VISUAL PHYSICS

SHORT NOTES

CHAPTER

Sounds

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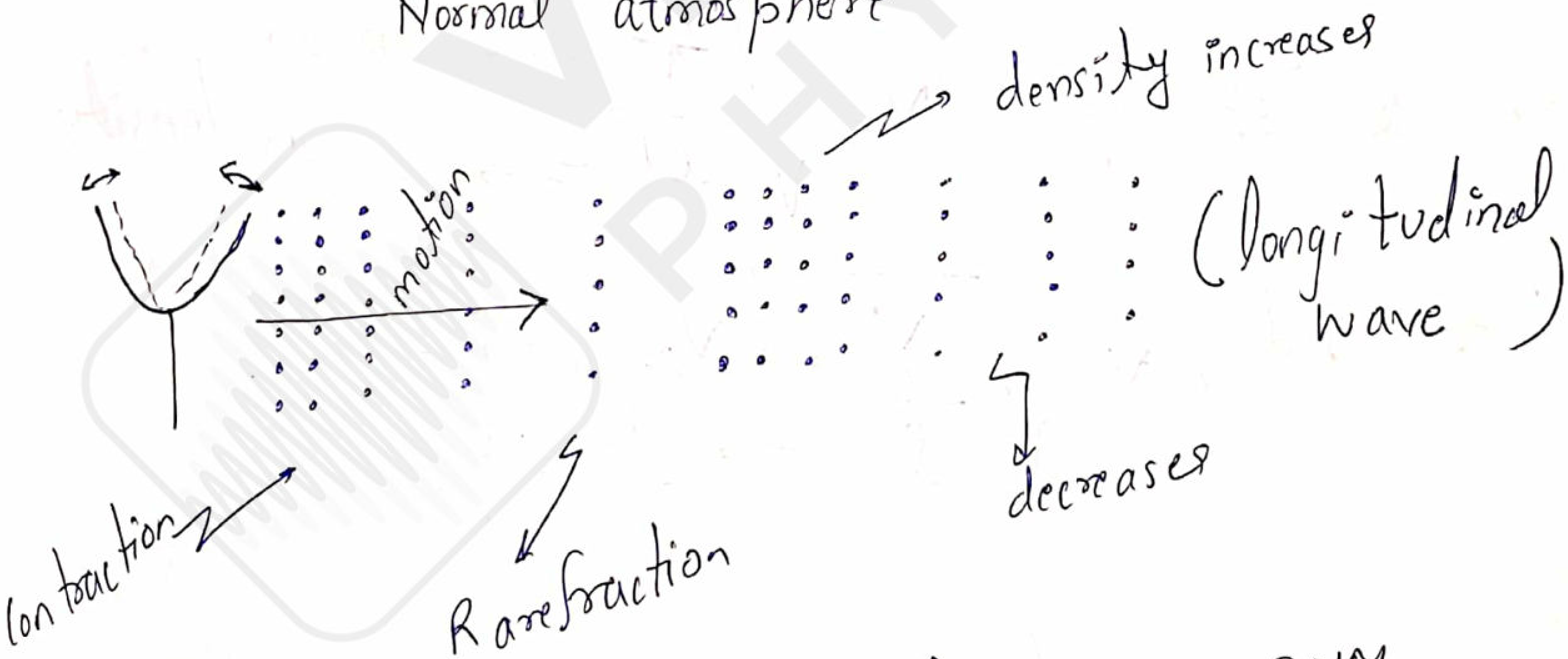
SOUNDS

→ Sound waves travel through any material medium with a speed that depends on proteries of medium.

→ Through air, elements of air vibrate to produce changes in density & pressure along the direction of motion of wave.



If vibration is of sinusoidal or say SHM

$$\boxed{\Delta p = \Delta p_{max} \sin [\omega(t - x/v)]}$$

Δp_{max} → maximum change in pressure above normal pressure

Speed of sound wave

→ Speed of sound depends on compressibility and density of medium.

$$V = \sqrt{\frac{B}{\rho}}$$ B → bulk modulus, ρ → density

→ * Speed of all mechanical wave:

$$V = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}}$$

e.g. for s/p string $V = \sqrt{\frac{T}{\mu}}$ T → Tension, μ → linear density

for rod, $V = \sqrt{\frac{Y}{\rho}}$ Y → Young's modulus, ρ → density.

NEWTON's Formula:

Newton considered compression & Rarefaction as isothermal process i.e $pV = \text{constant}$

$\Rightarrow \quad V\Delta p + p\Delta V = 0$

$\Rightarrow \quad V\Delta p = -p\Delta V$

$$-p = \frac{\Delta p}{\Delta V/V}$$

$$\Rightarrow \boxed{p = -\frac{\Delta p}{\Delta V/V}}$$

now bulk modulus, $B = -\dfrac{\Delta p}{\Delta V/V}$

$\Rightarrow \quad p = B$ (for newton)

Hence,

$$V = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{p}{\rho}}$$

for atmospheric air

$p = 1.013 \times 10^5$ pa

& $\rho = 1.29$ kg/m^3

$\Rightarrow \boxed{V = 280 \text{ m/s}} \rightarrow$ less than experimental value (332 m/s)

Laplace's Correction.

→ Laplace pointed that contraction & Rarefraction for sound travel are actually adiabatic.

⇒ $$PV^{\gamma} = \text{Constant}$$

$$P(\gamma V^{\gamma-1})\Delta V + V^{\gamma}\Delta P = 0$$

⇒ $$\cancel{dP}\ \frac{\Delta P}{-\left(\frac{\Delta V}{V}\right)} = \gamma P = B$$

⇒ $$V = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{\gamma P}{\rho}}$$

$\gamma = 1.4$ for air

⇒ $$\boxed{V = 332\ m/s}$$

* Hence agreement with experimental value

Speed of sound in Gas $$\boxed{V = \sqrt{\frac{\gamma P}{\rho}}}$$

different for different gas

$$\boxed{\gamma = \frac{C_P}{C_V}}$$

density of gas

→ Effect of pressure

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

As $pV = nRT = \frac{m}{M} RT$

m → mass in volume V

M → Molar mass

$$p\Delta V = \frac{\Delta m}{M} RT$$

$$p = \frac{\Delta m}{\Delta V} \frac{RT}{M}$$

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

$$\boxed{\frac{p}{\rho} = \frac{RT}{M}} \rightarrow \text{Constant}$$

* Hence $\frac{p}{\rho}$ is constant, so changing pressure will not speed of sound in gas

Effect of density :

two gases. With same pressure p but different densities ρ_1 & ρ_2 & γ_1, γ_2

so, $$\boxed{\frac{v_1}{v_2} = \sqrt{\frac{\gamma_1}{\gamma_2}\frac{\rho_2}{\rho_1}}}$$

Effect of Temperature :

As, $$pV = nRT$$

$$pV = \frac{m}{M}RT$$

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

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

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

in k (absolute Temperature)

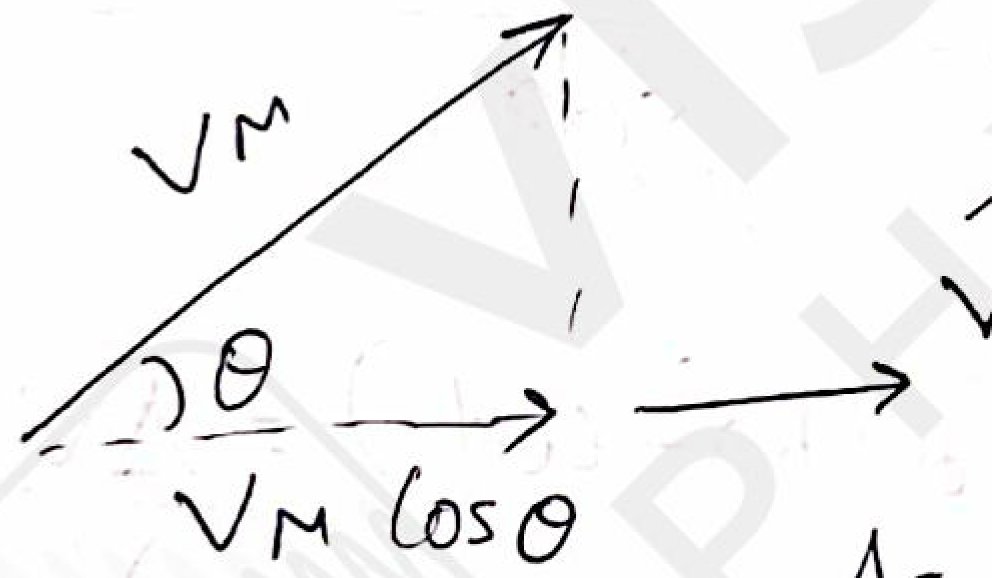
Effect of Humidity :

→ Increase in Humidity, the density of air decreases

as $\boxed{v \propto \frac{1}{\sqrt{\rho}}}$ → Hence speed of sound increases

Effect of wind :

As sound is carried by air, so its speed is affected by the wind velocity.



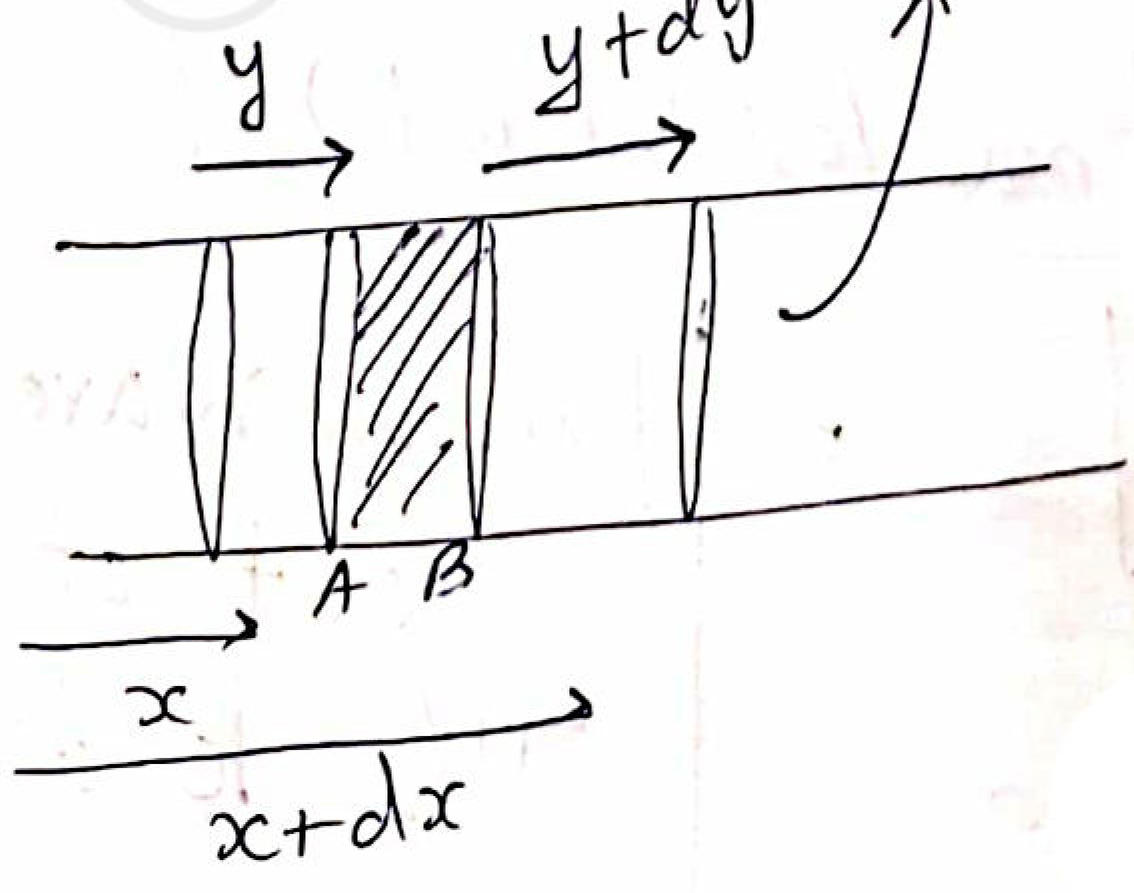
speed of sound

$\boxed{\text{so net speed} = v + v_M \cos\theta}$

As vice-versa

pressure Wave :

S = cross-section Area.



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

amplitude of disturbance in particles position

$$dy = Ak\cos(kx - \omega t)\,dx$$

$$dV = +S\,dy = +SAk\cos(kx - \omega t)\,dx$$

volume of section AB is:

$$V = S\,dx$$

$$\frac{dV}{V} = \frac{dy}{dx} = \frac{\cancel{S}Ak\cos(kx - \omega t)\cancel{dx}}{\cancel{S}\cancel{dx}}$$

$$\frac{dV}{V} = Ak\cos(kx - \omega t) = \frac{\Delta V}{V}$$

$$\Delta p = -B\left(\frac{\Delta V}{V}\right) = -BAk\cos(kx - \omega t)$$

$$\boxed{\Delta p = -\Delta p_{max}\cos(kx - \omega t)}$$

$$\boxed{\Delta p_{max} = BAk}$$

Maximum change in pressure from normal atmospheric pressure

⇒ pressure wave is out of phase by $\pi/2$ to displacement

☆

Intensity:

The rate at which energy transported by the wave transfers through a unit Area 'A' perpendicular to the direction of travel of wave.

$$\Rightarrow \quad I = \frac{\text{power}}{\text{Cross section Area}}$$

i.e. $$I = \frac{\text{power}}{\text{Cross-section - Area}} = \frac{\text{Energy/time}}{\text{Cross-section - Area}}$$

As we know from mechanical waves nature

$$\text{power transmitted} = \frac{1}{2}\mu\omega^2 A^2 V$$

$$\mu = \frac{\text{mass}}{\text{length}}$$

so, $$I = \frac{1}{2}\frac{\mu\omega^2 A^2 V}{\text{Area}}$$

$$\frac{\mu}{\text{Area}} = \frac{\text{mass}}{\text{Area} \times \text{length}} = \frac{\text{mass}}{\text{volume}} = \rho$$

$$\Rightarrow \quad \boxed{I = \frac{1}{2}\rho v(\omega A)^2}$$

as, $\Delta p_m = ABk$

$$\Rightarrow A = \frac{\Delta p_m}{Bk}$$

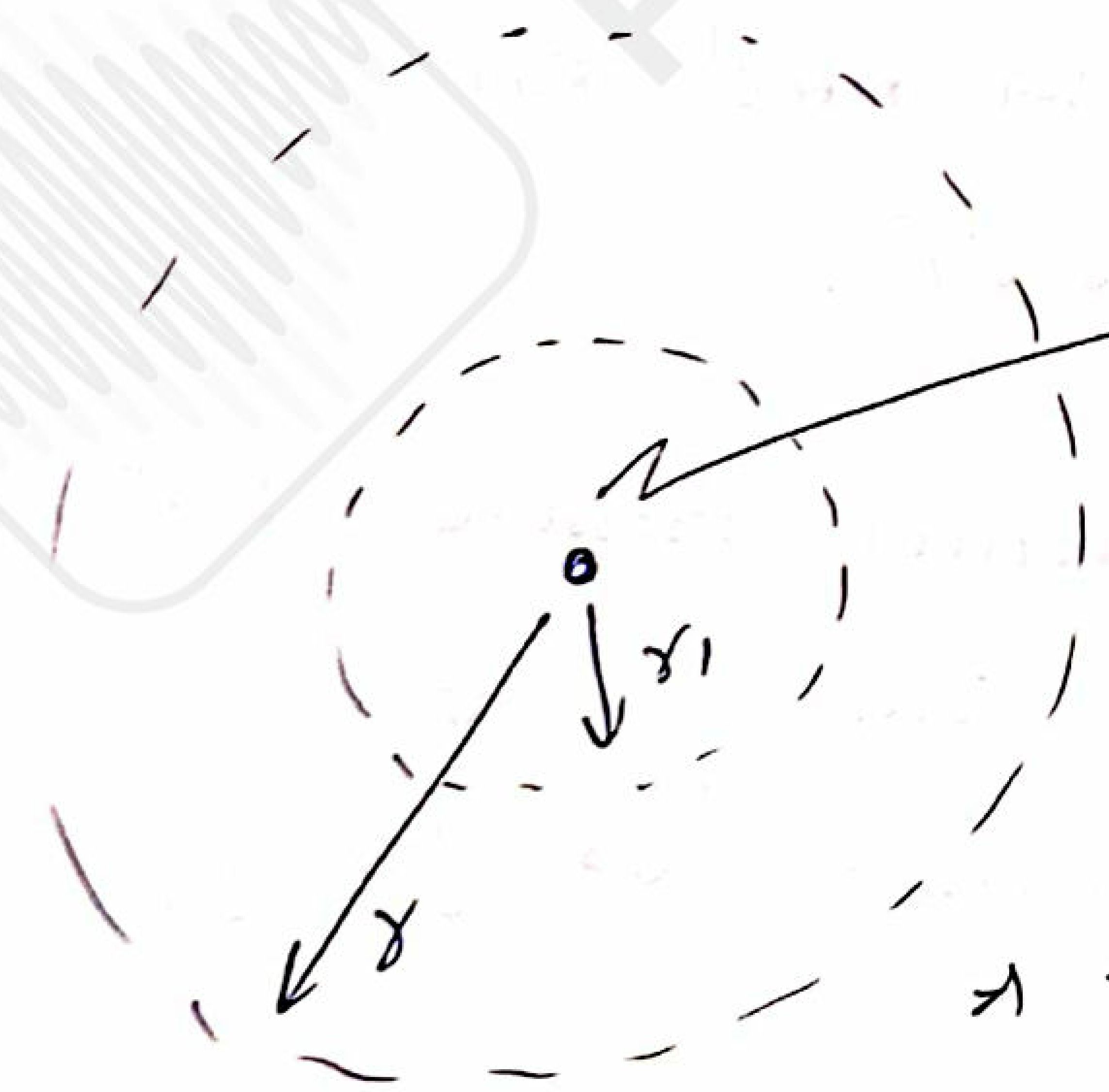
$$I = \frac{1}{2}\rho v \omega^2 \left(\frac{\Delta p_m}{Bk}\right)^2 = \frac{1}{2}\rho v \omega^2 \frac{\Delta p_m^2}{B^2 k^2}$$

as $k = \omega / V$ & $B = V^2 \rho$

$$\therefore \quad I = \frac{1}{2}\rho v \omega^2 \frac{\Delta p_m^2}{B^2\left(\frac{\omega^2}{V^2}\right)}$$

$$\Rightarrow \boxed{I = \frac{\Delta p_m^2}{2\rho V}}$$

Also, for a source emitting power in all direction



Source p_{av} ↳ average power

$$I = \frac{p_{av}}{Area}$$

$$\Rightarrow I \propto \frac{1}{Area}$$

$$\boxed{I \propto \frac{1}{r^2}}$$ → Inverse square law

frequency → number of cycles per second

pitch → Brain Interprets frequency primarily in terms of a subjective quality called pitch.

Sound level in decibels : → measure sound loudness

$$\beta = 10\log\left(\frac{I}{I_0}\right)$$

I_0 → reference intensity, $1\times10^{-12}\ W/m^2$

so $\beta_1 = 10\log\frac{I_1}{I_0}$

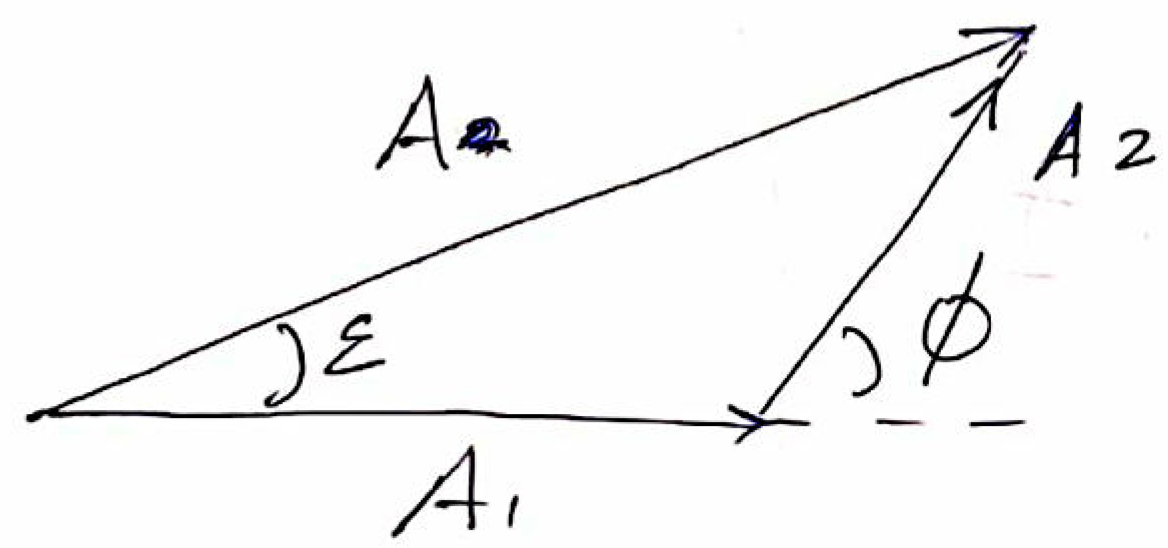
$\beta_2 = 10\log\frac{I_2}{I_0}$

$\beta_1 - \beta_2 = 10\log\left(\frac{I_1}{I_2}\right)$

→ study shows we need ear plugs if sound level exceed 90 dB.

Interference:

As discussed in mechanical waves, Sound waves Interfere in same way.



$$A = \sqrt{A_1^2 + 2A_1A_2\cos\phi + A_2^2}$$

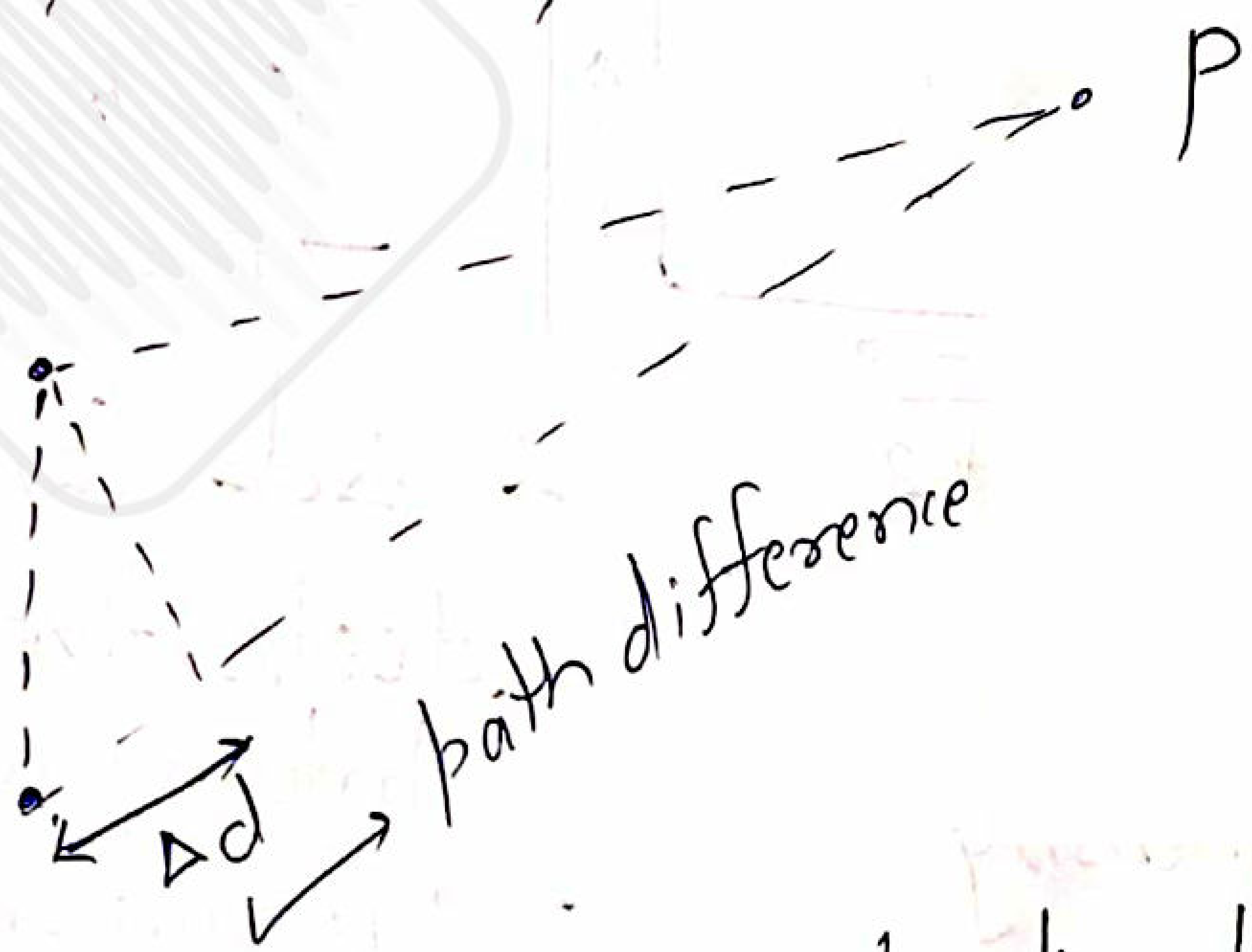
$$\boxed{\tan\varepsilon = \frac{A_2\sin\phi}{A_1 + A_2\cos\phi}}$$

let's have two Coherent sources of sound.

same frequency

phase difference does not changes with time.

$\rightarrow \quad \phi_1(t) - \phi_2(t) = \Delta\phi(t) = \text{Constant}$



so if $\Delta d = n\lambda \rightarrow$ Constructive Interference

$\Delta d = \left(n + \frac{1}{2}\right)\lambda \rightarrow$ destructive Interference so, for Constructive Interference

Amplitude = $2A$ (if both source produce wave of A, amplitude)

$\Rightarrow I \propto A^2$

$\rightarrow I_{constructive} = 4 \times I$

& $I_{destructive} = 0$

$A_{resultan} = A - A = 0$

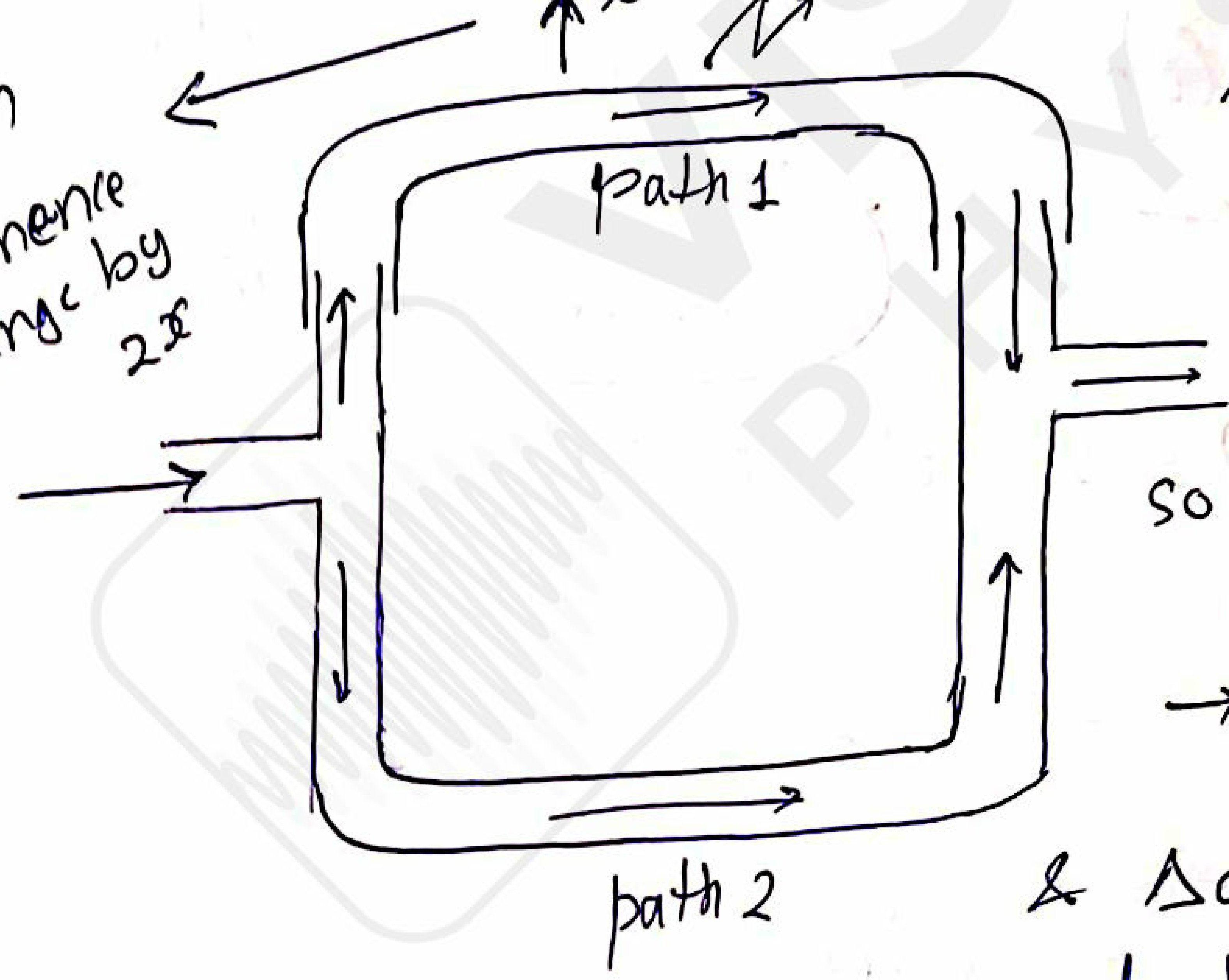
Quincke's Tube:

$\uparrow x$ = displacement

→ can move and hence path difference can be changed.

Δd = path difference

path difference change by $2x$



so for $\Delta d = n\lambda$

Constructive Interence

→ maximum Intensity

& $\Delta d = (2n+1)\dfrac{\lambda}{2}$

destructive Interference

→ minimum Intensity

so, from going to max to min Intensity we need to change path difference by $\dfrac{\lambda}{2}$

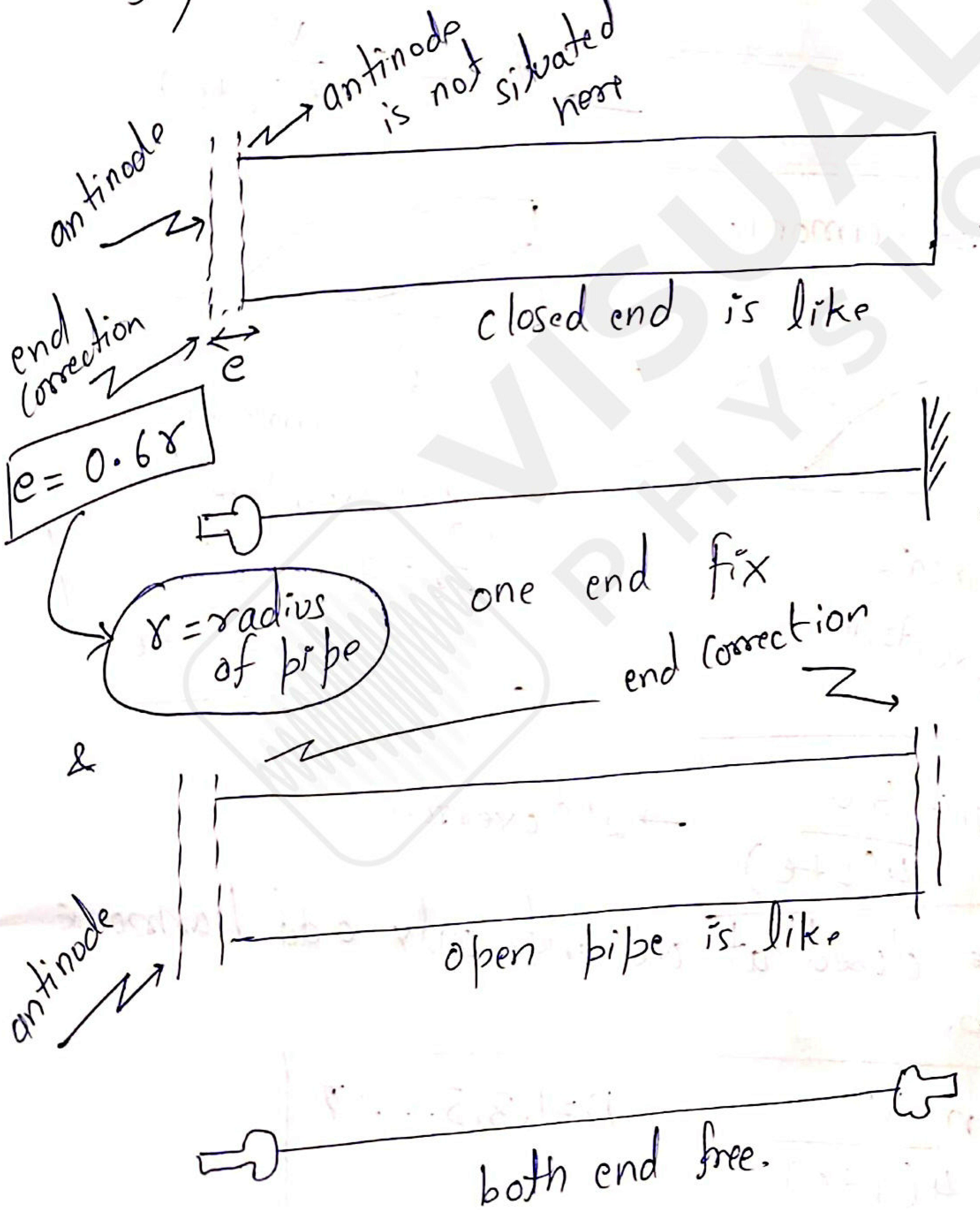
Hence need to slide, $x = \lambda/4$

→ Hence we can find wavelength

Harmonics :

As In previous Mechanical waves chapter, We set up standing waves on string i.e. transverse waves

Here We can set up standing waves in column or say air column.



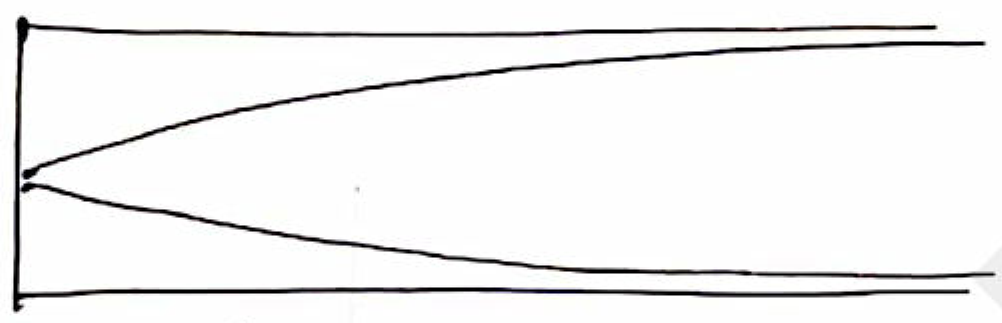
end correction is just one difference between strings & air column standing waves

so for one end closed
fundamental mode:

$$L+e = \frac{\lambda}{4}$$

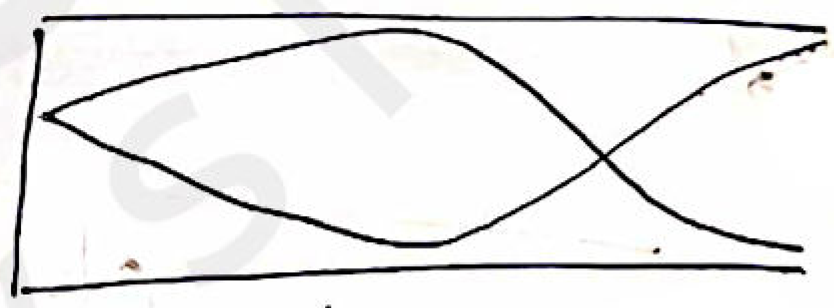
$$f = \frac{V}{\lambda} = \frac{V}{4(L+e)} \rightarrow \text{first harmonic}$$

now next possible standing wave



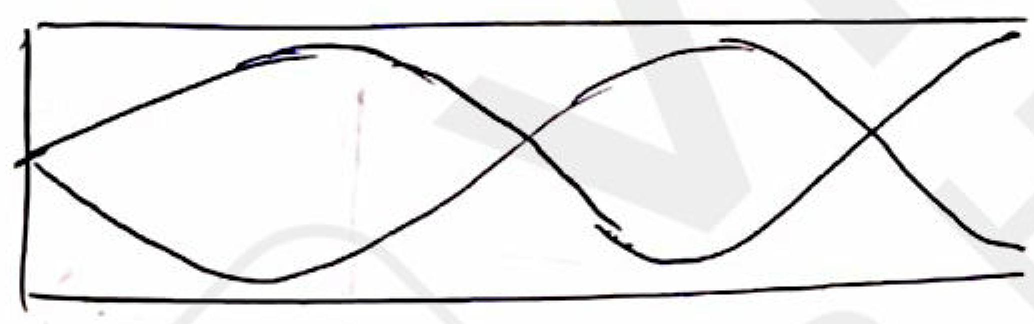
$$\rightarrow f_1 = \frac{V}{\lambda} = \frac{V}{4(L+e)}$$

first harmonic



3rd harmonic
1st overtone

$$\boxed{f_3 = 3f_1 = \frac{3V}{4(L+e)}}$$



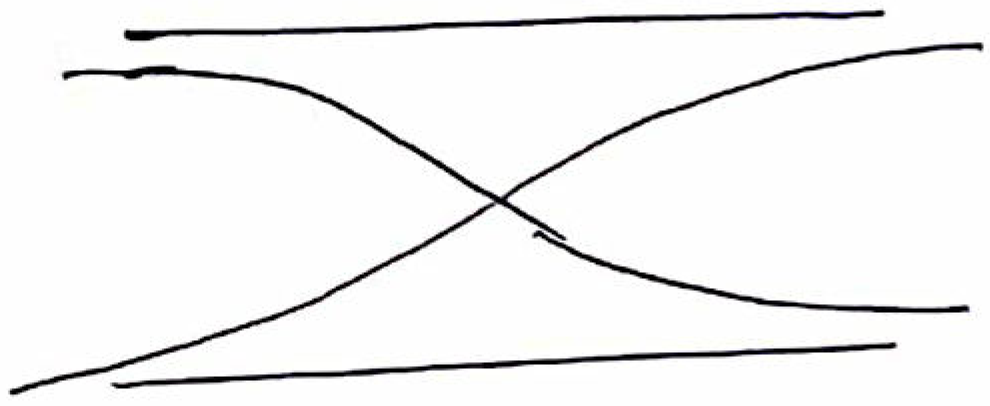
5th harmonic
2nd overtone

$$\boxed{f_5 = 5f_1 = \frac{5V}{4(L+e)}} \rightarrow 2^{nd} \text{ overton}$$

so for pipe closed at one end, only odd harmonic can set up.

$$\rightarrow \boxed{f_n = n\frac{V}{4(L+e)} \quad , \; n = 1, 3, 5 \ldots}$$

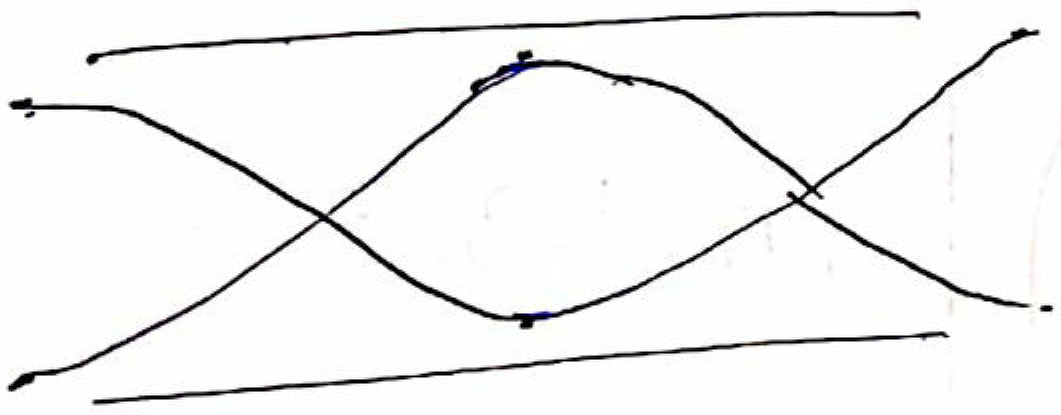
for open pipe:



$\lambda = 2(L+2e)$

$$\boxed{f_1 = \frac{v}{\lambda} = \frac{v}{2(L+e)}}$$

↳ first harmonic



$2\left(\frac{\lambda}{2}\right) = L+2e$

$\lambda = L+2e$

$f_2 = \frac{v}{\lambda} = \frac{v}{L+2e}$

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

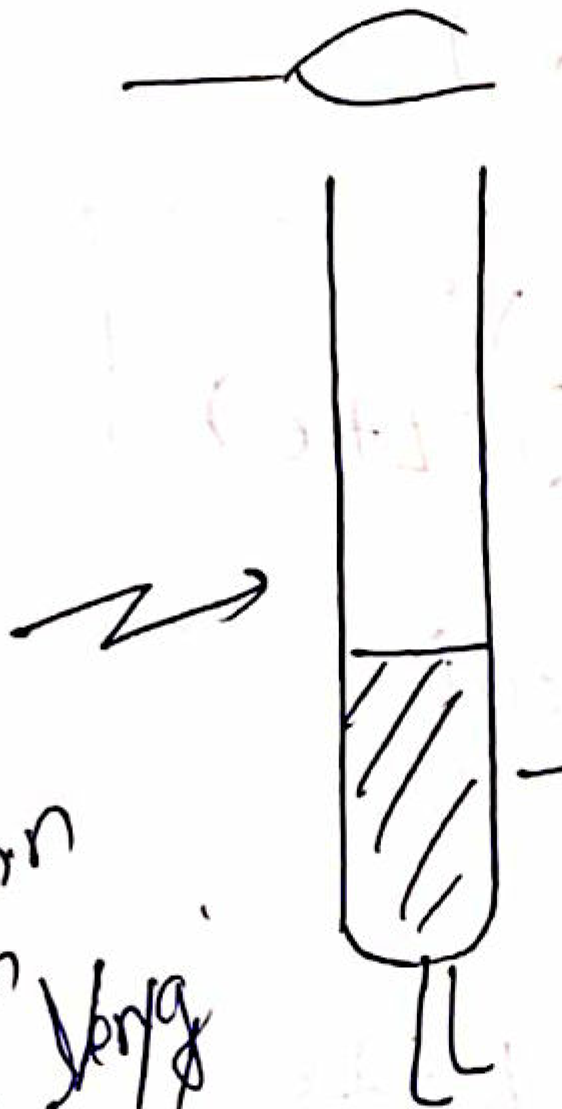
→ 2^{nd} harmonic, 1^{st} overtone

All harmonics are possible.

$$\boxed{f_n = n\frac{v}{2(L+2e)}}$$

$n = 1, 2, 3 \ldots$

Resonance Column method to measure speed of sound

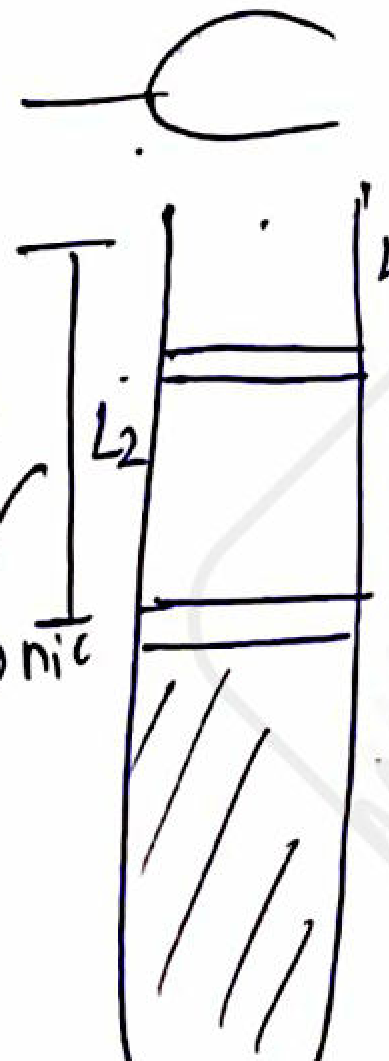


act as closed column from one end.

level of water can be measure & vary

as, if $\boxed{f = n\left(\frac{v}{4(L+e)}\right)}$, $n = 1, 3, 5.$

$\hookrightarrow$ standing wave produce.



L_1 Length corresponding first harmonic

second harmonic

level of water

So, $f = \frac{v}{4(L_1+e)}$

& $f = \frac{3v}{4(L_2+e)}$

So, $(L_2 - L_1) = \frac{2v}{4f} = \frac{v}{2f}$

$\Rightarrow \boxed{v = 2f(L_2 - L_1)}$

Beats:

→ When two waves of slight different frequency Interfere.

as $k = \frac{\omega}{V}$

let $y_1 = A\sin\omega_1\left(t - \frac{x}{V}\right)$

& $y_2 = A\sin\omega_2\left(t - \frac{x}{V}\right)$

$y_{net} = y_1 + y_2$

$y_{net} = A\sin\omega_1\left(t - \frac{x}{V}\right) + A\sin\omega_2\left(t - \frac{x}{V}\right)$

As speed 'V' remain same.
↳ depends on medium property.

$y_{net} = A\left[\sin\omega_1\left(t - \frac{x}{V}\right) + \sin\omega_2\left(t - \frac{x}{V}\right)\right]$

$$\boxed{y_{net} = 2A\cos\left[\frac{(\omega_1 - \omega_2)}{2}\left(t - \frac{x}{V}\right)\right] \times \sin\left[\frac{(\omega_1 + \omega_2)}{2}\left(t - \frac{x}{V}\right)\right]}$$

now if $\omega_1 \simeq \omega_2$
very little difference

Hence,

$$\boxed{\frac{\omega_1 - \omega_2}{2} << \frac{\omega_1 + \omega_2}{2}}$$

frequency of amplitude variation

represent frequency of signal of time varying Amplitude

$$\boxed{\frac{\omega_1 - \omega_2}{2}} \rightarrow \text{beat frequency}$$

only when $\boxed{\omega_1 \approx \omega_2}$

very close to each other

if $\omega_1 > \omega_2$

☆ We can't recognize beats as $\frac{\omega_1 - \omega_2}{2}$ will be high

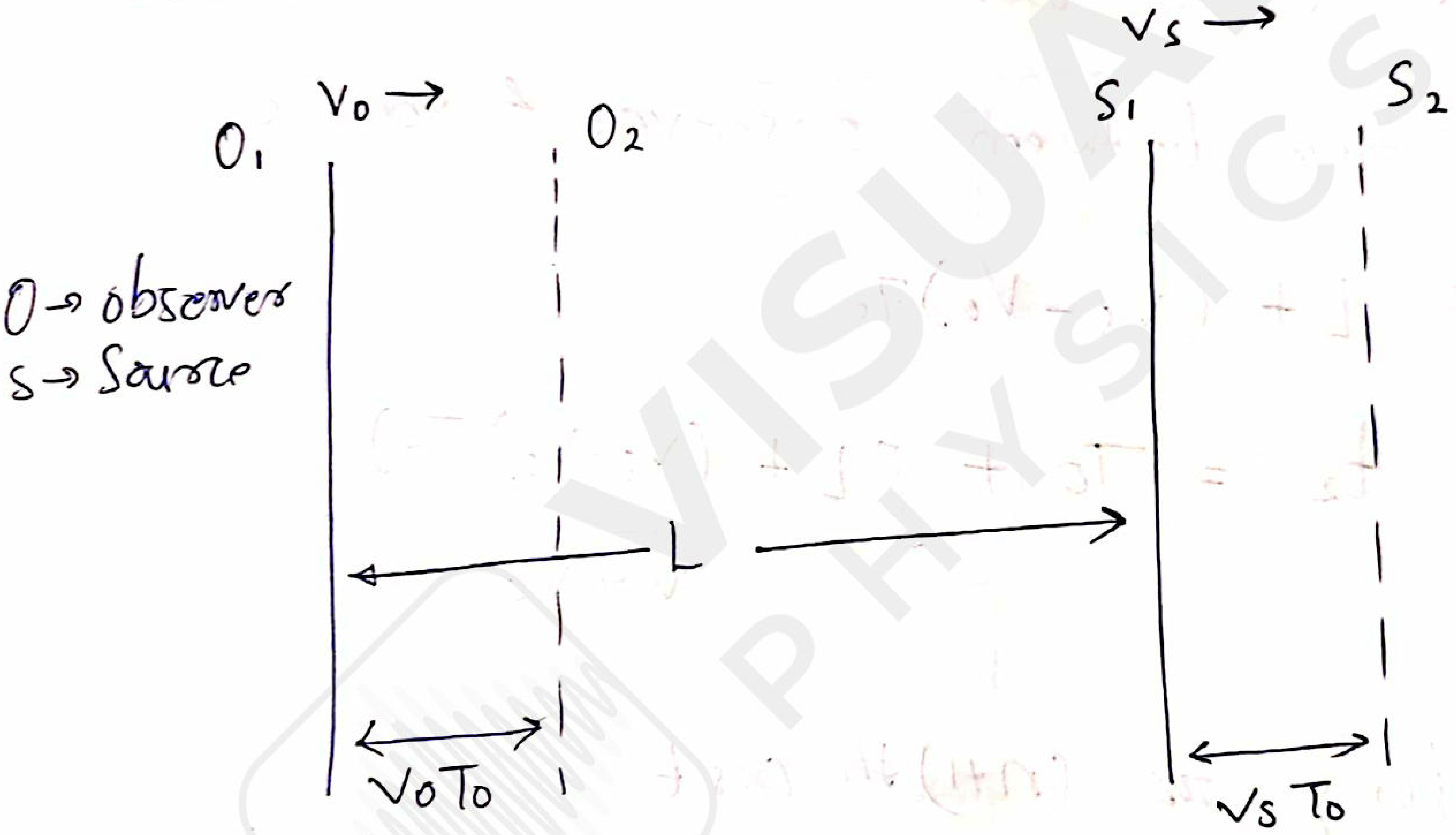
$$\boxed{\omega_{beat} = \frac{\omega_1 - \omega_2}{2}}$$

for waves having different frequencies

Dobbler Effect:

→ When their is relative motion between sound Source & observer, the frequency heared will be different than the frequency produced by Source.

if observer & Source both moving:



V_o → observer velocity, V_s → Source velocity.

V → velocity of sound.

T_0 → time period of wave

f_0 → frequency of sound produce by source

$L \rightarrow$ Distance between O_1 & S_1 at $t = 0$

now speed of sound relative to observer

$\underline{v + v_0}$

so time to reach first crest $= \dfrac{L}{(v+v_0)} = t_1$

now after one time period, T_0

distance between observer & source

$$L' = L + (v_s - v_0)T_0$$

so, $$t_2 = T_0 + \frac{[L + (v_s - v_0)T_0)}{v + v_0}$$

similarly for $(n+1)$th crest

$$t_{n+1} = nT_0 + \frac{[L + n(v_s - v_0)T_0]}{v + v_0}$$

so time Interval between

$t_{n+1} - t_1$

$$= nT_0 + [L + n(v_s - v_0)T_0]/(v + v_0) - L/(v + v_0)$$

so time interval between two crest means observed Time period : T

$$T = t_{n+1} - t_n$$

$$T = T_0 + \frac{(V_s - V_0) T_0}{(V + V_0)}$$

$$T = T_0 \left[1 + \frac{(V_s - V_0)}{(V + V_0)} \right]$$

$$\boxed{T = T_0 \left[\frac{V + V_s}{V + V_0} \right]}$$

→ frequency, $f = \frac{1}{T}$, $f_0 = \frac{1}{T_0}$

$$\boxed{f = f_0 \left[\frac{V + V_0}{V + V_s} \right]}$$

★ The direction from observer to source is positive.

if observer moves towards source, $V_0 \rightarrow +ve$

if observer moves away from source, $V_0 \rightarrow -ve$

if source moves away from observer, $V_s \rightarrow +ve$

if source moves toward observer, $V_s \rightarrow -ve$

so if observer is stationary

$$\boxed{f = f_0\left[\frac{v}{v+v_s}\right]}$$

& if source is stationary

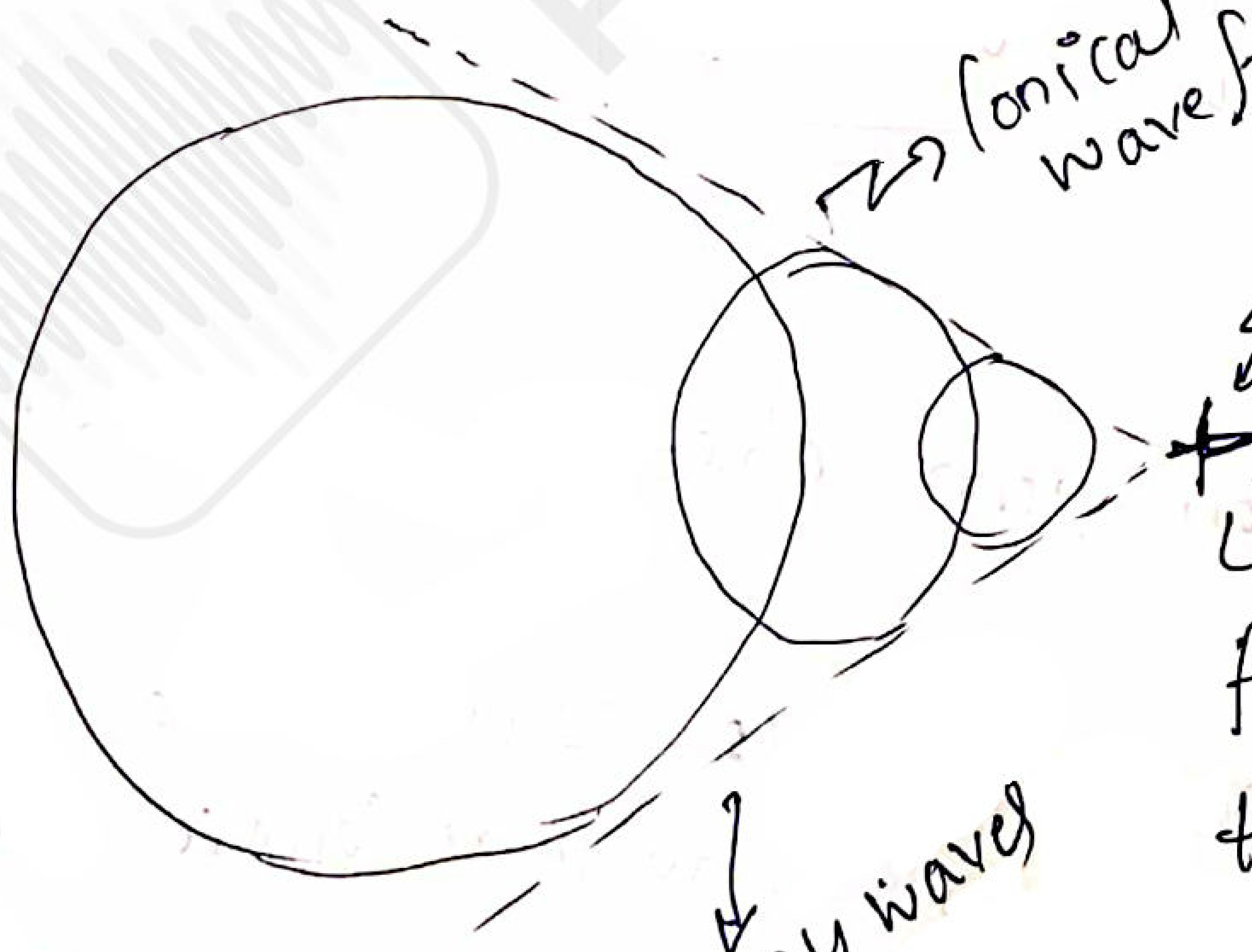
$$\boxed{f = f_0\left(\frac{v+v_0}{v}\right)}$$

★ from observer to source direction is positive

<u>Shock Waves</u> :

if $\boxed{v_s > v}$

means (source move with greater speed than the speed of sound)



$$\boxed{\text{mach number} = \frac{V_s}{V}}$$

shock waves produce because the object is moving with speed greater than speed of sound.
(even if it not producing any sound itself)