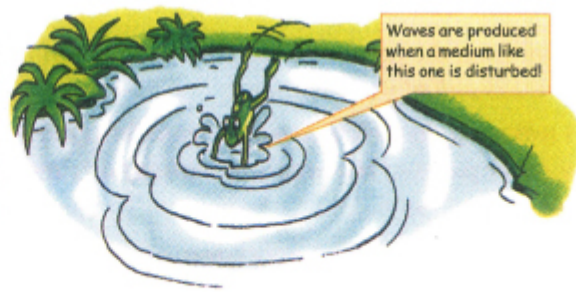
11 WAVES



WAVES, PRODUCTION AND PROPAGATION

We make and use waves everyday in different forms. All forms of waves transfer or transmit energy from one place to another through a medium or a vacuum. Radio and television communications are possible because waves are produced at the transmitting station and are transferred in form of energy to our radio and television sets. The radio and television sets only transform the energy of the wave to sound and pictures. All forms of communications involve the making of waves at one end, and the use of waves at the other end. The energy of the sun reaches us here on earth in the form of waves. One common form of wave to be discussed in this chapter is the **water wave**. We will also consider some properties of waves.

OBJECTIVES

At the end of this section, students should be able to:

- generate mechanical waves; state the important characteristics of waves;
- produce circular and plane waves using ripple tanks;
- generate and demonstrate longitudinal and transverse waves using suitable materials;
- classify waves into longitudinal and transverse waves by using mode of vibration and direction of propagation;
- identify the crest, trough, amplitude, wavelength and points in phase on a given sine waveform;
- explain compression, rarefaction, period, cycle and frequency as they apply to waves;
- derive and use the relationship between wave velocity, wavelength and frequency;
- identify light as electromagnetic waves.

What is a wave?

If a stone is dropped into a still pond or pool of water, the following will be observed:

â€¢ the water is disturbed where the stone hits the water surface;

â€¢ ripples travel out from the point where the water is disturbed.

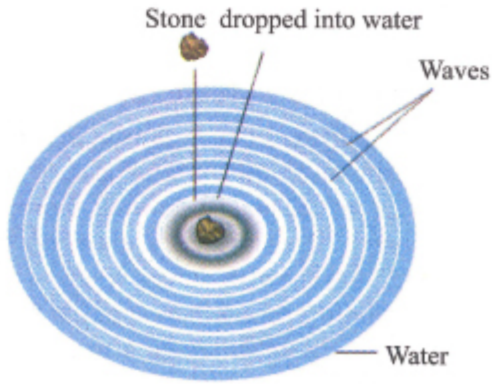


Figure 11.1: When a stone is dropped in water it produces ripples.

A ripple is a travelling disturbance called a pulse. The kinetic energy of the stone is transferred to the water and moves away from the point of disturbance as a **ripple** or **pulse**. A continuous periodic disturbance of the water surface generates succession of ripples or pulses, which travel away from the point of disturbance. ***The motion of the ripples away from the point of disturbance is called wave motion.***

A wave is a disturbance which transfers energy from the point where a medium is disturbed to other parts of the medium without any transfer of the particles of the medium between the points.

A wave motion is a succession of ripples transferring energy through a vacuum or a medium without transferring particles of the medium between the points.

Two important characteristics of waves are the **wave motion** and the **vibration of the particles of the medium**. Waves transfer energy away from the point where the medium is disturbed to other parts while the particles of the medium vibrate about their mean positions.

Mechanical waves do not transfer particles of the medium along with energy. The particles vibrate but remain in their fixed positions. We can demonstrate that waves do not carry particles along with the experiment below.

â€¢ Generate waves on a pool of water by dipping a long stick at regular interval.

â€¢ Place a cork on the path of the wave moving away from the point of disturbance.

â€¢ Observe the movement of the cork. What do you notice about its movement as the wave passes under it?

As the wave pass under the cork, it moves up and down (to and fro) but does not travel along with the wave. This proves that waves transfers only energy as it travels through a medium.

Types of waves

Waves are classified as **mechanical** or **electromagnetic.**

Mechanical waves

A mechanical wave needs a medium to transfer its energy away from the source.

Energy is transferred through the medium but the particles of the medium are not carried along by the wave. They only vibrate about their mean or fixed position. Mechanical waves include waves travelling through springs, water waves and sound waves.

Production of mechanical waves

A stone dropped in water makes the water particles vibrate. The result of disturbing the medium is that waves are set up in the medium.

1. Mechanical waves in ropes and springs

To produce a mechanical wave in a rope, one end of the rope is fixed and the free end is moved up and down as shown in Figure 11.2. A pulse travels along the rope. If the hand is moved up and down periodically, successions of pulses travel along the rope to set up a mechanical wave in the rope.

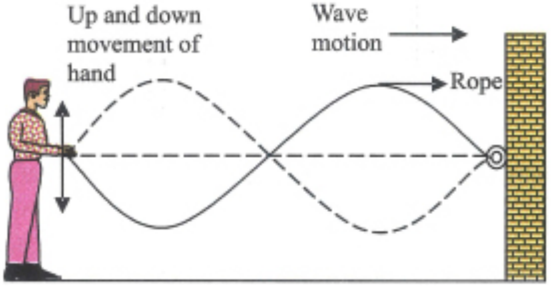


Fig. 11.2: Producing a mechanical wave in a ropes

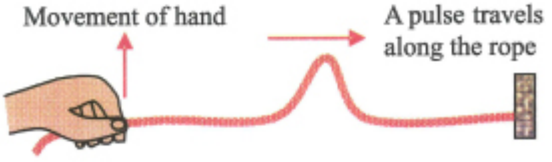


Figure 11.3: Production of mechanical wave in a rope

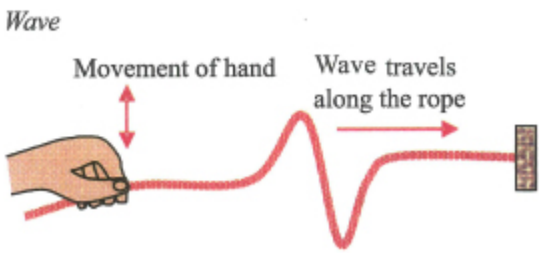


Figure 11.4: Mechanical waves in a rope

Mechanical waves can be produced in springs as shown in Figure 10.5.

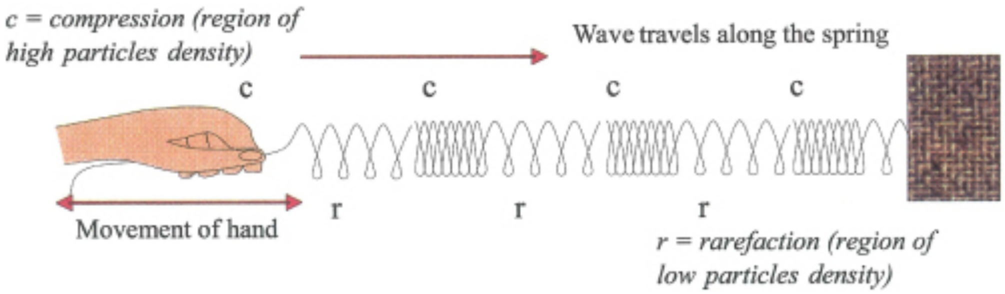


Figure 11.5: Mechanical waves in springs

2. Water waves

The ripples produced in Figure 10.1 are waves travelling on water. Water waves are mechanical wave. They are produced in the school laboratory using a ripple tank. (Figure 10.6).

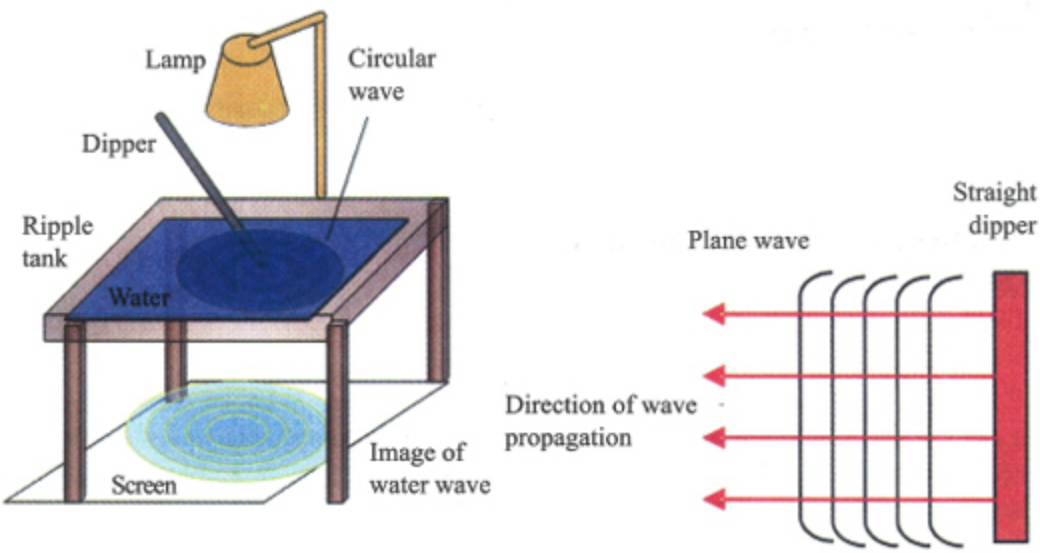


Figure 11.6: Ripple tank and production of circular and plane waves

A ripple tank is a shallow tank with a glass base, a lamp placed above the tank and a white screen placed under it. The lamp is used to form the image of the ripples or waves produced on the white screen.

Waves are produced by dipping an object in and out of water at regular intervals. Circular or spherical waves are produced by dipping a finger, the sharp point of a pencil or a spherical dipper into the water. Plane waves are produced by using a straight dipper like a ruler or the side of a rod.

Wave front

Any periodic disturbance of a medium always generates waves. The waves produced spreads out from the source of the waves to other parts of the medium. The particles A, B and C in Figures 11.7 and 11.8 are always the same distance from the source of the waves and also are subject to the same vibration. They are said to be in phase.

Wave front is the line or curve which joins all the particles vibrating in phase. There are two types of wave fronts; the **circular**

or spherical wave front and the **plane or straight wave front**. Circular wave front spreads out in all directions as the wave travels away the source while the plane wave front spreads out in one direction only.

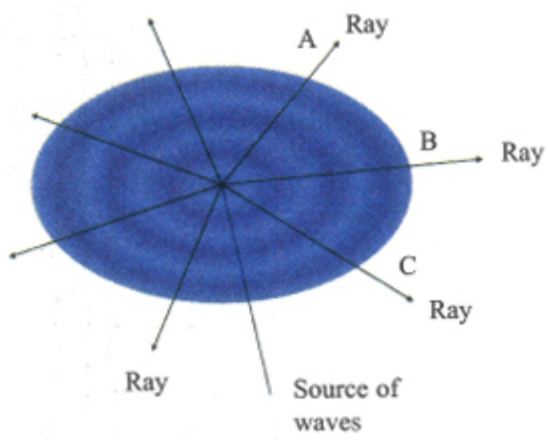


Fig. 11.7: Circular or spherical wave fronts

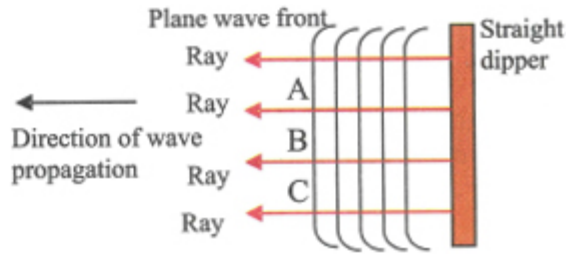


Figure 11.8: Straight and plane wave fronts

The lines normal or radial to the wave fronts are called rays. Rays indicate the direction the wave is travelling. Plane wave fronts have parallel rays while circular wave fronts diverge in all directions as the wave spreads from the source of the wave.

Electromagnetic waves

Electromagnetic waves do not need a medium to transfer its energy from one point to another.

Electromagnetic waves consist of electric and magnetic fields vibrating at right angles to each other. The family or group of waves called electromagnetic waves are radio waves, infrared waves, visible light, ultra-violet rays, X-rays and gamma rays. Electromagnetic waves can pass a vacuum travelling at a constant speed of 3.0 Ã— 10 ^{8}m. There are basically two major ways of classifying waves.

(1) Requirement or non-requirement of medium of propagation, (i.e. **mechanical wave** and **electromagnetic wave).**

(2) Wave direction compared with the direction of vibration of the particle of the medium, (i.e. transverse or longitudinal wave.)

A wave which travels along a medium transferring energy from one part of the medium to another, is a **progressive wave**. A progressive wave is also called **travelling wave** because it transfers energy outward from the source.

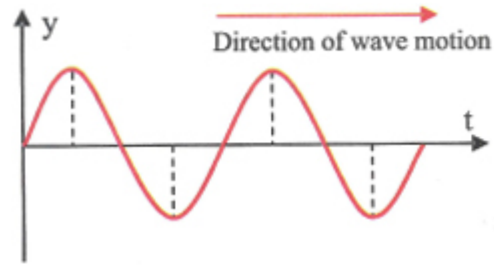


Figure 11.9: Progressive or travelling wave

A **standing or stationary wave** is formed when two waves travelling in the opposite direction meets or by superimposition of **incident wave** and its **reflection**. The amplitude of a standing or stationary wave varies along the wave.

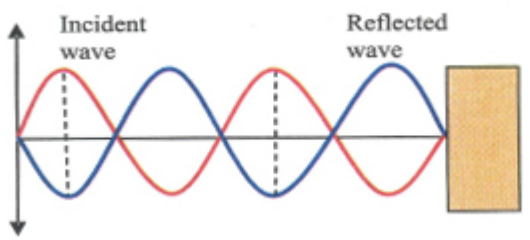


Figure 11.10: Standing or stationary wave

Progressive or travelling waves are divided into **transverse** and **longitudinal** waves.

Transverse waves

A transverse wave is a wave in which the vibration of the medium transmitting the wave is at right angles (perpendicular) to the direction the wave is travelling.

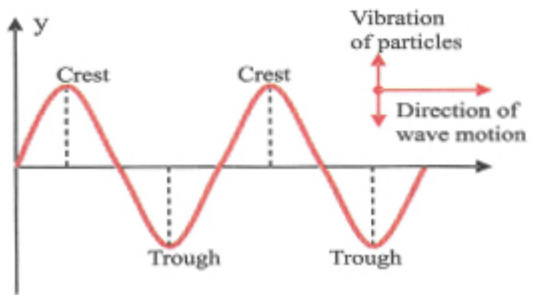


Figure 11.11: A transverse wave

As the wave passes through the medium, its particles vibrate (move up and down). Vibration of the particles in a transverse wave is perpendicular to the direction the wave is travelling. The peak of the wave is called **crest** while its lowest depression is called **trough.**

Crest is the region of maximum upward displacement of the particles from the equilibrium position.

Trough is the region of maximum downward displacement of the particles from the equilibrium position.

Examples of transverse waves are: all electromagnetic waves, water waves and waves in ropes and stings.

Longitudinal waves

In a longitudinal wave, the vibration of particles of the medium are parallel to the direction the wave is travelling.

A longitudinal wave is a wave whose direction of propagation in a medium is parallel to the vibration of the particles of the medium transmitting it.

c = compression (region of squeezed particles)

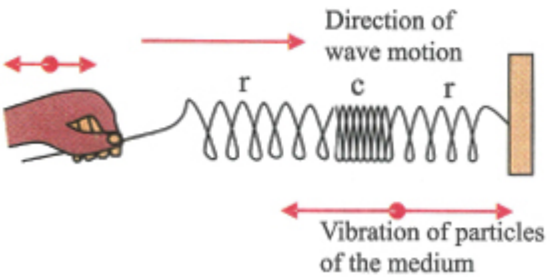


Figure 11.12: A longitudinal wave

r = rarefaction (region of dispersed particles)

As the particles vibrate, they are squeezed or compressed in some parts of the medium. The region where the particles are squeezed is called **compression** (c). A region of the compressed particles is followed by a region of spaced out (dispersed) particles called **rarefaction** (r).

Sound waves are waves formed in a compressed spiral spring as shown above are examples of longitudinal waves.

Describing waves

The transverse and longitudinal waveforms are shown below. They are used to define the terms used in describing waves.

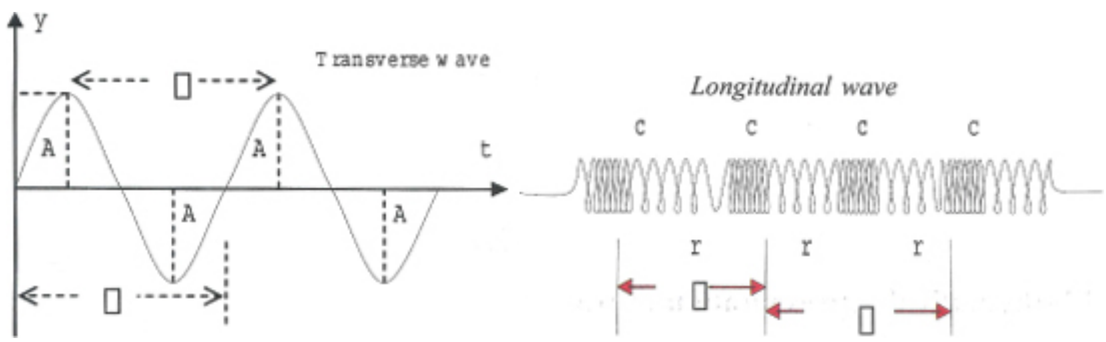


Figure 11.13: Transverse wave and longitudinal waves

Amplitude (A)

Amplitude is the maximum upward or downward displacement of the particles from the equilibrium position. The amplitude is represented by (A) in the transverse progressive waveform above and the unit is metre (m).

Cycle: ***A cycle is one complete vibration or oscillation of a particle.***

Wavelength(Î»)

Wavelength is the distance between two points on the waveform, which are vibrating in phase. The points may be two successive crests or two successive troughs. We can then define ***wavelength as the distance between two successive crests or troughs***. The unit of wavelength is metre (m).

Frequency (f)

Frequency is the number of vibrations completed in one second. The unit of frequency is hertz (Hz).

Period (T)

Period is the time it takes to complete one vibration or cycle. The unit of period is seconds (s).

$$\text{period} = \frac{1}{\text{frequency}} \text{ or frequency} = \frac{1}{\text{period}}$$

Wave velocity (v)

Wave velocity is the distance the wave travelled in one second. The unit of wave velocity is metre per second (ms^{-1}).

$$\text{Wave velocity} = \frac{\text{Wavelength}}{\text{Period}}$$

$$v = \frac{\lambda}{T}$$

Relationship between velocity, frequency and wavelength

Wave velocity, wavelength and frequency are connected by the equation:

$$V = \lambda \times f$$

Proof:

$$\text{Wave velocity} = \frac{\text{Wavelength}}{\text{Period}}$$

$$v = \frac{\lambda}{T} = \lambda \times \frac{1}{T} \text{ but } \frac{1}{T} = f \text{ (frequency)}$$

$$\therefore \quad v = \lambda f$$

Mathematical representation of wave motion

A progressive wave can be represented graphically by a sine or cosine curve as shown in Figure 11.9. Such waves are formed by causing the medium to vibrate. The displacement of the particles of the medium at any time is given by:

$y = A\sin\omega t$

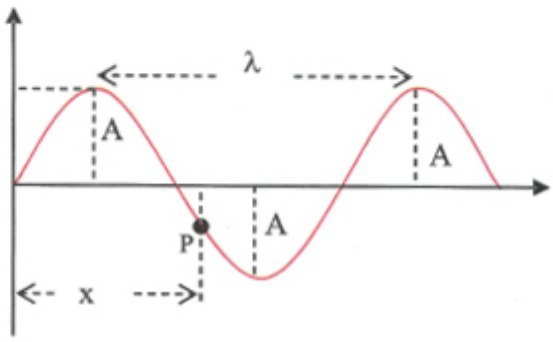
$y = A\sin\dfrac{2\pi t}{T} \qquad (\omega = \dfrac{2\pi}{T})$

$y = A\sin\dfrac{2\pi v t}{\lambda} \qquad (\dfrac{1}{T} = f = \dfrac{v}{\lambda})$

$y = A\sin\dfrac{2\pi x}{\lambda} \qquad (x = vt)$

$y = A\sin\dfrac{2\pi x}{\lambda}$

A = amplitude of the wave, λ = wavelength,
v = wave velocity, T = period of vibration,
x = the distance of the wave from the source at time (t).



Phase

In phase

Phase is an important characteristic of a wave. Wave is transmitted through a medium by vibrating particles. These particles are at different positions from the source of the wave and move in different directions. Phase is the term used to describe the position of the particle on the waveform. ***Particles which are in the same relative position and moving in the same direction, are in phase***. Two waves are travelling in phase if they arrive at the same spot with their crests or troughs. Such waves reach their maximum points at the same time.

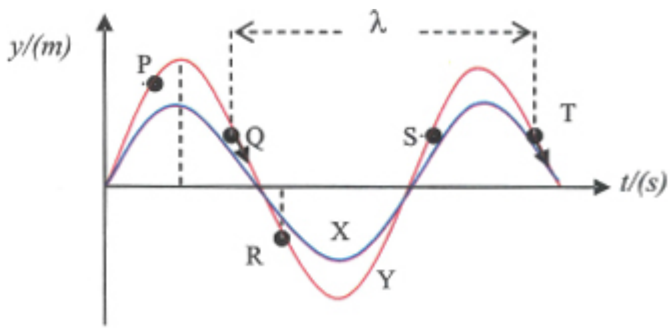


Figure 11.14a: Waves in phase

The waves X and Y are in phase because their crests and troughs arrive at the same spot at the same time. The points Q and T on the wave Y are in phase because they are in the same relative position and are moving in the same direction.

Out of phase

Particles which are in different positions on the waveform are out of phase. Two waves are out of phase if their crests or troughs arrive at the same spot at different times.

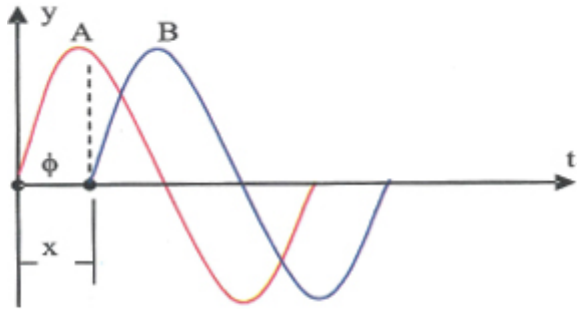


Figure 11.14b: Waves out of phase by Ï•

The waves A and B above are out of phase by Ï• the phase angle difference between the starting points of the waves. The wave A started after the wave B had travelled x metres from the source. If Ï• = 180Â° or Ï€ radians the two waves are anti-phase. The crest of A arrives at a spot with the trough of B.

General progressive wave equation

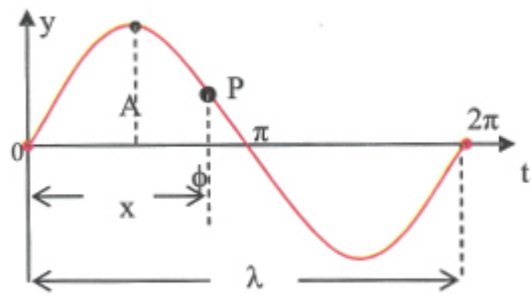


Figure 11.15

For the progressive waveform above, the particle, O is at the source while the particle P has travelled a distance (x) from the source. The phase angle difference between O and P is Ï•. Starting with the progressive wave equation:

$$y = A\sin\frac{2\pi x}{\lambda}$$

and taking into consideration that O and P are out of phase by Ï•, we modify the equation above to

$$y = A\sin(\frac{2\pi x}{\lambda} - \phi)$$

Taking simple ratios of the angles (Ï• and 2Ï€) and the linear distances (x and Î») gives:

$$\frac{\phi}{2\pi} = \frac{x}{\lambda} \quad \Rightarrow \quad \phi = \frac{2\pi x}{\lambda} = \frac{2\pi vt}{\lambda} \qquad (x = vt)$$

$$\therefore\ y = A\sin(\frac{2\pi x}{\lambda} - \frac{2\pi vt}{\lambda})$$

$$y = A\sin\frac{2\pi}{\lambda}(x - vt)$$

The letters have their usual meanings. A, Î» and x are as shown in figure 10.15.

Worked examples

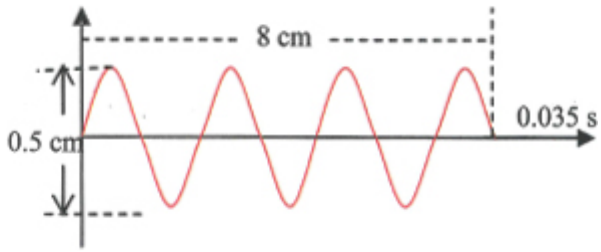
1. A radio station broadcast at a wavelength of 20 m. Calculate the frequency of transmission if the velocity of the wave is 3.0 Ã— $10^8 ms^{-1}$.

Solution

$f = \frac{v}{\lambda}$ f = frequency, v = wave velocity and λ = wavelength

$f = \frac{3.0 \times 10^8}{20} = 1.5 \times 10^7 s^{-1}$.

2. The diagram below represents a wave profile. Calculate the wavelength, frequency, wave velocity, period and amplitude.



Solution

(i) $\lambda = \frac{\text{Distance occupied by the waves}}{\text{number of waves}}$

$\lambda = \frac{8cm}{3.5} = 2.29\,cm$

(ii) $f = \frac{\text{Number of completed vibrations}}{\text{Time}}$

$f = \frac{3.5}{0.035} = 100\,Hz$

(iii) $v = \lambda f = 2.29 \times 100 = 229\text{ cm s}^{-1}$

$\therefore v = 2.29\text{ m s}^{-1}$

(iv) $T = \frac{1}{f} = \frac{1}{100} = 0.01$ second

(v) Amplitude (A) = ½ × 0.5 cm =0.25 cm.

3. A progressive transverse wave profile in a stretched rope is given by:

y = 2.5sin (0.2Ï€x – 40 Ï€t).

The units of x and y are in centimetres and t is time measured in seconds. Calculate the:

(a) amplitude of the wave;

(b) wavelength of the wave;

(c) wave velocity;

(d) frequency of the wave.

Solution

To solve this problem, we will compare the given wave equation with the general wave equation.

$$y = A\sin\left(\frac{2\pi x}{\lambda} - \frac{2\pi vt}{\lambda}\right)$$

$$y = 2.5\sin(0.2\pi x - 40\pi t).$$

(a) Amplitude (A) = 2.5 cm.

By comparing the equations above:

(b) $\frac{2\pi x}{\lambda} = 0.2\pi x$

$$\frac{2}{\lambda} = 0.2 \quad \Rightarrow \lambda = \frac{2}{0.2} = 10\,cm$$

(c) $\frac{2\pi vt}{\lambda} = 40\pi t$

$$\frac{2v}{10} = 40 \quad \Rightarrow v = \frac{40 \times 10}{2} = 200\,cm\,s^{-1}$$

(d) $f = \frac{v}{\lambda} = \frac{200}{10} = 20\,Hz$

Summary

â€¢ A wave is a disturbance which transfers energy from the point where the medium is disturbed to other parts of the medium without any transfer of the particles between the points.

â€¢ Waves transfer energy only as they travel through a medium while the particles of the medium vibrate about their mean positions.

â€¢ Wave front is the line or curve which joins all the particles vibrating in phase. Two types of wave fronts are the circular or spherical wave front and the plane or straight wave front.

â€¢ Rays are the lines normal or radial to the wave fronts. Rays indicate the direction of the wave is travelling.

â€¢ A transverse wave is one in which the particles of the medium transmitting the wave vibrate at right angle (perpendicular) to the direction the wave is travelling.

â€¢ Crest is the region of maximum upward displacement of the particles from the equilibrium position.

â€¢ Trough is the region of maximum downward displacement of the particles from the equilibrium position.

â€¢ A longitudinal wave is a wave whose direction of propagation in a medium is parallel to the vibration of the particles of the medium transmitting it.

â€¢ The region in a wave where the particles are squeezed is called compression (c). The region of the compressed particles is followed by a region of spaced out (dispersed) particles called rarefaction (r).

- â€¢ A mechanical wave needs a medium of propagation to transfer its energy to other parts of the medium.
- â€¢ Electromagnetic waves do not need a medium to transfer its energy from one point to another.
- â€¢ Amplitude is the maximum upward or downward displacement of the particles from the equilibrium position.
- â€¢ Wavelength is the distance between two successive crests or troughs.
- â€¢ Wave velocity is the distance the wave travelled in one second. Frequency is the number of vibrations completed in one second.
- $\text{Wave velocity} = \dfrac{\text{Wavelength}}{\text{Period}}$
- â€¢ A progressive wave is a wave which is free to travel outward from the point of disturbance to other parts of the medium.
- â€¢ A standing or stationary wave is a wave which is trapped in the medium. It is not free to travel away from medium.
- â€¢ Phase refers to particles which are in the same relative position and are moving in the same direction. Two waves are travelling in phase if they arrive at the same spot with their crests or troughs. Particles, which are in different positions on the waveform, are out of phase. Two waves are out of phase if their crests or troughs arrive at the same spot at different times.

Practice questions 11a

1. (a) What is a wave?
   (b) In an experiment to find the wave velocity of water wave, a girl used a vibrating dipper of frequency 20 Hz to produce a wave of wavelength 5 cm. What is the speed of the wave?
2. (a) What is a wave motion?
   (b) How will you demonstrate that a mechanical wave transmits only energy?
   (c) Describe the motion of the particles of the medium.
3. State two:
   (i) differences between a mechanical wave and an electromagnetic wave;
   (ii) examples of each for mechanical and electromagnetic waves.
4. (a) Define the following: transverse wave and longitudinal wave.
   (b) State the differences between transverse and longitudinal waves.
   (c) Give two examples each of transverse and longitudinal waves.
5. (a) Define the terms *frequency, wavelength* and *wave velocity;*
   (b) Derive a mathematical equation linking the three terms in (a) above.

(c) A radio station broadcasts at a frequency of 1.062 Ã— 10^8Hz. At what wavelength is the station broadcasting if the speed of wave is 3.0 Ã— 10^8ms^{-1}?

6. (a) Explain the terms: **phase, in phase** and **out of phase** as applied to waves.

(b) Make a sketch of a transverse waveform and indicate on your sketch:

(i) two points vibrating in phase;

(ii) two points vibrating out of phase;

(iii) a particle whose relative positions is $\frac{3}{2}\pi$ from the origin of your sketch.

7. What is a progressive wave?

A progressive wave profile is given by:

$$y = A\sin\frac{2\pi x}{\lambda}$$

(i) What do the symbols A, x and Î» represent?

(ii) Sketch the wave and indicate the positions of A, x and Î».

(iii) A particular wave profile is given by: y = 0.08sin (10 Ï€ x) Calculate the wavelength of the wave.

8. (a) Define wavelength, frequency and wave velocity;

(b) Radio waves transmitted from certain a radio station is represented by the wave equation

y = 0.75sin (0.67Ï€x – 2 Ã— 10^8Ï€t).

Calculate the:

(i) wavelength of the wave;

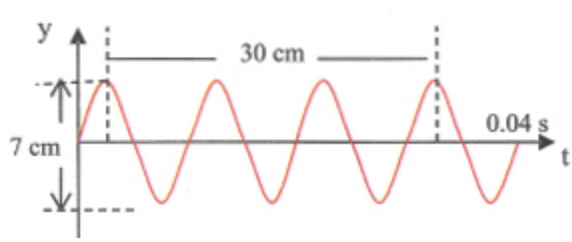
(ii) frequency of the wave;

(iii) velocity of the wave.

y, x are in metres while *t* is in seconds

9. (a) Define frequency and period of a wave,

(b)



The diagram above is a transverse progressive wave profile. Use the diagram to answer the following questions.

(i) What is the wavelength of the wave?

(ii) What is the period and frequency of the wave?

(iii) Calculate the speed of the wave in ms^{-1}.

WAVE PROPERTIES

The study of waves is an important branch of physics with applications in other branches. The properties common to all types of waves: heat, sound, light or water waves are **reflection, refraction, diffraction** and **interference. Polarisation** is the property of transverse waves only.

â€¢ The first three properties (reflection, refraction and diffraction) are both properties of waves and particles.

â€¢ The first four properties (reflection, refraction, diffraction and interference) are both properties of transverse waves and longitudinal waves.

â€¢ Polarisation is the property of transverse waves alone. **Longitudinal waves cannot be polarised.**

OBJECTIVES

At the end of this topic, students should be able to;

- produce plane and circular waves using a ripple tank and use them to demonstrate the reflection of water waves;
- demonstrate the reflection of sound and heat waves;
- demonstrate refraction of water waves and sounds;
- demonstrate stationary or standing waves;
- state and explain four properties of waves;
- demonstrate polarisation of light waves.

Reflection of waves

A wave is reflected when it is sent back or it bounces back after hitting an obstacle. All waves are reflected when they strike a hard surface or a boundary. Water waves are reflected from obstacles in their path. Light, heat and sound waves are also reflected by different types of surfaces. Reflection of water waves is studied using a ripple tank.

Reflection of water waves

(i) Reflection of plane parallel waves from a plane surface

A ripple tank Figure 11.6 is used to produce plane parallel wave fronts. When the incident wave fronts meet a plane surface, they are reflected from the surface. The waves are reflected such that the angle of incident of the wave is equal to the angle of reflection of the wave.

Angle i = Angle r

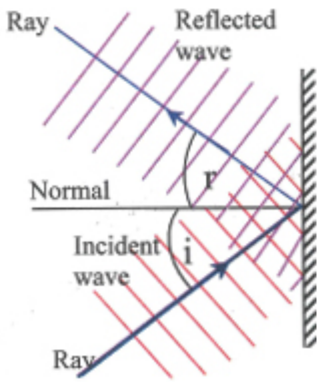


Figure 11.16: Reflection of plane parallel wave from a plane surface

- â€¢ The incident wave, the reflected wave and the line normal to the reflecting surface lie on the same plane.
- â€¢ The angle the incident wave makes with the line normal to reflecting surface is equal to the angle between the reflected wave and the line normal to the surface.

(ii) Reflection of plane parallel waves from curved surfaces

Reflection of plane parallel waves from curved surfaces produces circular or spherical wave fronts. The reflected waves converge at a point called the focus (F) if the reflecting surface is concave. For a convex reflecting surface, the reflected wave spreads (diverges) as if it is coming from the focus F behind the reflector.

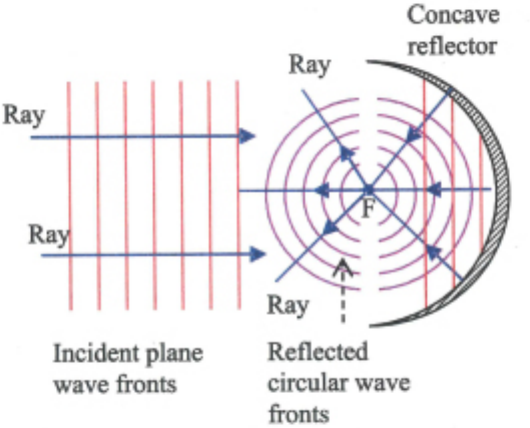


Figure 11.17: Reflection from a concave surface

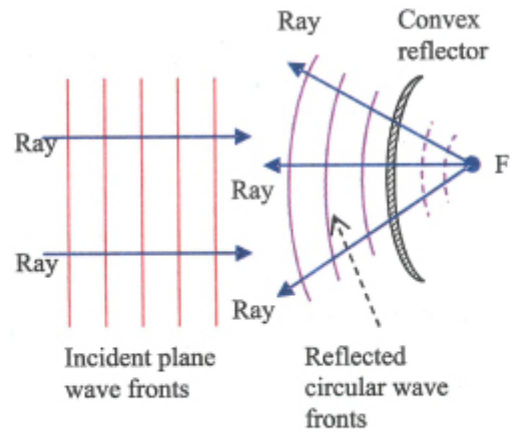


Figure 11.18: Reflection from a convex surface

Reflection of sound waves

Sound waves are reflected when they strike a hard smooth surface. We demonstrate the reflection of sound as follows:

â€¢ Cut two cardboard papers, fold them to form tubes and arrange them as shown in Figure 11.19.

â€¢ Place a wristwatch or a clock at the end of tube A, put your ear at the end of tube B and move the tube B until the tick of the clock is heard.

â€¢ Measure the angles between the tubes A and B and the screen. What do you notice?

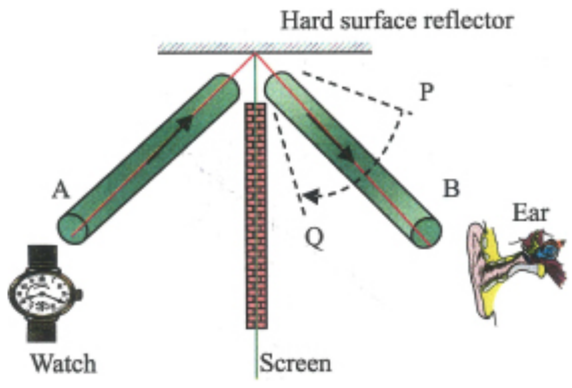


Figure 11.19: Reflection of sound

Sound is reflected off a hard surface. The tick of the watch at A is heard when the ear is in the position B. No sound is heard at the positions P and Q. Reflection of sound obeys the laws of reflection of waves.

Reflection of heat radiation

Heat radiation also known as infrared waves are reflected just like other waves such that it obeys the laws of reflection. Reflection of heat can be demonstrated with the arrangement in Figure 11.20.

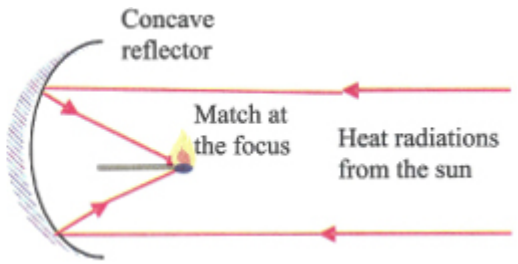


Figure 11.20: Demonstrating reflection of heat

A concave reflector is used to bring parallel heat rays to its focus. A matchstick or black carbon paper positioned at the focus is ignited. This shows that heat rays are reflected by the concave reflector to the focus.

Refraction of waves

If a wave enters a new medium, its speed changes; the speed increases in the new medium if it is less dense and decreases if it is denser than the former medium.

Refraction is the change in speed of a wave as it leaves a medium and enters a new medium.

The change in the speed of a wave may cause its direction to change. When the wave enters the new medium at right angle, the speed changes but the direction does not change.

can demonstrate this by using a ripple tank.

- â€¢ A ripple tank is used to generate plane parallel wave fronts.
- â€¢ One end of the tank is made shallow by placing a rectangular glass block in it.
- â€¢ As the wave passes from the deep water to the shallow water, the velocity of the wave decreases in the shallow water but the wave continues in the same direction.

The frequency of the dipper (wave) is still the same (constant) but the speed decreases in the shallow water, therefore the wavelength decreases in the shallow water. The wave pattern is as shown in Figure 10.21.

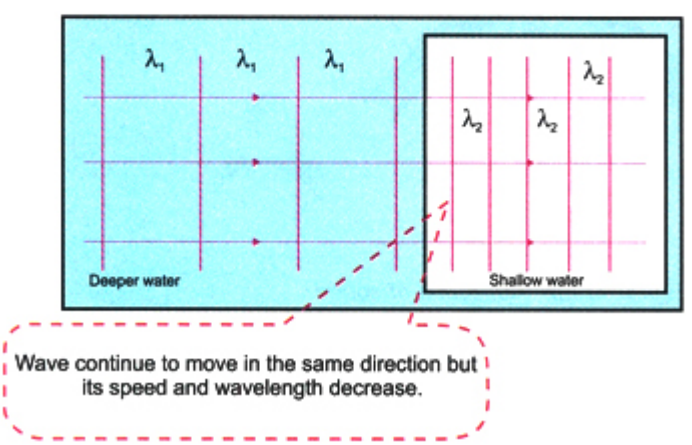


Figure 11.21: Demonstrating change in the speed of a wave as it moves from deep to

shallow water

When the wave enters a new medium at an angle less than 90Â° (obliquely), it bends or changes direction. In this case, refraction is the change in speed or direction of the wave in the new medium.

Refraction is the change in direction of a wave as it passes from one medium to another.

The angle (i) between the normal to the two media and the incident ray is the **angle of incidence**. The angle (r) formed between the refracted ray and the normal to the two media is the **angle of refraction.**

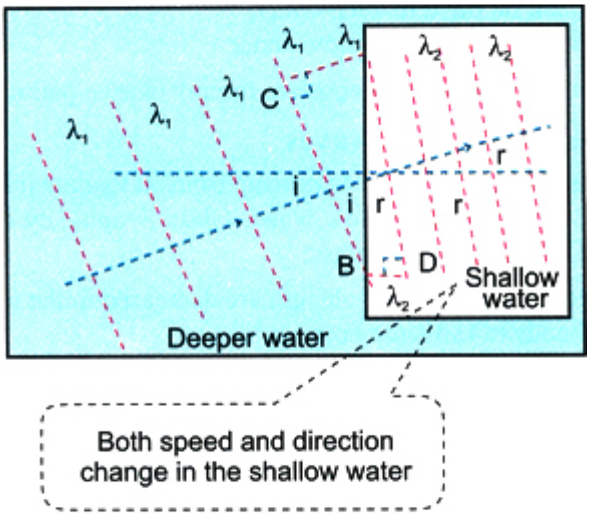


Figure 11.22: Demonstrating change in speed and direction due to refraction

As the wave hits the boundary of the two media at an angle (i) < 90Â°, it bends towards the normal in the shallow water. Again, the wavelength in the shallow water is shorter than the wavelength in the deep water; hence, the wave travel, more slowly in the shallow water. When the incident and the reflected waves are viewed with a stroboscope turning at the frequency of the dipper they appear stationary. This means that the frequency does not change as the wave crosses from the deep water to the shallow water.

Refractive index

Refractive index (n) or the **index of refraction** is defined by:

$$\text{Refractive index} = \frac{\sin i}{\sin r}$$

i = angle of incident in the first medium

r = angle of refraction in the second medium

Using Î”ABC and Î”ABD in Figure 11.22;

$$\sin i = \frac{AC}{AB} = \frac{\lambda_1}{AB} \quad and \quad \sin r = \frac{BD}{AB} = \frac{\lambda_2}{AB}$$

$$\text{Refractive index } ({}_1n_2) = \frac{\sin i}{\sin r} = \frac{\frac{\lambda_1}{AB}}{\frac{\lambda_2}{AB}} = \frac{\lambda_1}{\lambda_2}$$

$$\text{Refractive index } ({}_1n_2) = \frac{\lambda_1}{\lambda_2}$$

Î»$_1$ = Wavelength of wave in deep water;

Î»$_2$ = Wavelength of wave in shallow water.

We can also define refractive index in terms of the speeds of the waves in the two media.

$$\text{Refractive index } ({}_1n_2) = \frac{v_1}{v_2}$$

v_1 = speed of wave in deep water;

v_2 = speed of wave in shallow water.

The refractive index is a constant for any chosen pair of media.

Refraction of light waves

Light waves are refracted on passing from air to glass just as water wave refracted when it passes from deep water to shallow water. Glass is optically denser than air. If light passes from air (optically less dense) to glass:

â€¢ the velocity and wavelength are decreased in the glass medium;

â€¢ it bends towards the normal;

â€¢ refractive index $({}_an_g) = \frac{v_a}{v_g} = \frac{\lambda_a}{\lambda_g}$

â€¢ frequency remains constant as the wave passes from air to glass.

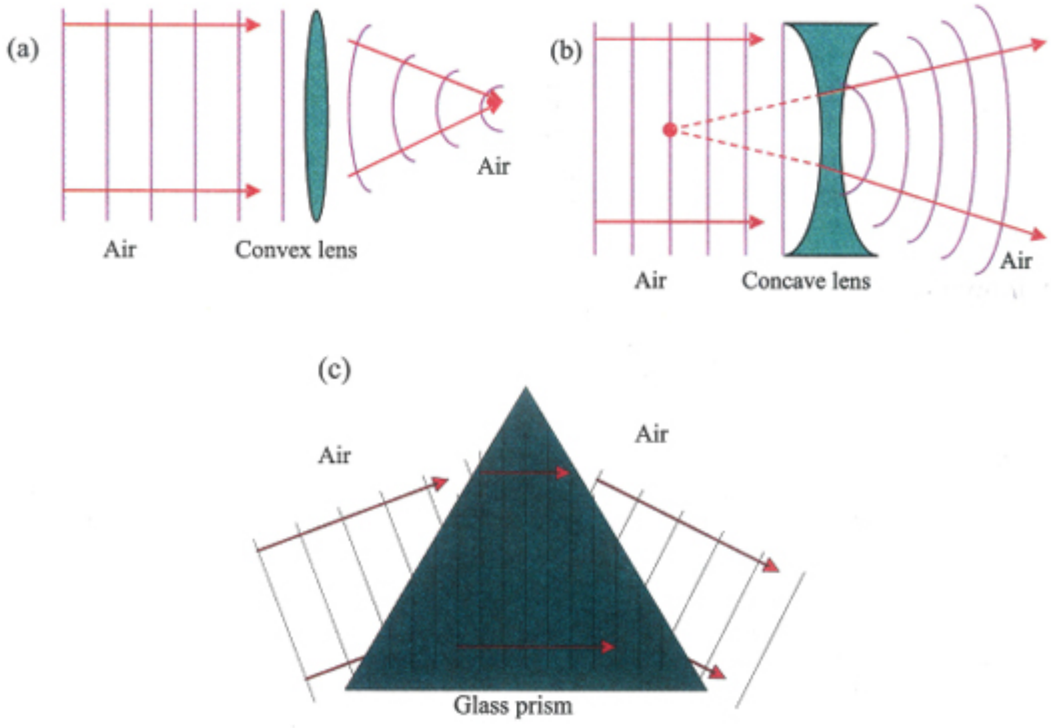


Figure 11.23 Refraction of light waves through lenses

The convex lens Figure 11.22 (a) refracts light waves such that it converges at the focus F. The parallel light waves appear to spread or diverge from the focus F behind the concave lens Figure 11.22 (b). The refraction through a glass prism is shown in figure 11.22 (c).

Worked example

The velocity of a particular wave in air is 3.0 Ã— 10^8ms^{-1}. Calculate the;

(a) wavelength of the wave if the frequency is 2.0 Ã— 10^8 Hz.

(b) velocity and wavelength of the wave in a medium of refractive index 1.25.

Solution

(a) $\text{Wavelength} = \frac{\text{Velocity}}{\text{Frequency}} = \frac{3.0\times10^8}{2.0\times10^8} = 1.5\,m$

(b) ${}_a n_g = \frac{v_a}{v_g}$

$$1.25 = \frac{3.0\times10^8}{v_g}$$

$$v_g = \frac{3.0\times10^8}{1.25} = 2.4\times10^8\,ms^{-1}$$

$${}_a n_g = \frac{\lambda_a}{\lambda_b} \Rightarrow 1.25 = \frac{1.5}{\lambda_g}$$

$$\lambda_g = \frac{1.5}{1.25} = 1.2m$$

Summary

- â€¢ **Reflection**is the bouncing off or sending back of waves after hitting an obstacle. All waves can be reflected. Sound waves are reflected when they strike a hard smooth surface. Heat waves are reflected by polished surfaces just as light waves are reflected. Refraction is the change in speed of a wave as it enters a new medium.
- â€¢ **The laws of reflection:**
  - â€¢ The incident wave, the reflected wave and the normal to the surface reflecting the wave, all lie on the same plane.
  - â€¢ The angle of incident is equal to the angle of reflection.
- â€¢ **Refraction** is the change in direction of a wave as it passes from one medium to another. Refraction is also a change in the speed of the wave as it passes from one medium to another. All waves are refracted when they enter a new medium.
- â€¢ Waves are refracted or bent towards the normal if they pass from a less dense medium to a denser medium. Both the wavelength and speed decrease in the denser medium but the frequency remains constant.
- â€¢ **Refractive index**is ratio of speed of wave in the first medium to the speed of wave inthe second medium.
- Refractive index $({}_1n_2) = \frac{v_1}{v_2}$

v_1 = speed of wave in the first medium;
v_2 = speed of wave in the second medium.

Practice questions 11b

1 (a) State the properties of waves;

(b) What property of wave is used to distinguish between longitudinal and transverse wave?

2 What is reflection of wave? State the laws of reflection of waves.

(b) Make a sketch of reflection of a plane wave on a plane surface. Indicate on your sketch the directions of incident and reflected waves, angle of incident and angle of reflection.

3 (a) Define refraction and refractive index of a medium.

(b) Waves generated in deep water have wavelengths of 15cm and speed of $25cms^{-1}$. If the wavelength reduces to 12cm in shallow water calculate the:

(i) frequency of the waves;

(ii) refractive index of the shallow water;

(iii) speed of the wave in the shallow water.

Past questions

1. An electromagnetic radiation has a speed of 3 Ã— $10^8 ms^{-1}$and a frequency of 10^6 Hz, calculate its wavelength.

A. 3.3 Ã— 10^3 m.

B. 3.0 Ã— 10^2 m.

C. 3.0 Ã— 10^{-2} m.

D. 3.3 Ã— 10^{-3} m. **WASSCE**

2. A body oscillates in simple harmonic motion according to the $x = 0.05\cos(3\pi t + \frac{\pi}{3})$ where *x* is expressed in metres. What does 0.05 represent?

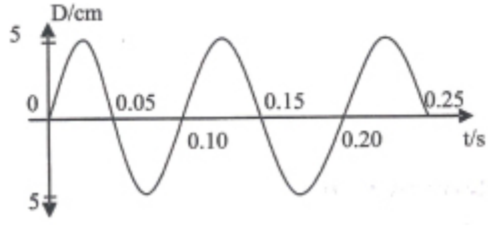
A. Velocity.

B. Frequency.

C. Period.

D. Amplitude. **WASSCE**

3.



The diagram above represents the displacement D versus t graph of a progressive wave. Deduce the frequency of the wave.

A. 20 Hz.

B. 10 Hz.

C. 5 Hz.

WASSCE

D. 4 Hz.

4. Which of the following properties is **NOT** exhibited by sound waves?

A. Diffraction.

B. Interference.

C. Polarisation.

D. Reflection.

E. Refraction. **NECO**

5. Compressions and rarefactions are terms associated with

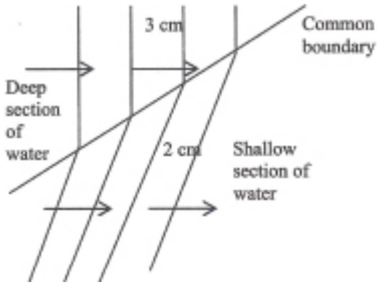
A. transverse waves.

B. electromagnetic waves.

C. longitudinal waves.

D. water waves. **WASSCE**

The diagram represents plane waves of speed 15 cms^{-1} travelling from deep to shallow part of a swimming pool. The wavelengths of the waves in the deep and shallow parts are 3 cm and 2 cm respectively.



6. Which of the following properties explains the change in the direction of the waves?

A. Diffraction.

B. Reflection.

C. Refraction.

D. Interference. **WASSCE**

7. Calculate the refractive index of the shallow part of the pool.

A. 0.67

B. 1.50

C. 2.00

D. 3.00 **WASSCE**

8. Calculate the speed of the wave in the shallow part.

A. 0.100 ms^{-1}.

B. 0.225 ms^{-1}.

C. 0.300 ms^{-1}.

D. 0.450 ms^{-1}. **WASSCE**

9. A slinky spring fixed at one is place horizontal on a table. The free end is displaced parallel to the table and released. The resulting waveform is

A. transverse.

B. longitudinal.

C. stationary.

D. electromagnetic. **WASSCE**

10. A radio wave has a wavelength of 150 m. If the velocity of radio waves in free space is 3 Ã— 10^{8}ms^{-1}, calculate the frequency of the radio wave.

A. 4.5 Ã— 10^{10} Hz.

B. 5.0 Ã— 10^{9} Hz.

C. 4.5 Ã— 10^{9} Hz.

D. 2.0 Ã— 10^{6} Hz. **WASSCE**

11. Water waves are generated by dropping a stone into a calm pool of water. If a small piece of cork is floating in the path of the waves, the cork, as the wave progresses, will

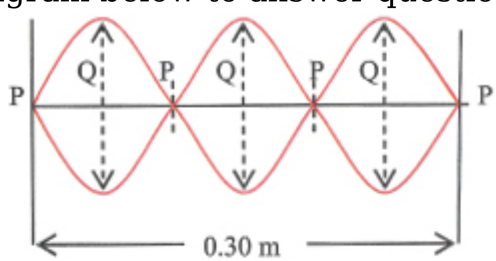
A. sink into the water.

B. move up and down about the same position.

C. move toward the centre of the pool.

D. move along with the waves towards the bank of the pool. **WASSCE**

Use the diagram below to answer questions **12** and **13.**



The diagram illustrates the resultant wave motion produced when progressive waves and their reflections from a rigid boundary interfere.

12. Which of the following statements is **not** correct?

A. The pattern represents the production of beats.

B. The points represented by P are nodes.

C. The energy associated with the waves is maximum at the points represented by Q.

D. The pattern represents a stationary wave. **WASSCE 2001 N**

13. If the speed of the wave is 5.0 ms^{-1}, calculate their frequency.

A. 17.0 Hz.

B. 25.0 Hz. **WASSCE 2001 N**

C. 33.0 Hz.

D. 50.0 Hz.

14. Surface waves travelling in deep water at 15 ms^{-1} are incident at a shallow water boun-dary. If the angles of incident and refraction are 45Â° and 30Â° respectively, calculate the speed of the waves in s hallow water.

A. 8.1 ms^{-1}.

B. 10.0 ms^{-1}.

C. 10.6 ms^{-1}.

D. 22.5 ms^{-1}.

WASSCE

15. A wave is represented by the equation

y = 0.5sin0.4Ï€(x – 60 t)

where the distance *(x)* is measured in centimetres and time *(t)* in seconds. What is the wavelength of the wave?

A. 0.2 cm

B. 0.4 cm.

C. 0.8 cm.

D. 5.0 cm.

E. 10.0 cm.

NECO

16. If two waves of equal frequency and amplitude travel in the opposite directions along a string, the wave set up in the string is called

A. transverse.

B. progressive.

C. longitudinal.

D. stationary.

WASSCE

17. A wave has amplitude equal to 4.0 m, angular speed $\frac{1}{3}\pi$ $rads^{-1}$ and phase angle $\frac{2}{3}\pi$ $rads^{-1}$. The displacement of the wave particle is given as

A. $y = 4\sin\frac{\pi}{3}(t + 2x)$.

B. $y = 4\sin\frac{\pi}{3}(t + \frac{\pi}{2})$.

C. $y = 4\sin\frac{\pi}{3}(2t + 1)$.

D. $y = 4\sin\frac{\pi}{3}(2t + 2)$.

WASSCE

18. The *amplitude* of a wave is the

A. distance between two successive troughs of the wave.

WASSCE

B. separation between adjacent particles.

C. maximum displacement of the wave particle from the equilibrium position.

D. Distance travelled by a wave in a complete cycle of its motion.

19. Which of the following is mechanical wave?

A. Micro wave.

B. Water wave.

C. X-ray.

D. Infrared ray. **WASSCE**

20. Two waves from a source combine at a point such that the crests of one wave arrive simultaneously as the troughs of the other. This phenomenon is known as

A. diffraction.

B. reflection.

C. interference.

D. refraction.

E. dispersion. **WAEC**

21. A wave is represented by the equation

y = 0.2sin0.4Ï€(x – 60t)

where all distances are measured in centimetres and time t in seconds. Calculate the speed of the wave.

A. 0.2 cms^{-1}.

B. 0.4 cms^{-1}.

C. 1.3 cms^{-1}.

D. 12.0 cms^{-1}.

E. 60.0 cms^{-1}. **WAEC**

22. In a waveform a crest and the adjacent trough are out of phase by

A. 45Â°.

B. 90Â°.

C. 180Â°.

D. 270Â°.

E. 360Â°. **WAEC**

23. Which of the following are both mechanical and transverse?

A. Infrared rays.

B. Gamma rays.

C. Soundwaves.

D. Water waves.

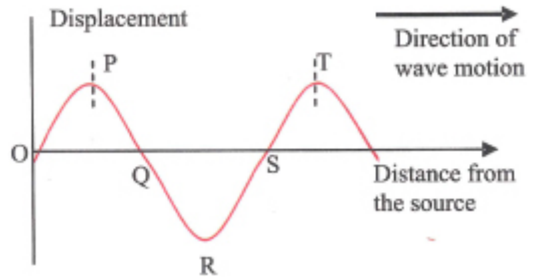
E. Micro waves. **WAEC**

24. An electromagnetic wave of frequency 5.0 Ã— 10^{14} Hz, is incident on the surface of water refractive index $\frac{4}{3}$. Taking the speed of the wave as 3.0 Ã— 10^{8} ms^{-1}, calculate the wavelength of the wave in water.

A. 2.2 Ã— 10^{-6} m.
B. 1.7 Ã— 10^{-6} m.
C. 8.0 Ã— 10^{-7} m.
D. 6.0 Ã— 10^{-7} m.
E. 4.5 Ã— 10^{-7} m.

WAEC

25.



The diagram above represents the profile of a transverse wave. Which of the following points are in phase?

A. O and P
B. O and Q
C. O and R
D. O and S
E. O and T

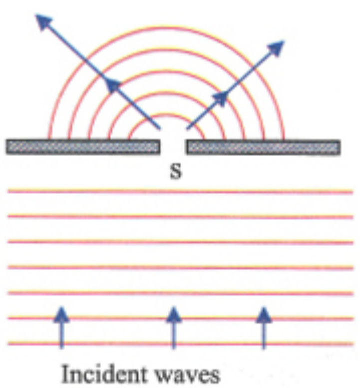
WAEC

26. Whenever light waves are restricted to a specific plane, they are said to be

A. diffracted.
B. refracted.
C. diffused.
D. regularly reflected.
E. Plane-polarised.

WAEC

27.



The diagram above shows waves passing through a slit S. Which wave phenomenon is illustrated by the diagram?

A. Reflection.
B. Refraction.
C. Polarisation.
D. Diffraction.
E. Dispersion. **WAEC**

28. Which of the following is/are common to all waves?
I Diffraction II Refraction III Interference
A. I only
B. III only
C. I and III only
D. I, II and III. **JAMB**

29. Which of the following is the exclusive property of a transverse wave?
A. Diffraction
B. Refraction.
C. Compression.
D. Polarisation. **JAMB**

30. (a) A wave travelling from a medium A with a speed $\overline{v_A}$ passes into another medium B in which it travels with a speed $\overline{v_B}$. Show that the refractive index of B with respect to A is

$${}_A n_B = \frac{\lambda_A}{\lambda_B}$$

where Î»$_A$ and Î»$_B$ are the wavelengths of the wave in A and B respectively.

(b) The distance between two successive crests of water waves travelling at 3.6 ms^{-1} is 0.45 m, calculate the frequency of the waves.

WASSCE

31. (a) What is a wave motion?
(b) A wave is represented by the equation
y = 2sinÏ€(0.5Ã— – 200t)
where all distances are measured in centimetres and time in seconds. For this wave, calculate its:
(i) frequency;
(ii) wavelength;
(iii) speed.

NECO

32. State three properties of waves.

WASSCE

33. Explain the phenomena of

(i) interference;
(ii) diffraction.

WAEC

34. (a) What is a wave motion?

(b) The equation $y = A\sin\frac{2\pi}{\lambda}(vt - x)$ represents a wave-train in which y is the vertical displacement of the particle at distance x from the origin in a medium through which the wave is travelling. Explain, with the aid of diagram, what 1 and A represent.

WAEC

35. (a). Explain
   (i) wave motion;
   (ii) stationary wave.

(b) (i) List **four** physical properties of a wave.
   (ii) Define *amplitude* and use it to distinguish between the node and antinode of a stationary wave.
   (iii) List the factors on which the frequency of vibration in a stretched string depends.

(c) The equation y = 5 sin (3x – 4t) where y is in millimetres, x is in metres and t is in seconds represent a wave motion. Determine the
   (i) frequency;
   (ii) period and
   (iii) speed of the wave.

WASSCE