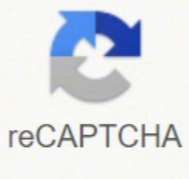




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In solids, similar arguments can be made. In a crystalline solid, atoms or group of atoms are arranged in a periodic lattice. In these, each atom or group of atoms is in equilibrium, due to forces from the surrounding atoms. Displacing one atom, keeping the others fixed, leads to restoring forces, exactly as in a spring. So we can think of atoms in a lattice as end points, with springs between pairs of them.

In the subsequent sections of this chapter we are going to discuss various characteristic properties of waves.

15.2 TRANSVERSE AND LONGITUDINAL WAVES

We have seen that motion of mechanical waves involves oscillations of constituents of the medium. If the constituents of the medium oscillate perpendicular to the direction of wave propagation, we call the wave a transverse wave. If they oscillate along the direction of wave propagation, we call the wave a longitudinal wave.

Fig. 15.2 shows the propagation of a single pulse along a string, resulting from a single up and down jerk. If the string is very long compared

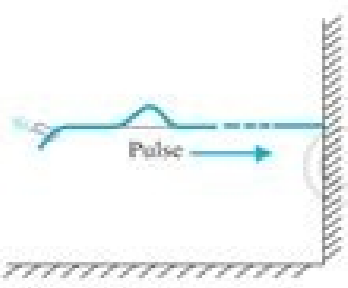


Fig. 15.2 When a pulse travels along the length of a stretched string in the direction x , the elements of the string oscillate up and down (y -direction)

to the size of the pulse, the pulse will damp out before it reaches the other end and reflection from that end may be ignored. Fig. 15.3 shows a similar situation, but this time the external agent gives a continuous periodic sinusoidal up and down jerk to one end of the string. The resulting disturbance on the string is then a sinusoidal wave. In either case the elements of the string oscillate about their equilibrium mean

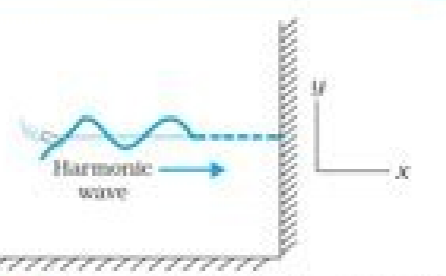


Fig. 15.3 A harmonic (sinusoidal) wave travelling along a stretched string is an example of a transverse wave. An element of the string in the region of the wave oscillates about its equilibrium position perpendicular to the direction of wave propagation.

position as the pulse or wave passes through them. The oscillations are normal to the direction of wave motion along the string, so this is an example of a transverse wave.

We can look at a wave in two ways. We can fix an instant of time and picture the wave in space. This will give us the shape of the wave as a whole in space at a given instant. Another way is to fix a location, i.e. fix our attention on a particular element of string and see its oscillatory motion in time.

Fig. 15.4 describes the situation for longitudinal waves in the most familiar example of the propagation of sound waves. A long pipe filled with air has a piston at one end. A single sudden push forward and pull back of the piston will generate a pulse of condensations (higher density) and rarefactions (lower density) in the medium (air). If the push-pull of the piston is continuous and periodic (sinusoidal), a

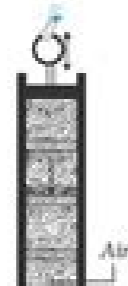


Fig. 15.4 Longitudinal waves (sound) generated in a pipe filled with air by moving the piston up and down. A volume element of air oscillates in the direction parallel to the direction of wave propagation.

Class 11 CBSE Physics **Waves** **PHYSICS**

$v = \frac{\omega}{k} = \frac{2\pi\nu}{2\pi/\lambda} = \nu\lambda$

Since λ , ν and v are all constants, $v \propto \sqrt{T}$.

Hence, the speed of sound in air increases with increase in temperature.

(i) Let v_d and v_w be the speeds of sound in dry air and moist air respectively.

Let ρ_d and ρ_w be the densities of dry air and moist air respectively.

We know the formula:

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

Therefore, the speed of sound in moist air is

$$v_w = \sqrt{\frac{\gamma P}{\rho_w}}$$

And the speed of sound in dry air is

$$v_d = \sqrt{\frac{\gamma P}{\rho_d}}$$

On dividing equations (i) and (ii) we get

$$\frac{v_w}{v_d} = \sqrt{\frac{\rho_d}{\rho_w}}$$

Hence, the presence of water vapour reduces the density of air, i.e.,

$$\rho_w < \rho_d$$

$$v_w > v_d$$

Hence, the speed of sound in moist air is greater than it is in dry air. Thus, in a gaseous medium, the speed of sound increases with humidity.

15.8 You have learnt that a travelling wave in one dimension is represented by a function $y = f(x, t)$ where x and t must appear in the combination $x - vt$ or $x + vt$, i.e., $y = f(x \pm vt)$. Is the converse true? Examine if the following functions for y can possibly represent a travelling wave:

(i) $y = (x + vt)^2$

(ii) $y = \log \left[\frac{x + vt}{b} \right]$

(iii) $y = \frac{1}{x + vt}$

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are much more difficult to compress than gases and have much higher values of bulk modulus. For air (15°C), solids and liquids have higher mass densities (ρ) than gases. But the corresponding increase in bulk modulus (B) of solids and liquids is much higher. This is the reason why the speed waves travel faster in solids and liquids.

We can estimate the speed of sound in a gas in the ideal gas approximation. For an ideal gas, the pressure P , volume V and temperature T are related by gas Chapter 13,

$$PV = \mu R T \quad (15.21)$$

where μ is the number of molecules in volume V , R is the Boltzmann constant, and T the temperature of the gas in kelvin. Therefore, an infinitesimal change is follows from Eq (15.21) that

$$\mu R T = P V \Rightarrow \mu R \Delta T = \Delta P V + P \Delta V$$

Hence, substituting in Eq (15.16), we have

$$v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma R T}{\mu}}$$

This relation was first given by Newton and is known as Newton's formula.

Example 15.8 Calculate the speed of sound in air at 30°C. Assume the ratio of specific heats of air is $\gamma = 1.4$.

Solution We know that 1 mole of any gas occupies 22.4 litres at STP (0°C, 1013 hPa), density of air at STP is

$$\rho = \frac{28.97 \text{ g}}{22.4 \text{ L}} = 1.293 \text{ kg m}^{-3}$$

According to Newton's formula for the speed of sound in a medium, we get for air at 30°C

$$v = \sqrt{\frac{\gamma R T}{\mu}} = \sqrt{\frac{1.4 \times 8.31 \text{ J mol}^{-1} \text{ K}^{-1} \times 303 \text{ K}}{28.97 \text{ g mol}^{-1}}} = 349 \text{ m s}^{-1} \quad (15.22)$$

The result shown in Eq (15.22) is about 10% smaller as compared to the experimental value of 331 m s⁻¹ as given in Table 15.1. Where did we go wrong? If we examine the basic assumption made by Newton that the pressure would be constant during propagation of sound we understand, we find that this is not correct. It was pointed out by Laplace that pressure variations in the propagation of sound waves are not that small since for the present variations, they are adiabatic and not isothermal. For adiabatic process the ideal gas satisfies the relation (see Section 12.4),

$$P V^\gamma = \text{constant}$$

i.e., $\mu R T^\gamma = \text{constant}$

or $P \mu^{-\gamma} T^\gamma = \text{constant}$ where γ is the ratio of the specific heats, $C_{p,m}/C_{v,m}$.

Thus, for an ideal gas the adiabatic bulk modulus is given by

$$B = \gamma P$$

The speed of sound is, therefore, from Eq (15.16), given by

$$v = \sqrt{\frac{\gamma P}{\rho}} \quad (15.23)$$

This modified Newton's formula is referred to as the Laplace correction. For air at 30°C, the value of v is 331.3 m s⁻¹, which agrees with the measured speed.

15.9 THE PRINCIPLE OF SUPERPOSITION OF WAVES

What happens when two wave pulses travelling in opposite directions cross each other (Fig. 15.10)? It turns out that wave pulses continue to retain their identities after they have crossed. However, during the time they overlap, the wave pattern is different from either of the pulses. Figure 15.10 shows the situation when two pulses of equal and opposite shapes move towards each other. When the pulses overlap, the resultant disturbance in the string, seen by an observer who is in the plane, is in accordance with the principle of superposition of waves.

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