4 Heat, light and sound

HAVE YOU EVER WONDERED …

- why you can't see clearly under water?
- why a doona keeps you warmer than just a sheet?
- how 3D glasses work?
- why the sky is blue?
- how musical instruments make different sounds?
- why diamonds sparkle?

After completing this chapter students should be able to:

- describe how different forms of energy such as heat, light and sound are transferred
- explain that the way energy is transferred depends upon the medium through which it travels
- describe situations in which energy is transferred in the form of waves, such as sound and light
- explain how your ears convert sound to electrical signals that your brain interprets as sound, and how your eyes convert light to electrical signals that your brain interprets as an image
- explain the impact of the cochlear implant and the bionic eye
- discuss how changes in frequency and amplitude of a sound wave affect the pitch and intensity heard by a listener
- recall that light is a form of energy that travels as an electromagnetic wave
- identify that light rays obey the law of reflection and that this can be used to produce an image in a mirror
- explain how refraction occurs and some of the effects that this produces
- outline how heat is transferred in terms of conduction, convection and radiation, and describe examples of each.

4.1 Heat

In cold weather, you seek extra jumpers or thicker doonas to keep you warm. When it is really hot, you wear less and use cooling systems like fans and airconditioners. Heat is a form of energy that you can sense through receptors in your skin. Heat can be lost from your skin as you stand in front of a fan, or be gained as your body absorbs radiant heat from the flames of a log fire.

INQUIRY science 4 fun

Feeling hot, feeling cold

Can you fool the receptors in your skin?

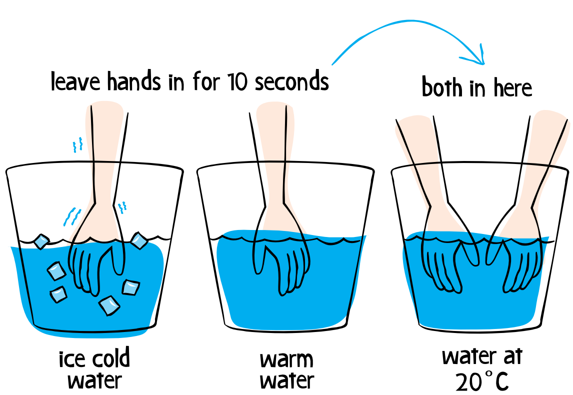
Collect this …

Yes

- plastic container half-full with very cold water (straight from a refrigerator with ice added)
- plastic container half-full with warm water (35–40°C)
- plastic container half-full with water at about 20°C
- thermometer
- paper towel

Do this …

1. Put one hand into the very cold water and the other hand into the very warm water and leave them there for 10 seconds.
2. Now put both hands into the water at 20°C.



Record this …

Describe what you felt.
Explain why you think this happened.

Heat

Thermometers measure temperature, but do not measure heat. Heat is a form of energy and describes the total energy of all particles within an object. Saucepans A and B in Figure 4.1.1 both contain boiling water. Although their temperatures are the same, saucepan A contains double the volume of water. Hence it has twice the heat energy of saucepan B.

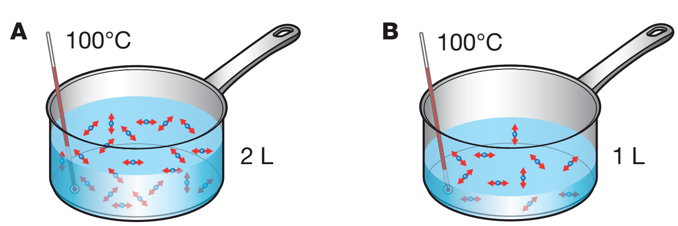


Figure 4.1.1 Saucepan A contains more heat energy because it contains more particles at the same temperature compared with saucepan B.

In Figure 4.1.2 the same amount of heat energy is supplied to two saucepans, X and Y. The saucepan with less water (X) shows the greatest temperature rise. This is because the heat energy in X is shared by fewer particles. These particles each absorb more energy and move faster. This increases the temperature of the water in X compared to Y.

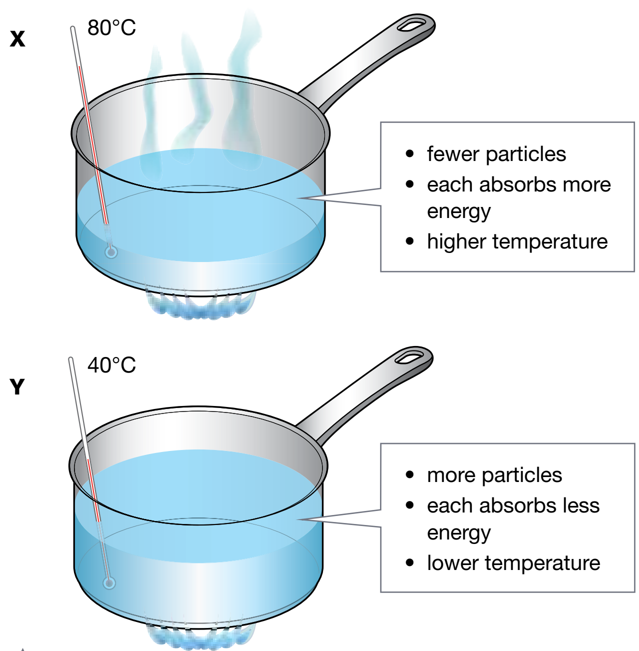


Figure 4.1.2 With fewer particles to absorb the heat energy in saucepan X, each particle has greater kinetic energy than the particles in saucepan Y, and as a result the temperature in saucepan X is higher.

Temperature

In everyday language, the words *heat* and *temperature* generally mean the same thing. However, for scientists, heat and temperature are very different. **Temperature** indicates how hot or how cold something is. It depends on how quickly the particles inside it are moving and is a measure of the average kinetic energy of these particles. Hotter substances have particles that are moving faster than the particles of cooler substances.

Temperature can be measured in a number of ways. Receptors in your skin give you an idea of how hot or cold something is, but these receptors can be fooled at times. A **thermometer** gives an accurate reading of temperature. A thermometer contains a liquid (alcohol or mercury) within a narrow glass tube. This liquid expands when heated and contracts when cooled. Temperature is read from a scale corresponding to the expansion and contraction of the liquid. Temperature is commonly measured in degrees Celsius (°C). The Fahrenheit (°F) and Kelvin (K) scales are also used to measure temperature.

INQUIRY science 4 fun

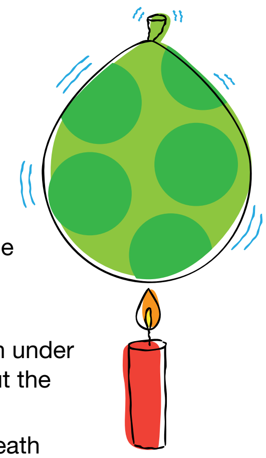
Burning a balloon!

Can you heat water in a balloon without bursting the balloon?

No

Collect this ...

- two balloons
- matches
- candle

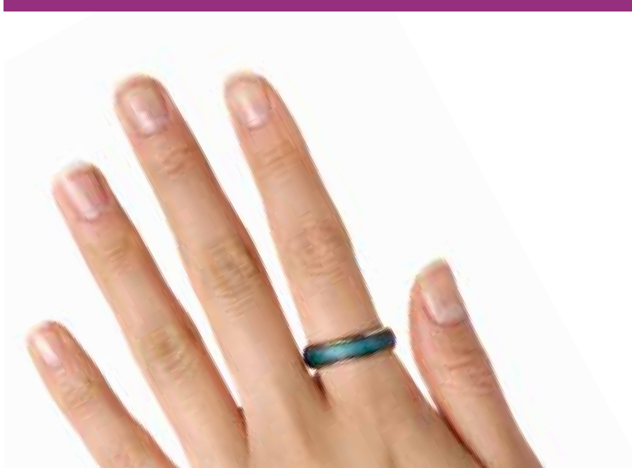


Do this ...

1. Blow up a balloon and tie its end.
2. Hold a lit candle below the balloon.
3. Observe what happens.
4. Now hold another balloon under a tap and fill it up to about the size of a rockmelon.
5. Place a lit candle underneath this second balloon, and again observe what happens.

Record this ...

Describe what happened.
Explain why you think this happened.



SciFile

Mood rings

Mood rings contain heat-sensitive liquid crystals. Particles in these crystals twist in different temperatures, changing colour. A green colour indicates a normal state, and a change to deep blue means you are heating up. This could indicate a happy or passionate mood change!

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Temperature scales

Figure 4.1.3 Anders Celsius

In 1593 Galileo invented an early type of thermometer. He suggested that a scale to measure temperature could range from that of the coldest day of winter up to that of the hottest day of summer. This approach made sense at the time, because temperature scales were used to describe the weather and not much else.

In 1714 a German scientist, Gabriel Fahrenheit, produced a mercury-filled thermometer. Zero on his scale was the lowest temperature he could produce from mixing salts and ice. He chose the temperature of the human body as another fixed point on his scale, which he set as 96 degrees. This scale, called the Fahrenheit scale, is still used in the United States of America today.

In 1742, the Swedish astronomer Anders Celsius proposed the Celsius scale, which is now commonly used in Australia and in most countries of the world. He named the scale 'centigrade', from the Latin meaning '100 steps'. Zero was set as the boiling point of water, with 100 degrees being the freezing point of water. After Celsius died from tuberculosis in 1744, thermometers were produced that had this scale reversed.

The British scientist William Thomson (later called Lord Kelvin) proposed a different temperature scale in 1848. He believed that zero on the scale should be the lowest temperature possible. As temperature drops, particles lose kinetic energy, until they barely move at all. This happens at –273°C, at a point known as **absolute zero**. The Kelvin scale begins at absolute zero, or 0 K. (The term *degree* is not used in the Kelvin scale, but each step in this scale is the same size as those in the Celsius scale.) The coldest place in the universe lies in deep space, where temperatures may be as low as three degrees above absolute zero. Scientists use the Kelvin scale.

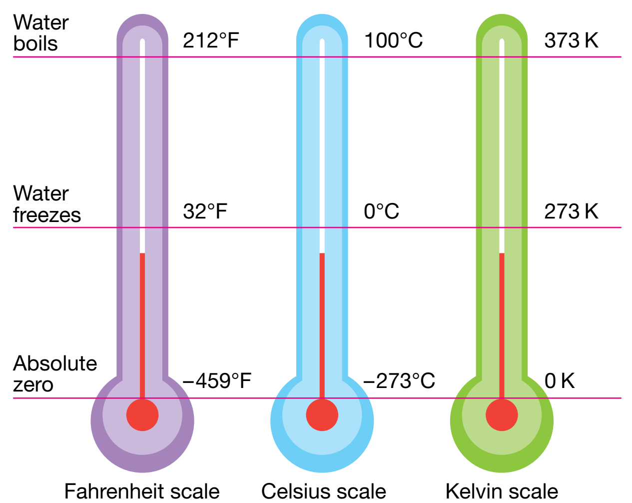


Figure 4.1.4 These three thermometers show the three scales commonly used to measure temperature. They were proposed by Gabriel Farenheit (1686–1736), Anders Celsius (1701–1744) and Lord Kelvin (1824–1907).

Heat transfer

Heat flows from areas of higher temperature to those of lower temperature. The greater the temperature difference, the faster heat flows from one object into another. This process of heat transfer can happen in three ways:

- conduction
- convection
- radiation.

Conduction

Hold an ice cube and your hand gets cold. This is because heat flows from your skin into the ice, lowering the temperature of your skin in the process. You know that the ice cube is absorbing this heat because it starts to melt. Heat has flowed from the higher-temperature hand into the lower-temperature ice cube. Figure 4.1.5 shows some examples of heat flow.

Figure 4.1.5 Heat will flow from your hands into an ice block, but from a hot cup into your hands.

Hotter substances have particles that are moving at a faster rate than cooler substances. Rapid jiggling or vibration of the particles in a hot mug of soup makes the particles in a metal spoon vibrate faster too, increasing the temperature of the spoon. This vibration of particles is passed on from one particle to the particle next to it, and as this process continues along the spoon you may feel the handle getting hot. This process of heat transfer by vibrating particles is called **conduction** and is shown in Figure 4.1.6.

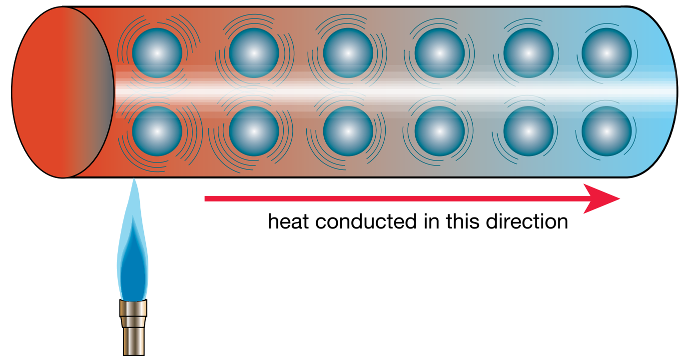


Figure 4.1.6 Particles near the flame vibrate more quickly as they absorb heat energy. These vibrations, from particle to particle, conduct the heat along the solid.

Conductors

Materials vary in how effectively they conduct heat. Holding a glass of ice-cold lemonade feels much colder than holding a polystyrene cup of ice-cold lemonade. Glass is a better conductor than polystyrene. As a result, heat flows from your warm hand into the cooler glass and your hand feels cold. When holding the polystyrene cup, your hand is not losing heat and so it still feels warm.

Substances that transfer heat easily are known as **conductors**. Metals, such as the saucepan shown in Figure 4.1.7, are good conductors of heat.

1 p108

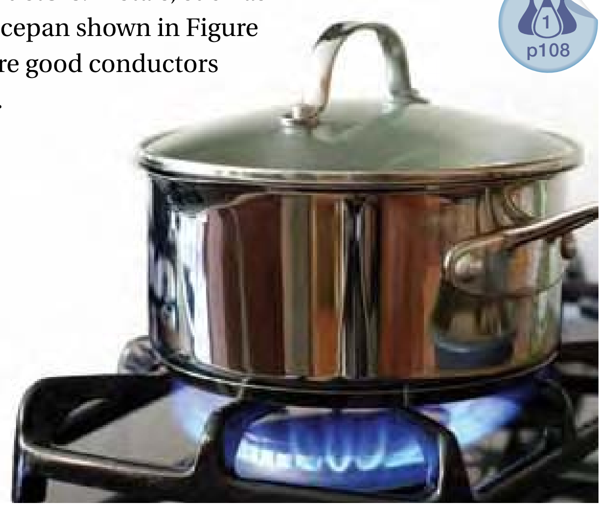


Figure 4.1.7 Metals, particularly copper and gold, are good conductors of heat.

Insulators

Plastic, air, cloth, wood and rubber are all very poor conductors of heat, and sometimes can block heat transfer completely. Such substances are known as **insulators**. The handles of a saucepan are usually made from insulating materials to allow us to lift them without burning our hands. An Esky uses insulating materials to keep food and drinks cool.

Gases are poor conductors of heat. Air trapped by woollen jumpers and blankets helps to insulate our bodies from losing heat. Ski parkas, doonas and sleeping bags are filled with cotton filling that also traps air and helps to protect us from the cold, as seen in Figure 4.1.8. Similarly, animals living in cold climates, such as those shown in Figure 4.1.9, have adaptations that help them stay warm.

4.1 2 p109

Figure 4.1.8 Wool fibres and the cotton filling inside a ski parka trap air and help prevent heat loss from your body.

Figure 4.1.9 These animals must stay warm in very cold conditions. Polar bears rely on body fat and a thick coat of fur for insulation, whereas penguins have layers of fat and feathers that they can fluff up to trap more air.

Convection

As air is heated, its particles gain energy and move further apart. This hot air is less dense than cool air, and so it is pushed upwards by cooler air around it. This method of heat transfer is called **convection**, and the air flow it creates is called a convection current. Such a current is shown in Figure 4.1.10, transferring heat from an open fire. Heat is transferred by convection in liquids and gases because their particles can move around, rather than remaining fixed like those within a solid. Figure 4.1.11 shows how liquid in a saucepan is heated by convection.

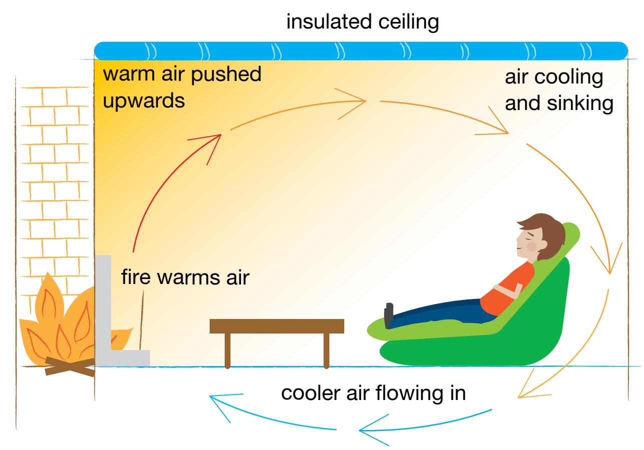


Figure 4.1.10 As air warms, it becomes less dense and is pushed up by cooler air that is sinking. These convection currents gradually spread heat from the open fire through the air in the room. A ceiling fan on winter mode would help to mix the air.

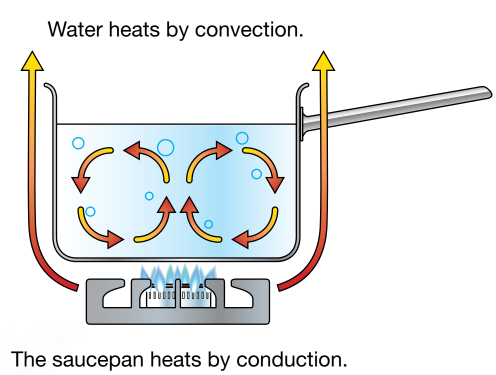
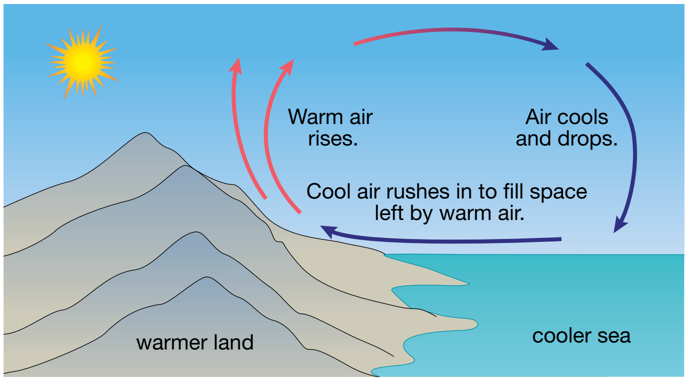
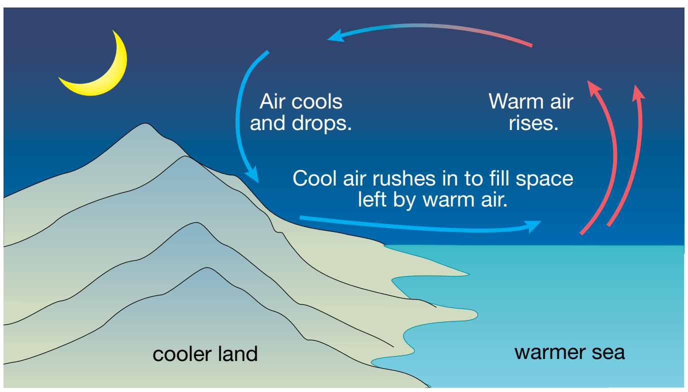


Figure 4.1.11 Particles gain heat from the hot base of the saucepan and rise to near the top of the saucepan. Cooler liquid sinks down and is then heated, and the cycle continues.

Convection explains the formation of a sea breeze during the day and a breeze towards the sea at night. This process is shown in Figure 4.1.12. Convection also circulates heat in a hot water system. This is shown in Figure 4.1.13.



A sea breeze during the day



A land breeze at night

Figure 4.1.12 In the daytime, land heats up more quickly than the sea. Hot air is pushed upwards by cooler air that flows in towards it, producing a sea breeze. At night, the sea retains its heat for longer than the land. Warm air is pushed upwards above the sea as cool air flows from the land towards it.

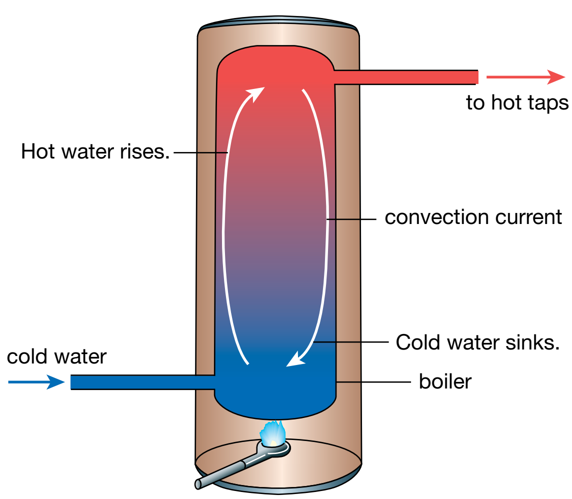


Figure 4.1.13 Convection assists in circulation of water in a hot water system.

INQUIRY science 4 fun

Ups and downs!

Can you see convection currents in action?

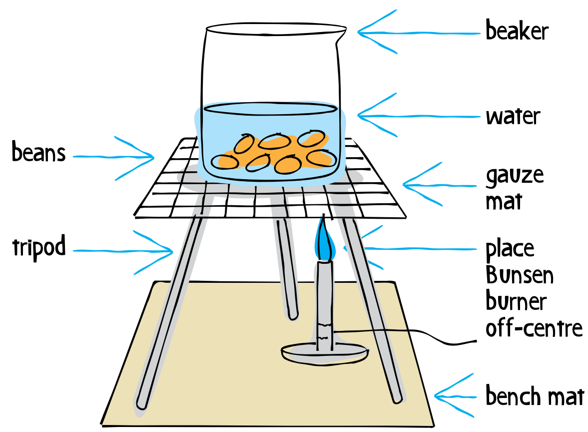
No

Collect this …

dried beans, such as borlotti beans or chickpeas
Bunsen burner, gauze mat, tripod and bench mat
large beaker of water

Do this …

1 Add dried beans to cover the base of the beaker.
2 Heat this carefully over a Bunsen burner.



Record this …

Describe what happened.
Explain why you think this happened.

SciFile

Home insulation

Heat transfer in a home occurs by conduction, convection and radiation. In winter, warm air flows out of the house, and in summer, warm air flows in. Insulation added to the ceiling and walls of a home helps to stop this transfer of heat and makes your home more energy efficient.

Radiation

If you sit on a deck chair on a sunny balcony, you can feel the heat from the Sun on your skin. Heat has travelled through empty space between the Sun and the Earth to reach you (Figure 4.1.14). It cannot be transferred by conduction or convection on its journey because there are no particles to vibrate or flow in the vacuum of space. The Sun transfers its heat energy through a process called **radiation**.

Figure 4.1.14 Radiation from the Sun travels through the vacuum of space to reach us. It is cooler in the shade because this radiation has been blocked.

Radiation transmits heat as invisible waves that travel at the speed of light (around 300 000 km per second). Infra-red radiation is heat energy that is transmitted this way. All objects release, or emit, some infra-red radiation.

The hotter something is, the more heat it radiates. You can feel the difference in the radiant heat produced by an oven set to a low temperature compared to a hot oven when you open the oven door. Similarly, the red-hot coals of an open fire radiate such enormous heat that you cannot sit too close to them.

When radiated heat hits a surface, it may be absorbed into it, reflected from it or transmitted through it, as shown in Figure 4.1.15. Often radiation will be partially absorbed, reflected or transmitted according to the materal and its colour.

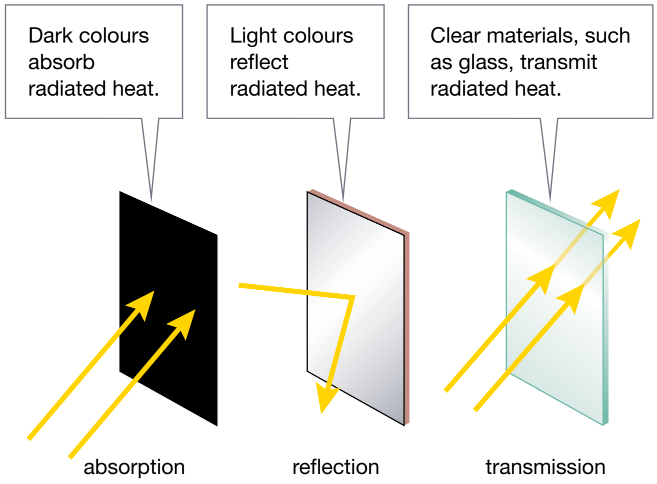


Figure 4.1.15 When radiation hits an object, it may be absorbed, reflected or transmitted.

A dark-coloured car heats up more quickly in sunlight than a lighter-coloured car. This happens because dark-coloured objects are good absorbers of radiation, whereas lighter colours reflect much of it and don't heat up as rapidly. Darker objects also lose heat by radiation faster than lighter colours. Solar hot water systems utilise this absorption of heat energy from the Sun by using black collection panels, as shown in Figure 4.1.16.

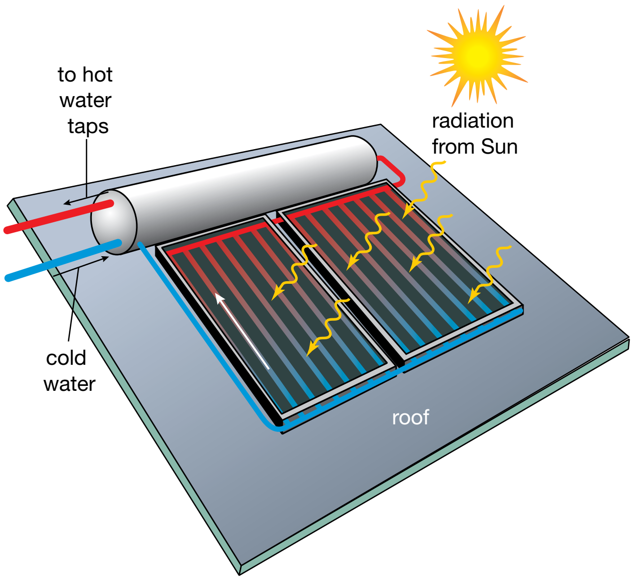


Figure 4.1.16 Heat energy radiated by the Sun is absorbed by the cold water within the black collection panels of a solar hot water system. Some systems rely upon the natural convection of the hot water to circulate the water without the use of a pump.

4.2

3 p110

4.1 Unit review

Remembering

1 **State** the temperature on the Fahrenheit, Celsius and Kelvin scales at which water freezes.

2 **Recall** how heat transfers by selecting the correct alternative in each statement below.
  - a Heat always flows from an object of higher temperature to one of *lower/higher* temperature.
  - b Insulators are *good/poor* conductors of heat.
  - c Gases are *good/poor* conductors of heat.
  - d On a warm day, a house is warmer upstairs because of *conduction/convection* currents.
  - e The element of a hot water system will be located near its *top/base* and the heat is spread by convection.

3 **List** three insulators.

Understanding

4 **Describe** how heat is conducted along a metal rod.

5 Figure 4.1.2 on page 100 shows saucepans X and Y of water being supplied with equal amounts of heat energy. **Explain** why the temperature rise in saucepan X is greater.

6 A wetsuit traps a layer of water between the wearer and the fabric of the suit.
  - a **State** whether water is a good or poor conductor of heat.
  - b **Explain** how this design helps to keep the wearer of the suit warm.

7 **Explain** why the vents for a ducted heating system are usually placed near the floor and not the ceiling.

8 You lose a lot of heat from your head. For most people, their hair protects them from losing too much heat from their heads.
  - a **Explain** why hair is an effective insulator.
  - b **Describe** a hair style that would give you excellent insulation.

Applying

9 Heat transfer can occur by conduction, convection or radiation. **Identify** the main method of heat transfer in each situation below.
  - a Your feet get hot when you are walking on sand at the beach.
  - b Your back feels warm when you are sitting in the sun.
  - c You boil water in an electric kettle.
  - d You feel cold when you dive into a swimming pool.
  - e You feel warm air as you walk into a school disco held in a hall.

Analysing

10 **Compare** heat and temperature.

11 **Compare** the Fahrenheit, Celsius and Kelvin temperature scales.

12 Two identical bathtubs are filled to the same level with water. The particles in bathtub A move with greater speed than the particles in bathtub B. **Analyse** this situation to answer the following.
  - a **State** in which bathtub the water will be at a higher temperature.
  - b **State** which bathtub has more heat energy.
  - c As the water cools, each bath loses heat energy. **List** three places this heat energy could go.

Evaluating

13 Figure 4.1.17 shows the experimental set-up for a radiation experiment. The same sized black and white cardboard squares are attached to two thermometers close to an incandescent globe.

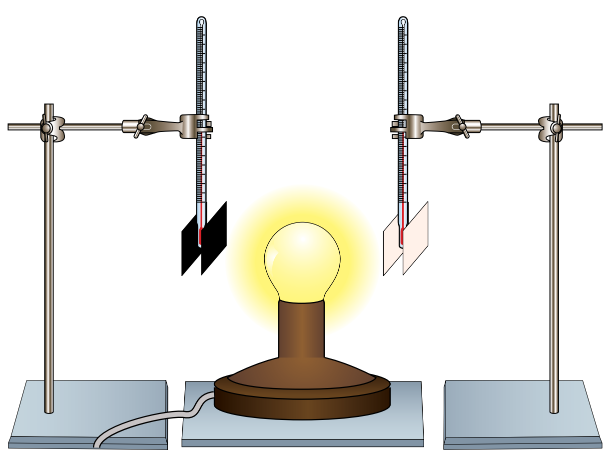


Figure 4.1.17

a **Propose** what the student performing the experiment is trying to test.
b **State** three variables that must be controlled to ensure a fair test.
c **Predict** which thermometer will show the highest reading after 5 minutes.
d **Discuss** reasons for your answer to question c.

14 **Propose** reasons why it is important for babies to wear a hat on a cool and windy day.

15 You walk barefoot on carpet in the living room of your house and your feet feel warm, yet when you walk into the bathroom and stand on the ceramic tiles your feet feel cold. The carpet and tiles are at the same temperature. **Propose** an explanation for why this is the case.

16 On a hot day, you have a choice of travelling in a red car, a white car or a black car, all of the same model. All have been parked in the sunlight for three hours.
a **Identify** which car you would choose.
b **Justify** your choice.

Creating

17 **Design** a new type of suit that will keep you warm in cold conditions. Draw a diagram of your design, labelling what it is made from and how it keeps the heat in.

Inquiring

1 Some animals help regulate their body temperature by heat loss through their ears. Research how animals absorb and emit heat. Prepare a multimedia presentation about the process used by three different animals.

2 Research the structure of double-glazed windows. Explain how these prevent heat loss.

3 Research how a thermos is designed to prevent heat loss. Explain how this happens, using labelled diagrams to assist your response.

4 Discover more about your body's largest organ—your skin. Create a poster with text in which you discuss either:
a different skin conditions (such as acne, warts, dermatitis, freckles and moles), or
b different forms of skin cancer, facts about each, what they look like, and how to prevent it.

5 Design and conduct an investigation into the cooling effect of a fan or an airconditioner on a warm glass of water. You could investigate how the effectiveness of the cooling device varies as the glass is positioned further away, or when the device is operated on different power settings.

6 Some manufacturers of mood rings claim that these rings can reveal a person's mood. Investigate and assess these claims.

SciFile

Feeling chilly?
Naked mole rats are the only known mammals not in control of their body temperature. Their bodies are warmed to the temperature of their burrows, about 30°C.

4.1 Practical activities

1 Comparing materials

Purpose

To compare how well plastic, wood and metal conduct heat.

Materials

- plastic spoon
- metal spoon
- wooden icy-pole stick
- 250 mL beaker
- small beads or similar
- butter
- very hot water (from a kettle)
- stopwatch
- ruler

SAFETY

Handle hot water with care.

Procedure

1. Predict how well plastic, wood and metal conduct heat.
2. Put a dob of butter near the top of the handle of the plastic spoon.
3. Push a bead onto the dob of butter.
4. Repeat for the metal spoon and icy-pole stick. Make sure the beads are placed at equal heights and use the same amount of butter each time.
5. Carefully place the spoons and the icy-pole stick into very hot water in the beaker as shown in Figure 4.1.18.
6. Time how long each bead takes to fall off, and record your results in a table like the one shown in the Results section.

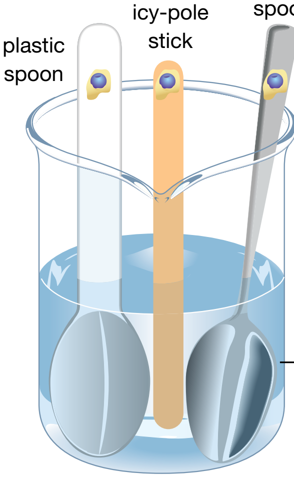


Figure 4.1.18

Results

In your workbook, construct a table like the one shown here.

Time taken to drop (seconds)		
Bead on plastic spoon	Bead on icy-pole stick	Bead on metal spoon

Discussion

1. **State** which of the materials used was the best conductor of heat and whether your prediction was correct.
2. **Assess** which material was the best insulator.
3. **Explain** why it was important that the beads were all placed at the same height in the experiment, and that the same amount of butter was used.

2 Testing insulators

Purpose

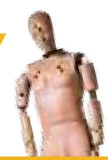
To test how effective different materials are in insulating heat.

Materials

- empty soft drink cans
- a range of insulating materials such as: newspaper strips, cloth, cotton wool, foam, polystyrene beads, foam packing bullets, fibreglass insulation, carpet scraps
- thermometer or temperature probe
- cardboard box
- hot water
- beaker
- stopwatch or clock

SAFETY

Handle hot water with care.



You may use a temperature probe to gather temperature data.

Procedure

1. Carefully measure 200 mL of hot water using a beaker, and pour this into your can.
2. Place the can inside the box.
3. Record the initial (starting) temperature of the water, and then measure and record the temperature every 2 minutes for 10 minutes. Put all your measurements in a table like that shown below.

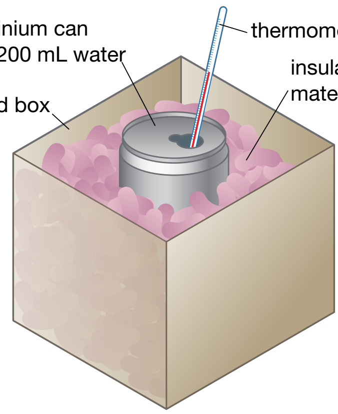


Figure 4.1.19

4. Repeat, using water at the same initial temperature and packing one of the insulating materials into the space between the can and the box, as shown in Figure 4.1.19.
5. Repeat the process, using a second insulating material.

Results

1. In your workbook, construct a results table like the one shown below. Insert the names of two insulating materials you are going to test.
2. On the same set of axes, similar to those shown in Figure 4.1.20 on page 110, **construct** a line graph for each sample tested, to show the temperature drop over time. Alternatively, use data-logging equipment to produce a graph.

Time (minutes)	Water temperature (°C)		
	Can with no insulating materials (air only)	Can with insulating material A	Can with insulating material B
0			
2			
4			
6			
8			
10			

Testing insulators continues

Testing insulators continued

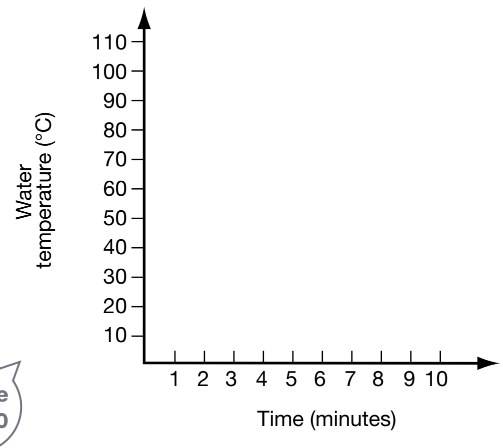


Figure 4.1.20

Discussion

1 **Assess** which material was the best insulator.
2 **Explain** why it was important to test one can with no insulating materials.
3 **Identify** any sources of error in your experiment.
4 **Outline** any improvements that could be made to the design of the experiment.
5 **Design** another experiment that you could carry out with this equipment to test heat loss or heat gain. **Explain** which variables you would need to control.

3 Comparing heat radiation

Purpose

To compare how different colours radiate heat.

Materials

- silver, white and black aluminium cans
- thermometer or temperature probe

Procedure

Design a prac to compare the amount of heat that is radiated over a time period from silver, white and black aluminium cans containing equivalent volumes of water at the same temperature. If available, you may wish to use a temperature probe to gather your data. With your teacher's permission, conduct your experiment.

Results

1 Write a report on your findings.
2 Construct a line graph to display your results.

Discussion

Construct a conclusion to summarise your findings.

4.2 Sound

Indigenous Australians developed the didgeridoo thousands of years ago. The player blows air into the didgeridoo while vibrating his lips. The didgeridoo itself makes only one note, a low rumbling sound. The unique depth of sound and tone of the didgeridoo are produced by the player changing the shape of his vocal tract by changing the position of his tongue. Musical instruments like a guitar produce sound using strings that vibrate. Other devices, such as ultrasound machines, rely on the reflection of sound waves to produce an image of the structures inside the human body.

INQUIRY science 4 fun

Hear this!

Sound vibrates the air particles as it travels through them. What happens to a sound wave when you push air particles closer together?

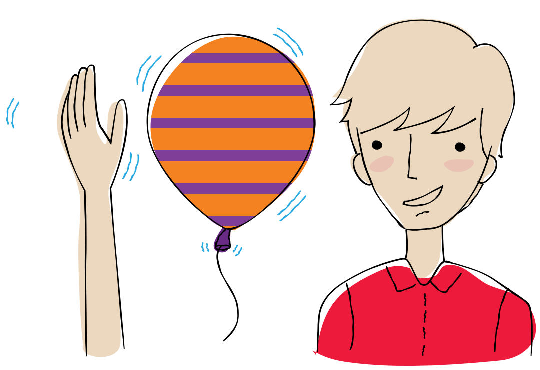
Yes

Collect this ...

- a balloon

Do this ...

1 Blow up the balloon and tie off the end.
2 Hold it close to one of your ears.
3 Have a partner lightly tap on the other side of the balloon.



Record this ...

Describe what you could hear.

Explain what you think makes this happen.

What is sound?

Sound is produced when something *vibrates*, which means to move back and forth very quickly. Table 4.2.1 on page 112 shows some common sounds and the objects that vibrate to produce them. When something vibrates, it passes the vibration into its surrounding environment, such as air. The vibration creates regions of space in which the air particles are bunched together, called **compressions**, and regions in which they are more spread out, called **rarefactions**. A **sound wave** is the movement of alternating compressions and rarefactions. This is shown in Figure 4.2.1 on page 112. These sound waves travel away from the source of a sound, in the same way that ripples of water move outwards when a stone is dropped into a pond. Because a sound wave relies upon particles that vibrate for it to be transmitted, a solid (such as a railway track), a liquid (such as water in a swimming pool) or a gas (such as air) is needed for a sound to be produced.

Table 4.2.1 Common sounds and their sources

Sound	Vibrating source
Speech	Flaps of skin, called vocal cords
Drum	Drum skin
Piano	String inside piano—when you strike a key, the string is struck by a hammer
Saxophone	Reed inside the mouthpiece
Car stereo system	Speaker cone
A bell ringing	Metal casing of the bell (when struck)

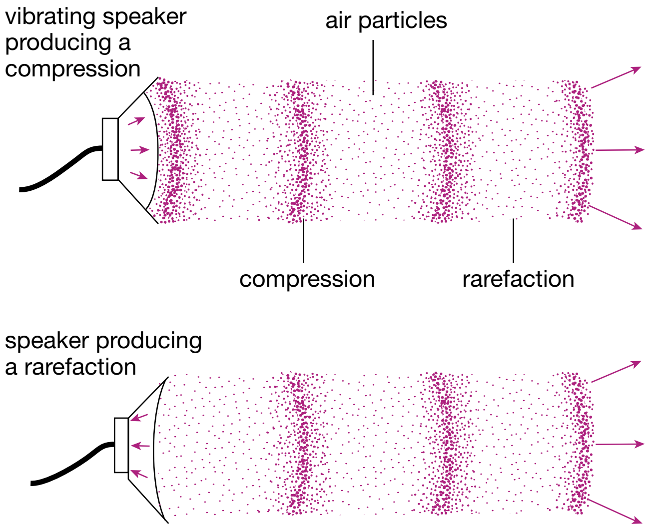


Figure 4.2.1 A vibrating speaker produces regions in which air particles are close together, called compressions, and regions in which air particles are spaced further apart, called rarefactions. The energy moves through air as a sound wave.

Types of waves

A wave carries energy from one point to another. This can happen in a couple of ways. The energy carried by waves at the beach moves horizontally, but the particles making up the wave actually move in a vertical direction, as shown in Figure 4.2.2. This explains why a boat in the ocean bobs up and down as a wave travels to the shore. This type of wave is called a **transverse wave**.

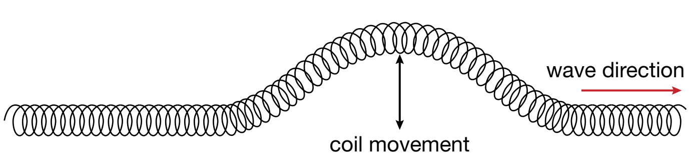


Figure 4.2.2 In a transverse wave, particles move at right angles to the direction of movement of the wave.

A sound wave differs from a transverse wave. In a sound wave, the particles that make up the wave move back and forth in the same direction that the wave is travelling. This type of wave is called a compression, or a **longitudinal wave**, and is shown in Figure 4.2.3.

p122

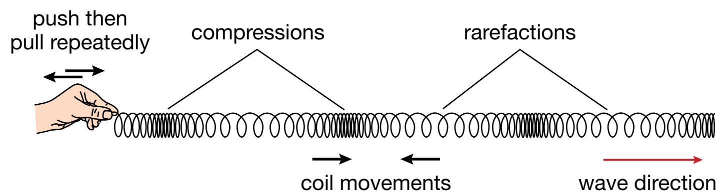


Figure 4.2.3 In a longitudinal wave, particles move in the same direction that the wave is moving.

The speed of sound

The more closely packed the particles in a medium (a 'medium' is the surrounding environment), the faster a sound wave will travel through it. As a result, sound travels faster through solids than through liquids, and faster through liquids than through gases. Table 4.2.2 shows the speed of sound in several materials. Sound travels faster in warmer air than in cooler air, because the particles in warmer air move with greater kinetic energy.

Table 4.2.2 Speed of sound in various materials

Material	Speed of sound (metres/second)
Air (at 0°C)	331
Air (at 18°C)	342
Water	1440
Wood	4500
Steel	5100
Glass	5200

Where does sound go?

You can usually hear when people are at home in your house from noise in the kitchen, living room or bedrooms. Sound passes through thin walls and is transmitted short distances through most materials.

Hard surfaces, such as concrete or bathroom tiles, reflect sound waves. This reflected sound is heard as an **echo**. The time difference between sending and receiving sound waves can be measured. This difference can be used to calculate the depth of objects in the sea, using a technique called sonar (**so**und **na**vigation and **r**anging), shown in Figure 4.2.4.

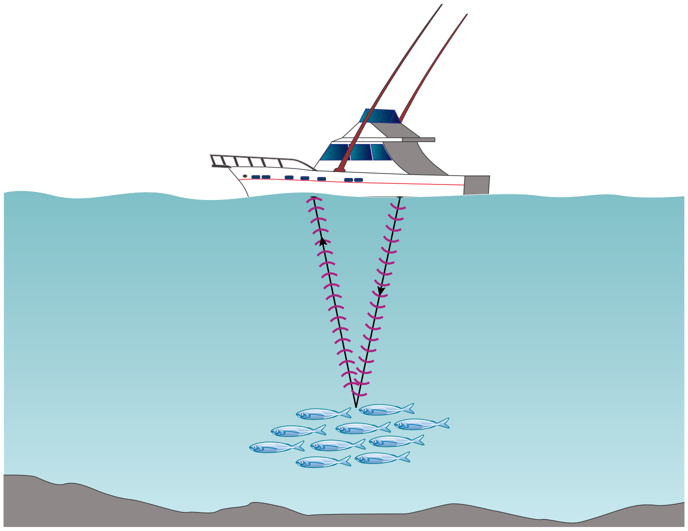


Figure 4.2.4 Sonar can be used to calculate the depth of objects in the sea, such as a school of fish.

SKILL BUILDER

Sonar calculations

Sound travels at about 1500 metres/second in sea water. Sonar measures the time it takes for sound to return to the ship. This data may be used to calculate how deep the water is, or how deep a school of fish are.

To calculate depth:

1. Halve the time it takes for the sonar signal to return. This gives the time it takes for the signal to reach the bottom or the fish.
2. Multiply this by the speed of sound in sea water (i.e. × 1500).

WORKED EXAMPLE

Sonar calculations

Problem

Sound travels at a speed of about 1500 m/s in sea water.

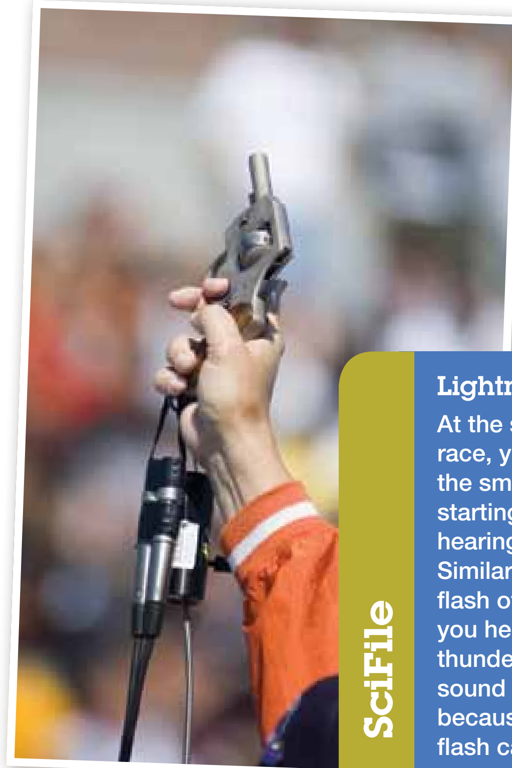
a It took 0.4 seconds for a sound pulse sent from the ship in Figure 4.2.4 to return. Calculate the depth of the fish.

b Calculate the depth of the fish, given that the sound took 1 second to return.

Solution

a If it took 0.4 seconds for a pulse to return, then the sound reached the fish after 0.2 seconds. The sound pulse travelled at 1500 m/s, so this means that the fish are located $0.2 \times 1500 = 300$ m below the ship.

b If the sound returned in 1 second, then it reached the fish in 0.5 second. The fish are located $0.5 \times 1500 = 750$ m below the ship.



SciFile

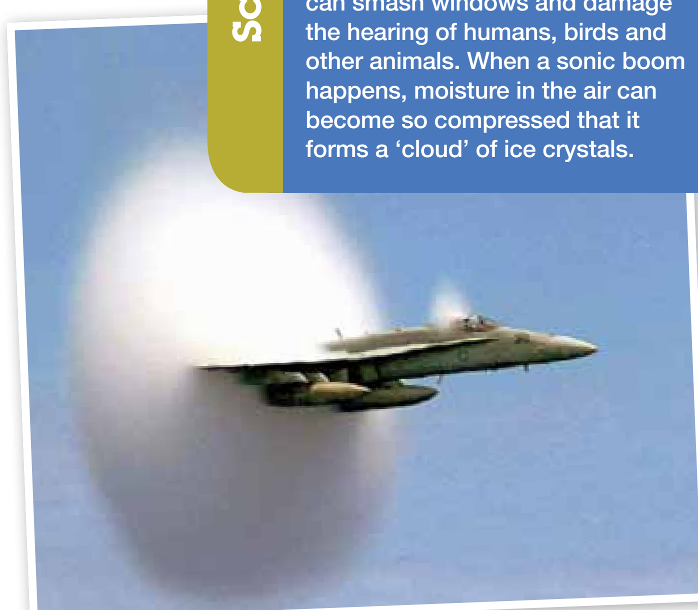
Lightning speed

At the start of a running race, you may notice the smoke from the starting pistol before hearing its sound. Similarly, you see a flash of lightning before you hear the rumble of thunder. You hear the sound of thunder because the lightning flash causes the surrounding air to expand rapidly. The reason you see the lightning before hearing the thunder is that light travels much faster than sound.

SciFile

Boom!

Fighter jets regularly travel at supersonic speeds—faster than the speed of sound. As the jet catches up to and then overtakes the sound waves it has produced, a very loud ‘sonic boom’ is heard. Sonic booms can smash windows and damage the hearing of humans, birds and other animals. When a sonic boom happens, moisture in the air can become so compressed that it forms a ‘cloud’ of ice crystals.



Soft materials like curtain fabric, carpet and cushions (Figure 4.2.5) absorb sound and convert it into heat. This reduces the reverberation, or length of time a sound is heard. Sound absorption like this is needed in concert halls, so that there is no overlap between the sounds being performed and their echoes, which would otherwise distort what you hear. Figure 4.2.6 compares how well some materials absorb sound.

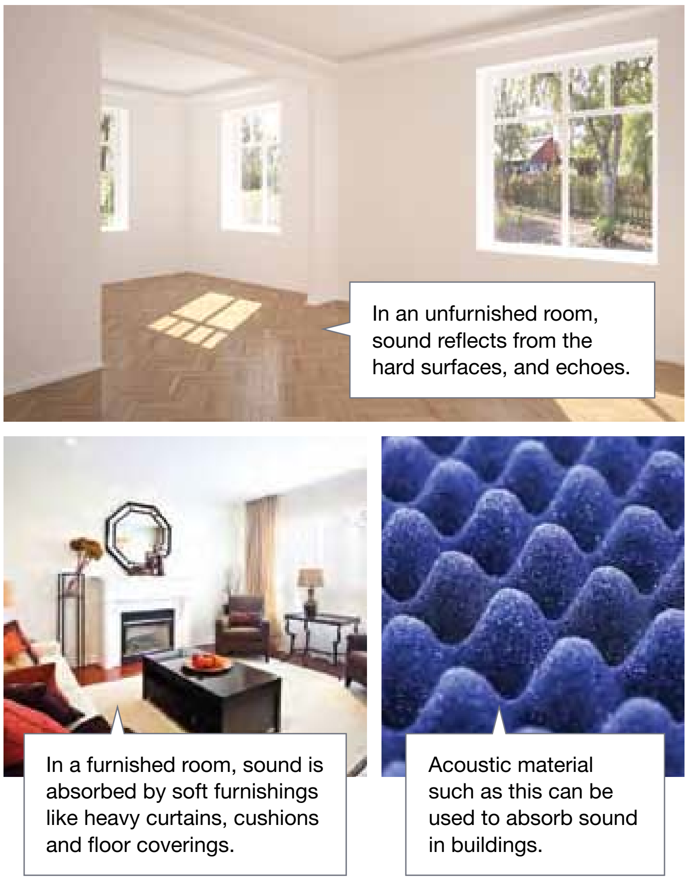


Figure 4.2.5 Different materials will give a room different reverberation times.

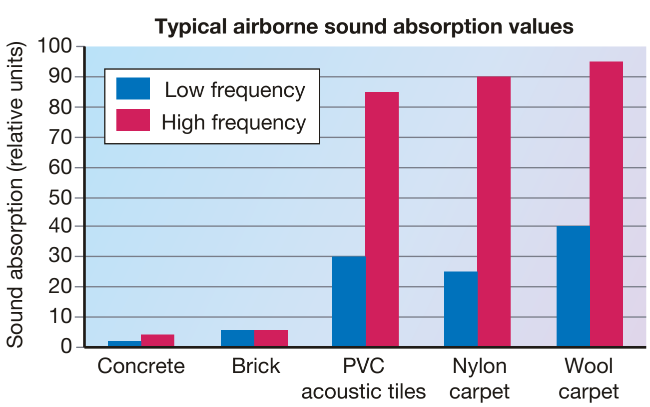


Figure 4.2.6 This graph compares the sound absorbtion levels of different materials.

Frequency and pitch

A dog has a low-pitched growl, whereas a bird chirps with a high-pitched sound. The different sounds can be compared by analysing their sound waves using a cathode ray oscilloscope (CRO), as shown in Figure 4.2.7. A source that vibrates rapidly produces sound of a higher pitch, or **frequency**, than one that vibrates more slowly. The number of vibrations a sound makes each second is called the frequency of a wave. Frequency is measured in **hertz** (**Hz**).The **wavelength** of a sound is the distance between successive peaks. It is measured in metres. Figure 4.2.8 shows that graphs of louder sounds have larger peaks, meaning louder sounds have greater amplitude than softer sounds. Sounds with higher frequency produce soundwaves that are shorter in wavelength with the compressions and rarefactions bunched closer together than sounds at a lower frequency, resulting in a shorter wavelength.

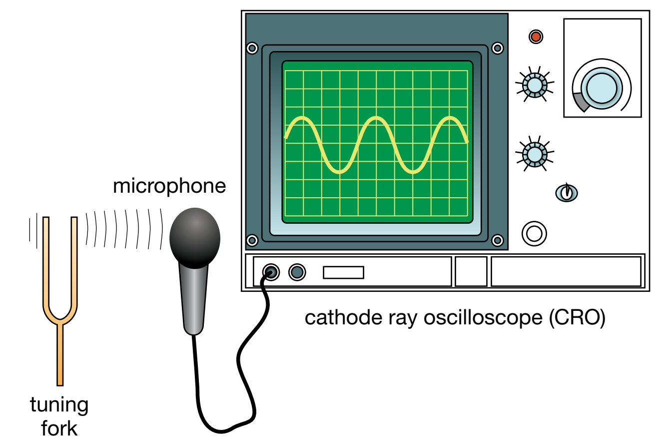


Figure 4.2.7 A CRO converts sound waves into electrical signals that can be viewed on a screen. The trace shown on the screen is a graph that shows how the pressure of particles making up the sound wave changes as the wave travels.

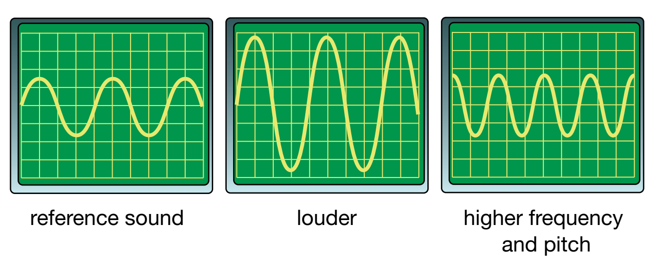


Figure 4.2.8 A loud sound has a taller graph on a CRO than a quiet sound. Higher-frequency sound waves have a short wavelength.

2 p122

The Doppler effect

Have you ever heard the wail of an ambulance siren rushing past? When an ambulance travels towards you, the sound waves it emits bunch up. This makes the sound of its siren higher in pitch. As the ambulance moves away, its sound waves are spread further apart and the sound is lower in pitch. Called the Doppler effect, this occurrence is named after the Austrian physicist Christian Doppler, who described it in 1842.

SciFile

INQUIRY science 4 fun

Straw clarinets

How does changing the length of a flute or a clarinet change the sound it produces?

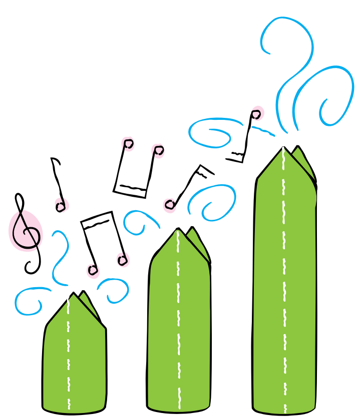
Collect this …

- a straw
- a pair of scissors

Yes

Do this …

1. Squash the end of a straw.
2. Cut the top off the straw to make a point.
3. Blow into the pointy end of the straw.
4. Try different positions until you get a buzzing sound.
5. As you are making the sound, have a partner carefully cut the other end of your straw.
6. Keep cutting, making the straw shorter and shorter.



Record this …

Describe how the sound changed as the straw got shorter.

Explain how you think the straw produced a sound.

Our ability to hear higher frequencies of sound reduces as we age. Young people can typically hear a range of frequencies up to 20 000 Hz, yet most people over 65 years cannot hear frequencies above 5000 Hz. Hence, mobile phone ringtones like the mosquito (16 000 Hz) cannot be heard by older adults.

Many animals, such as dogs and cats, can hear sound frequencies that are outside our human range of hearing. **Ultrasound** is the name given to sound waves with frequencies above our hearing range. Bats emit squeaks with frequencies up to 200 000 Hz, which reflect off surfaces around them and are used by the bat to avoid obstacles and to locate food. Elephants can hear a range of frequencies lower than our own hearing range. These frequencies are called **infrasound**.

Computer analysis of the way ultrasound reflects from living tissue can be used to create an image, like the one shown in Figure 4.2.9.

Figure 4.2.9 Ultrasound waves pass easily through fluids and soft tissue but are reflected from other layers within an organ or foetus. Echoes of these waves are detected and analysed by computer to create the image, such as this 3D image of a human foetus.

SciFile

Teenager repellent!

The Mosquito (or mosquito alarm) emits a high-frequency sound of around 17 000 Hz. This can typically be heard only by people under the age of 25. The device has been used around the world to discourage youths from hanging around outside shops or railway stations. Now, teenagers have had the last laugh—using the sound of the mosquito alarm to signal incoming text messages.

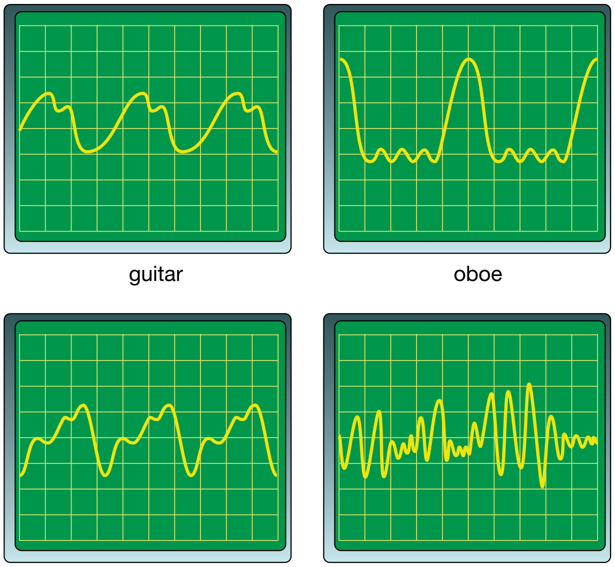


Figure 4.2.11 Musical notes played using an instrument have a smooth, repeating pattern when viewed on the CRO. Different types of instrument produce characteristic sounds. Background noise shows up as a uneven mixture of waves.

Musical instruments

All musical instruments produce sounds by vibrations (Figure 4.2.10). They do this in different ways and produce sounds of differing characteristic qualities. These differences can be compared by playing the sound into a microphone attached to a cathode ray oscilloscope. Typical traces from some instruments are shown in Figure 4.2.11.

On a guitar, a violin and a piano, vibrations are produced by strings. Changing the length of the string alters the frequency of the sound produced. Longer strings vibrate more slowly, producing lower-pitched sound than shorter strings. When you press a string against the neck of a guitar, you shorten the effective length of that string.

Figure 4.2.10 Each of these musical instruments uses vibration to create its sound. Guitars use vibrating strings, saxophones use a reed and drums use a ‘skin’.

In percussion instruments like drums, the skin stretched over the top of the drum vibrates when you hit it. In instruments like the triangle or the cymbal, the instrument itself vibrates.

In wind instruments, a column of air vibrates. When you play a flute or a recorder, the length of this vibrating column of air is increased when you cover holes along the tube, and shortened when you leave the holes open. A longer vibrating column of air produces a lower sound than a shorter vibrating air column.

How you hear: the ear

Your ears collect sound waves, amplify their vibrations and convert these into electrical impulses. Your brain then interprets these impulses as sound. Figure 4.2.12 illustrates the parts of the ear and describes how they function.

SciFile

Popping ears

As an aircraft takes off, or if you go up into the hills, the air pressure outside your eardrum falls, but the air pressure inside your ear remains the same. This pushes against your eardrum. When your ears ‘pop’, the Eustachian tube opens and releases air through your nose and throat, which balances the air pressure on your eardrum.

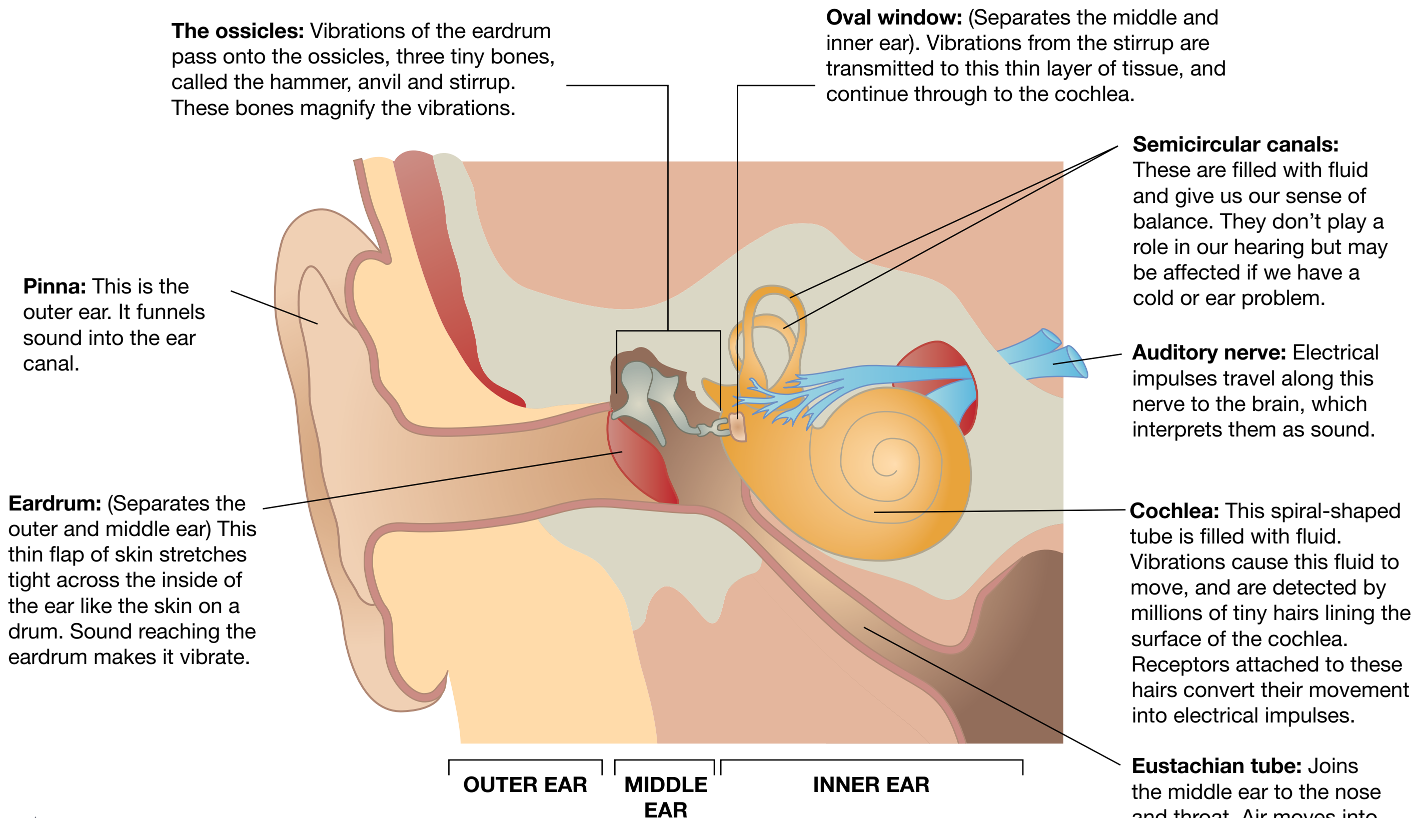


Figure 4.2.12 These structures work together to allow vibrating air entering the ear to be interpreted by our brain as a sound.

4.3 4.4

Over 1 million Australians have a hearing disability, ranging from mild hearing loss to complete deafness. These problems can be because:

- the ear canal is blocked with wax, preventing the passage of sound waves
- the middle ear is filled with fluid
- the eardrum has been ruptured by an extremely loud noise or as the result of infection
- sensory cells of the ear have been damaged by loud noise
- a defect in the auditory nerve or the tiny hairs of the cochlea prevents sound impulses being transmitted correctly to the brain.

The cochlear implant, or bionic ear (shown in Figure 4.2.13), has helped many people with serious inner-ear damage to hear sound for the first time.

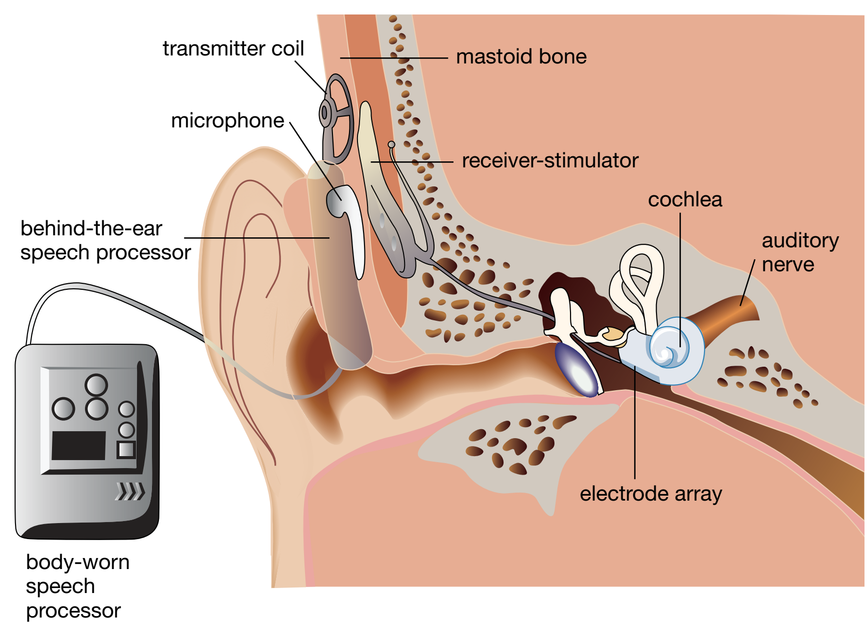


Figure 4.2.13 The cochlear implant, or bionic ear, is an Australian invention. It was developed in the 1970s by a group of scientists led by Professor Graeme Clark. It assists people by converting sounds into electrical impulses that are sent to the brain.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

Workplace hearing protection

Figure 4.2.14 Some workplaces are noisier than others, like the airport where this man works.

Delicate cells in your ears can be damaged by loud noise. They need to be protected from excessive noise in the workplace.

Many people work in jobs that use noisy machinery (Figure 4.2.14). Loudness can be measured using a device called a sound level meter. Loudness is measured in **decibels** (unit symbol dB). The decibel scale is shown in Figure 4.2.15, alongside some common examples of similar sound levels.

Exposure to noise levels above 85 dB for long periods can permanently damage your hearing. The degree of damage depends on how loud the noise is, and how long you are exposed to it. People spend much of their day in their workplace, and so exposure to constant loud noise can have a significant effect on their hearing.

Noise destroys delicate sensory cells in the inner ear, called hair cells. These cells detect vibration and send electrical signals to the brain. Such damage can be seen in Figure 4.2.16. If affected, these cells cannot be replaced.

Repeated exposure to loud noise can also lead to **tinnitus**, a condition in which a person hears a permanent ringing in their ears. Noise-induced hearing loss (NIHL) has been recognised as a major industrial disease in Australia and around the world. It makes hearing higher-frequency sounds more difficult. In turn, this can lead to problems communicating, increased fatigue, stress and anxiety.

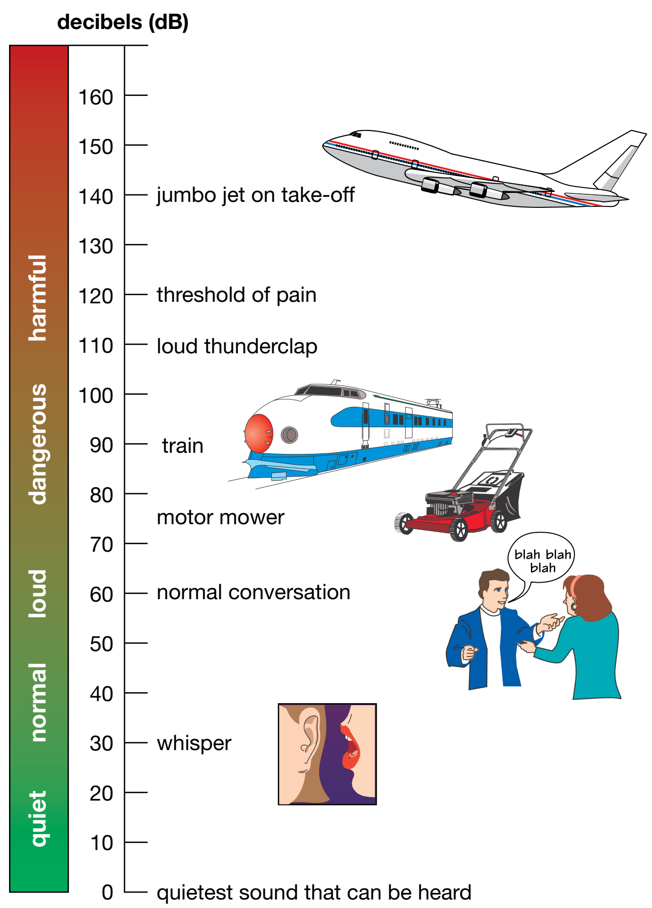


Figure 4.2.15 Sound intensity level, or loudness, is measured using the decibel scale.

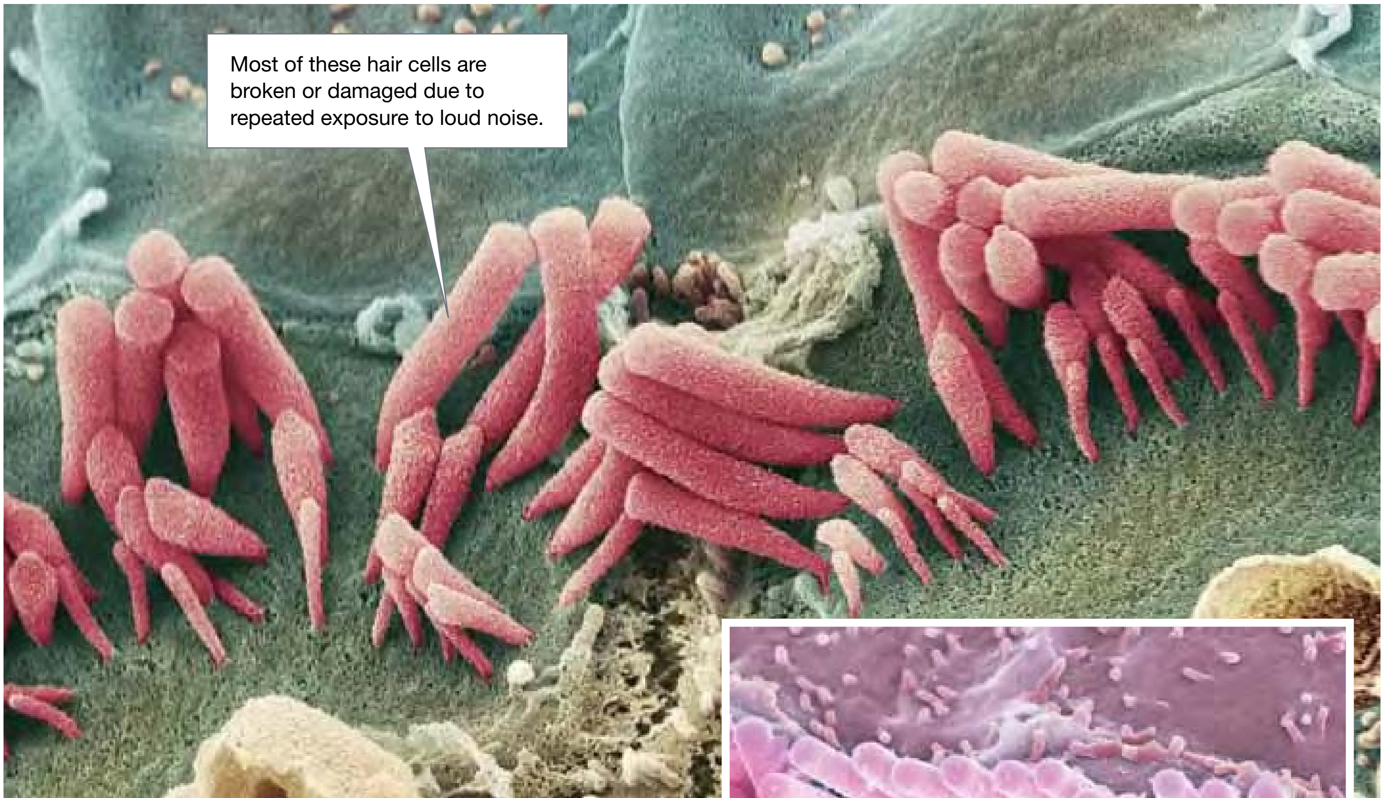


Figure 4.2.16 These images show the effect that loud sounds can have upon tiny hair cells in the inner ear.

A code of practice exists for maintaining noise within acceptable levels in workplaces. Workplaces are assessed for their noise levels. Employers operating worksites with high levels of noise are directed to:

- as first priority, try to reduce noise levels by:
  - replacing outdated, noisy machinery with quieter alternatives where possible
  - ensuring that machinery is regularly maintained
  - reducing metal-to-metal contact in machinery by inserting materials to dampen sound
- block noise transmission by:
  - shifting noisy machinery to more remote areas of the workplace
  - fitting sound-absorbing materials to the ceiling or walls
  - using sound-absorbing curtains to screen off an area or machine
- ensure that all areas of loud noise are signposted as hearing protector areas
- ensure that workers are not exposed to sound intensity levels greater than 85 dB averaged over an 8-hour period
- ensure that affected workers wear personal hearing protectors, such as correctly fitted earmuffs or earplugs (shown in Figure 4.2.17), and that these workers undergo regular hearing tests to monitor their hearing.

Figure 4.2.17 Earmuffs and earplugs reduce the pressure variations on ears. This helps prevent the eardrum and hair cells from being damaged by loud noises.

4.2 Unit review

Remembering

1 **State** whether the following are true or false.
  a Sound is produced by vibrations.
  b Regions of high air pressure are called rarefactions.
  c A sound wave can travel in a vacuum.
  d Waves at the beach are called transverse waves.

2 **Name** the unit that is used to measure the frequency of a sound wave.

3 **List** the causes of four types of hearing loss.

Understanding

4 **Explain** why sound travels faster through solids than through liquids.

5 Theo discovers after an audit that his printing workshop is excessively noisy and is putting his workers at risk. **Describe** three ways he could reduce the noise level.

6 Think of an example to help you **define** the term *reverberation*.

7 Refer to Figure 4.2.16 on page 119 and **explain** why Australian workers are not allowed to be exposed to noise levels above 85 dB averaged over an 8-hour working day.

8 Refer to Figure 4.2.12 on page 117 and answer the following questions about the ear.
  a **Describe** the function of the eardrum.
  b **Describe** the role of the ossicles.
  c **Explain** how these electrical impulses travel to the brain.

Applying

9 **Use** the speed of sound in water as 1500 m/s to **calculate** the following.
  a Mia and Eve are on a fishing trip. They send an ultrasound pulse into the water below their boat and it takes 0.2 seconds to return. **Calculate** how far below the boat the fish are likely to be.
  b Oceanographers mapping the ocean floor direct an ultrasound pulse beneath their ship. It takes 6 seconds to return to them. Given that this pulse reflected from the ocean floor, **calculate** how deep the ocean is at this point.

10 **Use** Figure 4.2.15 on page 118 to estimate the sound level intensity (in dB) of:
  a city traffic
  b two people arguing loudly
  c a chip packet crinkling in a movie theatre
  d a car backfiring.

11 Light travels 300 000 km every second. The time it takes to see a flash of lightning a few kilometres away is almost zero. Assuming you see a lightning strike as it happens, and count 6 seconds before hearing the rumble of thunder produced by the strike, **calculate** how far away you are from the storm. Assume the speed of sound is 340 m/s.

Analysing

12 Figure 4.2.18 illustrates three traces of sounds on a cathode ray oscilloscope.

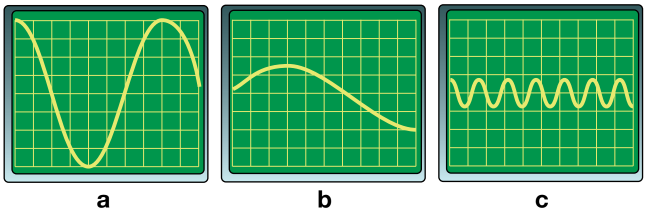


Figure 4.2.18

Identify:
  a the sound with the highest frequency
  b the sound with the lowest frequency
  c the loudest sound.

13 **Analyse** Figure 4.2.12 on page 117 to **explain**:
  a the shape of the pinna
  b where vibrations are converted to electrical signals.

Evaluating

14 **Analyse** Figure 4.2.6 on page 114 to answer the following questions.
  a **State** which material listed best absorbs high-frequency sounds.
  b **State** which material reflects the greatest proportion of sounds.

c **Propose** a reason why this material does not absorb much sound.

d **Explain** what happens to the sound energy absorbed by materials.

15 A blind person buying a house may make clicking noises to find out how big a room is. **Propose** how clicking could provide this information.

16 **Propose** how a speech recognition system would operate.

17 Use the information in Figure 4.2.19 to answer the questions below.

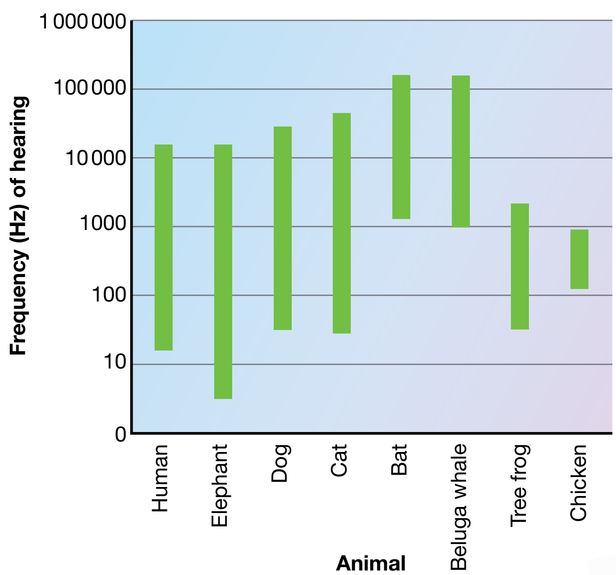


Figure 4.2.19 This chart compares the range of hearing of humans and several animals. Note that the vertical scale is a logarithmic scale, meaning each division on the scale is ten times as large as the previous division.

a From the animals shown, **identify** which can hear the highest-frequency sounds.

b **Identify** which animal or animals can hear the lowest frequency.

c The bat and the beluga whale rely on echolocation using ultrasound. **Propose** why they need to have a higher hearing range than humans.

d Dog whistles are audible to dogs but not to humans. **Propose** the frequency range of such whistles.

e **State** whether a chicken can hear any of the sounds heard by a bat.

Inquiring

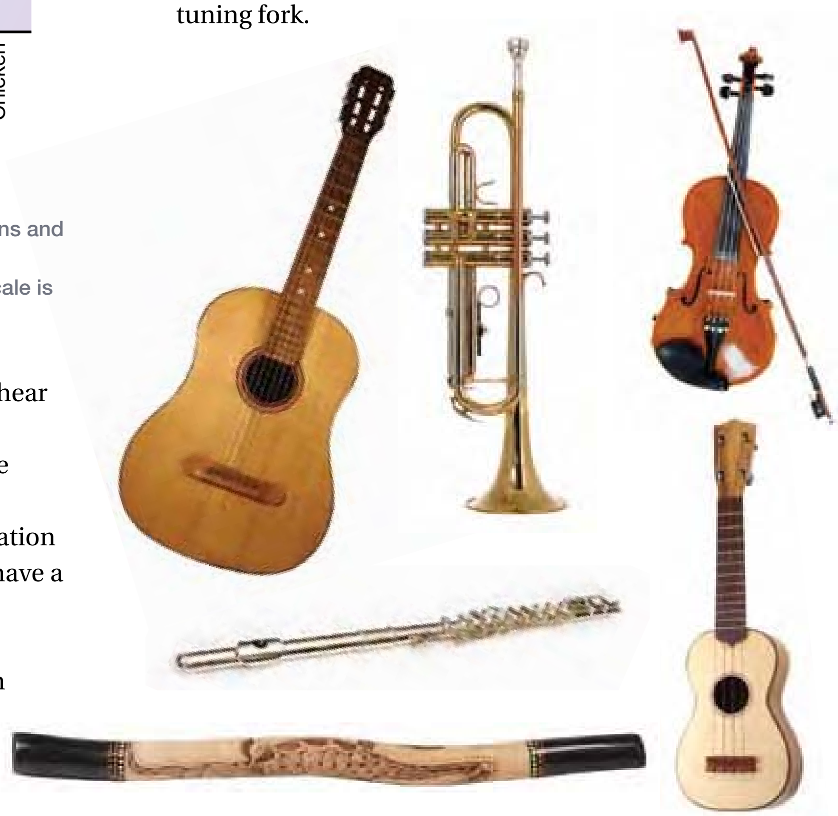
1 It is easy to listen to sounds above 105 dB when using an iPod, particularly when increasing the volume in a noisy environment. Create a brochure outlining recommendations on how to use an iPod safely without risking your hearing.

2 Some people are calling for devices such as the Mosquito alarm to be banned because it breaches human rights. Research this issue and list arguments for and against such a ban.

3 Construct an instrument capable of making sound that also allows you to change the pitch. Explain how your instrument produces these different sounds.

4 Use a sound-level meter to investigate how well various materials absorb sound.

5 Use a microphone and cathode ray oscilloscope to investigate the differences in sound made by a range of musical instruments (for example, guitar, violin, ukulele, didgeridoo, flute, trumpet, oboe) and compare these to the sound produced by a tuning fork.



4.2 Practical activities

1 Making waves

Purpose

To use a slinky to model transverse and longitudinal waves.

Materials

- a slinky spring

Procedure

1. Hold one end of a slinky. A partner holds the other end.
2. Move your end of the slinky up and down at a regular speed, as shown in Figure 4.2.20a.
3. Sketch a side view of the waves you made. These are called transverse waves, and are like water waves.
4. Try to alter how you produce the waves so that they are bunched closer together, with greater frequency.
5. You and your partner hold each end still.
6. Tap one end of the spring horizontally so that a pulse travels through the spring, as shown in Figure 4.2.20b.
7. Try to draw what is happening here from a side view. This is a longitudinal wave, like a sound wave.
8. Try to alter how you produce these waves to increase their frequency.

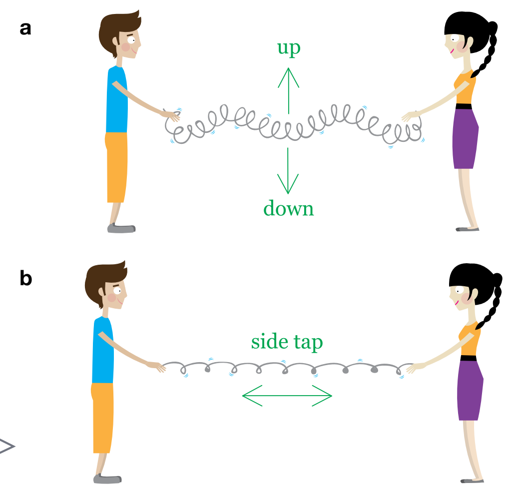


Figure 4.2.20

Discussion

1. **Describe** how the slinky moves when:
   - a a transverse wave passes through
   - b a longitudinal wave is transmitted.
2. **Explain** how you were able to increase the frequency of:
   - a the transverse waves
   - b the longitudinal waves.
3. **State** which of the two wave types you produced is more like a sound wave.

2 Good vibrations

Purpose

To investigate the differences in producing high-pitched and low-pitched sounds.

Materials

- 5 beakers (or glasses) of the same size
- water
- a pen or a chopstick
- a ruler

Procedure

Part A

1. Hold a ruler over the edge of a bench and flick it so it vibrates.
2. Listen to how the pitch changes as you reduce the length of ruler vibrating.

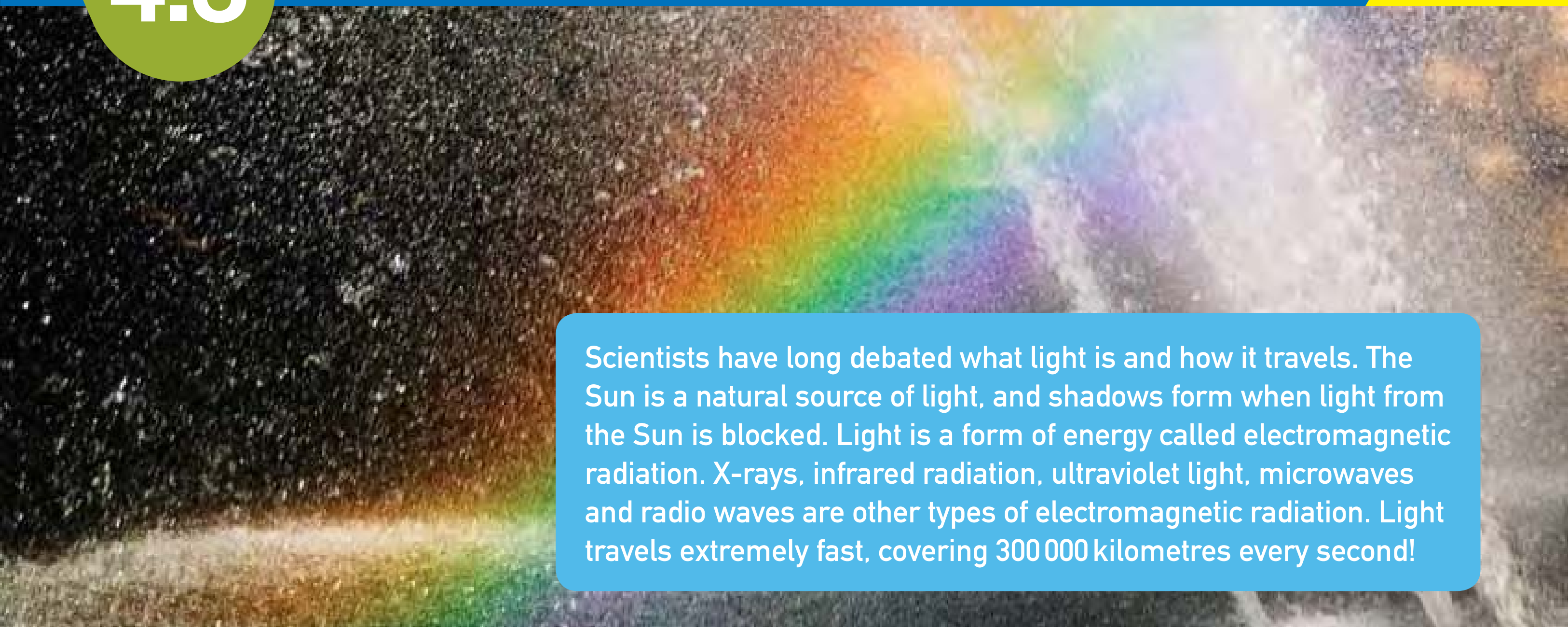
Part B

3. Line up the beakers (or glasses) on your bench.
4. Fill each beaker to a different depth with water.
5. Carefully tap the glass of each using a pen, chopstick or other object, and listen to the variation in pitch.

Discussion

1. **State** which length of vibrating ruler made the lowest sound and which made the highest sound.
2. **Construct** a diagram that shows the difference between sound waves produced.
3. **Describe** the pitch of sound produced by the beaker with the least amount of water.
4. **Deduce** how the length of the ruler and the depth of the water in the beaker are related to the pitch of the sound they produce.
5. **Explain** whether you think the vibrations would be faster or slower when producing high-pitched sounds.

4.3 Light



Scientists have long debated what light is and how it travels. The Sun is a natural source of light, and shadows form when light from the Sun is blocked. Light is a form of energy called electromagnetic radiation. X-rays, infrared radiation, ultraviolet light, microwaves and radio waves are other types of electromagnetic radiation. Light travels extremely fast, covering 300 000 kilometres every second!

Properties of light

Like infrared radiation, light is a form of energy called electromagnetic radiation. It travels as a wave, called an electromagnetic wave. This has a complex structure, shown in Figure 4.3.1. Like a sound wave, an electromagnetic wave has a specific frequency and wavelength. But unlike a sound wave, which requires a medium such as air to be transmitted, an electromagnetic wave does not. Infrared radiation and light from the Sun travel through the vacuum of empty space to reach Earth. A sound wave may travel at around 340 metres per second, whereas a light wave travels at some 300 000 km per second.

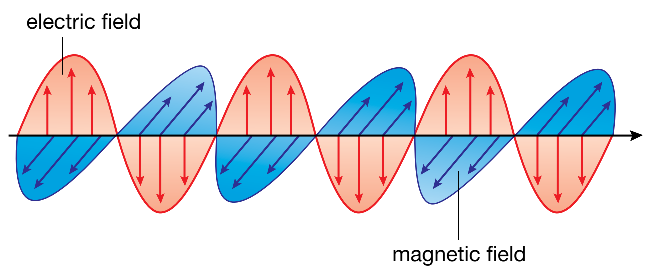


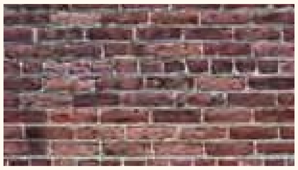
Figure 4.3.1 Light travels as an electromagnetic wave. It consists of alternating electric and magnetic fields.

When light hits a surface, it may be:

- transmitted through it
- reflected off it, or
- absorbed into it.

Table 4.3.1 outlines examples of these three situations.

Table 4.3.1 Transparent, translucent and opaque materials

Light hits a surface and:	This material is called:	Examples	
Almost all light is transmitted through the substance. A clear image can be seen through it.	**Transparent**	Clear glass, shallow water	
Some light may be reflected, and light that passes through is scattered. An image seen through it is fuzzy.	**Translucent**	Tissue paper, fingernails, frosted glass	
Light is either reflected from or absorbed into the substance, and no light is transmitted. No image can be seen through it.	**Opaque**	A brick, a piece of wood, a desk, a football	

An object that releases or emits light is said to be luminous. Most objects around you, however, do not produce their own light. They are non-luminous (such as the Moon, shown in Figure 4.3.2). You see most of the things around you because light bounces off them and then into your eyes. This process is called reflection and is shown in Figure 4.3.3.

Figure 4.3.2 Although the Moon looks bright in the night sky, it is non-luminous. It doesn't make its own light but reflects light from the Sun instead. Stars are the only objects in space that make their own light.

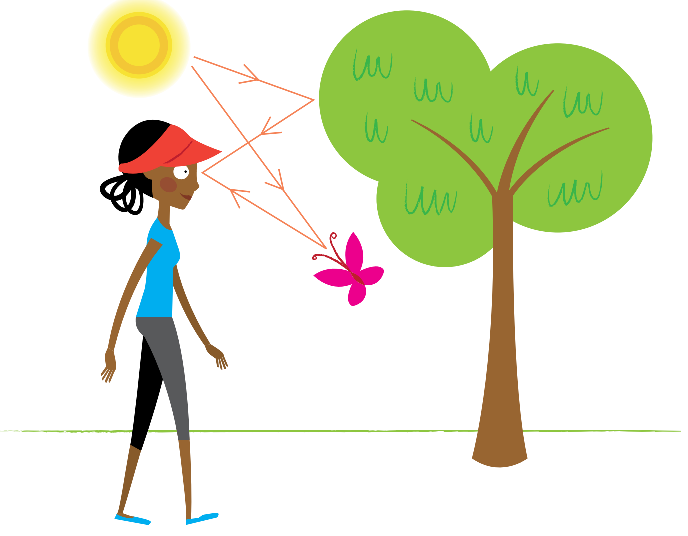


Figure 4.3.3 This girl can see the tree and the butterfly because light from the Sun is reflected from these objects and then enters her eyes.

Diffuse and regular reflection

When light reflects off a very smooth surface such as a mirror or a window, as shown in Figure 4.3.4, it undergoes **regular reflection**. This produces a clear image, as shown in Figure 4.3.5.

Figure 4.3.4 You can see an image when light is reflected from a very smooth surface.

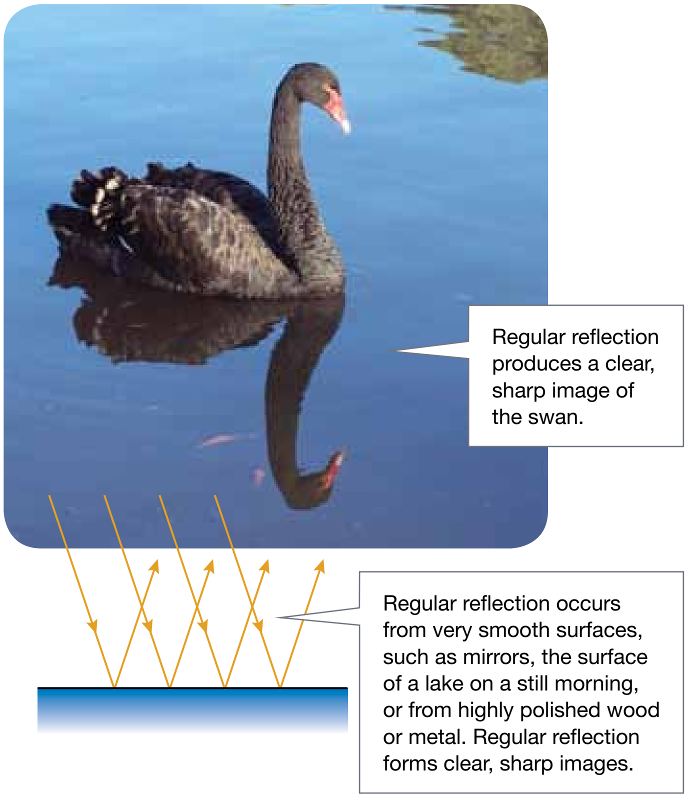


Figure 4.3.5 Regular reflection occurs from very smooth surfaces and forms clear, sharp images.

The surfaces of most objects are quite rough when viewed up close. These surfaces reflect light in many directions, and do not form an image. This is called **diffuse reflection** and is shown in Figure 4.3.6.

Figure 4.3.6

Many surfaces appear smooth but are rough compared with the surface of a mirror. Diffuse reflection occurs from these rough surfaces and no clear image is formed.

The Law of Reflection

If a billiard ball is hit at right angles to the cushion of the table, the ball bounces straight back along the same path. If the ball is hit at an angle to the cushion, it will bounce off the cushion at the same angle. Figure 4.3.7 shows an incoming ray, known as an **incident ray**, being reflected off a mirror in the same way that the billiard ball bounces off a cushion. This is called the **Law of Reflection**.

A dotted imaginary line, called the **normal**, is shown in Figure 4.3.7 at right angles to the surface of the mirror. This is used to measure the **angle of incidence** (shown as *i*) and the **angle of reflection** (*r*).

According to the Law of Reflection:

angle of incidence = angle of reflection

$$i = r$$

Mirror on the Moon

In 1969, Neil Armstrong and Buzz Aldrin left a device called a corner reflector on the Moon. Researchers have used the reflection of laser light from this device to accurately measure the distance from the Earth to the Moon, and have discovered that this distance increases by 4 cm each year.

SciFile

p132

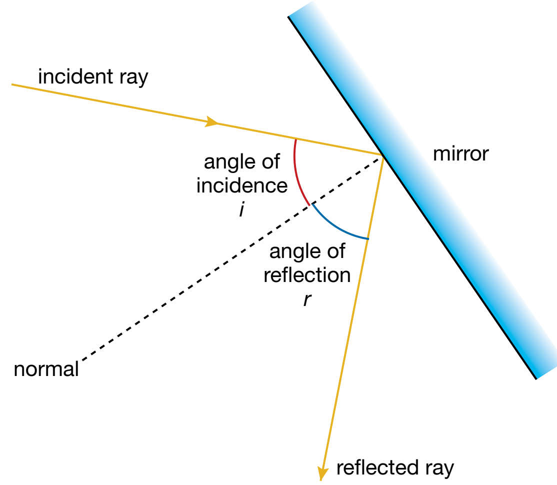


Figure 4.3.7

The Law of Reflection states that the angle of incidence of a light ray is equal to the angle of reflection.

INQUIRY science 4 fun

Image finder

How far behind a mirror is an image located?

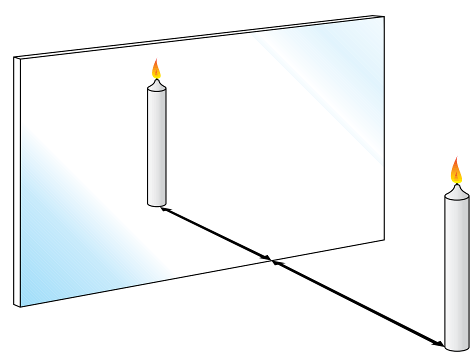
Collect this …

- 2 birthday candles
- 2 dobs of Blu Tack
- sheet of glass
- sheet of paper

Yes

Do this …

1 Draw a line down the middle of a sheet of paper.
2 Hold the glass so that it stands along this line.
3 Position a lit birthday candle with Blu Tack in front of the glass, as shown in the diagram.



4 Carefully look into the glass at the image formed.
5 Move an unlit candle behind the glass so that the image of the flame rests on its wick.
6 Measure the distance from each candle to the glass.

Record this …

Describe what happened.

Explain why you think this happened.

Plane mirrors

A flat mirror is also called a **plane mirror**. When you stand in front of a mirror in a fitting room when trying on clothes, your image is the same size as you. It is the same distance behind the mirror as the distance you are standing in front of it. Your image is identical to you in every way except that it is reversed sideways: your right side appears in the mirror as your left, and vice versa, as the example in Figure 4.3.8 shows. This reversal is called **lateral inversion**.

Figure 4.3.8 Although this boy is brushing his teeth with his right hand, his image appears to hold the toothbrush in the left hand. The image is laterally inverted.

Forming an image

When a plane mirror produces an image of an object, such as a candle, it looks as though this object is really positioned inside or behind the mirror. Figure 4.3.9 shows why this happens. Light that has reflected from the candle reaches your eyes. Your brain is used to light travelling in straight lines, so it extends this light back inside the mirror to where it appears to have come from. As a result,

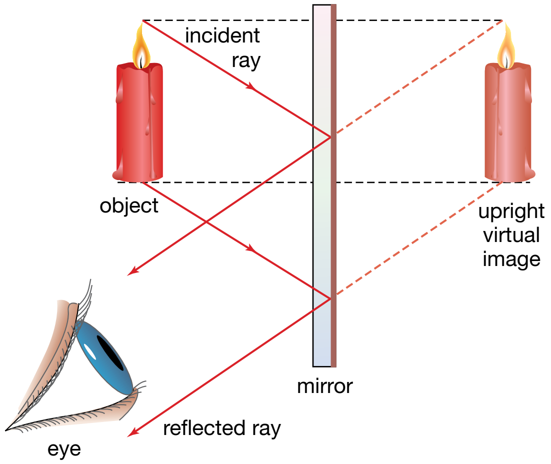


Figure 4.3.9 A plane mirror produces a virtual, upright image that is the same size as the object but reversed sideways (laterally inverted).

the candle appears to be inside the mirror. This is called a **virtual image**, because the rays of light do not really meet to produce this image.

An image seen in a plane mirror:

- is upright (normal way up)
- is the same size as the object
- is laterally inverted (reversed sideways)
- is virtual
- appears to be located as far inside the mirror as the object is in front.

4.5

Refraction

The straw resting in the glass shown in Figure 4.3.10 appears to be bent. The straw is not bent at all. It appears this way because light was bent as it travelled out from the water in the glass to the air. This bending of light is called **refraction**.

Figure 4.3.10 This straw appears disjointed at the surface of the water in the glass and the square grid pattern on the table below it appears curved, when viewed through the water in the glass.

Light refracts when it travels from one transparent substance into another. Figure 4.3.11 shows light bending towards the normal as it enters a glass block, and bending away from the normal when it exits it.

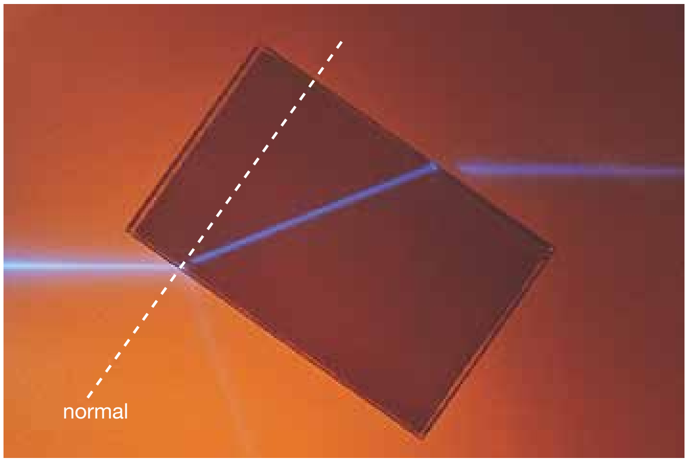


Figure 4.3.11 Light bends towards the normal when it enters this glass block and bends away from the normal when leaving. Some light is also reflected from the edges of the glass.

Why does refraction occur?

Light travels at different speeds through different substances. The differences in its speed result in different amounts of bending, or refraction, as light passes from one substance into another. The **refractive index** is a measure of how easily light travels through a substance. Light entering the glass block from air slows down and bends towards the normal. A car that hits a flooded section of road behaves in a similar way. The first wheel entering the water slows down while the other continues at the same speed, causing the car to slow down on one side and swerve inwards, towards the normal. This is what is happening in Figure 4.3.12. As light leaves a glass block, it speeds up and bends away from the normal.

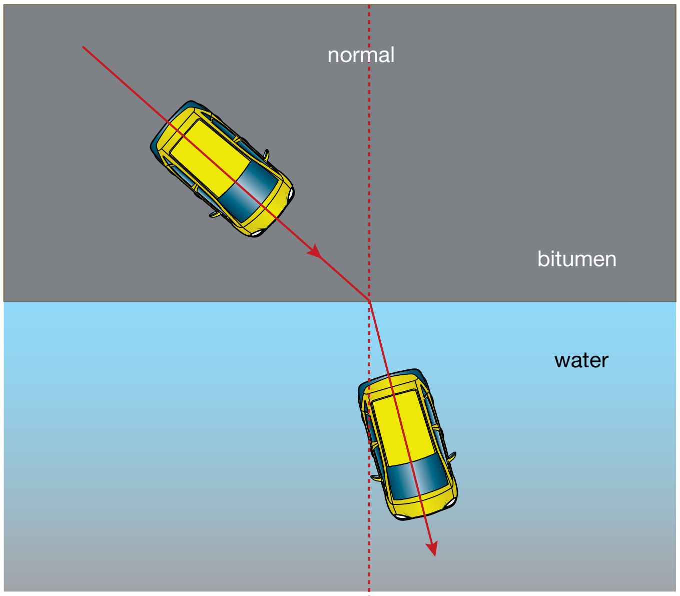


Figure 4.3.12 A car that enters a pool of water on a road will slow down and its path will bend towards a normal line.

The higher the refractive index of a substance, the more light bends when it enters the substance from air. Light travels more slowly in glass, water, diamond and Perspex than it travels through air. Table 4.3.2 shows the speed of light in a few common substances, and the refractive index of each.

Table 4.3.2 Speeds of light in different media

Medium	Speed of light (km/s)	Refractive index
Air	300 000	1.00
Ice	231 000	1.31
Water	226 000	1.33
Perspex	200 000	1.49
Glass	197 000	1.52
Diamond	124 000	2.42

The angle an incoming ray of light makes with the normal is called the angle of incidence, *i*. The angle that the refracted ray makes with the normal is called the **angle of refraction**, ***r***. Figure 4.3.13 shows that light bends towards the normal when entering a substance of higher refractive index, and bends away from the normal when entering a substance of lower refractive index. Light that hits another substance head on is not bent, but continues straight through.

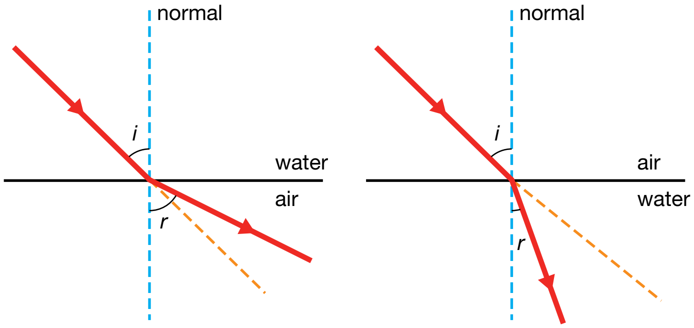


Figure 4.3.13 Light bends away from the normal when entering a substance of lower refractive index. It bends towards the normal when entering a substance of higher refractive index.

SciFile

Forensic refraction

Investigators can link pieces of broken glass to a window pane smashed at a crime scene if the refractive indices of both samples of glass match. Fragments of glass from car headlights left at a hit-and-run accident can be used to identify the model of the car they came from, and eventually its driver.

INQUIRY science 4 fun

The reappearing coin

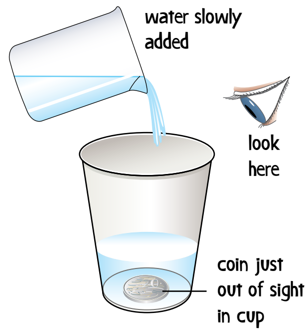
Can you make a coin appear before your eyes?

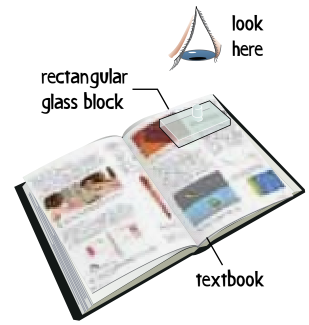
Collect this ...

- coin
- opaque cup (one that is not see-through) or an evaporating basin
- pencil or pen
- 100 mL beaker of water
- rectangular glass block

Do this ...

1 Put the coin in the cup.
2 Move back until the coin is just out of sight.
3 Have your partner pour water into the cup from the beaker.
4 Can you see the coin again?
5 Now place a rectangular glass block on top of this page of your textbook.
6 Study the print through the block and compare this to when the block is removed.





Record this ...

Describe what happened when you viewed the coin and when you looked through the glass block.

Explain why you think these things happened, using diagrams to assist your response.

Depth illusions

When someone is standing in a swimming pool, their legs look shorter than normal. Similarly, rocks on the bottom of a stream always look like they are in shallower water than they actually are. These depth illusions, like that seen in Figure 4.3.14, occur because light from an object under water is bent away from the normal when it leaves the water surface into air. When you look at this refracted light, your brain traces the light reaching your eyes back in a straight-line path. This makes the object appear to be positioned closer to the surface.

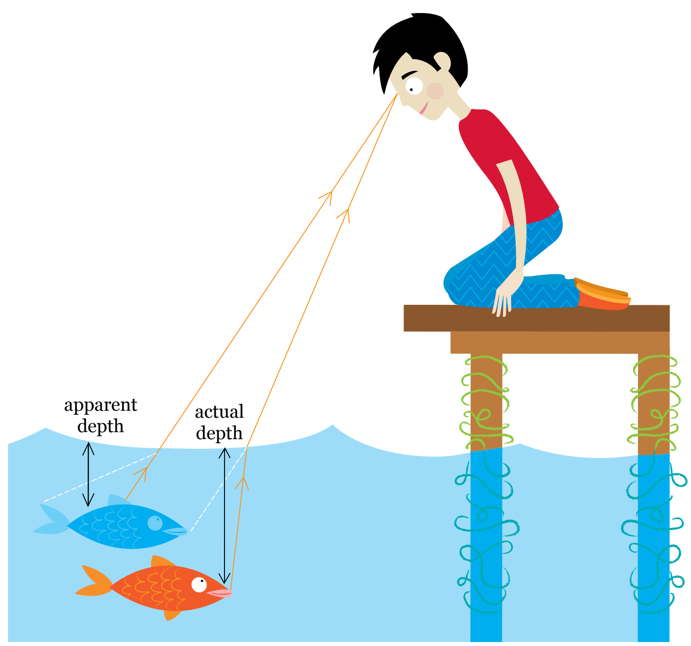


Figure 4.3.14 Light from the fish bends away from the normal when it enters the air. Its apparent depth, or the depth it appears to be, is less than its true depth in the water. For this reason, hunters using spears to catch fish learn to aim the spear slightly below where they see the fish in the water.

SciFile: Underwater vision

When you are under water looking at objects without goggles or a mask, they appear blurry. Light reaching the corneas of your eyes from water doesn't bend as much as it would if it had come from air. As a result, you can't focus properly. If you wear goggles or a mask, light enters your eyes from air rather than from water. This makes everything clearer!

Total internal reflection

When light enters a substance of lower refractive index, such as from glass into air, it is refracted away from the normal. Figure 4.3.15 shows what happens to this ray as the angle of incidence increases. At an angle of incidence called the **critical angle**, light is refracted so far from the normal that it runs along the boundary of the two substances. For any angles of incidence greater than this, there is no refracted ray. Light is reflected from the boundary as though it was a mirror. This is called **total internal reflection**. Total internal reflection of light explains some effects of light, such as the imaginary shark seen in Figure 4.3.16. It is also the reason diamonds sparkle (see Figure 4.3.17).

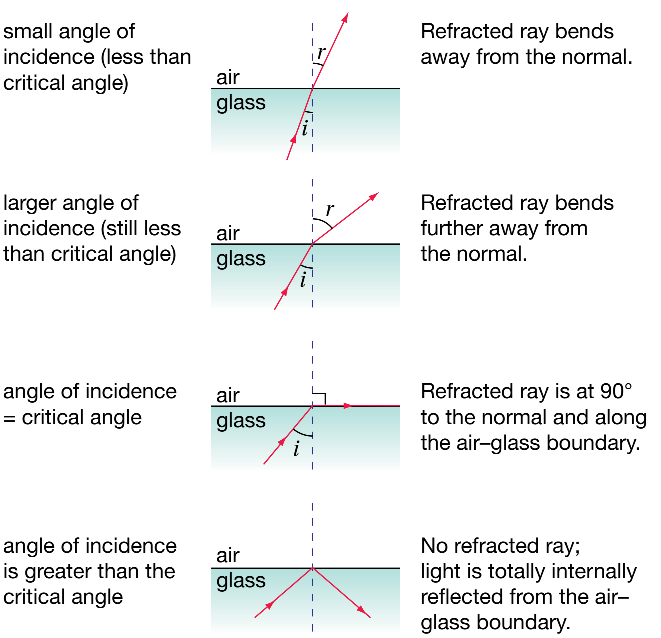


Figure 4.3.15 What light does at the air–glass boundary depends on its angle of incidence.

Figure 4.3.16 Light from this shark has been totally internally reflected to produce the illusion of a shark swimming upside down above the real one.

4.7

2 p133

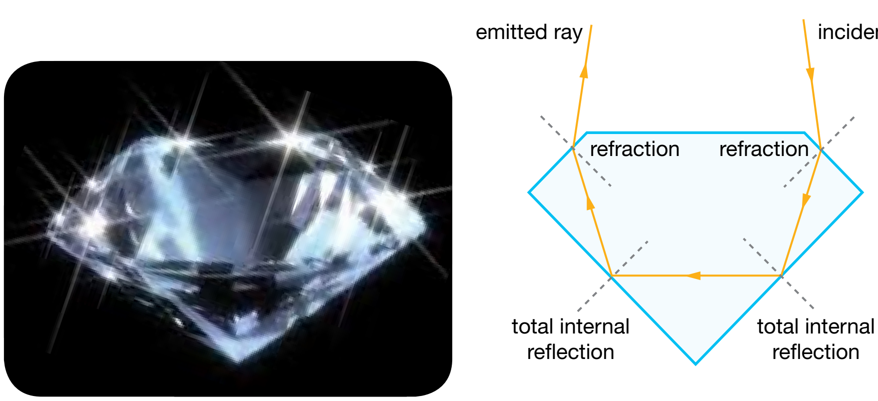


Figure 4.3.17 Diamond has a high refractive index and a low critical angle for a diamond–air boundary, of about 23°. Jewellers cut the facets of a diamond so that most light falling on the diamond will strike the back of the diamond at an angle larger than the critical angle. This means the light is reflected twice within the diamond before it emerges, making it look more brilliant.

4.3 Unit review

Remembering

1 a **State** which letter in Figure 4.3.18 represents the:
- i incident ray
- ii reflected ray
- iii normal
- iv angle of incidence
- v angle of reflection.

b **Name** the law that is demonstrated in Figure 4.3.18.

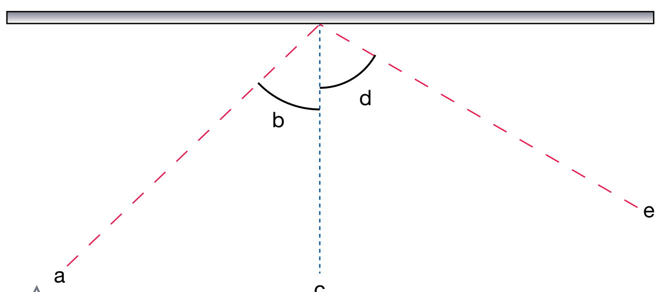


Figure 4.3.18

2 **List** five properties of an image formed by a plane mirror.

3 **State** which of the following alternatives makes each sentence true.
- **a** Light is refracted *away from/towards* the normal when it passes from glass into air.
- **b** Light travels at a higher speed through *glass/air*.
- **c** Total internal reflection can only occur when light passes into a substance of *lower/higher* refractive index.

Understanding

4 **Define** the term *lateral inversion*.

5 a If you looked into the mirror shown in Figure 4.3.9 on page 126, **explain** why the image of the candle would appear to be inside the mirror.

b **Explain** why light rays cannot originate from inside the mirror.

c **State** the name of this type of image.

6 **Explain** why the boy shown in Figure 4.3.14 on page 128 thinks the fish is closer to the surface than it really is.

7 a **Explain** why everything looks blurry if you open your eyes under water.

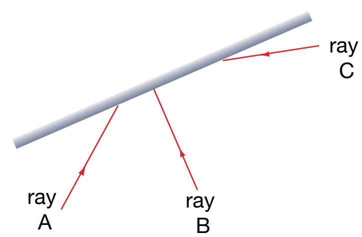
b **Describe** what you can do to make your underwater vision clear.

Applying

8 **Identify** whether the following objects are luminous or non-luminous.
- **a** the star Betelgeuse
- **b** traffic lights
- **c** the planet Venus
- **d** fireworks
- **e** a glow worm
- **f** a bicycle reflector
- **g** lightning

9 Figure 4.3.19 shows three rays of light hitting a mirror. **Use** this diagram to carry out the following tasks.
- **a** Copy the diagram and use a ruler to draw a normal at 90° to the mirror for each of rays A, B and C.
- **b** Extend where each ray will be reflected in front of the mirror.
- **c** **Use** a protractor to **determine** which ray has the largest angle of reflection.

Figure 4.3.19



10 **Identify** in each of the following situations whether light will bend towards or away from the normal. Light travels from:
- **a** water to glass
- **b** diamond to air
- **c** water to Perspex
- **d** water to ice
- **e** glass to diamond
- **f** air to Perspex.

Analysing

11 **Classify** the following objects as transparent, translucent or opaque.
- **a** a basketball
- **b** air
- **c** a pair of sheer stockings
- **d** shallow water
- **e** a piece of lightweight cotton fabric

12 **Use** a Venn diagram to **compare** light waves and sound waves.

13 a **Compare** the speeds of light in air, ice, water, glass, Perspex and diamond listed in Table 4.3.2 on page 127 with their refractive indices.

b **Describe** how you think the refractive index of a substance affects the speed at which light travels through it.

Evaluating

14 **Propose** why total internal reflection never occurs when light travels into a substance of greater refractive index.

15 If a sample of glass was found at the scene of a burglary, **propose** how this could be used as evidence in a criminal investigation.

Creating

16 a **Explain** why AMBULANCE is often painted onto the front of an ambulance with its letters laterally inverted.

b **Construct** a sign that says AMBULANCE, but laterally inverted.

c **Create** a list of ten words, written in capital letters, as they would appear in a plane mirror.

17 Copy each diagram in Figure 4.3.20 and draw the normal to the point where light meets each boundary. **Construct** a ray on each diagram to show the likely path of each ray through each material.

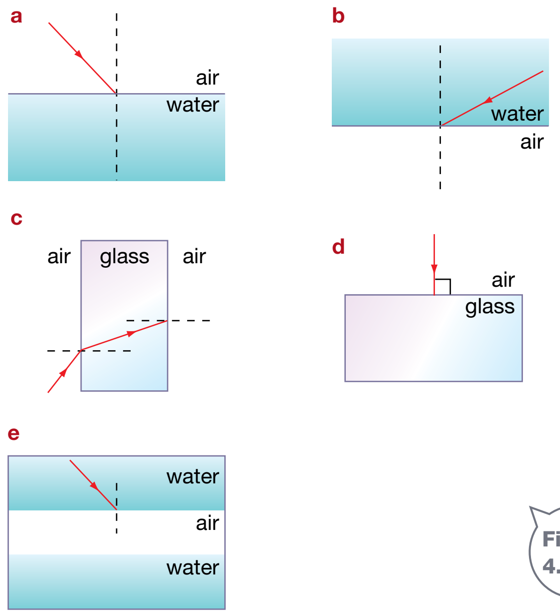


Figure 4.3.20

18 The critical angle of light passing from water into air is 48.6°. **Construct** a diagram to demonstrate how light bends when travelling from water into air at an angle of:

a 60°

b 48.6°

c 25°.

Inquiring

1 Light has a complex structure. For many years, scientists have debated whether it travels as a particle, or as a type of wave, because it has properties of both waves and particles. Construct a timeline to show how ideas about light have changed over time.

2 Research the phenomenon of bioluminescence, and describe how animals with this unique ability use it.

3 Research how laser light is produced. Investigate how it is used to read a bar code on a product for purchase. Create a multimedia presentation that explains how this process works.

4 The effect shown in Figure 4.3.21 is produced by refraction. Set up your own equipment and try to create your own refaction image using a digital camera.

Figure 4.3.21

4.3 Practical activities

1 Law of reflection

Purpose

To verify the law of reflection.

Materials

- light box and power supply
- sheet of white paper
- plane mirror
- ruler
- pencil
- protractor

Procedure

1. Set up the equipment as shown in Figure 4.3.22, marking the positions of the back of the mirror and the normal line.

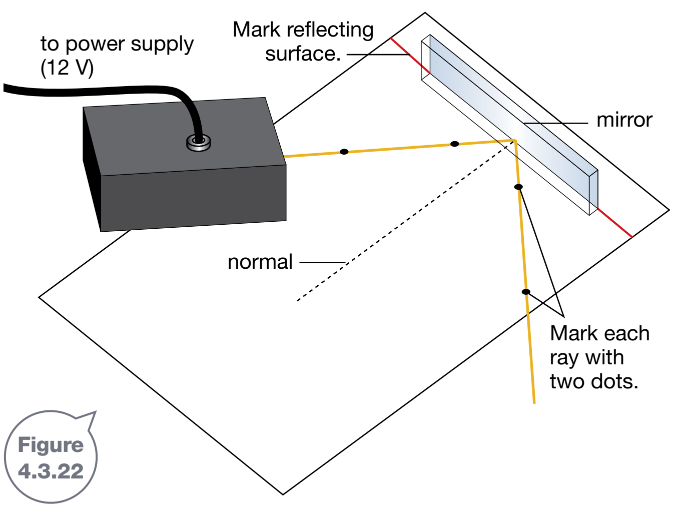


Figure 4.3.22

2. Direct a ray of light on an angle towards the centre of the mirror.
3. Mark the position of the incident and reflected rays using two dots, and then use your ruler to draw these rays on the paper. Label these 'ray 1'.
4. Repeat this process for three more rays of differing angles.
5. Direct a ray at right angles into the mirror and observe its reflection.

Results

1. Copy the results table below into your workbook.

Ray	Angle of incident ray	Angle of reflected ray
1		
2		
3		
4		

2. Select a ray from your diagram and measure the angle that its incident ray (incoming ray) makes to the normal. Enter the angle in the table.
3. For the same ray, measure the angle that the reflected ray makes to the normal. Enter this angle in the table.
4. Complete the table for each ray tested.

Discussion

1. **Assess** whether your results support the Law of Reflection.
2. **Describe** what happened when you directed light at right angles to the mirror.
3. **Explain** whether the Law of Reflection is still obeyed in the case in question 2, in which the angle of the incident ray is zero.
4. **List** at least three examples where you have observed the Law of Reflection in action (e.g. at the cricket when the ball bounces off the pitch).

2 Bending light

Purpose

To observe and measure the refraction of light as it passes through a transparent block.

Materials

- plastic or glass rectangular block and semicircular block
- light box and single-slit slide
- 12V power supply
- sheet of white paper
- protractor
- ruler
- pencil

Procedure

1 Set up the equipment as shown in Figure 4.3.23. Trace around the glass block with a pencil and use a protractor to rule a normal at 90° to the surface half way along the edge.

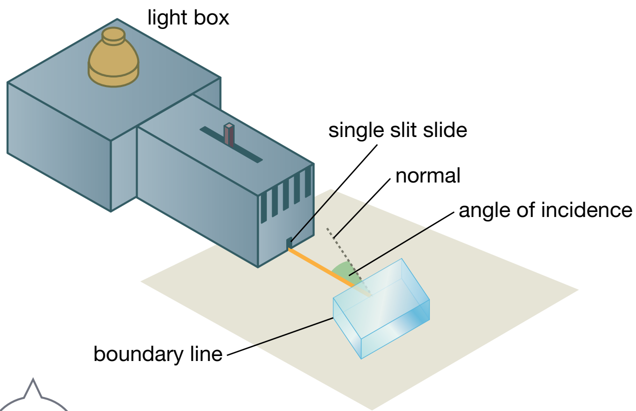


Figure 4.3.23

2 Direct a single ray of light at the centre of the block.

3 Mark a series of dots on the paper to trace the path of light incident on, refracted through and refracted out the other side of the glass block.

4 Remove the glass block and use a ruler to draw the path the light followed on the paper. Add a normal at the point where light left the glass block.

5 Make angle measurements with a protractor to complete a copy of the results table shown below.

6 Replace the rectangular glass block with the semicircular block, with its curved side facing the incoming light.

7 Move the light box in an arc to alter the angle of incidence of light at the centre of the block. Find the critical angle for the semicircular block and investigate what happens for smaller and larger angles of incidence.

Results

Copy and complete the following table.

	Angle of incidence	Angle of refraction
Light entering glass from air		
Light entering air from glass		

Discussion

1 **State** whether light bends towards or away from the normal when it:

a enters the glass block

b leaves the glass block.

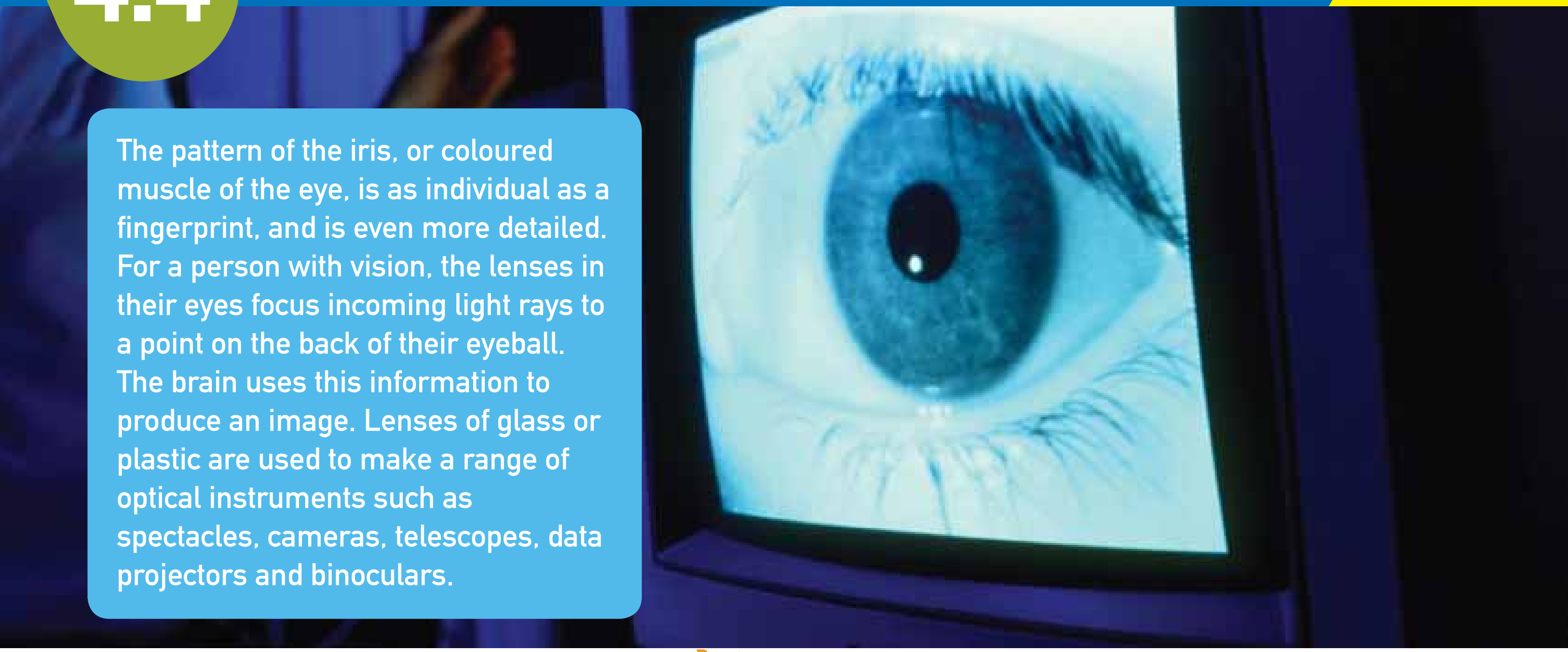
2 **Compare** the size of the angle at which light hit the glass block with the angle at which it leaves.

3 **Describe** whether all the light hitting the glass block was refracted through it, or whether some light followed a different path.

4 **State** the critical angle for the semicircular block.

5 **Describe** what you observed happening with the semicircular block when the angle of incidence was smaller or larger than the critical angle.

4.4 Lenses and the eye



The pattern of the iris, or coloured muscle of the eye, is as individual as a fingerprint, and is even more detailed. For a person with vision, the lenses in their eyes focus incoming light rays to a point on the back of their eyeball. The brain uses this information to produce an image. Lenses of glass or plastic are used to make a range of optical instruments such as spectacles, cameras, telescopes, data projectors and binoculars.

INQUIRY science 4 fun

Forming an image

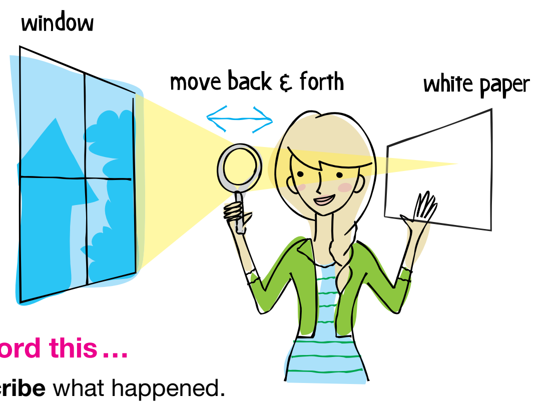
Collect this ...

Yes

- magnifying glass
- sheet of white paper

Do this ...

1 Hold the magnifying glass in front of a light source, such as sunlight through a window, a candle or a light globe.
2 Hold the sheet of paper as a screen in one hand and the lens in the other.
3 Try to focus an image on the sheet of paper by moving the lens back and forth.



Record this ...

Describe what happened.

Explain why you think this happened, using a diagram to assist your response.

Convex lenses

A lens is a transparent piece of plastic or glass that is shaped to curve outwards or inwards. A lens refracts light and is used in many optical devices and in spectacles to form an image. A lens that bulges outwards is called a **convex lens**. These lenses, such as the one shown in Figure 4.4.1, cause light rays to come together, or converge. If a convex lens is held close to an object, it can be used as a magnifying glass. In this case, it produces an upright and enlarged virtual image.

When held close to an object, a convex lens produces an enlarged, virtual image.

Figure 4.4.1

Lenses refract light to produce different types of images. A magnifying glass is a convex lens.

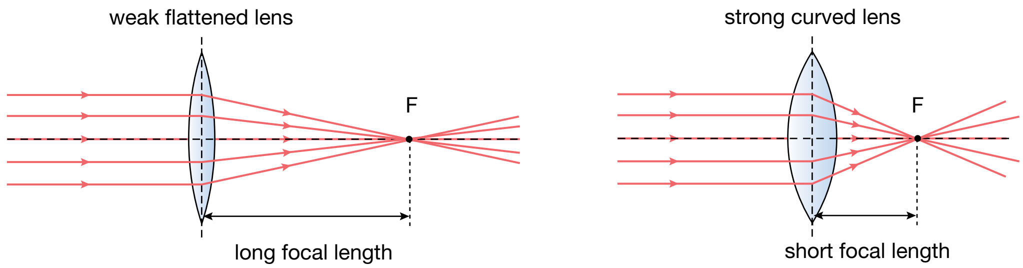


Figure 4.4.2 Parallel rays of light are brought together at a point called the focus (F) on the other side of a convex lens. The greater the curve of the lens, the stronger the lens is and the shorter its **focal length**, or distance between the lens and the focus.

If light reaches a convex lens from a distance, the convex lens can be used to focus the light on a screen to form an image. Figure 4.4.2 shows two convex lenses of different strengths focusing light to a point called the focus of the lens (F). Light is focused to a point on a screen when you see a film at the movies. This is the type of image that is formed by the convex lenses in your eyes. This type of image is called a **real image**.

SKILL BUILDER

Ray tracing using convex lenses

The position and nature of an image produced by a lens can be determined by drawing a ray diagram.

For images produced using a convex lens, two rays are drawn:

- *Ray 1:* Light travelling parallel to the principal axis is refracted through the principal focus of the lens. The object is shown as 'O' and focal points by a dot, as shown in Figure 4.4.3.

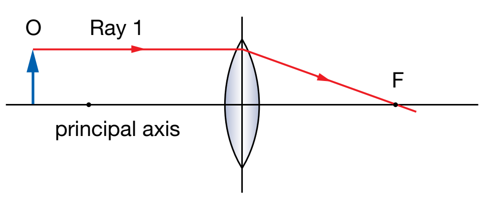


Figure 4.4.3

- *Ray 2:* Light travelling from the tip of the object passes straight through the centre of the lens, as shown in Figure 4.4.4.

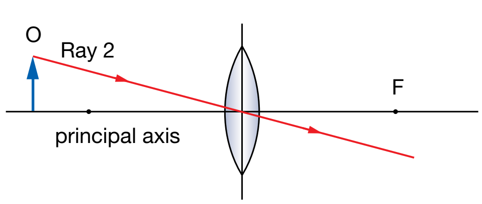


Figure 4.4.4

Objects placed outside the **focal length** of a convex lens always produce a real, inverted image. An example is shown in Figure 4.4.5.

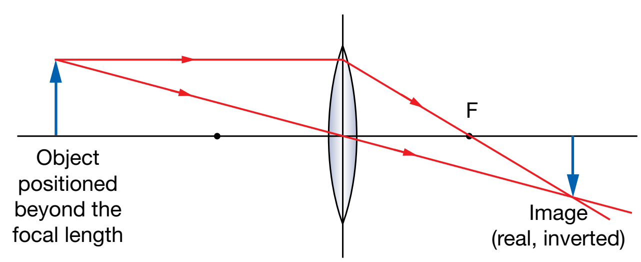


Figure 4.4.5

Objects positioned within the focal length of the lens always produce a virtual, upright image. In this case, to find the image we trace rays 1 and 2 back to where they appear to have come from, as shown in Figure 4.4.6.

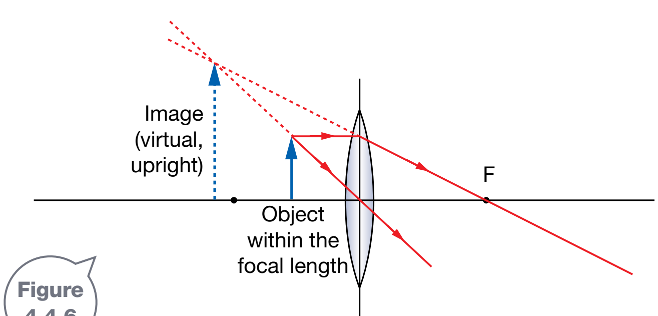


Figure 4.4.6

WORKED EXAMPLE

Images from convex lenses

Use ray tracing to identify the location and nature of the image produced by the convex lens in each situation shown below.

Problem 1

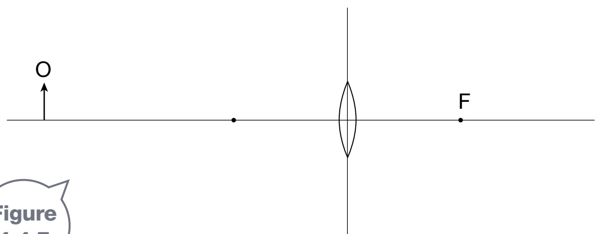


Figure 4.4.7

Solution 1

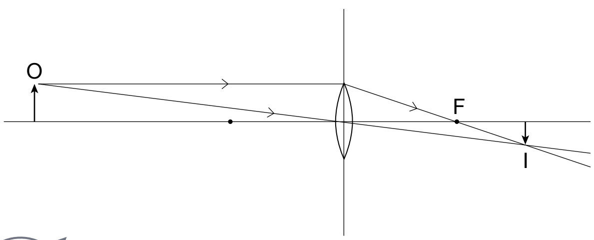


Figure 4.4.8 Image is real, inverted and smaller (diminished).

Problem 2

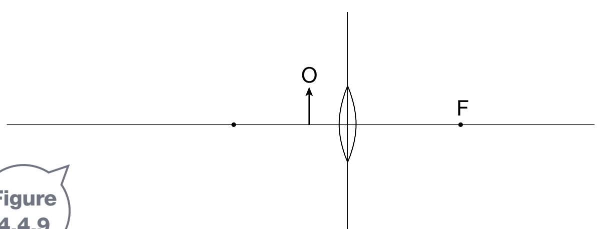


Figure 4.4.9

Solution 2

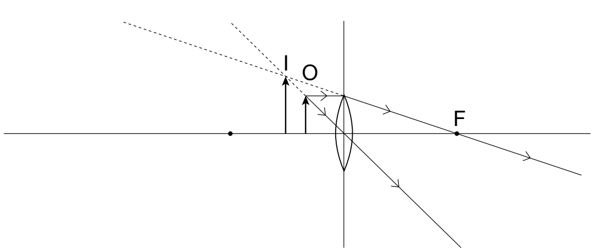


Figure 4.4.10 Image is virtual, upright and enlarged.

Concave lenses

A lens that curves inwards is called a **concave lens**. These lenses cause light to diverge, or spread out. They spread parallel light rays as though the rays have come from a point behind the lens, as shown in Figure 4.4.11. A concave lens only produces images that are smaller, upright and virtual.

p142

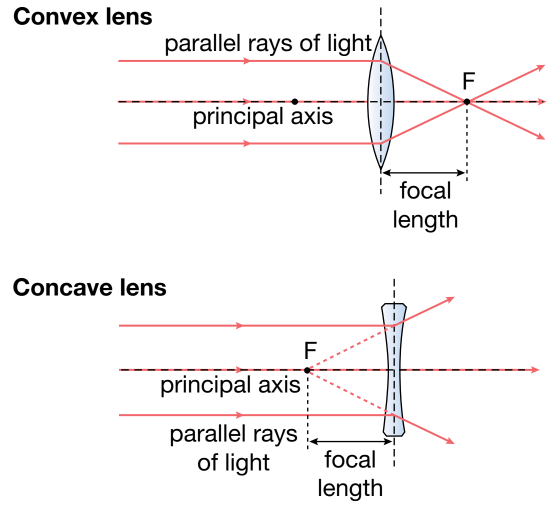


Figure 4.4.11 A concave lens causes light to diverge. To measure the focal length of a concave lens, you must trace the path of the rays leaving the lens to the single point where they appear to have come from. This point is the focus (F) of the lens.

The eye

The most incredible optical instrument we have is our eyes. Figure 4.4.12 shows the structure of the human eye. Light that enters the eye is refracted by the **cornea** and focused by the **lens**, which is convex. Figure 4.4.13 shows how incoming light is focused to form a clear, upside-down image on the **retina**, at the back of the eye. This image is converted into a series of electrical signals, which then travel along the **optic nerve** to the brain. The brain interprets this information as an image.

SciFile

Turning the world upside down

Experiments have been conducted in which people have worn lenses that flip the world upside down. After about a week of bumping into the furniture, they reported that their brain adjusted its view and perceived this view as the right way up. When the glasses were then taken off, everything was upside down again for a while!

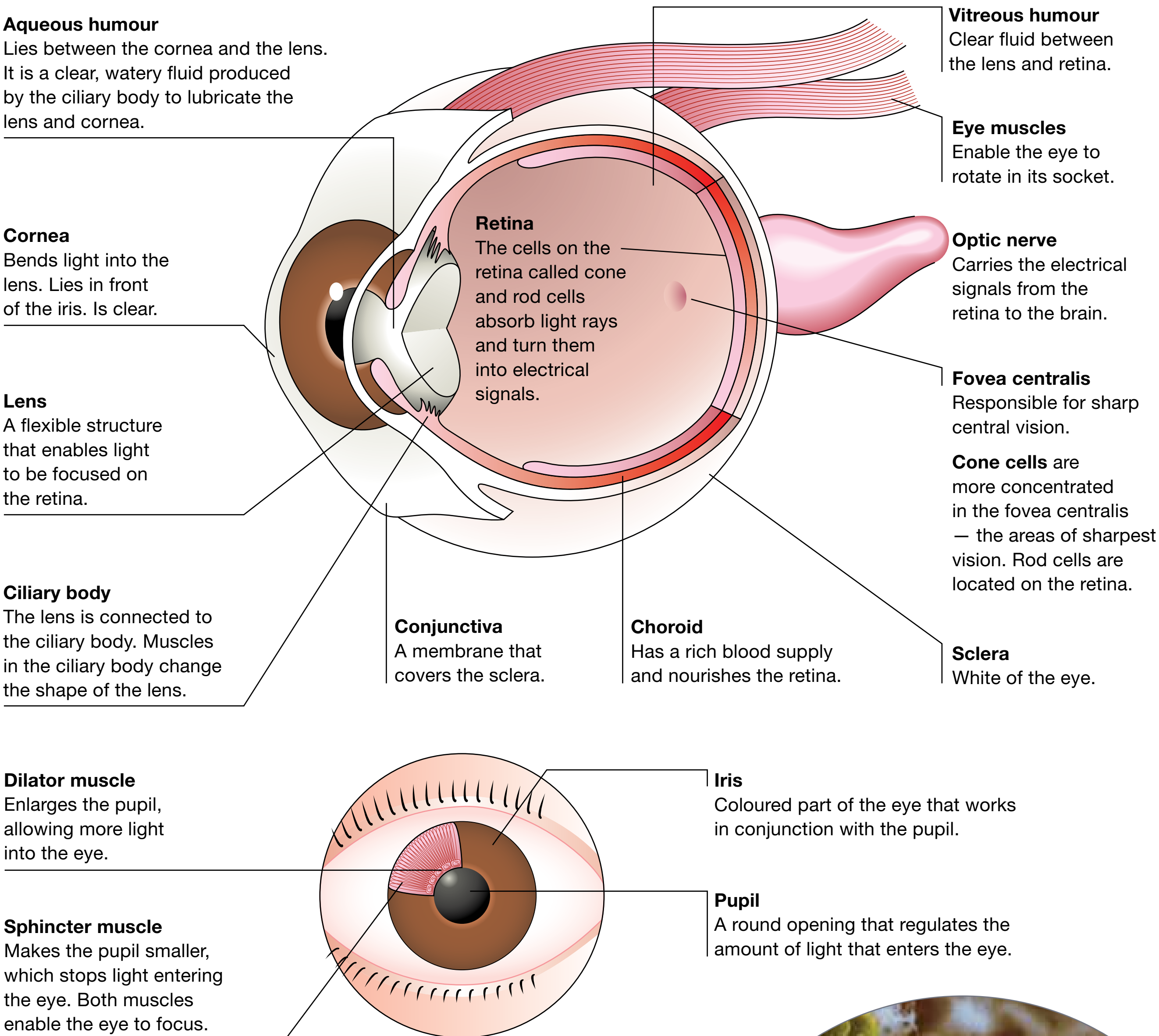


Figure 4.4.12 These structures of the eye work together to provide vision.

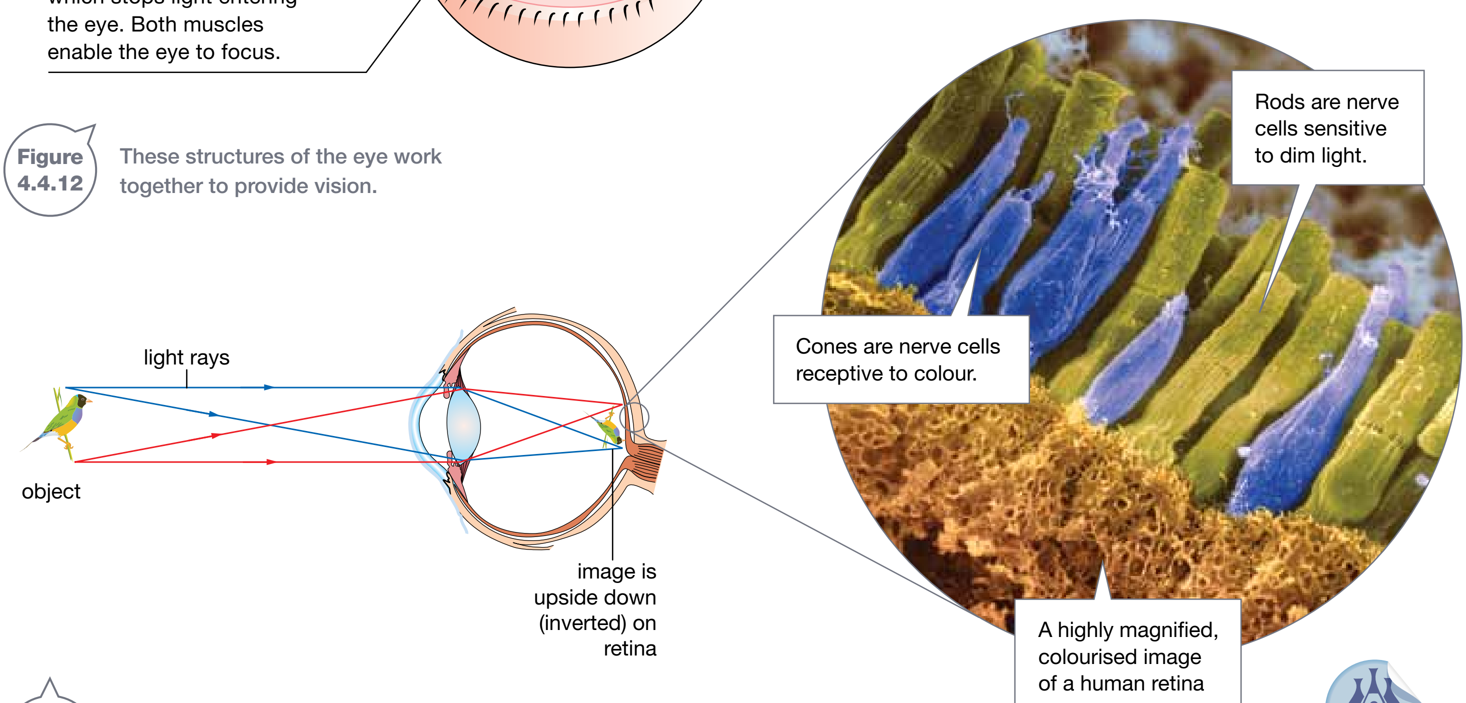


Figure 4.4.13 The brain interprets the upside-down image formed on the retina as an upright image.

2 p142

Vision problems

The lenses in your eyes focus on objects at different distances by changing focal length. When the muscles attached to the lens contract, the lens stretches, becoming quite flat, and able to focus on distant objects. When these muscles relax, the lens gets much fatter and bends light more, allowing close objects to become focused. This is shown in Figure 4.4.14. The ability of the lens to change shape is called **accommodation**. Unfortunately, as we age, the lenses harden, making accommodation more difficult.

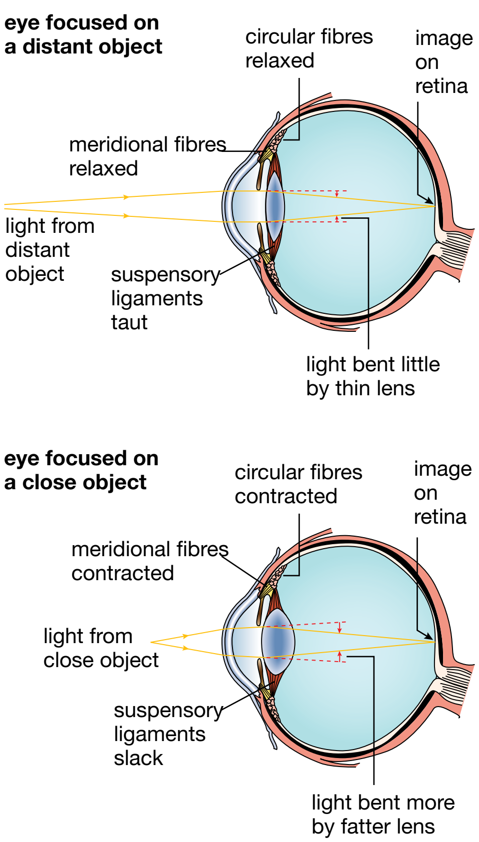


Figure 4.4.14 A 40-year-old has just one-quarter of the accommodating ability they had when younger. By age 45 almost everyone needs some form of glasses.

If light is not focused to a point at the retina, then a person will not see a clear image. This commonly leads to **short-sightedness (myopia)** or **long-sightedness (hyperopia)**.

People who are short-sighted can focus on close objects, such as a book, but distant objects, such as children in a playground, are not clear. Figure 4.4.15 shows how a concave lens is used to correct short-sightedness.

A person who is long-sighted can see distant objects clearly, but has trouble focusing on close objects. They need to use glasses when reading or doing close work. Figure 4.4.16 shows how a convex lens is used to correct long-sightedness.

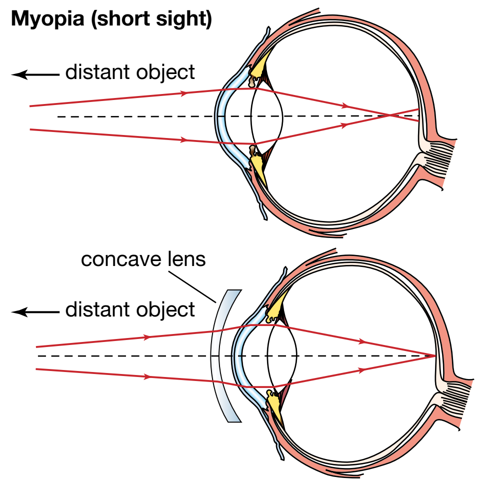


Figure 4.4.15 The eyeball is too long in a person who is short-sighted. A concave lens of appropriate strength can correct this problem.

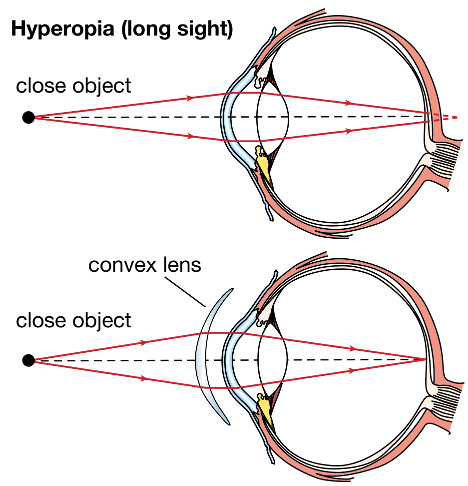


Figure 4.4.16 This person is long-sighted because their eyeball is slightly too short. A convex lens can correct this problem.

Bifocals or graded lenses may be used if a person has more than one type of vision problem. These lenses are strongest at the bottom, so a person looks down through this region to read, and looks straight through the lenses to focus on objects further away.

Some people wear contact lenses rather than glasses. These small lenses are worn directly on the cornea of the eye and are made from hard plastic, or from water-absorbing materials. Because contact lenses are in continual contact with the surface of the eye, they must be kept very clean and sterilised regularly. Another treatment for vision problems, rather than wearing glasses, is to undergo laser surgery. Such treatment reshapes the surface of a patient's cornea to alter how it focuses light.

4.8

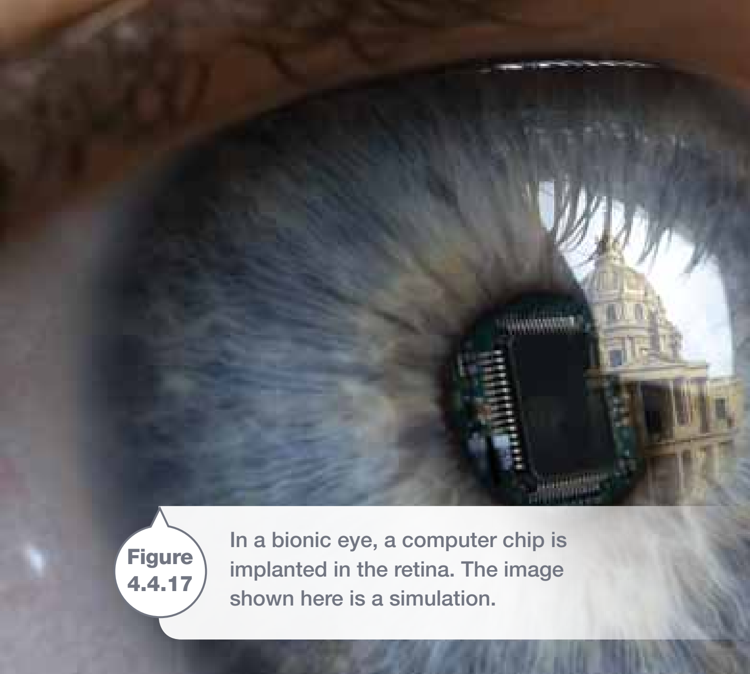


Figure 4.4.17 In a bionic eye, a computer chip is implanted in the retina. The image shown here is a simulation.

SCIENCE AS A HUMAN ENDEAVOUR

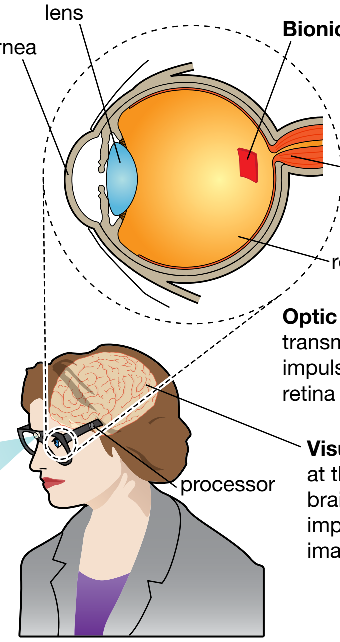
Use and influence of science

The bionic eye

Imagine having very little or no vision. The bionic eye is new technology under development that can improve vision.

Bionic Vision Australia is developing prototypes of a bionic eye. Such a device can change the lives of people who have gone blind from eye diseases such as macular degeneration or retinitis pigmentosa. Macular degeneration is the leading form of blindness in the industrialised world. These diseases affect how the rods and cones of the retina detect light patterns. In a bionic eye, a chip containing an array of electrodes is implanted in the retina to mimic the function of the damaged cells.

The bionic eye system has a number of parts, as shown in Figure 4.4.18. Figure 4.4.19 shows the type of vision provided by early prototypes of the bionic eye. This vision is a series of light and dark regions. At the moment, patients take some time to learn how to interpret this pattern of light as vision. However, even this low-resolution image can give the person an awareness of their surroundings, and help them in moving around. The key challenge for researchers in this field is to fit more electrodes onto the chip implanted on the patient's retina. As the number of electrodes increases, enormous leaps in quality of vision will be possible.



Video camera fitted to a pair of glasses captures a stream of images

Wireless processor converts camera images into digital signals which are sent to the implant using wireless technology

Bionic implant a chip with an array of 1000 electrodes is attached to the damaged retina. This recieves signals from the processor, using them to stimulate the optic nerve

Optic nerve transmits electrical impulses from the retina to the brain

Visual centre at the back of the brain, translates nerve impulses into the images we see

Figure 4.4.18 How a bionic eye works

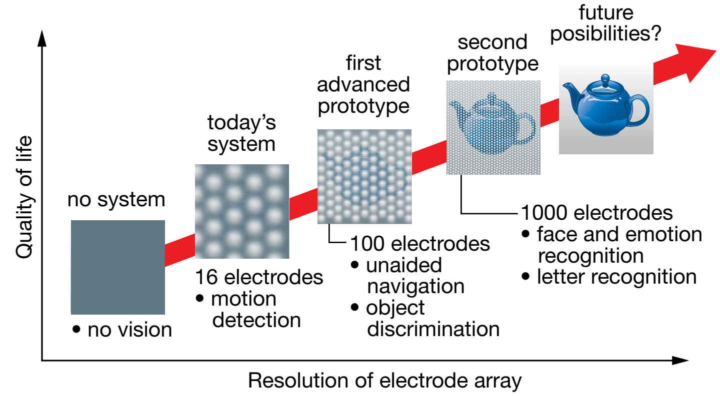


Figure 4.4.19 Prototypes of the bionic eye, and the vision they provide.

4.4 Unit review

Remembering

1 **Recall** the language of lenses by matching the correct word from the list below to each of the statements that follow. (Note: Some words can be used more than once.)

focus real virtual convex concave

- a In using a lens, this is the point at which distant light rays meet, or appear to meet.
- b This type of image cannot be produced on a screen or a sheet of paper.
- c This type of lens always produces upright, diminished, virtual images.
- d A convex lens produces this type of image from a distant object.

2 **State** which of the two alternatives makes each of these statements true.

- a Light entering the eye is refracted by the lens and the *cornea/retina*.
- b To produce a clear image, light must be focused on the *retina/lens*.
- c The image travels as a series of *light/electrical* signals along the optic nerve to the brain.
- d The aqueous humour is a clear fluid that lies between the cornea and the *retina/lens*.

Understanding

3 The following table lists the typical focal lengths for different optical devices.

Object	Focal length (m)
Spectacles	1
Camera lens	0.05
Microscope objective lens	0.004

- a **State** which object uses the lens with the shortest focal length.
- b **Explain** the reason that this device would require the shortest focal length.

4 Is the image formed on your retina real or virtual? **Explain** your answer.

5 **Describe** what happens to the pupils of your eyes when you are:

- a in a dark cinema
- b outside playing in the sun.

6 Tran is short-sighted and forgets to bring his glasses to the cinema. **Predict** whether you think he would prefer to sit near the front or the back to watch the movie.

7 **Explain** how a pair of bifocal glasses works.

8 **Describe** what happens when a person undergoes laser eye surgery.

Evaluating

9 At a 30-year high school reunion, 29 of a class of 34 are wearing glasses. **Propose** an explanation for this, given that only five of the class wore glasses at school.

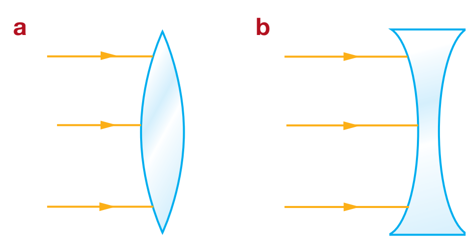
10 Su-Lin asks Joe to pass her a convex lens of focal length 25 cm from a box containing many different strength lenses. **Propose** how Joe could work out which was the lens Su-Lin wants.

11
- a **State** the two major eye diseases that may be treated using the bionic eye.
- b **Construct** a flowchart that explains how each component of the bionic eye functions.
- c **Describe** the biggest challenge facing bionic eye researchers.
- d **Propose** how having a bionic eye affects the lives of patients today.
- e **Predict** the effect that this device will have when the resolution is even more detailed.

Creating

12 Copy the lenses shown in Figure 4.4.20 and **construct** the path the light rays will take as they pass through each lens.

Figure 4.4.20



13 a Copy the diagrams in Figure 4.4.21. **Construct** a ray tracing diagram in each case.

b **Use** your diagrams to **describe** the type of image that will be formed using these convex lenses.

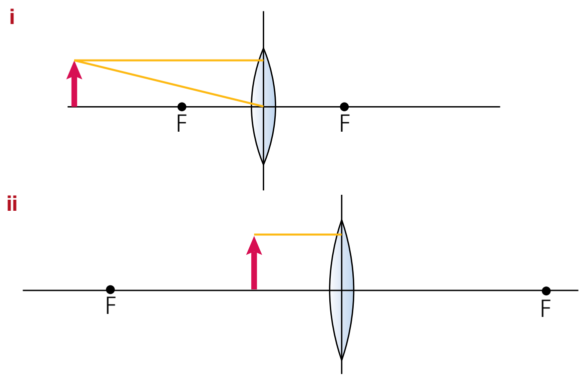


Figure 4.4.21

14 **Construct** a diagram to show the difference in the appearance of the lens in Vishwar's eyes as he looks down to read a TV guide and then looks up to watch TV.

15 **Construct** a flowchart that lists the structures and fluids light travels through on its journey from entering your eye until it reaches your retina.

Inquiring

1 Combinations of different types of lenses are used in a range of optical instruments, such as binoculars (like the ones shown in Figure 4.4.22), data projectors, cameras, telescopes and microscopes. Research one of these instruments and then construct a labelled diagram that explains how it operates.

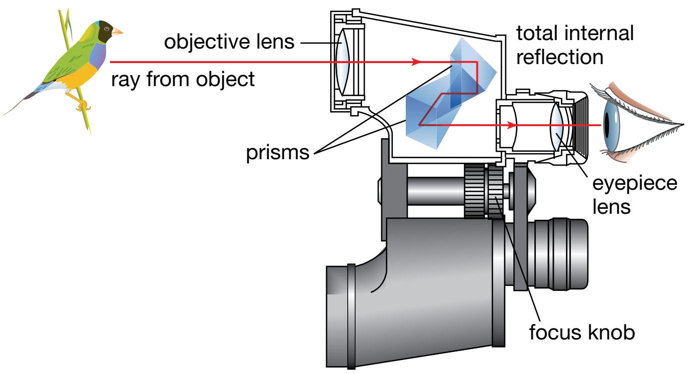


Figure 4.4.22

2 Create a booklet, poster or multimedia presentation to explain key stages in the development of photography, from the camera obscura through to digital cameras used today.

3 Explore the Bionic Vision Australia website to summarise the current progress in development of the bionic eye.

4 Find a news report on a patient who has received a bionic eye implant. Summarise how this technology has benefited them, and describe any aspects that they may have found difficult.

5 Search the internet for instructions on how to make a simple pinhole camera. Construct your camera and investigate how to get the best possible images.

4.4 Practical activities

1 Comparing curved mirrors and lenses

Mirrors can be curved and can produce real and virtual images in a similar way to a lens. A concave mirror curves inwards like a cave, whereas a convex mirror bulges outwards. A concave mirror can be used to produce a real image. Concave mirrors are used in astronomical telescopes.

Purpose

To investigate how light is reflected and refracted from curved mirrors and lenses.

Materials

- light box with 12V power supply
- multiple-slit slide
- set of curved mirrors and lenses of differing strengths
- pencil
- several sheets of white paper

Procedure

1. Place a multiple-slit slide in the light box and position it on a sheet of white paper.
2. Place a concave mirror in the path of the light rays as shown in Figure 4.4.23.
3. Use a pencil to mark two dots for each incident and reflected ray on the sheet of paper.

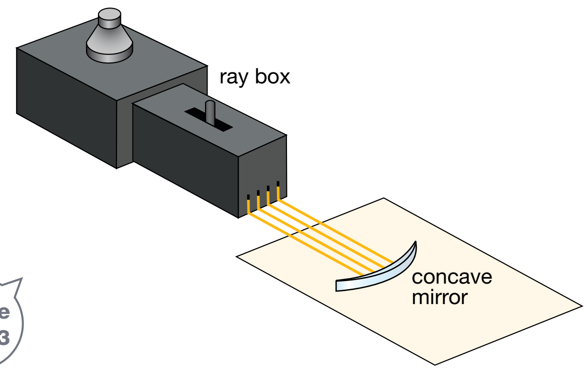


Figure 4.4.23

4. Remove the mirror and trace these rays onto the page, also showing the position of the mirror.
5. Repeat the procedure for a concave mirror of differing curvature, two convex mirrors, two concave lenses and two convex lenses, all of differing thickness. Use a new sheet of paper for each sketch.

Discussion

1. **Describe** differences between how the concave and convex mirrors reflected light.
2. **Describe** the effect of using a more curved mirror.
3. **Compare** the way light passed through the convex and concave lenses.
4. **Describe** the effect of using a thicker convex lens compared to a thinner lens.

2 Finding your blind spot

There are no light-sensitive cells at the point on your retina where it joins the optic nerve. You are blind in this spot.

Purpose

To identify your blind spot.

Materials

your textbook

Procedure

1. Hold this page of your textbook at arm's length.
2. Close your left eye and stare at the cross in Figure 4.4.24 with your right eye.
3. Move the book closer to your face, while still looking at the cross. Be aware of the dot while you do this.

Finding your blind spot

Figure 4.4.24

Discussion

1. **Propose** why you don't normally notice your blind spots.
2. **Explain** what happened when the dot disappeared.
3. If you look at the dot to check that is still there while doing this test, it won't work. **Propose** why this is the case.

Chapter review 4

Remembering

1 **List** the three processes of heat transfer.
2 **Name** the only process that can transfer heat through the vacuum of space.
3 **State** whether sound travels fastest in a solid, a liquid or a gas.
4 **List** the parts that make up the middle ear.
5 A beam of light hits a plane mirror at an angle of 45°. **State** the angle at which it is reflected.

Understanding

6 **Explain** how a sea breeze forms.
7 **Describe** what is likely to happen to infrared radiation that hits:
  a a black plastic pot plant
  b a white shade sail over a sandpit
  c a glass window on a boat.
8 Kim toasts marshmallows on an open fire. Although she can't see any flames, she can still feel heat from the fireplace. **Explain** why.
9 **Describe** how the pitch of a violin string can be changed.
10 **Predict** the sizes of angles x, y and z in Figure 4.5.1.

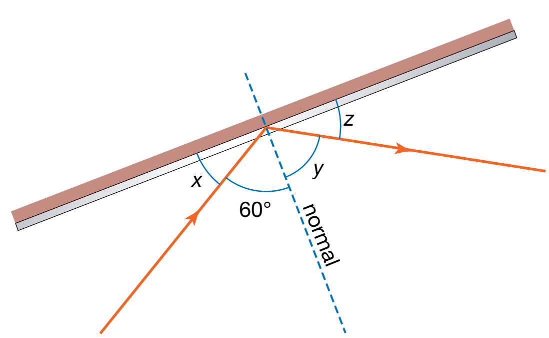


Figure 4.5.1

11 **Explain** whether an image projected from a data projector onto a wall is real or virtual.

Applying

12 **Identify** what vibrates in each musical instrument below to produce a sound.
  a a harp   b a trumpet   c a bongo drum
13 A periscope is used in a submarine to allow sailors to see what is above the surface of the water. Copy Figure 4.5.2 and complete the path of a ray of light to **demonstrate** how this works.

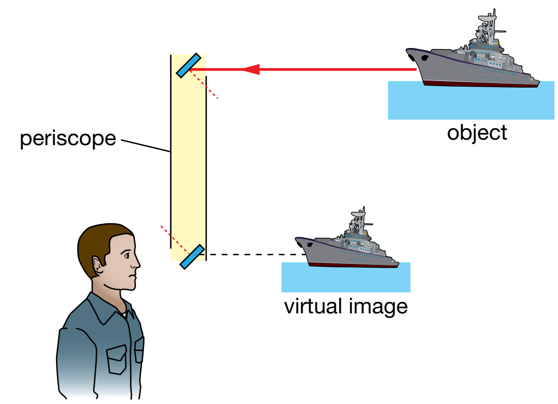


Figure 4.5.2

14 Perspex has a greater refractive index than that of ice.
  a **Identify** in which material light travels faster.
  b If light travels from ice into Perspex, **state** whether it will bend towards or away from the normal.
15 A light ray travels through material X and hits the boundary of the transparent material Y at an angle of 40° to the surface. It is then refracted into material Y at an angle of 35°. **Identify** whether X or Y has the greater refractive index.

Evaluating

16 a **Use** Table 4.2.2 on page 112 to calculate how far sound would travel through:
    i water in 5 seconds   ii glass in 5 seconds.
  b **Propose** why sound travels faster through glass than through water.
17 **Propose** reasons why light travels faster in ice than in water.

Creating

18 A seagull circling overhead spies a fish below, as shown in Figure 4.5.3. **Construct** a diagram to show where the fish appears to be when seen by the seagull.

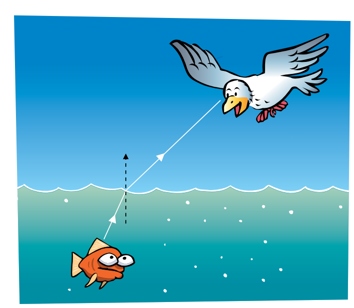


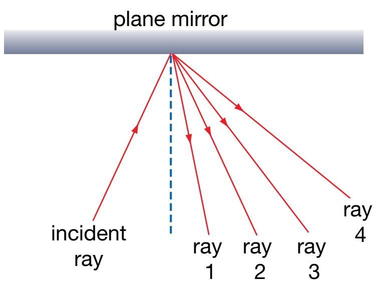
Figure 4.5.3

19 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter:

heat, temperature, conduction, convection, radiation, sound, frequency, wavelength, light, image

Thinking scientifically

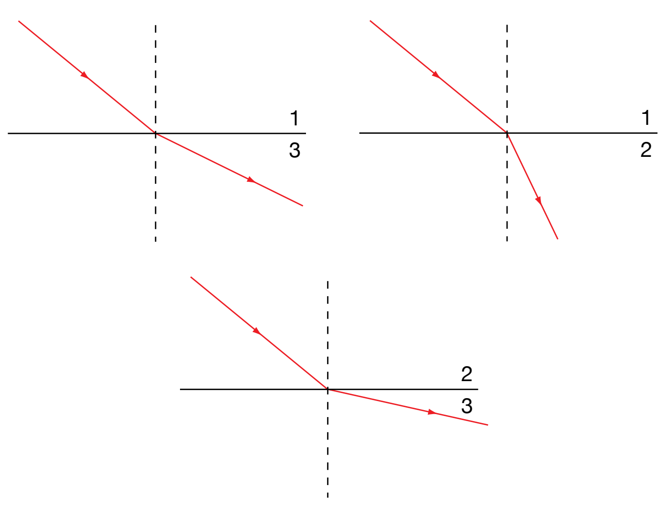
Q1 Light reflects from a plane mirror at an angle equal to the angle at which it hits the mirror. Josh directs a ray from a light box onto a plane mirror, as shown in the diagram.



The reflected ray in Josh's experiment is:

A ray 1
B ray 2
C ray 3
D ray 4

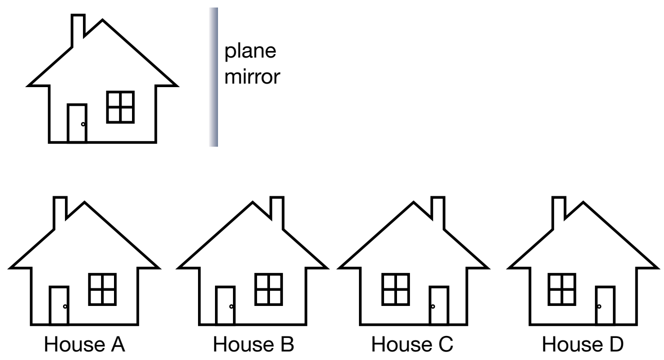
Q2 Light refracts (bends) towards the normal when it travels from one medium into another of higher refractive index. It bends away from the normal when travelling into a substance of lower refractive index. Study the ray diagrams as light travels between materials 1, 2 and 3.



The materials listed from least to greatest refractive index are:

A 1, 2, 3
B 3, 1, 2
C 2, 1, 3
D 1, 3, 2

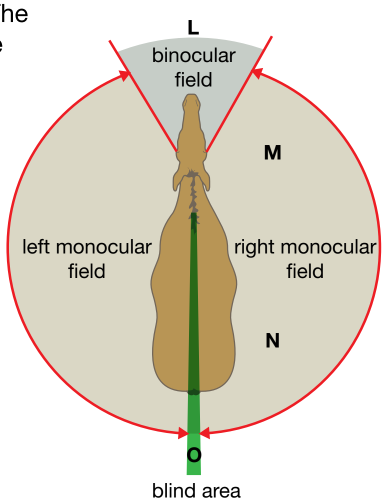
Q3 In a plane mirror, light is laterally inverted (reflected from left to right). Select the correct image of the house as it appears when reflected through a plane mirror.



A House A
B House B
C House C
D House D

Q4 A horse has one of the largest pairs of eyes of any animal. The horse has binocular vision and therefore a limited field of view. In this field of view, the horse can easily judge distances between objects. It also has a wide field of monocular vision to the left and right, called its left and right monocular fields. The horse cannot judge distances as effectively between objects it sees in these fields. In a small region behind the horse, it has no vision.

The diagram shows these fields of view, as seen from above the horse.



Identify which of the 1-metre tall objects, L, M, N and O, can be seen by the horse without turning its head.

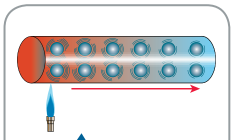
A only L
B only M and N
C L, M and N
D only L and O

Glossary

Unit 4.1

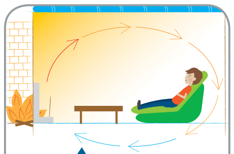
Absolute zero: the lowest possible temperature, –273°C

Conduction: a method of heat transfer in which heat is passed by vibration of particles


Conduction

Conductor: a substance that allows heat to flow through it

Convection: transfer of heat in a liquid or gas due to less dense, warmer matter rising and denser, cooler matter falling


Convection

Insulator: a material that does not conduct heat

Radiation: movement of heat in the form of electromagnetic waves, which can travel through a vacuum

Temperature: a measure of the average kinetic energy of particles in a substance that results in how hot or cold the substance is

Thermometer: an instrument used to measure temperature

Unit 4.2

Compression: a region of high pressure where particles are close together

Decibel (dB): unit used to measure loudness

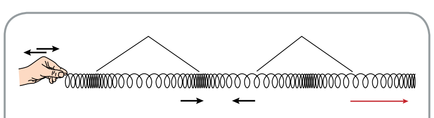
Echo: a sound that is reflected and heard a second time

Frequency: the number of waves passing a point every second

Hertz (Hz): the unit used to measure frequency

Infrasound: the sounds produced by waves of very low frequency, less than 20 Hz

Longitudinal wave: a wave in which the vibration is in the same direction that the wave is travelling

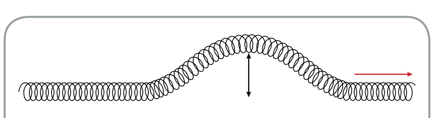

Longitudinal wave

Rarefaction: a region of low pressure, in which particles are far apart

Sound wave: regions of high and low pressure originating from a vibrating object and transmitted through a medium

Tinnitus: constant ringing in the ears caused by prolonged exposure to loud sounds

Transverse wave: a wave in which the vibration is at right angles to the direction the wave is travelling


Transverse wave

Wavelength: the distance from one peak of a wave to the next

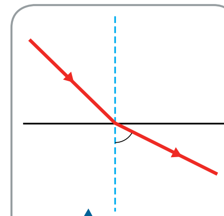
Ultrasound: the sounds produced by waves of greater frequency than humans can hear (greater than 20 000 Hz)

Unit 4.3

Angle of incidence, *i*: the angle an incoming ray makes with the normal

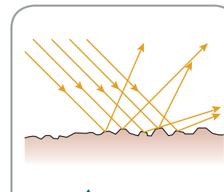
Angle of reflection, *r*: the angle a reflected ray makes with the normal

Angle of refraction, *r*: the angle a refracted ray makes with the normal


Angle of refraction

Critical angle: the angle of incidence of light that produces an angle of refraction of 90°

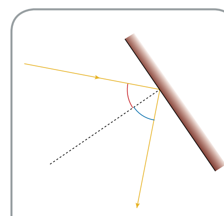
Diffuse reflection: reflection of light in many directions from an uneven surface, such as a book or a backpack


Diffuse reflection

Incident ray: incoming ray

Lateral inversion: the sideways or left-to-right reversal of an image in a plane mirror

Law of Reflection: the law stating that light is reflected at the same angle that it is incident, or $i = r$


Law of Reflection

Normal: an imaginary line that is drawn at right angles to a surface that light is incident upon

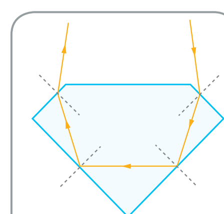
Plane mirror: a flat mirror

Refraction: the bending of light as it enters or leaves different substances

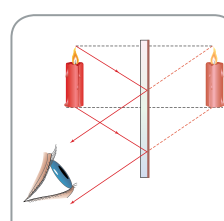
Refractive index: a measure of how easily light travels through a substance

Regular reflection: reflection of light from a very smooth surface, such as still water or a mirror; it produces a clear image

Total internal reflection: when light is completely reflected from the boundary of two substances; it occurs when the angle of incidence is greater than the critical angle


Total internal reflection

Virtual image: a type of image formed in which the rays of light do not actually meet, but only appear to meet at a point inside the mirror


Virtual image

Unit 4.4

Accommodation: the ability of the lens of the eye to change its shape to adjust its focus

Concave lens: a lens that curves inwards

Convex lens: a lens that bulges outwards

Cornea: a transparent covering over the iris of the eye; it bends light into the lens

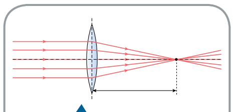
Focal length: the distance from a lens to its focus

Lens: in the eye it is a flexible structure that enables light to be focused on the retina

Long-sightedness (hyperopia): the inability to focus on close objects because the eyeball is too long

Optic nerve: a nerve that carries an electrical signal from the retina to the brain.

Real image: an image formed when rays of light do actually meet



Real image

Retina: nerve tissue at the back of the eye, consisting of cone cells and rod cells; light is converted into an electrical signal here

Short-sightedness (myopia): the inability to focus on distant objects because the eyeball is too short