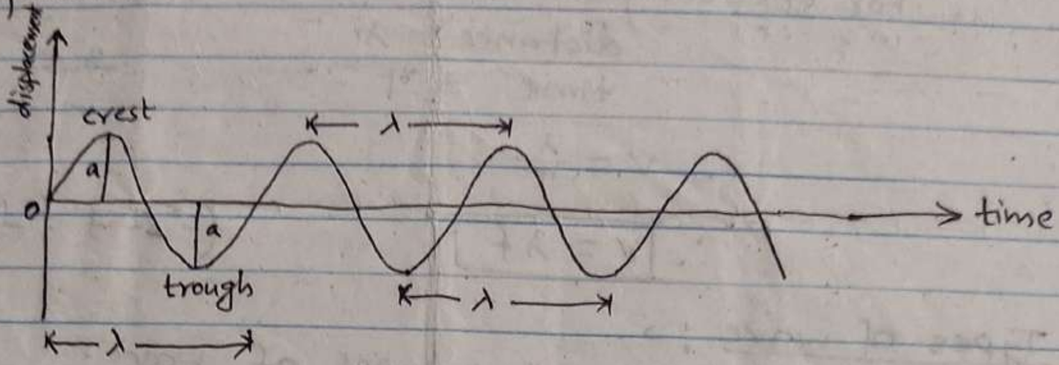
Unit-4 : Waves and sound

Unit-4.1 : Waves

Wave :→ A wave is a form of disturbance which travels from one part of medium to another due to the repeated periodic motion of the particles of the medium about their mean positions.



Some important terms :→

1) **Crest :→** The maximum displacement of the particles of medium above the equilibrium position is called crest.
2) **Trough :→** The maximum displacement of the particles of medium below the equilibrium position is called trough.
3) **Amplitude (a) →** The maximum displacement of the particles of medium from the equilibrium position is called amplitude.
4) **Wavelength (λ) :→** The distance travelled wave in one complete oscillation is called wavelength. It is denoted by λ.
   It is also the distance between any two nearest crests or troughs.
5) **Frequency (f) :→** The number of oscillations completed by the particles of the medium in one second is called frequency. It is denoted by f.
6) **Time period (T) :→** The time taken by the particles of the medium to complete one oscillation is called time period.

$$\text{Time period } (T) = \frac{1}{f}$$

$$\therefore \boxed{f = 1/T}$$

Wave velocity (v) :→ The distance travelled by wave in one second is called wave velocity.

i.e. wave velocity (v) = $\frac{\text{distance travelled by wave}}{\text{time taken}}$

For one complete oscillation,

distance = λ

time = T

$\therefore v = \frac{\lambda}{T}$

$\therefore \boxed{v = \lambda f}$ $\quad (\because f = \frac{1}{T})$

Types of wave :→

There are two types of wave.

i) Transverse wave

ii) Longitudinal wave.

1) **Transverse wave :→** The wave in which the particles of the medium vibrate perpendicularly to the direction of propagation of the wave is called transverse wave.

Ex:- waves in plucked string, waves on the surface of water etc.

It travels producing crests and troughs in medium.

It can propagate only in solids and at the surface of liquids.

2) **Longitudinal wave :→** The wave in which the particles of the medium vibrate parallely to the direction of propagation of wave is called longitudinal wave.

Ex:- sound waves, waves in compressed string etc.

It travels producing compressions and rarefactions in medium.

It can propagate in all type of media i.e. solid, liquid and gas.

<u>Progressive wave</u> :→ A wave that travels from one region of medium to another is called progressive wave.

Both transverse and longitudinal waves are progressive waves.

<u>principle of superposition</u> :→

when two or more waves are passing through a medium at the same time, the resultant displacement at any point is equal to the vector sum of their individual displacements at that point.

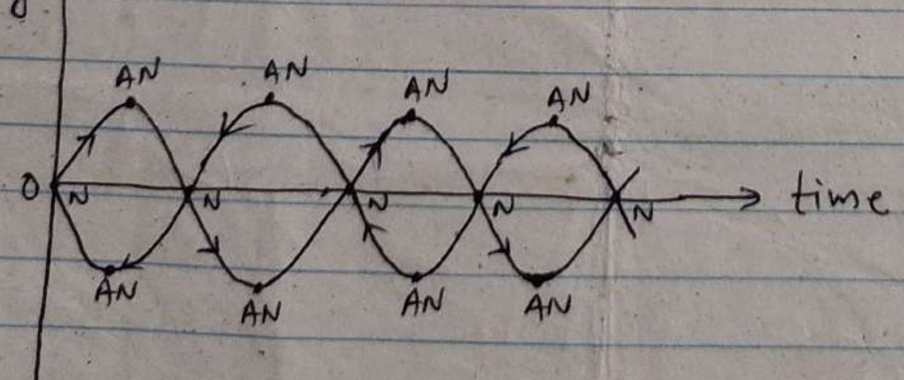
Let, y_1, y_2, y_3 --- be the displacements at a point due to individual waves then,

Resultant wave $(y) = y_1 + y_2 + y_3 + \cdots$

<u>Stationary or standing wave</u> :→

when two waves of same amplitude and frequency travel with same speed in opposite direction to each other in a medium then they superimpose producing a stationary wave.

In stationary wave, there are some points which have zero displacements called <u>nodes</u> and the points which have maximum displacements called <u>antinodes</u>.



unit-4.2 Characteristics of sound

$\sqrt{}$ 2071

Newton's formula for velocity of sound in gas :→

Newton assumed that the process of compressions and rarefactions is very slow and the temperature of the medium remains constant. Hence, sound waves propagate through isothermal process.

For isothermal process,

$$PV = constant \quad \text{———} (1)$$

Differentiating both sides, we get,

$$Pdv + vdP = 0$$

$$\therefore Pdv = -vdP$$

$$\therefore P = -\frac{vdP}{dv}$$

$$\therefore P = \frac{dP}{-\frac{dv}{v}} = B$$

where, B is Bulk modulus of air.

So, velocity of sound $(v) = \sqrt{\frac{B}{\rho}}$

$$\therefore v = \sqrt{\frac{P}{\rho}} \quad \text{———} (2)$$

The velocity of sound at NTP is calculated as,

$$P = 1.013 \times 10^5 N/m^2$$

density $(\rho) = 1.293 \ kg/m^3$

$$\therefore \text{velocity } (v) = \sqrt{\frac{P}{\rho}} = \sqrt{\frac{1.013 \times 10^5}{1.293}} = 280 m/s$$

This value does not agree with the experimental value which is 332 m/s.

Laplace correction :→

Laplace corrected Newton's formula and assumed that the process of compression and rarefaction is very rapid and temperature of the medium does not remain constant. Hence, sound waves propagate through adiabatic process.

For adiabatic process,

$$PV^{\gamma} = \text{constant} \quad ; \text{ where, } \gamma = 1.4$$

Differentiating both sides, we get,

$$V^{\gamma} dP + \gamma P V^{\gamma-1} dV = 0$$

Dividing both sides by $V^{\gamma-1}$, we get,

$$V dP + \gamma P dV = 0$$

$$\gamma P dV = -V dP$$

$$\gamma P = -\frac{V dP}{dV}$$

$$\therefore \gamma P = \frac{dP}{-\frac{dV}{V}} = B$$

So, velocity of sound in air is calculated as,

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

$$= \sqrt{\frac{1.4 \times 1.013 \times 10^5}{1.293}}$$

$$= 331.2 \text{ m/s}$$

This value agrees with the experimental value.

Factors affecting velocity of sound in gas :→

1) Effect of temperature :→

For one mole of gas,

$$PV = RT \quad \text{——— (1)}$$

Let, M is the molecular mass and ρ is the density of gas, then, density $(\rho) = \frac{M}{V}$

$$\therefore V = \frac{M}{\rho}$$

So, eq^n (1) becomes,

$$P\frac{M}{\rho} = RT$$

$$\therefore \frac{P}{\rho} = \frac{RT}{M} \quad \text{—— (2)}$$

Then, velocity of sound in gas $(v) = \sqrt{\frac{\gamma P}{\rho}}$

$$\therefore v = \sqrt{\frac{\gamma RT}{M}}$$

since, γ, M and R are constants for a gas,

$$\therefore \boxed{v \propto \sqrt{T}}$$

Hence, velocity of sound in gas is directly proportional to the square root of absolute temperature.

Let, v_1 and v_2 be the velocities of sound at the temperatures T_1 and T_2 respectively.

Then, $$\boxed{\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}}$$

2) <u>Effect of pressure</u> :→

From eqⁿ (2), $\frac{P}{\rho} = \frac{RT}{M}$

If temperature of gas remains constant then,

$$\frac{P}{\rho} = \text{constant}$$

so, velocity of sound $(v) = \sqrt{\frac{\gamma P}{\rho}}$ = constant

Hence, velocity of sound in gas is independent of pressure if temperature remains constant.

3) <u>Effect of density</u> :→

Let, v_1 and v_2 be the velocities of sound in gases of densities ρ_1 and ρ_2 respectively then,

$$v_1 = \sqrt{\frac{\gamma P}{\rho_1}}$$

$$v_2 = \sqrt{\frac{\gamma P}{\rho_2}}$$

Dividing,

$$\therefore \frac{v_1}{v_2} = \sqrt{\frac{\rho_2}{\rho_1}}$$

i.e. $$\boxed{v \propto \frac{1}{\sqrt{\rho}}}$$

Hence, velocity of sound in gas is inversely proportional to the square root of the density of gas.

4) Effect of humidity :→

The density of humid air or moist air is less than the density of dry air.

since, $v \propto \frac{1}{\sqrt{\rho}}$

Hence, velocity of sound is ~~[illegible]~~ greater in moist air than in dry air.

5) Effect of wind :→

If the wind blows in the direction of sound then velocity of sound increases and if wind blows in the direction opposite to the sound then velocity of sound decreases.

~~6) Effect of freq.~~