Waves

Wave effects *and* Wave properties

Ideas you have met before

How sound behaves

Sound travels as longitudinal waves being passed on by particles of a medium; the denser the medium, the faster sound travels.

The greater the amplitude of the sound wave, the louder the sound.

The greater the frequency of the sound wave, the higher the pitch.

How light behaves

Light travels as transverse waves that can travel through a vacuum.

White light can be split into a spectrum of colours.

When light 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.

What is true about waves

Energy can be transferred by waves.

Waves can be represented diagrammatically, showing wavelength, frequency and amplitude.

Waves can be transmitted, reflected or absorbed by different media.

In this chapter you will find out

Effects of waves

- Living cells can be damaged by light and other waves, depending on their frequency.
- Audio equipment converts sound into a changing pattern of electric current.

Waves and energy

- When a wave travels through a substance, particles move to and fro.
- Energy is transferred in the direction of movement of the wave.
- Waves of higher amplitude or higher frequency transfer more energy.

Modelling waves

- A physical model of a transverse wave demonstrates it moves from place to place, while the material it travels through does not.
- The model describes the properties of speed, wavelength and reflection.

Exploring sound

We are learning how to:

- Understand how sound waves vary in frequency.
- Apply ideas about frequency to understand ultrasound.
- Understand practical applications of ultrasound.

In space, no-one can hear you scream. Sound needs a **medium** – a substance to travel through. Sound is a series of vibrations in the medium – one set of particles bumping into the next, carrying the vibrations through. The denser the material – the quicker the sound travels.

Hitting the high notes

Because sounds are vibrations, we can measure the rate of vibration, or the number of vibrations per second. The more vibrations per second, the higher the **frequency**. The lowest note on a piano keyboard has a frequency of around 32 vibrations per second. If you could see the piano string vibrating, it would go back and forth 32 times each second. We call this 32 **hertz**, written as 32 Hz. The top note on the piano is over 4000 Hz – 4000 vibrations per second. It's the frequency that determines how high or low a note sounds.

You will know that someone's voice sounds different through a telephone. Phones have a range of frequencies between 500 Hz and 2000 Hz. This doesn't give perfect reproduction but it's quite good enough to understand what people are saying. Humans can actually hear notes of up to 20 000 Hz, though this becomes less with age.

FIGURE 2.4.1a: Opera singers can reach very high notes.

1. What are the units of frequency?
2. Why is there no point in having a sound system that plays notes higher than 20 000 Hz?
3. If a trumpet was playing a note of 200 Hz, that's 200 vibrations per second. What, in this instrument, is vibrating at this rate?

Going higher still

Although humans can't hear anything much higher than 20 000 Hz, some other animals can. Bats use frequencies around 40 000 Hz to navigate and cats can hear some of these notes and try to catch them. Frequencies that humans can't hear are referred to as **ultrasound**.

FIGURE 2.4.1b: A bat uses ultrasound to navigate in the dark.

4. Which of these frequencies are ultrasound?
   a) 500 Hz
   b) 50 000 Hz
   c) 5000 Hz
   d) 500 000 Hz
5. The prefix 'ultra' can mean 'beyond'. Suggest whether this applies to its use in the term 'ultrasound'.

FIGURE 2.4.1c: Jewellery can be cleaned by ultrasound. The object is put in a dish of liquid and the ultrasound makes it vibrate for several minutes.

Using ultrasound

Sounds that people can't hear might be thought to be rather pointless but in fact they have a number of uses. One of these is cleaning. As ultrasound is a set of very rapid vibrations it can be used to shake dirt from something. This works well, for example, with old coins or jewellery that has been buried for years.

FIGURE 2.4.1d: Before (left) and after (right), the ultrasonic cleaning of a piece of old copper plating.

Another application is to massage muscles. If muscles have become stressed or damaged, ultrasound may assist by the vibrations stimulating blood flow and reducing tension in the muscles.

FIGURE 2.4.1e: Massaging muscles with ultrasound.

6. Some people clean old coins by immersing them in vinegar. How is using ultrasound different?
7. Why might ultrasonic cleaning be safer than using an acid?
8. Why might using ultrasound on tense muscles be different to having a massage?

Know this vocabulary

medium
frequency
hertz
ultrasound

Sound systems

We are learning how to:

- Understand the function of microphones and loudspeakers.
- Understand how audio equipment responds to different frequencies.

Sound has a limited range and it can't really be stored, so engineers and scientists have devised ways of converting it to and from electrical signals. These can be sent over much greater distances and saved in various ways. We can talk to people all over the world and listen to recordings made over a century ago.

Detecting sound

Sound is detected using a **microphone**, which transfers energy from pressure waves into an electrical **signal**. There are various ways of doing this, but one is called a moving coil microphone. As sound waves arrive, the vibrations make a coil of wire vibrate. The coil is next to a magnet, so this produces a flow of current.

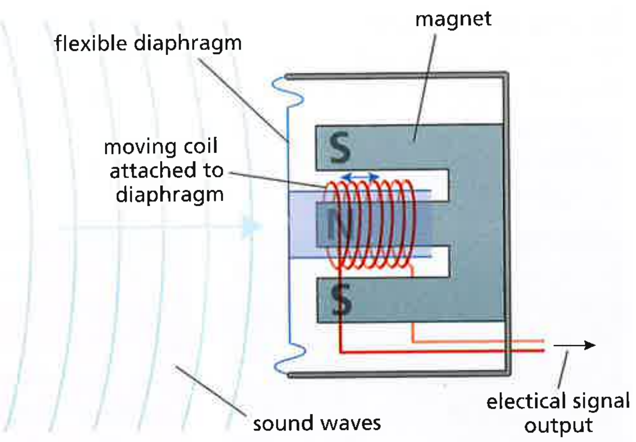

FIGURE 2.4.2a: A microphone.

1. Which part of the microphone picks up the vibrations?
2. What do you think will happen to the electrical output if the noise is greater?
3. Why does the microphone need to be fairly close to the sound source?

Playing the sound back

It's not a great deal of use turning the pressure wave of sound into an electrical signal unless you can turn it back again afterwards. This is done with a **loudspeaker**. Earphones can be used instead, of course; these are essentially tiny loudspeakers.

The electrical signal is fed into a coil of wire, which sits in a magnetic field. As the signal changes, so the coil vibrates. The coil is attached to a **cone** and this vibrates too. The vibrating cone makes the air vibrate.

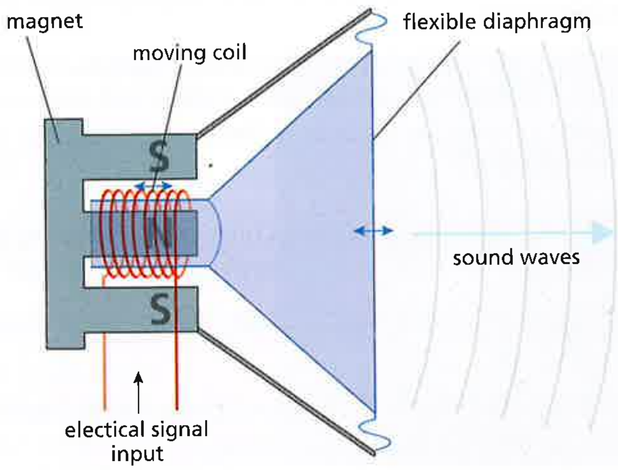

FIGURE 2.4.2b: A loudspeaker.

4. Why does the cone need to be made of something light?
5. Which components do the microphone and loudspeaker have in common?
6. Why might someone say that a loudspeaker is a microphone working in reverse?

Making audio recordings

Sounds vary according to how loud they are and also how high they are. If the sound is converted to an electrical signal, this has to be able to capture this information too. This is possible because the electrical signal isn't a steady flow of current, such as from a battery, but keeps changing both in size and direction.

If the sound is louder, the microphone **diaphragm** will be moved in and out further, producing a greater voltage. If the sound is higher the diaphragm will oscillate more rapidly, so the signal will change in direction more quickly. When the sound is played back, the same thing happens in reverse. A stronger signal will make the loudspeaker cone move further back and forth, transferring more energy to the air as pressure waves. If the signal is changing direction more rapidly, the loudspeaker cone will oscillate more rapidly, making a higher note.


FIGURE 2.4.2c: The stage is set for a band to play to an audience, using amplifiers and microphones.

7. What kind of note will the loudspeaker make if it oscillates slowly but travels in and out quite a long way?
8. In the sound system in a concert hall, the microphones are connected to the loudspeakers using amplifiers. What do you think the amplifiers do to the electrical signal and why?
9. Explain using ideas about **energy transfer** why having earphones turned up too loud is dangerous.

Did you know...?

The top-selling pop song at the end of August 1964 was 'Have I the Right?' by The Honeycombs. The song was recorded in the flat of record producer Joe Meek and the characteristic foot stamping sound was made by the group stamping on the wooden stairs. Meek had fixed five microphones to the bannisters with bicycle clips.

Know this vocabulary

microphone
signal
loudspeaker
cone
diaphragm
energy transfer

Exploring light

We are learning how to:

- Understand light can vary in frequency.
- Describe UV light and its risks.
- Explain the uses of UV light.

We are used to seeing a wide range of colours – the world would look dull if it was in black and white. However, that doesn't mean that we can detect all the available colours. Ultraviolet light is invisible to humans but used by many other animals. Hedgehogs are particularly sensitive to UV light.

FIGURE 2.4.3a: A rainbow.

Colour and frequency

Light travels as waves and we can measure the **wavelength** of a wave. Different colours of light have different wavelengths. If we alter the wavelength of light – we change its colour.

Red light has the longest wavelength of any light that we can see and violet has the shortest. If waves have a longer wavelength than red or a shorter wavelength than violet our eyes cannot see them.

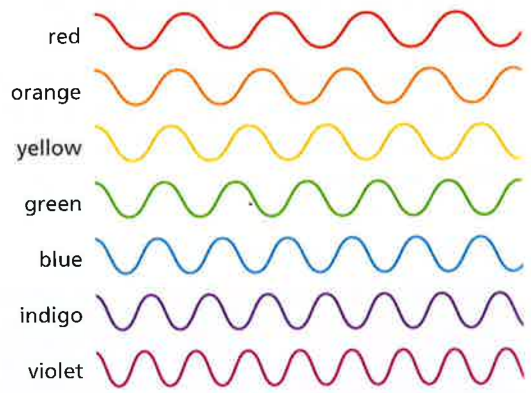

FIGURE 2.4.3b: Different colours of light have different wavelengths.

The wavelengths themselves, even of red light, are all extremely short. Green light has a wavelength of around 500 nm. One nm is 1 nanometre and there are 1 000 000 000 nanometres to a metre. This means that if you look at a 1 mm division on a ruler it's long enough to fit in 2000 waves of green light. Red light is around 700 nm and violet light is down to 400 nm.

1. What colour do you think light with a wavelength of 600 nm would be?
2. Estimate the wavelength of yellow light.
3. Why isn't white light on the chart?

Beyond the spectrum of visible light

Just because we can only see waves with wavelengths between 400 and 700 nm, it doesn't mean that other wavelengths don't exist. It just means that our eyes can't detect them. Visible light is part of a much bigger group of waves called electromagnetic waves.

If the wavelength is more than 700 nm it is called infrared. This is the type of waves used in TV remote controls. If it is less than 400 nm it is called **ultraviolet**, which is sometimes shortened to UV. Although we can't see ultraviolet light, it is important, being both beneficial and dangerous. Large amounts of UV light travel from the Sun and most of it is filtered out by the upper layers of the atmosphere. The small amount that does get through is important for a healthy life in that it stimulates the production of vitamin D, which strengthens bones. However, it also causes suntans, sunburns and increases the likelihood of skin cancer.

If the wavelength is shorter, it means the **frequency** is higher. Generally speaking, waves with a higher frequency carry more **energy** and these are potentially more dangerous to living things.

4. What does suntan lotion do to UV waves?
5. The ozone layer filters out most of the UV radiation reaching the Earth. Why has there been concern recently about the release of chemicals that damage the ozone layer?
6. What is sensible advice about making sure that we get a moderate but not excessive amount of UV radiation on our bodies?

Did you know...?

Most of the vitamin D we need for healthy bones comes from being out in the sunlight. Especially during the winter, people who spend most or all of the time indoors run the risk of vitamin deficiency.

Uses of UV light

This picture shows the same flower but as it appears to humans (left), and bees (right). Bees and butterflies are much better than we are at detecting UV light. The flowers need to attract both of these types of insect for purposes of pollination. They reflect UV light from the Sun in such a way as to appear colourful and attractive to these insects. The flowers look plain to us, but this doesn't matter to the plant – we're not the intended audience.

FIGURE 2.4.3c: How a bee sees.

7. Why do some flowers need to attract the attention of insects?
8. Although some insects can see a wider range of colours, their vision isn't as sharp as ours. Why doesn't this matter?

Know this vocabulary

wavelength
ultraviolet
frequency
energy

Comparing transverse and longitudinal waves

We are learning how to:

- Understand longitudinal waves.
- Understand transverse waves.
- Compare types of wave.

A slinky is a good way of modelling waves. It can be used to model both longitudinal and transverse waves. It also shows how energy is transferred from one place to another.

FIGURE 2.4.4a: We can model waves with a slinky.

Longitudinal waves

If we push and pull the end of a slinky we make a **longitudinal** wave. Energy travels from one end right the way to the other. The actual coils of the spring oscillate to and fro.

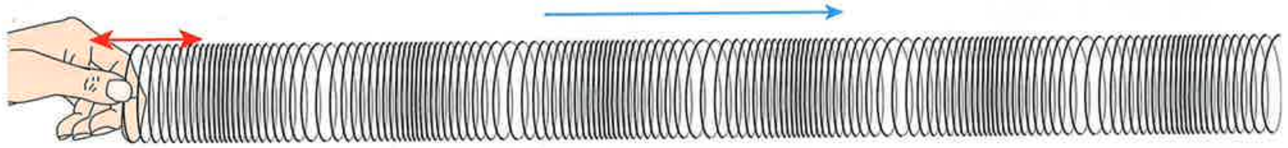

FIGURE 2.4.4b: Demonstrating a longitudinal wave.

This represents how sound travels. The hand pushing the wave to and fro is doing the same job as the vibrating string or column of air. The coils of the spring show what the air is doing. It doesn't have to be air, of course; other materials can be used and quite a few work better than air. If you put your ear to the table top you can clearly hear someone tapping their nails on the surface, even if it's some distance away.

Longitudinal waves work using changing pressure. There are areas of high pressure (shown in the figure where the coils are closer together) and areas of low pressure (where the coils are further apart. We can measure the length of a wave by measuring the distance from one point of high pressure to the next.

1. Why is a longitudinal wave sometimes referred to as a **compression** wave?
2. Why do you think a wooden table top carries sound more quickly than air does?
3. Could you measure **wavelength** by using areas of low pressure instead of high pressure?

Did you know…?

Earthquakes produces two types of wave. P waves (primary) are longitudinal waves and s waves (secondary) are transverse. They are affected by different types of rocks in different ways and scientists use readings from different parts of the world to find out the structure of the Earth.

Transverse waves

We can also use the slinky to model **transverse** waves. In this case we lay the slinky on a table and waggle one end from side to side (or up and down). Although energy is being supplied across the direction of travel, the waves still carry the waves along.

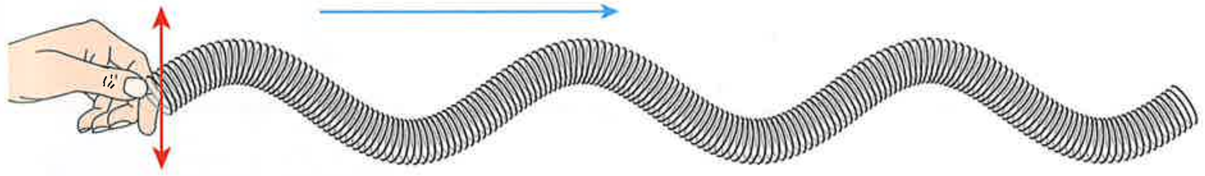

FIGURE 2.4.4c: Demonstrating a transverse wave.

This represents how light travels. It's easy to see how we could measure wavelength – it's simply how long one complete wave is. We can alter how much we move the spring to and fro; this alters the **amplitude**.

4. The word 'transverse' means 'across'. Why are these waves known as transverse waves?
5. If you took a photo of a transverse wave on a slinky, where would you measure from and to, to get the wavelength?
6. Why are both longitudinal and transverse waves known as energy carriers?

Comparing wave types

There are similarities and differences between longitudinal and transverse waves. They both carry energy, they both have a length that can be measured and they both have a speed that can be measured. We can count how many waves per second leave one end (or arrive at the other) and this will give us the **frequency**.

There are differences though, and the main one is the way that energy is supplied at the transmission end (and received at the other end). In a longitudinal wave it is in the same direction as the wave travels, whereas it is at right angles in a transverse wave.

7. Draw a picture of a transverse wave. Now draw a second wave that has twice the wavelength and half the amplitude of the first one.
8. If you model a transverse wave using a slinky lying across a table top you can either move the end up and down or side to side. Why do these both make transverse waves?

Know this vocabulary

longitudinal
compression
wavelength
transverse
amplitude
frequency

Exploring waves

We are learning how to:

- Use water waves to model wave behaviour.
- Understand and apply the processes of reflection and absorption.

We are used to seeing ripples in a pond or a bath tub. Water waves can get to enormous sizes, however, and it's not difficult to believe that they carry a lot of energy. Water waves are actually quite useful in science because we can use them to explore and model how waves behave.

FIGURE 2.4.5a: Waves on a pond.

Ripples in a pond

Water waves are **transverse** waves with the surface of the water moving up and down. The waves form **crests** and **troughs**, where the level is higher or lower than when the water is calm.

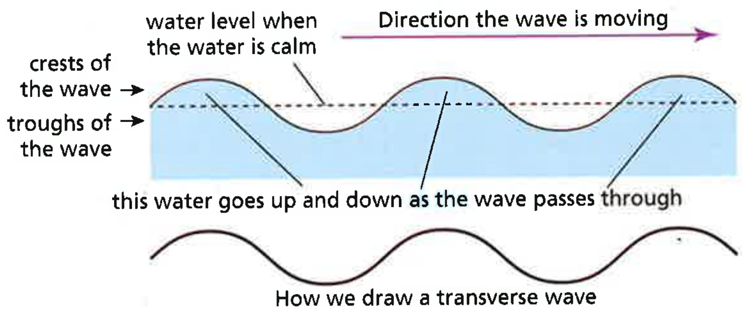

FIGURE 2.4.5b: Cross-sections through a ripple on water; volumes of water oscillate up and down as the wave passes.

The wave has a direction; we can see where it is coming from and going to. This means that we can measure its speed.

We can also take the shape of the waves as they appear from the side. This makes it clear that they are transverse; we can see how long each wave is and how high (or low). This is called the **amplitude** and is measured from the level of the water when it is calm, either to the peak of a crest or to the bottom of a trough.

1. Describe the difference between a crest and a trough.
2. Sketch a cross-sectional view of a water wave and show on it how you would measure:
   a) the wavelength
   b) the amplitude.

Reflection

Just as sound waves are reflected by hard surfaces, so water waves can undergo reflection. Their behaviour can be explored using a water tank. If some single straight water ripples are generated in the tank, then blocking their path shows how the wave is reflected (Figure 2.4.5c). The wave is reflected by the barrier and the angle it is reflected at is the same as the angle it arrived at.

Did you know...?

The Severn Bore is a wave that travels upstream on the River Severn, reaching up to 2 m in height and travelling at up to 20 km/h. People regularly surf it and the record is held by Steve King who travelled over 10 km on it in a standing position in 2006.

3. What do you notice about where the angles are measured from?
4. Suggest why a bumpy surface does not produce a reflected wave that is the same shape as the wave that arrived.
5. Compare this with what happens to light approaching a mirror.
6. Suggest what would happen if a sponge was used instead of a rigid barrier.

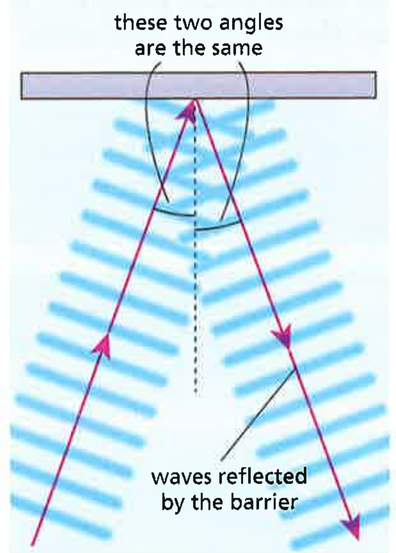

FIGURE 2.4.5c: Ripples of water bounce off the barrier.

When two waves meet

When two pebbles are thrown into water, the ripples produced meet one another (Figure 2.4.5d). You can see what happens when the ripples meet. When two waves from different starting places meet, they either combine to make a bigger wave or cancel each other out. This is called **superposition**.

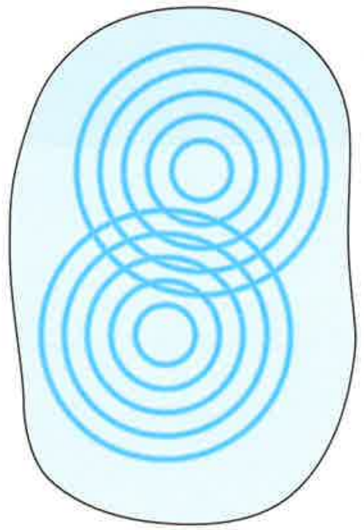

FIGURE 2.4.5d: The circles show the crests of the waves produced when two pebbles are thrown into water. They spread outwards.

If the crests coincide, the waves add together and make a bigger wave.

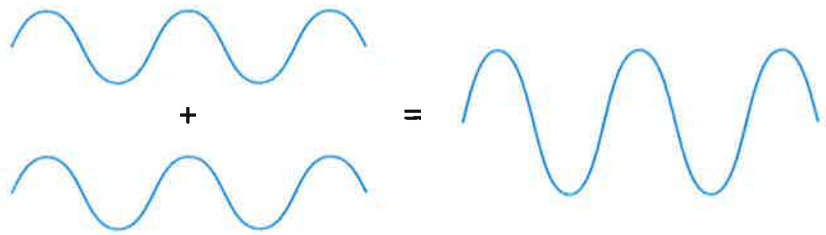

FIGURE 2.4.5e: Superposition produces bigger waves.

If the crests of one wave coincide with the troughs of the other, the waves cancel out, resulting in no wave.

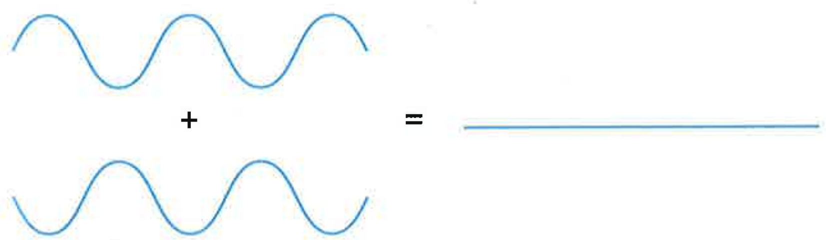

FIGURE 2.4.5f: Superposition can lead to waves cancelling one another out.

7. Explain what is meant by superposition.
8. Explain the result of combining two waves when the crests of one coincide with the troughs of the other.

Know this vocabulary

transverse
crest
trough
amplitude
wavelength
superposition

Checking your progress

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

- Recognise the difference between longitudinal and transverse waves.
- Describe the properties of different transverse and longitudinal waves.
- Compare and contrast properties of sound waves, waves in water and light waves.
- Describe the effect that changing the frequency has on sound.
- Understand that human ears can detect a certain range of frequencies.
- Explain the difference between sound and ultrasound.
- Describe the effect that changing the frequency has on the colour of light.
- Understand that human eyes can detect a certain range of frequencies.
- Explain how ultraviolet differs from visible light.
- Recall that energy is transferred by waves.
- Explain that some waves carry more energy than others.
- Relate ideas about some waves carrying more energy to frequency and amplitude.

- Recall that sound is a pressure wave.
- Describe how a microphone turns the pressure wave of sound into an electrical signal.
- Explain how audio equipment turns sound into a changing current.
- Recognise that energy may be transferred by different types of waves.
- Explain how a loudspeaker turns an electrical signal into a pressure wave of sound.
- Explain how sound waves can be used to clean objects or to massage muscles.
- Explain the terms absorption, transmission and reflection.
- Use wave models to explain absorption, transmission and reflection.
- Suggest what happens when two waves combine.

Questions

KNOW. Questions 1–6

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

1. Which one of these is not shown by the waveform of a wave? [1]

a) The source of the wave
b) The frequency of the wave
c) The length of a single complete wave
d) The amplitude of a wave

2. Which of the following describes what happens when a water wave hits a barrier? [1]

a) It is absorbed.
b) It is reflected.
c) It is refracted.
d) It passes through.

3. Which of the following is true of light waves, but not of waves in water? [1]

a) They travel through empty space.
b) They are transverse waves.
c) They can be reflected.
d) They are not longitudinal waves.

4. Which of these is true about ultrasound compared to sounds that we can hear? [1]

a) It has a higher frequency.
b) It is louder.
c) It has a lower frequency.
d) It has a lower amplitude.

5. Which of these rows shows the correct combination of responses? [1]

TABLE 2.4.7

	Transverse waves	Longitudinal waves
A	Energy is transferred in the direction of the movement of the wave.	No energy is transferred in this type of wave.
B	Energy is transferred in the direction of the movement of the wave.	The vibration is at right angles to the direction of the wave.
C	The vibration is at right angles to the direction of the wave.	Energy is transferred in the direction of the movement of the wave.
D	The vibration is at right angles to the direction of the wave.	The vibration is at right angles to the direction of the wave.

6. Which of these explains what a microphone does: [1]

a) It turns a quieter sound into a louder sound.
b) It turns an electrical signal into a pressure wave of sound.
c) It turns a pressure wave of sound into an electrical signal.
d) It changes the frequency of a sound.

APPLY. Questions 7–9

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

7. State one similarity and one difference between longitudinal and transverse waves. [2]

8. Alex is looking in a shop window and realises he can see both what's inside the shop and also a reflection of himself. Explain what this shows about light waves and glass. [2]

9. Bats use echolocation to locate obstacles and also prey in the dark. They make sounds and detect the echoes. What properties of sound waves are being used? [2]

EXTEND. Questions 10–11

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

10. Suggest why ultrasound can be used to clean metal that has been buried for years. [2]

11. Which of the pairs of waves in Figure 2.4.7a would cancel each other out? [1]

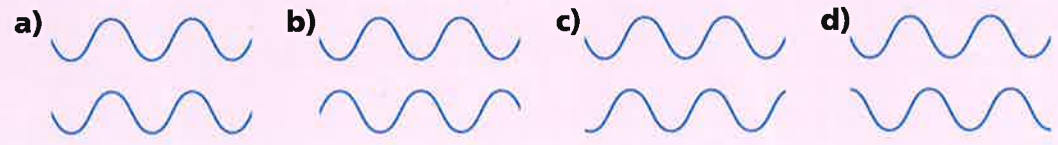

FIGURE 2.4.7a