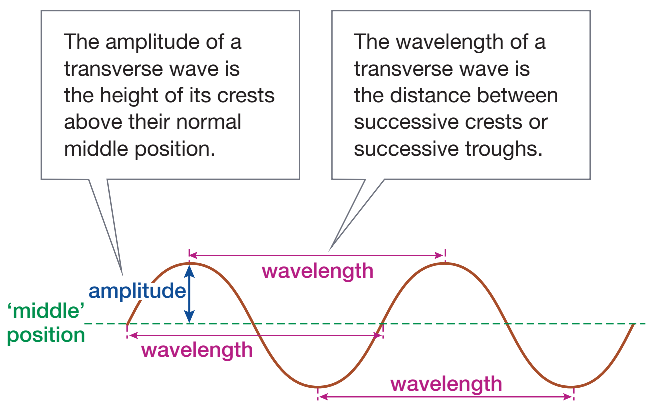


Figure 5.1.3 The amplitude and wavelength of a transverse wave. The number of these waves passing a given point each second is the frequency of the wave.

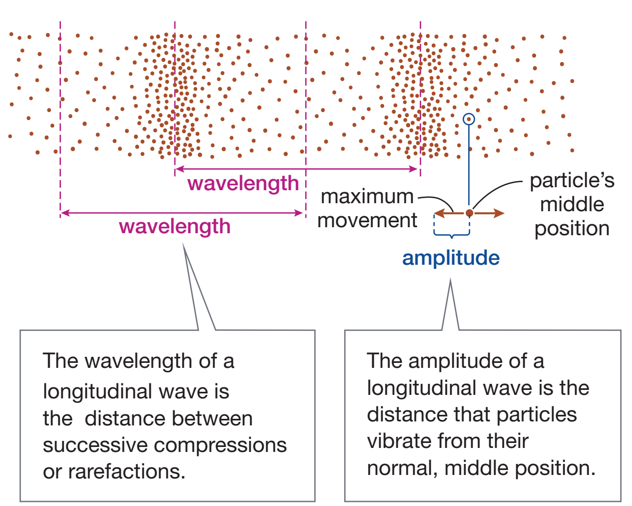


Figure 5.1.4 The amplitude and wavelength of a longitudinal wave. Again, the number of waves passing a given point each second reveals its frequency.

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)
λ = 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,

$$\begin{aligned} v &= f\lambda \\ &= 0.1 \times 6 \\ &= 0.6\text{ m/s} \end{aligned}$$

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

$$\begin{aligned} \lambda &= \frac{v}{f} \\ &= \frac{330}{4100} \\ &= 0.08\text{ m} \end{aligned}$$

This means the sound wave has a wavelength of approximately 8 cm.

5.1

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.

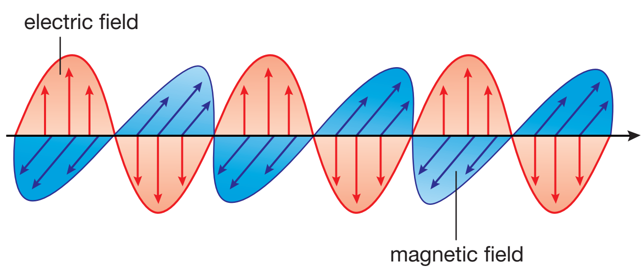


Figure 5.1.5 Electromagnetic waves travel as two interconnected electric and magnetic fields moving as transverse waves.

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.

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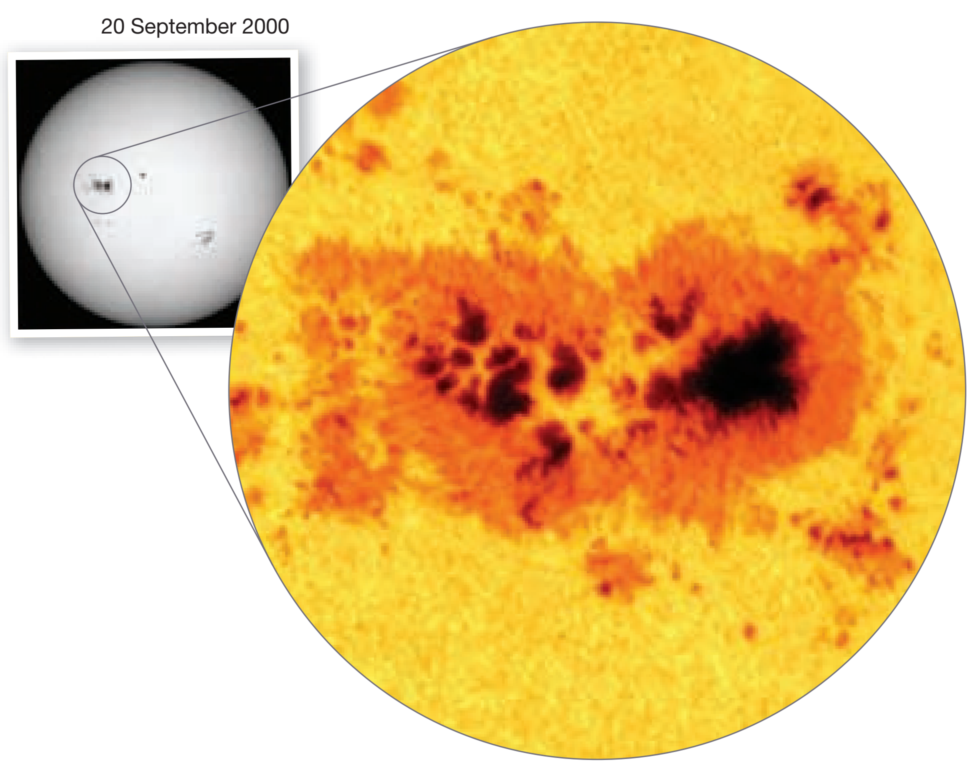
Solar flares

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.



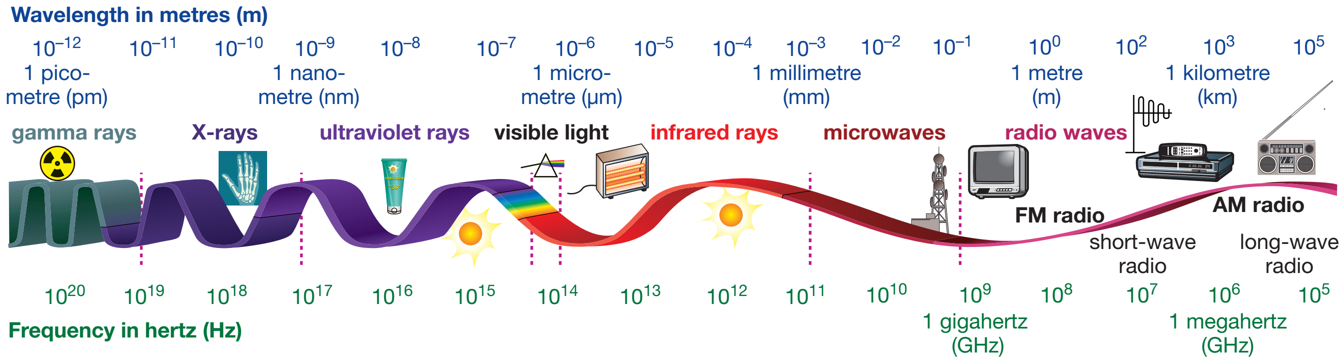


Figure 5.1.6 The electromagnetic spectrum shows the complete range of electromagnetic waves that are possible. These waves travel at the speed of light. The shorter the wavelength and the higher the frequency, the more energy is carried by the radiation.

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 1.0×10^4 (or simply 10^4)

(b) 470 000 can be written as 4.7×10^5

(c) 21 000 000 000 000 000 000 becomes 2.1×10^{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 1.0×10^{-7} (or simply 10^{-7})

(b) 0.0006 becomes 6.0×10^{-4}

(c) 0.00000000000000000000098 becomes 9.8×10^{-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).

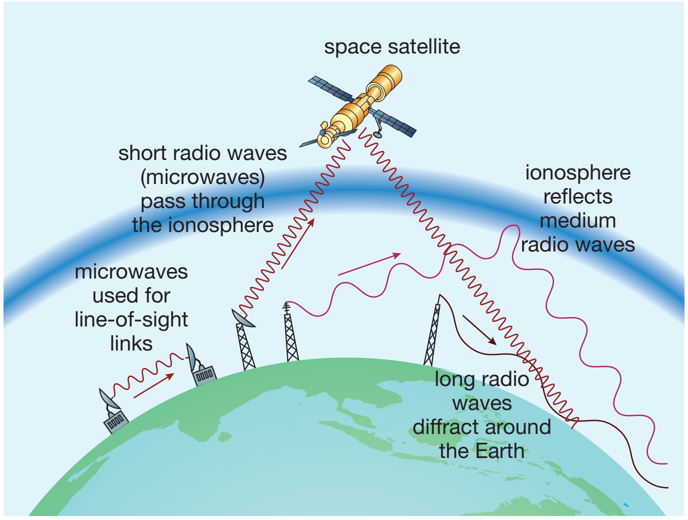


Figure 5.1.8 The wavelengths of radio waves can vary from kilometres to tens of centimetres. Long and short radio waves are useful for communication.

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.

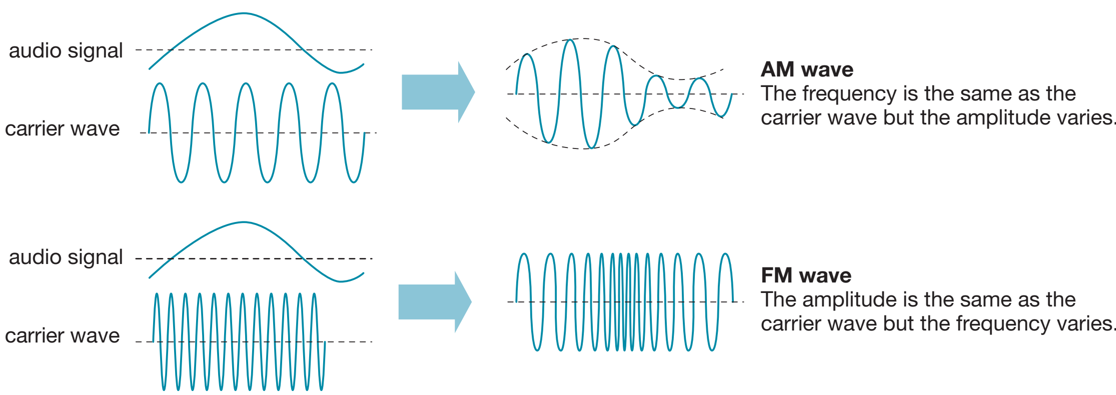


Figure 5.1.9 AM radio stations transmit waves that are amplitude modulated (in other words AM waves). In FM broadcasts, the carrier wave is frequency modulated. Each radio user, such as CB radio, the police or a radio station, operates on its own specific frequency.

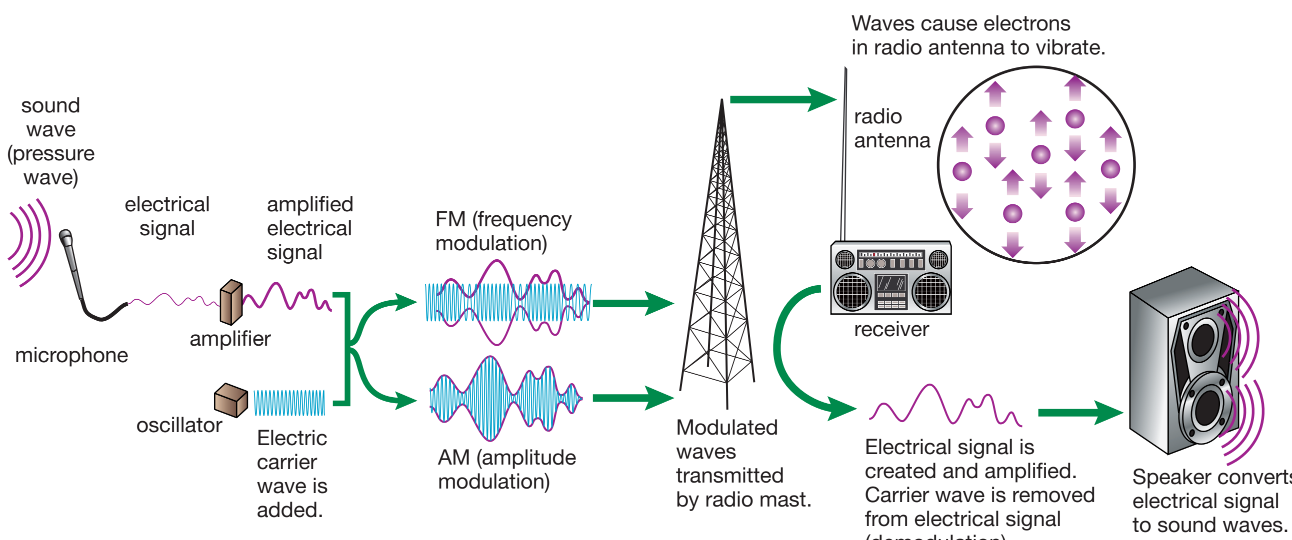


Figure 5.1.10 The steps used when broadcasting and receiving a radio signal.

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

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.

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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.

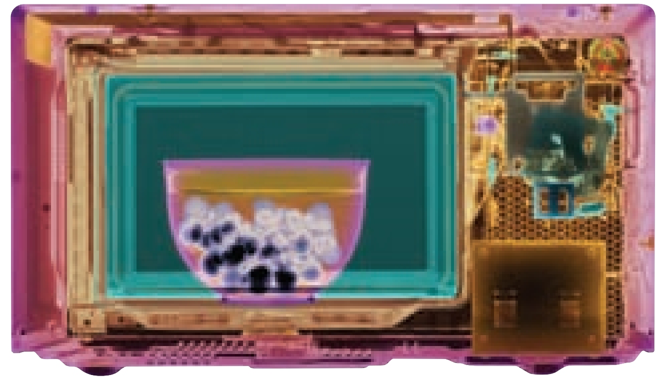

Figure 5.1.11 The wavelengths of microwaves are suitable for making particles in food vibrate, which makes the food heat up.

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.

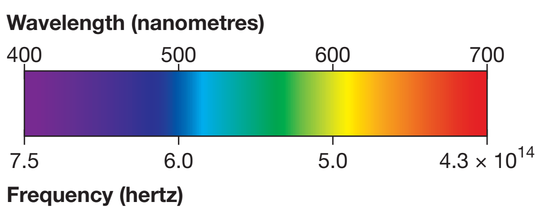

Figure 5.1.13 Visible light is a very small portion of the complete electromagnetic spectrum. It is the only band that is visible to our eyes. About 1000 waves of visible light fit into 1 mm.

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.

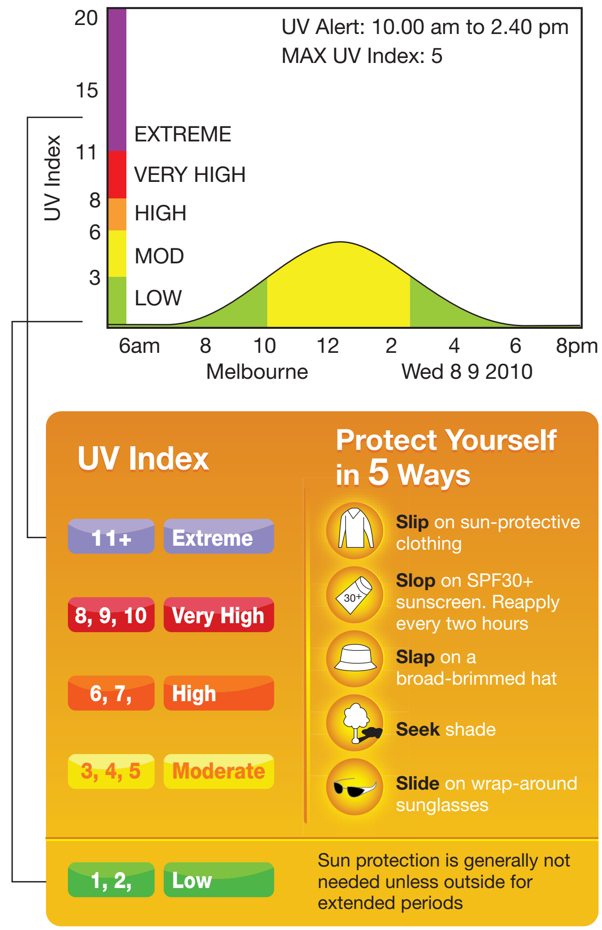

Figure 5.1.14 The Bureau of Meteorology issues daily Sunsmart UV alerts for each capital city in Australia. These alerts warn you when you need to be careful of UV exposure while outside.

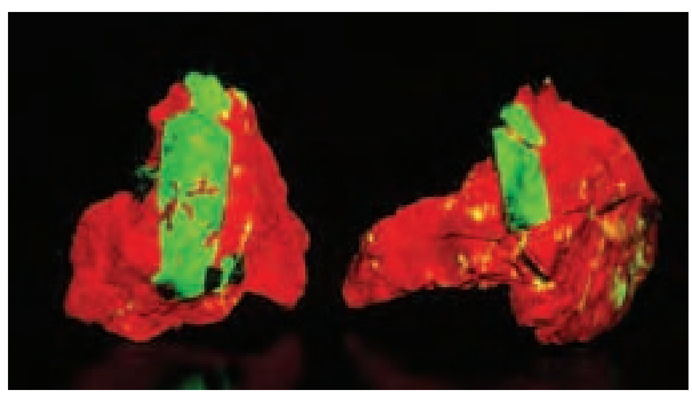

Figure 5.1.15 Many rocks including calcite, gypsum, ruby, talc, opal, quartz and fluorite are fluorescent and glow under UV light.

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.

SciFile

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.

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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.

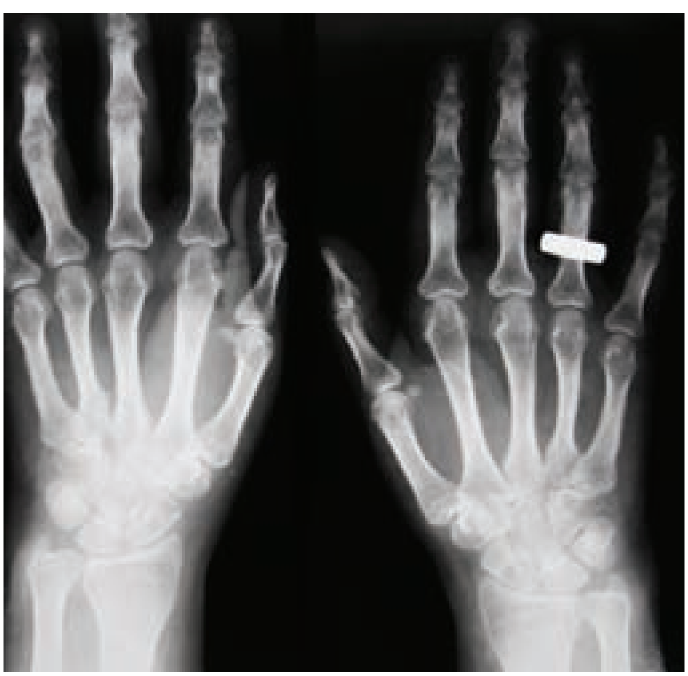


Figure 5.1.16 X-rays can travel through human flesh, but not through bone. This makes them useful in producing images of the structures inside the body.

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 5.1.17 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.

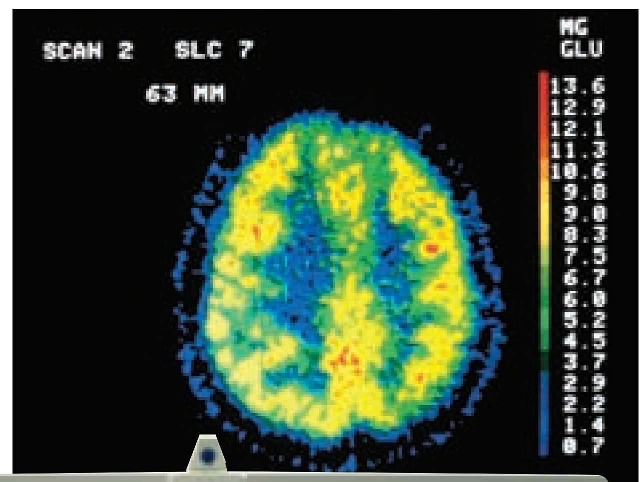


Figure 5.1.18 PET scans allow doctors to study how parts of a patient are functioning. They are often viewed together with a CT (computed tomography) scan, which provides anatomic information regarding their body structure.

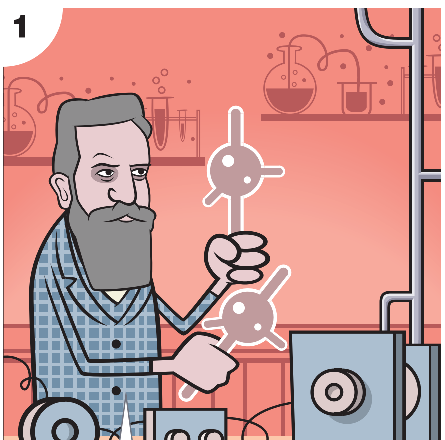
Figure 5.1.19 Wilhelm Röentgen

Wilhelm Röentgen was a German scientist. In 1895, he made a great discovery.

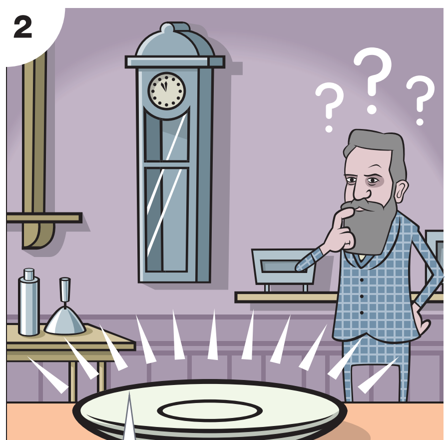
SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

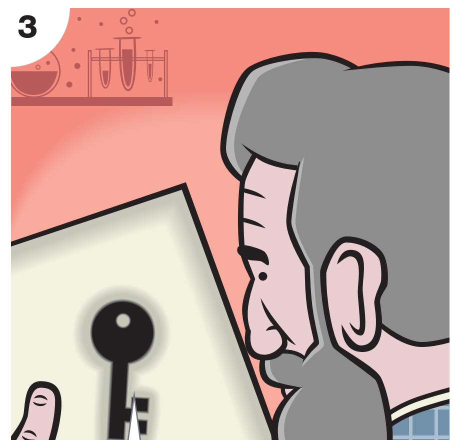
The discovery of X-rays



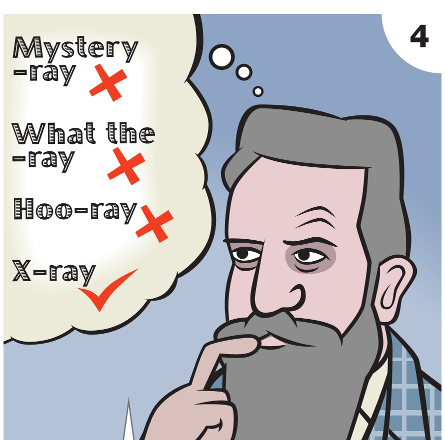
In 1895, Wilhelm Röentgen was experimenting with electrical discharges inside gas tubes. Röentgen pumped the air out of the tubes, pumped in various gases and turned on the electricity.



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.

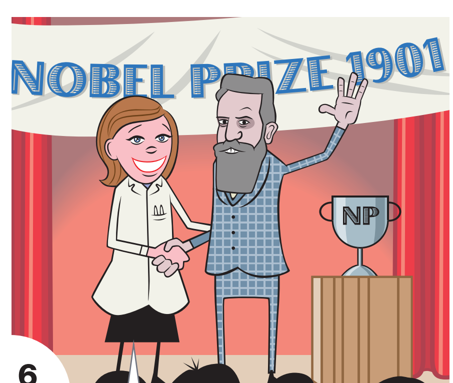


Röentgen started to investigate. He developed a photographic plate that had been left in a drawer near the tube and found the image of a key that was on top of the desk. Something was passing through glass, cardboard and wood, but was stopped by metal.



Röentgen deduced that some sort of ray must be responsible. As it was a mystery, he called it an 'X'-ray.

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.



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.

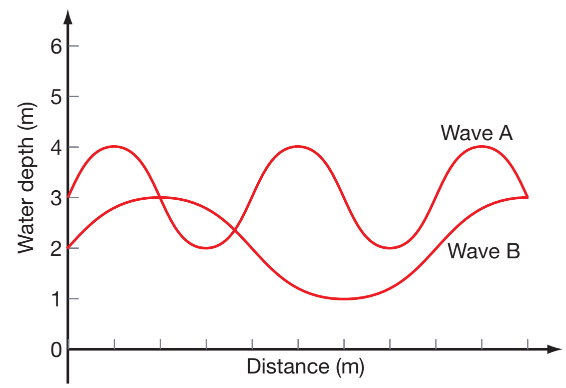


Figure 5.1.20

14 **Apply** your understanding of scientific notation to convert the numbers below into numerals ('normal' numbers).

- **a** 2.5×10^{6} m
- **b** 10^{-12} m
- **c** 5.7×10^{14} Hz
- **d** 1.2×10^{-9} m

Analysing

15 **Use** Figure 5.1.6 on page 151 to **classify** the following frequencies of electromagnetic radiation.

a
- **i** 1.0×10^{14} Hz
- **ii** 1.0×10^{22} Hz
- **iii** 1.0×10^{10} Hz
- **iv** 1.0×10^{6} Hz
- **v** 1.0×10^{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.)

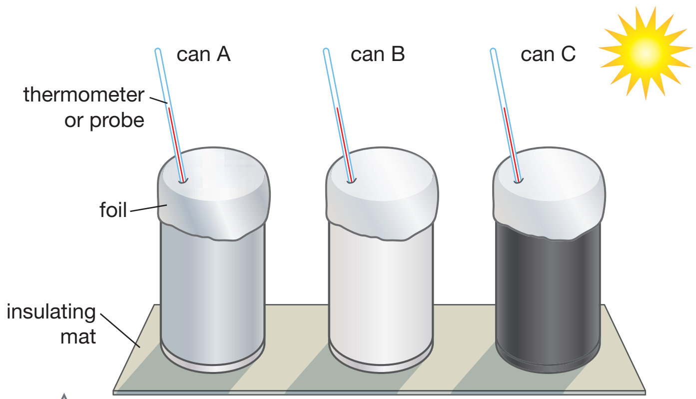


Figure 5.1.22

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**.

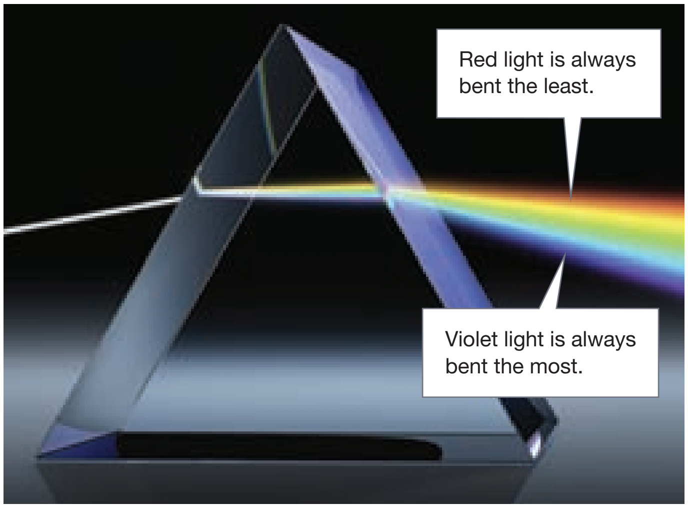


Figure 5.2.1 When white light passes through a prism, each individual frequency of light is bent, or refracted, a slightly different amount.

SciFile

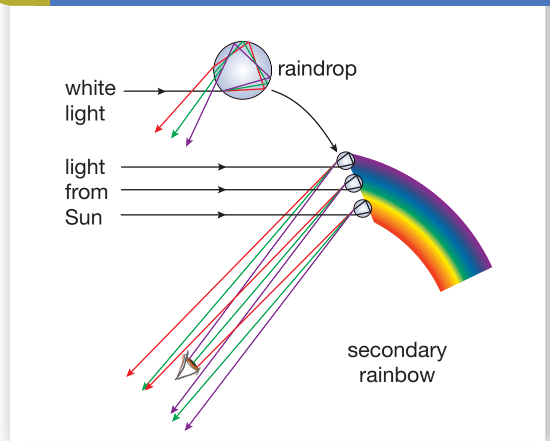
Seven colours?

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.

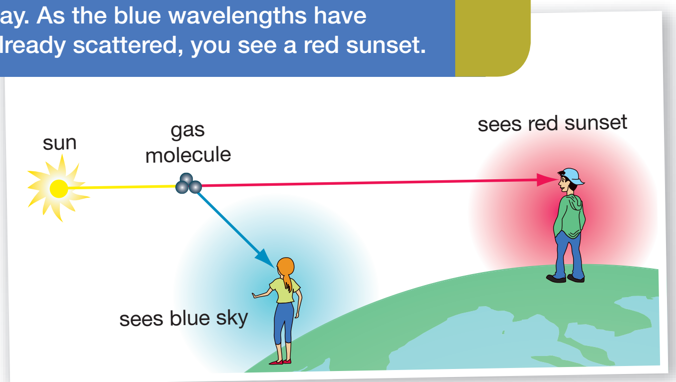


Each individual colour of light has a different wavelength and frequency. The wavelengths of visible light are extremely small, ranging from violet light with wavelengths around 400 nm, through to red light with wavelengths around 700 nm. To get an idea of how small this is, consider that 1 nm (nanometre) = 1.0×10^{-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.

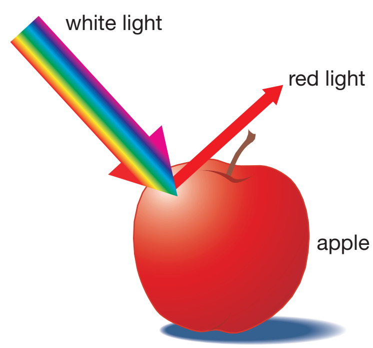


Figure 5.2.2 A red apple reflects red light and absorbs the remaining six colours of the visible spectrum.

INQUIRY science 4 fun

Blue skies

Can you create your own patch of blue sky and a red sunset?

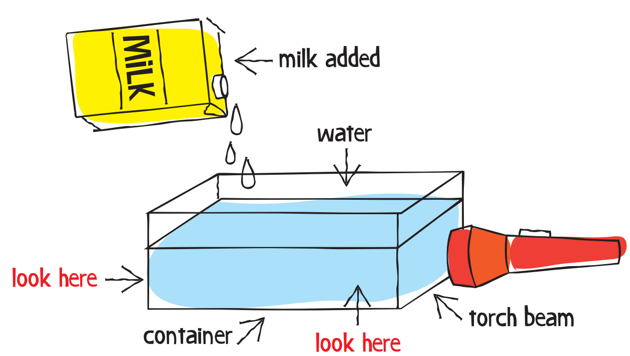
Yes

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.

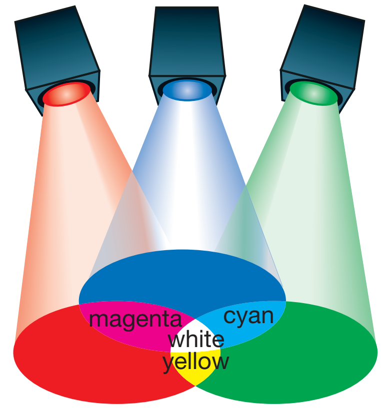


Figure 5.2.4 Red and blue light produce magenta light, red and green light produce yellow light, and blue and green light produce cyan light. Combinations of the primary colours of light (red, green and blue), produce white light.

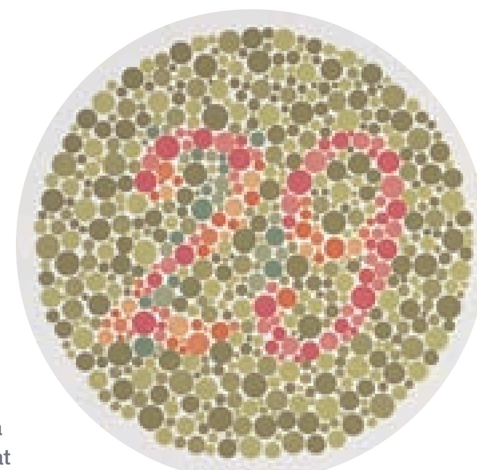


Figure 5.2.5 A person with normal vision will see a particular number in a test like this one. What number can you see?

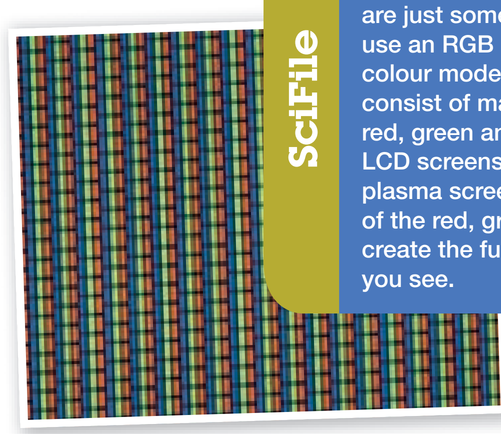
Primary colours

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.



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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.

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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.

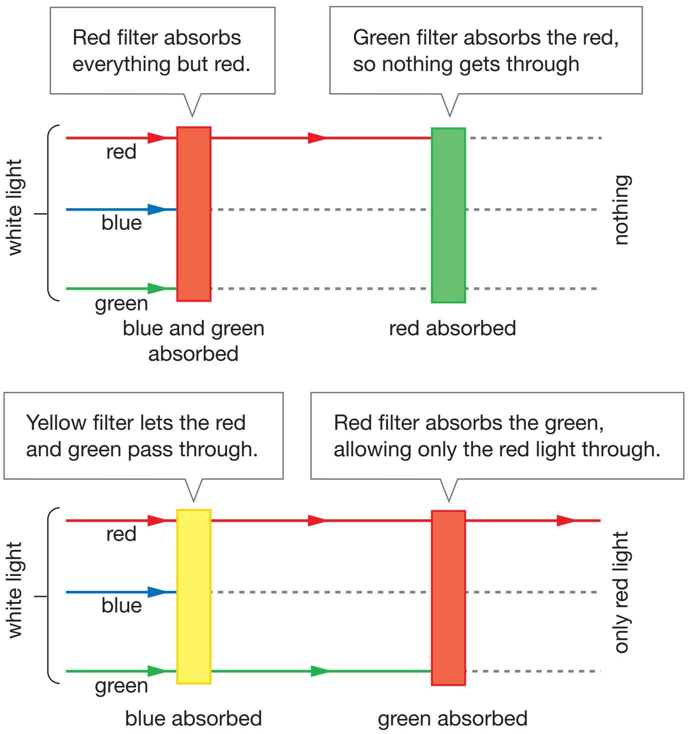


Figure 5.2.6 Different coloured filters absorb different colours, and so they affect what you see.

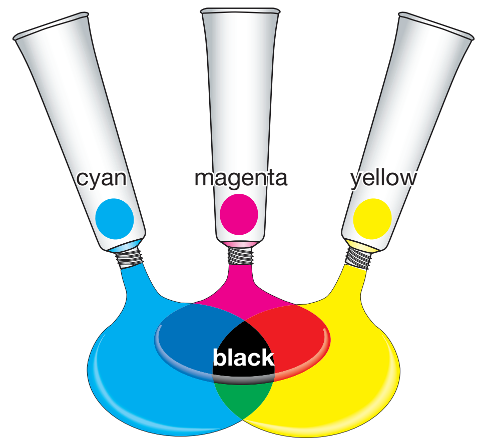


Figure 5.2.8 Combinations of the three subtractive colours, cyan, magenta and yellow, can produce every colour of the spectrum.

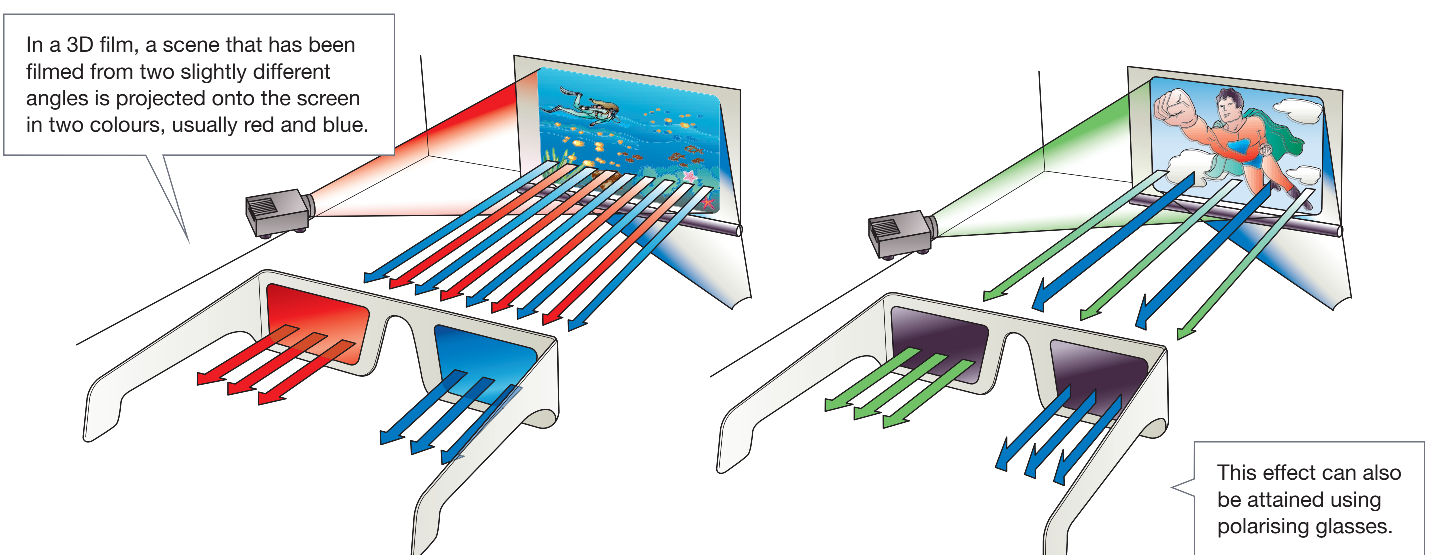


Figure 5.2.7 When you wear 3D glasses with a red and blue filter, each eye receives a slightly different view of the movie scene. Your brain interprets this as 3D vision.

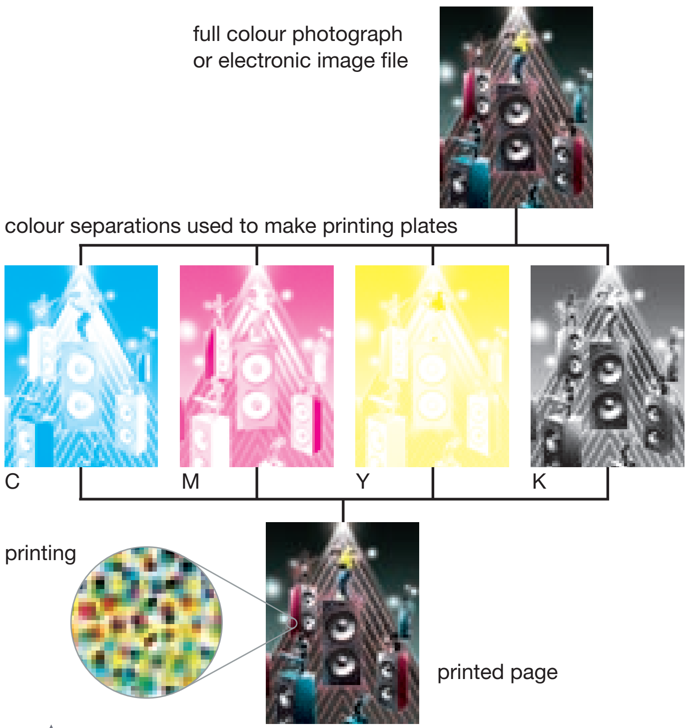


Figure 5.2.9 Colour printers produce a full spectrum of printed colour by using only four inks: cyan, yellow, magenta and black.

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.

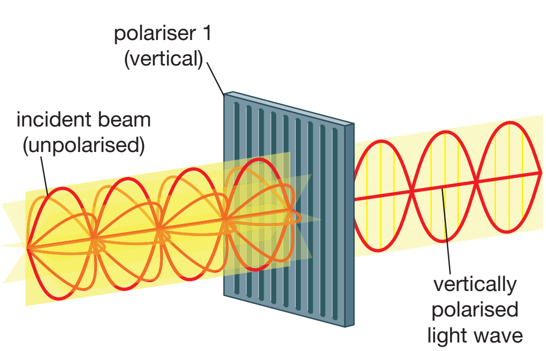


Figure 5.2.10 Electromagnetic radiation travels as a 3D wave, with electric and magnetic fields vibrating at right angles. A polariser only allows one plane of vibration to pass through it, the rest being absorbed.

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.

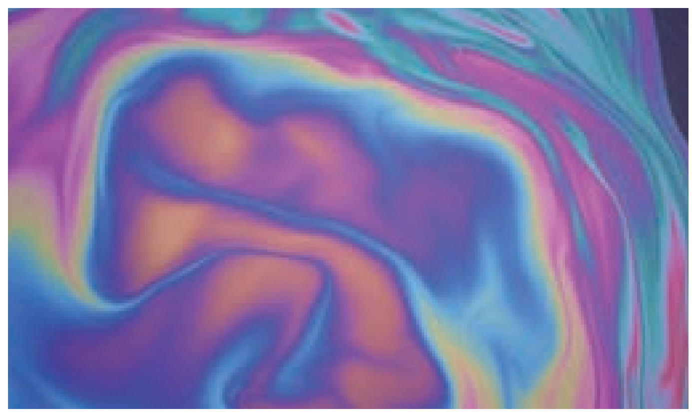


Figure 5.2.11 These colours are the result of thin film interference of light reflected from two layers of the oil slick.

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.

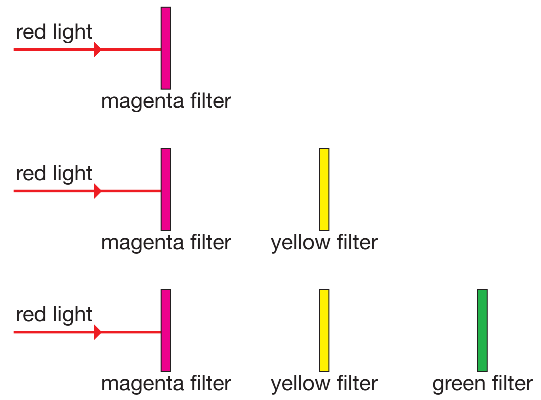


Figure 5.2.12

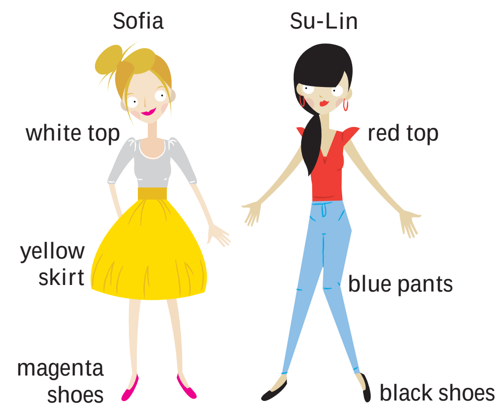


Figure 5.2.13

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.

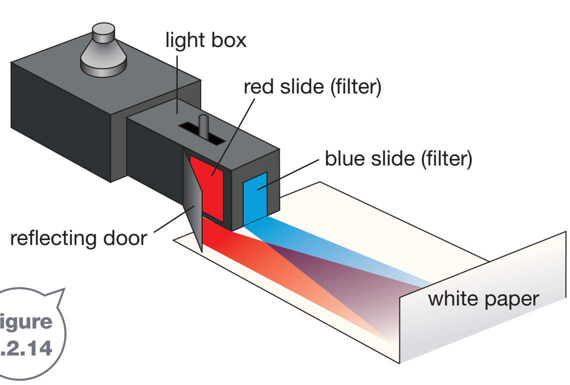


Figure 5.2.14

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.

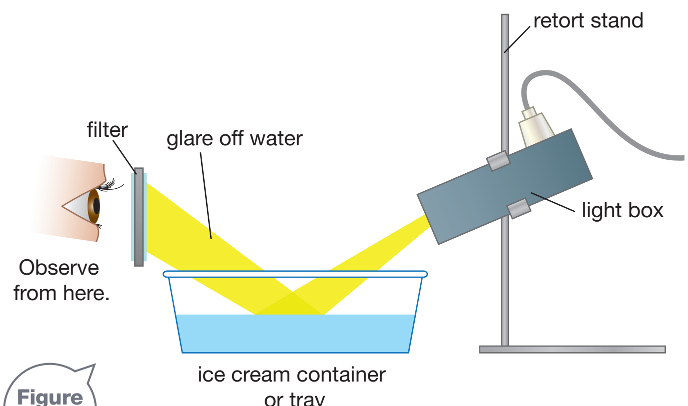


Figure 5.2.15

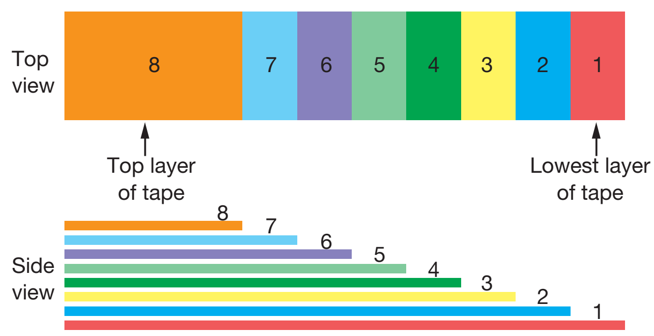


Figure 5.2.16

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.

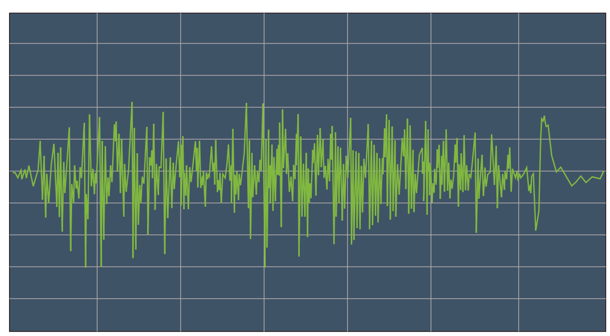


Figure 5.3.1 An analogue signal replicates the message it transmits.

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.

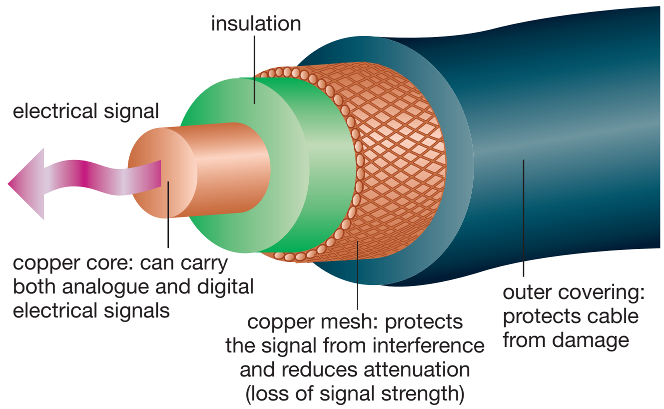


Figure 5.3.2 The inner core of this coaxial cable transmits analogue and digital signals. The outer layers protect the signal from interference and loss of strength.

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.

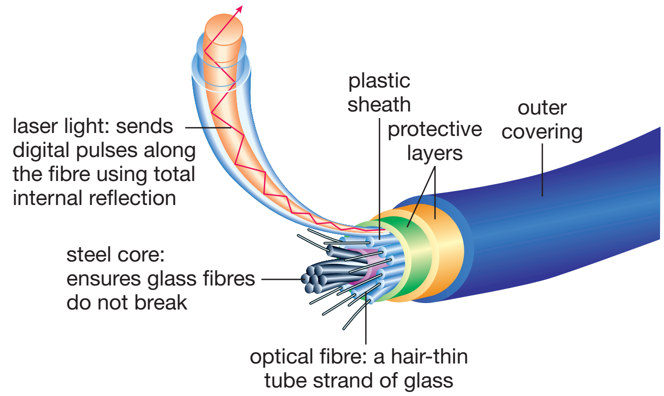


Figure 5.3.3 A fibre optic cable is made up of many single optical fibres.

INQUIRY science 4 fun

Bendy light

Light travels in straight lines. So can you make it turn a corner?

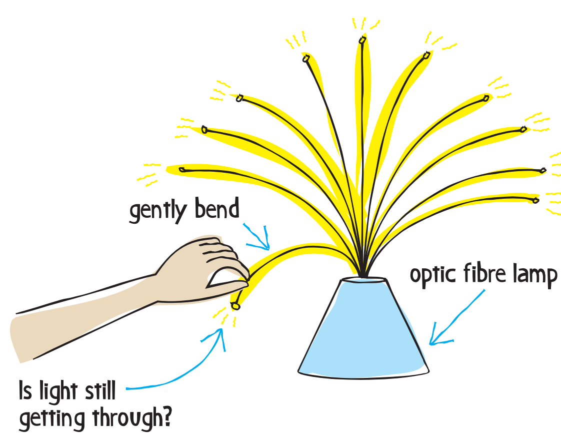
Yes

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

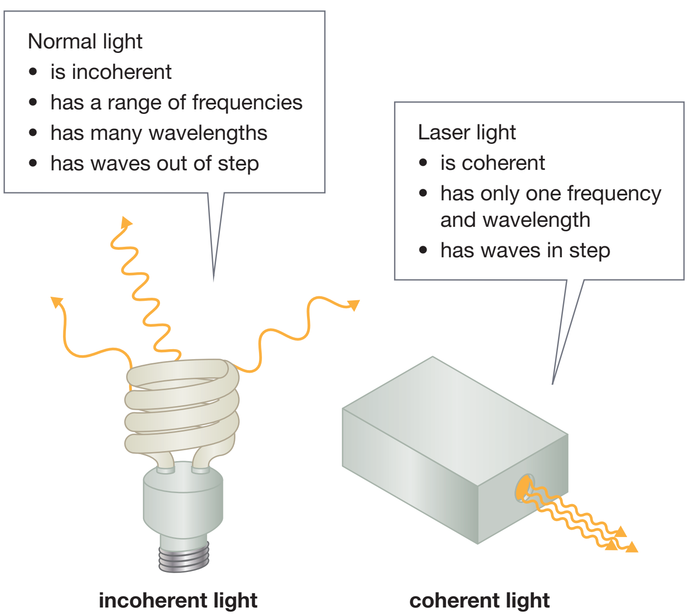


Figure 5.3.4 Light from an ordinary light globe produces light with a range of frequencies. A laser produces light of one frequency that is coherent.

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.

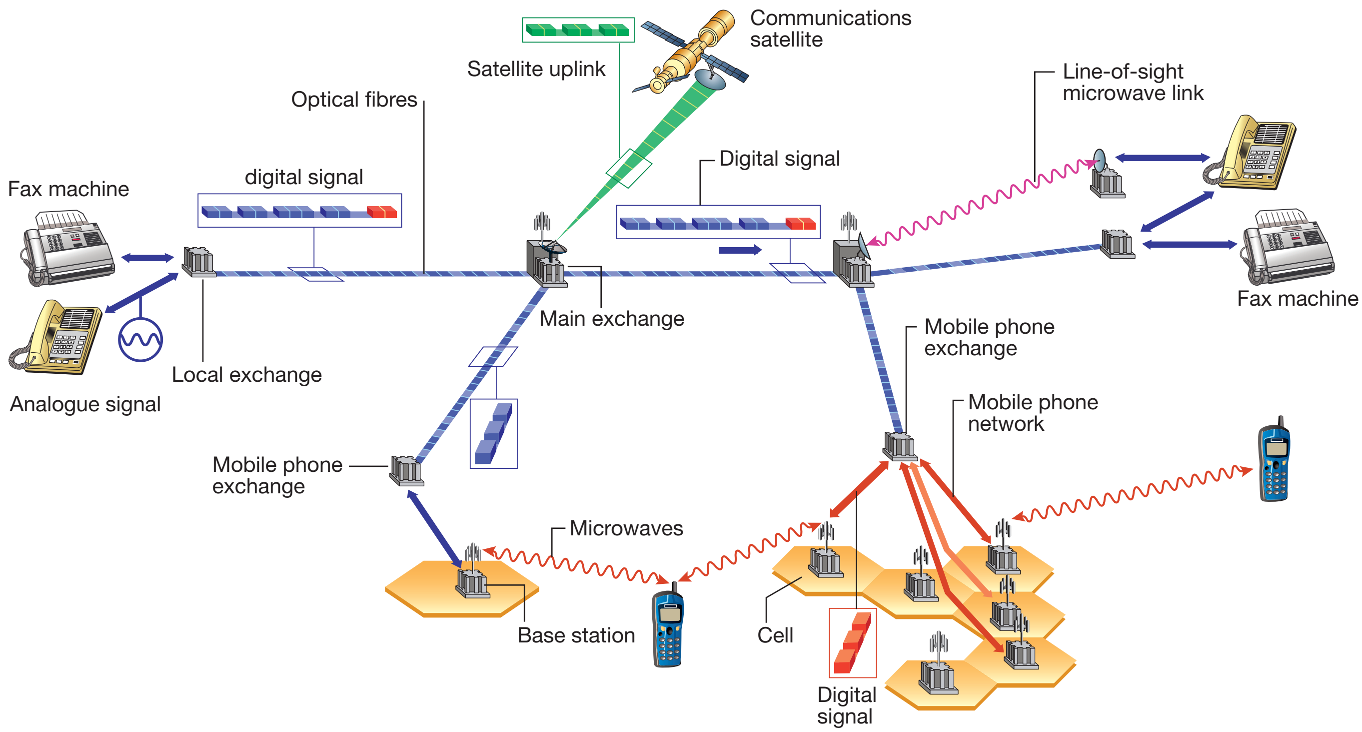


Figure 5.3.5 A modern communications network relies upon a number of channels of transmission, including copper cable, microwave links, satellite links and optical fibre. The short connections from a house to the communications network are usually made with copper wire.

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.

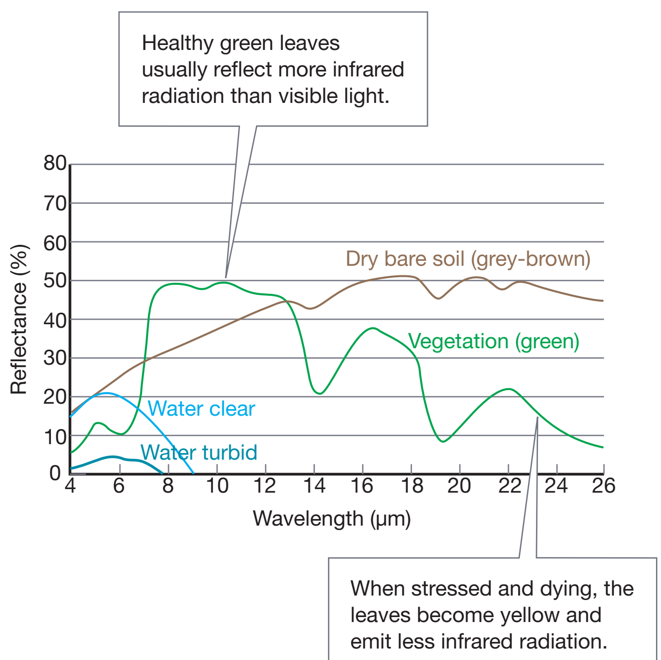


Figure 5.3.7 Knowing the way different substances reflect radiation can be used to provide information about an unknown surface.

5.7

2 p178

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.

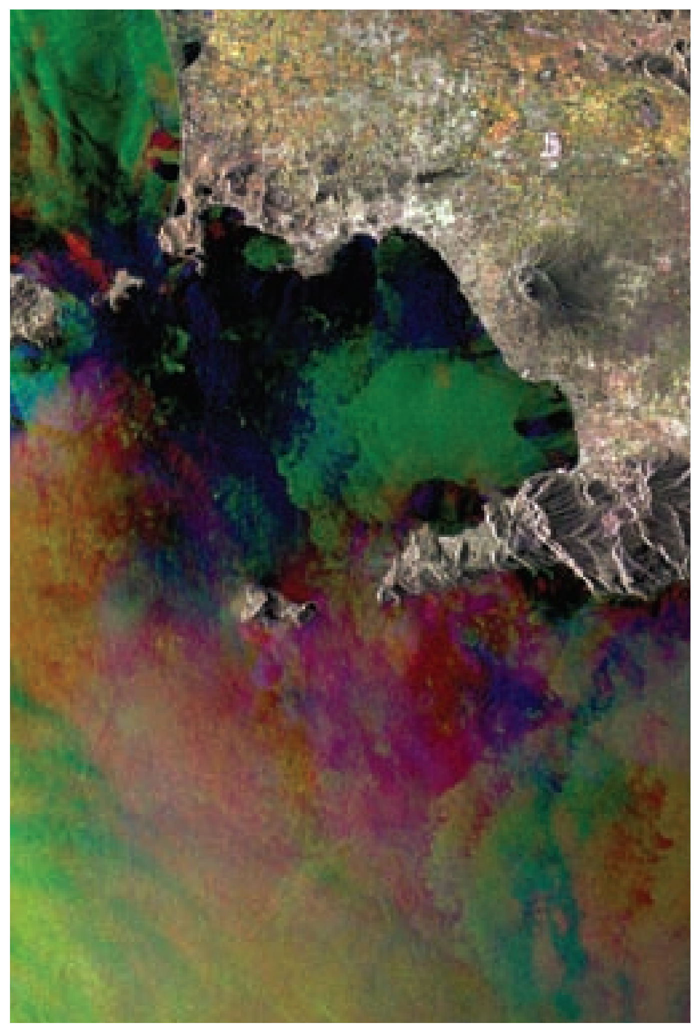


Figure 5.3.8 This satellite image shows the seas around Naples, Italy. The different colours indicate different sea surface roughness due to winds. It was taken in 2004 using the SAR (a type of radar) on board the European ERS-2 satellite.

SCIENCE AS A

HUMAN ENDEAVOUR

Use and influence of science

Wifi helps CSIRO scientist win top gong

Figure 5.3.9 Dr John O'Sullivan

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.

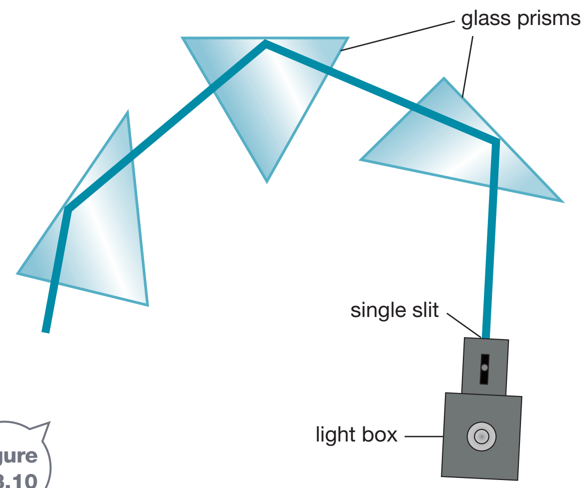


Figure 5.3.10

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

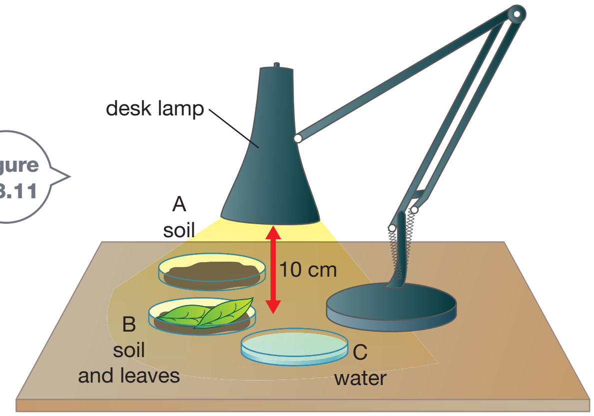
Warning: Do not touch the hot globe.

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

5.8

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

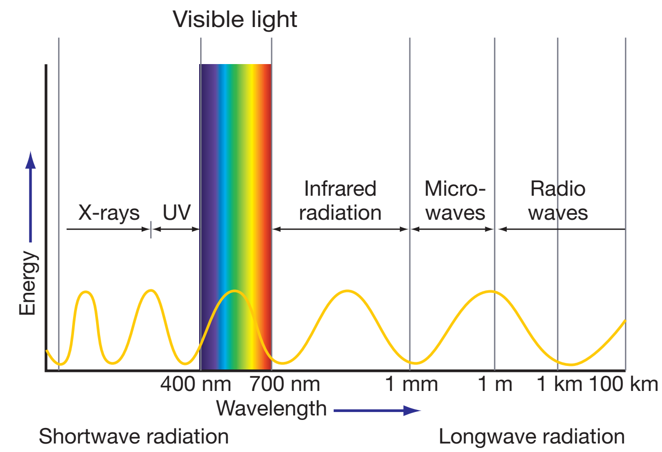
Which of the following lists the effective radiation dose absorbed by a person in order of increasing dose?

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 4.0×10^{-7} m, predict which wavelength below would be classed as infrared radiation.

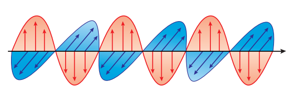
A 2.0×10^{7} m
B 2.0×10^{3} m
C 2.0×10^{-9} m
D 2.0×10^{-5} m

Glossary

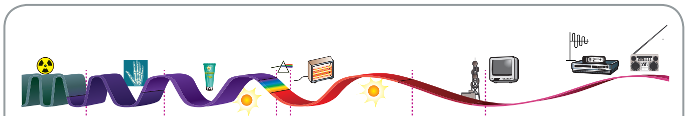
Unit 5.1

Electromagnetic radiation: a range of electromagnetic waves consisting of oscillating electric and magnetic fields travelling at the speed of light

Electromagnetic spectrum: the entire range of frequencies of electromagnetic radiation, from high-energy gamma rays to low-energy radio waves



Electromagnetic radiation



Electromagnetic spectrum

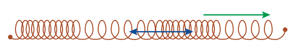
Electromagnetic wave: transverse electric and magnetic fields positioned at right angles to each other and travelling through empty space at the speed of light

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

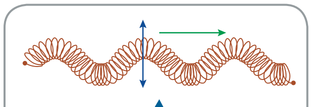


Longitudinal wave

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