PHY 102

COMPILED BY OLAKUNLE

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RIV UXG

27. WAVES

27.1 Wave

A wave is a disturbance which travels through a medium and transfers energy from one point to another, without any permanent displacement of the medium itself. And wave motion is a process of transferring a disturbance (in form of kinetic energy) from one point to another in a medium without any transfer of the particles of the medium.

27.2 Class of Waves

Waves are generally classified into: (i) mechanical waves (ii) electromagnetic waves.

Mechanical waves: These are waves that require a material medium for their propagation, e.g. water waves in ripple tank, sound waves, etc.

27.3 Ripple Tank

Ripple tank is an experimental setting used to study water waves. A rectangular dish with clear glass vase consisting of a pond of water. A dipper is used in producing water waves. The dipper is in a form of a vertical plane metal or small square. An electronic motion is fixed on the dipper or at the back in order to cause rotation. The electric motor makes the dipper vibrate up and down on the water. A lamp is fixed at the upper part of the system, which lights up the water surface from above or below so that the ripples can be seen.

When the electric motion is switched on and the dipper is adjusted and dipped inside the water, wave travels across the water. An instrument called *stroboscope* is used to make the wave appear stationary in the whole process. Thus, the water can be seen moving across the surface. The waves are studied when they appear stationary.

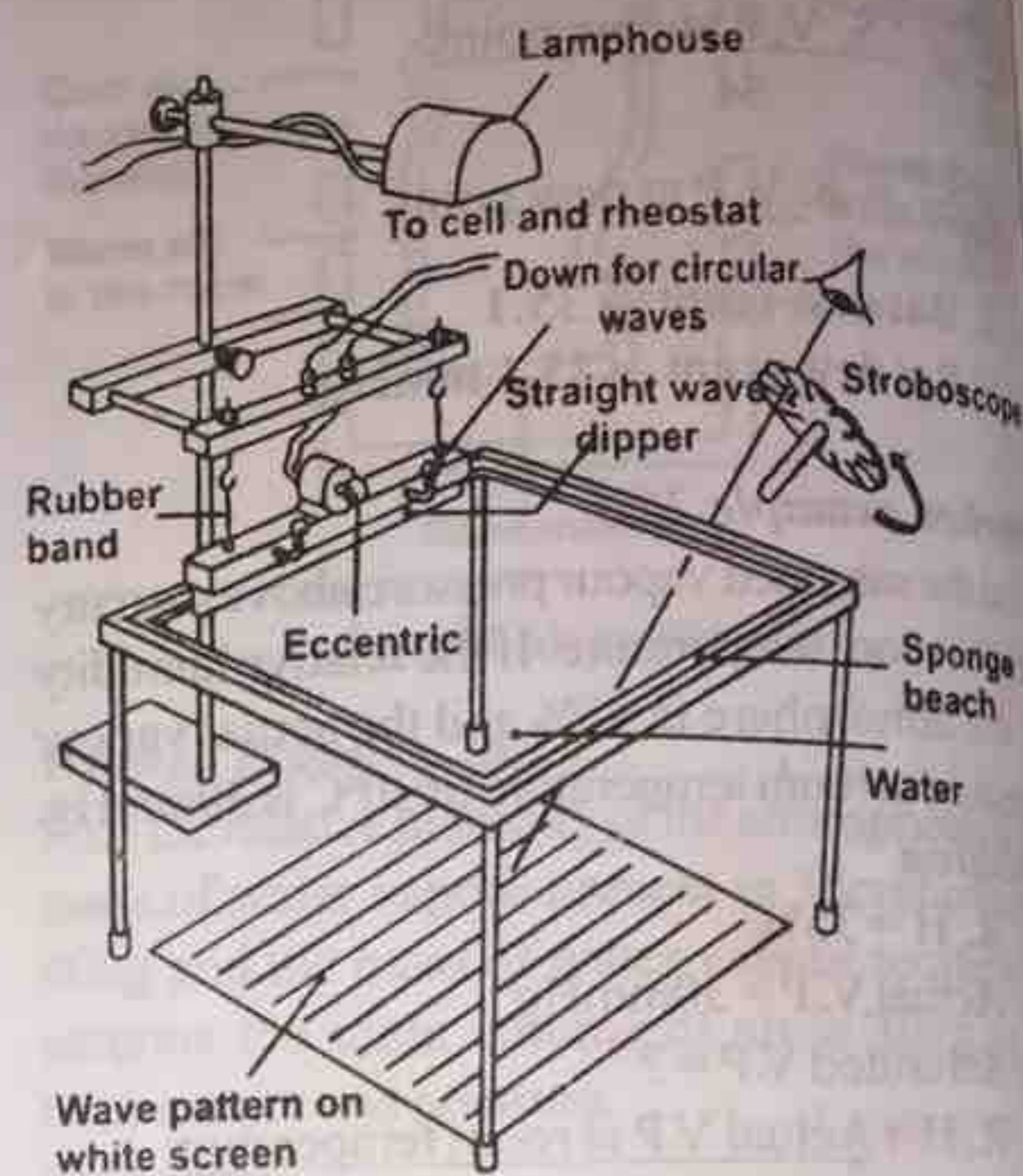

Fig. 27.1 The ripple tank

27.4 Electromagnetic Waves

These are waves that do not require or need a material medium for its propagation, but they travel successfully in free space (vacuum).

They travel with the speed of light in a vacuum(3×10^8m/s) on a straight line. They exhibit or show all properties associated or connected with light. They are undeflected in electric and magnetic fields. Electromagnetic waves are produced when electrical charges are accelerated and each with a particular wavelength and frequency but the same velocity.

Electromagnetic spectrum: Electromagnetic spectrum is defined as the range of all radiation possessing the special characteristics of electromagnetic waves arranged in order of their wavelength or frequency. The electromagnetic spectrum is made up of: radio waves, infra-red radiation, visible (light) rays, ultra-violet rays, x-rays, gamma (γ) rays, etc. They can also be represented in their first alphabet as RIVUXG in their correct order.

R	I	V	U	X	G
Radio rays	Infra-red rays	visible light	ultra-violet rays	X-rays	gamma rays

→ Increasing velocity, decreasing wavelength, Increasing frequency.

Electromagnetic spectrum

Radiation	Wavelength(m)	Frequency (Hz per sec)
Radio waves	10^{-3}	10^{4}
Infra-red	10^{-6}	10^{10}
Visible (ROYGBIV) light	$(4.5\text{-}70) \times 10^{-7}$	10^{12}
Ultra-violet	10^{-8}	10^{14}
X -rays	10^{-10}	10^{16}
Gamma rays	10^{-12}	10^{18}

27.5 Uses of Electromagnetic Waves

1. Radio-waves: These are first spectra of low frequency and velocity but of longer wavelength than any other spectrum. Their wave ranges from 10^{-2}m-10^{-3}m. They are used for carrying radio signals from the station to the radio set..

2. Infra-red radiation: The wave has longer wavelength and produces sensation of heat. It ranges from 10^{-5}m-10^{-6}m. It is also used for vision in the dark. (snooper-scope)

3. Visible light: It provides radiant energy and makes things possible to be seen. The wavelength ranges from 4.5×10^{-7}m red light to 7.0×10^{-7}m in violet.

4. Ultra -violet rays: These are the spectra that are formed beyond the violet end of the visible spectrum. They cause some materials to fluorescent and affect photographic plates. Their wavelength varies from 10^{-7}m to 10^{-8}m..

5. X-rays : The rays have very short wavelength of the order 10^{-10}m but also have a very high frequency and acceleration in which they move. They can be easily detected by placing a photographic plate along their path of propagation. It is used for medical diagnosis.

6. Gamma rays: These are the spectra of the highest frequency but of shortest wave length of the order 10^{-12}m. They are produced by radio active material by using Geiger muller tube detector. They give a great penetrating power and are unaffected by magnetic and electric field. They are used for cancer treatment and quality control.

27.6 Distinctions / Differences between Electromagnetic Waves and Mechanical Waves.

Electromagnetic waves	Mechanical waves
1. Travel with the velocity of speed of light (3.0×10^{8}m/s)	Travel with a velocity less than the speed of light.
2. Material medium is not required but travels successfully through vacuum (free space)	Material medium is required.

27.7 Types of Mechanical Waves

1. Transverse wave: This is wave which travels perpendicularly in the direction of the propagation or vibration of the waves. Examples are water waves in ripple tank, waves on plucked string and electromagnetic waves such as light waves, radio-waves, x-rays, etc.

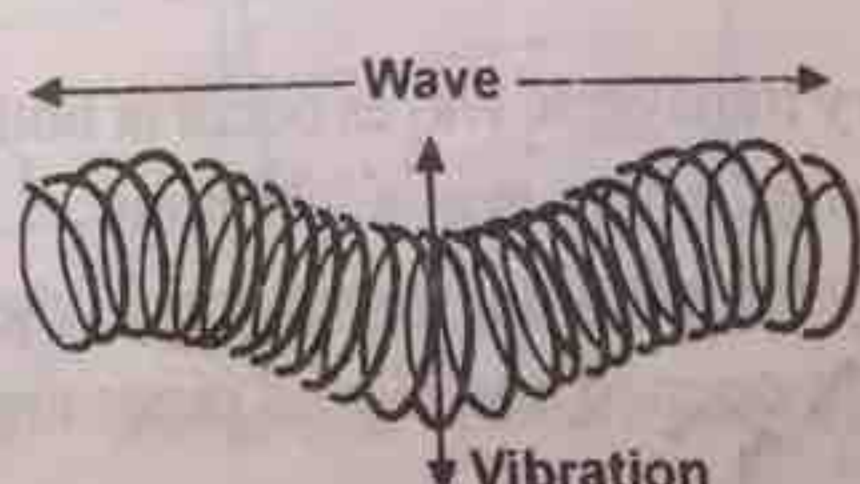

Fig. 27.2 Transverse wave

Transverse wave occurs when a piece of rope is tied on one end to a fixed point. It is seen to move up and down in a direction perpendicular to its length.

2. Longitudinal waves: These are waves in which the vibration occurs in the same direction travelled by wave, e.g. sound waves in the direction of air particles is the same as the sound waves. Most musical instruments are played either by vibration of stretched strings or by the vibration of air pipe. Vibrations are also in the form of longitudinal wave.

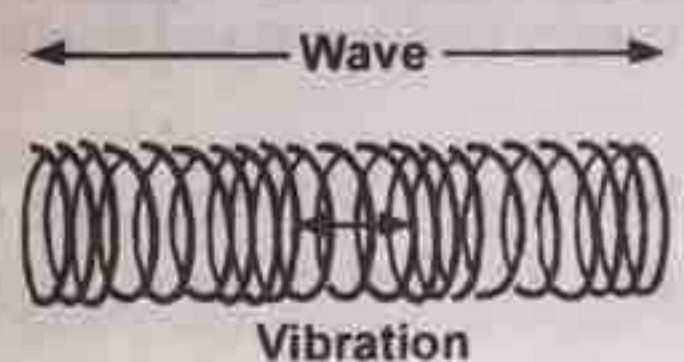

Fig. 27.2 Longitudinal waves

3. Standing/Stationary waves: When two simple harmonic waves of the same amplitude, frequency and time, are travelling in opposite directions in a linear or straight line, the resultant wave obtained is called *stationary waves.*

Thus, stationary/standing waves are due to the interference of two waves travelling in opposite direction. For them to interfere, they must have the same frequency and amplitude. e.g. sinusoidal waves.

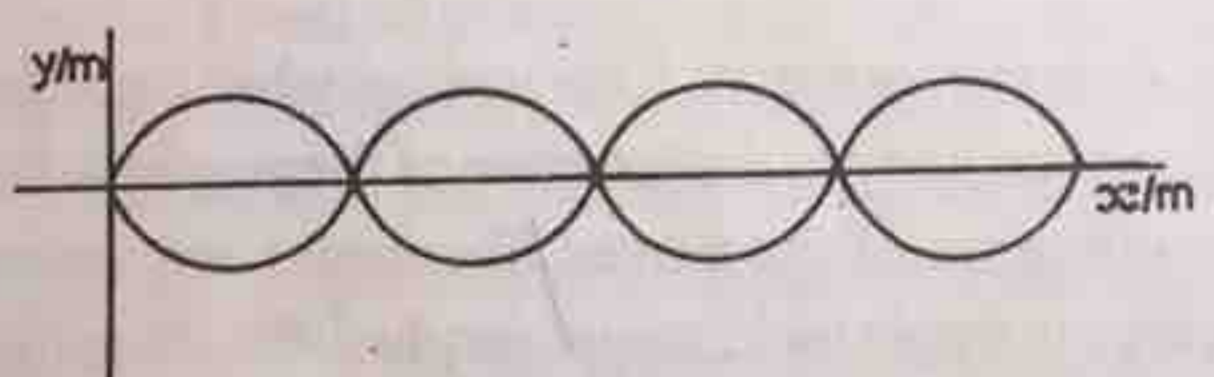

Fig. 27.3 Standing/Stationary waves

Stationary transverse waves occur at both ends of a fixed string, when set into vibration.

Stationary longitudinal waves occur when the air particles in opened and closed pipes are set into vibration.

4. Progressive or Travelling waves: This occurs when a travelling wave moves continuously from one point to another. It is a continuous process of vibrations of either a string or air pipe. Vibrations of particles in a progressive wave are of the same frequency and amplitude, but the phase of the vibration changes for different points along the wave. Examples of progressive waves are longitudinal and progressive waves.

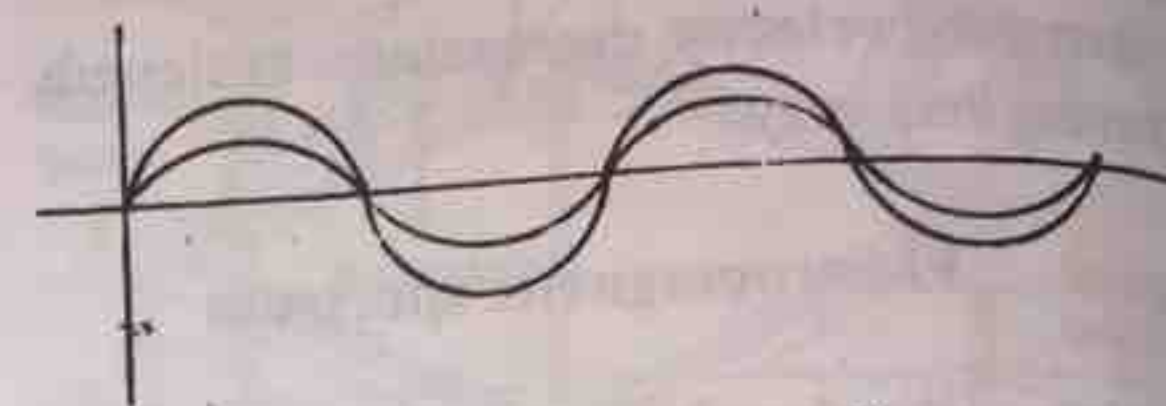

Fig. 27.4 Progressive or travelling waves

27.8 Terms Used in Wave Motion

1. Amplitude: This is the maximum displacement of a particle from the point of rest. It is denoted by A and measured in metre(m).

2. Wavefront: Wavefront is any line or section taken through an advancing wave in which all particles are in the same phase. It indicates a series of up and down movements along the water wave and stroboscope.

3. Phase: Phase is defined as the ratio of the displacement of the vibrating particle at any instant to the amplitude of the vibrating particles.

4. Vibration: This is the "to and fro" movement of a particle from the one extreme position to the other and back.

5. Wavelength: This is the distance between two successive crests or troughs of the wave. It is denoted by λ (lamda) and measured in metre(m).

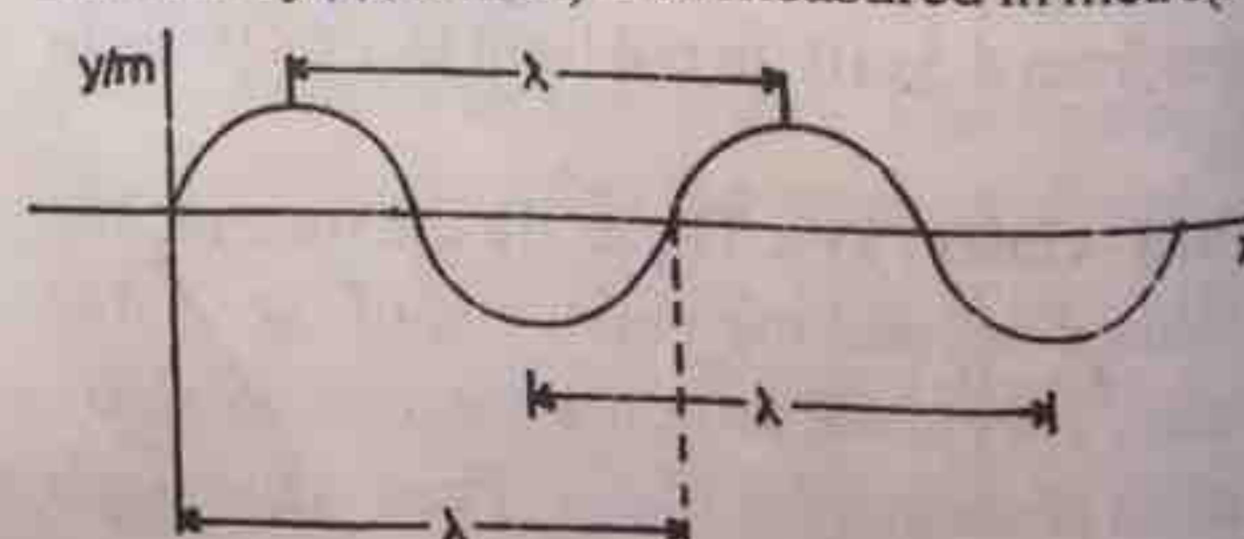

Fig. 27.5 Wavelength

6. Period: This is the time taken for one complete oscillation. It is denoted by T, measured in seconds.

Thus, $T = \frac{2\pi}{w}$

$w = 2\pi f$

$$T = \frac{2\pi}{2\pi f} = \frac{1}{f}$$

7. **Frequency (f):** The number of cycles which the wave completes in one second is called the frequency, f. Frequency is measured in cycles per second which are called Hertz (Hz). Large units are Kilo Hertz, KHz, and Mega Hertz, MHz. 1KHz $= 10^3$Hz, 1MHz $= 10^6$ Hz).

27.9 Properties of Waves

1. **Reflection:** This is the change in the direction of waves when they hit an obstacle. The type of waves formed depends on the type of obstacle they hit or meet. For instance, straight and parallel waves are set up from a plane metal strip standing upright in the water of a ripple tank. Similarly, when the plane metal is replaced by curved metal strips, the reflection rays form a spherical wave.

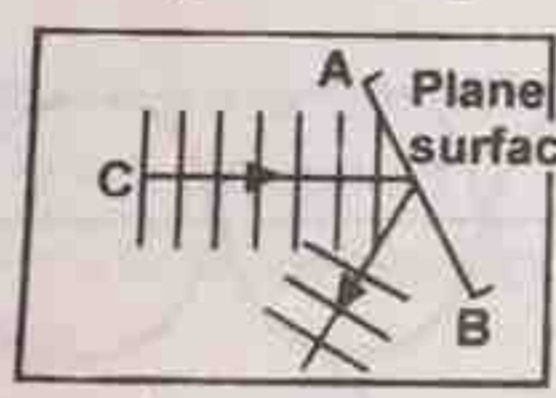

Fig. 27.6(a) Reflection on a plane surface in a ripple tank

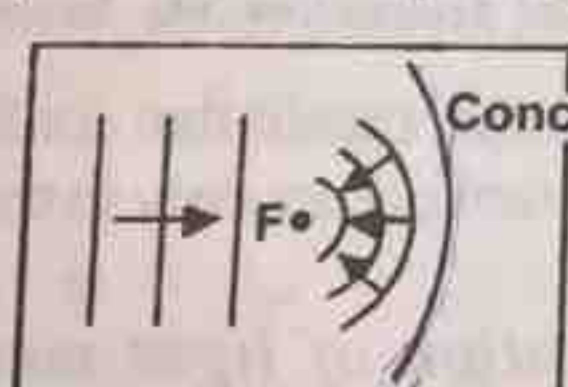

Fig. 27.6(b) Reflection on a concave surface in a ripple tank

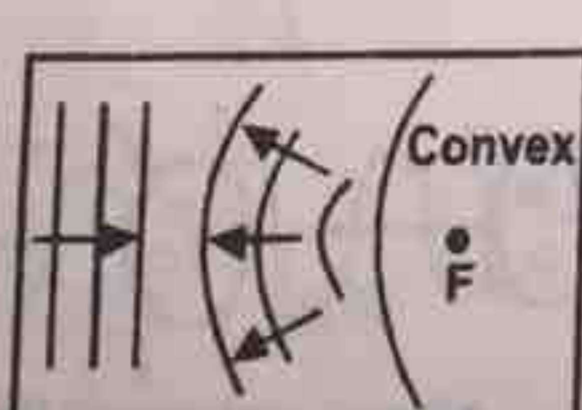

Fig. 27.6(c) Reflection on a convex surface in a ripple tank

2. **Refraction:** This occurs between two media, when wave direction of propagation changes as it enters a different medium. When straight waves pass from deep to shallow water, their wavelength becomes shorter. During this process, the frequency remains the same, but the wave-length varies. It is clear from Figure 27.7 below that wavelength has changed from λ_1 to λ_2.

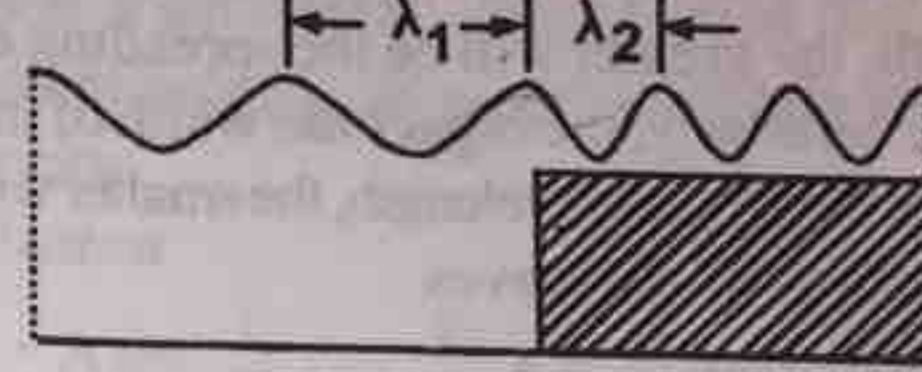

Fig. 27.7 Refraction in shallow and deep waters

***NB:** Waves travel more slowly in shallow water (same frequency shorter wavelength)*

Therefore, the refractive index for water passing from deep to shallow water:

$$n = \frac{\sin i}{\sin r} = \frac{\lambda_1/AB}{\lambda_2/AB} = \frac{\lambda_1}{\lambda_2}$$

velocity in deep water $= V_1 = f\lambda_1$

velocity in shallow water $= V_2 = f\lambda_2$

Thus, refraction index(n), $\frac{V_1}{V_2} = \frac{\text{velocity in deep water}}{\text{velocity in shallow water}}$

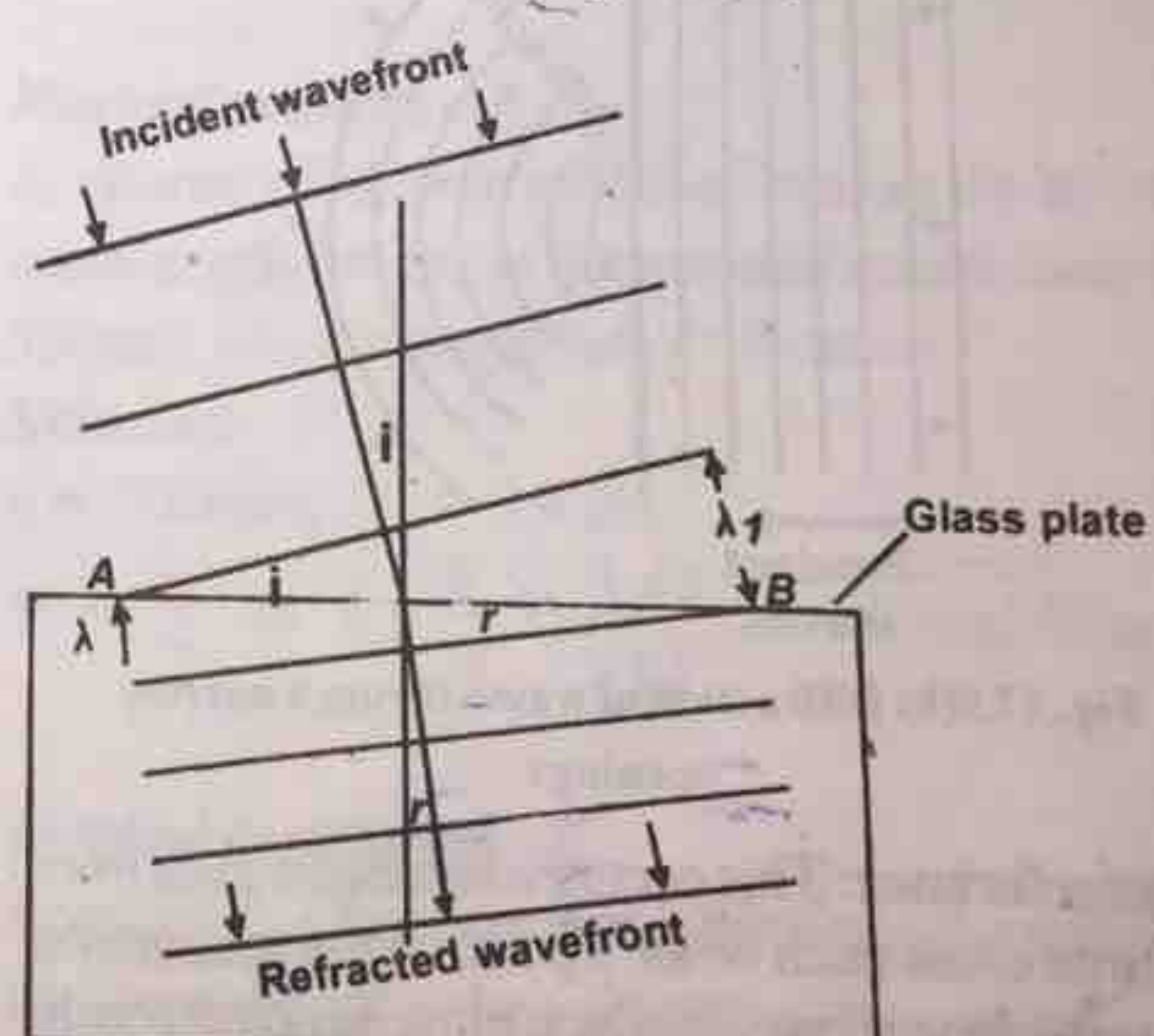

Fig. 27.8 Refraction of waves at a plane boundary

Huygens (Figure 27.8) considered the case of plane light waves being refracted from one medium