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Waves & Optics (B.Sc.)

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Chapter 4
Sound

Sound: Sound waves, production and properties. Intensity and loudness of sound. Decibels. Intensity levels. musical notes. musical scale. Acoustics of buildings (General idea).
(6 Lectures)

Q:derive an expression for velocity in longitudinal sound waves in a solid.

Ans:

consider a solid cylindrical rod of cross-sectional area A. Let PQ and RS be two transverse sections of the rod at distances x and $x+\Delta x$, respectively, from a fixed point O, where we have chosen the x axis to be along the length of the rod (see Fig. 11.7).

Let the longitudinal displacement of a plane be denoted by $\xi(x)$. Thus the displacements of the planes PQ and RS are $\xi(x)$ and $\xi(x+\Delta x)$, respectively. In the displaced position, the distance between the planes $P'Q'$ and $R'S'$ is

$$\xi(x+\Delta x)-\xi(x)+\Delta x = \xi(x)+\frac{\partial \xi}{\partial x}\Delta x-\xi(x)+\Delta x$$

$$= \Delta x+\frac{\partial \xi}{\partial x}\Delta x$$

The elongation of the element is $(\partial\xi/\partial x)\Delta x$, and therefore, the longitudinal strain is

$$\frac{\text{Increase in length}}{\text{Original length}} = \frac{(\partial\xi/\partial x)\Delta x}{\Delta x} = \frac{\partial \xi}{\partial x} \qquad \textbf{(37)}$$

Since Young's modulus Y is defined as the ratio of the longitudinal stress to the longitudinal strain, we have

$$\text{Longitudinal stress} = \frac{F}{A} = Y\times \text{strain}$$

$$= Y\frac{\partial \xi}{\partial x} \qquad \textbf{(38)}$$

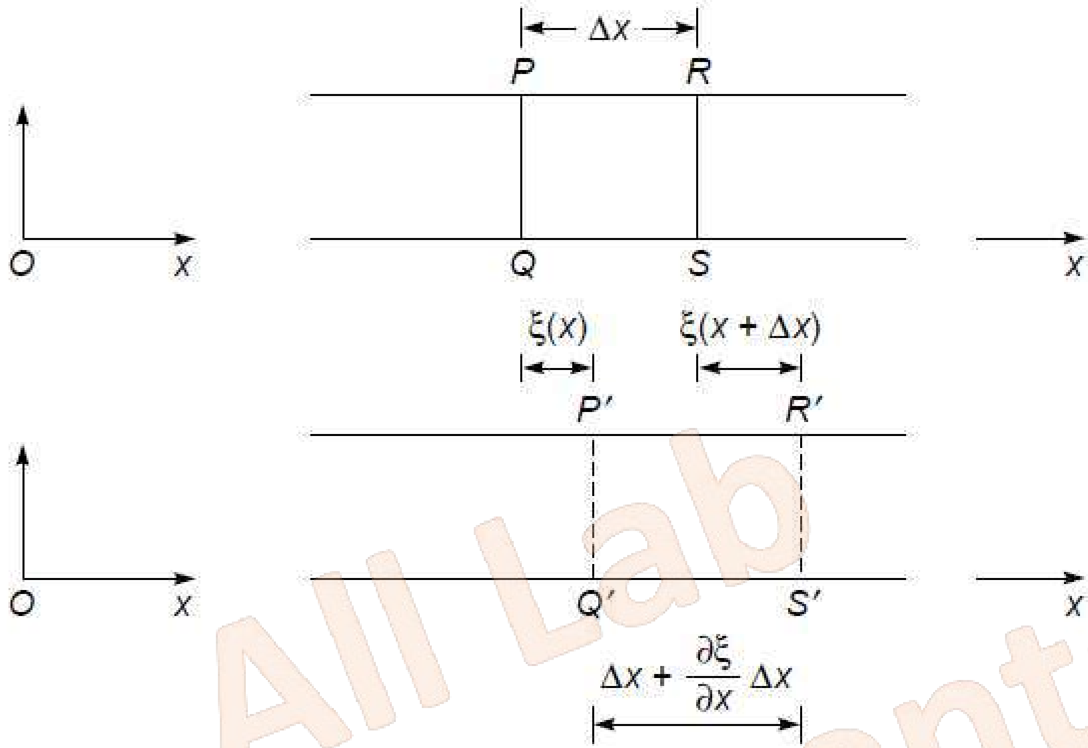


Fig. 11.7 Propagation of longitudinal sound waves through a cylindrical rod.

where F is the force acting on the element $P'Q'$. Thus

$$F(x) = YA \frac{\partial \xi}{\partial x} \tag{39}$$

and, therefore,

$$\frac{\partial F}{\partial x} = YA \frac{\partial^2 \xi}{\partial x^2} \tag{40}$$

Now, if we consider the volume $P'Q'S'R'$, then a force F is acting on the element $P'Q'$ *in the negative x* direction, and a force $F(x + \Delta x)$ is acting on the plane $R'S'$ *along the positive x* direction. Thus the resultant force acting on the element $P'Q'S'R'$ will be

$$F(x+\Delta x) - F(x) = \frac{\partial F}{\partial x}\Delta x$$

$$= YA\,\frac{\partial^2 \xi}{\partial x^2}\Delta x \qquad \textbf{(41)}$$

If ρ represents the density, then the mass of the element is $\rho A\,\Delta x$. Thus the equation of motion will be

$$\rho A\,\Delta x\frac{\partial^2 \xi}{\partial t^2} = YA\,\Delta x\frac{\partial^2 \xi}{\partial x^2}$$

or
$$\frac{\partial^2 \xi}{\partial x^2} = \frac{1}{v_l^2}\frac{\partial^2 \xi}{\partial t^2} \qquad \textbf{(42)}$$

where
$$v_l = \left(\frac{Y}{\rho}\right)^{1/2} \qquad \textbf{(43)}$$

represents the velocity of the waves and the subscript *l* refers to the fact that we are considering longitudinal waves.[7]

The above derivation is valid when the transverse dimension of the rod is small compared with the wavelength of the disturbance so that one may assume that the longitudinal displacement at all points on any transverse section (such as *PQ*) is the same. In general, if one carries out a rigorous analysis of the vibrations of an extended isotropic elastic solid, one can show that the velocities of the longitudinal and transverse waves are given by[8]

$$v_l = \left[\frac{Y}{\rho}\frac{1-\sigma}{(1+\sigma)(1-2\sigma)}\right]^{1/2} = \left(\frac{K+(4/3)\eta}{\rho}\right)^{1/2} \quad \textbf{(44)}$$

$$v_t = \left[\frac{Y}{\rho}\frac{1}{2(1+\sigma)}\right]^{1/2} = \left(\frac{\eta}{\rho}\right)^{1/2} \quad \textbf{(45)}$$

where σ, η, and K represent the Poisson ratio, modulus of rigidity, and bulk modulus, respectively. In this case, the transverse wave [whose velocity is given by Eq. (45)] is due to the restoring forces arising because of the elastic properties of the material, whereas corresponding to the transverse waves discussed in Sec. 11.6, the string moved as a whole and the restoring force was due to the externally applied tension.

Q:what are sound waves? How they are produced? Explain compression and rarefraction.

Ans:

Vibration of an object is what produces sound waves. The vibrating object moves in one direction and *compresses* the air directly in front of it. As the vibrating object moves in the opposite direction, the pressure on the air is lessened so that an expansion, or *rarefaction*, of air molecules occurs. One compression and one rarefaction make up one longitudinal wave. The vibrating air molecules move back and forth parallel to the direction of motion of the wave receiving energy from adjacent molecules nearer the source and passing the energy to adjacent molecules farther from the source.

Pitch is determined by the frequency of the tone that the ear receives. High notes are produced by an object that is vibrating a greater number of times per second than for a low note. The loudness of a sound depends upon the subjective effect of intensity of sound waves on the ear. In general, more intense sounds are louder, but the ear does not respond similarly at all frequencies. Two tones of the same intensity but with different pitches may then appear to have different loudness.

Chapter 5
Wave optics

Wave Optics: Electromagnetic nature of light. Definition and Properties of wave front. Huygens Principle. (3 Lectures)

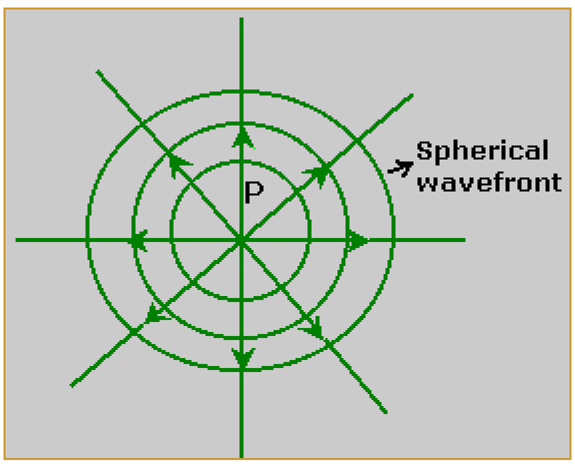
Q: what are wavefronts?explain different types of wavefronts.

Ans:

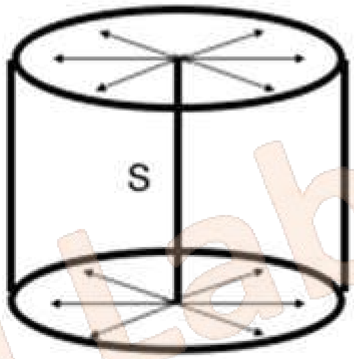
A wavefront is defined as the continuous locus of all the particles which are vibrating in the same phase. The perpendicular line drawn at any point on the wavefront represents the direction of propagation of the wave at that point and is called the 'ray'.

Types of Wavefronts : The wavefronts can be of different shapes. In general we experience two types of wavefronts.

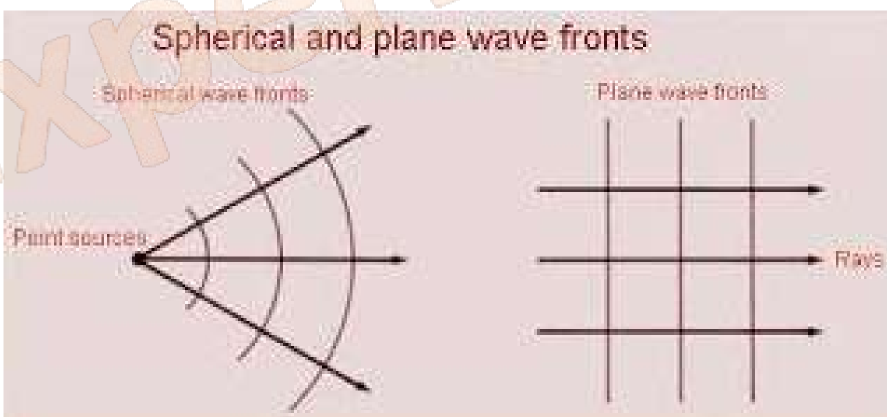
(i) Spherical Wavefront : If the waves in a medium are originating from a point source, then they propagate in all directions. If we draw a spherical surface centred at point-source, then all the particles of the medium lying on that spherical surface will be in the same phase, because the disturbance starting from the source will reach all these points simultaneously. Hence in this case the wavefront will be spherical and the rays will be the radial lines [Fig. 1].



(ii) Cylindrical Wavefront : If the waves in a medium are originating from a line source, then they too propagate in all directions. In this case the locus of particles vibrating in the same phase will be a cylindrical surface. Hence in this case the wavefront will be cylindrical. (Fig. 2)



Plane Wavefront : At large distance from the source, the radii of spherical or cylindrical wavefront will be too large and a small part of the wavefront will appear to be plane. At infinite distance from the source, the wavefronts are always plane and the rays are parallel straight lines. (Fig. 3)



Q: what is huygen's priniciple.

Ans:

Huygens's Principle:

every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets. If the propagating wave has a frequency, f, and is transmitted through the medium at a speed, v, then the secondary wavelets will have the same frequency and speed.

This principle is quite useful, for from it can be derived the laws of reflection and refraction