WAVES

Types of Waves

Pulses

Pulses are disturbances or a single wave motion. A continuous production of pulses will give rise to a progressive wave (wave train).

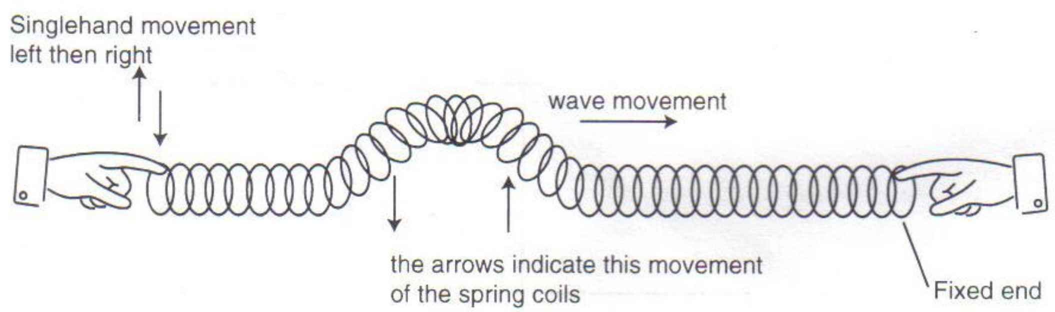


Fig. 8.1 *Producing a single pulse in a slinky.*

Progressive Waves

A progressive wave is the movement of a disturbance which carries energy away from a source.

Stationary Waves

A stationary wave is a disturbance which does not travel and is produced by the simultaneous traveling of two identical waves in opposite directions. Net energy is not taken to nor delivered to the source.

There are two types of waves:

i. Transverse Waves
ii. Longitudinal Waves

Transverse Waves

If you hold a slinky, while having the other end fixed, and waggled it from side to side, you will see that coils of the slinky move in the same way as your hand movement. The wave moves in one direction while the oscillations of the slinky move at right angles to it.

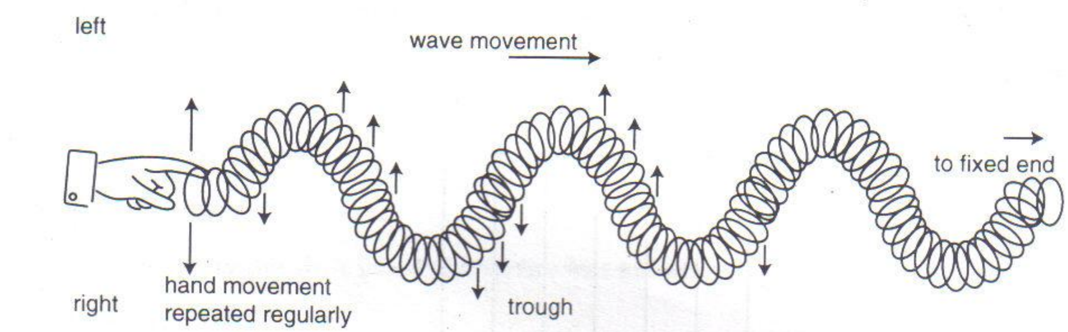


Fig. 8.2 ***Transverse wave***

A transverse wave is one which the displacement of the particles is at right angles to direction the wave is traveling.

Longitudinal Waves

If you push and pull one end of a slinky (while the other end is fixed) you will notice that the parts of the slinky move forward and backwards in the same direction the wave is moving.

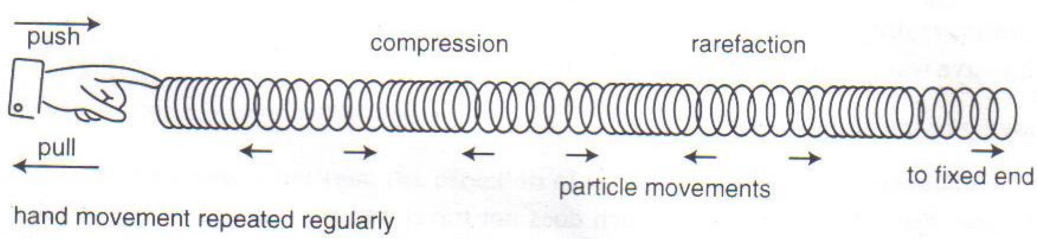


Fig. 8.3 ***Longitudinal wave***

A longitudinal wave is one in which the displacement of the particles is in line or parallel to the direction in which the wave is moving.

Ripple Tank

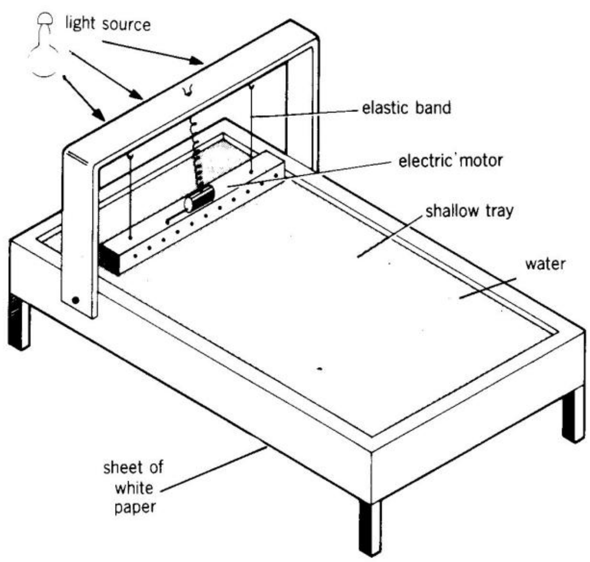


Fig. 20.4 Ripple tank

We can also use a ripple tank to observe waves. If we set up the ripple tank as shown in the diagram (and dip a pencil into the water without touching the bottom or shaking the tank), we will see that pulses create waves which have circular wave fronts.

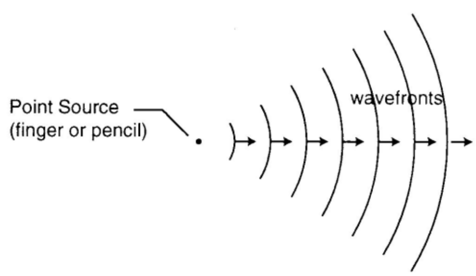


Fig 8.4a: Circular wavefronts in ripple tank.

If we take a straight bar and dip it in and out of the ripple tank quickly, the waves that are produced are called plane surface waves.

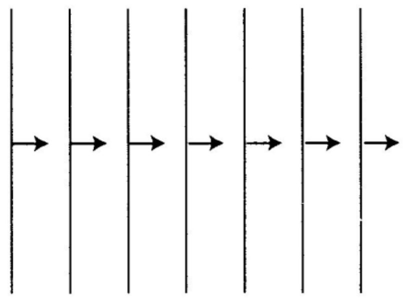


Fig 8.4b. Plane wave fronts in ripple tank.

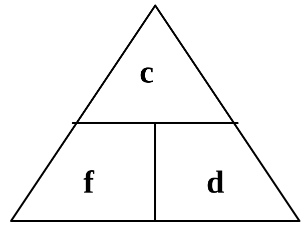
Wave Parameters

Speed (*c / v*) **Units:** ***m/s***

The speed is the distance moved forward by the crest/ trough (compression / rarefaction) in one second. This is the speed of propagation or travel of the wave.

speed = frequency * wavelength

$$c = f * d$$
$$v = f * \lambda$$



Frequency (*f*) **Units:** ***Hertz (Hz)***

The frequency is the number of waves passing any given point in one second or the number of complete vibrations made in one second.

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

Wavelength (*λ*) **Units:** ***metre***

The wavelength is the distance between two adjacent or successive crests/ troughs/ compressions/ rarefactions. Therefore, the wavelength is the distance between two successive particles which are exactly at the same point in their points at the same time and moving in the same direction.

Period (*T*) **Units:** ***seconds***

The period is the time taken for a particle to complete one oscillation.

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

Amplitude

The amplitude is the height of the crest or the depth of a trough measured from the undisturbed position (i.e. It is the maximum displacement of a particle from the rest position)

Phase

The phase is a measure of timing relationship between two waves or two different points on one wave.

Graphs

We can use two types of graph to represent a wave:

(A) Displacement – Position Graph

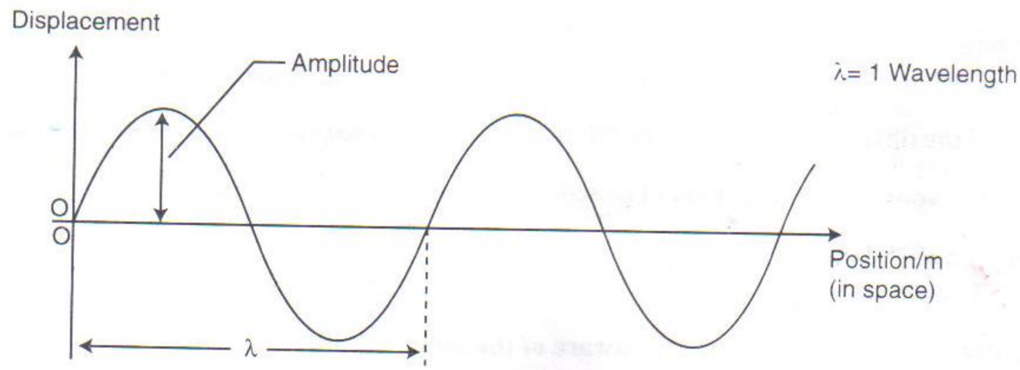


Fig. 8.5 *Displacement-position graph of a wave*

A displacement - position graph is like a photograph of a transverse wave at a given instant in time. It gives the information about the displacements at different positions along the wave ***at a given instant***.

It is not possible to determine if the wave is a transverse or longitudinal by looking at the graph. It is not possible to extract time related information from this graph.

(B) Displacement – Time Graph

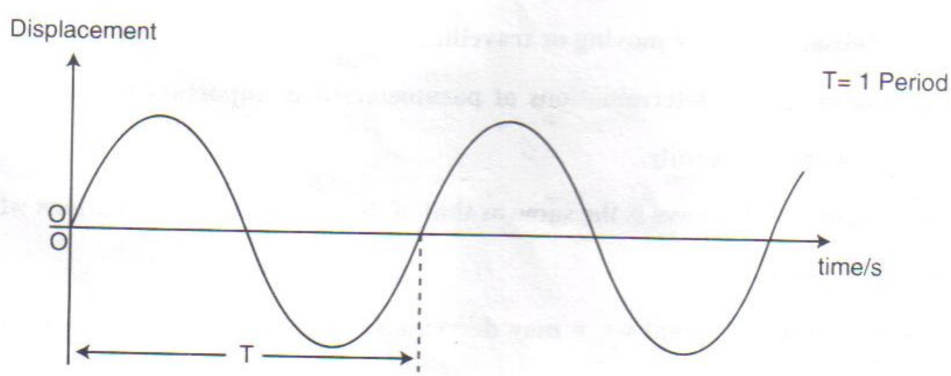


Fig. 8.6 *Displacement-time graph of a wave.*

The displacement – time graph applies to the vibration of an arbitrarily chosen single particle in a wave. It is not possible to determine if the wave is transverse or longitudinal and it is not possible to deduce the wavelength or the speed from this graph.

Summary

Displacement – Position Graph	**Displacement – Time Graph**
Represents all the wave particles at an instant	Represent the motion of ONE wave particle over a period of time
Can obtain: ▪ Amplitude ▪ Wavelength	Can obtain: ▪ Amplitude ▪ Period
Cannot determine time – related information	Cannot determine wavelength or speed related information.
Cannot determine if the wave is a transverse or longitudinal wave	Cannot determine if the wave is a transverse or longitudinal wave

Properties of Waves

All waves have the same properties of

i. Reflection
ii. Refraction
iii. Diffraction

Reflection

We can use water waves to observe their behaviour. Observation of the water waves show that when they reach a barrier or the boundary of the water, they are sent backwards (reflected). The properties of water waves are similar to those of light rays and the effect is similar to that of light rays reflecting in a mirror.

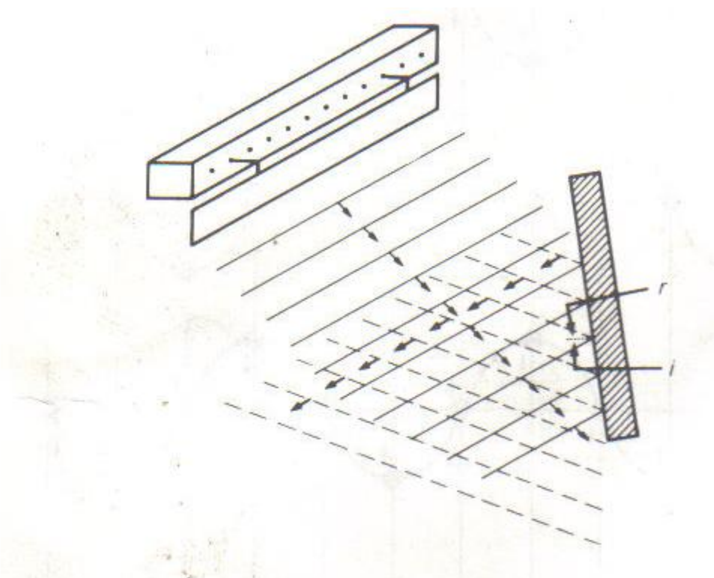
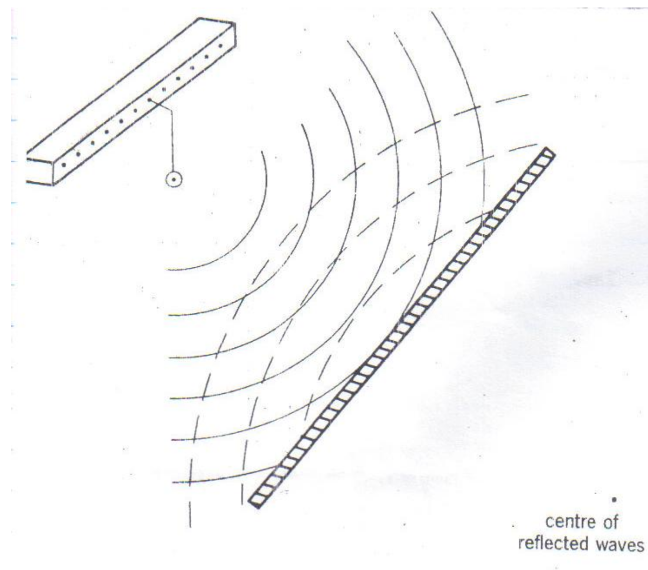


Fig. 20.5 Plane waves



Reflection of circular waves

The laws which govern the reflection of light also apply to the reflection of waves, provided that we can properly relate the wave diagrams to the equivalent ray diagrams.

Laws of Reflection:

i. The angle of incidence and the angle of reflection are equal
ii. The incident ray, the reflected ray and the normal all lie in the same plane

Refraction

Water waves refract as they move from one depth of water to another. Refraction occurs because the wave changes speed as it crosses the boundary.

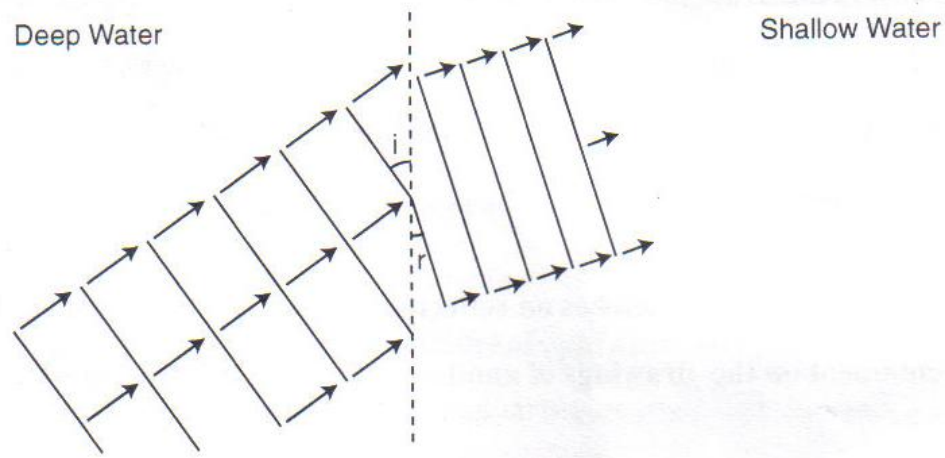


Fig. 8.8 *Oblique refraction of plane waves.*

We can observe this change when surface water waves are at a boundary between deep and shallow water.

This phenomenon relates the change of direction to the change of speed as the wave travels from deep to shallow water.

The frequency of the wave remains unchanged during refraction but the velocity and the wavelength changes.

We can find the refractive index of the wave by using Snell's Law

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Diffraction

Waves bend around gaps and edges of obstacles. This bending is called diffraction. Plane waves can generate circular waves when diffraction occurs.

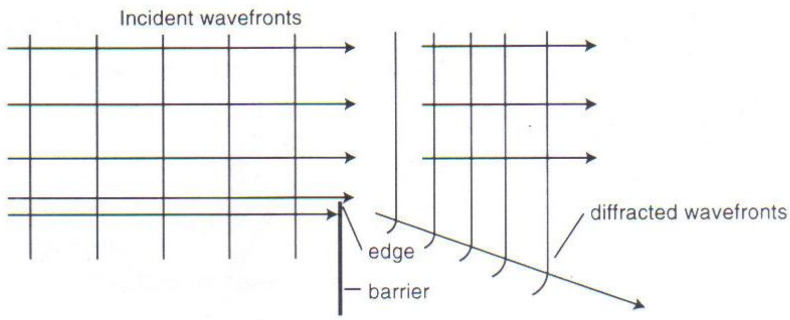


Fig. 8.13 *Diffraction at an edge*

When the wavelength is small compared to the gap we can see diffraction at each edge.

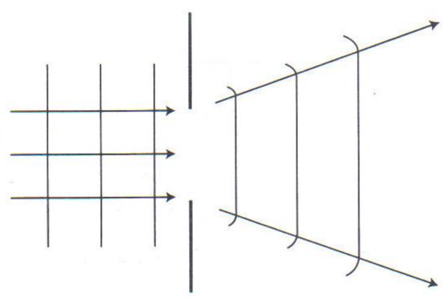


Fig. 8.12 *Diffraction at wide gap*

When the gap is small compared to the wavelength we obtain circular waves.

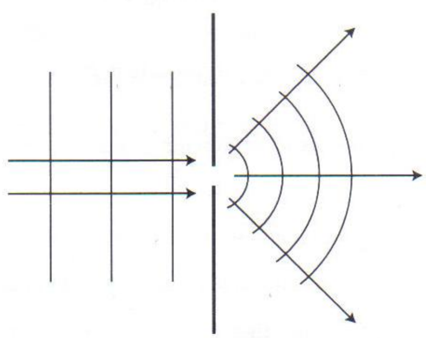


Fig. 8.14 *Diffraction at a narrow gap*

We can obtain greater diffraction either by decrease the size of the gap or increasing the wavelength of the incident wave.

There is no change in frequency or wavelength results from diffraction.

Interference

When two waves of the same kind meet each other (superpose), their individual effects combine and a resulting effect is produced. The net displacement is the sum of the original displacements of the two waves.

We can demonstrate this type of interference by using a monochromatic source of light and double slit as shown in the diagram below.

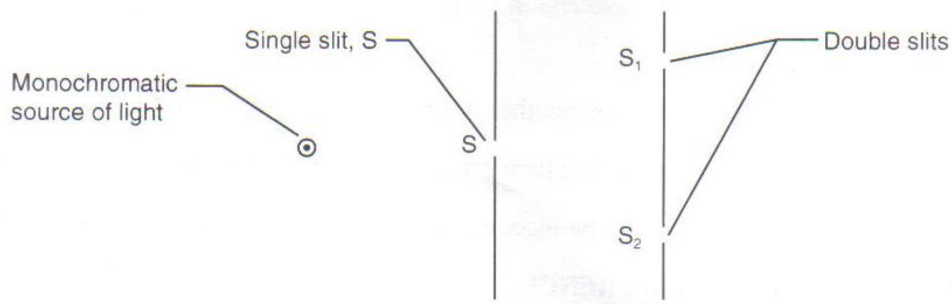


Fig 8.9 *Plan of two coherent sources of light*

The emerging wavetrains of light will have the same frequency and a constant phase relationship with each other. The two illuminated slits are called ***COHERENT SOURCES*** of light.

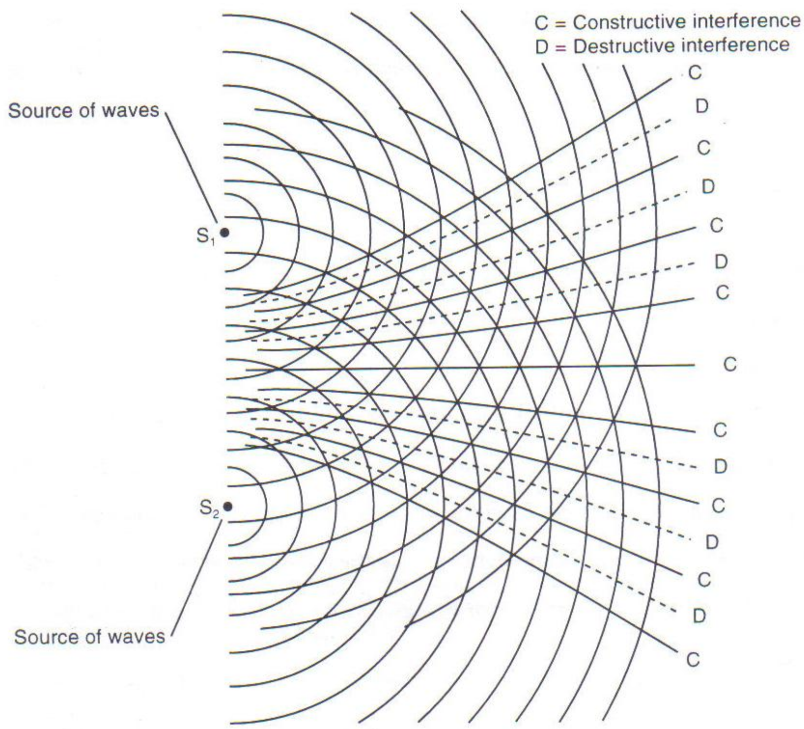


Fig 8.16 *Interference pattern of two coherent point sources of water waves.*

We can also demonstrate interference by using the ripple tank. The same effect can be obtained by using plane waves that are incident to two small gaps. Circular waves are formed at gaps and interference occurs as a result of the circular wave overlapping.

If the slit spacing increases then the lines of interference becomes close together. However, if the wavelength of the wave increases then the lines of interference moves further apart.

Constructive Interference

When two waves meet in phase, i.e. the crest of one wave falls on the crest of another wave (or trough of one wave falls on the trough of another wave), the result is a large displacement.

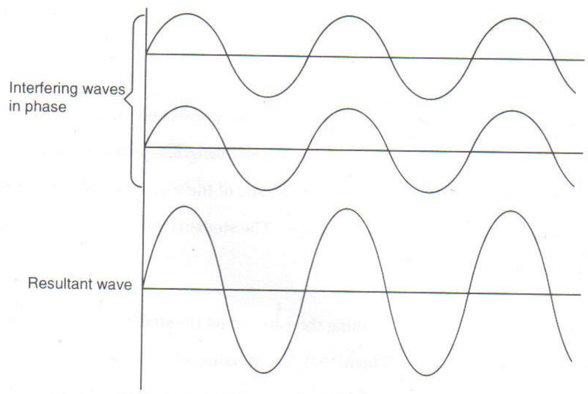


Fig 8.10 *Constructive interference.*

Destructive Interference

When two waves meet out of phase, i.e. the crest of one wave falls on the trough of another wave), the result is cancellation.

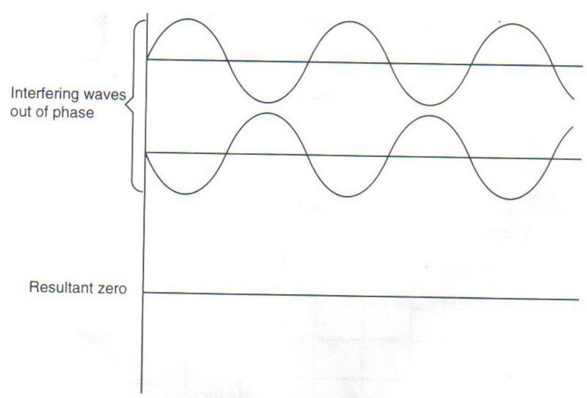


Fig 8.11 *Destructive interference.*

SOUND WAVES

Production and Propagation

Sound is produced by vibrating systems. The table below gives examples of musical instruments and the vibrating systems linked to them.

MUSICAL INSTRUMENT	VIBRATING SYSTEM
guitar	strings
drum	stretched skin
flute	column of air
whistle without ball	air
tuning fork	prongs

The vibrating systems affect the particles of the medium in which they vibrate. Sound is propagated as a longitudinal wave and sound energy moves in a set of compressions and refractions.

We can demonstrate that sound does not travel in a vacuum by using one of the apparatus below.

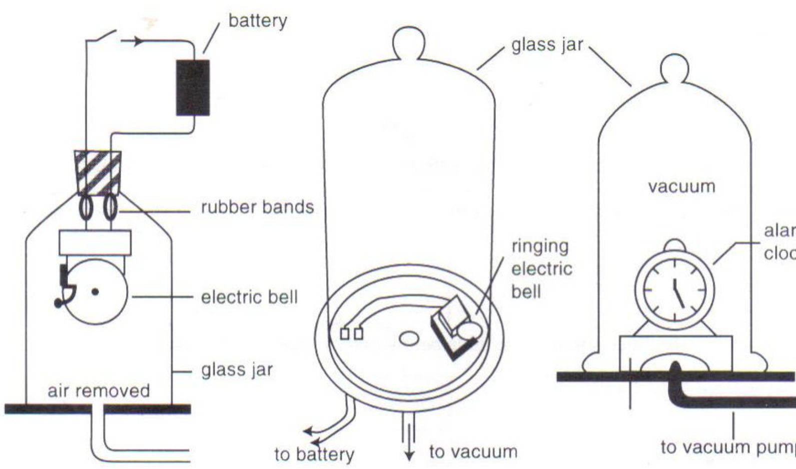


Fig. 8.18 Three ways to show that sound waves cannot pass through a vacuum.

Before the vacuum pump is turned on, air is in the pump and the bell is heard. However, when the air is pumped out, no sound is heard even though the hammer is hitting the gong. This demonstrates that sound cannot be transmitted in a vacuum: a material medium is necessary.

Speed

The speed of sound in air is approximately 330 m/s at a temperature of 0^oC but varies depending on the temperature.

We can estimate the speed of sound in air. First find a large wall or building which will be used as a reflector for sound. Then stand a known distance, about 100 m, from the wall and clap hands together and listen for an echo. Repeat the clapping until the echo is heard clearly.

Increase the clapping until each clap coincides with the echo heard. Measure the time for 50 claps and divide by 50 to find the time taken for one clap. This is the time for the sound to travel to the wall and return as the echo.

We can calculate the speed of sound by using the equation:

$$\textit{speed} = \frac{2 * \textit{distance between the wall and the source}}{\textit{time interval between echoes}}$$

Audio Frequencies

Sound can be produced with different frequency and can be classified as a pure note, a musical note or noise. When notes are composed with a single frequency they are usually pleasing to the ear.

Musical notes consist of waves having fundamental frequencies and other frequencies called overtones. These overtones are produced when the vibrations take place in a different manner from that of the fundamental.

Noise is sound which made up of a mixture of frequencies which are not overtones and maybe unpleasant to the ear.

Musical notes have three main properties:

The Pitch
The pitch of a note is its position in the musical scale. It measures how high or low the note sounds. As the frequency increases the pitch also increases.

Loudness
Loudness is the magnitude of the sensation produced when a sound reaches the ear. The larger the amplitude of the vibrations reaching the ear, the louder the sound is heard.

Quality
The quality distinguishes between musical notes of the same frequency played on different instruments. The way an instrument sounds is called its quality or tone.

Reflection

We can demonstrate that sound waves can be reflected, by using apparatus shown in the diagram below.

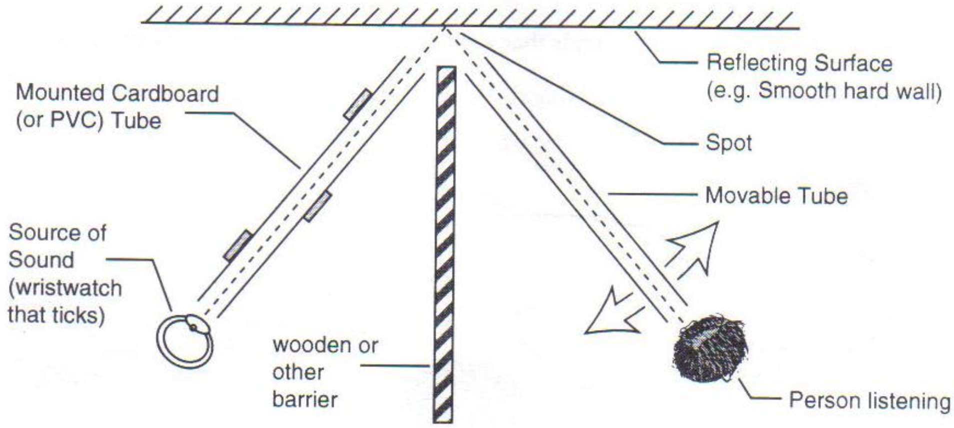


Fig. 8.19 ***Reflection of sound.***

A cardboard tube is mounted using a retort stand and directed towards a hard smooth wall. A mark was made where the sound beam is expected to strike and another tube was placed where the reflected tube would be. The tube was adjusted until a position was found where the reflected sound was the loudest.

From this experiment we can determine that the angle of incidence is equal to the angle of reflection and that sound obeys the law of reflection.

Hard smooth surfaces reflect sound. However, soft surfaces such as curtains and carpets are good absorber of sound. Reflected sound is called an echo and plays an important role in allowing us to hear sounds.

Refraction

We can demonstrate that sound waves can be refracted, by using apparatus shown in the diagram below.

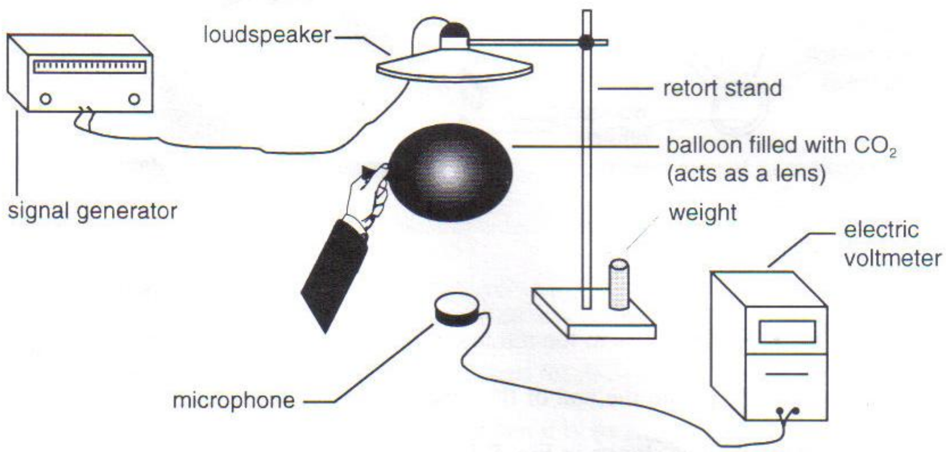


Fig 8.20 *To show refraction of sound waves.*

A loudspeaker is connected to a signal generator and hung in a retort stand. A microphone is connected to an electronic voltmeter directly below the loudspeaker. The signal generator is turned on and level of sound picked up by the microphone on the electronic voltmeter is noted.

A balloon filled with carbon dioxide is placed between the loudspeaker and the microphone and the level of sound picked up by the microphone is noted.

The balloon acts as a lens since sound travels more slowly in carbon dioxide than in air at the same temperature and pressure. Thus the sound is refracted and focused and this explains why the level of sound increases when the balloon is placed in the space.

Diffraction

Sounds of high frequency have waves of small wavelengths and sounds of low frequency have waves of great wavelengths. Diffraction of sound occurs when the gap is the same size compared to that of the wavelength of the sound. If the gap is just wider than the wavelength the sound spreads and allows us to hear around corners. If the gap is much larger than the wavelength, it does not spread as much and the diffraction is limited.

ELECTROMAGNETIC WAVES

Electromagnetic (e.m.) radiation is an example of transverse wave because it involves electric and magnetic fields oscillating perpendicular to the direction in which the radiation is travelling. All e.m. waves travel with equal speed in a vacuum. The character of an e.m. wave is determined by its frequency. The electromagnetic spectrum is a classification of e.m. waves according to their frequencies. The number of complete vibrations in one second is the frequency of the e.m. wave. Since all e.m. waves have the same speed in a given medium, the wavelength of any e.m. wave is determined solely by its frequency, as can be seen from the basic wave equation,

$v = f\lambda$ (symbols have their usual meanings)

So in any particular "medium" (vacuum included), f and λ are inversely proportional to each other.

The electromagnetic spectrum consists of the following types of radiation in order of decreasing frequency: gamma-rays, X-rays, ultra-violet rays, visible light, infra-red rays, microwaves and radiowaves. Each type of radiation encompasses a range of frequencies but it should be emphasized that each type of radiation merges into the next and that there are no sharp lines of demarcation between adjacent types. In other words, the e.m. spectrum is a continuous spectrum.

A unique characteristic of electromagnetic waves is their speed in a vacuum. Regardless of the character of the e.m. radiation, the speed is the same in a vacuum and equal to 3×10^8 ms^{-1} a speed which is of fundamental physical significance.

E.m. waves are distinguished by their frequencies (or wavelengths in a given medium). Below is a table of the different types of e.m. waves and their respective ranges of frequencies and wavelengths in a vacuum.

Range of Frequencies and Wavelengths for e.m. waves

TYPE OF E.M. RADIATION	RANGE OF FREQUENCIES	RANGE OF WAVELENGTHS (IN A VACUUM)
Gamma rays	(∞ to 5 x 10^{18}) Hz	(0 to ~ 6) x 10^{-11} m
X-rays	(∞ to ~ 5 x 10^{17}) Hz	(0 to ~ 6) x 10^{-10} m
UV rays	(~ 8 x 10^{16} to ~ 8 x 10^{14}) Hz	(~ 4 to ~ 400) x 10^{-9} m
Visible Spectrum	(~ 1 x 10^{15} to ~ 4 x 10^{14}) Hz	(~ 3 to ~ 7) x 10^{-7} m
IR rays	(~ 4 x 10^{14} to ~ 3 x 10^{11}) Hz	(~ 7 x 10^{-7} to ~ 1 x 10^{-3}) m
Radio Waves	(~ 5 x 10^{10} to 0) Hz	(~ 1 x 10^{-3} to ~ 1 x 10^{5}) m

Radio waves comprise micro-waves, TV waves, short waves and long waves (for broadcasting).

The wavelengths increase in the order in which they are listed, microwaves having the least and the long radiowaves the greatest wavelength.

The properties of e.m. radiations are determined by their frequencies.

Gamma rays	**X-rays**	**Ultraviolet**	**Visible light**	**Infra-red Radiation**	**Radio Waves**

The electromagnetic spectrum

All these go by the name of electromagnetic radiation. They are all transverse waves, and they all travel through a vacuum at the sped of light. At the right hand end of the chart, radio waves have a relatively great wavelength. These wavelengths must penetrate the atmosphere better than visible light, since radio signals are not cut off on a foggy day.

Different radio stations use different wavelengths for their broadcasts. These radio waves are produced by high frequency oscillations of electrons in aerials. Radio waves with wavelengths of a few centimeters are used for line-of-sight links, satellite links and possible local distribution systems.

Uses of Electromagnetic Radiation

In the physical world electromagnetic waves are involved in a vast number of natural and artificial processes.

Every object in our environment emits and receives electromagnetic radiation of different frequencies and wavelengths in an inevitable process of energy transfer.

The electromagnetic radiation involved in this underlying process, whether naturally occurring or artificially set-up, usually bears characteristics which can convey information about its source, the physical processes involved in its production and even about the media through which it may have been transmitted before being received.

The Earth is continuously being bathed in electromagnetic radiation emitted by the Sun, unquestionably still its most important source of energy. Both man and other living creatures are virtually dependent on the e.m. waves received from the Sun.

The study of electromagnetic radiation has enabled us to obtain information about the position, size, temperature and aspects of the processes which occur in the Sun and other celestial objects. Knowledge about e.m. waves has enabled mankind to utilize many of the more subtle properties and characteristics of all types of electromagnetic radiation to accomplish some of his goals.

Its great speed of transmission, its rectilinear and non-rectilinear propagation, its ability to retain its original frequency, its invisibility, its relatively easy generation and detection, have all been the bases of uses or applications of electromagnetic radiation of a wide range of frequencies.

From a general perspective, electromagnetic radiation is used for illumination, for penetration of matter, for surveying and measurement, for signals and communications in general and for transmission of energy in highly collimated or focused beams.

The hazards presented by over-exposure to some forms of electromagnetic radiation require that its uses and applications be based on sound scientific principles.

Read and make notes on:

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- vibrations in a vacuum
- reflection of sound
- refraction of sound waves
- beats
- music and noise
- direction and measuring sound
- human ear
- the problem of noise

Page 435 - 439

- electromagnetic family
- above visible light
- below visible light
- radio waves