Sound & Light Waves

Sound Waves:-

It is the form of energy which produces, in us, the sensation of hearing.

- **Properties:-**
  - (a) Longitudinal in nature.
  - (b) It requires a material medium for its propagation.
  - (c) Sound waves can be reflected.
  - (d) Sound waves suffer refraction.
  - (e) Sound waves show the phenomenon of interference
  - (f) Sound waves shows diffraction
  - (g) Sound propagates with a velocity much smaller than that of light.
  - (h) Sound gets absorbed in the medium through which it passes.
- **Loudness (L)or Intensity (I):-**

  $L \propto \log I$

  So, $L = K \log_{10}(I_1/I_0)$

  Unit of intensity of sound is **bel**.
- **Intensity (I) and Amplitude (A):-** $I \propto A^2$
- **Intensity(I) and distance from the source (r):-** $I \propto 1/r^2$
- **Pitch or Shrillness:-**Pitch is a sensation which determines the shrillness of sound. It is subjective and cannot be measured quantitatively. It depends up on frequency and relative motion between the sources and the listener.
- **Quality or Timber:-** It is that characteristic of a musical sound which enables us to distinguish between two notes of the same pitch and loudness produced by two different sources.
- **Velocity u of longitudinal wave (sound) [Newton's Formula]:-**

  $u = \sqrt{E/\rho}$

  Here E is the coefficient of elasticity and ρ is the density of medium.
- **Velocity of sound in solids:-**

  $u = \sqrt{Y/\rho}$

  Here Y is the young's modulus of elasticity and ρ is the density.
- **Velocity of sound in liquids:-**

  $u = \sqrt{B/\rho}$

  Here B is the Bulk modulus of elasticity and ρ is the density.

- **Velocity of sound in gases:-**

  $u = \sqrt{\gamma P/\rho}$

  Here, γ ($=c_P/c_V$) is the adiabatic ratio, P is the pressure and ρ is the density.

- **Various factors affecting velocity of sound:-**

  (a) Effect of density:- The velocity of sound in a gas varies inversely as the square root of its density. $u_1/u_2 = \sqrt{[\rho_2/\rho_1]}$

  (b) Effect of moisture:- $u_m/u_d = \sqrt{[\rho_d/\rho_m]}$

  Since, $\rho_m < \rho_d$, then, $u_m > u_d$

  This signifies sound travels faster in moist air.

  (c) Effect of pressure:- $u = \sqrt{\gamma P/\rho} = \sqrt{\gamma k}$ = constant

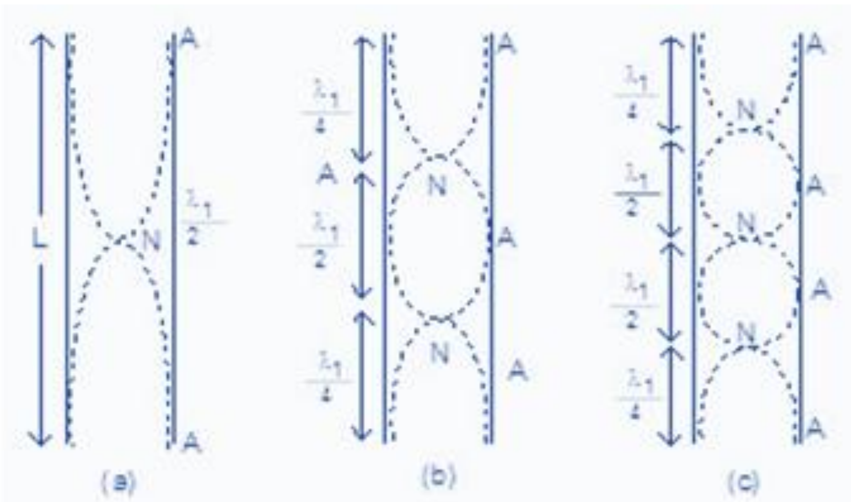
  This signifies, change of pressure has no effect on the velocity of sound.

  (d) Effect of temperature:- $u_t/u_0 = \sqrt{\rho_0/\rho_t} = \sqrt{T/T_0}$

  Thus, velocity of sound varies directly as the square root temperature on Kelvin's scale.

  (e) Temperature coefficient of velocity of sound (α):- $\alpha = u_0/546 = (u_t-u_0)/t$

- **Overtones in open pipe:-** An open pipeis open at both ends. Since air is free to vibrate at an open end, we must get an antinode at the open end.



  (a) **Fundamental frequency:-**

  Wavelength, $\lambda=2l$

  Frequency, $f=u/2l = (1/2l)\sqrt{(\gamma P/\rho)}$

  Here l is the length of the pipe and u is the velocity of sound.

  (b) **First overtone (Second Harmonic):-**

  Wavelength, $\lambda_1=l$

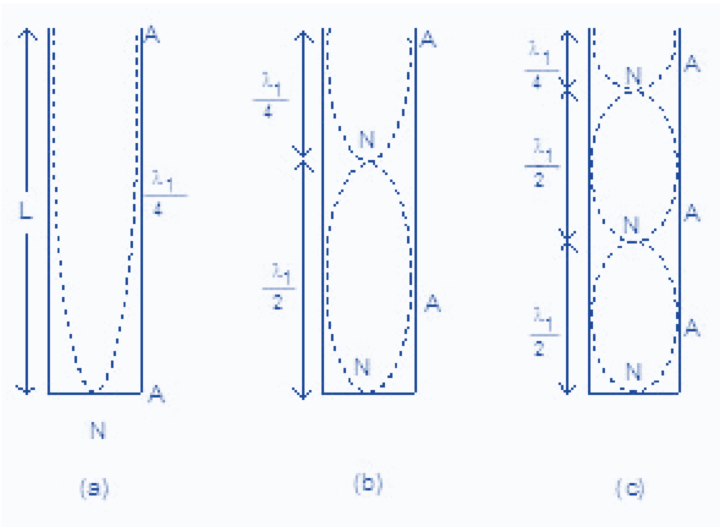
  Frequency, $f_1=2f$

(c) **Second overtone (Third Harmonic):-**

Wavelength, λ_2=2l/3

Wavelength, f_2=3f

- **Overtones in closed pipe:-**Since air, at a closed end, is not free to vibrate, there must be a node at a closed end always.



(a) Fundamental frequency:-

Wavelength, λ=4l

Frequency, F=u/4l = (1/4l)$\sqrt{}$(γP/ρ)

Here l is the length of the pipe and u is the velocity of sound.

(b) First overtone (Third Harmonic):-

Wavelength, λ_1=(4/3)l

Frequency, F_1=3F

(c) Second overtone (Fifth Harmonic):-

λ_2 = 4l/5

$F_2 = 5F$

- **Comparison of fundamental frequencies of a closed end of an open pipe:-** $f = 2F$
- **Doppler's Effect:-**Theapparent change in pitch of a note, due to the relative motion between the source and the listener is called Doppler's effect.

(a) Source in motion, listener at rest:-

(i) Source approaching the listener:-

Modifying wave length, λ' = V-a/f

Apparent frequency, f' = [V/V-a]f

Change in frequency, ?f = (a/V-a)f

Here V is the velocity of sound in air and a is the velocity of source when it moves towards the listener.

(ii) Source going away from the listener:-

Apparent frequency, $f' = [V/V+a]f$

Change in frequency, ?f = -(a/V+a)f

(iii) Source crossing the listener:-

Apparent frequency of the source before crossing = (V/V-a) f

Apparent frequency of the source after crossing = (V/V+a) f

Change in frequency, ?f = $-(2aV/V^2-a^2)f$

(b) Source at rest, listener in motion:-

(i) Listener moving away from source:-

Apparent frequency, $f' = [V-b/V]f$

Change in frequency, ?f = (-b/V)f

Here b is the velocity of listener.

(ii) Listener moving towards the source:-

Apparent frequency:-$f' = [V+b/V]f$

Change in frequency, ?f = (+b/V)f

(iii) Listener crossing the source:-

Apparent frequency of the source before crossing = (V+b/V) f

Apparent frequency of the source after crossing = (V-b/V) f

Change in frequency, ?f =-2fb/V

(c) **Source and listener both in the medium:-** Change in frequency due to relative motion of source and listener.

Source *(S)*#	Listener (*L*) (*X*)	Nature of velocities	Expression for ***f*** '
# $\xrightarrow{a}$	X $\xrightarrow{b}$	+ve, +ve	*f* ' = (*V-b/V-a*) *f*
# $\xrightarrow{a}$	$\xleftarrow{-b}$ X	+ve, -ve	*f* ' = (*V+b/V-a*) *f*
$\xleftarrow{-a}$ #	$\xleftarrow{-b}$ X	-ve, -ve	*f* ' = (*V+b/V+a*) *f*
$\xleftarrow{-a}$ #	X $\xrightarrow{b}$	-ve, +ve	*f* ' = (*V-b/V+a*) *f*

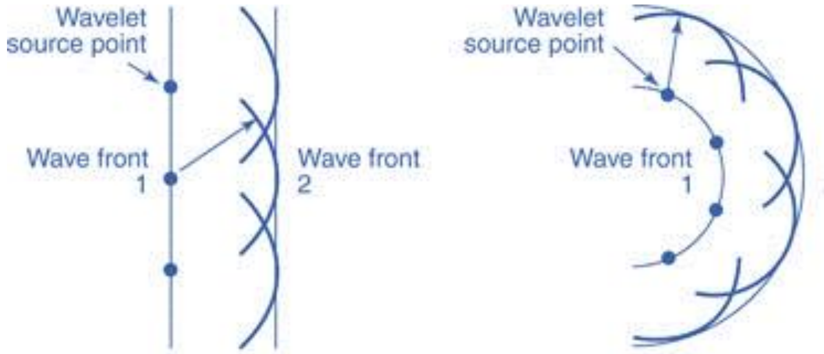
(d) Effect of motion of medium:-

Apparent frequency:-$f' = [(R-b)/(R-a)]\, f$

Here, $R = V + \omega\cos\theta$, ω is the velocity of wind, θ is the angle between direction of propagation of sound and that of wind.

Huygens Principle:- Wave-front of a wave, at any instant , is defined as the locus of all the particles in the medium which are being disturbed at the same instant of time and are in the same phase of vibration.

(a) Each point on a wave front acts as a source of new disturbance and emits its own set of spherical waves called secondary wavelets. The secondary wavelets travel in all directions with the velocity of light so long as they move in the same medium.



(d) The envelope or the locus of these wavelets in the forward direction gives the position of new wave front at any subsequent time.

- **Determination of Phase Difference:-**

  The phase difference between two waves at a point will depend upon

  (a) The difference in path lengths of the two waves from their respective sources.

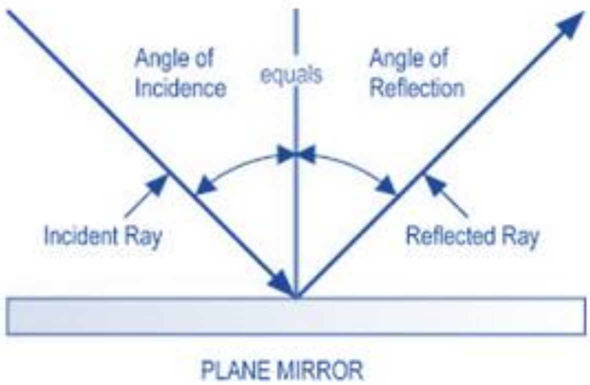
  (b) The refractive index of the medium

  (c) Initial phase difference between the source if any.

  (d) Reflections, if any, in the path followed by waves.

- **Reflection of plane wave at plane surface (Laws of reflection):-**

  (a) The incident ray, the reflected ray and normal to the reflecting surface at the point of incidence, all lie in one plane and that plane is perpendicular to the reflecting surface.



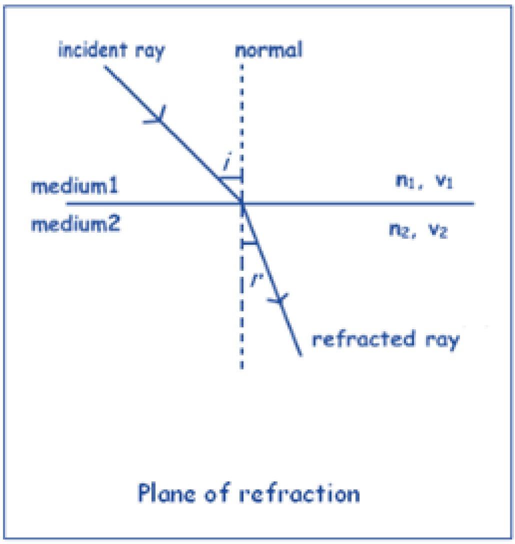
(b) The angle of incidence is equal to the angle of reflection.

So, $\angle i = \angle r$

This signifies angle of incidence is equal to the angle of reflection.

- **Refraction of light:-**

  Refraction is the phenomena by virtue of which a wave going from one medium to another undergoes a change in velocity.



(a) The sine of the angle between the incident ray and the normal bears a constant ratio to the sine of the angle between refracted ray and the normal.

$\sin i/\sin r = v_1/v_2 = {}^1\mu_2$ = constant

Here, v_1 and v_2 are the velocities of sound in first and second medium respectively. ${}^1\mu_2$ is the refractive index of the second medium with respect to first.

(b) The incident ray, the refracted ray and the normal to the refracting surface lie in the same plane.

- **Interference:-** The modification in the distribution of light energy obtained by the superposition of two or more waves is called interference.
- **Principle of superposition:-** It states that a number of waves travelling, simultaneously, in a medium behave independent of each other and the net displacement of the particle, at any instant, is equal to the sum of the individual displacements due to all the waves.
- **Displacement equation:**- $y = R \sin 2\pi/\lambda\ (vt+x/2)$
- **Amplitude:-** $R = 2a \cos \pi x/\lambda$
- **Intensity:-** $I = K4a^2 \cos^2 (\pi x/\lambda)$ $[I = KR^2]$
- **Maxima:-** A point having maximum intensity is called maxima.

  $x = 2n\ (\lambda/2)$

  A point will be a maxima if the two waves reaching there have a path difference of even multiple of $\lambda/2$.

  $I_{max} = 4Ka^2 = 4i$ (Here, $i = Ka^2$)

- **Minima:-** A point having minimum intensity is called a minima.

  x = (2n+1) (λ/2)

  A point will be a minima if the two waves reaching there have a path difference of odd multiple of λ/2.

  $I_{min} = K.\ 4a^2 \times 0 = 0$
- **Condition for constructive interference:-**

  Path difference = (2n)λ/2

  Phase difference = (2n)π
- **Condition for destructive interference:-**

  Path difference = (2n+1)λ/2

  Phase difference = (2n+1)π
- **Coherent Sources:-** Coherent sources are the sources which either have no phase difference or have a constant difference of phase between them.
- **Conditions for interference:-**
  (a) The two sources should emit, continuously, waves of same wavelength or frequency.
  (b) The amplitudes of the two waves should be either or nearly equal
  (c) The two sources should be narrow.
  (d) The sources should be close to each other.
  (e) The two sources should be coherent one.
- **Young's double slit experiment:-**

  Path difference, $x = yd/D$

  Maxima, $y = n\lambda D/d$

  Here, n = 0,1,2,3….

  Minima, y = **(**2n+1) $\lambda D/d$

  Here, n = 0,1,2,3….
- **Fringe Width:-** It is the distance between two consecutive bright and dark fringes.

  $\beta = \lambda D/d$
- **Displacement of fringes due to the introduction of a thin transparent medium:-**
  (a) Shift for a particular order of fringes:-

  ?y = (β/λ) (μ-1)t

  (b) Shift across a particular point of observation:-

  μ = ($m\lambda/t$) +1
- **Lloyd's single mirror:-**

  ?$\lambda = \beta\ .2a/D$
- **Power of lens:-** $P = 100/f$
- **Magnifying power or magnification of a simple microscope:-** M= 1+(D/f)
- **Magnifying power or magnification of a compound microscope:-**

  M= $L/f_0\ (1+D/f_e)$

  Here, f_0 is the focal length of the objective, f_e is the focal length of the eyepiece and L is the length of the microscope tube.
- **Magnification of astronomical telescope in normal adjustment:-**

  $M = f_0/f_e$

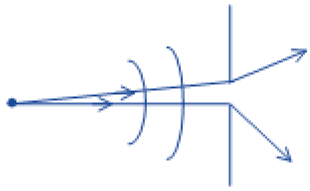
- **Magnification of astronomical telescope, when the final image is formed at the distance of distinct vision:-**

  $M = (f_0/f_e)\,[(f_e+D)/D]$

- **Magnifying power *M* of Galileo's telescope:-**

  M = focal length of objective/focal length of eye lens = F/f

- **Diffraction:-** Diffraction is the bending or spreading of waves that encounter an object (a barrier or an opening) in their path.



(a) In Fresnel class of diffraction, the source and/or screen are at a finite distance from the aperture.

(b) In Fraunhofer class of diffraction, the source and screen are at infinite distance from the diffracting aperture. Fraunhofer is a special case of Fresnel diffraction.

If I_m represents the intensity at O, its value at P is

$I_\theta = I_m\,(\sin\alpha/\alpha)^2$

Here, α = ?/2 = $\pi a \sin\vartheta/\lambda$

A minimum occurs when, $\sin\alpha = 0$ and α is not equal to zero.

so $\alpha = n\pi$, $n = 1, 2, 3...$

So, $\pi a \sin\vartheta/\lambda = n\pi$

Or, $a \sin\vartheta = n\lambda$

Angular width of central maxima of diffraction pattern = $2\vartheta_1 = 2\sin^{-1}(\lambda/a)$

[ϑ_1 gives the angular position of first minima]

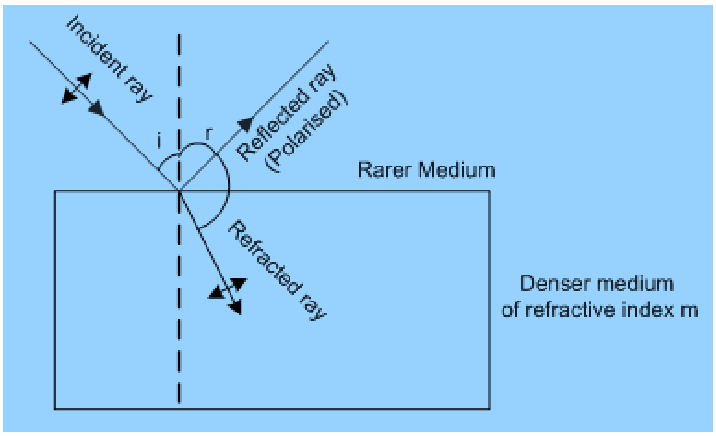
- **Polarization: -** Polarization of two interfering wave must be same state of polarization or two source of light should be un polarized.

- **Brewster Law:-**

  ?According to this law when un polarized light is incident at polarizing angle (i) on an interface separating a rarer medium from a denser medium, of refractive index m as shown in Fig., below such that,

  $\mu = \tan i$

  Then light reflected in the rarer medium is completely polarized. Reflected and refractive rays are perpendicular to each other.



- **Reduction in Intensity:-** Intensity of polarized light is 50% of that of the un polarized light, i.e.,

  $I_p = I_u/2$

  Here, I_p = Intensity of polarized light.

  I_u = Intensity of un polarized light.