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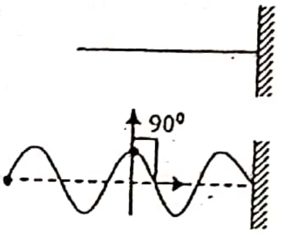
Q.1. a) What is transverse wave?
b) Necessary and desired characteristics for propagation of wave in a medium.
c) Draw diagram to show propagation of transverse wave in a medium.

+1 / Ch 10 / Unit 10B / Q1 / Transverse Wave

Ans.a) **Transverse Wave:**

A transverse wave motion is that wave motion, in which individual particles of the medium execute simple harmonic motion about their mean position in a direction perpendicular to the direction of propagation of wave motion.

Example1.	Wave on a string as shown in *fig.*
Example2.	Light wave is also transverse [Non-Mechanical, no medium required]



b) **Elasticity:** So that particles can return to their mean position after being disturbed.

Inertia: So that particles can store energy and overshoot their mean position.

Minimum Friction: Among the particles of the medium ensures minimum loss of energy so that wave can travel long distances.

Density: Density of the medium should be uniform so that wave can travel uniformly in all directions.

c) $y_1 = -A\sin(wt - 0)$

$y_2 = -A\sin(wt - \frac{\pi}{2})$

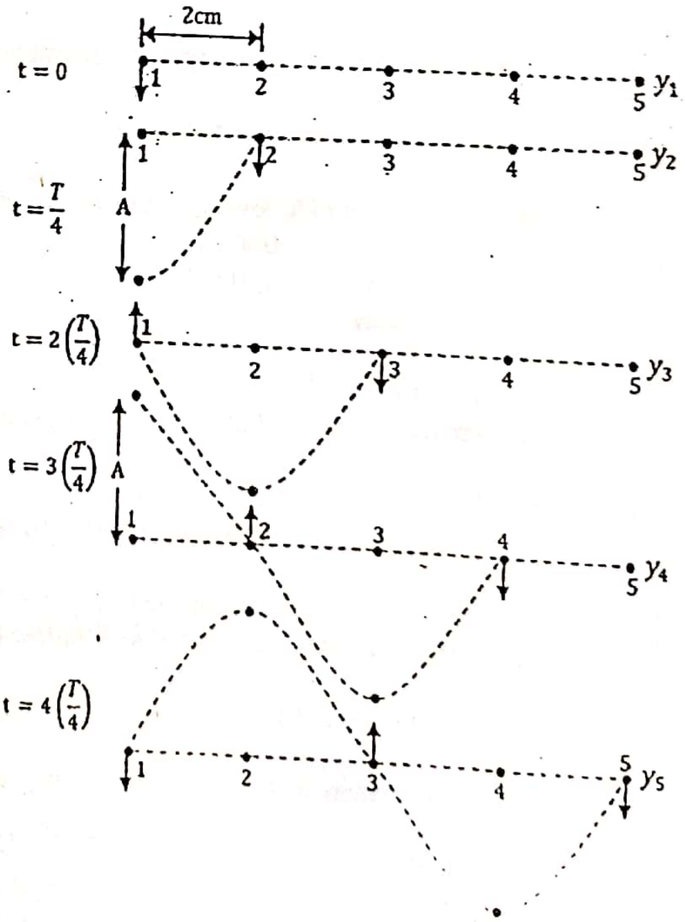
$y_3 = -A\sin(wt - \frac{2\pi}{2})$

$y_4 = -A\sin(wt - \frac{3\pi}{2})$

$y_5 = -A\sin(wt - \frac{4\pi}{2})$

$$\boxed{y = A\sin(wt - \frac{2\pi}{\lambda}x)}$$

$$\boxed{y = A\sin(wt - kx)}$$



Q2. a) What are longitudinal waves? Examples?

b) Define

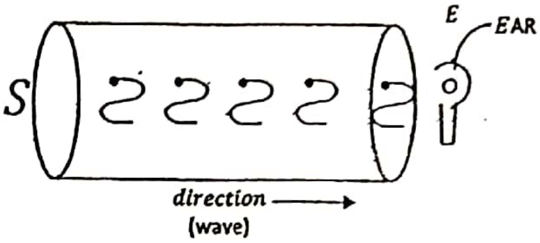
i) λ ii) f iii) T

Ans.a) **Longitudinal waves:**

Longitudinal wave motion is that wave motion in which individual particles of the medium execute SHM about their mean position along the same direction along which the wave is propagated.

Explanation:

Wave travels from S to E along *x-axis* through oscillations of particle no.1, 2, 3, 4 & 5. Source(S) causes disturbance of particle no.1 and particle 1 executes SHM along *x-axis* as shown in figure. Particle no.1 hands over this disturbance to particle no.2, particle 2, hands over this disturbance to particle no.2, disturbance reaches particle no.5 and at the end to E (*ear*). This is how wave travels from S to E parallel to x-axis.



b) **Wave length λ :**

It is equal to the distance travelled by the wave during the time, any one particle of the medium completes one vibration about its mean position.

Frequency f :

It is defined as the number of vibrations completed by particle in one second.

Time Period T :

It is defined as the time taken by the particle to complete one vibration about its position.

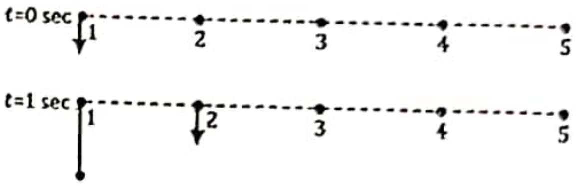
$$f = \frac{1}{T}$$

+1 / Ch 10 / Unit 10B / Q2 /
Longitudinal Wave

Q3. **Write and explain characteristics of mechanical wave motion?**

Ans.

1. Wave motion is a sort of disturbance which travels through a medium.
2. A material medium is essential for the propagation of mechanical waves. The medium must possess three properties, *viz* elasticity, inertia and minimum friction amongst the particles of medium.
3. When a wave motion passes through a medium, particles of the medium only vibrate simple harmonically about their mean position.
4. There is a continuous phase difference amongst successive particles of the medium *i.e*, particle no.2 starts vibrating slightly later than particle 1 and so on.



In figure: Time gap → 1 sec

Phase difference → $\frac{\pi}{2}$

5. The velocity of the particles during their vibration is different at different positions. All particles have maximum velocity when they pass through their mean position and at extreme positions, their velocity is *ZERO*.
6. The velocity of wave motion through a particular medium is constant. It depends only on the nature of the medium. The velocity of wave motion does not depend upon its frequency or wave length or intensity.

Eg: $v = f\lambda$

Male → (100 Hz) x (3m) = 300m/sec

Female → (200 Hz) x (1.5m) = 300m/sec

Female voice has higher frequency than male voice. So, female voice has low wave length than the male voice. Velocity of sound is constant.

7. Energy is propagated along with the wave motion without any net transport of the medium.

+1 / Ch 10 / Unit 10B / Q3 / Characteristics Of Mechanical Wave Motion

Q4. a) **What is sound, ultrasonic and infra sonic waves?**
b) **Plot sensitivity of ear v/s frequency graph.**

Ans.a) **Sound:**

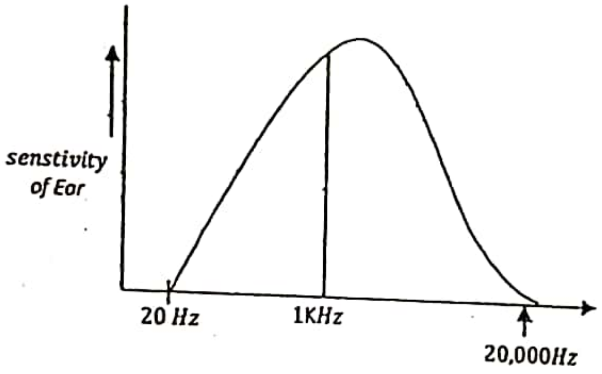
→ Sound is wave having frequency more than $20Hz$ and less than $20,000Hz$.

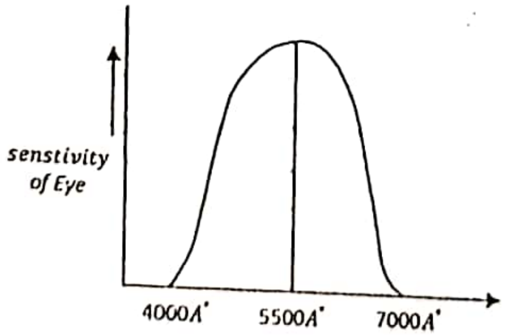
→ Any vibration whose frequency is greater than $20,000Hz$ is called *Ultrasonic Vibration.*,

→ The sound waves which have frequencies less than $20Hz$ are called *Infrasonic Waves.*

→ These both cannot be heard by human ear.

b)





+1 / Ch 10 / Unit 10B / Q4 /
Sound Sensitivity Of Ear

Q5. Prove using dimensions, speed of transverse wave on a string is given as

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

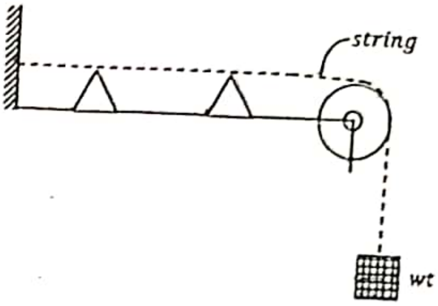
Where $T \rightarrow$ tension in string, $m \rightarrow$ mass per unit length.

Ans. **Step 1.**

$$v \propto T^a m^b$$

$$v = K\, T^a m^b$$

$$LT^{-1} = K\,[MLT^{-2}]^a \left[\frac{M}{L}\right]^b$$



Using principle of homogeneity of equation

$$M^0LT^{-1} = [MLT^{-2}]^a\,[ML^{-1}]^b$$

$$M^0L^1T^{-1} = [M^aL^aT^{-2a}]\,[M^bL^{-b}]$$

Step 2.

$$M^0LT^{-1} = [M^{a+b}]\,[L^{a-b}]\,[T^{-2a}]$$

Step 3.

Compare powers of M, L, T

$$\Rightarrow \quad a + b = 0 \quad \text{———} ①$$

$$a - b = 1 \quad \text{———} ②$$

$$-2a = -1$$

$$\Rightarrow \quad \boxed{a = \frac{1}{2}}$$

Put in ① $b = -a$

$$\Rightarrow \boxed{b = -\frac{1}{2}}$$

Step 4.

$$v \propto T^{1/2}\, m^{-1/2}$$

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

+1 / Ch 10 / Unit 10B / Q5 /
Speed Of Transverse Wave On
A String Under Tension

Q6. **Prove using dimensions, speed of longitudinal wave in a gas i.e.,**

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

$B \rightarrow$ Bulk modulus and $\rho \rightarrow$ Density

Ans. $$B = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{\Delta V/V}$$

Formula for Bulk Modulus $= \frac{M^1L^1T^{-2}/L^2}{M^0L^0T^0}$

$$[B] = [M^1L^{-1}T^{-2}]$$

Step 1. $v \propto B^a \rho^b$

Step 2. $\left(\frac{L}{T}\right) = [M^1L^1T^{-2}]^a \, [ML^{-3}]^b$

$$\left(\frac{L}{T}\right) = [M^aL^{-a}T^{-2a}] \, [M^bL^{-3b}]$$

Step 3. Compare powers of M, L, T

$$M^0LT^{-1} = [M^{a+b}] \, [L^{-a-3b}] \, [T^{-2a}]$$

$\Rightarrow$ $a + b = 0$ ———— ①

$-a - 3b = 1$ ———— ②

$-2a = -1$

$$\boxed{a = \frac{1}{2}}$$

Put in ①

$b = -a$

$$\boxed{b = -\frac{1}{2}}$$

Step 4. $v \propto B^{1/2} \rho^{-1/2}$

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

+1 / Ch 10 / Unit 10B / Q6 /
Speed Of Longitudinal Wave In
A Gas Sound In Air

Q7. **Derive Newton's formula for speed of sound.**

+1 / Ch 10 / Unit 10B / Q7 /
Newton's Formula For Speed
Of Sound

Ans. Isothermal Process

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

$$B = \frac{\Delta P}{-\Delta V/V} \quad \text{———} ①$$

For isothermal process,

$$P.V = \text{constant}$$

Differentiate both sides

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

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

$$\text{As} \quad v = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{P}{\rho}} = \sqrt{\frac{1.01 \times 10^5}{1.29}}$$

$$\simeq 280 \text{ m/sec}$$

Q8. **Laplace correction for speed of sound.**

+1 / Ch 10 / Unit 10B / Q8 /
laplace Correction

Ans. <u>**Adiabatic Process:**</u>

Sound travels at such a high speed
→ No time to exchange heat

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

$$B = ?$$

$$B = \frac{\Delta P}{-\Delta V/V} \quad \text{———} ①$$

For Adiabatic Process

$$PV = \text{constant}$$

Differentiate both sides

$$P.d(V^{\gamma}) + V^{\gamma}\,dP = 0$$

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

$$\gamma P = \frac{dP}{-dV/V} \quad \text{———} ②$$

$$velocity = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma}\left(\sqrt{\frac{P}{\rho}}\right) \qquad \left[\sqrt{\frac{P}{\rho}} = 280 m/sec\right]$$

$$= 1.2 \times 280$$

$$\boxed{\text{Velocity, } v = 336 \text{ m/sec}}$$

Very close to practical value of speed of sound i.e. 332m/sec

Q9. **Discuss the effect of following factors on speed of sound:**

a) Density **b) Pressure** **c) Temperature**

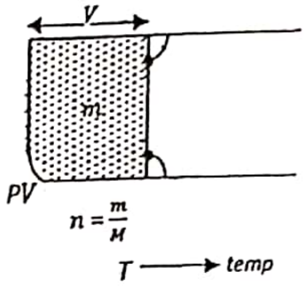
d) Humidity **e) Wind Velocity**

Ans. For a gas, $PV = \text{n R T}$

$$= \left(\frac{m}{M}\right) \text{R T}$$

$$P = \frac{m}{V}\frac{RT}{M}$$

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



a) **Density:**

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

$$v \propto \frac{1}{\sqrt{\rho}}$$ [condition γ, P→ constant]

b) **Pressure:**

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

$\frac{P}{\rho} = \frac{RT}{M}$ remains constant for isothermal condition for a given gas

$v \rightarrow$ constant does not depend on P

c) **Temperature:**

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

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

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

+1 / Ch 10 / Unit 10B / Q9 /
Effect Of Various Factors On
Speed Of Sound

d) **Humidity:**

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

$$\frac{v_{moist}}{v_{dry}} = \frac{\sqrt{\frac{\gamma P}{\rho_{moist}}}}{\sqrt{\frac{\gamma P}{\rho_{dry}}}}$$

$$\boxed{\frac{v_{moist}}{v_{dry}} = \sqrt{\frac{\rho_{dry}}{\rho_{moist}}}}$$

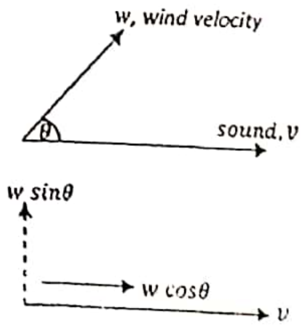
$\rho_{moist} < \rho_{dry}$

So

$v_{moist} > v_{dry}$

Dry air has more density than moist air, hence dry air has less velocity of sound.

That is why sound travels faster on a rainy day than on a dry day

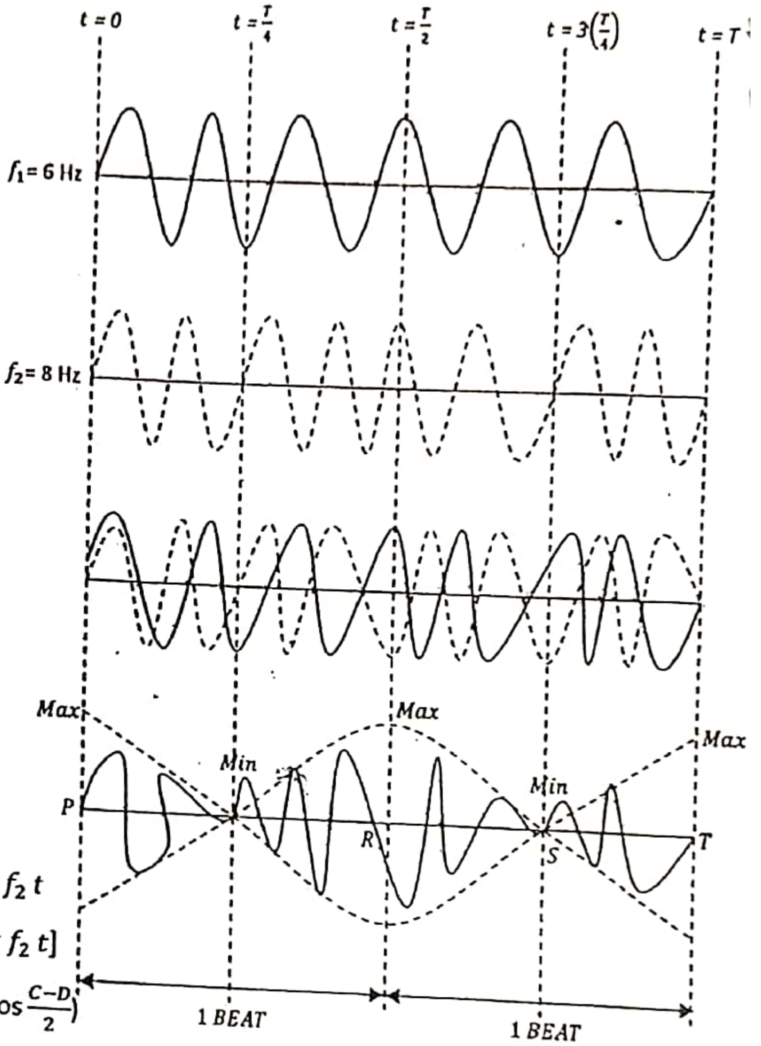


e) **Wind:** $\boxed{v_{eff} = v + w\cos\theta}$

Q10. a) What are beats?

b) Discuss formation of beats by analytical methods?

GRAPHICAL:



Ans.a) Beats:

The phenomenon of regular variation in the intensity of sound with time at a particular position, when two sound waves of nearly equal frequencies superimpose on each other, is called *Beats.*

b) Analytical Method:

Let us consider two waves of equal amplitude r and slightly different frequencies f_1 & f_2. Let displacement be y_1 & y_2 at time t.

$$y_1 = r \sin y_1 t$$

$$= r \sin 2\pi f_1 t$$

$$y_2 = r \sin w_2 t$$

$$= r \sin 2\pi f_2 t$$

According to superposition principle, resultant displacement y at same time t is

$$y = y_1 + y_2$$

$$= r \sin 2\pi f_1 t + r \sin 2\pi f_2 t$$

$$= r [\sin 2\pi f_1 t + \sin 2\pi f_2 t]$$

(using $\sin C + \sin D = 2 \sin \frac{C+D}{2} . \cos \frac{C-D}{2}$)

$$y = 2r \sin 2\pi (f_1 + f_2) t . \cos\pi (f_1 - f_2) t$$

$$\boxed{y = A \sin \pi (f_1 + f_2) t} \quad ①$$

where

$$\boxed{A = 2r \cos \pi (f_1 - f_2) t}$$

resultant amplitude

Amplitude A will be max. when

$$\cos\pi (f_1 - f_2) t_{max} = \pm 1 \cos K_x,$$

$$\cos\pi (f_1 - f_2) t = K\pi \quad \text{(where K=0, 1, 2 ------)}$$

$$t = \frac{K}{f_1 - f_2}$$

+1 / Ch 10 / Unit 10B / Q10 /
Beats

Q11. a) What is Doppler's effect?

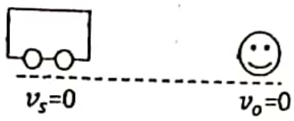
b) Discuss apparent frequency for different cases in Doppler's effect.

Ans.a) **<u>Doppler Effect</u>:**

Apparent change in frequency of sound due to relative motion of source and observer is termed as Doppler effect.

$$f_{apparent} = \left[\frac{V \quad V_{obs}}{V \quad V_{source}}\right] f$$

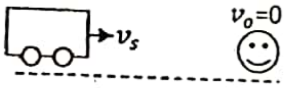
b) **Case 1.** Both observer and source are at rest



$$\boxed{f_{apparent} = \left[\frac{V \quad 0}{V \quad 0}\right] f}$$

$$\boxed{f_{apparent} = 1\, f}$$ (say 100)

Case 2: Source moving towards observer at rest

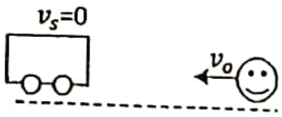


$$f_{apparent} = \left[\frac{V \quad 0}{V \quad V_s}\right] f$$

Case 3. Source moving away from observer at rest

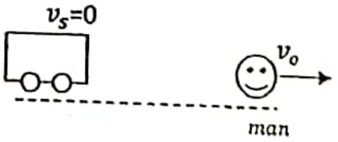
$$f_{apparent} = \left[\frac{V \quad 0}{V + V_s}\right] f$$

Case 4. Observer moving towards source at rest



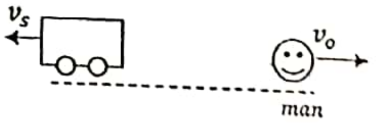
$$f_{apparent} = \left[\frac{V + V_0}{V \quad 0}\right] f$$

Case 5. Source at rest, observer moving away



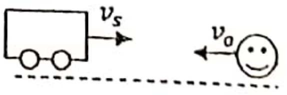
$$f_{apparent} = \left[\frac{V - V_0}{V \quad 0}\right] f$$

Case 6. Both source and observer moving away



$$f_{apparent} = \left[\frac{V - V_0}{V - V_s}\right] f$$

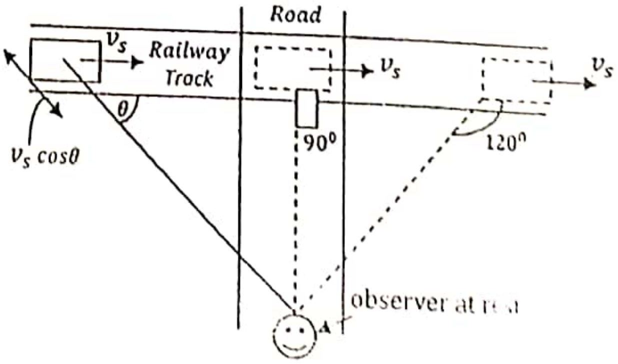
Case 7. Both source and observer moving towards each other



$$f_{apparent} = \left[\frac{V + V_0}{V - V_s}\right] f$$

Case 8. Source and observer not in same plane

$$f_{apparent} = \left[\frac{V \qquad 0}{V - V_s \cos\theta}\right] f$$



+1 / Ch 10 / Unit 10B / Q11 /
Doppler's Effect

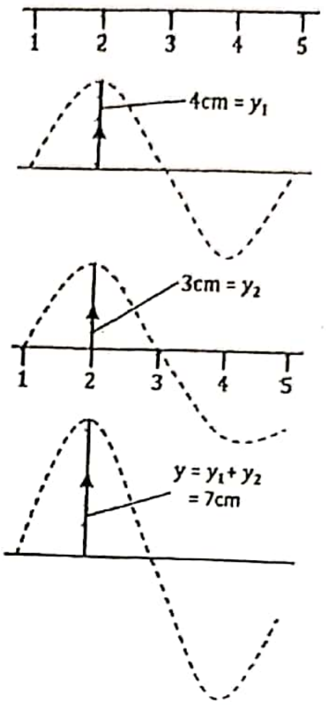
Q12. a) **What is superposition principle?**

b) **Derive expression for '*Nodes*' and '*Antinodes*' on a string (standing wave).**

Ans.a) **Superposition Principle:**

The displacement at any time due to any number of waves the vector sum of the individual displacements due to each one of the waves at that point at the same time.

$$\vec{y} = \vec{y_1} + \vec{y_2} + \vec{y_3} + \text{------------} + \vec{y_n}$$



Example:

y_1 = 4cm due to one wave

y_2 = 3cm due to another wave

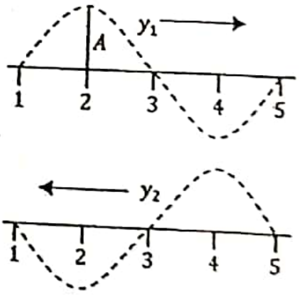
$y = y_1 + y_2$

= 4 + 3

= 7cm due to both waves

b) $y_1 = A \sin(w.t - k.x)$ for wave moving along *+ve x-axis*

$y_2 = A \sin(wt + k.x)$ for wave moving along *-ve x-axis*



As per superposition principle

$$y = y_1 + y_2$$

$$= A \sin(wt - k.x) + A \sin(wt + k.x)$$

$$= A [\sin(wt - k.x) + \sin(wt + k.x)]$$

$$= A\left[2 \sin\left(\frac{wt - kx + wt + kx)}{2}\right) \cos\left(\frac{wt - kx - wt - kx)}{2}\right)\right]$$

$$= A [2 \sin wt \cos(-k.x)]$$

$$= A [2 \sin wt \cos k.x]$$

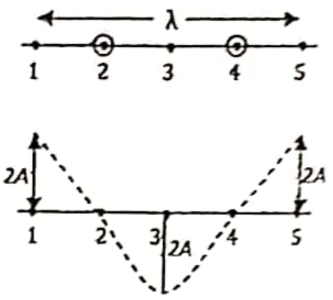
$$\boxed{y = 2A [\sin wt \cos k.x]}$$

+1 / Ch 10 / Unit 10B / Q12 / Super Position Principle And Standing Wave

Discussion:

1. $$y = \underbrace{[2A\cos(k.x)]}_{\text{Amplitude depends on } x} \sin wt$$

2. **Nodes:** Nodes are point always at rest.



$$\underbrace{2A}_{\text{Never ZERO}}\cos(k.x) = 0$$

$$\cos(k.x) = 0$$

$$\therefore k.x = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \text{------------}$$

$$\frac{2\pi}{\lambda}x = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \text{------------}$$

$$\boxed{x = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \text{------------}}$$

Point no. → 2, 4 are nodes

3. **Antinodes:** Points having maximum displacement are called *antinodes.*

$$2A\cos(k.x) = \pm 2A$$

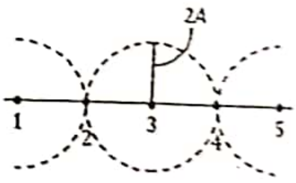
$$\cos(k.x) = \pm 1$$

$$k.x = 0, \pi, 2\pi, 3\pi, \overset{(+1)}{4\pi}, \underset{(-1)}{5\pi}, \text{------------}$$

$$\frac{2\pi}{\lambda}x = 0, \pi, 2\pi, 3\pi, 4\pi, 5\pi, \text{------------}$$

$$\boxed{\lambda = 0, \frac{\lambda}{2}, \frac{2\lambda}{2}, \frac{3\lambda}{2}, \frac{4\lambda}{2}, \frac{5\lambda}{2}, \text{------------}}$$

Point no. → 1, 3, 5 are antinodes



4. Particles in between two consecutive nodes are in phase

5. Particles in between two consecutive nodes have different amplitude which depends on x $\underbrace{2A\cos(k.x)}$

6. Particles in consecutive segments are out of phase by 180^0 (π rad)

Modes of vibration in a string:

1. **Fundamental Note [1st Harmonic]**

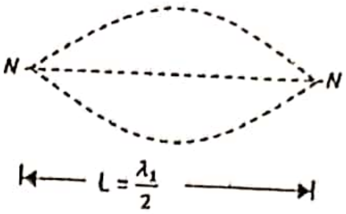
$$L = \frac{\lambda_1}{2}$$

$$\boxed{\lambda_1 = 2L}$$

$$v = f\lambda$$

$$f_1 = \frac{v}{\lambda_1}$$

$$\boxed{f_1 = \frac{v}{2L}}$$ (say $100H_z$)

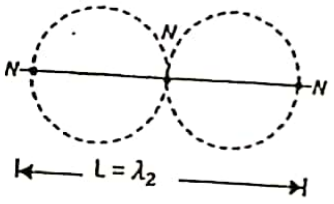


2. **2nd Harmonic [1st overtone]**

$$f_2 = \frac{v}{\lambda_2}$$

$$\boxed{f_2 = 2\left(\frac{v}{2L}\right)}$$

$$= 2f_1$$ (say 2 x $100H_z$)

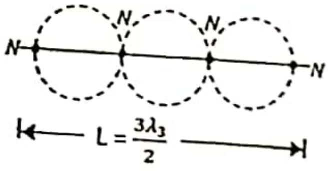


3. **3rd Harmonic [2nd overtone]**

$$f_3 = \frac{v}{\lambda_3}$$

$$\boxed{f_3 = 3\left(\frac{v}{2L}\right)}$$

$$= 3f_1$$ (say 3 x $100H_z$)

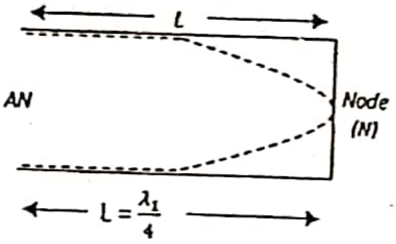


Q13. **Discuss formation of standing waves in closed organ pipe?**

Ans.

1. **1st Harmonic (Fundamental Note):**

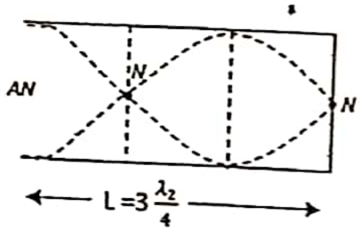
Particle at closed end is fixed, so it will act as Node (*N*). Particle at open end is free to oscillate, so it will act as antinode (*AN*)



$$f_1 = \frac{v}{\lambda_1}$$

$$\boxed{f_1 = \frac{v}{4L}}$$ (say 100Hz)

2. **3rd Harmonic (1st overtone):**



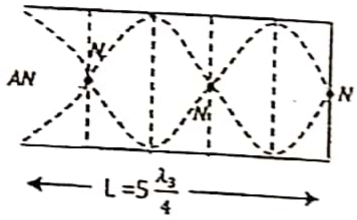
$$f_2 = \frac{v}{\lambda_2}$$

$$= \frac{v}{\frac{4}{3}L}$$

$$= 3\left(\frac{v}{4L}\right)$$

$$\boxed{f_2 = 3f_1}$$ (say 300Hz)

3. **5th Harmonic (2nd overtone):**



$$f_3 = \frac{v}{\lambda_3}$$

$$= \frac{v}{\frac{4}{5}L}$$

$$= 5\left(\frac{v}{4L}\right)$$

$$\boxed{f_3 = 5f_1}$$ (say 500Hz)

Discussion:

a) Odd harmonics are present (1, 3, 5 -------- etc.)
Even harmonics are missing (2, 4, 6 -------- etc.)

b) Quality of sound is poor as some of the harmonics are missing.

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Q14. **Discuss formation of standing waves in open organ pipe?**

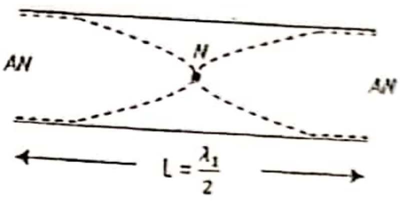
Ans.

1. **1st Harmonic (Fundamental Note):**

$$f_1 = \frac{v}{\lambda_1}$$

$$\boxed{f_1 = \frac{v}{2L}}$$

(say 100Hz)



2. **2nd Harmonic (1st overtone):**

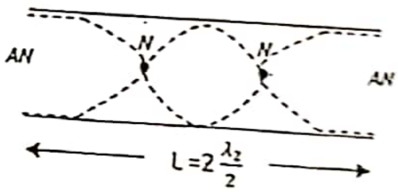
$$f_2 = \frac{v}{\lambda_2}$$

$$= \frac{v}{L}$$

$$= 2\left(\frac{v}{2L}\right)$$

$$\boxed{f_2 = 2f_1}$$

(say 200Hz)



3. **3rd Harmonic (2nd overtone):**

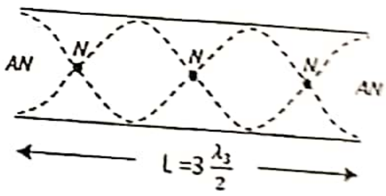
$$f_3 = \frac{v}{\lambda_3}$$

$$= \frac{v}{\frac{2}{3}L}$$

$$= 3\left(\frac{v}{2L}\right)$$

$$\boxed{f_3 = 3f_1}$$

(say 300Hz)



Discussion:

a) All harmonics are present.

b) Quality of sound is good as all harmonics are present.

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