Waves

Sound *and* Light

Ideas you have met before

Different types of sound

Sounds are only possible when a vibration occurs. Banging on a drum or plucking a guitar produces vibrations that cause a sound to be made.

We can change the vibrations of a sound by giving them more energy. The stronger the vibrations, the louder the sound.

Some sounds we hear have a high pitch, like a whistle or a siren. Some have a low pitch, like the rumble of thunder. When we change the pitch, we change how rapidly an object vibrates.

How sounds behave

We hear sounds because the vibrations travel through a material, like air, to the ear.

Sounds may be reflected by hard materials and absorbed by soft materials.

Sounds get fainter as they travel further from the source.

How light behaves

Light appears to travel in straight lines.

Shadows have the same shape as the objects that made them because of light travelling in straight lines.

How we see things

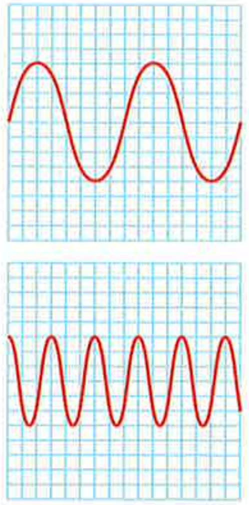
We see objects because they emit or reflect light into our eyes.

We can see objects that don't emit their own light because they reflect light from other sources into our eyes.

We can explain this using the idea that light travels in straight lines.

In this chapter you will find out

What sound is

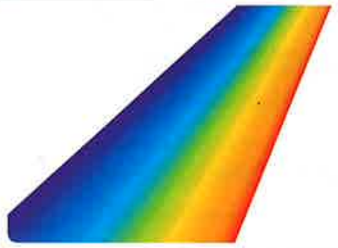


- Energy is transferred by sound in the form of waves.
- Sound travels as longitudinal waves (vibrations) passed on by particles of a material.
- Sounds can be represented by waveforms, showing wavelength, frequency and amplitude.
- The greater the amplitude of the waveform, the louder the sound.
- The greater the frequency (and the shorter the wavelength), the higher the pitch.
- The ear is a detector of sound waves of a certain frequency range.

How sound behaves

- The denser the medium, the faster sound travels.
- Sound is transmitted, reflected or absorbed by different types of surface.
- Echoes occur when sound waves are reflected by hard materials.

What light is



- Light travels as transverse waves that carry energy.
- White light can be split into a spectrum of colours.
- Coloured light causes an object to appear a different colour.

How light behaves

- Light waves can travel through a vacuum.
- Light can be reflected, absorbed and refracted.
- When it is reflected, the angle of incidence equals the angle of reflection. Light can form an image in a mirror.
- Light can be refracted through lenses and prisms.
- Wave properties can be described using a ray diagram as a model.

Exploring sound

We are learning how to:

- Identify how sounds are made.
- Describe how sound waves transfer energy.
- Explain how loud and quiet sounds are made.

Sounds are made in different ways and by many different things. We need to understand what sound is, what all sounds have in common and how they vary.

Making sounds

If you place a finger over your voice box when speaking or singing, you will feel the **vibration** of your voice box. This is where the sound comes from.

When an instrument is plucked or blown through, the string or the air vibrates. Often the vibrations are too small to see.

All vibrations result in a sound. The vibrations from the object are passed on to air particles. These air particles bump into others and the wave progresses. Eventually the energy of the vibrations is transferred to your ears. The speed of sound in air is just over 343 m/s, around a million times slower than light.

1. What causes the sound when a bell is rung?
2. How does the sound from a concert reach the audience?


FIGURE 1.4.1a: How does a guitar make a sound?

Making waves

Energy is transferred by sound in the form of waves. In Figure 1.4.1b a slinky spring provides a model that shows how these waves work. When you push the end of a slinky back and forth, some of the coils squash together and others pull apart. A wave of energy passes along the length of the spring. A wave like this which travels in the same line as the vibrations of the source is called a **longitudinal wave**.

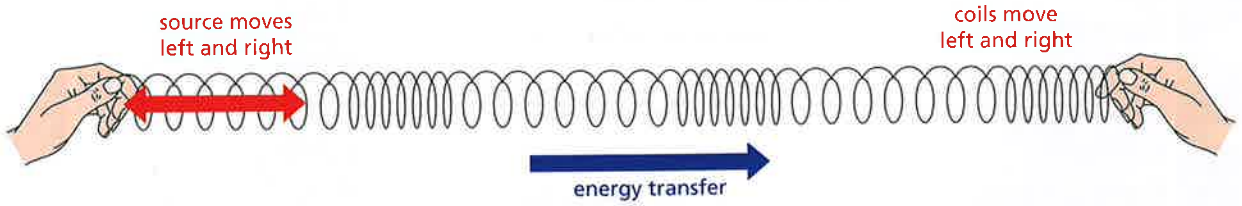


FIGURE 1.4.1b: Why is this called a longitudinal wave?

A sound wave works in the same way as the slinky spring. Vibrations push air particles together and also pull them apart, creating a longitudinal wave of energy. The energy is transferred from the source of the vibration to our ears.

3. Describe the movement of air particles in a longitudinal sound wave.
4. Explain how a longitudinal wave can transfer energy from one store to another.

Loudness of sounds

The **volume** of a sound a measure of how loud the sound is. Sounds can be made louder by increasing the energy in the vibration. Plucking a string harder, blowing harder through a wind instrument or beating a drum harder will all transfer more energy. The loudness of sound is measured in a unit called a **decibel (dB)**. The loudest sound that humans can listen to without damage to their hearing is about 120 dB.

The size of a vibration is represented by its **amplitude**. Figure 1.4.1d shows that the amplitude is the maximum distance that a particle travels, from its middle position, in the to-and-fro vibration. The greater the amplitude, the greater the energy of the vibration and the louder the sound. In other words, a bigger wave will transfer more energy and be heard as a louder sound.

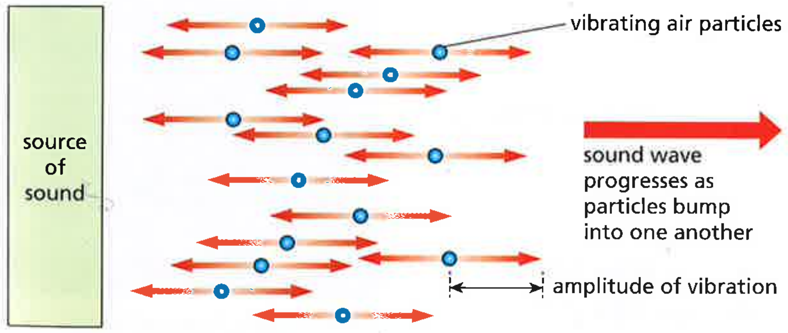


FIGURE 1.4.1d: What effect will a smaller amplitude have?

5. Look at Table 1.4.1. Match the sounds to the correct loudness.
6. The loudness of a sound also depends on the distance from the source. Explain what happens to the energy as you get further away.

Did you know...?

The ocean-dwelling tiger pistol shrimp is known to produce sounds of over 200 dB. It uses the sound as a defence mechanism. The vibrations can kill prey and fish up to 2 metres away!


FIGURE 1.4.1c: A pistol shrimp.

TABLE 1.4.1

Sound	Loudness (dB)
1 whisper	a) 80
2 phone ringtone	b) 140
3 jet engine	c) 100
4 motorbike	d) 30

Know this vocabulary

vibration
longitudinal wave
volume
decibel (dB)
amplitude

Describing sound

We are learning how to:

- Explain what is meant by pitch.
- Understand frequency, wavelength and amplitude.
- Relate sounds to displayed waveforms.

There are many different types of sound. Think of the sounds made by a whale compared with the high-pitched screeching of a monkey, or the sound of a bass guitar compared with a violin. Differences in sound waves arise from different characteristics of the sound waves.

What is pitch?

A ship's horn produces a sound that is very deep and low – this is known as a low **pitch**. Whistles, alarms and sirens produce high-pitched sound.

The pitch of a note depends on the **frequency** of the vibration producing the sound. A high frequency means more vibrations are produced per second. Frequency is measured in the unit **hertz**, abbreviation Hz; 1 Hz is one vibration per second. A high frequency gives a high pitch, and a low frequency gives a low pitch. Musical notes change in pitch by changing the frequency of the vibration. Feel your voice box as you make sounds of different pitches. What do you notice?

1. Describe one other sound with a low pitch and one other sound with a high pitch.
2. What is meant by the 'frequency' of a note?

FIGURE 1.4.2a: How would you describe the scream of a monkey?

Wavelength, frequency and amplitude

Waves transfer energy. If no energy is being supplied, the wave can be represented by a horizontal straight line, like still water in a pond. If energy is then supplied, the wave starts to rise and fall – we say it is being displaced.

We can show this on a graph, such as Fig 1.4.2c. The amplitude shows how much the wave is being displaced vertically and the energy is being transferred from left to right.

The higher the frequency of a wave, the shorter the **wavelength**. The maximum displacement is the **amplitude**. The energy transferred by the wave depends on this. The larger the amplitude of a sound wave, the louder the sound.

FIGURE 1.4.2b: Energy is being transferred by waves; the water is being displaced above and below its level when at rest.

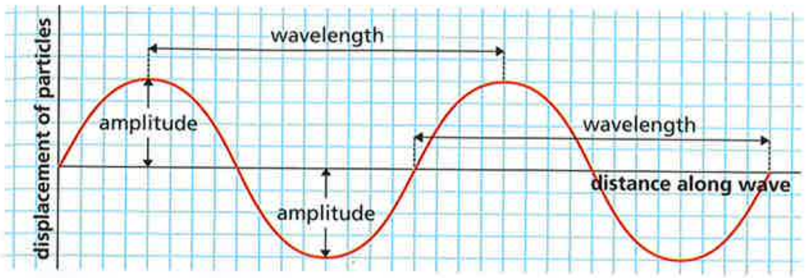


FIGURE 1.4.2c: Parts of a wave.

3. Why is it more useful to use the wave representation in Figure 1.4.2c, compared with a drawing of a longitudinal vibration, as in Figure 1.4.1d?
4. How could you tell from a **waveform** whether a sound is getting:
   a) louder? **b)** higher pitched?

Interpreting sound waves

All sound waves can be detected using a microphone and shown as a waveform on a screen of a device called a cathode ray **oscilloscope** (or CRO). The microphone receives the sound waves and converts them into electrical signals. Some typical examples are shown in Figure 1.4.2d. The waveforms produced by a CRO are very useful as they show both the amplitude and the frequency of a sound wave. As the sound alters, so the waveform displays changes.

5. **a)** Which wave in Figure 1.4.2d results from the loudest sound?
   b) Which wave results from highest-pitch sound?
   c) Which wave is transferring the most energy? Explain your answer.
6. Draw waves to represent a loud high-pitched flute note and a quiet low-pitched flute note.
7. Look at the graph in Figure 1.4.2e, which shows the sound wave detected from a gun as time progresses. Describe what is happening to the frequency, wavelength and amplitude of the wave.

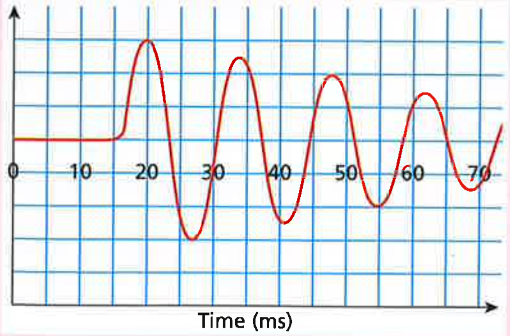


FIGURE 1.4.2e: Sound wave from a gun

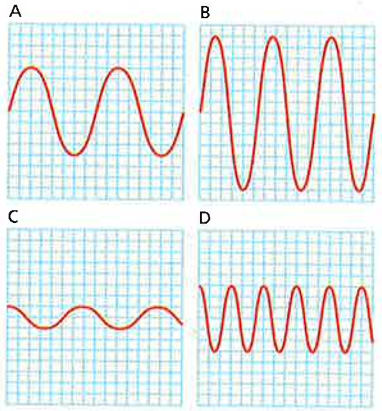


FIGURE 1.4.2d: How are these waves different?

Did you know...?

Microphones have a thin diaphragm made of plastic or metal. This vibrates when even small sound vibrations hit it. These vibrations are converted into an electrical signal that can be fed to a loudspeaker. The electrical signal is then converted back into vibrations, which are heard as sound.

Know this vocabulary

pitch
frequency
hertz (Hz)
wavelength
amplitude
waveform
oscilloscope

Hearing sounds

We are learning how to:

- Explain what is meant by audible range.
- Understand how the ear detects sounds.
- Apply ideas about sound to explaining defects in hearing.

The ability to hear is important in all animals for communication, hearing predators, knowing when there is danger and seeking prey. The human ear relies on a combination of processes and perfectly evolved mechanisms to allow us to identify the wide range of sound waves we receive.


FIGURE 1.4.3a: Good hearing is essential for detection of predators.

What can we hear?

We know that some notes are higher than others and what those high notes are like. Some notes can be painful to listen to, such as very high ones. In fact, there's a limit as to what we can hear. Sounds are made by things vibrating and the number of times per second something vibrates is the frequency. Humans can usually hear frequencies up to around 20 000 Hz (20 kHz).

We can also hear frequencies down to 20 Hz so the human audible range (or **auditory range**) is 20 Hz to 20 kHz. Some animals can hear much higher frequencies – dogs up to 45 kHz and cats up to 64 kHz.

1. How many Hertz in 1 kHz?
2. Why would you not be impressed by an advert for a personal stereo that claimed it had maximum frequencies of 30 kHz?
3. Dog whistles can be heard by dogs but not by humans. They can have a range of frequencies – but between what limits?

Structure of the human ear

The function (job) of the ear is to transfer energy by sound into electrical impulses that are interpreted by the brain. Figure 1.4.3b describes what happens to the sound waves as they enter the ear.

4. Suggest why incoming sound vibrations need to be amplified (amplitude made bigger) in the ear.
5. Where in the ear are:
   a) Electrical signals transmitted to the brain?
   b) Sound vibrations amplified?
   c) Vibrations first detected?

Did you know…?

Elephants can hear frequencies 20 times lower than the lowest frequency we can hear. They use their trunks as well as their ears to detect low frequency vibrations. This enables them to hear other elephants up to 6 km away.

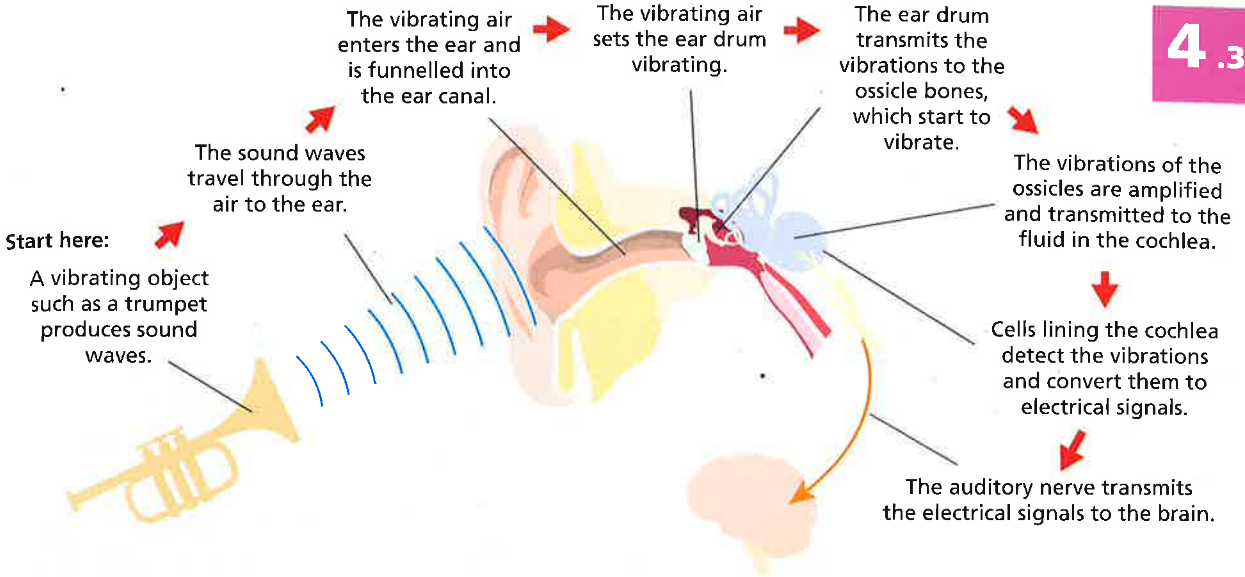


FIGURE 1.4.3b: How we hear.

Factors affecting hearing

Several factors can affect the health of our ears. Read about these in Table 1.4.3.

TABLE 1.4.3: Causes of ear damage and what can be done.

Causes of poor hearing or ear damage	Possible solutions
Ear canal can become blocked with wax.	Have the ear canal cleaned out.
Very loud sounds can rupture the ear drum.	Ear drum may heal itself over a long period of time.
Ear drum can be damaged by infection.	Use antibiotics to get rid of the infection.
Ossicles can become fused together.	An operation is needed.
Infection may occur in the middle ear.	Use antibiotics to get rid of the infection.
Hair cells and nerves in the cochlea may be damaged by loud noises.	There is no cure.
In older people, nerve cells may deteriorate.	There is no cure.

6. Why can some ear problems not be cured?
7. Who is most likely to be most at risk of having problems with poor hearing?

Know this vocabulary

auditory range

Understanding how sound travels through materials

We are learning how to:

- Recognise how the speed of sound changes in different substances.
- Explain why the speed of sound varies between solids, liquids and gases.

Whales are known to transmit sounds in the ocean over distances of 700 km. If whales were to transmit these same sounds in the air, would they travel faster or slower?

FIGURE 1.4.4a: How do sounds from whales travel under water?

Sound in a vacuum

Most of the sounds that you hear are transmitted by vibrating air **particles** (particles of gas). Sounds can also travel through solids and liquids. Sound waves need particles of matter to transmit energy. As the particles vibrate, the energy is passed on to adjacent particles and carried in the form of a wave.

Sounds cannot travel through a **vacuum**, nor through space, which has hardly any particles in it.

1. Why can sound not travel through a vacuum?
2. How is it possible for sounds to travel through solids?

Speed of sound through different materials

Table 1.4.4 shows the speeds that sound travels through different materials.

3. a) In which material does sound travel the fastest?
   b) In which material does sound travel the slowest?
   c) Does sound travel fastest in solids, liquids or gases?

TABLE 1.4.4: Speed of sound in different materials.

Material	Speed of sound (m/s)
air	343
carbon dioxide	259
copper	5010
diamond	12 000
lead	1960
oxygen	316
steel	5960
water	1482

Sound and particles

Particles of matter in solids, liquids and gases differ in their arrangement and behaviour. This affects how well sound waves can travel through them. The speed at which the wave moves depends on the arrangement of the particles, the elastic nature of the forces between them, and how fast the particles are moving.

- In a gas the particles are very far apart. Sound travels slowly because the particles do not collide very often.
- In a liquid the particles are much closer to one another. Sound travels more quickly because the particles are able to collide with each other much more frequently. Sound travels about five times faster through liquids than it does through gases.

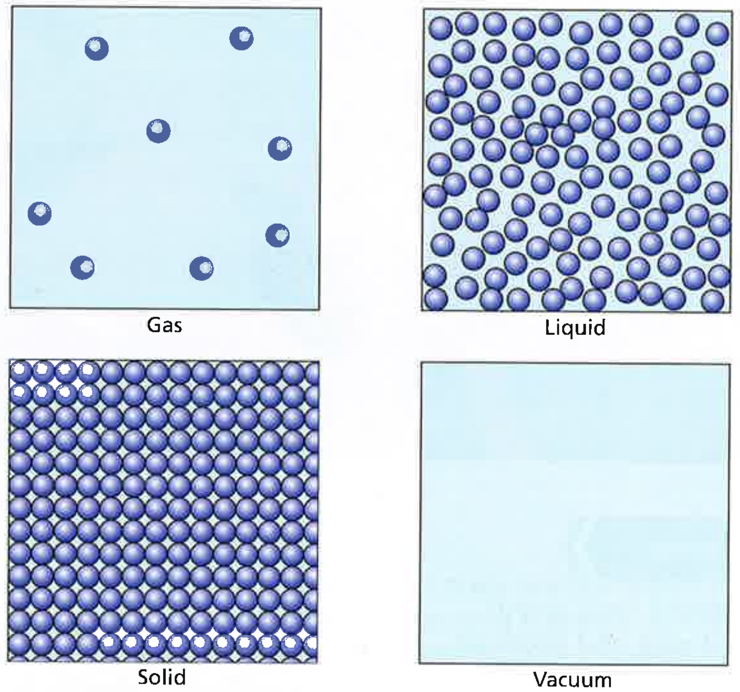


FIGURE 1.4.4b: The particle theory of matter explains how sound travels through solids, liquids and gases. Why does sound not pass through a vacuum?

- In a solid the particles are packed very closely together. Also, the forces between the particles are more elastic. The vibrating particles collide with neighbouring particles and bounce back very quickly, so the sound wave progresses very quickly.

4. Draw a particle diagram with arrows showing how sound travels through a liquid.
5. Why do you think sound travels much faster through some solids compared to others?
6. Temperature can also affect the speed of sound. Develop a **hypothesis** to explain why.

Did you know...?

Native Americans used to put an ear to railway tracks to know when trains were coming. This is a dangerous thing to do because you can never tell how soon the train will arrive.

Know this vocabulary

particle
vacuum
hypothesis

Learning about the reflection and absorption of sound

We are learning how to:

- Recognise which materials reflect the quality of sound.
- Analyse the effect of different materials on sound waves.
- Use ideas about energy transfer to explain how soundproofing works.

Concert halls are designed for good acoustics – so that the music sounds good to the whole audience. This means controlling the amount of echo and making sure sound reaches all corners. Different materials and shapes are used to achieve this.

FIGURE 1.4.5a: Some materials help to reflect sound and others help to absorb it.

Effect of materials on sound waves

An **echo** is a sound wave that is reflected back to our ears. Hard, flat surfaces reflect sound well and produce strong echoes.

Soft surface materials that contain lots of air pockets, like fabric, foam and sponge, are not good at reflecting sound, but absorb it. This process is called **absorption**. The sound waves transfer energy to the air in the pockets so less is reflected.

1. What do we mean by 'absorbing' sound?

2. a) What would you hear if the sound waves from a bell were directed at a metal panel?

b) What would you hear if the sound waves from a bell were directed at a panel made of sponge?

3. When might it be useful to absorb sound waves?

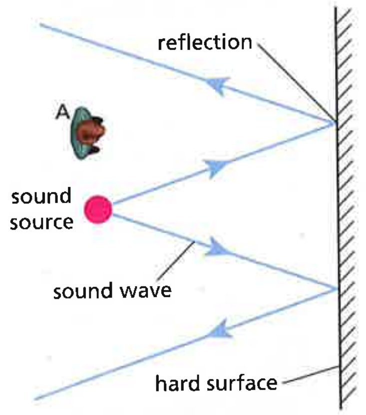


FIGURE 1.4.5b: Imagine you are standing in position A. What kind of echoes will this sound produce? How can the echoes be reduced?

Effect of shapes on sound waves

Some materials can be shaped to reflect sounds in different ways. Look at the jagged surface in Figure 1.4.5c. When sound waves hit this surface, the reflected waves do not bounce back to the source. They are, instead reflected randomly, mostly away from the source.

The curved surface, on the other hand, reflects the sound until all the energy focuses towards a particular point. The sound at this point will be the loudest, whereas in places away from it, hardly any sound will be heard at all.

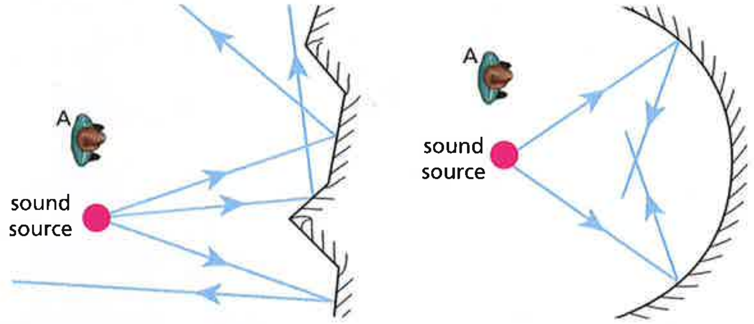


FIGURE 1.4.5c: How sound is reflected off a jagged and a curved surface.

4. Imagine you are standing in position A in each of the diagrams in Figure 1.4.5c. Describe what you will hear if the surface is:

a) jagged **b)** curved,

compared with standing in position A, in Figure 1.4.5b, opposite a flat surface.

Soundproofing

When sound waves hit soft surfaces, they are absorbed by the air pockets. The sound waves become trapped, bouncing around in the air pockets, until all the energy is transferred as heat. Any sound reflected from the surface is therefore much quieter, as the sound waves have much less energy.

These soft materials are useful as **soundproofing**. A vacuum is also useful in soundproofing. Sheets of glass with a near-vacuum between them (very few gas particles) are very effective in stopping sound.

In the outdoor environment, trees, embankments and dense bushes are often used for soundproofing around mining areas.

5. What happens to the energy of the sound wave during absorption?

6. Suggest a soundproofing plan for a hospital in a busy town centre.

FIGURE 1.4.5d: This material is used in soundproofing. What makes it a good choice?

Did you know...?

A 'whispering gallery' is the name given to a large circular room, where a whisper made in one place is reflected to the opposite side of the room and heard there but nowhere else. St Paul's Cathedral contains one.

Know this vocabulary

echo
absorption
soundproofing

Exploring properties of light

We are learning how to:

- Describe how light passes through different materials.
- Explain the difference between scattering and specular reflection.
- Explain how shadows are formed in eclipses.

Simple sundials can be made easily. The pointer is made of an opaque material that blocks light and produces a shadow. The position of the shadow can be used to tell the time.


FIGURE 1.4.6a: A sundial works because it casts a dark shadow.


FIGURE 1.4.6b: Frosted (translucent) glass provides some privacy because it does not allow all the light to pass through it.

See-through?

Light passes through gases, some liquids and some solids. Materials that light can pass through freely are said to be **transparent**. They do not produce shadows.

Other materials cast shadows by either completely or partially blocking the passage of light. **Opaque** materials block the passage of light waves completely, producing a dark shadow, whereas **translucent** materials only allow some of the light to pass through, casting weak shadows.

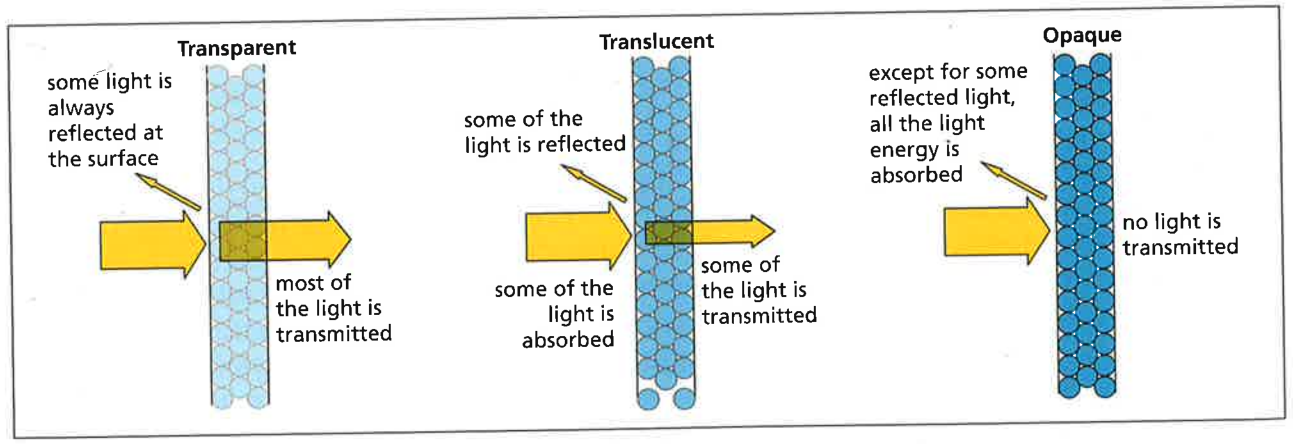


FIGURE 1.4.6c: What happens to light when it falls on transparent, translucent and opaque materials.

1. Give three examples of transparent materials.
2. Compare the shadows produced by an opaque material and those by a translucent material.
3. Explain why an opaque object casts a shadow.

Did you know…?

You can see through a piece of frosted glass (make it 'see-through') simply by putting a piece of clear sticky tape on it.

Solar eclipses

A solar eclipse happens when the Moon is between the Earth and the Sun. For a viewer on the Earth the effect is spectacular; for a few minutes the sky is plunged into darkness and a vivid ring of light is seen. However, it isn't the same for everyone.

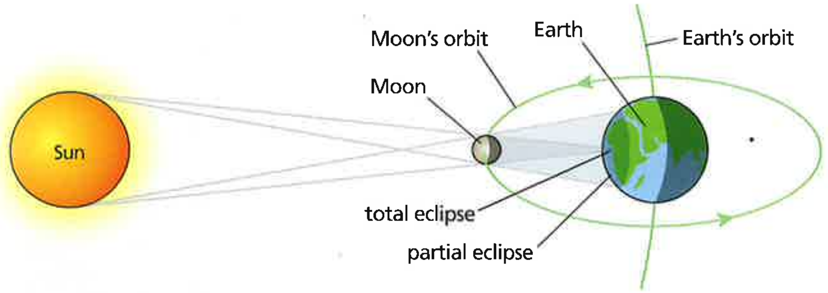


FIGURE 1.4.6d: The arrangement of the Sun, Moon and Earth during a solar eclipse.

The Moon's shadow isn't big enough to cover the whole of the Earth. Only people in a small area see a total eclipse. Just outside that, viewers experience a partial eclipse and in other places, nothing at all. This is because light travels in straight lines. The Moon is much smaller than the Sun so its shadow is smaller still.


FIGURE 1.4.6e: A total eclipse is an amazing sight but you have to be in the right place.

4. What would you see if you were in an area of partial eclipse?
5. Why does the effect only last for a few minutes?

Lunar eclipses

We also get an eclipse when the Earth blocks light from the Sun landing on the Moon. The three bodies are in alignment but this time the Earth is in the middle. The effect on Earth is quite different though; there is no shadow racing across the surface of the Earth but the Moon is bathed in a deep red light.

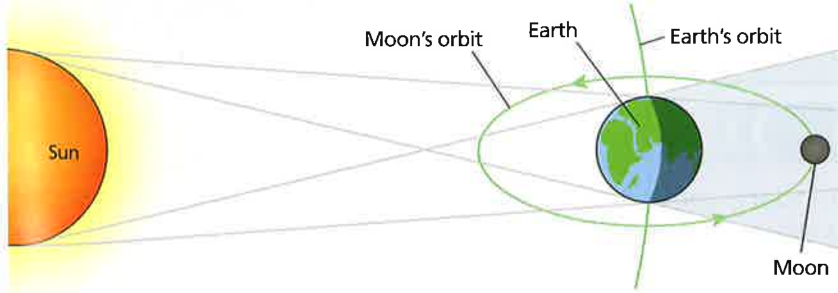


FIGURE 1.4.6f: The arrangement of the Sun, Earth and Moon during a lunar eclipse.


FIGURE 1.4.6g: The Moon being eclipsed.

6. Explain why lunar eclipses are only visible from certain parts of the Earth.
7. Draw and label a diagram to suggest whether lunar eclipses can be partial or total.

Know this vocabulary

transparent
opaque
translucent

Exploring reflection

We are learning how to:

- Describe how a mirror reflects light.
- Explain the difference between specular and diffuse reflection.
- Apply the law of reflection.

Light bounces off all kinds of surfaces – it's how we see the world around us. Often this reflected light scatters but if we use a mirror it follows a very particular route.

Explaining reflection

Light travels as waves. However, because a light wave travels in a straight line until it reaches a boundary, a **ray model** allows us to show clearly in a diagram the direction of the light and how it can change its direction when it meets a surface.

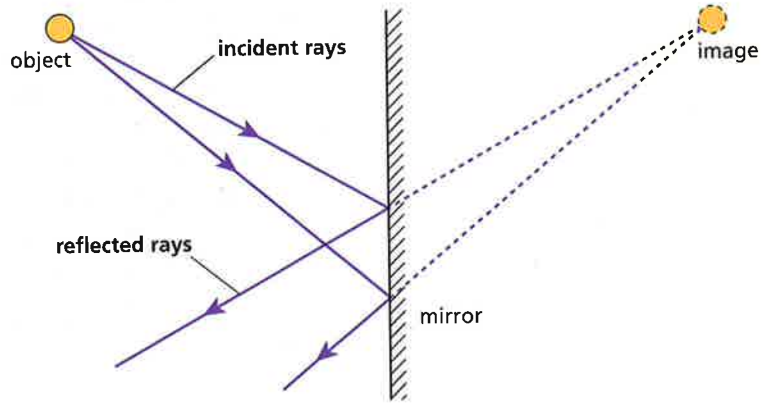


FIGURE 1.4.7b: The solid lines represent light rays. The dashed lines show where the light rays appear to be coming from – the image. This is the same distance from the mirror as from the object to the mirror.

1. Describe what Figure 1.4.7b shows.
2. Describe how the ray diagram showing image formation in a mirror needs to be changed if the object is:
   a) further away; **b)** closer.

Specular and diffuse reflection

When light hits a surface or a boundary, some or all of it is reflected – it bounces back in a direction away from the surface. The reflection produced by a flat, smooth, shiny surface is called specular reflection. All the light is reflected in the same direction. It allows us to see an **image**. A rough reflective surface bounces light back in many directions. We can think of the surface as being a mixture of small flat surfaces at different angles. The effect is called diffuse reflection, or **scattering**.

FIGURE 1.4.7a: Refraction causes the spoon to look as if it has broken into two parts.

FIGURE 1.4.7c: The specular reflection of light from a mirror allows you to see an image.

Did you know...?

An image ia a pictorial representation, usually two dimensional, of a physical object.

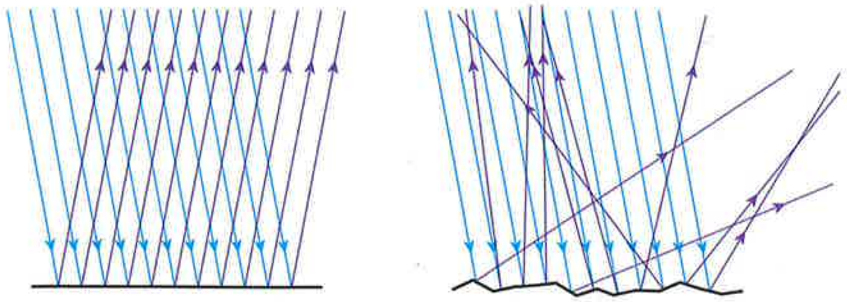


FIGURE 1.4.7d: The diagram on the left shows specular reflection. The one on the right shows diffuse reflection (scattering).

3. Describe the difference between specular reflection and diffuse reflection.
4. Explain why scattering happens at rough surfaces.
5. Explain why reflections in lakes or ponds cannot be seen if the water is choppy.

Angles of reflection

If a ray of light is reflected by a mirror, the angle of the reflected ray is always exactly the same as the angle the ray came in at. As Figure 1.4.7f shows, the angles are not measured from the surface but from a line called the **normal line**, which is drawn at right angles to the surface. The incoming ray is called the incident ray and the outgoing ray is called the reflected ray. We can say:

angle of incidence = angle of reflection

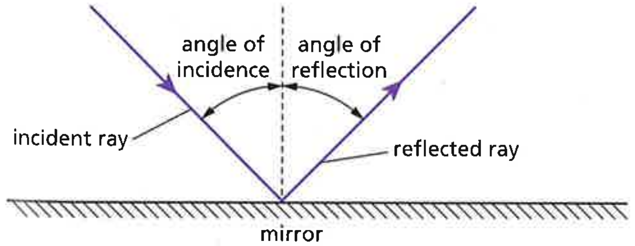


FIGURE 1.4.7f: The ray of light is reflected at the same angle it approached the mirror at.

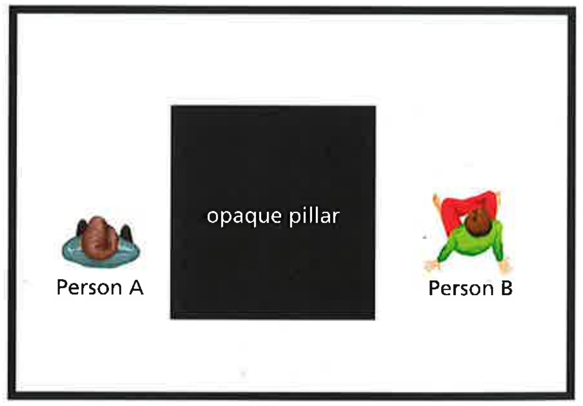


FIGURE 1.4.7g

6. What angle would light be reflected at if the angle of incidence were 20°?
7. What angle would light be reflected at if the angle between the incident ray and the surface of the mirror were 60°?
8. If we used a curved mirror, would the law of reflection still apply?
9. Copy Figure 1.4.7g and add two mirrors and rays to show how the person at A could see the person at B.

FIGURE 1.4.7e: The result of specular reflection in a calm lake.

Did you know...?

Glass is capable of both reflecting light and letting it pass through – it depends on the angle. If you stand in front of a shop window you can see both what's in the shop but also reflections of things behind you.

Know this vocabulary

ray model
incident ray
reflected ray
image
scattering
normal line
angle of incidence
angle of reflection

Exploring refraction

We are learning how to:

- Describe how light is refracted when it enters a different medium.
- Explain how this can cause it to change direction.
- Apply ideas about refraction to understanding lenses.

We usually think of light travelling in straight lines and usually it does. However, we can make it bend by making it pass through a transparent material that is either denser or less dense.

FIGURE 1.4.8a: Optical lenses.

Refraction

Light travels through transparent materials, such as glass and air. However, its speed depends on the density of the material. The denser the transparent material, the slower light travels through it. Glass is denser than air, so light travels through it slower than it travels through air.

Although we often draw light as rays, we need to remember that it is a series of transverse waves that transfer energy. Sometimes to explain what is happening we need to show the wave crests.

When the light slows down, the wavelength of its waves becomes shorter. Each of the crests catches up with the one in front. If the light then emerges into a less-dense medium it will speed up again. This effect is called **refraction**, and can cause the direction of the light to change.

Notice in Fig 1.4.8b the way the direction of the ray alters. When the ray goes into a denser medium (such as entering glass from air) it bends towards the normal. When it enters a less dense medium (such as entering air from glass) it bends away from the normal.

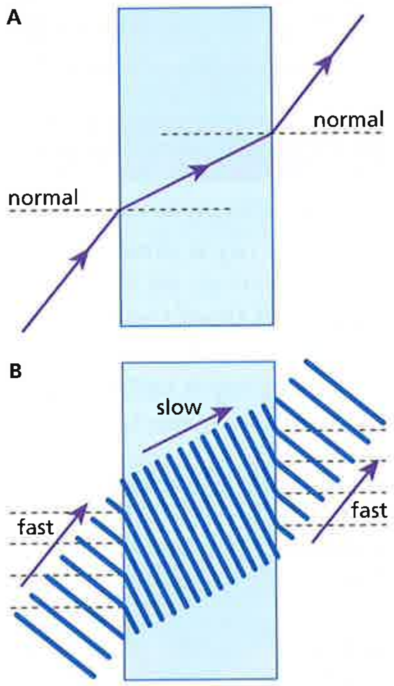


FIGURE 1.4.8b: A: ray model to show refraction of light; B: the wavelength shortens in a denser material.

1. Describe what happens to light waves when they travel into a dense material.
2. Sketch a diagram to suggest what would happen if a light ray hit a glass rod as shown in Figure 1.4.8c.

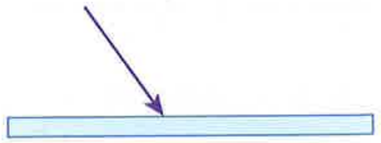


FIGURE 1.4.8c: A light ray hitting a glass rod – what happens?

Explaining how lenses work

Prisms come in different shapes but the most common ones are triangular. A ray of light passing through this will be refracted as it enters and as it leaves.

We can use ideas about refraction and prisms to explain how a **lens** works. Remember what happens when light is refracted – if it enters a denser medium it is refracted towards the normal and if it enters a less dense medium it will be refracted away from the normal. We can apply this to a triangular prism. Think about what happens when light enters it and when it leaves it.

Now consider the shape of a **convex lens**. We can think of it as being two prisms and a block (Figure 1.4.8d). It's not a perfect model but it's close enough. Look at the three parallel rays approaching. The upper one will be refracted downwards and the lower one upwards. The middle one will come through the middle and the three of them will meet. What the lens will then do is to bring rays together to produce a focused image. This can be caught on a screen.

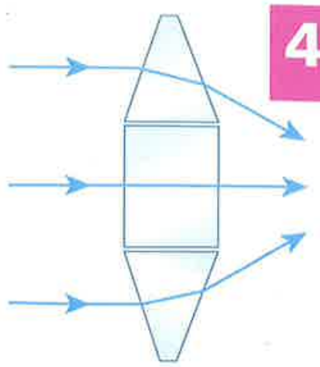


FIGURE 1.4.8d: We can simplify a convex lens to two prisms and a rectangular block to understand how it works.

3. Unless there's an object at the point where the rays meet in Figure 1.4.8d, they won't stop there. Sketch how they meet and where they will go next.
4. What difference do you think it will make if the convex lens is thinner? Show your ideas on a ray diagram.
5. Try constructing a ray diagram for a concave lens.

Did you know...?

The distance from a convex lens to the point where it makes parallel rays meet is called the focal length. The stronger the lens, the shorter the focal length.

Types of lens

Lenses are used in cameras, projectors, microscopes and telescopes. They come in many different shapes and sizes but there are two main types.

A convex lens bulges outwards in the middle. It makes light rays bend towards one another. A magnifying glass or hand lens is a common example of a convex lens. If we shine parallel light rays into a convex lens, they will meet each other at a focus and cross over. We sometimes call this a converging lens.

A **concave lens** is thicker around the edge and curves inwards in the middle. It makes light rays spread out. If we shine parallel rays into a concave lens they will travel away from each other. This is sometimes called a diverging lens.

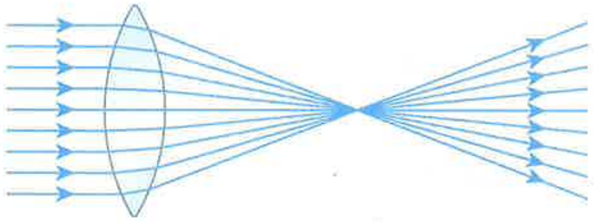


FIGURE 1.4.8f: A convex lens causes rays of light to converge.

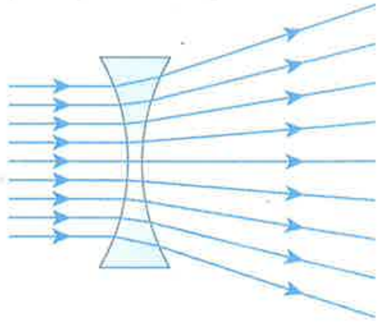


FIGURE 1.4.8g: A concave lens causes rays of light to diverge.

6. Suggest what a hand lens does with the light that passes through it from the object you are looking at.
7. Explain why:
   a) a convex lens is called a converging lens;
   b) a concave lens is called a diverging lens.

Know this vocabulary

refraction
lens
convex lens
concave lens

Seeing clearly

We are learning how to:

- Describe how the human eye works.
- Explain how the eye focuses on objects different distances away.
- Apply ideas about lenses to the correction of vision.

Our eyes have to cope with seeing things under many different conditions. Sometimes the object is close, or it may be far away, but we still need a clearly focused image. Our eyes are usually good at coping with this but may need a bit of help.

The human eye

Light enters an eye through the cornea and then travels through the lens. These both refract light rays, focusing them on a common point. An image forms on the **retina**. The optic nerve sends information to the brain, which interprets it.

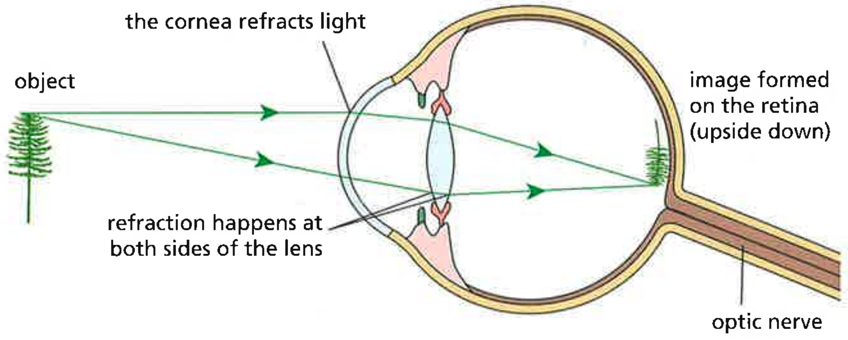


FIGURE 1.4.9b: How the eye works.

1. Name the parts of an eye that refract light.
2. Explain what the lens does to the rays of light.
3. Explain why the image formed on the retina is upside down.
4. Suggest why the lens in the human eye is a convex lens.

Looking at different objects

To see something, the rays need to be focused on the back of the eye. We need to be able to focus on objects that are close to us and also ones that are a long distance away. To do this, the lens in the eye changes shape.

For a distant object, a thin lens is sufficient to focus the rays on the back of the eye.

If an object is near, the light rays coming from it need to be refracted through a greater angle so the lens becomes fatter and more powerful.

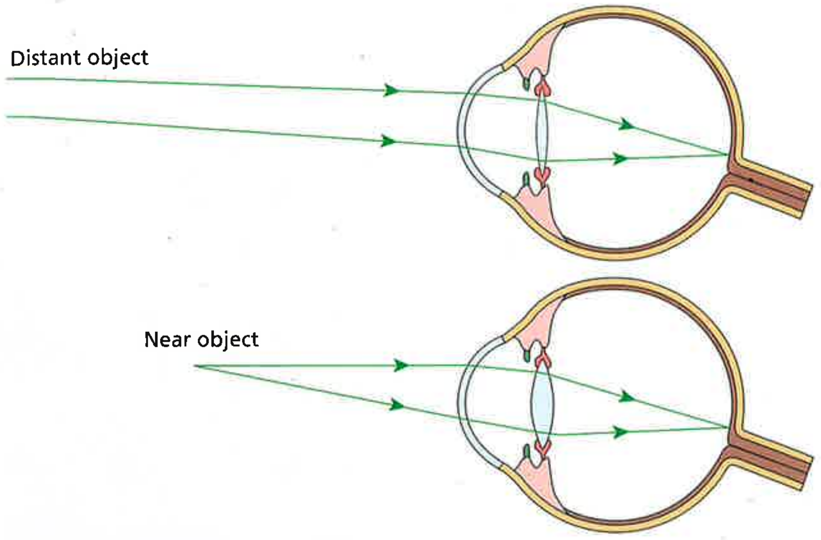


FIGURE 1.4.9c: The lens in the eye changes shape to focus on objects different distances away.

5. How is the lens in the eye different to the type of lens that would be used in spectacles?
6. Why do you think there's a limit as to how close an object you can focus on?

Correcting vision

Some people have eyes that won't focus properly on objects a certain distance away. What the lens in the eye should do is to focus rays on the back of the eye (on the retina). We'll look at two common defects. Look at Figure 1.4.9d.

One of these conditions is nearsightedness; the lens in the eye makes the rays meet before they reach the retina. The remedy is spectacles with concave lenses, which compensate by making the light rays diverge.

The other condition is farsightedness. This is the opposite situation; the lens in the eye doesn't make the rays close in sharply enough at the retina. The remedy is convex spectacle lenses.

7. If an object is near, light rays spread out from it and some may enter the eye. Draw a diagram to show how the eye will focus these and explain why it needs a strong lens.

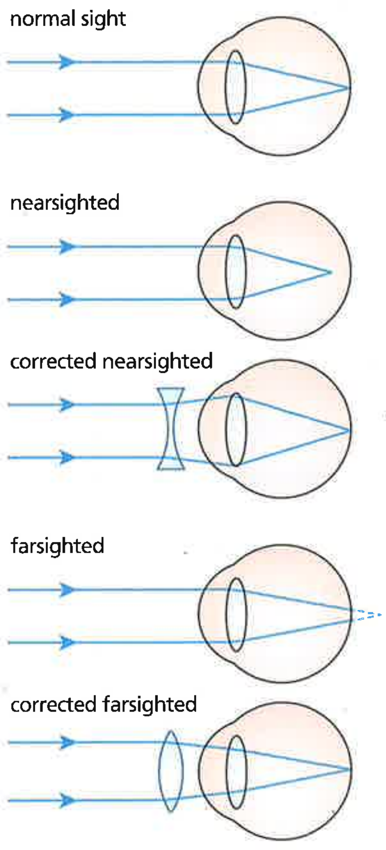


FIGURE 1.4.9d: How the lenses of glasses help to correct problems with vision.

Know this vocabulary

retina

Exploring coloured light

We are learning how to:

- Describe how a spectrum can be produced from white light.
- Compare the properties of light at different frequencies.
- Explain how light of different wavelengths can be split and recombined.

Some days it can be raining and, at the same time, the sun can be shining. This is when a rainbow can often be seen. To make a rainbow, sunlight and droplets of water are needed.

Spectrum from white light

Sunlight is made up of light waves of different **frequencies** and so different **wavelengths**. The range of wavelengths that the human eye can detect as different colours is called the visible **spectrum**. Seen together they make what is called white light. This white light can be split up to produce the colours of the spectrum. For example, if sunlight is shone through a triangular prism, it is refracted into different colours (Figure 1.4.10a and c).

1. Describe the spectrum obtained when white light passes through a triangular prism.
2. Which colours appear at each edge of a rainbow?

FIGURE 1.4.10a: A prism produces a spectrum from white light.

Different frequencies

In a vacuum all light travels at the same speed – 3000 million metres per second. Each colour of light has its own frequency. If light enters a denser medium – such as going from air into glass – it slows down, but the higher frequencies slow down more.

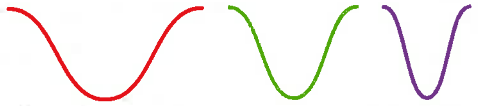


FIGURE 1.4.10b: In the visible spectrum, waves of red light have the longest wavelengths and waves of violet light, the shortest.

When a light wave passes into and out of a glass prism, the wave is refracted. The shorter its wavelength, the more it is refracted – so violet light is refracted more than red light. The 'white light' is split up and spreads out to form a spectrum.

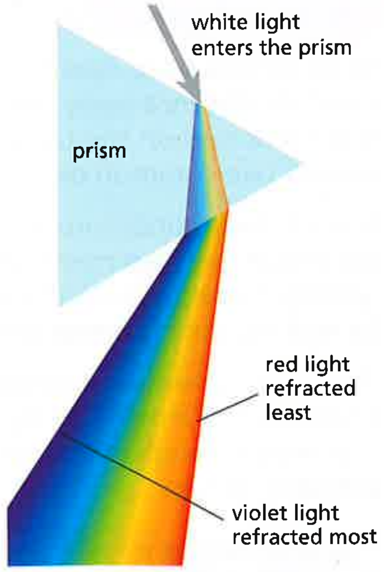


FIGURE 1.4.10c: The white light is split up by refraction.

Waves with different wavelengths can be combined – this is additive colour mixing. It is different from mixing paints. Mixing red, blue and green light produces white light. Mixing red, blue and green paint produces muddy brown paint.

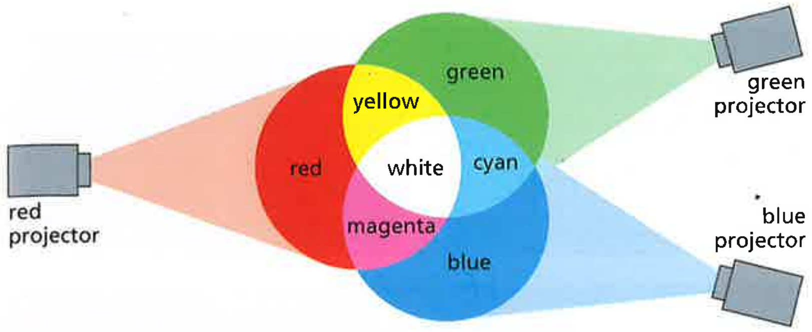


FIGURE 1.4.10d: Recombining waves to make white light.

3. Explain the relationship between the wavelength and the frequency of a wave.
4. Explain why white light spreads out to produce a visible spectrum when it passes through a prism.
5. If a white panel were lit with a red spotlight and a green spotlight, what colour would it appear to be?

Frequency and behaviour

Some materials are coloured, but you can see through them, such as coloured plastic sheets and solutions of food dyes. They absorb light waves of certain frequencies. The light that passes through consists of light with frequencies that were not absorbed.

Opaque coloured materials also absorb light waves of certain frequencies, but the light with other frequencies is reflected.

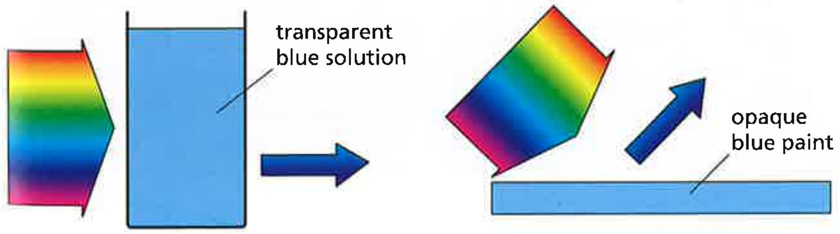


FIGURE 1.4.10e: A blue solution absorbs wavelengths of light other than blue. Only blue light passes through. Blue paint absorbs wavelengths of light other than blue. Blue light is reflected. No light passes through.

6. Explain why a solution of red food colouring is red, but also transparent.
7. What colour would a green box seem to be if illuminated with:
   - a) white light?
   - b) red light?
   - c) green light?
   - d) blue light?

Did you know…?

Light with frequencies lower and higher than those at the extremes of the visible spectrum cannot be seen by the human eye. Infrared radiation has frequencies lower than that of red light. Ultraviolet radiation has frequencies higher than that of violet light.

Know this vocabulary

frequency
wavelength
spectrum

Checking your progress

To make good progress in understanding science you need to focus on these ideas and skills.

☐ Recognise that sound energy is transferred by waves and describe how sound waves are made in different situations.	☐ Explain how longitudinal waves carry sound. Relate the terms frequency, wavelength and amplitude to sounds.	☐ Interpret and devise wave diagrams to represent different sounds of different frequency and amplitude.
☐ Know that sound consists of vibrations in a medium.	☐ Know that sound travels faster in some media than others.	☐ Understand that the denser the medium, the faster the sound travels.
☐ Recognise an echo as a reflection of sound.	☐ Recognise that some materials are good at reflecting sound and others can absorb it.	☐ Explain what is meant by reflection and absorption of sound.
☐ Know that sound can be represented by a waveform.	☐ Explain how the waveform represents the amplitude and wavelength of the sound.	☐ Interpret waveforms for different sounds.
☐ Understand that we hear sound because of vibrations travelling through a medium.	☐ Explain that we can hear a certain range of frequencies.	☐ Suggest how various ear problems might affect a person's hearing.
☐ Recognise that light can be reflected by some materials and absorbed by others.	☐ Explain the differences between transparent, translucent and opaque materials.	☐ Use diagrams to explain the difference between specular reflection and scattering.

☐ Describe the ray model of light, using the idea that light travels in straight lines.	☐ Explain the difference between reflection and refraction, and describe what happens when light waves are refracted.	☐ Use ray diagrams to explain reflection and refraction.
☐ Use the conventions of a ray diagram correctly.	☐ Use a ray diagram to show what happens when light is reflected.	☐ Use a ray diagram to show what happens when light is refracted.
☐ Recognise convex and concave lenses.	☐ Explain how convex and concave lenses affect light.	☐ Explain how lenses can be used to correct defects of vision.
☐ Describe the formation of a spectrum from white light.	☐ Explain how white light can be split into a continuous spectrum of colours, called the visible spectrum.	☐ Use the concepts of reflection and absorption of light to explain why some materials (transparent, translucent and opaque) are coloured.
☐ Explain how shadows are formed.	☐ Explain how solar and lunar eclipses occur.	☐ Explain why eclipses may be total or partial.
☐ Describe how light of different colours varies in terms of frequency.	☐ Explain how various colours can be obtained by using the three primary colours.	☐ Explain how the colour of an object is affected by the colour of light it is illuminated with.

Questions

KNOW. Questions 1–4

See how well you have understood the ideas in this chapter.

1. What range of frequencies of sound can most people hear? [1]

- **a)** Below 20 Hz
- **b)** Between 20 and 20 000 Hz
- **c)** Above 20 000 Hz
- **d)** There is no range

2. Draw a waveform which represents a loud, low-pitched (i.e. deep) note. Label it to show how you have represented those qualities. [2]

3. A light ray approaches a glass block at 30° to the normal. When it enters the block, which of these does the ray do? [1]

- **a)** Bend towards the normal
- **b)** Continue travelling in the same direction as before
- **c)** Bend away from the normal
- **d)** Travel along the normal

4. How does sound travel in a vacuum compared with in air? [1]

- **a)** It travels faster in a vacuum
- **b)** It travels at the same speed as in air
- **c)** It travels slower in a vacuum
- **d)** It won't travel at all in a vacuum

APPLY. Questions 5–9

See how well you can apply the ideas in this chapter to new situations.

5. Look at the different waves shown in 1.4.12a. Wave a) represents a note played in the middle of a piano. Which wave best represents a siren? [1]

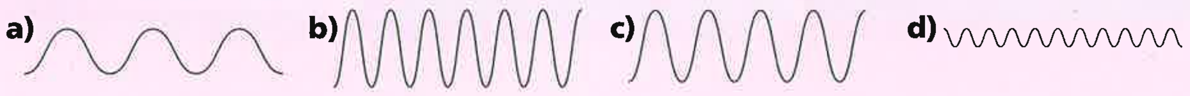


FIGURE 1.4.12a

6. Emily's family are moving house. Their lounge is empty, with no curtains, carpets or furniture, and it sounds 'echoey'. Which of these statements is correct? [1]

- **a)** Hard surfaces are good at absorbing sound.
- **b)** Sound travels faster than light.
- **c)** Sound travels faster in an empty room.
- **d)** Soft surfaces such as curtains are good at absorbing sound.

7. Think about what happens to sunlight when it passes through transparent materials, and then explain why we see different colours in stained glass windows. [2]

8. Draw and label diagrams to show the different effects that concave and convex lenses have on parallel rays of light. [1]

9. Explain whether you would expect sound to travel through water faster, slower or at the same speed as in air, and why. [2]

EXTEND. Questions 10–12

See how well you can understand and explain new ideas and evidence.

10. Ultrasound is high-frequency sound, beyond the auditory range of humans. A bat sends out an ultrasound signal. It receives an echo just 0.5 seconds later. How far away is its prey? (Distance = speed × time; the speed of sound in air is 330 m/s.) [2]

11. Imagine looking at a small object through a block of glass. Complete a copy of Figure 1.4.12b to show where the object appears to be (its image). [1]

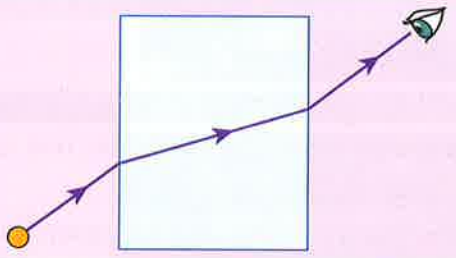


FIGURE 1.4.12b

12. A periscope has an arrangement of mirrors to enable the user to see around obstacles. Complete the diagram to show:

- **a)** how light rays travel from the object to the user;
- **b)** that the object does not appear upside down. [3]

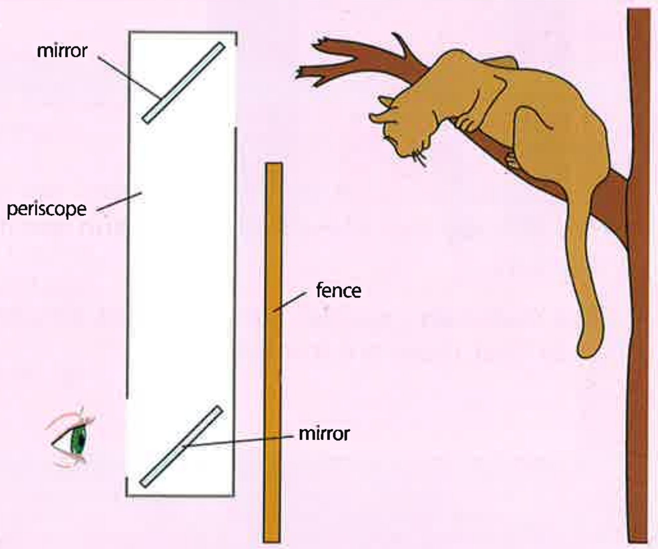


FIGURE 1.4.12c