Waves and Sound

Wave

A wave is a vibratory disturbance in a medium which carries energy from one point to another point without any actual movement of the medium. There are three types of waves

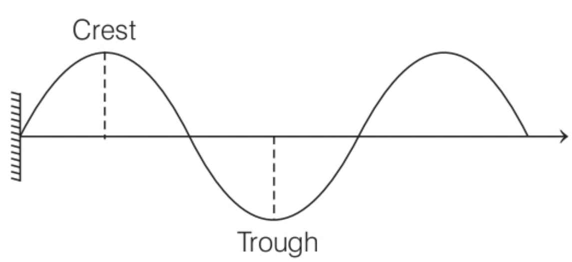
(i) **Mechanical Waves** Those waves which require a material medium for their propagation, are called mechanical waves, e.g. sound waves, water waves etc.

(ii) **Electromagnetic Waves** Those waves which do not require a material medium for their propagation, are called electromagnetic waves, e.g. light waves, radio waves etc.

(iii) **Matter Waves** These waves are associated with electrons, protons and other fundamental particles.

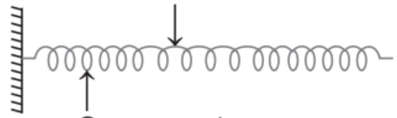
Nature of Waves

(i) **Transverse Waves** A wave in which the particles of the medium vibrate at right angles to the direction of propagation of wave, is called a transverse wave.



These waves travel in the form of crests and troughs.

(ii) **Longitudinal Waves** A wave in which the particles of the medium vibrate in the same direction in which wave is propagating, is called a longitudinal wave.



These waves travel in the form of compressions and rarefactions.

Some Important Terms Related to Wave Motion

(i) **Amplitude** The amplitude of a wave is the magnitude of maximum displacement of the particles from their equilibrium position, as the wave passes through them.

(ii) **Wavelength** The distance between two nearest points in a wave which are in the same phase of vibration is called the wavelength (λ).

(iii) **Time Period** Time taken to complete one vibration is called time period (T).

(iv) **Frequency** The number of vibrations completed in one second is called frequency of the wave.

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

Its SI unit is hertz.

Angular frequency, $\omega = \dfrac{2\pi}{T}$

Its SI unit is rad s^{-1}.

(v) **Velocity of Wave or Wave Velocity** The distance travelled by a wave in one second is called velocity of the wave (v).

Relation among velocity, frequency and wavelength of a wave is given by

$$v = f\lambda$$

Sound Waves

Sound is a form energy which produces a sensation of hearing in our ears. Sound waves are longitudinal in nature.

Sound waves are of three types

(i) **Infrasonic Waves** The sound waves of frequency range 0 to 20 Hz are called infrasonic waves.

(ii) **Audible Waves** The sound waves of frequency range 20 Hz to 20000 Hz are called audiable waves.

(iii) **Ultrasonic Waves** The sound waves of frequency greater than 20000 Hz are called ultrasonic waves.

Sound waves require medium for their propagation. Sound waves can travel through any material medium (i.e. solids, liquid and gases) with speed that depends on the properties of the medium.

Sound waves cannot propagate through vacuum.
If v_s, v_l and v_g are speed of sound waves in solid, liquid and gases, then

$$v_s > v_l > v_g$$

Sound waves (longitudinal waves) can reflect, refract, interfere and diffract but cannot be polarised as only transverse waves can polarised.

Velocity of Longitudinal (Sound) Waves

Velocity of longitudinal (sound) wave in any medium is given by

$$v = \sqrt{\frac{E}{\rho}}$$

where, E is coefficient of elasticity of the medium and ρ is density of the medium.

Newton's Formula

According to Newton, the propagation of longitudinal waves in a gas is an **isothermal process**. Therefore, velocity of longitudinal (sound) waves in gas

$$v = \sqrt{\frac{E_T}{\rho}} = \sqrt{\frac{p}{\rho}}$$

where, E_T is the isothermal coefficient of volume elasticity and it is equal to the pressure of the gas.

Laplace's Correction

According to Laplace, the propagation of longitudinal wave is an **adiabatic process**. Therefore, velocity of longitudinal (sound) wave in gas should be

$$v = \sqrt{\frac{E_s}{\rho}} = \sqrt{\frac{\gamma p}{\rho}}$$

where, E_s is the adiabatic coefficient of volume elasticity and it is equal to γp.

Factors Affecting Velocity of Longitudinal (Sound) Wave

(i) **Effect of Pressure** The formula for velocity of sound in a gas.

$$v = \sqrt{\frac{rp}{\rho}} = \sqrt{\frac{RT}{m}}$$

Therefore, $\left(\frac{p}{\rho}\right)$ remains constant at constant temperature.

Hence, there is no effect of pressure on velocity of longitudinal wave.

(ii) **Effect of Temperature** Velocity of longitudinal wave in a gas

$$v = \sqrt{\frac{\gamma\, p}{\rho}} = \sqrt{\frac{RT}{M}}$$

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

$$\Rightarrow \quad \frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

Velocity of sound in a gas is directly proportional to the square root of its absolute temperature.

If v_0 and v_t are velocities of sound in air at 0°C and t°C, then

$$v_t = v_0 \left(1 + \frac{t}{273}\right)^{1/2}$$

or

$$v_t = v_0 + 0.61\, t$$

(iii) **Effect of Density** The velocity of sound in gaseous medium

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

$$\Rightarrow \quad \frac{v_1}{v_2} = \sqrt{\frac{\rho_2}{\rho_1}}$$

The velocity of sound in a gas is inversely proportional to the square root of density of the gas.

(iv) **Effect of Humidity** The velocity of sound increases with increase in humidity in air. Thus, speed of sound in moist air is slightly greater than in dry air.

Note Speed of sound in air is independent of its frequency. Sound waves with different frequency travels with the same speed in air but their wavelengths in air are different.

Shock Waves

If speed of a body in air is greater than the speed of sound, then it is called **supersonic speed**. Such a body leaves behind it a conical region of disturbance which spreads continuously. Such a disturbance is called a shock wave.

Characteristics of Musical Sound

Musical sound has three characteristics

(i) **Intensity or Loudness** Intensity of sound is energy transmitted per second per unit area by sound waves. Its SI unit is watt/metre^2. Intensity is measured in decibel (dB).

(ii) **Pitch or Frequency** Pitch of sound directly depends on frequency.

A shrill and sharp sound has higher pitch and a grave and dull sound has lower pitch.

(iii) **Quality or Timbre** Quality is the characteristic of sound that differentiates between two sounds of same intensity and same frequency.

Quality depends on harmonics and their relative order and intensity.

Speed of Transverse Motion

On a stretched string $v = \sqrt{\frac{T}{m}}$

where, T = tension in the string and m = mass per unit length of the string.

Speed of transverse wave in a solid $v = \sqrt{\frac{\eta}{\rho}}$

where, η is modulus of rigidity and ρ is density of solid.

Plane Progressive Simple Harmonic Wave

Equation of a plane progressive simple harmonic wave

$$y = a \sin 2\pi \left(\frac{t}{T} - \frac{x}{\lambda} \right)$$

or

$$y = a \sin \frac{2\pi}{\lambda} (vt - x)$$

where, y = displacement, a = amplitude of vibration of particle,
λ = wavelength of wave, T = time period of wave,
x = distance of particle from the origin
and v = velocity of wave.

Important Relation Related to Equation of Progressive Wave

Wave velocity,

$$v = \frac{\text{Coefficient of } t}{\text{Coefficient of } x} = \frac{\omega}{k}$$

where, $k = \frac{2\pi}{\lambda}$ is called propagation constant of wave motion. It is also called angular wave number.

Wavelength, $$\lambda = \frac{2\pi}{\text{Coefficient of } x} = \frac{2\pi}{k}$$

Angular wave number, $k = \frac{2\pi}{\lambda}$ rad m^{-1}

Time period $$T = \frac{2\pi}{\text{Coefficient of } t} = \frac{2\pi}{\omega}$$

Frequency $$f = \frac{\text{Coefficient of } t}{2\pi} = \frac{\omega}{2\pi}$$

Particle velocity $$v_p = \frac{dy}{dt} = a \cos \frac{2\pi}{T}\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$

$$(v_p)_{\max} = a\left(\frac{2\pi}{T}\right) = a\omega$$

Also, $v_p = -v \times$ slope of wave at that point.

Phase of the vibration is the angle of sine in equation of plane progressive wave. It is denoted by ϕ.

$$\phi = 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$

Relation between phase difference, path difference and time difference

$$\Delta\phi = \frac{2\pi}{\lambda}\Delta x \quad \text{or} \quad \Delta\phi = \frac{2\pi}{T}\Delta t$$

Energy in a Wave

Regarding the energy in wave motion, we comes across three terms namely, energy density (u), power (P) and intensity (I).

1. **Energy Density** (u)

The energy density is defined as the total mechanical energy (kinetic + potential) per unit volume of the medium through which the wave is passing.

So, kinetic energy per unit volume

$$\Delta K = \frac{1}{2}\rho\omega^2 A^2 \cos^2 (kx - \omega t)$$

Potential energy per unit volume

$$\Delta U = \frac{1}{2}\rho\omega^2 A^2 \cos^2(kx - \omega t)$$

Total energy per unit volume

$$\Delta E = \Delta K + \Delta U = \rho\omega^2 A^2 \cos^2 (kx - \omega t)$$

Thus, energy density

$$u = < \Delta E > = < (\Delta K + \Delta U) >$$

$$= \rho\omega^2 A^2 < \cos^2 (kx - \omega t) > = \frac{1}{2}\rho\omega^2 A^2$$

$$u = \frac{1}{2}\rho\omega^2 A^2$$

2. **Power** (P)

The instantaneous rate at which energy is transferred along the string if we consider a transverse wave on a string, is called power.

In unit time, the wave will travel a distance v . If S be the area of cross-section of the string, then volume of this length would be Sv.

Thus, $$P = \text{Energy density} \times \text{Volume}$$

$$= \frac{1}{2}\rho\omega^2 A^2 \times SV = \frac{1}{2}\rho\omega^2 A^2 SV$$

3. **Intensity** (I)

Flow of energy per unit area of cross-section of the string in unit time is known as intensity of the wave.

Thus, $$I = \frac{\text{Power}}{\text{Area of cross-section}} = \frac{P}{S}$$

or $$I = \frac{1}{2}\rho\omega^2 A^2 V$$

Superposition of Waves

Two or more progressive waves can travel simultaneously in the medium without effecting the motion of one another. Therefore, resultant displacement of each particle of the medium at any instant is equal to vector sum of the displacements produced by two waves separately. This principle is called principle of superposition.

Interference

When two waves of same frequency travel in a medium simultaneously in the same direction, then due to their superposition, the resultant intensity at any point of the medium is different from the sum intensities of the two waves. At some points the intensity of the resultant wave is very large while at some other points it is very small or zero. This phenomenon is called **interference of waves.**

Constructive Interference

Phase difference between two waves $= 0, 2\pi, 4\pi$

$$\text{Maximum amplitude} = (a + b)$$

$$\text{Intensity} \propto (\text{Amplitude})^2 \propto (a + b)^2$$

In general, $$\text{amplitude} = \sqrt{a^2 + b^2 + 2ab\cos\phi}$$

Destructive Interference

Phase difference between two waves $= \pi, 3\pi, 5\pi$

Minimum amplitude $= (a \sim b) =$ Difference of component amplitudes.

$$\text{Intensity} \propto (\text{Amplitude})^2$$

$$\propto (a - b)^2$$

A vibrating tunning fork, when rotated near an ear produced loud sound and silence due to constructive and destructive interference.

Beats

When two sound waves of nearly equal frequencies are produced simultaneously, then intensity of the resultant sound produced by their superposition increases and decreases alternately with time. This rise and fall intensity of sound is called beats.

The number of maxima or minima heard in one second is called beats frequency.

> The difference of frequencies should not be more than 10. Sound persists on human ear drums for 0.1 second. Hence, beats will not be heard if the frequency difference exceeds 10.

Number of beats heard per second $= n_1 - n_2$

$=$ difference of frequencies of two waves.

Maximum amplitude $= (a_1 + a_2)$

Maximum intensity $= (\text{Maximum amplitude})^2 = (a_1 + a_2)^2$

For loudness, time intervals are $\frac{1}{n_1 - n_2}, \frac{2}{n_1 - n_2}, ...$

Reflection of Wave

The rebouncing back of waves when it strikes a hard surface is called reflection of wave.

If equation of incident travelling wave is

$$y(x, t) = a \sin(kx - \omega t)$$

Equation of reflected wave

$$y(x, t) = a \sin(kx + \omega t)$$

Note If a wave is incident obliquely on the boundary between two different media, the transmitted wave is called the refracted wave.

Echo

The repetition of sound caused by the reflection of sound waves at a distant surface, *e.g.* a cliff, a row of building etc is called an echo.

Sound persists in ear for 0.1 s.

The minimum distance from a sound reflecting surface to hear an echo is 16.5 m.

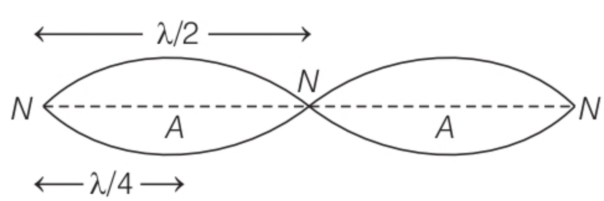
If first echo be heard after t_1 second, second echo after t_2 second, then third echo will be heard after $(t_1 + t_2)$ s.

Stationary or Standing Waves

When two similar waves propagate in a bounded medium in opposite directions, then due to their superposition a new type of wave is obtained, which appears stationary in the medium. This wave is called stationary or standing waves.

Equation of a stationary wave, $y = 2a \sin \frac{2\pi t}{T} \cos \frac{2\pi x}{\lambda}$

Nodes (N) and antinodes (A) are obtained alternatively in a stationary waves.



At nodes, the displacement of the particles remains minimum, strain is maximum, pressure and density variations are maximum.

At antinodes, the displacement of the particles remains maximum, strain is minimum, pressure and density variations are minimum.

The distance between two consecutive nodes or two consecutive antinodes $= \frac{\lambda}{2}$.

The distance between a node and adjoining antinode $= \frac{\lambda}{4}$.

All the particles between two nodes vibrate in same phase.

Particles on two sides of a node vibrate in opposite phase.

n consecutive nodes are separated n by $\frac{(n-1)\lambda}{2}$.

Position of Nodes

Nodes are the points on the string where the amplitude of oscillation of constituents is zero.

i.e.,

$$\sin kx = 0$$

$$kx = n\pi \qquad \text{where, } n = 0, 1, \ldots$$

$$\frac{2\pi}{\lambda} x = n\pi$$

$$x = \frac{n\lambda}{2}$$

Position of Antinodes

Antinodes are the points where the amplitude of oscillation of the constituents is maximum.

for maximum amplitude $\sin kx = \pm 1$

$$\Rightarrow \qquad kx = (2n+1)\frac{\pi}{2} \qquad \text{where, } n = 0, 1, 2, \ldots$$

$$\frac{2\pi}{\lambda} x = (2n+1)\frac{\pi}{2}$$

or

$$x = (2n+1)\frac{\lambda}{4}$$

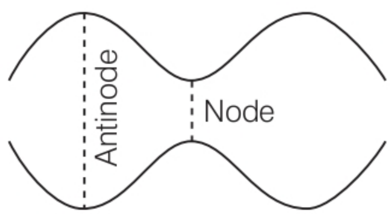
For $n = 0, 1, 2, \ldots$

Some Important Points Related with Stationary Waves

Some important points related with stationary waves are given below.

(i) Standing wave is an example of interference. Nodes means destructive interference and antinodes means constructive interference.

(ii) Two identical waves moving in opposite directions along the string will still produce standing waves even, if their amplitudes are unequal. This is the case when an incident travelling wave is only partially reflected from a boundary, the resulting superposition of two waves having different amplitudes and travelling in opposite directions gives a standing wave pattern of waves whose envelope is shown in figure.



The standing wave ratio (SWR) is defined as

$$\frac{A_{max}}{A_{min}} = \frac{A_i + A_r}{A_i - A_r}$$

where A_i and A_r are the amplitude of incident and reflected ray respectively.

For 100% reflection, SWR $= \infty$ and for no reflection, SWR $= 1$.

(iii) In this pattern, at antinode position, displacement is maximum and hence velocity is maximum, but strain is minimum.

Strain = slope of stationary wave pattern $\left(\frac{dy}{dx}\right)$

At nodal position, displacement and velocity is minimum but strain is maximum.

(iv) When a wave is reflected off a real surface, part of energy is absorbed by the surface. As a result, energy, intensity and amplitude of reflected wave is always less than that of incident wave. Two waves differ in their amplitude having same frequency and wavelength and propagate in reverse or opposite direction always give stationary wave pattern by their superposition.

(v) The intensity of a travelling wave is given by

$$I = \frac{1}{2}\rho A^2 \omega^3 v$$

i.e., $$I \propto A^2$$

So, we can write, $\frac{I_1}{I_2} = \left(\frac{A_1}{A_2}\right)^2$ if ρ, ω and v are same for two waves.

For example, when an incident travelling wave is partly reflected and partly transmitted from a boundary, we can write

$$\frac{I_i}{I_r} = \left(\frac{A_i}{A_r}\right)^2$$

as incident and reflected waves are in the same medium hence, they have same values of ρ and v. But we cannot write

$$\frac{I_i}{I_t} = \left(\frac{A_i}{A_t}\right)^2$$

where A_t is the amplitude of transmitted wave.

as they have different value of ρ and v.

(vi) In standing wave nodes are permanently at rest, so no energy can be transmitted across them *i.e.,* energy of one region is confined in that region. However, this energy oscillates between elastic PE and KE of the particles of the medium. When particles are at mean position, KE is maximum while elastic PE is minimum. When particles are at their extreme positions KE is minimum while elastic PE is maximum.

Vibrations in a Stretched String

When a string of definite length l, rigidly held at both ends. If this string is plucked and released, then a stationary transverse wave is set up in it. If n is the frequency of vibrating string, then

(i) $n \propto \frac{1}{l}$, where l is length of string or $nl = \text{constant}$

(ii) $n \propto \sqrt{T}$, where T is tension in string or $\frac{n}{\sqrt{T}} = \text{constant}$

(iii) $n \propto \frac{1}{\sqrt{\mu}}$, where μ is mass per unit length of a string.

From this we have, $n \propto \frac{1}{r}$, where r is radius of string

and $n \propto \frac{1}{\sqrt{\rho}}$, where ρ is density of string.

Vibrations of a String Fixed at One End

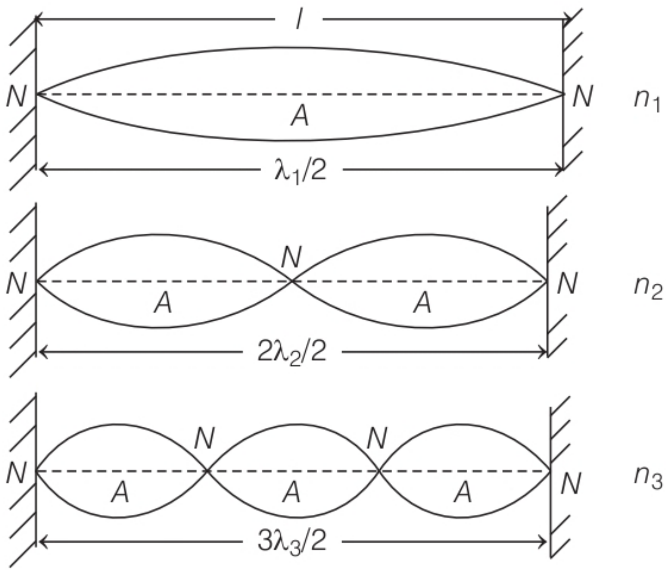
Fundamental frequency of vibration or first harmonic is $n_0 = \frac{v}{4l}$

Frequency of third harmonic, $n_1 = \frac{3v}{4l} = 3n_0$

Frequency of fifth harmonic, $n_2 = \frac{5v}{4l} = 5n_0$

$$n_0 : n_1 : n_2 .... = 1 : 3 : 5 : .....$$

Standing Waves in a String Fixed at Both Ends



$$v = \sqrt{\frac{T}{m}}$$

Fundamental frequency or frequency of first harmonic

$$n_1 = \frac{v}{2l} = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

Frequency of first overtone or second harmonic

$$n_2 = 2 \cdot \frac{v}{2l} = 2n_1$$

Frequency of second overtone or third harmonic

$$n_3 = 3 \cdot \frac{v}{2l} = 3n_1$$

$\therefore \quad n_1 : n_2 : n_3 : \ldots = 1 : 2 : 3 : \ldots$

Organ Pipes

Organ pipes are those cylindrical pipes which are used for producing musical (longitudial) sounds. Organ pipes are of two types

(i) **Open Organ Pipe** Cylindrical pipes open at both ends.

(ii) **Closed Organ Pipe** Cylindrical pipes open at one end and closed at other end.

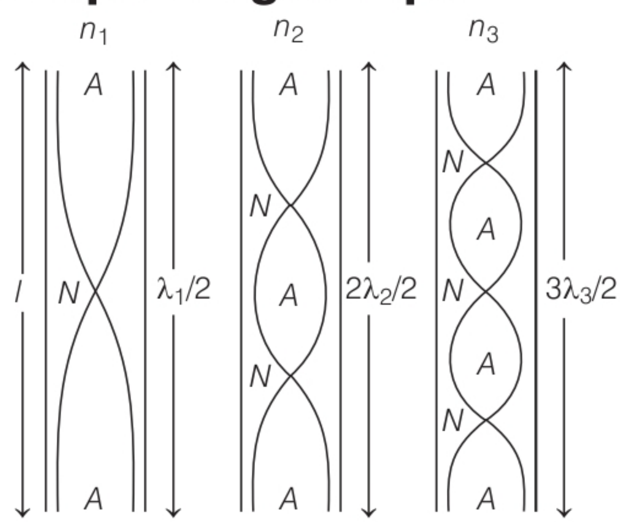
Terms Related to Vibrating Air Columns/Strings

Fundamental Note It is the sound of lowest frequency produced in fundamental note of vibration of a system.

Overtones Tones having frequencies greater than the fundamental note are called overtones.

Harmonics When the frequencies of overtone are integral multiples of the fundamental, then they are known as **harmonics**. Thus the note of lowest frequency n is called fundamental note or **first harmonics.** The note of frequency $2n$ is called **second harmonic** or **first overtone.**

Vibrations in Open Organ Pipe



Fundamental frequency or frequency of first harmonic $n_1 = \frac{v}{2l}$

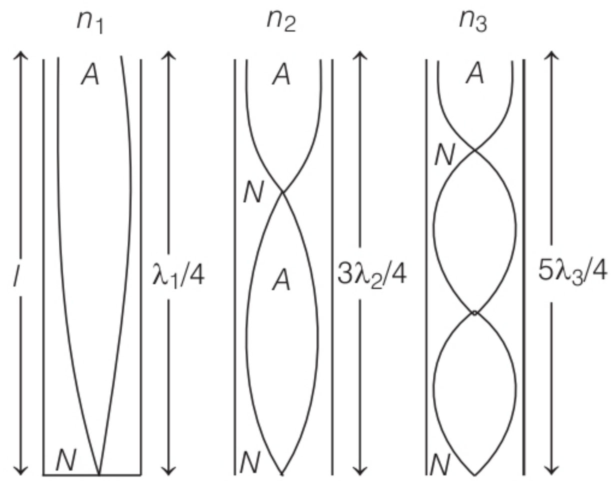
Frequency of first overtone or second harmonic $n_2 = 2\frac{v}{2l} = 2n_1$

Frequency of second overtone or third harmonic $n_3 = 3\frac{v}{2l} = 3n_1$

$$\therefore \qquad n_1 : n_2 : n_3 : \ldots = 1 : 2 : 3 : \ldots$$

Therefore, even and odd harmonics are produced by an open organ pipe.

Vibrations in Closed Organ Pipe



Fundamental frequency or frequency of first harmonic

$$n_1 = \frac{v}{4l}$$

Frequency of first harmonic or third harmonic

$$n_2 = \frac{3v}{4l} = 3n_1$$

Frequency of second harmonic or fifth harmonic

$$n_3 = 5 \cdot \frac{v}{4l} = 5n_1$$

$\therefore$ $$n_1 : n_2 : n_3 : \ldots = 1 : 3 : 5 : \ldots$$

Therefore only even harmonics are produced by a closed organ pipe.

End Correction

Antinode is not obtained at exact open end but slightly above it. The distance between open end and antinode is called end correction.

It is denoted by e.

Effective length of an open organ pipe $= (l + 2e)$

Effective length of a closed organ pipe $= (l + e)$

If r is the radius of organ pipe, then $e = 0.6\,r$

Factors Affecting Frequency of Wave in a Pipe

(i) Length of air column, $n \propto \frac{1}{l}$

(ii) Radius of air column, $n \propto \frac{1}{r}$

(iii) Temperature of air column, $n \propto \sqrt{T}$

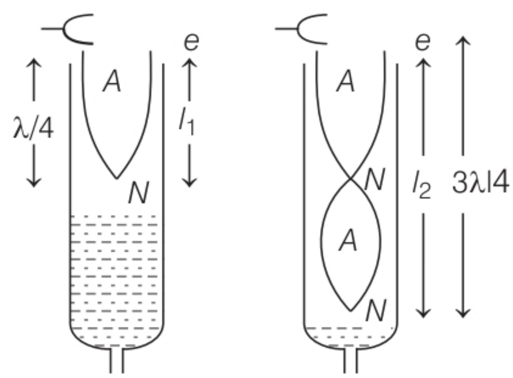
(iv) Pressure of air inside air column, $n \propto \sqrt{p}$

(v) Density of air, $n \propto \frac{1}{\sqrt{\rho}}$

(vi) Velocity of sound in air column, $n \propto v$

Resonance Tube

Resonance tube is a closed organ pipe in which length of air column can be changed by changing height of liquid column in it.



For first resonance, $$\frac{\lambda}{4} = l_1 + e$$

For second resonance,

$$\frac{3\lambda}{4} = l_2 + e$$

$$\text{Velocity of sound } v = n\lambda = 2n\,(l_2 - l_1)$$

$$\text{End correction, } e = \frac{l_2 - 3l_1}{2}$$

Melde's Experiment

In longitudinal mode, vibrations of the prongs of tuning fork are along the length of the string.

$$\text{Frequency of vibration of string} = \frac{\text{frequency of tuning fork}}{2}$$

$$n_L = \frac{p}{l}\sqrt{\frac{T}{m}}$$

In transverse mode, vibrations of tuning fork are at 90° to the length of string.

Frequency of vibration of string = Frequency of tuning fork.

$$n_T = \frac{p}{2l}\sqrt{\frac{T}{m}} = \frac{n_L}{2}$$

In both modes of vibrations, Melde's law

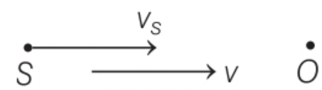
$$p^2 T = \text{constant, is obeyed.}$$

Doppler's Effect

The phenomena of apparent change in frequency of source due to a relative motion between the source and observer is called Doppler's effect.

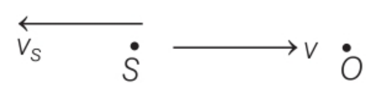
(i) **When Source is Moving and Observer is at Rest** When source is moving with velocity v_s, towards an observer at rest, then apparent frequency

$$n' = n\left(\frac{v}{v - v_s}\right)$$



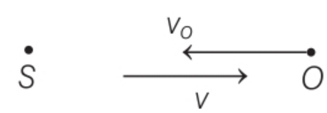
If source is moving away from observer, then

$$n' = n\left(\frac{v}{v + v_s}\right)$$



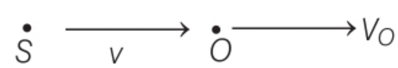
(ii) **When Source is at Rest and Observer is Moving** When observer is moving with velocity v_o, towards a source at rest, then apparent frequency.

$$n' = n\left(\frac{v + v_o}{v}\right)$$



When observer is moving away from source, then

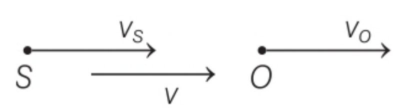
$$n' = n\left(\frac{v - v_o}{v}\right)$$



(iii) **When Source and Observer Both are Moving**

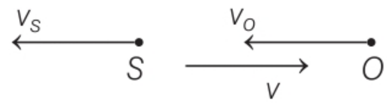
(a) When both are moving in same direction along the direction of propagation of sound, then

$$n' = n\left(\frac{v - v_o}{v - v_s}\right)$$



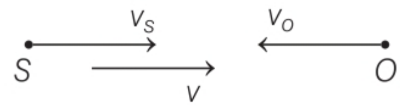
(b) When both are moving in same direction opposite to the direction of propagation of sound, then

$$n' = n\left(\frac{v + v_o}{v + v_s}\right)$$



(c) When both are moving towards each other, then

$$n' = n\left(\frac{v + v_o}{v - v_s}\right)$$

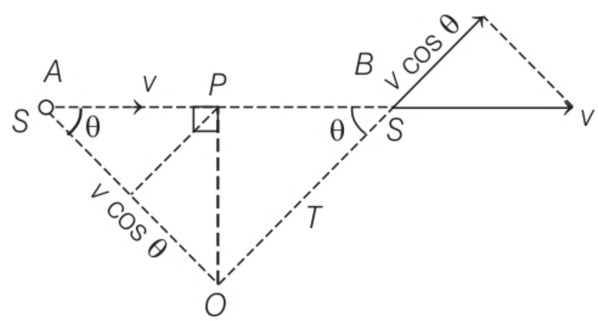


(d) When both are moving in opposite direction, away from each other, then

$$n' = n\left(\frac{v - v_o}{v + v_s}\right)$$

Transverse Doppler's Effect

As shown in figure, the position of a source is S and of observer is O. The component of velocity of source towards the observer is $v \cos \theta$. For this situation, the approach frequency (*i.e.* at A) is



$$n' = \frac{v}{v - v_s \cos\theta} \times n$$

n' which will now be a function of θ so, it will no more be constant.

Similarly, if then source is moving away from the observer (*i.e.* at B) as shown above, with velocity component $v_s \cos\theta$, then

$$n' = \frac{v}{v + v_s \cos\theta} \times n$$

If $\theta = 90°$, then $v_s \cos\theta = 0$ and there is no shift in the frequency. Thus, at point P, Doppler's effect does not occur.

Effect of motion of medium (air) on apparent frequency

If wind is also blowing with a velocity w, then in this condition the apparent frequency is given by

$$n' = n\left(\frac{v \pm w \pm v_o}{v \pm w \pm v_s}\right)$$

Doppler's effect in reflected sound

If a source of sound moving towards a stationary wall and there is a stationary observer.

Then, beat frequency heard by the observer is

$$n_b = \left(\frac{v}{v - v_s} - \frac{v}{v + v_s}\right)n$$

If car is approaching a wall, then beat frequency heard by the observer in car is

$$n_b = n\left(\frac{2u}{v - u}\right)$$

where, u is the velocity of car.

Rotating Effect of Source/Observer in Doppler's Effect

When the source is rotating towards/away from the observes frequency heard is

$$n = \left(\frac{v}{v \mp v_s}\right)n$$

When the observer is rotatiing towards/away from the source, frequency heard is

$$n = \left(\frac{v \pm v_0}{v}\right)n$$

When either source is at the centre when observer is rotating or *vice-versa*, then there will be no chage in frequency of sound heard.

Applications of Doppler's Effect

The measurement from Doppler effect has been used

(i) by police to check over speeding of vehicles.

(ii) at airports to guide the aircraft.

(iii) to study heart beats and blood flow in different parts of the body.

(iv) by astrophysicist to measure the velocities of planets and stars.