WAVE MOTION

Synopsis :

1. Sound is a form of energy produced by a vibrating body, which requires medium to **travel**
2. Sound travels in the form of waves.
3. The audiable sound has frequency range 20 Hz to 20 kHz (wavelength range 17 m to 17 mm)
4. The sound having frequency less than 20 Hz is called infrasonic sound.
5. The sound having frequency greater than 20,000 Hz are called ultrasonics.
6. Ultrasonic waves can be produced by Galton's whistle, magnetostriction oscillator and piezoelectric oscillator.
7. **Wave :** A disturbance created in the medium which propagates in the forward direction with constant velocity without changing its shape, is defined as a wave.
8. **Wave motion :** The mode of energy transfer in which a disturbance advances in the forward direction by affecting the medium without mass transfer, is defined as wave motion.
9. **Characteristics of wave motion :**
   a) Wave motion is a disturbance produced in the medium by the repeated periodic motion of the particles of the medium.
   b) Only the wave travels forward whereas the particles of the medium vibrate about their mean positions.
   c) There is a regular phase change between the various particles of the medium. The particle ahead starts vibrating a little later than a particle just preceding it.
   d) The velocity of the wave is different from the velocity with which the particles of the medium are vibrating about their mean positions. The wave travels with a uniform velocity whereas the velocity of the particles is different at different positions. It is maximum at the mean position and zero at the extreme position of the particle.
   e) The medium itself does not move.
   f) The energy and momentum are transferred in the medium.
10. The properties of medium necessary for wave propagation :
    a) The medium should have the property of **inertia**.
    b) The medium should posses the property of **elasticity**.
    c) The medium should have low resistance (**non viscous**).
11. Whenever disturbance is created in the medium then the particles of the medium start vibrating about their mean positions.
12. The particles of the medium transfer energy or momentum to their neighbouring particles and do not move themselves.
13. The particles of the medium are momentarily displaced.
14. The motion of the particles of the medium is simple harmonic motion i.e., the restoring force act in a direction opposite to that of displacement.
15. Types of waves : There are two types of waves, classified according to the vibration of the particles of the medium with respect to the direction of propagation of wave.
    a) Longitudinal waves
    b) Transverse waves
16. **Properties of longitudinal waves :**
    a) The particles of the medium vibrate simple harmonically along the direction of propagation of the wave.
    b) All the particles have the same amplitude, frequency and time period.

c) All the particles vibrating in phase will be at a distance equal to $n\lambda$. Here n=1, 2, 3 etc. It means the minimum distance between two particles vibrating in phase is equal to the wavelength.
d) The velocity of the particle is maximum at their mean position and it is zero at their extreme positions.
e) When the particle moves in the same direction as the propagation of the wave, it is in a region of compression.
f) When the particle moves in a direction opposite to the direction of propagation of the wave, it is in a region of rarefaction.
g) When the particle is at the mean position, it region of maximum compression or rarefaction.
h) When the particle is at the extreme position, the medium around the particles has its normal density, with compression on one side and rarefaction on the other.
i) Due to the repeated periodic motion of the particles, compressions and rarefactions are produced continuously. These compressions and rarefactions travel forward along the wave and transfer energy in the direction of propagation of the wave.
j) The medium must possess the property of volume elasticity for the propagation of these waves.
k) These waves can propagate in all types of medium. (solids, liquids and gases)
l) In these waves the pressure and the density vary.
m) These waves cannot be polarized.
Eg : Sound waves produced in musical instruments, waves produced along the length of string, wave propagating in gases and inside liquids etc.

17. **Properties of Transverse waves :**
a) In these waves the particles of the medium vibrate at right angles to the direction of propagation of waves.
b) Crest – The maximum displacements of particles on positive side are known as crests. Trough – The maximum displacements particles on negative side are known as troughs.
c) The medium must posses the property of rigidity for the propagation of these waves.
d) These waves can propagate only in solids as well as on the surface of water.
e) In these waves the pressure and the density do not vary.
f) These waves can be polarized.
Eg : Waves propagating on the surface of water, waves produced in stretched strings etc.

18. **Properties of Progressive waves :**
a) These waves propagate in the forward direction of medium with finite velocity.
b) Energy is propagated via these waves.
c) In these waves all the particles of the medium execute S.H.M. with same amplitude and same frequency.
d) In these waves all the particles of the medium pass through their mean position or positions of maximum displacements one after the other.
e) In these waves the velocity of the particle and the strain are proportional to each other.
f) This wave is an independent one.
g) In these waves equal change in pressure and density occurs at all points of medium.
h) In these waves equal strain is produced at all points.
i) In these waves all the particles of the medium cross their mean position once in one time period.
j) In these waves the average energy over one time period is equal to the sum of kinetic energy and potential energy.

k) The energy per unit volume of a progressive wave is $\frac{1}{2}\rho A^2\omega^2$ where ρ is the density of the medium.

l) The equation of a progressive wave along the positive direction of x-axis is $y = A\sin(\omega t - kx)$

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

or $y = A\sin 2\pi n\left(t - \frac{x}{V}\right)$ where y = displacement of a particle at an instant t ; A = amplitude; ω = angular frequency = $2\pi n$; T = time period and k = propagation constant or angular wave number or wave vector and is equal to $\frac{2\pi}{\lambda}$.

m) The time taken for one vibration of a particle is called **time period** or **period of vibration** ($T = \frac{1}{n}$).

n) The maximum displacement of a vibrating particle from its mean position is called **amplitude**.

o) The **phase** of vibration at any moment is the state of vibrating particle as regards its position and direction of motion at that moment.

p) Phase difference $\Delta\phi = \frac{2\pi}{\lambda} \times$ Path difference.

q) If the phase difference between two particles is 2π, then they are said to be in phase. If the phase difference is π, then they are said to be out of phase.

r) The distance travelled by a wave in the time in which the particles of the medium complete one vibration or the distance between two nearest particles in the same state of vibration (i.e., same phase) is called **wavelength** (λ).

19. **Properties of Stationary waves :**

a) All the particles except a few (at nodes) execute S.H.M.

b) The period of each particle is the same but the amplitude of vibration varies from particle to particle.

c) The distance between any two successive nodes or antinodes is equal to $\lambda/2$.

d) The distance between a node and a neighbouring antinode is equal to $\lambda/4$.

e) The wave is confined to a limited region and does not advance.

f) All the particles of a wave in a loop are in the same phase and the phase difference is zero.

g) Stationary waves are formed by combining two longitudinal progressive waves or two transverse progressive waves.

h) Due to persistence of vision, stationary waves appear in the form of loops.

i) These waves do not transfer energy.

j) The change in pressure or density or strain will be maximum at nodes and minimum at antinodes.

k) The particle velocity at a node is zero and at an antinode it is maximum.

l) The phase difference between the particles in adjacent loops in a stationary wave is π.

m) The equation of a stationary wave is $y = 2A\sin kx.\cos\omega t$ or $y = 2A\cos kx.\sin\omega t$.





n) In these waves the particles of the medium cross their mean positions twice in one time period.

o) In these waves average energy= kinetic energy= potential energy.

20. **Types of vibrations :**
    a) Whenever a body, capable of vibration, is displaced from its equilibrium position and then left to itself, the body begins to vibrate freely in its own natural way called the free or natural vibration of the body with a definite frequency. This frequency is called **natural frequency**.
    b) The free vibrations of a body have a unique frequency and it is dependent on the elasticity and inertia of the body and the mode of vibration.
    c) When a body is set into vibration with the help of strong periodic force having a frequency different from its natural frequency, then the vibrations of the body are called **forced vibrations**.
    If the amplitude of vibrations remain constant, then they are called **undamped vibrations**.
    e.g. Vibrations of the pendulum of a clock.
    If the amplitude of vibrations progressively decreases with time, then they are called **damped vibrations**. e.g. Vibrations of a tuning fork.
    d) Bells are made of metals and not of wood because wood dampens the vibrations while the metals are elastic.
    e) If the natural frequency of a vibrating body is equal to the frequency of the external periodic force and if they are in phase, the frequencies are said to be in **resonance**.
    i) Tuning a radio or television receiver is an example of electrical resonance.
    ii) Optical resonance may also take place between the atoms in a gas at low pressure.
    f) Theoretically the amplitude of resonant frequency should be infinitely very large. Due to damping forces, the amplitude won't be that much.

21. **Tuning fork :**
    a) A tuning fork produces a pure note.
    b) The prongs of a tuning fork vibrate transversely, while stem vibrates longitudinally.
    c) If a little wax is attached to one of the prongs of a tuning fork, its frequency decreases.
    d) If the temperature increases, the frequency of tuning fork decreases.
    e) If one of the prongs of a tuning fork is filed, its frequency increases.
    f) The frequency of a tuning fork varies
    i) directly as the thickness of the prongs in the plane of vibration
    ii) directly as the velocity of sound in the material of the fork and
    iii)inversely as the square of the length of the prongs.
    g) With rise in temperature, the frequency of a fork decreases which is about 0.01% for 1^0C rise in temperature.
    h) The two prongs of a vibrating tuning fork are in a phase difference of π.
    i) If one of the prongs of a tuning fork is broken, its frequency remains same but intensity of sound increases due to increase in amplitude.
    j) In a tuning fork, stationary vibrations are set up with two nodes and three antinodes.
    k) The natural frequency depends on 1) elastic constants, 2) dimensions and 3) more of vibration of the body. Eg : The frequency of a tuning fork is given by $n=\frac{t}{L^2}\sqrt{\frac{Y}{d}}$ where t is thickness of prongs, L is length, Y is Young's modulus of the material and d is its density.

22. **Vibrations of a string :**
    a) String can have only transverse vibrations that too when it is under tension.

b) The velocity of transverse wave propagating along a string or wire under tension is $V=\sqrt{\frac{T}{m}}$ where T is tension and m is linear density of the string or wire. $M=\frac{M}{l}=A.d=\pi r^2.d$ where M is total mass of wire of length 'l', A is area of cross-section of wire and r is its radius. Hence $V=\sqrt{\frac{T}{m}}=\sqrt{\frac{Tl}{M}}=\sqrt{\frac{T}{Ad}}=\sqrt{\frac{T}{\pi r^2 d}}$

c) If s is stress in the wire, S=T/A, hence $V=\sqrt{\frac{s}{d}}$; also $V=\sqrt{\frac{Y.Strain}{d}}$.

d) A wire held at the two ends by rigid support is just taut at temperature t_1. The velocity of transverse wave at a temperature t_2 is $V=\sqrt{\frac{Y\alpha(t_2 \sim t_1)}{d}}$ where α=co-efficient of linear expansion, Y=Young's modulus, d=density.

23. **Frequency of a vibrating string :**
   a) The waves formed in a string under tension are transverse stationary.
   b) Always nodes are formed at fixed ends and antinodes at plucked points and free ends.
   c) A string can have number of frequencies depending on its mode of vibration.

24. Fundamental frequency : When a string vibrates in a single loop, it is said to vibrate with fundamental frequency.
   a) Frequency is minimum and wavelength is maximum in this case.
   b) If l is the length of the string $l=\frac{\lambda}{2}\Rightarrow\lambda=2l$.
   c) The fundamental frequency, $n=\frac{1}{2l}\sqrt{\frac{T}{m}}$ where T=tension, m=linear density.
   d) The fundamental frequency is also given by $n=\frac{1}{2}\sqrt{\frac{T}{Ml}}=\frac{1}{2l}\sqrt{\frac{T}{Ad}}=\frac{1}{2l}\sqrt{\frac{T}{\pi r^2 d}}=\frac{1}{2l}\sqrt{\frac{s}{d}}$.
   e) For small change in tension in string, the fractional change in frequency is $\frac{\Delta n}{n}=\frac{1}{2}\frac{\Delta T}{T}$.
   f) The fundamental frequency is also called the first harmonic.

25. Overtones : If string vibrates with more number of loops, higher frequencies are produced called overtones.
   a) If string vibrates in p loops, it is called p^{th} mode of vibration or p^{th} harmonic or $(p-1)^{th}$ overtone. The corresponding frequency $n_p=\frac{p}{2l}\sqrt{\frac{T}{m}}$=p.n Hence, for a string, $n_p\alpha p$; $\frac{n_1}{n_2}=\frac{p_1}{p_2}$ when other, quantities are constant.
   b) The fundamental and overtone frequencies are in the ratio 1:2:3:4:….
   c) The wavelength is above case is $\lambda_p=\frac{2l}{p}$ i.e., wavelengths are in the ratio $1:\frac{1}{2}:\frac{1}{3}:...$

26. **Laws of transverse waves along stretched string :**
   a) Law of length : The frequency of a stretched string is inversely proportional to the length of the string $n\alpha 1/l$ where T & m are constants, nl=constant, $n_1l_1=n_2l_2$.
   b) Law of tension : The frequency of a stretched string is inversely proportional to square root of tension. $n\alpha\sqrt{T}$ when l & T are constant. $\frac{n}{\sqrt{T}}$=constant, $\frac{n_1}{\sqrt{T_1}}=\frac{n_2}{\sqrt{T_2}}$.

c) Law of mass : The frequency of a stretched string is inversely proportional to square root of linear density $n \alpha \frac{1}{\sqrt{m}}$ when l & T are constants. $n\sqrt{m}$ =constant; $n_1\sqrt{m_1} = n_2\sqrt{m_2}$.

27. Sonometer is used to determine the velocity of transverse waves in strings and to verify the laws of transverse waves.

$$RD = \frac{l_1^2}{l_1^2 - l_2^2}$$

28. Loudness, Pitch and quality of musical note :

a) Loudness of sound mainly depends on its intensity. Its units is bel or decibel. 1 bel=$\log \frac{I}{I_0}$. Where I is intensity of sound, $I_0=10^{-12}$ w/m^2, the minimum intensity audible to normal human being. 1 decibel=$10\log \frac{I}{I_0}$

b) The pitch mainly depends on frequency of fundamental tone.

c) The pitch is said to be one octave higher than a note when it has double frequency than the note.

d) Quality or timbre of sound depends on the overtones present in a note. The note produced by an open pipe is richer in quality than a closed pipe since it has more overtones.

e) Two sounds of same loudness and pitch can be distinguished using quality.

29. Intensity of sound :

a) The transfer of energy per unit time per unit area perpendicular to the direction of motion of a wave is called intensity of wave. $I=\frac{1}{A}.\frac{dE}{dt}$. Its S.I. unit is watt/m^2.

b) Intensity of a wave is given by $I=2\pi^2 dn^2 a^2 v = \frac{1}{2} dvw^2 a^2$. Where d is density of medium, v is velocity of sound, n is frequency, a is amplitude.

i) $I \alpha n^2 a^2$; $\frac{I_1}{I_2} = \frac{n_1^2 a_1^2}{n_2^2 a_2^2}$; intensity is proportional to square of frequency and amplitude.

ii) For a given frequency of sound, $I \alpha a^2$; $\frac{I_1}{I_2} = \frac{a_1^2}{a_2^2}$.

c) When two sound waves of amplitudes a_1 and a_2 with intensity I_1 and I_2 superimpose the resultant amplitude $a=\sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$ where ϕ is phase difference between the waves.

i) The resultant intensity $I=I_1+I_2+2\sqrt{I_1I_2}\cos\phi$.

ii) The maximum amplitude $a_{max}=a_1+a_2$ and the minimum amplitude $a_{min}=a_1-a_2$.

iii)The maximum intensity $I_{max}=a_{max}^2=\left(\sqrt{I_1}+\sqrt{I_2}\right)^2$.

The minimum intensity $I_{min}=a_{min}^2=\left(\sqrt{I_1}-\sqrt{I_2}\right)^2$

d) When wave travels uniformly in all directions from a point source, the intensity at a point varies inversely as the square of the distance of the point from source. $I \alpha \frac{1}{r^2}$; $\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$.

30. Velocity of sound :

a) In the case of water waves of longer wavelength, the speed depends only on the acceleration due to gravity. In shallow waters, the speed of water waves decreases. A wave approaching the shore

gradually slows down to zero speed. The velocity of waves in a canal is given by $C=\sqrt{gh}$, where g is acceleration due to gravity and h is the height of the waves.

b) The velocity of sound is maximum in solids, intermediate in liquids and minimum in gases.

c) Newton assumed that when sound waves travel in a gas, the changes in volume and pressure are isothermal.

d) Newton's formula for the velocity of a longitudinal wave in a homogeneous medium is $V = \sqrt{E/d}$ where E is the modulus of elasticity for a particular type of strain set up and d is the density of the medium.

In solids, $V = \sqrt{\frac{Y}{d}}$ where Y = Young's modulus

In liquids, $V = \sqrt{\frac{K}{d}}$ where K = bulk modulus

In gases, $V = \sqrt{\frac{P}{d}}$ where P = pressure of the gas.

e) The velocity of sound in air at S.T.P. as calculated by Newton's formula was found to be 280 ms^{-1}.

f) Laplace assumed that when sound waves travel in a gas, the changes in volume and pressure are adiabatic.

g) Newton-Laplace formula for the velocity of sound in a gas is $V = \sqrt{\frac{\gamma P}{d}}$ where γ is the ratio of specific heats of the gas.

h) Velocity of sound in a gas is given by $V = \sqrt{\frac{\gamma RT}{M}}$ i.e., the velocity of sound in a gas is directly proportional to the square root of absolute temperature (T).

$V \alpha \sqrt{T}$ or $\frac{V_1}{V_2} = \sqrt{\frac{T_1}{T_2}}$ or $\frac{V_1}{V_2} = \sqrt{\frac{t_1 + 273}{t_2 + 273}}$ and $V_t = V_0(1 + \frac{t}{546})$ or $V_0 = V_t(1 - \frac{t}{546})$ when 't' is small.

i) As the temperature increases, the velocity of sound increases approximately at the rate of 0.61 ms^{-1} per 1^oC rise in temperature.

j) The velocity of sound in a gas is independent of the change of pressure.

k) The velocity of sound in air at 819^oC is double the velocity of sound in air at 0^oC.

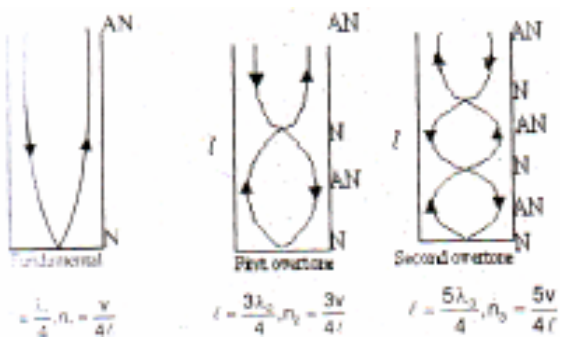
As the humidity increases, the density of air decreases and hence the velocity of sound increases

31. Standing wave in a organ pipe (Vibrations of air columns)

The mechanical waves in an organ pipe are longitudinal stationary.

In organ pipe, harmonics are formed with a displacement node at closed end and with displacement antinode at free end.

i. Close organ pipe:



a) Fundamental frequency is $f_C = \frac{V}{4l}$

b) In closed organ pipe, only odd harmonic are present.

c) Ratio of harmonic 1:3:5:.....

d) First harmonic is fundamental, third harmonic will be first overtone.

(p^{th} overtone = $((2P+1)^{th}$ harmonic)

e) The maximum possible wavelength is '$4l$'.

f) In general $\lambda = \frac{4l}{(2N-1)}$ where N = 1,2,3,... corresponding to order of mode of vibration.

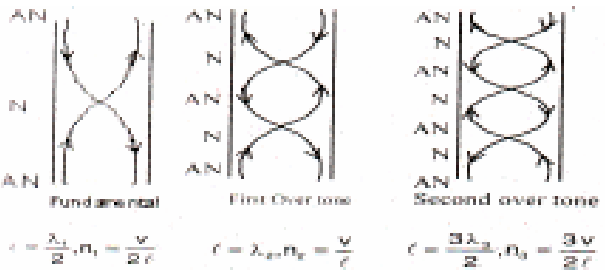
g) Frequency $n = \frac{(2N-1)V}{4l}$ N = 1,2,3,..... corresponding to order of mode of vibration.

h) Position of node from closed end x = 0, $\frac{\lambda}{2}, \lambda, \frac{3\lambda}{2}$ ...

i) Position of antinodes from closed end

x = $\frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}$, ...

ii. Open organ pipe:



i) Fundamental frequency is $f_0 = \frac{V}{2l}$

ii) In open organ pipe, all (even and odd) harmonic are present, the ratio of harmonics is 1:2:3:4:.....

iii) First harmonic is fundamental, second harmonic will be first overtone and so on .

(p^{th} overtone = $(P+1)^{th}$ harmonic)

iv) The maximum possible wavelength is '$2l$'.

v) Wave length $\lambda = \frac{2l}{N}$ (N= 1,2,3 .... corresponding to order of mode of vibration).

Frequency $n = \frac{NV}{2l}$.

vi) Position of node from one end x = $\frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}$ ....

vii) Position of antinodes from closed end x =0, $\frac{\lambda}{2}, \lambda, \frac{3\lambda}{2}$ .....

iii. End correction :

a) Due to finite momentum of air molecules in organ pipes reflection takes place not exactly at free end but slightly above it.

b) The distance of antinode from open end is called end correction and e = 0.6 r where 'r' is radius of pipe.

c) For closed organ pipe effective length L^1 = (L+e).

d) For open organ pipe effective length L^1 = (L+2e).

e) Hence with end correction fundamental frequency of closed pipe $f_C = \frac{V}{4(L+0.6r)}$.

Fundamental frequency of open pipe $f_0 = \frac{V}{2(L+1.2r)}$.

iv. Resonance Tube:

a) In a resonating air column experiment, if l_1, l_2 are the first and second resonating lengths then

$l_1 + e = \frac{\lambda}{4}, l_2 + e = \frac{3\lambda}{4}, l_2 - l_1 = \frac{\lambda}{2} \Rightarrow \Rightarrow \lambda = 2(l_2 - l_1)$

b) Speed of sound in air at room temperature is $V = 2n(l_2 - l_1)$ Where n be the frequency of the tuning fork.

c) $e = \frac{l_2 - 3l_1}{2}$

32. **BEATS :**

a) When two sounds of slightly different frequencies superimpose, the resultant sound consists of alternate waxing and waxing. This phenomenon is called beats.

b) One waxing and one waning together is called one beat.

c) If simple harmonic progressive waves of frequencies n_1 & n_2 travelling in same direction superimpose, the resultant wave is represented by $y=\left\{2a\cos 2\pi\left(\frac{n_1 - n_2}{2}\right)t\right\}\sin 2\pi\left(\frac{n_1 + n_2}{2}\right)t$.

d) The amplitude of resultant wave is $2a\cos 2\pi\left(\frac{n_1 - n_2}{2}\right)t$.

e) The maximum amplitude is 2a and minimum amplitude zero.

f) The frequency of resultant wave is $\left(\frac{n_1 + n_2}{2}\right)$.

g) The number of beats produced per second or beat frequency is equal to the difference of frequencies of nodes producing beats. $n=n_1 \sim n_2$.

h) If two sound waves of wavelengths λ_1 and λ_2 produce n beats per second, then velocity of sound can be determined by $n=\frac{V}{\lambda_1} \sim \frac{V}{\lambda_2}$ or $V = \frac{\lambda_1\lambda_2}{(\lambda_2 \sim \lambda_1)}$.

i) The maximum number of beats heard by a person is 10, since persistence of hearing is 1/10 sec.

j) The time internal between two consecutive maxima or minima is $\frac{1}{(n_1 \sim n_2)}$.

k) The time interval between consecutive maxima and minima is $\frac{1}{2(n_1 \sim n_2)}$.

l) Beats can be produced by taking two identical tuning fork and loading or filing either of them and vibrating them together.

m) When a tuning fork is loaded its frequency decreases and when it is filed frequency increases.

33. **ECHO :**

a) When a sound is produced and a listener hears it after reflection from an obstacle, the reflected sound is called and echo.

b) If d is the distance between source and the reflecting surface and t is the time taken to hear echo after sound is produced, $t=\frac{2d}{V}$ where V is velocity of sound.

c) The distance between source and reflecting surface d=Vt/2.

d) The minimum distance between source and the reflecting surface to hear a clear echo is V/20. It is equal to 16.5 m if V=300 m/s.

e) If a person standing between two parallel hills fires a gun and hears first echo after t_1 sec and the second echo after t_2 sec, the distance between two hills is $d=\frac{V(t_1+t_2)}{2}$.

f) In the above case, the third echo will be heard after (t_1+t_2) sec.

g) In the above case, if echos are heard at regular intervals of time 't' sec, the distance between two hills is d=V.t or d=(3/2)V.t.

h) If a motor car approaching a cliff with a velocity 'u' sounds the horn and the echo is heard after 't' sec, then the distance between the cliff and the original position of car is $d=\left(\frac{v+u}{2}\right)t$.

i) In the above case, the distance between the cliff and the point where the echo is heard is $d=\left(\frac{v-u}{2}\right)t$.

j) A road runs paralleled to a long vertical line of hills. If a motorist moving with a speed 'u' sounds the horn and hears the echo after 't' sec, then the distance between the road the cliff is $d=\frac{t}{2}\sqrt{v^2-u^2}$.

k) A road runs midways between two parallel rows of hills. If a motorist moving with speed 'u' sounds the horn and hears echo after 't' sec, then the distance between two rows of hills is $s=t\sqrt{v^2-u^2}$.

34. **DOPPLER EFFECT :**

The apparent change in frequency due to relative motion between the source and the listener is called **Doppler effect**.

35. Let V_O and V_s represents the velocities of a listener and a source respectively. Let V be the velocity of sound and n and n_1 be the true and apparent frequencies of the sound. Then if

a) the source alone is in motion towards the observer, $n_1=n\left(\frac{V}{V-V_s}\right)$. Clearly $n_1>n$.

b) the source alone is in motion away from the observer, $n_1=n\left(\frac{V}{V+V_s}\right)$. Clearly $n_1<n$.

c) the observer alone is in motion towards the source, $n_1=n\left(\frac{V+V_O}{V}\right)$. Clearly $n_1>n$.

d) the observer alone is in motion away from the source, $n_1=n\left(\frac{V-V_O}{V}\right)$. Clearly $n_1<n$.

e) the source and the observer both are in motion towards each other, $n_1=n\left(\frac{V+V_O}{V-V_s}\right)$.

f) the source and the observer both are in motion away from each other, $n_1 = n\left(\frac{V - V_O}{V + V_S}\right)$.

g) the source and the observer both are in motion, source following the observer, $n_1 = n\left(\frac{V - V_O}{V - V_S}\right)$.

h) the source and the observer both are in motion, observer following the source, $n_1 = n\left(\frac{V + V_O}{V + V_S}\right)$.

i) the source, observer and the medium all are moving in the same direction as the sound, $n_1 = n\left(\frac{V + V_w - V_O}{V + V_w - V_S}\right)$ where V_w = velocity of wind.

j) the source and the observer are moving in the direction of the sound but the direction of wind is opposite to the direction of the propagation of sound,
$n_1 = n\left(\frac{V - V_w - V_O}{V - V_w - V_S}\right)$.

36. If the source of sound is moving towards a wall and the observer is standing between the source and the wall, no beats are heard by the observer.
37. When source and observer are not moving along the same line then $n^{I} = n\left[\frac{V}{V - V_S \cos\theta}\right]$ where θ is angle between source velocity and line joining source and observer.
38. When source and observer do not move along the line joining them, then components of their velocities along the line joining them must be taken as velocity of observer and velocity of source in Doppler is formula $n = n_0\left(\frac{V + V_0 \cos\theta_2}{V - V_S \cos\theta_1}\right)$.
39. If $\vec{r}$ is unit vector along line joining source and observer, $\vec{v}$ is velocity of sound (taken from the source to observer), $\vec{v}_0$ is velocity of observer and $\vec{v}_s$ is velocity of source then Doppler's effect in vector form is $n^{I} = \frac{(\vec{v}.\vec{r} - \vec{v}_0.\vec{r})}{(\vec{v}.\vec{r} - \vec{v}_s.\vec{r})}n$.
40. Doppler effect in sound is asymmetric. This means the change in frequency depends on whether the source is in motion or observer is in motion even though relative velocities are same in both cases.
41. Motion of source produces greater change than motion of observer even though the relative velocities are same in both cases.

Eg : $n^{I} = \left(\frac{v}{v - u}\right)n$

$n^{II} = \left(\frac{v + u}{v}\right)n$

$n^{I} > n^{II}$

42. Doppler effect in sound is asymmetric because sound is mechanical wave requiring material medium and v, v_0, v_s are taken with respect to the medium.
43. Doppler effect in light is symmetric because light waves are electromagnetic (do not require medium)
44. Doppler effect is not applicable if
    1) $V_0 = V_s = 0$ (both are at rest)
    2) $V_0 = V_s = 0$ and medium is alone in motion

3) $V_0=V_s=u$ (V_0, V_s are in same direction)
4) V_s is $\perp$ to line of sight

45. Doppler effect is applicable only when, $V_0<<v$ and $V_s<<v$. (v=velocity of sound)
46. a) Doppler effect in sound is asymmetric.
    b) Doppler effect holds good for light also. An increase of frequency is called blue shift and it indicates that the source is approaching the observer. Red shift indicates that the source is receding from the observer.

$$\text{Red shift}(\Delta\lambda) = \frac{V}{c} \times \lambda$$

    c) Doppler effect in light is symmetric.
    d) The red shift observed by Hubble in many stars supports the 'Big Bang Theory' of the universe.

47. Uses of Doppler effect :

It is used in
a) SONAR
b) RADAR (Radio detection and Ranging used to determine speed of objects in space) (Radio waves)
c) To determine speeds of automobiles by traffic police.
d) To determine speed of rotation of sun and to explain Saturn's rings.
e) Led to the discovery of double stars/Binary stars.
f) In accurate navigation and accurate target bombing techniques.
g) In tracking earth's satellite.

48. Doppler's effect is used in the estimation of the velocities of aeroplanes and submarines, the velocities of stars and galaxies and the velocities of satellites.
49. If the observer is standing behind the source moving towards a wall with a velocity V_s, then the number of beats heard is equal to $n\left[\frac{V}{V-V_s} - \frac{V}{V+V_s}\right]$ and is approximately equal to $\frac{2nV_s}{V}$.

50. Absorption of sound :

a) When sound energy is incident on any surface of a substance, part of it is absorbed by the surface and rest is reflected.
b) Thick screens, carpets, mats, compressed fibre board, felt, wood and white lime floor are some good absorbers of sound.
c) An open window diffused all the sound energy incident on it.
d) The absorption co-efficient is defined as the ratio of sound energy absorbed by a surface to the sound energy absorbed by an open window of equal surface area. $a=\frac{Es}{Ew}$. The absorption co-efficient of open window is 1.
e) The S.I. unit of absorption co-efficient is metric sabine.
f) The absorption of a surface of area 's' is A=a.s.
g) If a room contains different surfaces of areas s_1, s_2, …. With absorption coefficients a_1, a_2…. respectively, the total absorption of the room $A=a_1s_1+a_2s_2+\ldots.=\sum as$.
h) The absorption co-efficient of a surface is determined by i) stationary wave method, ii) reverberation time method.
i) If i_1 and i_2 are the currents corresponding to maximum and minimum amplitudes in the stationary wave method, the absorption coefficient $a=\frac{4i_1i_2}{(i_1+i_2)^2}$.

j) It T_1 and T_2 are the reverberation times without and with the given material pasted on walls in a reverberation chamber, the absorption coefficient of the material is $a=\frac{0.17V}{s}\left[\frac{1}{T_2}-\frac{1}{T_1}\right]+a_0$, where a_0 is the absorption coefficient of walls of chamber in metric sabine and 's' surface area in square metre and V is volume of room.

51. Threshold of audibility :

a) The minimum intensity of sound at which it is audible is called threshold of audibility.
b) The weakest audible sound has intensity of 10^{-12} w/m^2.
c) An ordinary talk has intensity of sound 10^{-6} w/m^2.
d) The lowest change of intensity level that could be detected by human ear is 1 dB.

52. Reverberation and reverberation time :

a) The persistence of sound in an enclosure due to repeated reflections at walls, even after the original sound is stopped is called reverberation.
b) The time required by the sound intensity in a enclosure to decrease to threshold of audibility from an initial intensity of 10^6 times of this, after the sound is turned off is called reverberation time.
c) The reverberation time is proportional to the volume of enclosure (v) and inversely proportional to the total absorption (A) of the enclosure. $T \propto \frac{V}{A}$, $T=\frac{KV}{A}$.
d) In S.I. system $T=\frac{0.17V}{A}=\frac{0.17V}{\sum as}$. This formula is called sabines formula.
e) When volume is constant $\frac{T_1}{T_2}=\frac{A_2}{A_1}$.
f) A room with zero reverberation time is called dead room.

53. Reverberation time depends on
a) size of the (enclosure) room or auditorium.
b) Nature of reflecting materials on the wall, floor and ceiling.
c) The area of reflecting surface.
d) Intensity (or loudness of sound produced)

54. Reverberation times is independent of
a) Shape of the enclosure.
b) Position of the source of sound and listener.
c) Position of the absorbent in the enclosure.

55. Let T_0 is the reverberation time of an empty auditorium, T is reverberation time when n persons present in the auditorium. If the absorption of each person is $1/K^{th}$ of absorption of empty auditorium, then $\frac{T_0}{T}=1+\frac{n}{K}$.

56 Building Acoustics :

a) Auditoria, concert halls, cinema theaters etc. should follow the principles of architectural acoustics for quality, clarify and sound level of speech and music.
b) The hall should have optimum value of reverberation time, neither too low nor too high. For speech it is in between 0.5 and 1 sec and for music between 1 sec and 2 sec.
c) Loudness of sound must be sufficient at all points of the room.
d) Cylindrical or spherical surfaces on walls or ceiling are to be avoided to prevent focusing effect of sound. Parabolic surfaces are preferred for uniform distribution of sound.
e) Extraneous noise is not allowed into the hall.

f) Height of ceiling should not exceed 10 m to prevent echoes.
g) The musical effect produced due to regular successive reflections of sound at flight of stairs is called echelon effect. It is to be avoided.