WAVES

When an object is dropped on still water, ripples spread out in a circular form. This constitutes what is called a water wave.

A wave is also formed when a string tightly fixed between two points is plucked or hit at one point.

Other examples of waves are radio waves, microwaves, tv waves, light, x-rays, gamma-rays etc.

Water waves are used to produce electricity in some countries. Microwaves are used for cooking food.

Earthquakes produce shock waves that are very destructive, because they posses enormous and uncontrolled amount of energy that shake and destroy buildings. An example is the Japanese Tsunami.

Many waves are invisible but have visible effects.

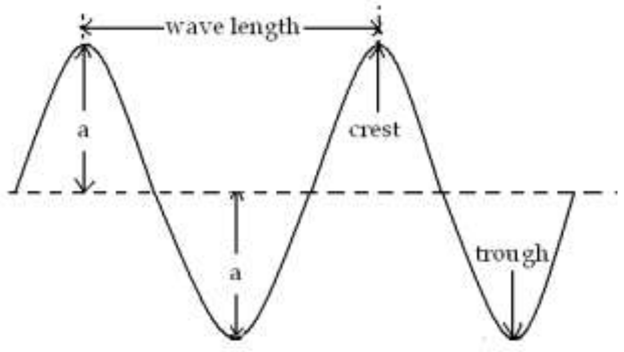
In this chapter, you will study the properties and characteristics of waves and their effects on matter.

When a wave passes through a medium, some of the wave energy is progressively absorbed. This loss of power is called attenuation.

Definition: *A wave is a disturbance which travels through a medium or space and transfer energy from one point to another without causing any permanent displacement of the medium.*

Describing waves

The figure below helps to explain the terminology used in waves



Wavelength (λ) represented by the Greek letter λ (lambda), is the distance between successive crests or troughs.

Wavefront is any line or section taken through an advancing wave in which all the particles are in the same phase.

Amplitude :– This is the maximum displacement of a particle, of the medium in which the wave is moving, from its rest position.

Period T, is the time taken to complete one full cycle. It is measured in seconds.

Frequency: – This is the number of cycles per second. S.I unit of frequency is the hertz (Hz). 1Hz = 1 cycle per second.

Velocity (speed) :- It is the distance moved by wave per second.
Now, the distance between adjacent wavefronts is one wavelength (λ).
Let t = time taken for a wavefront to advance to the position of the one next to it ahead
f = the frequency of the source.

Then $t = \frac{1}{f}$

$$\therefore \ velocity\ of\ the\ wave, V = \frac{Distance}{Time} = \frac{\lambda}{1/f} = f\lambda$$

$\therefore$**V = fλ**

i.e.Velocity = frequency x wavelength

Example:

A wave of wavelength 2m travels at a speed of $3x10^8ms^{-1}$. What is the frequency?

Phase:- This a state of displacement and movement in relation to a given reference. Thus, particles are said to be in phase if their displacement is the same and they are moving in the same direction.
Particles are in antiphase when they are at the same displacement but moving in opposite directions.

PROPERTIES OF WAVES

RIPPLE TANK

A ripple tank is a **shallow** glass tank of water used in schools to demonstrate the basic properties of waves.

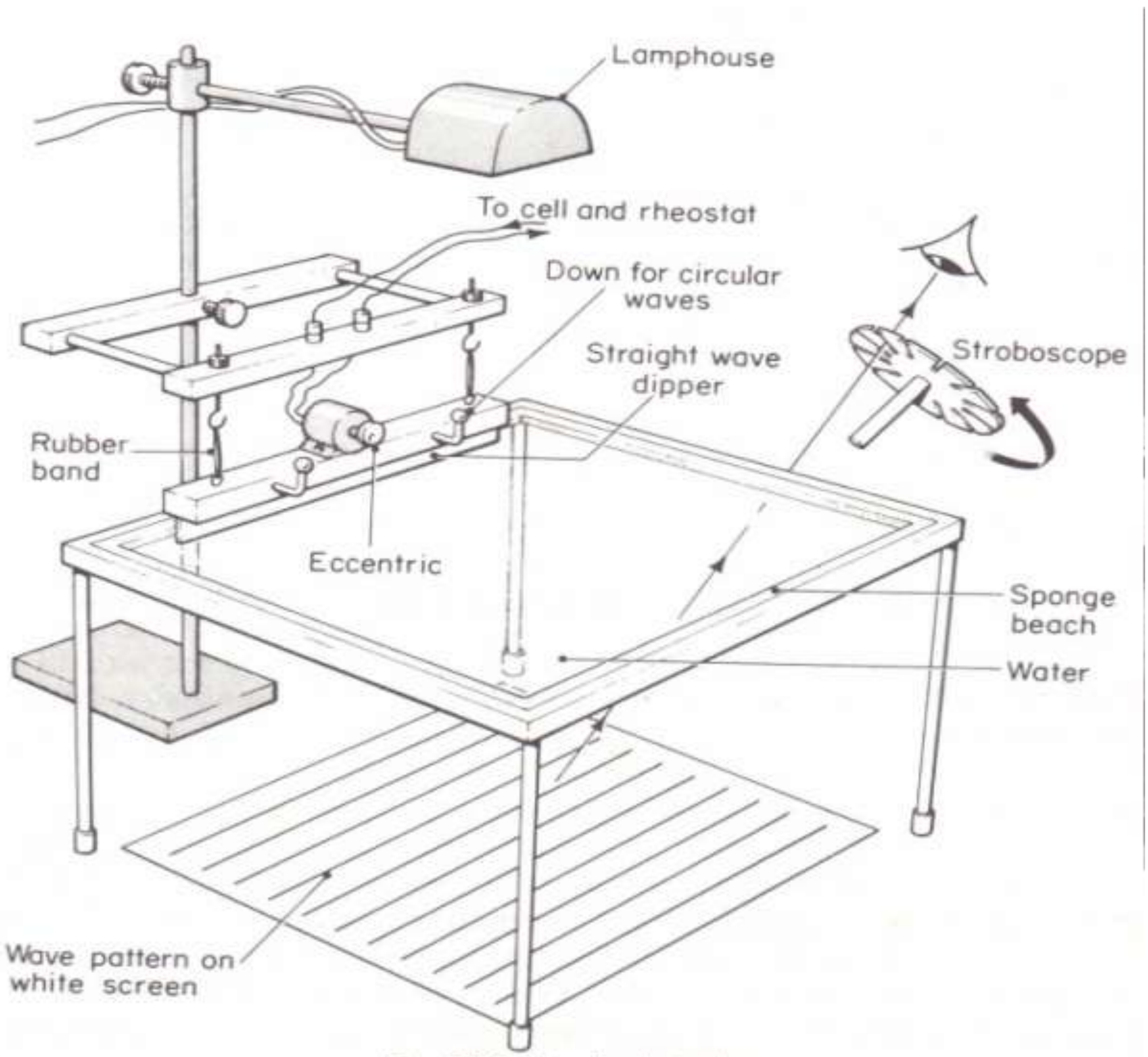
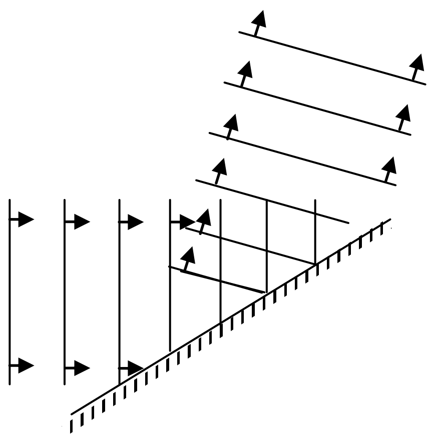


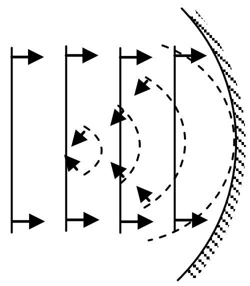
Fig. 26.3. The ripple tank

1. ***Reflection***

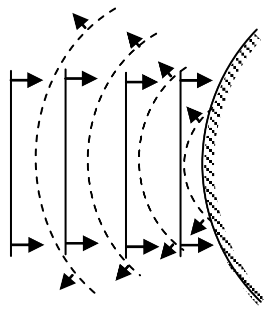
a) Straight waves on plane surface.



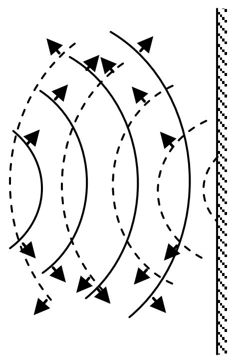
b) Straight waves incident on a concave circular reflector.



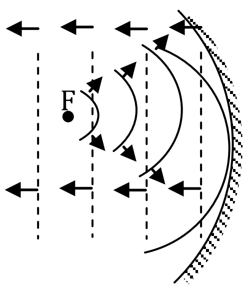
c) Straight waves incident a convex reflector.



d) Curved waves incident on a straight reflector.



e) Curved waves incident on curved reflector

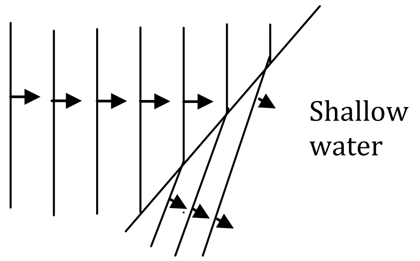


The shape of the reflected wavefronts depends on the relative position of the centre of the incident wavefronts. If the centre of the wave front coincides with the principal focus, F, of the reflector, the reflected wave fronts are straight and parallel. Otherwise they are curved either as concave or convex wave fronts.

2. *Refraction*

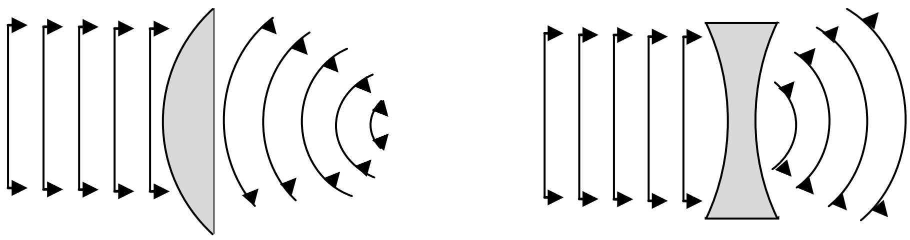
This is the change in direction of travel of a wave when it crosses from one medium to another due to change in speed.

a) Straight wave fronts meeting a plane boundary at an angle.



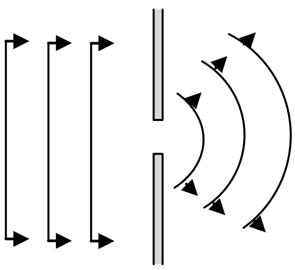
On crossing from deep to shallow:
- The speed of the wave decreases
- The wavelength decreases but
- The frequency remains the same
- Waves bend towards the normal line

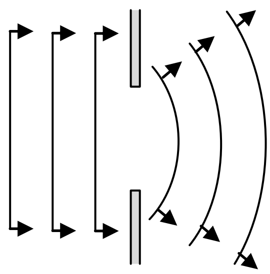
b) Refraction of straight waves at a curved boundary.



3. *Diffraction*

This is the spreading of waves when they pass through an opening or round an obstacle.

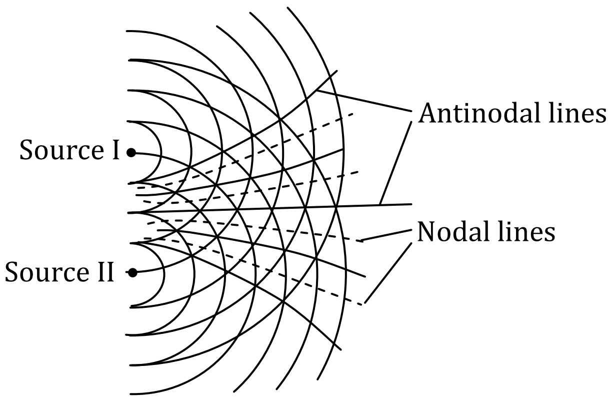

(i) Narrow aperture


(ii) Wider aperture

Diffraction is greater when the aperture is narrower

4. *Interference*

This is an overlap of two or more waves resulting in a pattern of alternate regions of high and low intensity.



Circular waves from sources I and II of the same frequency overlap in space.
At points where the two waves are exactly in phase the amplitude of the wave is increased and ***constructive interference*** is said to occur.A line joining such points in the direction of the wave is known as an ***antinodal line.***
At points where the waves are exactly antiphase, the amplitude of the resultant wave is zero (or minimum) and ***destructive inteference*** is said to occur. A ***nodal line*** joins points of destructive interference.

The distance between the nodal (or antinodal) lines increases:-

(i) As the distance from the sources S_1 and S_2 increases

(ii) When the separation of S_1 and S_2 is made smaller

(iii) If the wavelength increases (i.e as frequency decreases)

Types of Waves

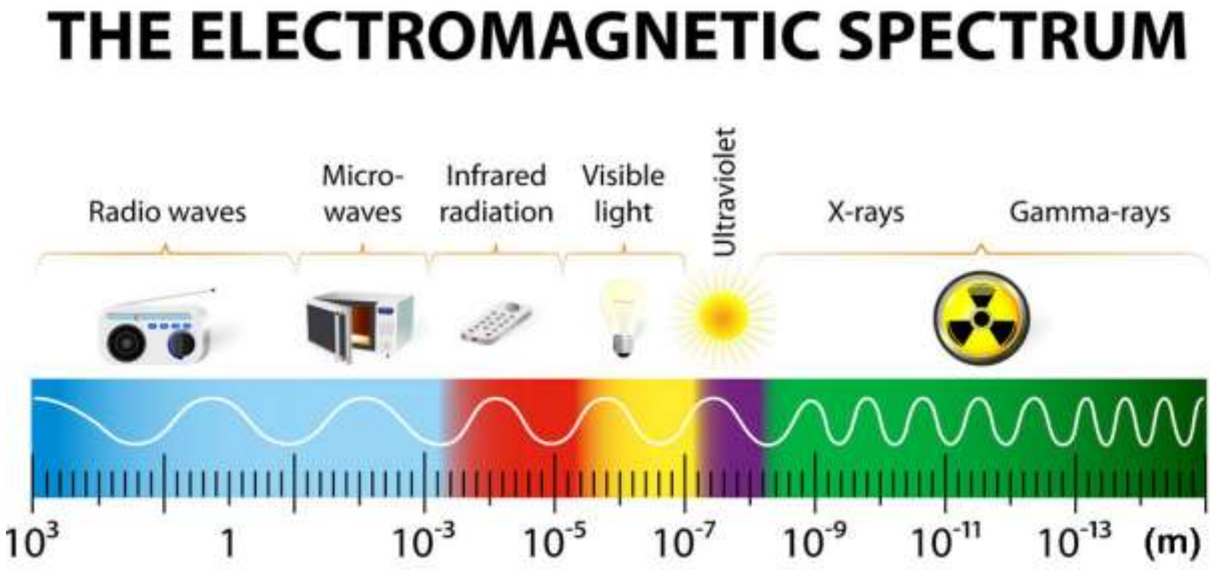
1) *Transverse wave*
   In a transverse wave the particles of the medium vibrate in a direction perpendicular to the direction of the wave travel e.g waves formed by a rope, water waves, (electromagnetic waves – these do not involve particles)

2) *Longitudinal waves*
   In these the particles of the medium vibrate in a direction parallel to the direction of wave travel e.g sound.

Electromagnetic Waves

These are produced by oscillations of electrical charge in a circuit. there are no particles involved. So, an electromagnetic wave does not require a material medium and therefore can travel through vacuum.

All electromagnetic waves are transverse and travel at the same speed. Examples include: X-rays, light, heat radiation, radio waves. Below is the electromagnetic spectrum.



MECHANICAL AND NON MECHANICAL WAVES

Mechanical waves require a material medium. Examples of mechanical waves are; sound waves, water waves, waves on strings, earthquake.

Non-mechanical waves don't require a material medium. Examples are electromagnetic waves. Have an electric and magnet component.

A mechanical wave travels by causing the particles of the medium to vibrate in a particular manner.
Non-mechanical waves do not cause particles of the medium to vibrate.

EXERCISE 1

SECTION A

1.

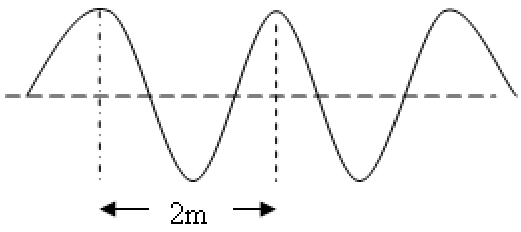


Figure above shows a wave produced in a string. If the frequency is 2Hz, at what speed do the waves travel along the string?

a. $0.5ms^{-1}$ b. $1.0ms^{-1}$ c. $2.0ms^{-1}$ d. $4.0ms^{-1}$

2. A longitudinal wave is one in which the

a) direction of propagation is parallel to that of the vibration producing it.

b) particles of the medium through which it travels move opposite to the direction of propagation.

c) direction of propagation is perpendicular to that of the vibration producing it.

d) particles of the medium through which it travels move together with it.

3. The number of complete oscillations made per second is referred to as

(a) periodic time (b) amplitude

(c) wave length (d) frequency

4. A source producing waves which travel a distance of 140cm in 0.08 s. If the distance between successive crests is 20cm, find the frequency of the source.

(a)	0.875Hz	(b)	8.750Hz
(c)	87.500Hz	(d)	8750Hz

5.

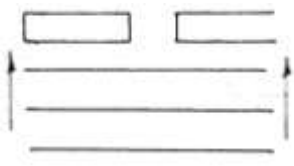


Fig.6

The diagram in the figure shows parallel wavefronts approaching a narrow gap. Waves passing through the gap are likely to under go

(a)	Reflection	(b)	refraction
(c)	diffraction	(d)	interference

6. Figure 3 shows waves spreading out from a point. The wavelength of the waves is

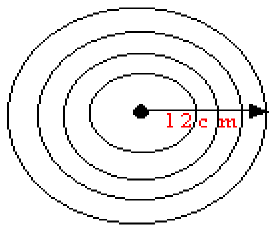


Figure 3

A. 3cm B. 6cm C. 9cm D. 12cm

7.

Vibrator	Wave Length	Frequency
Wave P	1,500 m	0.2 MHz
Wave Q	500 m	…………

The table above shows readings obtained by using a vibrator which produces waves of a constant velocity. Find the frequency of the wave Q.

A. 0.07MHz. B. 0.3 MHz. C. 0.6 MHz. D.1.2 MHz.

8. Which of the following statements is true about the wave traveling from one medium to another

(i) its frequency and wave length change

(ii) its frequency and velocity change

(iii) its velocity and wave length change

(iv) only the frequency remains unchanged

A. (i) only B. (i) and (ii) only

C. (i) and (iii) only D. (iii) and (iv) only

9. Water waves travel a distance of 36cm in 6s and the separation of successive troughs is 3.0cm. Calculate the frequency of the waves

A. 2Hz B. 12Hz. C. 18Hz D. 72Hz

10. The figure below shows circular waves incident on a plane reflector. Which of the following patterns represents the reflected waves.

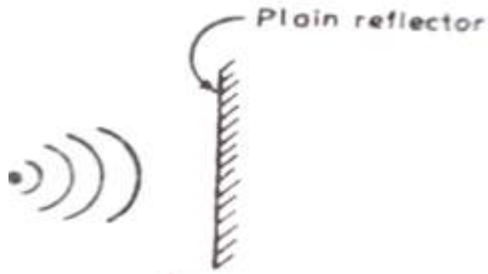
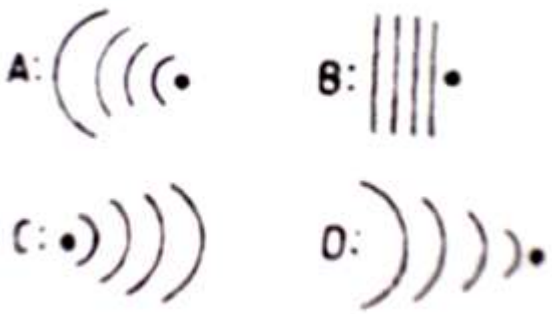


Fig.5



11. Which one of the following does not change when water waves travel through deep to shallow water

a) frequency

b) amplitude

c) velocity

d) wave length

12. Which of the following statements are true about refraction of waves

(i) the speed of waves changes

(ii) the wave-length changes

(iii) the direction of travel changes

(iv) the frequency changes

(a) (i) only

(b) (i) and (iii) only

(c) (ii) and (iv)

(d) (i), (ii) and (iii) only

13. Water waves are produced at a frequency of 5Hz and the distance between 10 successive crests is 18cm. calculate the velocity of the waves in ms^{-1}

(a) $9ms^{-1}$ (b) $0.09ms^{-1}$

(c) $0.1ms^{-1}$ (d) $1ms^{-1}$

14. Which of the following change(s) when water waves travel from a deep to a shallow region

1. Velocity

2. Amplitude

3. Wavelength

4. Frequency

A. 1 only

B. 2and 3 only

C. 1, 2 and 3 only

D. All

15. A vibrator produces waves which travel a distance of 12m in 4s. If the frequency of the vibrator is 2Hz, what is the wavelength of the waves?

a) 1.5m b) 3m c) 6m d) 24m

16. A vibrator produces waves which travel a distance of 35cm in 2s. If the distance between successive wave crests is 5cm, what is the frequency of the vibrator

A. 3.5Hz B. 7.0Hz C. 14.0Hz D.87Hz

SECTION B

1. (a) (i) Describe how the speed of waves in a ripple tank can be decreased

(ii) Explain the effect of decreasing the speed of the wave in (a) (i) on frequency

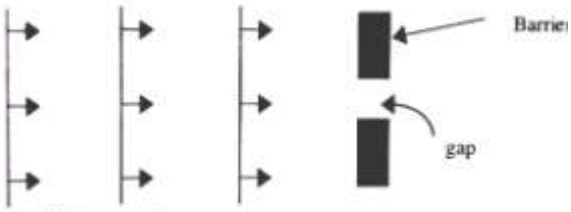
(b) With the aid of sketch diagrams, explain the effect of size of a gap on diffraction of waves

2. (a) With the aid of a diagram, explain the terms amplitude and wavelength as applied to wave motion.

(b) Derive an equation relating velocity, V, frequency, F and wave length of a wave.

3. (a) What is meant by a standing wave?

(b) Figure 11 shows plane waves approaching a gap in a barrier.



Plane waves

Fig. 11

(i) Show the diagram, the appearance of the waves after the barrier.

(ii) What is the effect of reducing the size of the gap?

4.

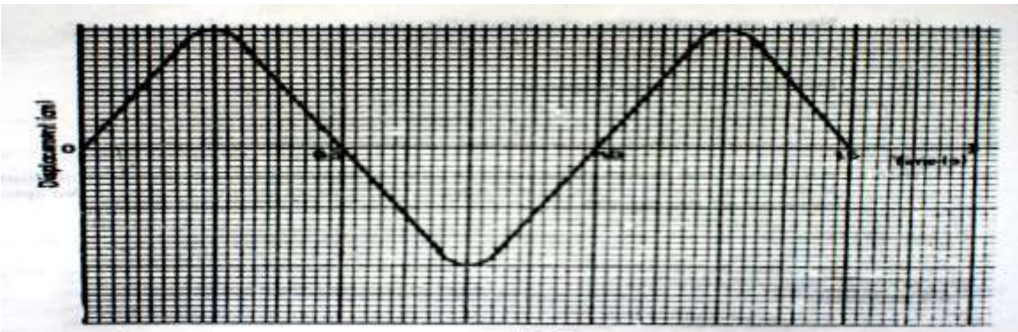


Fig.7

The diagram in the figure shows a section of a transverse wave of wave- length 4.0cm. find its

(i) frequency (ii) amplitude (iii) velocity

5. (a) The end Q of a rope is tied to a pole while the end P is moved up and down as shown in the figure below.

Sketch the resultant wave pattern between P and Q

(b) (i) Name the type of wave produced in (a) above.

(ii) Name one musical instrument which produces this type of wave.

6. (a) Describe how a straight wave is produced in a ripple tank.

(b) State the conditions of the occurrence of destructive interference of waves.

7. (a) What is a *transverse wave*?

(b) The diagram in figure 10 represents a wave traveling in water.

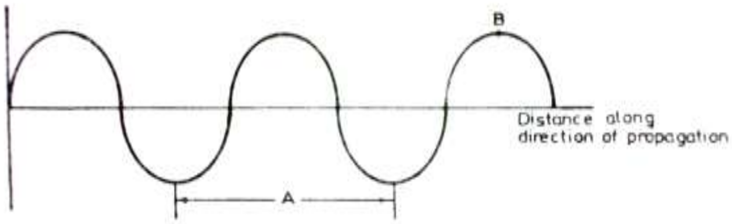


Fig 10

(i) Name the part labeled B .

(ii) If the distance represented by A is 20cm and the speed of the wave is 8.0 ms^{-1}, what is the frequency of the wave?

8. (a) Explain the difference between transverse and longitudinal waves.

Give one example of each

(b)

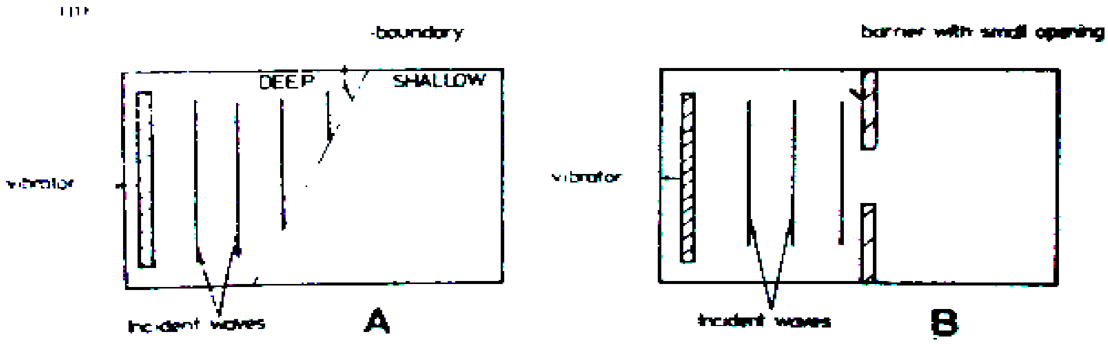


Fig. 3

The diagram in the above figure represents a place view of horizontal ripple tanks set up to study characteristics of water waves. The vibrators were set up to produce plane waves

(i) Draw diagrams to show the wave patterns in A and B

(ii) Explain what happens to the plane waves in each case.

9. A vibrator in a ripple tank vibrates at 5Hz. If the distance between 10 successive crests is 37.8cm, calculate

(i) the wavelength of the waves

(ii) the velocity of the waves

10. The figure shows waves propagating towards a concave reflector.

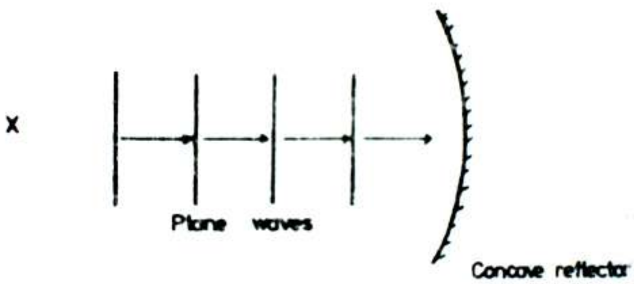
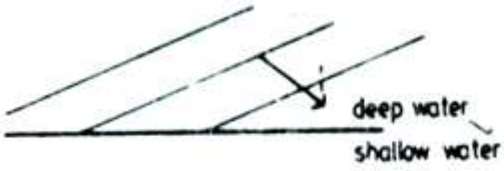


Fig. 2

(i) Draw a diagram to show how the waves will be reflected.

(ii) If the velocity of the waves is 320ms^{-1} and the distance between two successive crests is 10cm, find the period of the waves.

(b) Straight water waves travel from deep to shallow water as shown in the figure below



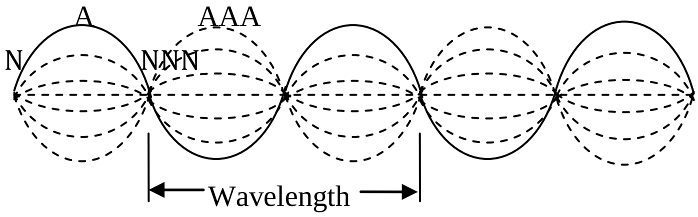
Copy and complete the wave front pattern in the shallow water.

Progressive and Stationary Waves

In a progressive wave the wave profile moves in the medium.

However, in a stationary wave the wave profile is stationary e.g. in a vibrating string of a stringed instrument.

Stationary waves

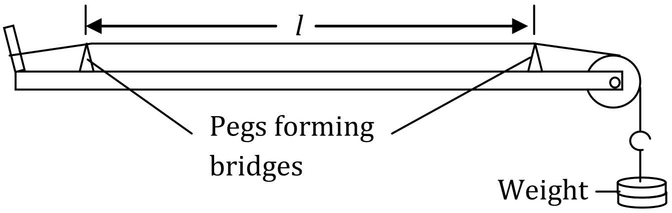


A node is appoint of zero amplitude. The particles at the node are not vibrating.
An antinode is a region of maximum amplitude. i.e moving from a node, the amplitude of vibration progressively becomes greater up to the antinode.
$\therefore$ Wavelength = 2NN = 4NA
i.e two loops make one wavelength.

Conditions for stationary wave
Two identical waves travelling in opposite directions must meet.

The Sonometer

This is an instrument used for studying behaviour of vibrating strings. It consists of a string or wire kept in tension by either a weight or other means.



When the string is gently plucked in the centre, waves travel out to the bridges and are then reflected back, thus setting up a stationary wave of the string (not of air).The

simplest wave produced will be that due to vibrations of the string as a single segment and the note given out is termed as the ***fundamental***.
If *l* is the distance between the pegs, then the fundamental has a wavelength equal to 2*l*.

Factors affecting the frequency of vibrating string

(i) ***Tension***: The higher the tension the higher the frequency.

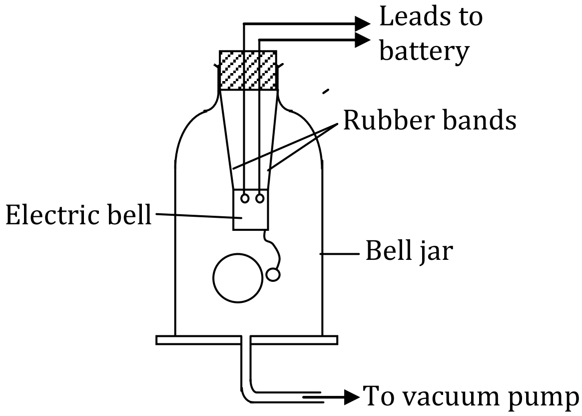
(ii) ***Length***: The longer the string the lower the frequency.

(iii) ***Mass per unit length***: The thicker the lower the frequency.

SOUND

Sound is a disturbance in a medium, carrying energy from one region to another with a frequency in the audio range. It is produced by vibration of its source. The vibrations cause the air in the neigbourhood to vibrate also at the frequency of the source. This disturbance travels out in the form of a longitudinal wave.
Sound, therefore, is a mechanical wave and cannot travel through a vacuum.
It can travel through matter in any state, i.e solid, liquid and gas. It obeys the same laws of reflection as light.

Experiment: To show that sound cannot travel through vacuum



- A small electric bell is hung from rubber bands inside a bell jar and switched on.
- A vacuum pump connected to the bell jar is operated to evacuate it.

Observation:
As the air is sucked out, the sound of the bell becomes fainter and fainter until it dies out completely, although the hammer can still be seen striking the gong. When now air is gradually allowed in, the bell is heard again and its loudness keeps on increasing with more let in.
This shows that actually sound requires a material medium for its propagation.

Factors affecting speed of sound in air

1) ***Temperature***:- speed of sound increases as temperature rises. This is because air particles move faster at higher temperature.

2) ***Humidity***:- speed of sound increases with humidity,

3) Speed of the air in which sound is moving

NB: Pressure does not affect speed of sound in air.

Sonic and Ultrasonic Sound

The audio frequency range for human beings is between 20Hz and 20,000Hz. If sound has a frequency higher than 20,000Hz, then it is ***ultrasonic*** and cannot be detected by the human ear.Sound of lower frequency than 20Hz is ***subsonic***.
If the speed of sound in air is 330 ms^{-1}, calculate the range of wavelength of audible sound to a human being.

Echoes

An echo is reflected sound. Echoes can be an advantage or a disadvantage
The characteristics of a building in relation to sound (i.e the absorption or reflecting behaviour for sound), is termed the *acoustics of a building*.
Reverberations are the multiple reflection of sound especially in a building.
In large halls multiple sound reflections can occur from roofs and floor. In some cases, this is undesirable e.g. in a concert hall. It may take about 5s for the organ to die away after the organist has stopped playing, whereas when the cathedral is full of people, this may take about 1s.This is because in an empty cathedral, the only surfaces to absorb sound are the roof, walls, floor and may be some additional furniture implying longer time for sound to die out but when it is full of people, people's soft bodies and clothes occupy much of the space and on the whole reflection of sound is reduced.

A building is said to be ***acoustically dead*** if no multiple reflections of sound occur in it. Such rooms are used in investigation of the properties of sound equipment.

Applications of Echoes

- In fathometers for measuring the depth of the sea.
- In ultrasound equipment used in hospitals for producing pictures of internal parts of the body.
- In industries for checking the quality of certain products.
- In radar equipment for finding distances of various objects from the transmitter using high frequency radio-waves.

Measurement of speed of sound in air by echo method

Two experimenters standing at least 100m from a wall are required

- One claps together two pieces of wood and listens to echoes
- He keeps clapping and gradually changing the frequency of the clapping until apparently no echo is heard.
- Then his colleague starts the stop clock and finds the time for a good number of claps e.g 30 or more.
-

The time taken between claps is calculated

$$\text{Then, speed of sound } = \frac{\text{2 x distance from the wall}}{\text{Time between claps}}$$

The value of velocity obtained may an error due to the following factors:
- Human reaction time in timing the sound when it is made and heard
- Interference due to sound and echo when the distance between is small
- Wind

Comparison of Sound Waves and Light Waves

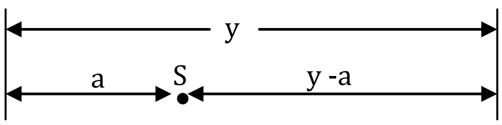
SOUND WAVES	LIGHT WAVES
- Mechanical in nature - Longitudinal in propagation - Need a material medium - Travel at much lower speeds - Havelonger wavelength	- Electromagnetic in nature - Transverse in nature - Can travel in vacuum - Travel at much higher speed - Have shorter wavelength

Exercise: Compare sound waves with water waves.

Example:

A boy standing between two parallel cliffs, but nearer to one of them, makes a loud noise. He hears one echo after 1s and another after 2s. If the speed of sound is 330 ms^{-1}, calculate the distance between the two cliffs.

Solution



Suppose that one cliff is a metres from the source S and that the cliffs are y metres apart. Then, if the distance 2a took 1 s, the distance 2(y – a) took 2 s.
Since the velocity of sound is the same for both distances, it follows that

$2a = 330 \times 1$

$\therefore \quad a = 165$ m

And $2(y - a) = 330 \times 2$

$\therefore \quad y - a = 330$

$\therefore \quad y = 330 + a = 330 + 165 = 495$ m

MUSICAL SOUNDS

Music is a combination of sounds of regular frequencies, while noise is a combination of sound of irregular frequencies.

Pitch: This is the position of a note on the musical scale. It depends on the frequency of the note i.e the higher the frequency the higher the pitch.
The ratio of frequencies of two notes is called the musical interval between them.

Intensity and Loudness of Sound

The intensity of sound is the rate of flow of energy per unit area perpendicular to the direction of the wave. It depends on:

1) Density of air

2) Frequency of sound

3) Amplitude

Quality (or Timbre) of a musical note

The same note played on two instruments does not sound the same. The notes are said to have different quality. This is because sounds (except those produced by tuning forks) are never of one frequency. They consist of a main, or ***fundamental note***, which usually dominates, plus others with smaller intensities and higher frequencies called ***overtones***.
The fundamental is the component of lowest frequency. The overtones have frequencies which are multiples of the fundamental frequency.
The quality of sound is determined by the number and intensity of overtones.

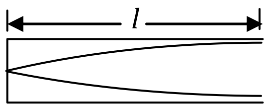
Harmonics and overtone in pipes

A harmonic is a note whose frequency is a simple multiple of the fundamental frequency.The fundamental is the first harmonic.
If f_o is the fundamental frequency, then a note of frequency $2f_o$ is the 2nd harmonic, that of $3f_o$ the 3rd harmonic, and so on.

Stationary Sound Waves in Pipes

There are two types of pipes, namely closed and open-ended. In a closed pipe one end is closed while in an open one both ends are open. A stationary wave will be formed in a pipe if the closed end corresponds to a node and the open end to an antinode. We shall compare the stationary waves in the two types.

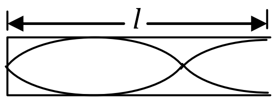
Closed-end pipe



The simplest harmonic, the fundamental, is one for which the length of the pipe is one quarter of the wavelength.
Let λ_o be the wavelength of the fundamental note and V the velocity of sound.

Then $l = \frac{1}{4}\lambda_o \therefore \lambda_o = 4l$ and the fundamental frequency,

$$f_o = \frac{V}{\lambda_o} = \frac{V}{4l}$$



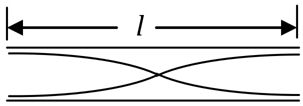
The next harmonic to be obtained is such that the length l of the pipe is equal to ¾ of the wavelength, say λ_1, as shown.
Thus, $l = \frac{3}{4}\lambda_1$

$\therefore \lambda_1 = \frac{4l}{3}$, and the frequency, $f_1 = \frac{V}{\lambda_1} = \frac{3V}{4l} = 3f_o$

i.e, the frequency is three times the fundamental frequency. So, this is the third harmonic. But realise that it is the first overtone.

You may prove that the next harmonic will have a frequency equal to $5f_o$, hence it will be the 5^{th} harmonic. Can you guess the next one?
It can be realised that only odd-numbered harmonics are possible in a closed pipe.

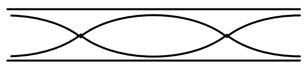
Open Ended Pipe



The simplest harmonic, the fundamental, is one for which the length of the pipe is half of the wavelength.

Let λ_o be the wavelength of the fundamental note and V the velocity of sound.
Then $l = \frac{1}{2}\lambda_o$, $\therefore \lambda_o = 2l$ and the fundamental frequency,

$$f_0 = \frac{V}{\lambda_0} = \frac{V}{2l}$$



The next harmonic to be obtained is such that the length l of the pipe is equal to the wavelength, say λ_1, as shown.

Thus, $l = \lambda_1$ and the frequency,

$$f_1 = \frac{V}{\lambda_1} = \frac{V}{l} = 2f_0$$

i.e, the frequency is twice the fundamental frequency. So, this is the second harmonic. In fact you may prove that in open-ended pipes all harmonics are possible.
So closed-end pipes produce purer but less loud sound since some harmonics are suppressed. On the other hand, open ended pipes produce louder sound but of more inferior quality.

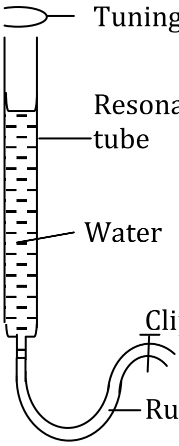
Resonance

Resonance is an increase in the amplitude of a vibrating system as a result of impulses received from some other system also vibrating at the natural frequency of the system.

Experiment: To Demonstrate Resonance in a closed Tube

- A resonance tube is almost filled with water

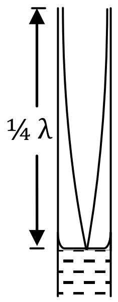
- A tuning fork is sounded near and above the mouth of the tube while the water level is allowed to fall gradually.



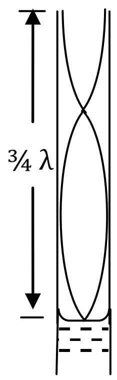
Observation:

At some level the sound suddenly becomes louder. Resonance is said to have occurred.

Explanation



Sound from the tuning fork travels down and is reflected by the water surface and a stationary wave is formed of a node corresponds to the water level.
The air column in the tube = ¼ λ



If the water level is lowered further, another point is reached lower down for which resonance again occurs. The air column = ¾ λ

Experiment to measure speed of sound in air by the resonance tube

- The resonance tube is first filled with water
- A tuning fork of known frequency is sounded near and above the mouth of the tube, and the water level is lowered slowly until the sound increases in intensity. Then the length of the air column is measured and noted. It is equal to a quarter of the wavelength (λ).
-

Let l = length of the air column

f = frequency of the fork

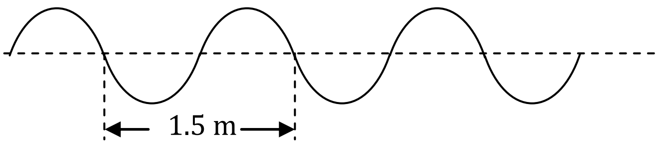
Then $\lambda = 4l$

$\therefore$ Velocity, $V = 4fl$

EXERCISE 2

1. A vibrator produces a sound wave that travels 660 m in 2s. Given that the wavelength is 1.32 m, find the frequency of the vibrator.

2. The figure shows a wave produced in a string at a frequency of 2 Hz.



Find the speed at which the waves travel.

3. An echo sounder on a ship sends down a pulse through the water and receives its echo 1.2 s later. What is the depth of the water, if the speed of sound in water is 1350 m s^{-1}?

4. A boy standing between two walls makes a loud sound. He hears the first echo after 1 s and the second after 2 s. find the distance between the two walls if the speed of sound is 330 ms^{1}