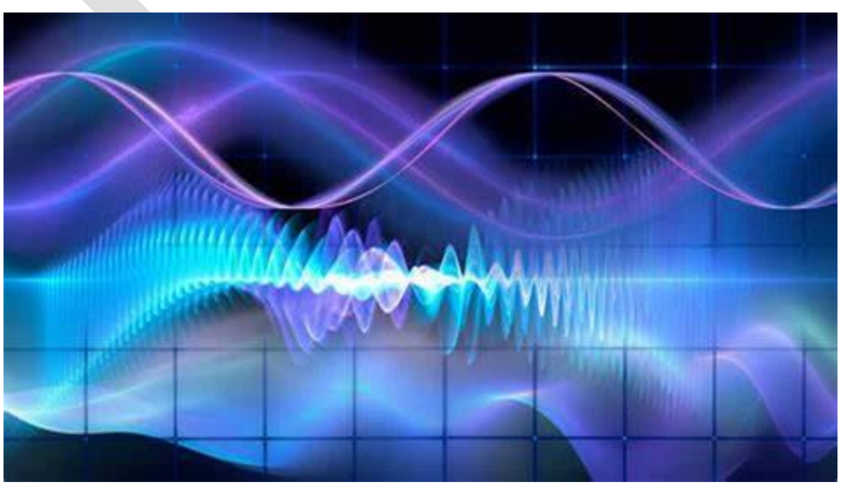
Edexcel IGCSE

Physics

CODE: (0625)

Unit 3

Waves

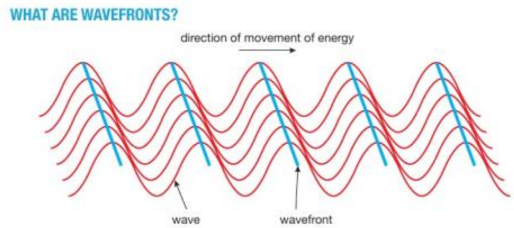


3.1 Properties of waves

What are waves?

Waves are a way of transferring energy from place to place. As we can see in Figure 10.1, we often use them to transfer information. All these transfers take place with no matter being transferred.

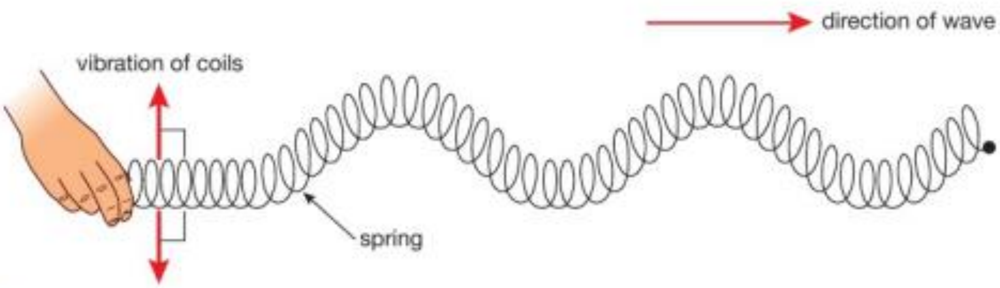
▲ Figure 10.2 Waves are produced if we drop a stone into a pond. The circular wavefronts spread out from the point of impact, carrying energy in all directions, but the water in the pond does not move from the centre to the edges.



▲ Figure 10.3 Wavefronts are created by overlapping lots of different waves. A wavefront is a line where all the vibrations are in phase and the same distance from the source.

Transverse waves

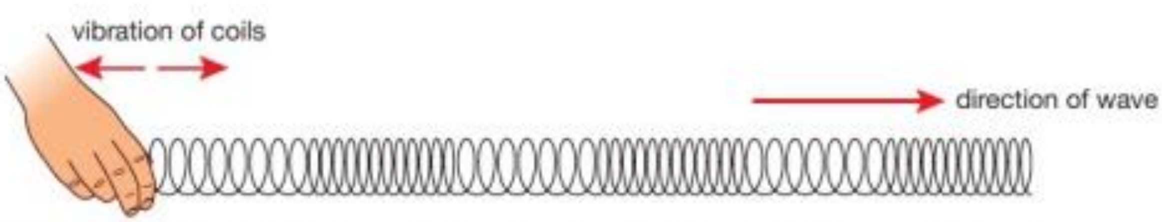
A transverse wave is an oscillation of energy or wave that oscillates at right angles to the direction of movement. Examples include light waves and waves on water's surface. Waves produced in ropes and springs can be observed as waves moving along the coils.



▲ Figure 10.4 A transverse wave vibrates at right angles to the direction in which the wave is moving.

Longitudinal waves

A longitudinal wave is a type of wave where the vibrations or oscillations are along the direction of the energy or wave, such as sound waves. This wave occurs when the coils of a spring vibrate along its length, demonstrating the energy's movement along its length.



▲ Figure 10.5 A longitudinal wave vibrates along the direction in which the wave is travelling.

Describing waves

When a wave moves through a substance, its particles will move from their equilibrium (resting position). The maximum movement of particles from their resting or equilibrium position is called its **amplitude (A).**

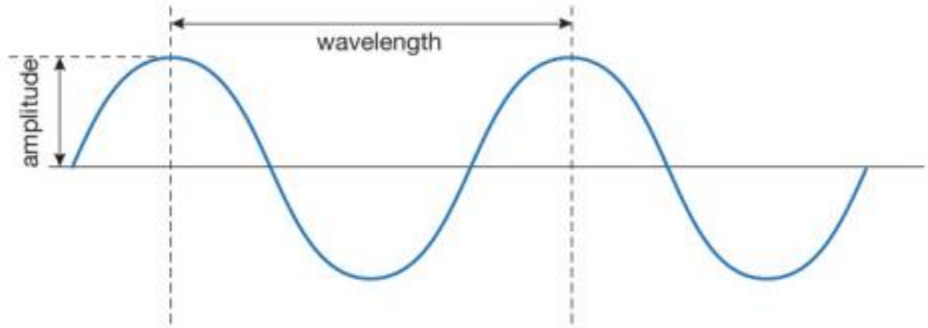


Figure 10.6 A wave has amplitude and wavelength.

A longitudinal wave is a type of wave where the vibrations or oscillations are along the direction of the energy or wave, such as sound waves. This wave occurs when the coils of a spring vibrate along its length, demonstrating the energy's movement along its length.

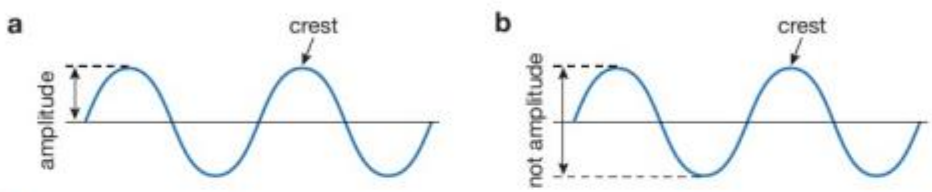


Figure 10.7 The amplitude of a wave is as shown in **a**, and not as in **b**.

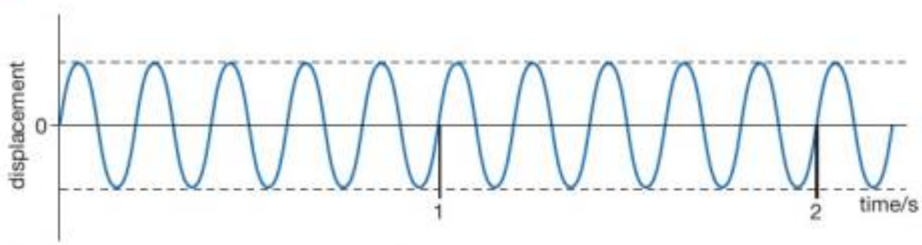


Figure 10.8 This graph shows a wave with a frequency of 5 Hz.

The time it takes for a source to produce one wave is called, the time of the wave *(T).* It is related to the frequency *(f)* of a wave by the equation:

$$\text{frequency, } f\text{ (Hz)} = \frac{1}{\text{time period, } T\text{ (s)}}$$

$$f = \frac{1}{T}$$

This equation can also be written as

$$T = \frac{1}{f}$$

The wave equation

There is a relationship between the wavelength (A), the frequency (f) and the wave speed (v) that is true for all waves:
wave speed, v (m/s) = frequency, f (Hz) x wavelength, λ (m)
v=fx λ

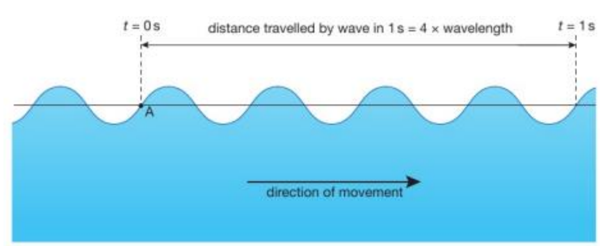


Figure 10.10 A wave with a frequency of 4 Hz

The ripple tank.

A ripple tank can be used to study water wave behavior by vibrating a wooden bar, creating ripples on the water surface, and observing the patterns created by a light above the tank.

Wavelength and frequency

The motor can be adjusted to produce a small number of waves each second. The frequency of the waves is small, and the pattern shows that the waves have a long wavelength.
At higher frequencies, the water waves have shorter wavelengths. The speed of the waves does not change.

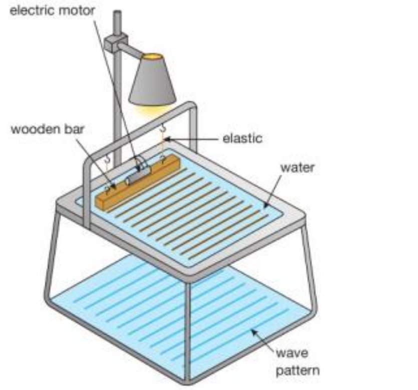


Figure 10.12 The light shines through the water and we can see the patterns of the waves.

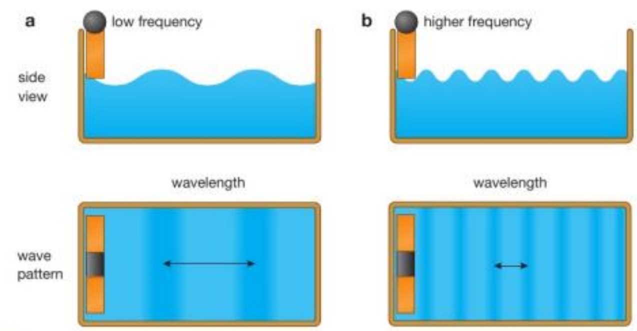


Figure 10.13 When the frequency of the waves is low, the wavelength is long. When the frequency is higher, the wavelength is shorter.

Reflection

Waves can be reflected, and when they hit a straight or flat barrier, the angle at which they leave the barrier is equal to the angle at which they meet it, as per the 'Law of Reflection'.

The **angle of incidence** is equal to the **angle of reflection.**

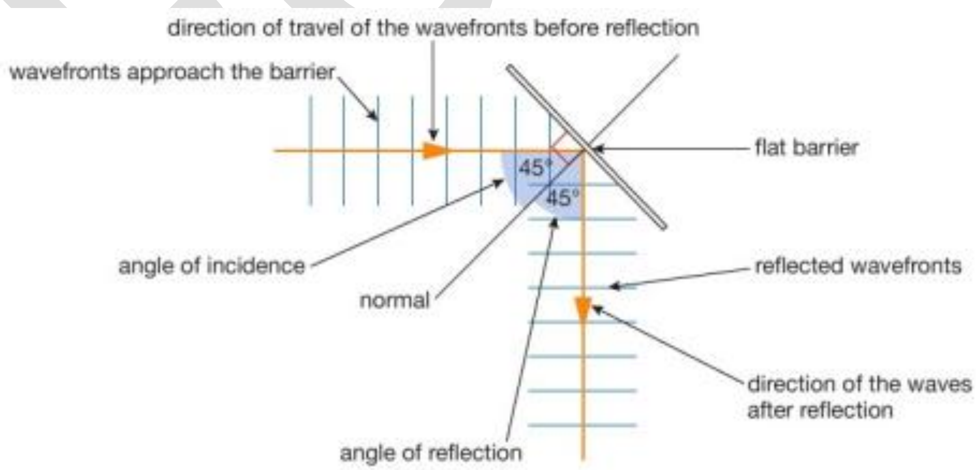


Figure 10.14 Waves striking a flat barrier are reflected. The angle at which they strike the barrier is the same as the angle at which they are reflected.

Reflection

The pencil in Figure 10.19 bends at the water's surface due to refraction, where light waves travel slower than air waves, causing them to change direction. This phenomenon is applicable to all waves, including light, sound, and water waves.

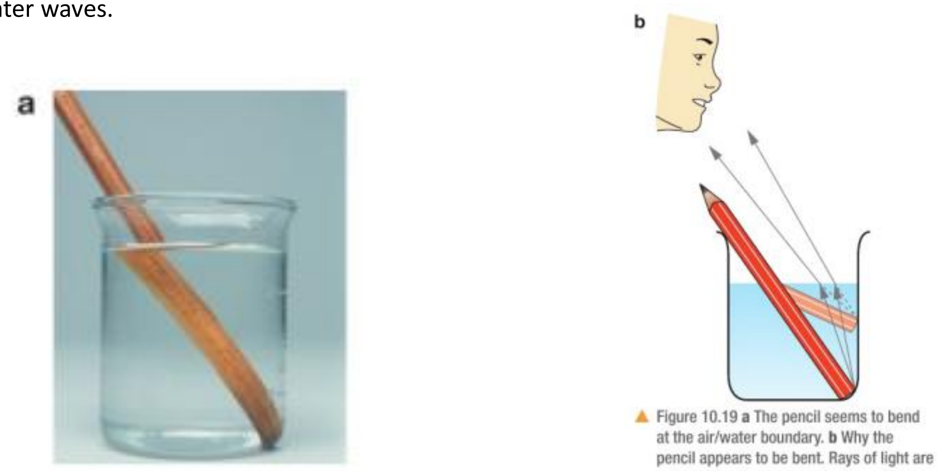


Figure 10.19 **a** The pencil seems to bend at the air/water boundary. **b** Why the pencil appears to be bent. Rays of light are refracted at the water surface.

The Doppler effect

The **Doppler effect** refers to the apparent changes in frequency caused by the movement of a source of waves. Ahead of the car, wavefronts compress, resulting in shorter wavelength and higher frequency waves. This results in a higher **pitch** sound, while behind the car, waves stretch out, resulting in a longer wavelength and lower frequency sound.

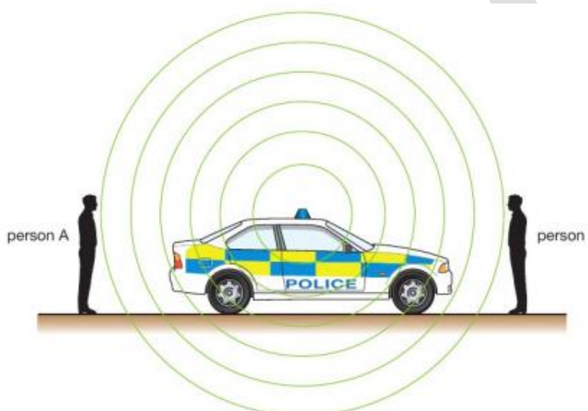


Figure 10.21 A stationary source of sound

Figure 10.22 A moving source of sound

3.2 electromagnetic spectrum

The **electromagnetic spectrum** (EM spectrum) is a continuous spectrum of waves, which includes the visible spectrum. At one end of the spectrum the waves have a very long wavelength and low frequency, while at the other end the waves have a very short wavelength and high frequency. All the waves have the following properties:

1 They all transfer energy.
2 They are all transverse waves.
3 They all travel at 300 000 000 m/s, the speed of light in a **vacuum** (free space).
4 They can all be reflected and refracted.

Radio waves

Radio waves are given out **(emitted)** by a transmitter. As they arrive at an aerial, they are detected and the information they carry can be received. Televisions and FM radios use radio waves with the shorter wavelengths to carry their signals.

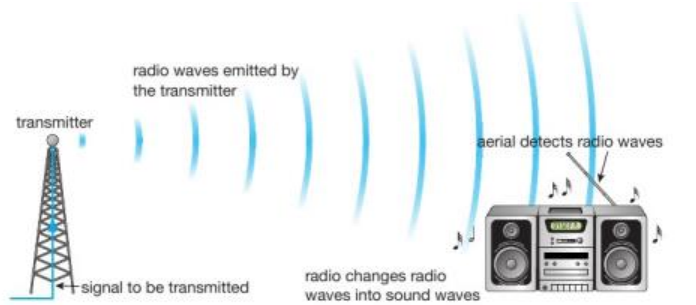


Figure 11.3 Radio waves are emitted by a transmitter and detected by an aerial.

Microwaves

Microwave ovens cook food faster due to the absorption of microwaves by water **molecules,** allowing it to cook throughout. Metal screens in microwave ovens reflect microwaves, preventing them from heating human body tissue. Mobile phones use less energy, so they don't cook the brain. However, overuse of mobile phones may harm the brain. Microwaves are used in communications, carrying signals to orbiting satellites and mobile phones. They can pass through various materials, including glass and brick, making them accessible in various locations. Overall, microwaves have potential health risks.

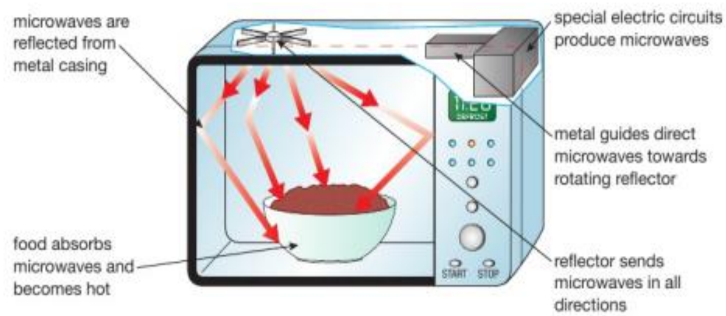


Figure 11.4 Food cooks quickly in a microwave oven because water molecules in the food absorb the microwaves.

Infrared

Infrared radiation is also used in remote controls for televisions, DVD players and stereo systems. It is very convenient for this purpose because the waves are not harmful. They have a **low penetrating** power and will therefore operate only over small distances, so they are unlikely to interfere with other signals or waves.

Visible light

Visible light, a part of the electromagnetic spectrum visible to the human eye, is used to read compact discs, barcodes, and optical fibers for communication or searching hard-to-reach areas. It can also be detected by sensors in digital cameras for still photographs or videos, and information stored on DVDs can also be read using visible light.

Ultraviolet light

The Earth's **ozone layer** absorbs significant amounts of Sun's UV radiation, but pollution is causing a decrease in ozone, potentially increasing skin cancer rates. UV light causes certain chemicals to glow, which is used in security marker pens, as the ink becomes visible under UV light.

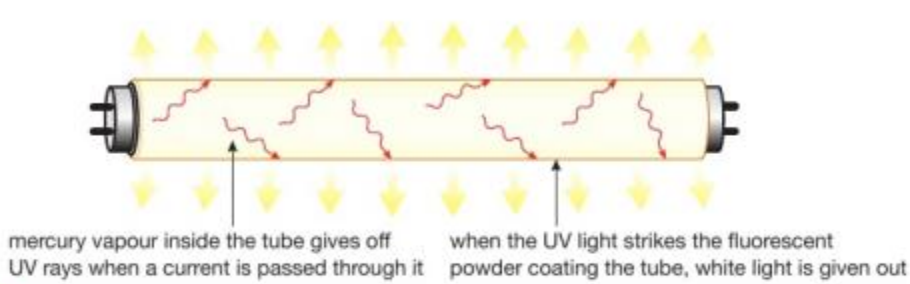


Figure 11.10 Fluorescent tubes glow when UV light hits the fluorescent coating in the tube.

X rays

X-rays pass easily through soft body tissue but cannot pass through bones. As a result, radiographs or x-ray picture can be taken to check a patient's bones.

Gamma rays

Gamma rays, like x-rays, can damage living cells, leading to mutations and cancer. They are used in **sterilizing** medical instruments, killing microorganisms, and treating cancer through radiotherapy. Large doses can kill cancerous growth, and lead screens, boxes, and aprons can prevent overexposure to gamma rays.

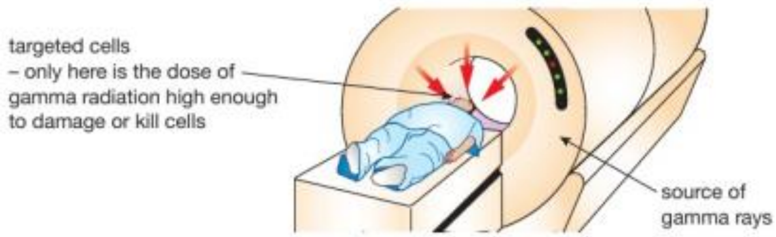


Figure 11.13 The gamma rays are aimed carefully so that they cross at the exact location of the cancerous cells.

3.3 Light waves

Seeing the light

There are many sources of light, including the Sun, the stars, fires, light bulbs and so on. Objects such as these that emit their own light are called luminous objects. When the emitted light enters our eyes we see the object. Most objects, however, are non-luminous. They do not emit light. We see these non- luminous objects because of the light they reflect.

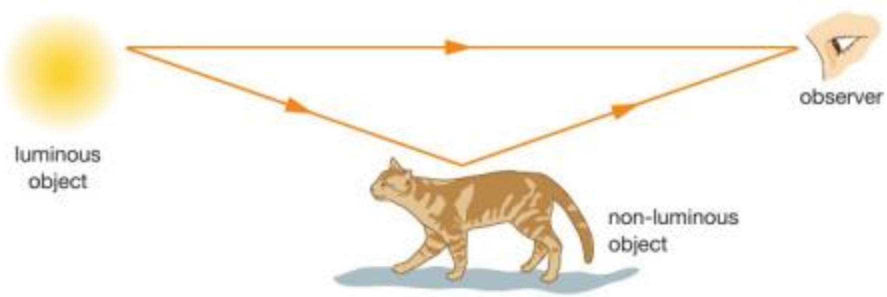


Figure 12.3 Luminous objects, such as the Sun, give out light. Non-luminous objects only reflect light.

Reflection

When a ray of light strikes a plane (flat) mirror, it is reflected so that the angle of incidence *(i)* is equal to the angle of reflection *(r).*

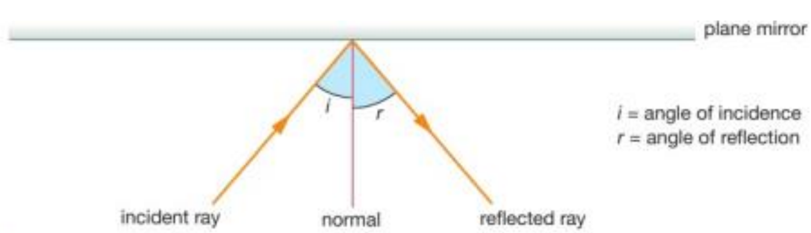


Figure 12.4 Light is reflected from a plane mirror. The angle of incidence is equal to the angle of reflection. The normal is a line at right angles to the mirror.

Mirrors can alter the direction of light rays, as seen in the periscope. The periscope uses two mirrors to change the direction of light. The first mirror reflects the rays at a 45° angle, turning them 90° and then turning them again. This allows the observer to see over or around objects.

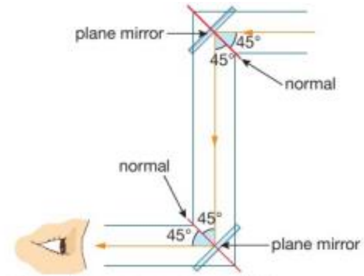


Figure 12.5 A periscope is used to see over or around objects.

Refraction

Light travels through various transparent media like air, water, and glass, and even through a vacuum. In vacuums and air, light travels at 300 000 000 m/s, while in other media, like glass, it travels at around 200 000 000 m/s. This slowing down of light as it crosses the border between the two media can cause a ray to change direction, known as **refraction.**

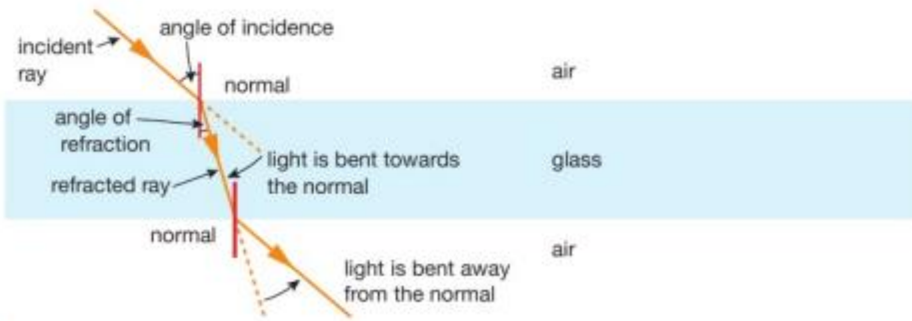


Figure 12.7 This light ray is being refracted twice – once as it travels from air into glass and then as it travels from glass to air.

As a ray enters a glass block, it slows down and is refracted towards the normal. As the ray leaves the block it speeds up and is refracted away from the normal.

If the ray strikes the boundary between the two media at 90°, the ray continues without change of direction (Figure 12.8).

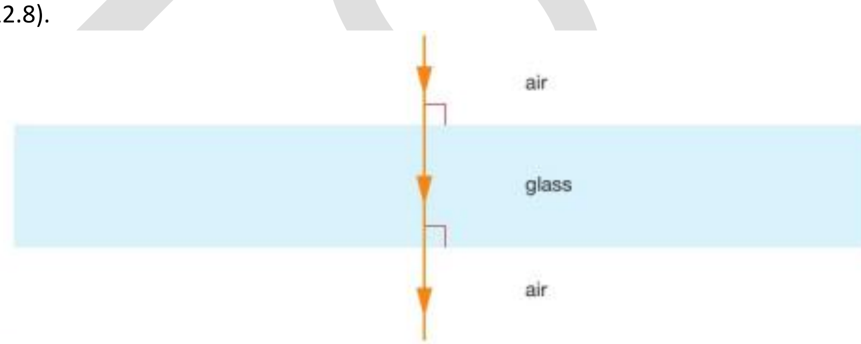


Figure 12.8 If the light hits the boundary at 90° the ray does not bend.

Refractive index

Different materials can bend rays of light by different amounts. We describe this by using a number called the **refractive index *(n)***

We can use the equation below to calculate the refractive index of a material:

n =sin i / sin r

where i is the angle of incidence and r is the **angle of refraction.**

Total internal reflection

Total internal reflection occurs when light rays from a glass into air are reflected away from the normal, with a small amount reflecting from the boundary. This occurs when light is traveling towards a less optically dense medium with a lower refractive index.

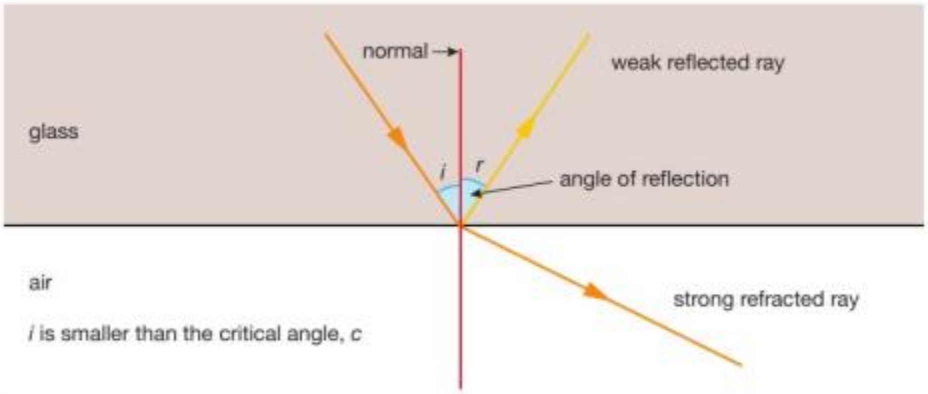


Figure 12.10 A ray of light travelling from glass to air

As the angle of incidence in a glass increases, the angle of refraction also reaches a critical angle (c), which is the smallest possible angle of incidence where light rays are completely internally reflected.

a

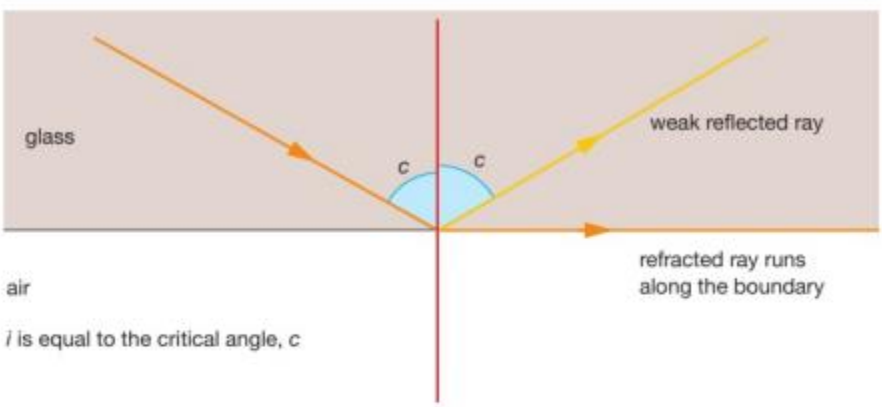


Figure 12.11a Ray of light strikes glass/air boundary at the critical angle

b

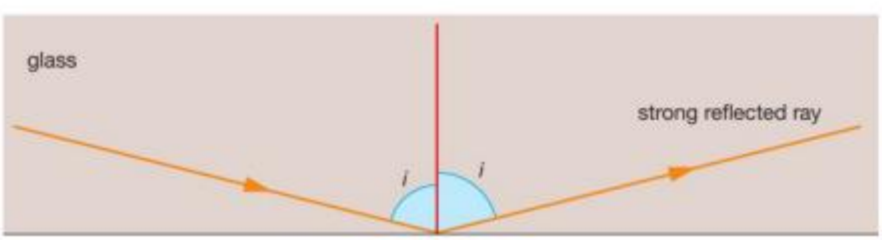
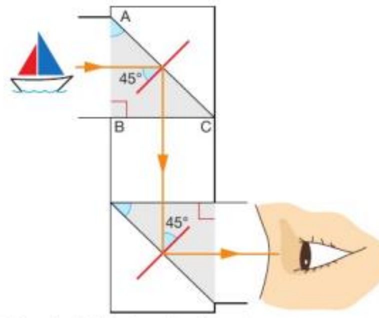


Figure 12.11b When i is greater than c total internal reflection occurs.

When i is greater than the critical angle, all the light is reflected at the boundary. No light is refracted. The light is totally internally reflected.

Using total internal reflection

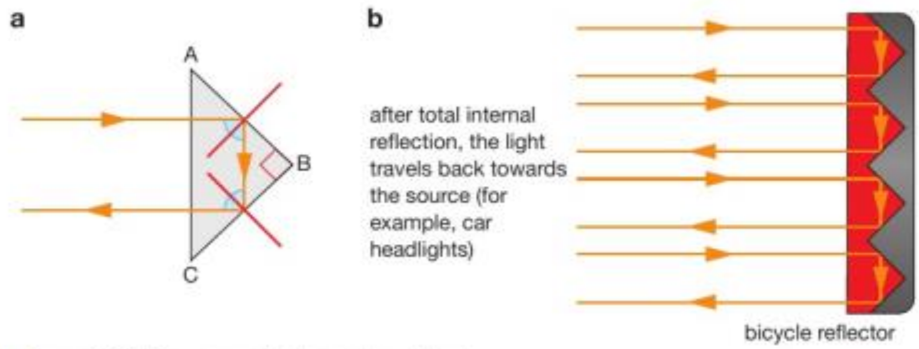


▲ Figure 12.15 Total internal reflection in a prismatic periscope

<u>The prismatic periscope</u>

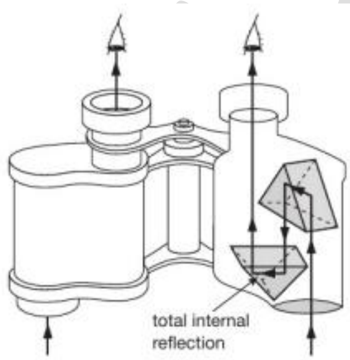
A prismatic periscope uses prisms to reflect light, producing brighter and clearer images than mirrors. Light passes through the first prism at 90°, then hits the second at 45°, resulting in a completely internally reflected ray. The ray then travels to a second prism, where it is internally reflected again, resulting in a parallel ray. This process ensures the ray's direction remains unchanged.

Bicycle and car reflection.



▲ Figure 12.16 Prisms can also be used as reflectors.

Light entering the prism in Figure 12.16 is totally internally reflected twice. It emerges from the prism travelling back in the direction from which it originally came. This arrangement is used in bicycle or car reflectors.



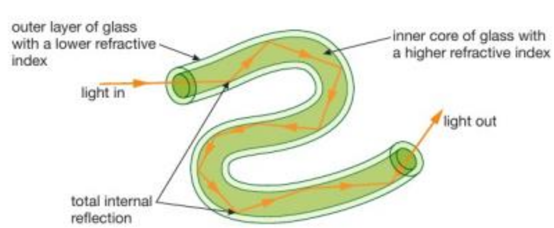
▲ Figure 12.18 Total internal reflection inside binoculars

▲ Figure 12.19 Prismatic binoculars

Binoculars utilize total internal reflection within prisms on each side, allowing them to achieve large **magnifications** and resembling telescopes, despite the need for long binoculars without prisms.

Optical fibers

Important **applications** of total internal reflection include optical fibre, a thin, thin piece composed of two different types of glass, with the center having a high refractive index glass surrounded by a lower refractive index glass.



▲ Figure 12.20 In an optical fibre, light undergoes total internal reflection.

The endoscope

By using optical fibres to see what they are doing, doctors can carry out operations through small holes made in the body, rather than through large cuts. This is called 'keyhole surgery'. This is less stressful for patients and usually leads to a more rapid recovery.

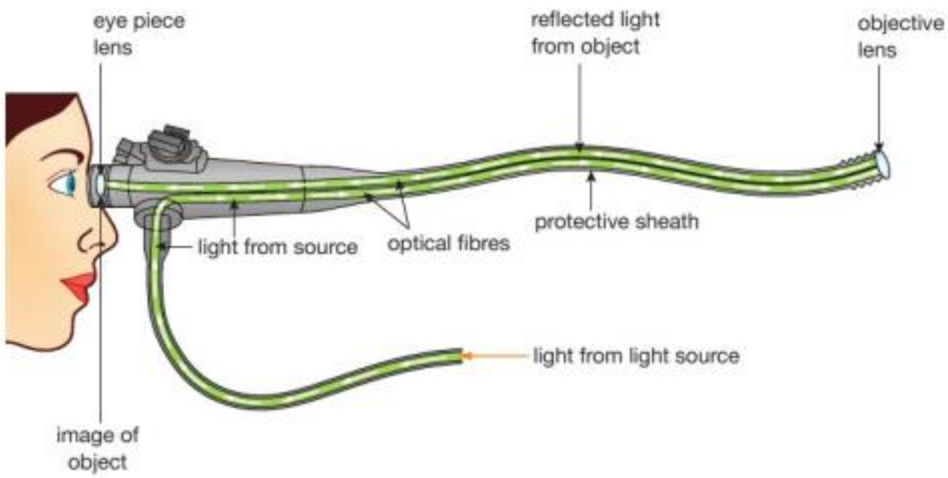


Figure 12.22 Optical fibres are used in endoscopes to see inside the body.

Optical fibers in telecommunication

Modern telecommunications systems use optical fibres instead of copper wires for message transmission, reducing energy loss. Electrical signals are converted into light energy by lasers, sent into optical fibres, and detected by a light-sensitive detector.

3.4 Sound

Sound waves.

Sounds are produced by objects that are vibrating. We hear sounds when these vibrations, travelling as sound waves, reach our ears.

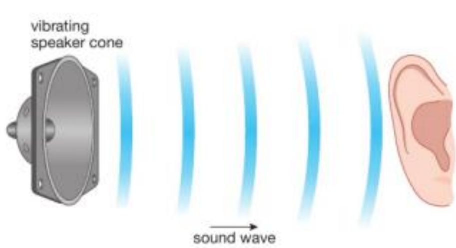


Figure 13.3 The loudspeaker vibrates and produces sound waves.

Figure 13.2 The sound produced by the speakers must be loud but also of good quality.

Reflection

Sound waves behave in the same way as any other wave. Ships often use echoes to discover the depth of the water beneath them. This is called **echo sounding.**

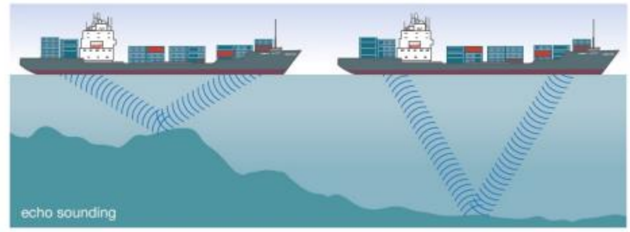


Figure 13.5 Reflected sound can be used to tell ships about the depth of the sea beneath them.

1. Sound waves are emitted from the ship and travel to the seabed (sea floor).
2. Some of these waves are reflected from the seabed back up to the ship.
3. Equipment on the ship detects these sound waves.
4. The time it takes the waves to make this journey is measured.
5. Knowing this time, the depth of the sea below the ship can be calculated.

The system of using echoes in this way is called **sonar** (Sound, Navigation and Ranging).

Refraction of sound

Sound waves can be refracted, with some parts traveling faster in warm air than cooler ones, causing a change in wave direction. Although not visible, refraction can sometimes be heard, as seen in clearer sounds from other sides of a pond or lake.

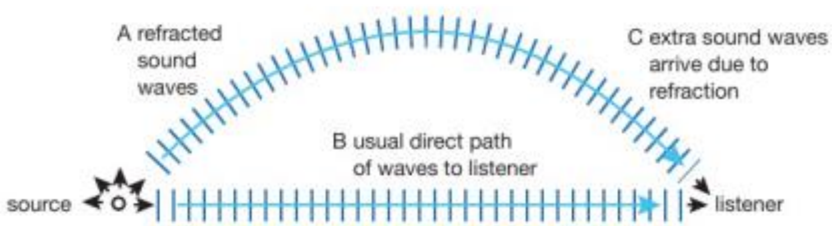


Figure 13.6 Why sometimes sounds travelling across water are louder than we expect

1 Most of the sound we hear travels to us in a straight line (Path B).
2 But some sound travels upwards (Path A).
3 If the temperature conditions are right, then as the sound waves travel through the air they are refracted and follow a curved path downwards (Path C).
4 We now receive two sets of sound waves.
5 So the sound we hear seems louder and clearer.

Pitch and frequency.

Small objects vibrate quickly, producing high-frequency sound waves with high pitch, while larger objects vibrate slowly, producing lower-frequency waves with lower pitch. Frequency, measured in hertz (Hz), is the number of complete vibrations a source makes each second.

Audible range

The audible range, or hearing range, is the range of frequencies that an average person can hear, with the size varying slightly and narrowing as we age. This range can be demonstrated using a signal generator and loudspeaker.

Loudness

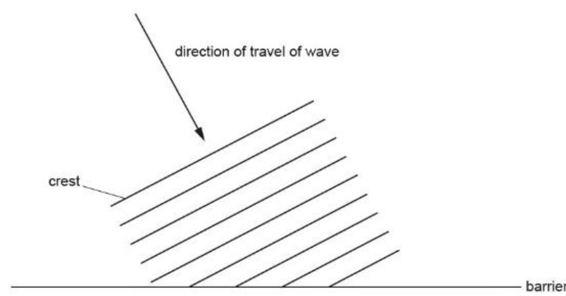
The drum in Figure 13.12 is hit hard, transferring energy from the stick, causing vibrations and loud sound waves. Conversely, when hit gently, less energy is transferred, producing smaller sound waves and quieter sounds.

Figure 13.13 Loud sounds and quiet sounds on an oscilloscope

Figure 13.14 A scientist measuring the sound level as a car passes him

Figure 13.12 If you hit a drum hard, you get a louder sound than if you beat it gently.

Revision questions



1) a) describe a method of using water waves to demonstrate refraction

b) Fig. 5.1 shows crests of a wave approaching a barrier where the wave is reflected.

On figure 5.1 draw three crest of the reflected waves

c)The wave has a wavelength of 36 cm and a speed of 1.2 m/s. Calculate the frequency of the wave.

d)Complete the following sentences.

An echo is the name for a reflected..................wave.

The waves that form an echo are a type of longitudinal wave. Longitudinal waves are made up of .... and rarefactions.

2)Fig. 6.1 shows wavefronts approaching a gap in a barrier.

(i)On Fig. 6.1, draw three wavefronts to the right of the barrier.

(ii) Fig. 6.2 shows the gap in the barrier increased to five times the gap in Fig. 6.1.

On Fig. 6.2, draw three wavefronts to the right of the barrier.

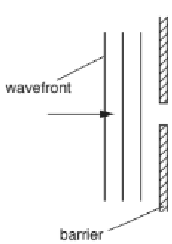


Fig. 6.1

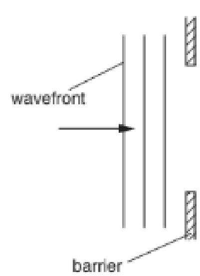
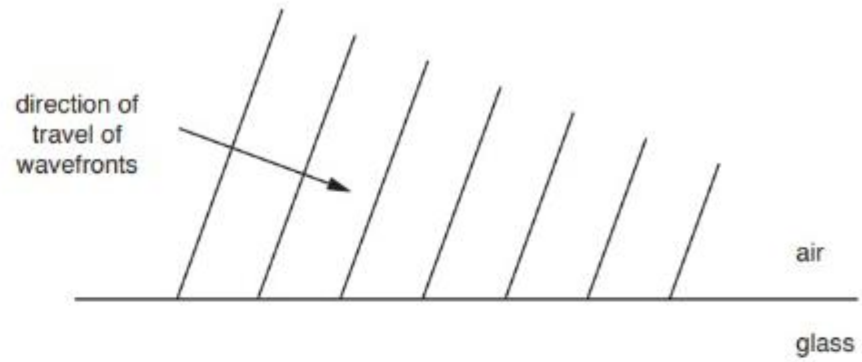


Fig. 6.2

3)a) A laser produces a beam of monochromatic light. State what is meant by the term monochromatic.
b) A wave, in air, is incident on a glass block. Fig. 7.1 shows the wavefronts at the air-glass boundary. The arrow shows the direction of travel of the wavefronts.



The wave undergoes reflection and refraction at the air-glass boundary.
On Fig. 7.1 draw:
(i) the wavefronts of the reflected wave
(ii) the wavefronts of the refracted wave.
c)A transverse wave is produced in a long, horizontal rope. The rope is much longer than the wavelength of the wave.
In the space below, sketch a diagram to show the appearance of the rope as the wave passes along it. Label two important features of the wave.

4) a) Fig. 7.1 shows a ray of light in water that is incident on a submerged, transparent plastic block.

State what happens to the speed of light as it enters the plastic block. Explain your answer.
b) Fig. 7.2 shows the two principal focuses F1 and F2 of a thin converging lens.

Fig. 7.2 also shows an object O of height 1.2cm placed close to the lens. Two rays from the tip of the object O are incident on the lens.
(i) On Fig. 7.2, continue the paths of these two rays for a further distance of at least 5 cm.
(ii) Using your answer to (b)(i), find and mark on Fig. 7.2 the image I of object O and label this image.
(iii) Determine the height of image I.

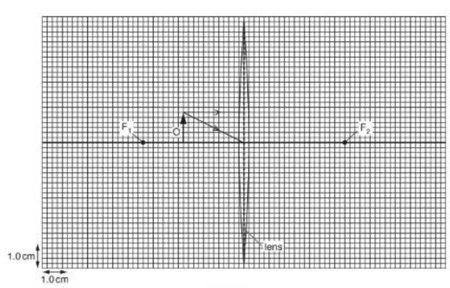


Fig. 7.2

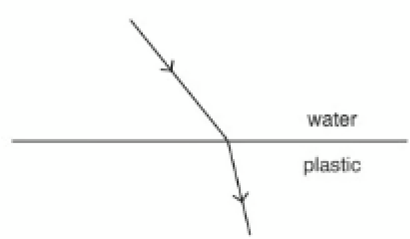


Fig. 7.1

5) a) Table 1.1 shows a list of the electromagnetic spectrum.

gamma						radio

Table 1.1

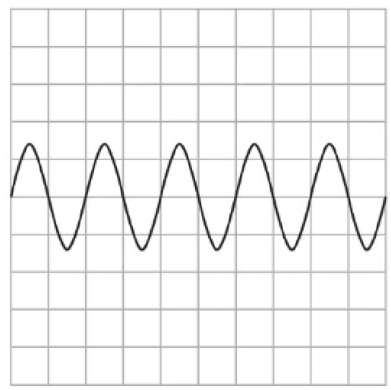
(i) Complete Table 1.1 by filling in the missing EM waves.
(ii) Suggest what the arrow is indicating.

b) Fig. 1.1 shows an X-ray of a broken bone.

Fig. 1.1

Describe the interaction between the x-rays and
(i) soft tissue.
(ii) bone.

6)Fig. 1.1 shows a radio wave. Each 1 cm square is equal to 2 m.



(i) State the wavelength of the radio wave in Fig 1.1.
(ii) Sketch on Fig. 1.1 a wave that has a greater amplitude and lower frequency.
b) A radio wave with a frequency of 20 GHz travels through the vacuum of space.
Calculate the wavelength of this radio wave.
c)State why sound waves and radio waves have different frequencies at the same wavelength.

7)a) Gamma rays are the highest energy waves in the electromagnetic spectrum.
State the maximum speed of gamma rays in a vacuum.
b) Calculate the frequency of a gamma ray with a wavelength of 6.5×10^{-13} m.
c) compare and contract gamma rays and radio waves. You should consider both their properties and their applications.
d)Gamma rays are dangerous to work with because they transfer large amounts of energy.
People who work with gamma radiation need to take precautions to keep themselves safe.
Suggest two ways that workers can keep themselves safe when working with gamma rays.

8) a) A healthy human ear can hear a range of frequencies.
Three frequency ranges are shown.
Draw a ring around the range for a healthy human ear.
O Hz - 20 Hz 10 Hz - 10 000 Hz 20 Hz - 20 000 Hz
b) Explain the meaning of the term ultrasound.
c) A student listens to two different sounds, P and Q.
The two different sounds are represented on a computer screen on the same scale.
Fig. 8.1 shows the screens.
State and explain how sound P is different from sound Q

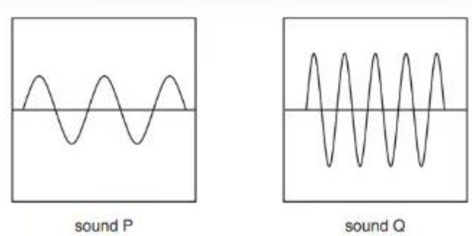


Fig. 8.1

9) a) This question is about measuring the speed of sound in air.
A student stands in front of a large wall. She hits a drum and hears an echo. Fig.8.1 shows the position of the student and the wall.

Fig. 8.1

(i) State the name of a piece of equipment for measuring the distance from the student to the wall.
(ii) Explain how sound forms an echo.

b) The student hits her drum repeatedly once per second. She walks away from the wall and listens for the echo. When the student is 170m from the wall she hears the echo from one beat of the drum at the same time as the next beat of the drum.
Use this information to determine the speed of sound. State the unit.