1 GENERAL WAVE PROPERTIES

This student can feel the heat waves from the Sun coming in through the windows of the train, she can hear the sound waves of her friend on the phone, the phone is using radio waves, and she can see around her with light waves.

The behaviour of waves affects us every second of our lives. Waves are reaching us constantly: sound waves, light waves, infrared heat, television, mobile-phone and radio waves, the list goes on. The study of waves is, perhaps, truly the central subject of physics.

There are two types of waves: longitudinal and transverse.

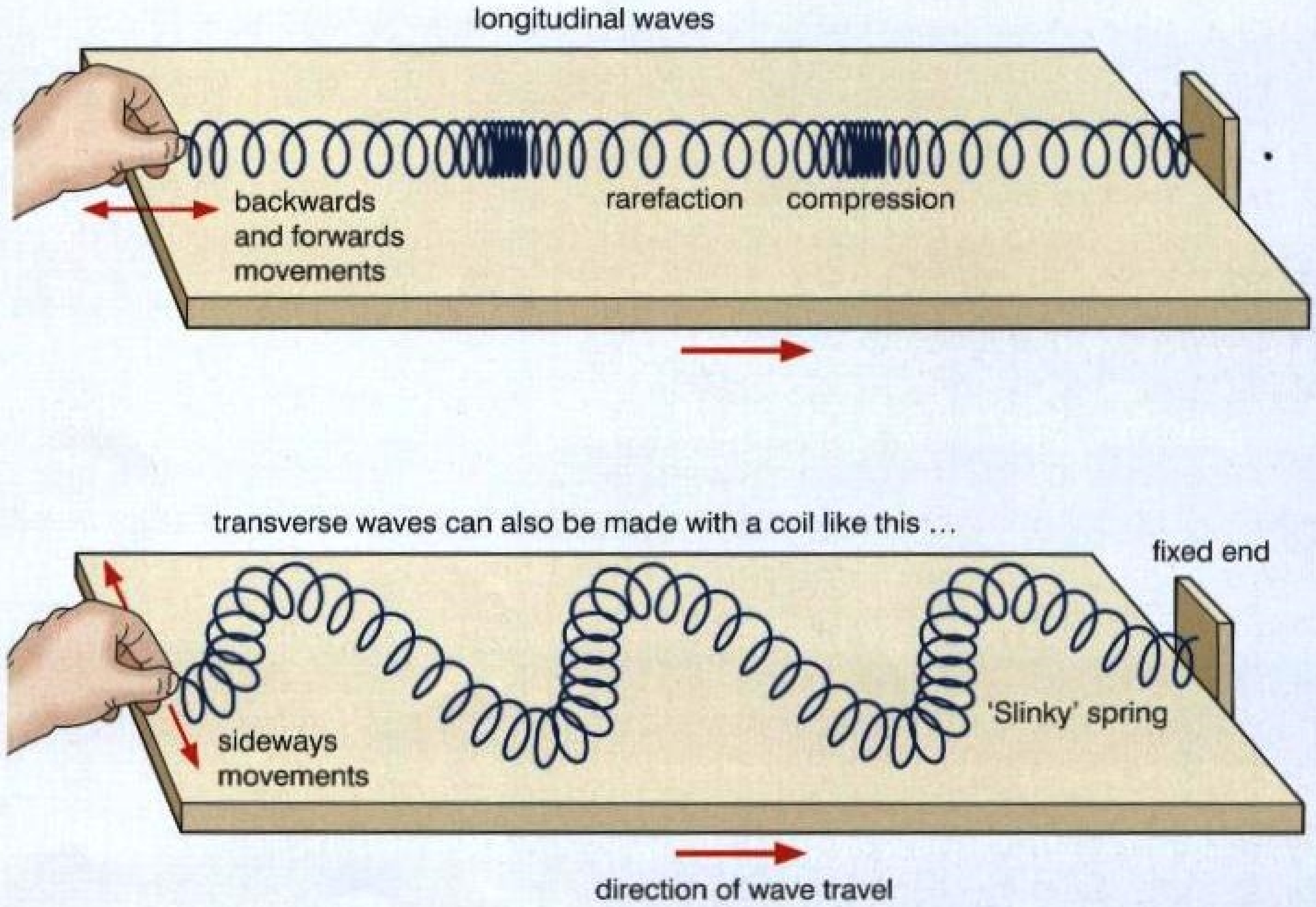
Longitudinal waves. This type of wave can be shown by pushing and pulling a spring. The vibrations of the spring as the wave goes past are backwards and forwards in the direction that the wave is travelling (hence the name 'longitudinal'). The wave consists of stretched and squashed regions travelling along. The stretching produces regions of rarefaction, while the squashing produces regions of compression. Sound is an example of a longitudinal wave.

Transverse waves. In a transverse wave the vibrations are at right angles to the direction of motion. Light, radio and other electromagnetic waves are transverse waves.

In the above examples, the waves are very narrow, and are confined to the spring or the string that they are travelling down. Most waves are not confined in this way. Clearly a single wave on the sea, for example, can be hundreds of metres wide as it moves along.

Water waves are often used to demonstrate the properties of waves because the **wavefront** of a water wave is easy to see. A wavefront is the moving line that joins all the points on the crest of a wave.

Longitudinal and transverse waves are made by vibrations.



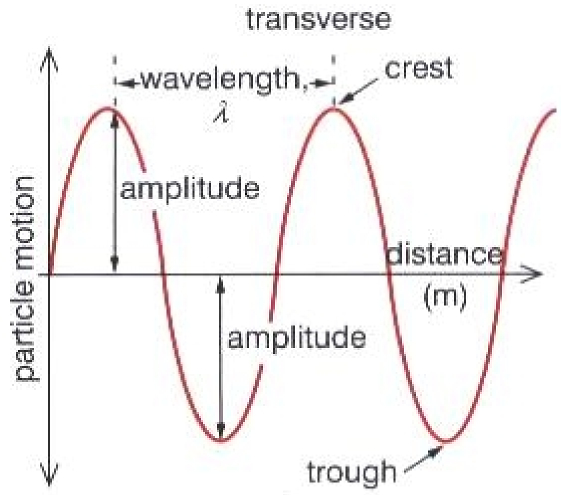
WHAT FEATURES DO ALL WAVES HAVE?

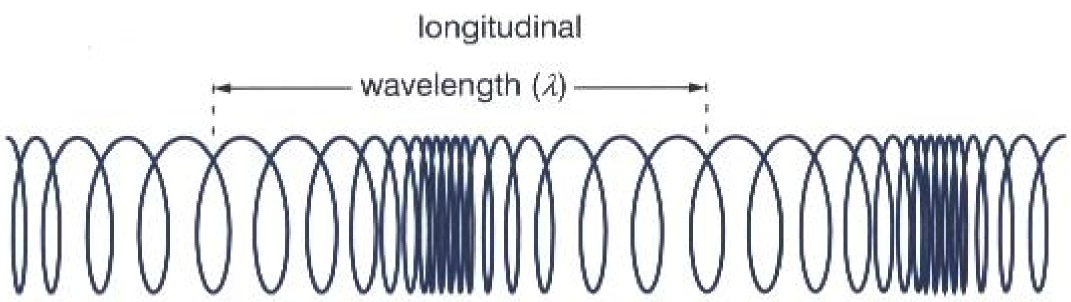
The speed a wave travels at depends on the substance or medium it is passing through.

Waves have a repeating shape or pattern.

Waves carry energy without moving material along.

Waves have a wavelength, frequency, amplitude and time period.





The **wavelength** is the distance between two adjacent peaks or, if you prefer, the distance between two adjacent troughs of the wave. In the case of longitudinal waves, it is the distance between two points of maximum compression, or the distance between two points of minimum compression.

The **frequency** is the number of peaks (or the number of troughs) that go past each second.

The **amplitude** is the maximum particle displacement of the medium from the central position. In transverse waves, this is half the crest-to-trough height.

The **speed** of the wave is simply the speed of the wave as it approaches a ship. The largest ocean wave ever measured accurately had a wavelength of 340 m, a frequency of 0.067 Hz (that is to say one peak every 15 s), and a speed of 23 m/s. The amplitude of the wave was 17 m, so the ship was going 17 m above the level of a smooth sea and then 17 m below. (The waves were 34 m from crest to trough.)

The **period** (T) is the time taken for each complete cycle of the wave motion. It is closely linked to the frequency (f) by this relationship:

$$\text{frequency (in hertz, Hz)} = \frac{1}{\text{period (in seconds, s)}}$$

The speed of a wave in a given medium is constant. If you change the wavelength, the frequency *must* change as well. If you imagine that some waves are going past you on a spring or on a rope, then they will be going at a constant speed. If the waves get closer together, then more waves must go past you each second, and that means that the frequency has gone up. The speed, frequency and wavelength of a wave are related by the equation:

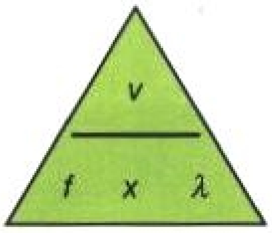
wave speed = frequency × wavelength

$v = f \times \lambda$

v = wave speed, usually measured in metres/second (m/s)

f = frequency, measured in cycles per second or hertz (Hz)

λ = wavelength, usually measured in metres (m)



WORKED EXAMPLES

1 A loudspeaker makes sound waves with a frequency of 300 Hz. The waves have a wavelength of 1.13 m. Calculate the speed of the sound waves.

Write down the formula:	$v = f \times \lambda$
Substitute the values for f and λ:	$v = 300 \times 1.13$
Work out the answer and write down the unit:	$v = 339$ m/s

2 A radio station broadcasts on a wavelength of 250 m. The speed of the radio waves is 3×10^8 m/s. Calculate the frequency.

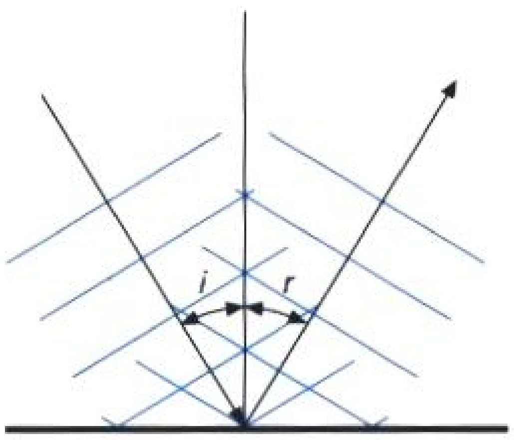
Write down the formula with f as the subject:	$f = \frac{v}{\lambda}$
Substitute the values for v and λ:	$f = \frac{3 \times 10^8}{250}$
Work out the answer and write down the unit:	$f = 1\,200\,000$ Hz or 1200 kHz

3 A tuning fork is used to play a middle C, which has a frequency of 256 Hz. Calculate the time period of the vibration.

Write down the formula with T as the subject:	$T = \frac{1}{f}$
Substitute the value of f:	$T = \frac{1}{256}$
Work out the answer and write down the unit:	$T = 0.0039$ s

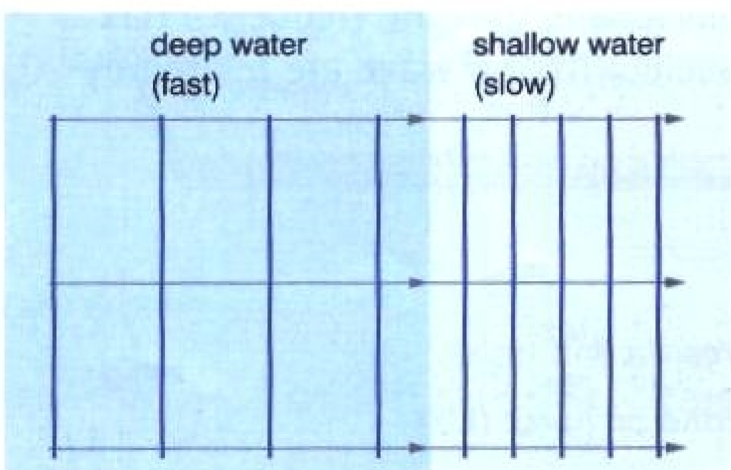
REFLECTION, REFRACTION AND DIFFRACTION

When a wave hits a barrier the wave will be **reflected**. If it hits the barrier at an angle then the **angle of reflection** will be **equal** to the **angle of incidence**. **Echoes** are caused by the reflection of sound waves.



Waves hit a barrier at an angle of incidence *i*. The waves bounce off with the angle of incidence *i* equal to the angle of reflection *r*. The reflected wave is the same shape as the incident wave.

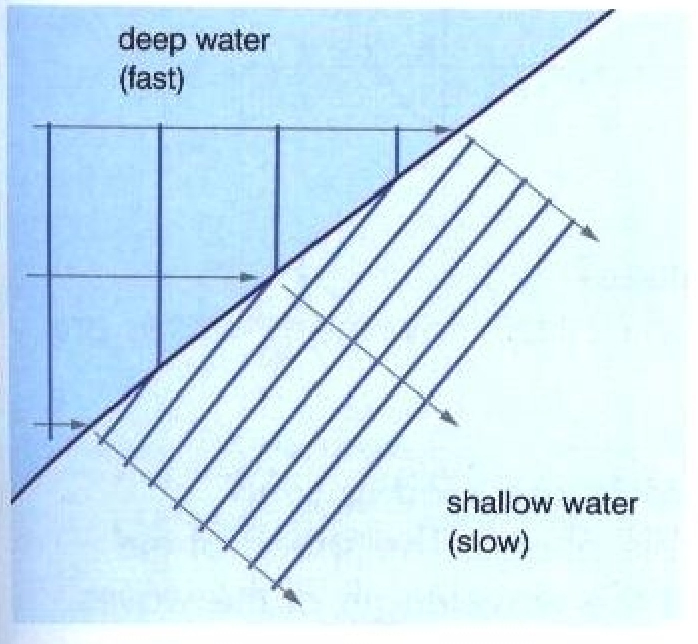
When a wave moves from one medium into another, it will either speed up or slow down. For example, a wave going along a rope will speed up if the rope becomes thinner. (This is why you can 'crack' a whip: the wave that is sent down the whip accelerates until it breaks the sound barrier.) And sound going from cold air to hotter air will speed up. When a wave **slows down**, the wavefronts crowd together – the **wavelength gets smaller**. When a wave **speeds up**, the wavefronts spread out – the **wavelength gets larger**. Note that in both cases, the same number of waves will pass you per second, the wavelength may have changed, but the frequency has not.



When waves slow down, their wavelength gets shorter.

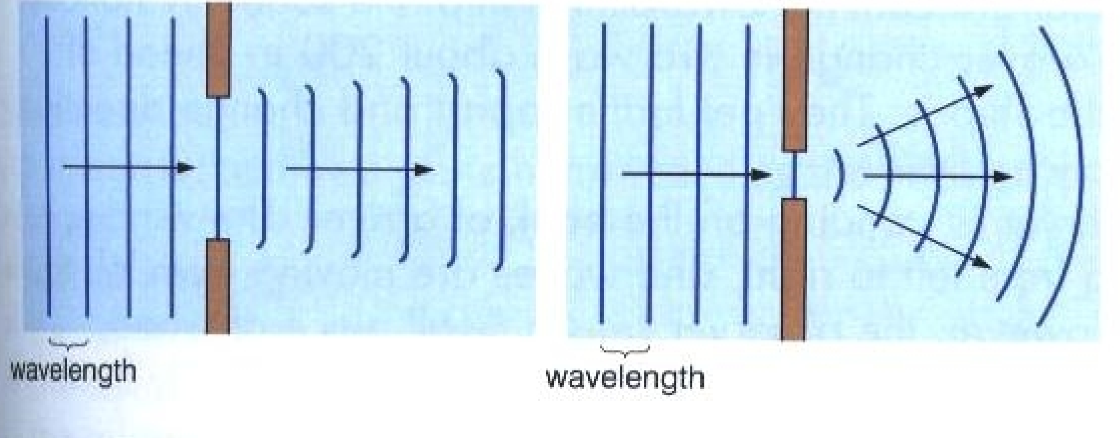
This surfer is successfully travelling along one wavefront. The next wavefront looks very close behind, but is probably still 50 m away. (This is an illusion caused by telephoto camera lenses.)

If a wave enters a new medium at an angle then the wavefronts also change direction. This is known as **refraction**. The amount that the wave is bent by depends on the change in speed. Water waves are slower in shallower water than in deep water, so water waves will refract when the depth changes.



If waves cross into a new medium at an angle, their wavelength and direction change.

Wavefronts change shape when they pass the edge of an obstacle or go through a gap. This process is known as **diffraction**. Diffraction is strong when the width of the gap is similar in size to the wavelength of the waves.



Diffraction is most noticeable when the size of the gap is similar to the wavelength of the waves.

In the first diagram the wavelength is much smaller than the aperture. An example is light coming in through a window and forming a beam of light across the room. In the second diagram, the wavelength is similar to the size of the aperture. Ocean waves spread out like this when they enter a harbour.

A* EXTRA

- High notes from a CD track have wavelengths of around 10–20 cm. For these to diffract efficiently and spread out as they leave the opening of the loudspeaker, a speaker with a smaller diameter is used. For lower notes, which have larger wavelengths, a speaker with a larger diameter is used in order to generate enough volume.

If the apertures are much smaller than the wavelength then the wave cannot go through the aperture at all, which is why the door of a microwave oven has an array of small holes for you to see inside. Light can travel in or out through the holes, but microwaves (with a wavelength of 12 cm) cannot do so.

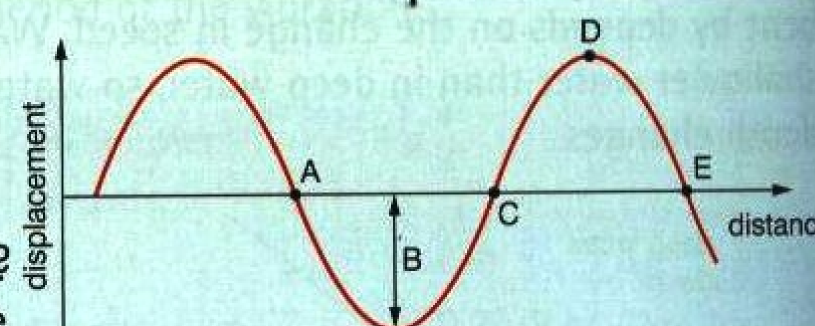
Short-wavelength signals with a wavelength of less than 1 m are used by television and mobile phone transmitters. These wavelengths are much smaller than the size of buildings, so the waves do not bend round the buildings, and you will not get a good television signal or mobile phone reception if there is a building between you and the transmitter.

To reduce this problem for mobile phones, the mobile phone companies use many transmitters in a city, and switch your phone to the transmitter with the best path to the phone. Satellite television does not have a problem because the receiver on the house has a direct view of the satellite.

Long-wavelength radio signals, with a wavelength of 100 m or so, bend round buildings and hills, and can give a good reception anywhere in a city and even hundreds of kilometres from the transmitter.

REVIEW QUESTIONS

Q1 The diagram shows a graph of displacement against distance.



- **a** Which letter shows the crest of the wave?
- **b** The wavelength is the distance between which two letters?
- **c** Which letter shows the amplitude?
- **d** The frequency of the wave is 512 Hz. How many waves are produced each second?

Q2 Radio waves of frequency 900 MHz are used to send information to and from a portable phone. The speed of the waves is 3×10^8 m/s. Calculate the wavelength of the waves. (1 MHz = 1 000 000 Hz, 3×10^8 = 300 000 000.)

Q3 What are the most likely explanations of the following effects? Explain carefully.

- **a** The captain of an ocean-going ship is proceeding slowly into waves that are coming towards the ship. He suddenly notices that the waves change in two ways about 200 m ahead of where the ship is. They get further apart and change direction quite noticeably.
- **b** An observer is standing on the bank of a river. The wind is blowing from left to right, and waves are moving from left to right. However, the observer sees a small piece of wood floating in the middle of the river that is moving slowly from right to left.
- **c** You find that you can listen to radio stations in all of the rooms in your home, but you cannot get a mobile phone signal in certain rooms even if you open the windows.

More questions on the CD ROM

Examination questions are on page 104.