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Where Minds Pollinate

Class 11
Physics

Chapter 9

Handwritten Notes

Chapter 9
Waves

Intensity of Waves:

Defination:
Amount of wave energy passing through an area of $1m^2$ (unit area) held perpendicular to the direction of propagation of waves in "1s" (unit time) is called intensity of waves. It is represented by "I". It is a scalar quantity and its SI unit "Wm^{-2}".

Formula:

$$\text{Waves intensity} = \frac{\text{Energy of waves passing}}{\text{Area} \times \text{time}}$$

$$I = \frac{E}{A \times t} = \frac{(E/t)}{A} = \frac{P}{A}$$

Unit:-

By definition of intensity of waves.

$$I = \frac{P}{A} = \frac{\text{Watt}}{m^2} = \frac{W}{m^2} = Wm^{-2}$$

$$I = Wm^{-2}.$$

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Doppler's Effect

Definition:
The apparent change in the frequency of sound due to the relative motion b/w the source of sound and listner of sound is called doppler's effect.

Explanation
Consider a stationary source of sound emitting sound waves of frequency "f", wavelength "λ" and speed "v". Then their relationship is given by,

$$v = f\lambda$$

original frequency of sound waves $= f = \frac{v}{\lambda}$.

original wavelength of sound waves $= \lambda = \frac{v}{f}$.

Case #1
Source at rest and listner moving.
⇒ **Listner moves towards stationary source;**

Stationary source emits sound waves of speed "v". When listner starts moving towards the stationary sound, speed of sound waves that appears to him becomes "$v + v_L$" but their wavelength remains same.

Therefore,

$$f' = \frac{V'}{\lambda}$$

$$f' = \frac{V+V_L}{(V/f)}$$

$$f' = \left(\frac{V+V_L}{V}\right) f \quad \text{—— (A)} \quad \because \frac{V+V_L}{V} > 1$$

$$f' > f$$

Hence, frequency of sound increases for the listner.

⇒ **Listner moves away from stationary source**

When listner moves away from the stationary source of sound, speed of sound that appears to him becomes "$V-V_L$" but their wavelength remains same.

Therefore:

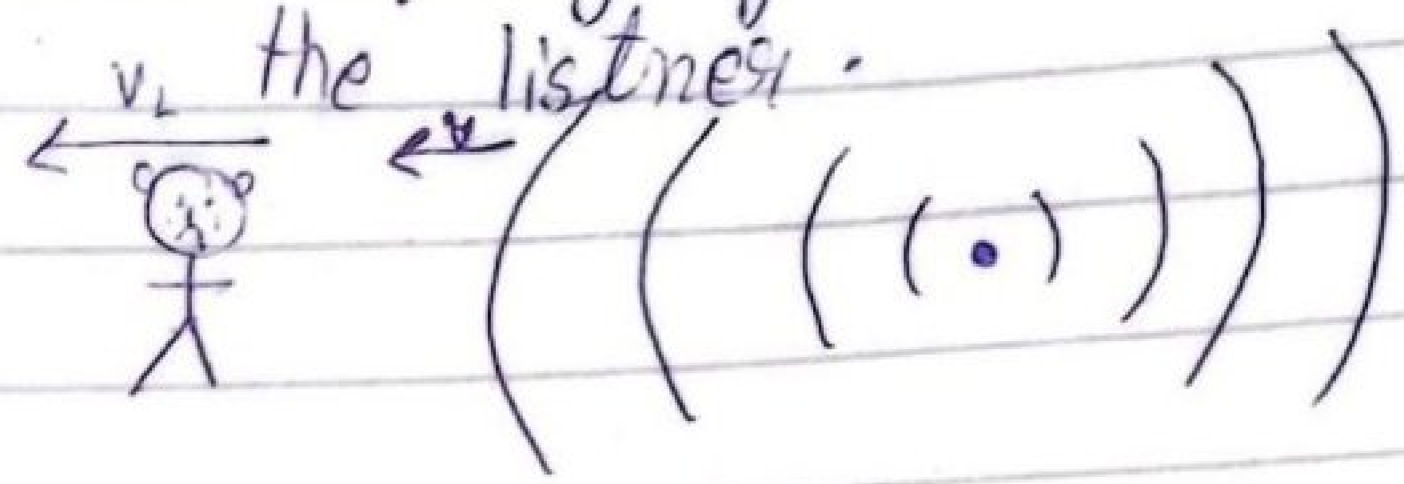
$$f' = \frac{V'}{\lambda}$$

$$f' = \frac{V-V_L}{(V/f)}, \quad f = \left(\frac{V-V_L}{V}\right) f \quad \text{—— (B)}$$

$$\left(\frac{V-V_L}{V}\right) < 1$$

$$f' < f$$

Hence, frequency of sound decreases for the listner.

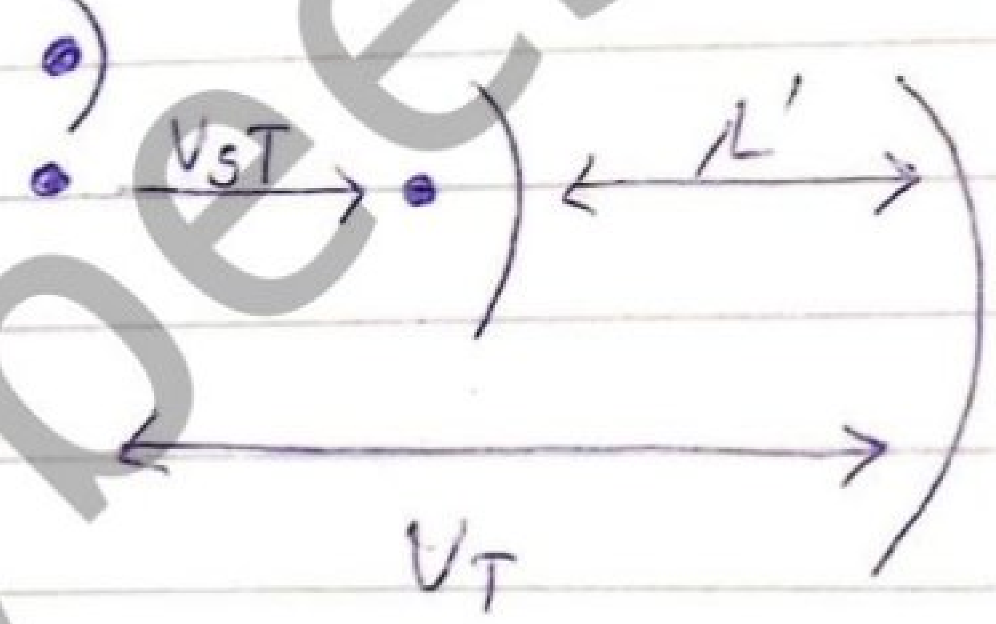


Case #2

Source moving and listner at rest.

A ⟹ Source moving towards stationary observer

When source moves towards stationary listner, wavelength of sound waves decreases but frequency remains same.



⟹ From diagram

$$VT = V_sT + \lambda'$$

$$\lambda' = VT - V_sT = T(V - V_s)$$

$$\lambda' = \frac{V - V_s}{f}$$

Now,

$$f' = \frac{V}{\lambda'} , \quad f' = \frac{V}{\left(\frac{V - V_s}{f}\right)}$$

$$f' = \left(\frac{V}{V - V_s}\right) f \quad \ldots\ldots (c)$$

$$f' > f.$$

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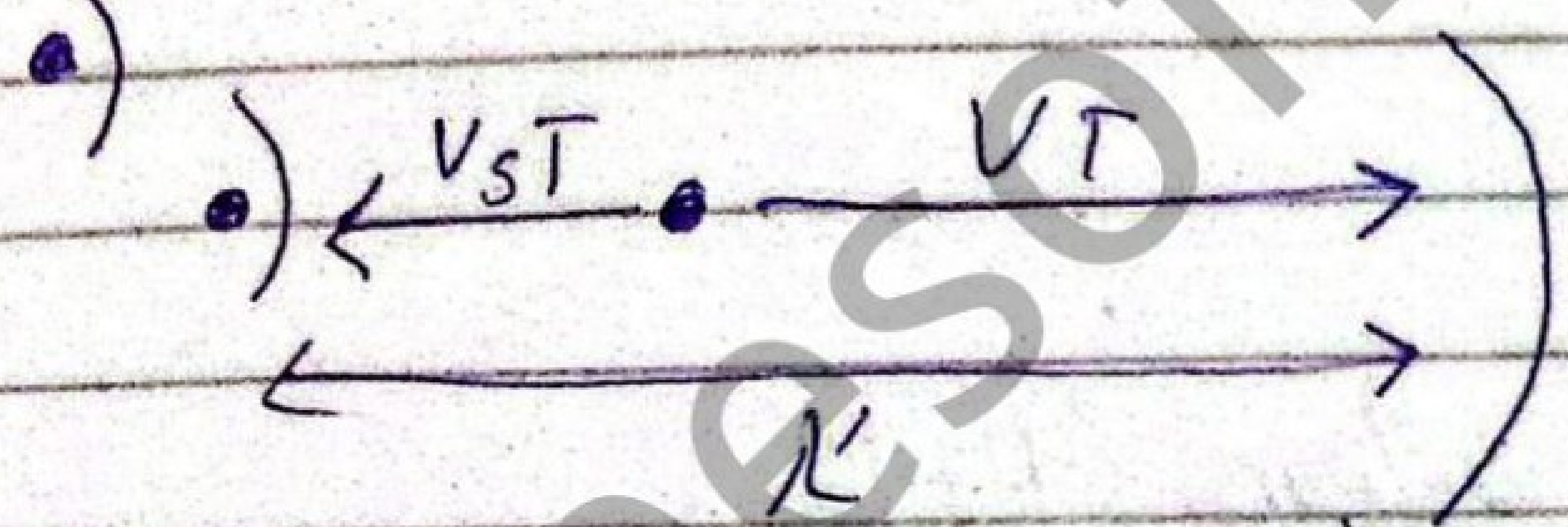
frequency of sound waves increases for the listner.

=> Source moving away from listner

When source remains moves away from the stationary listner, wavelength of sound waves increases but speed of sound waves remains same.



$$\lambda' = V_sT + VT = (V_s + V)T$$

$$\lambda' = \frac{V_s + V}{f}$$

Now,

$$f' = \frac{V}{\lambda'} \quad , \quad f' = \frac{V}{\left(\frac{V + V_s}{f}\right)}$$

$$f' = \left(\frac{V}{V + V_s}\right) f \quad \text{-----} \quad (1)$$

$$f' < f$$

frequency of sound waves decreases for the listner.

Applications of Doppler's Effect:-

Doppler's effect has many types of practical applications:-

(i) Weather Observations:

- Used to monitor cloud movement and weather patterns.
- Helps predict storms, wind speed, and other meterological changes.

(ii) Radar Systems (RADR)

- Radar sends radio waves that reflect off airplanes.
- If plane moves toward radar, frequency increases, wavelength decreases.
- If plane moves away, frequency decreases, wavelength increases.
- Doppler shift determine speed and direction of the plane.
- Some airplanes use radar-absorbing materials to reduce detection.

(iii) SONAR

- SONAR detects ships and submarines using ultrasonic or audible sound waves.
- Sound waves reflected from moving submarines change frequency.

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- Doppler shift calculate speed and direction of submarines.
- Velocities of Earth satellites are also measured using Doppler shift in radio waves.

iii) Astronomy

- Doppler effect helps astronomers study stars and glaxies.
- Blue shift :- star moving towards ~~away from~~ earth.
- Red shift ; star moving away from earth.
- Edwin Hubble observed red shifts in distant glaxies, showing that the universe is expanding.
- Comparing a star's spectrum with laboratory light allows calculation of the star's speed relative to earth.

(v) Radar Speed Traps;

- Police radar's emit microwave bursts that reflect off moving cars.
- Doppler shift in reflected waves calculates the speed of vehicles.
- Computers process this information to enforce traffic speed limits.

(vi) Medical Applications

- Doppler ultrasound (echocardiography) uses high-frequency sound waves to examine the heart and blood vessels.
- Reflected waves produce images showing blood flow and artery conditions.
- Helps detect:
  -> Blockages or obstructions in arteries.
  -> Narrowing or leakage of heart valves.
  -> Abnormal blood vessels.

Superposition of Waves:-

Superposition Principle:-

If a particle of ~~prin~~ medium is simultaneously acted upon by a number of waves then the resultant displacement of particle of medium is the vector sum of displacement caused by the individual waves.
This statement is called superposition principle.

Mathematically:-

$$\vec{y}_{net} = \vec{y}_1 + \vec{y}_2 + \vec{y}_3 + \cdots \vec{y}_n$$

Application:- The phenomenon of waves such as interference, beats and stationary waves are due to the superposition principle.

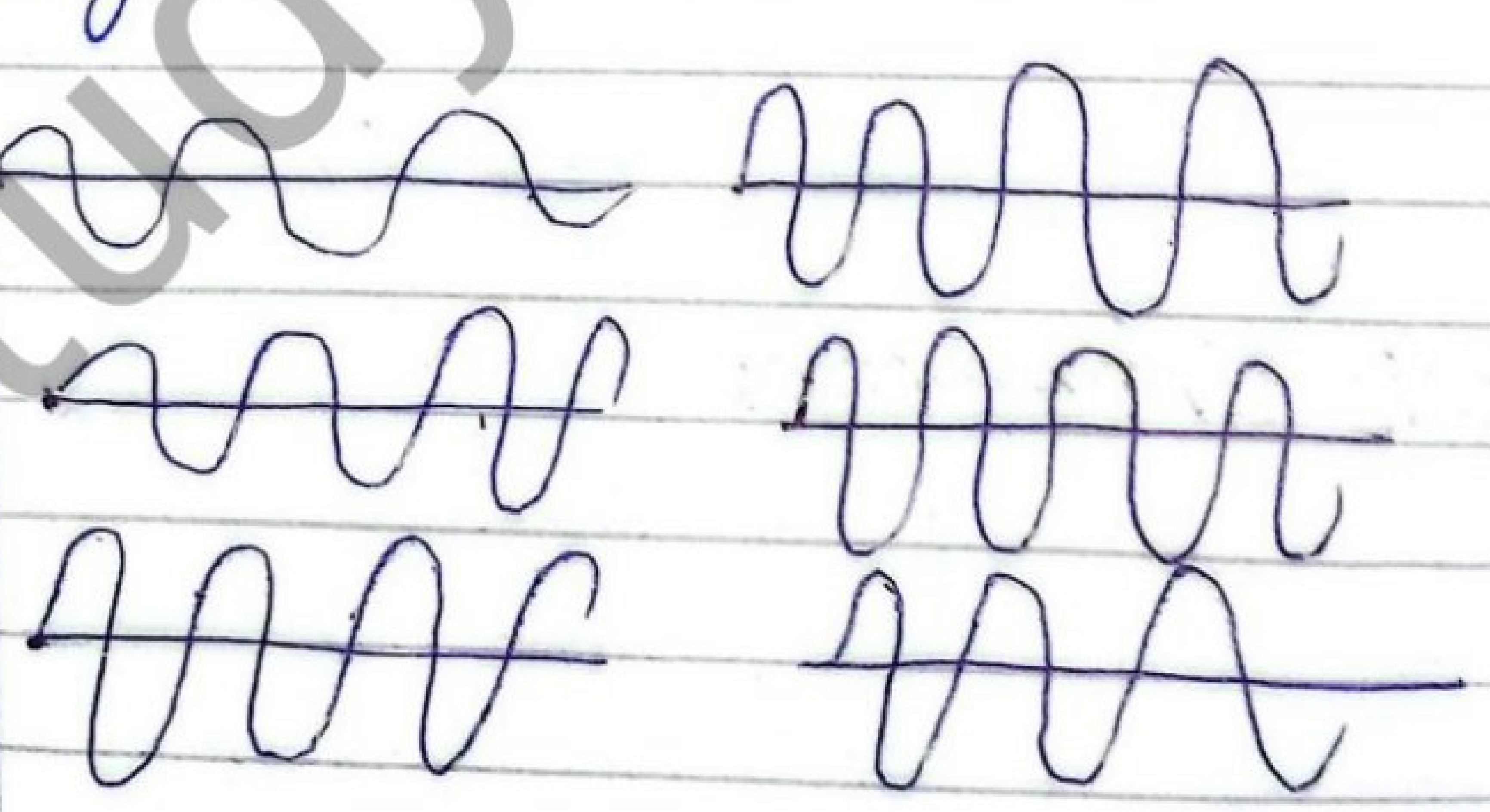
Interference of waves :-

Definition:
When two or more than two waves having same frequency and travelling in the same direction meet together, this phenomenon of waves is called interference of waves.

Types of interference:-
There are two types of interference of waves.
1- Constructive interference.
2- Destructive interference.

Constructive interference :-
When two or more than two waves interfere such that they ~~reinforce~~ the effect of each other is called constructive interference.

Diagram:-



Properties:-

- During constructive interference, crust of transverse wave falls on crust and trough on trough of waves.
- During constructive interference, compression of longitudinal waves falls on compression and rarefaction falls on rarefaction of waves.
- Both waves reinforce effect of each other and amplitude of resultant wave increases.
- For constructive interference, path difference b/w waves must by integral multiple of wavelength i.e:-

$$d = 0, \lambda, 2\lambda, 3\lambda, \ldots$$
$$d = m\lambda \text{ where } m = 0, 1, 2, 3, \ldots$$

- For constructive interference, phase difference b/w waves must be zero or even multiple of π i.e;

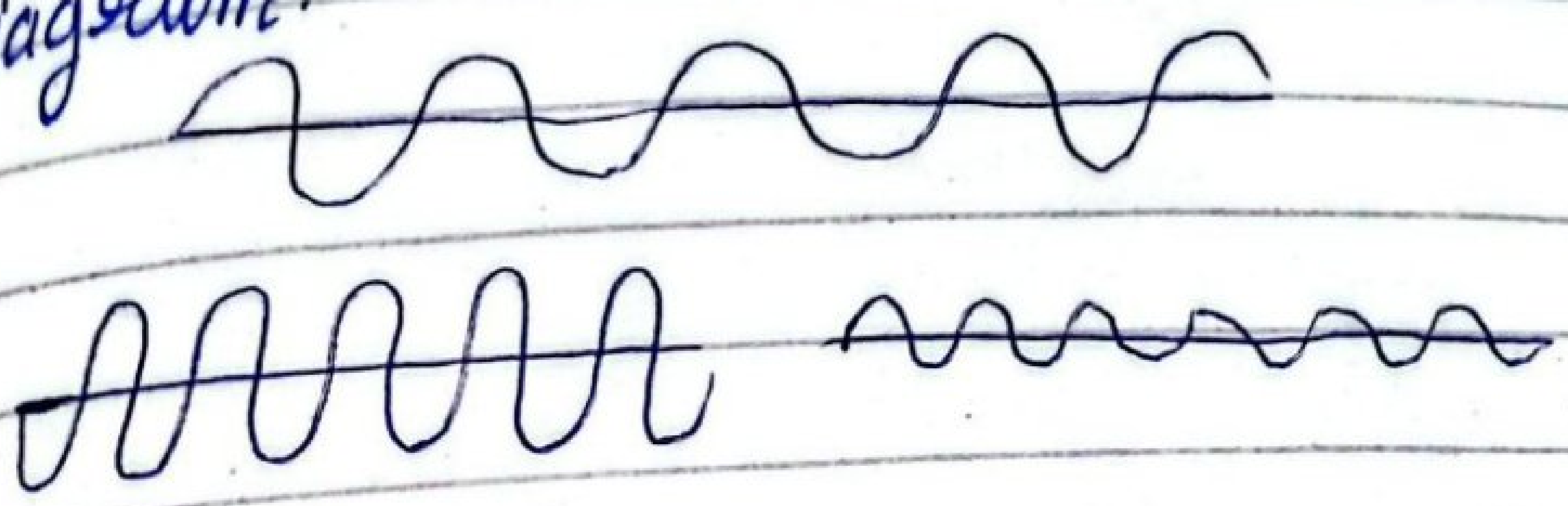
$$\Delta\phi = 0, 2\pi, 4\pi, 6\pi, \ldots$$
$$\Delta\phi = 2m\pi, \text{ where } m = 0, 1, 2, 3, \ldots$$

2- Destructive interference:-

Definition:

When two or more then two waves interfere such that they cancel or decrease the effect of each other is called destructive interference.

Diagram:



Properties:

- During Destructive interference, crust of one wave fall on trough and trough on crust of waves.
- During destructive interference of longitudinal waves, compression of one wave falls on rarefaction of 2nd wave and viceversa.
- Both waves cancel or decrease the effect of each other and amplitude of resultant wave decreases.
- For destructive interference, path difference b/w the waves must by odd multiple of half of wave length i.e;

$$d = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, \frac{7\lambda}{2}$$

$$d = (2m+1)\frac{\lambda}{2}$$

where, $m = 0, 1, 2, 3, \ldots$

- For destructive interference, phase difference b/w waves must odd multiple of π,

$$\Delta\phi = \pi, 3\pi, 5\pi, 7\pi \ldots$$

$$\Delta\phi = (2m+1)\pi$$

Condition for interference:-

Following conditions are necessary for interference of waves:-

- Waves must be travelling in the same direction
- Waves must arrive at the same place at the same time.
- Waves must be,
  - → In phase, for constructive interference.
  - → Out of phase (180°), for destructive interference.
- path difference must be,
  - → Integeral multiple of wavelength λ, for constructive interference.

$d = m\lambda$ (where = 0, 1, 2, 3, ...).

  - → odd integral multiple of $\frac{1}{2}\lambda$, for destructive interference.

$d = (m + \frac{1}{2})\lambda$ (where $m = 0, 1, 2, 3, \cdots$).

Interference of Sound waves:-

- Sound from a loudspeaker is sent into a tube with a T-shaped junction.
- The sound travels through two paths one fixed and one variable.
- When both paths are equal, waves reach the receiver in phase.
- Loud speaker is heard due to constructive interference.
- When the path difference is an odd multiple of $\frac{\lambda}{2}$, waves reach out of phase.

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- No sound is heard due to destructive interference.
- Blocking one path restores sound, proving silence is due to interference.

Beats

Definitions:-

- When two sound waves of slightly diff frequencies, travelling in the same direction, overlap, a periodic variation in loudness b/w max and min is produced.
- This phenomenon is called beats.

Explanation

- When two tuning forks of slightly diff frequencies vibrate together, we do not hear two separate notes.
- Instead, a single sound is heard whose intensity rises and falls due to interference.

Example:-

Consider two tuning forks:

-> Tuning fork A, $F_1 = 32\ Hz$.

-> Tuning fork B, $F_2 = 30\ Hz$.

Generation of Beats:

1. At $t = 0s$.

- Both tuning forks produce compressions together.
- Constructive interference occurs.
- Maximum sound is heard.

2- At $t = \frac{1}{4}$ s
- Compression from one fork falls on rarefaction of the other.
- Destructive interference occurs.
- No sound is heard.

3- At $t = \frac{1}{2}$ s
- Compression coincides with Compression.
- Constructive interference.
- Maximum sound is heard.

4- At $t = \frac{3}{4}$ s
- Compression falls on rarefaction.
- Destructive interference.
- No sound is heard.

5- At $t = 1$ s.
- Compression again falls on compression.
- Constructive interference
- Loud sound is heard.

→ Thus, loud and weak sounds are heard alternately, producing beats.

Beat frequency;
- Number of beats heard per second is called beat frequency.

$f_b = |f_1 - f_2|$

e.g:-

$f_b = |32 - 30| = 2\text{Hz}.$

- Hence, 2 beats per s^{-1} are heard

Conditions:- / Limitations.
If frequency difference is greater than 10 Hz. beat are not clearly heard.

Uses:-
→ Beats are used to tune musical instruments such as piano and violin.
→ Beats are used to determine unknown frequency of vibrating body.

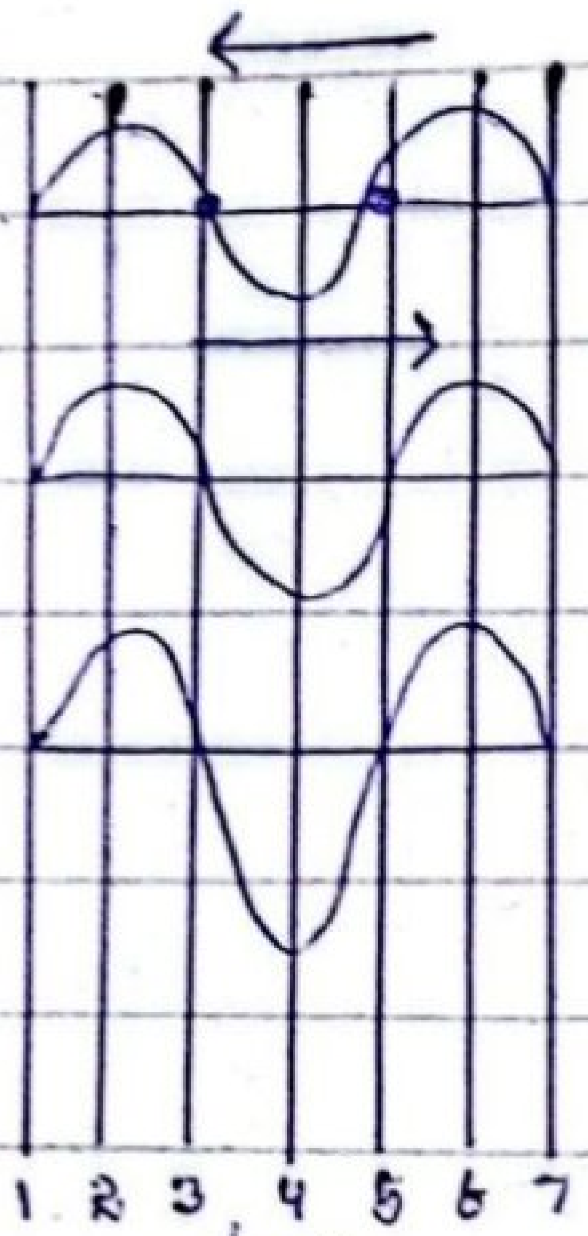
Stationary (Standing) Waves:-

When two identical waves having the same speed, frequency, and amplitude, travelling in opposite directions, superpose with each other, the wave formed is called a stationary wave.

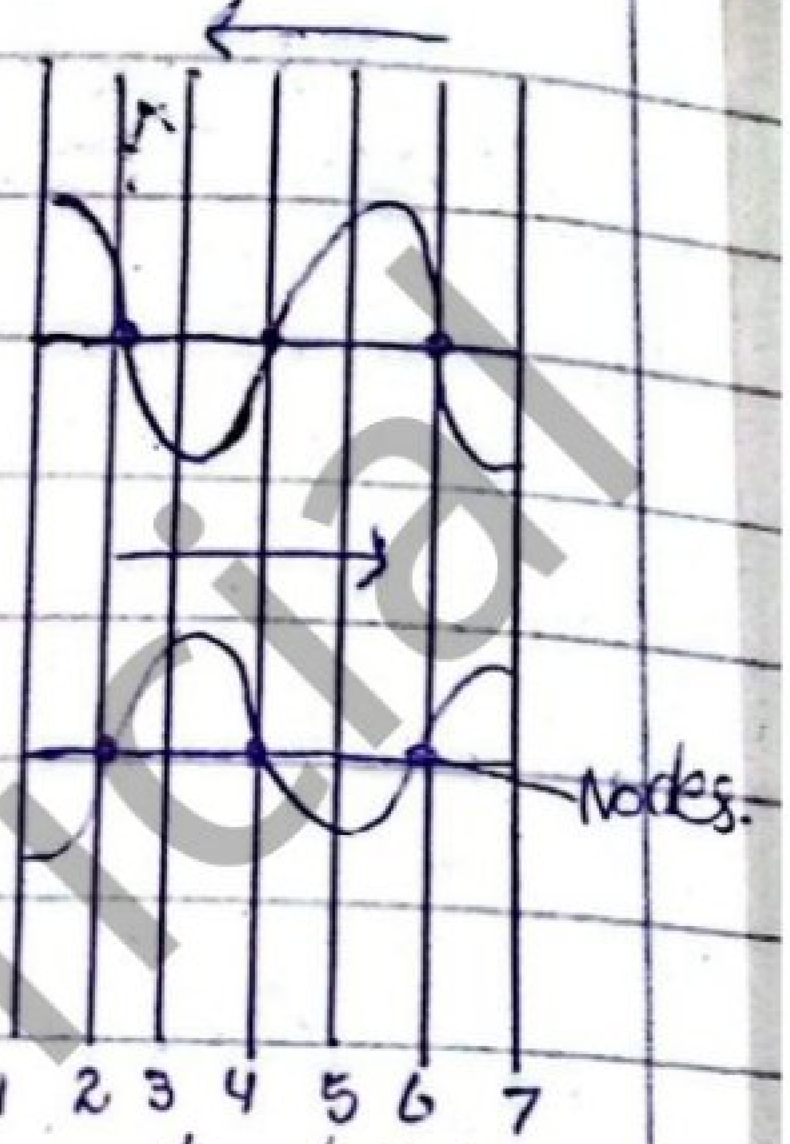
Formation of Stationary Waves:
- A stationary wave is produced when an incident wave reflects from a boundary and superposes with the reflected wave.
- Both waves have the same frequency and amplitude but travel in opposite directions.
- The wave appears to be standing still instead of moving forward.

Nodes:
- Nodes are points where the displacements is always zero.
- The particles at nodes do not vibrate.

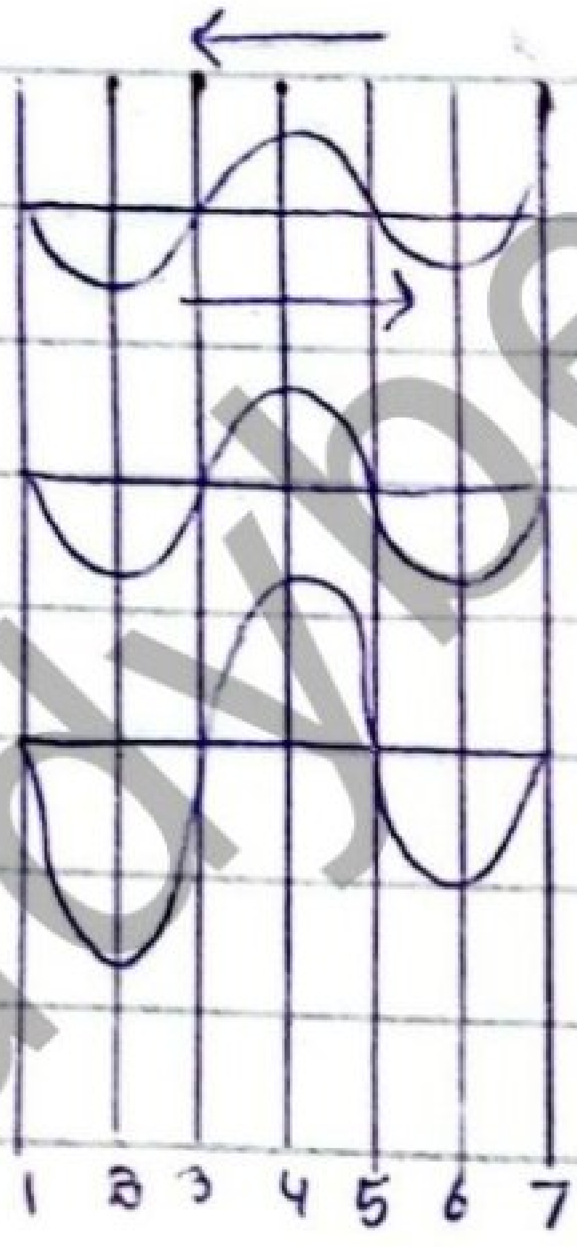
- In figure, points 1, 3, 5 and 7 are nodes.
- Nodes are usually represented by N.

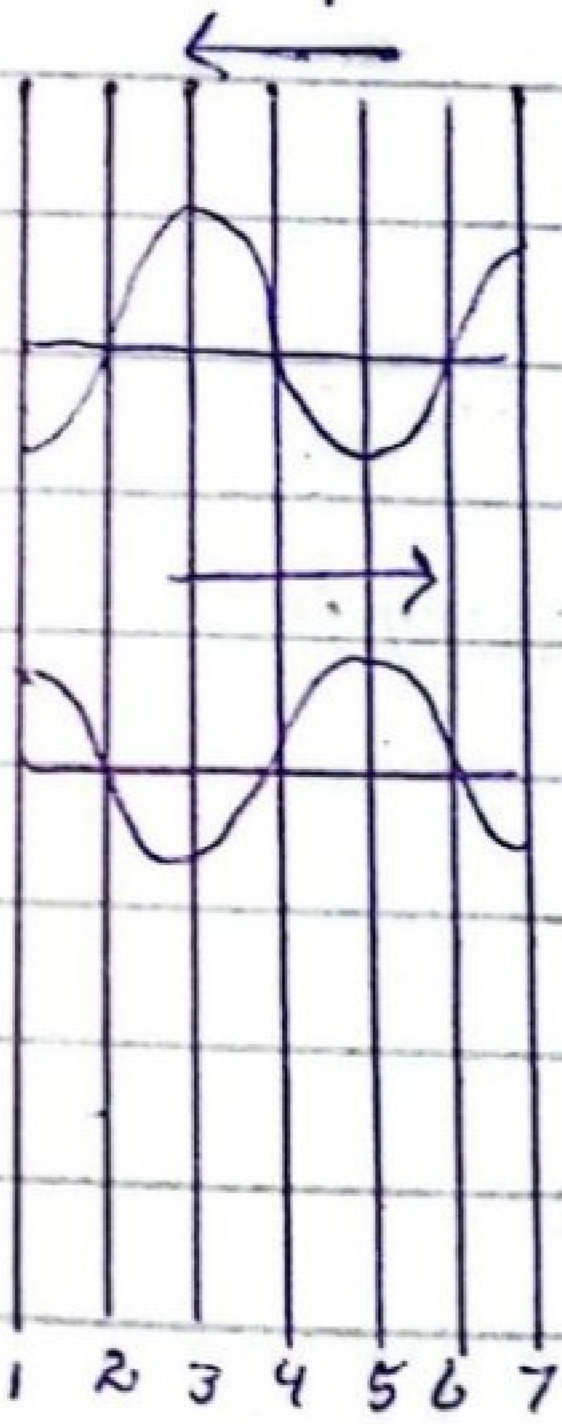


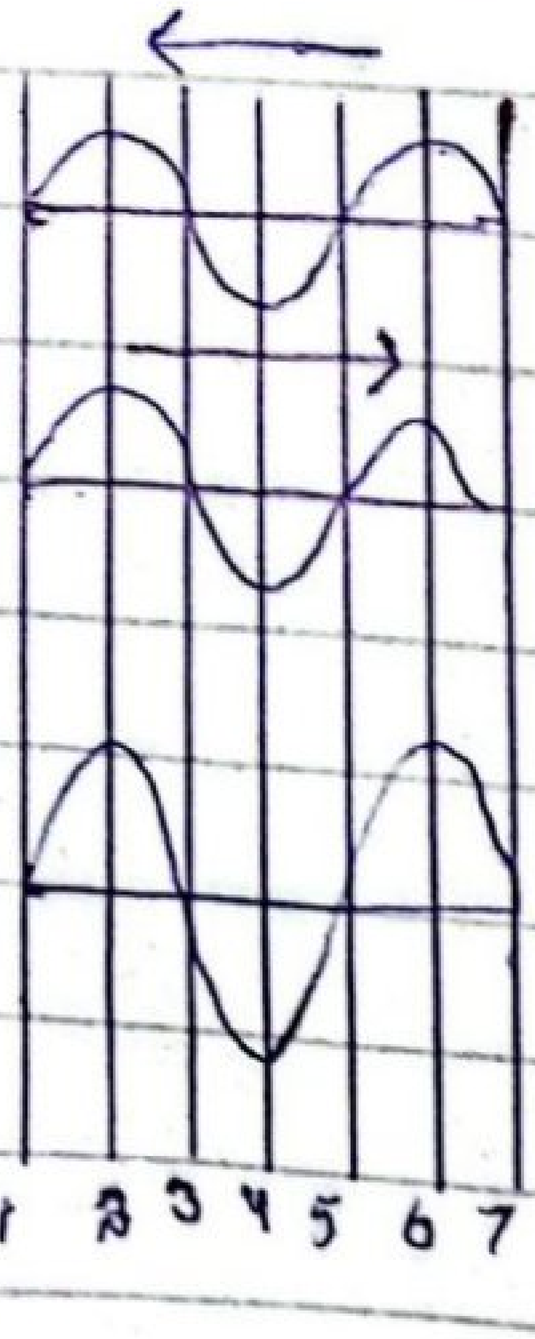
$t = 0$



$t = \frac{1}{4} T$







Antinodes:-

- Antinodes are points where the displacement is maximum.
- The particles at antinodes vibrate with maximum amplitude.
- In figure points 2, 4 and 6 are antinodes
- The amplitude at an antinode is equal to the sum of amplitudes of the component waves.
- Antinodes are represented by A.

Characteristics of stationary waves:-

- No energy transfer from particle to particle.
- The distance b/w two successive nodes or antinodes is equal to $\lambda/2$.
- The distance b/w adjacent node and anti-node is equal to $\lambda/4$.

Stationary Waves In a Stretched string:-

- A string fixed at both ends and under tension produces waves when it plucked.
- These waves travel along the string, reflect from the fixed ends, and move back.
- The incident and reflected waves superpose to form a pattern that appears fixed, called a stationary wave.

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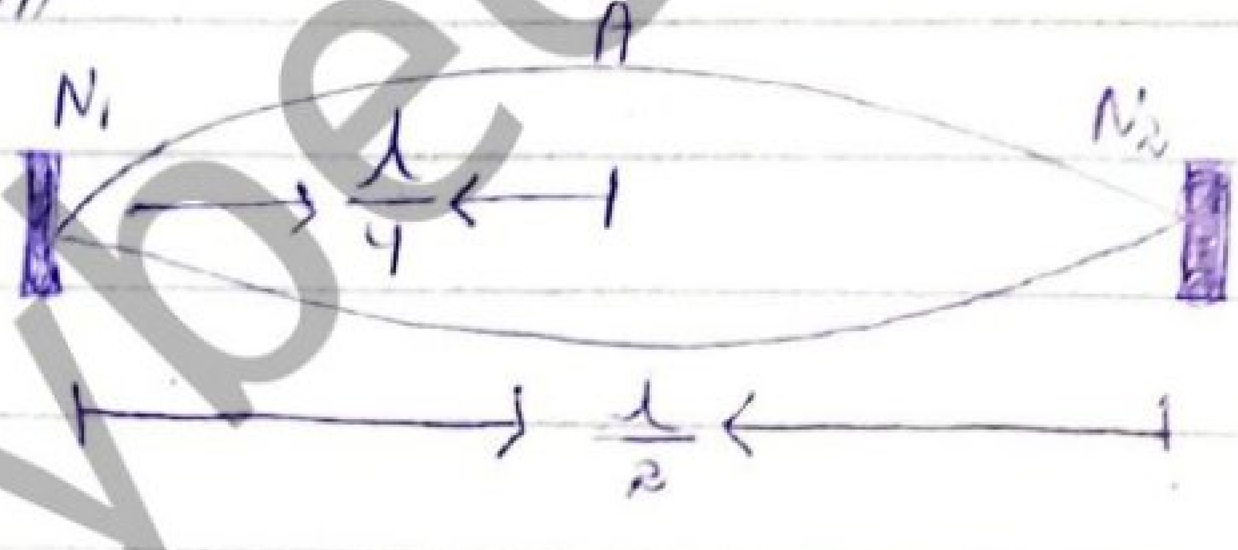
- The fixed ends always act as Nodes, while points of maximum vibration become antinodes.
- The formation of stationary wave depends on the tension, mass per unit length, and length of the string.

$$V = \sqrt{\frac{T \times L}{M}}$$

First Mode of vibration:-

when the string is plucked at the middle of its length then the string vibrates in a single loop as shown in figure.
Such a mode is called fundamental mode of vibration.



→ Distance b/w two constructive nodes = $\frac{\lambda}{2}$.

→ If λ_1 be the wave length and f_1 be the frequency of vibration in this mode, then $L = \frac{\lambda_1}{2} \rightarrow \lambda_1 = 2L$

Thus, speed of wave v is $v = f_1 \lambda_1$

(OR) $f_1 = \frac{v}{\lambda_1}$

putting value of $\lambda_1 = 2L$

we get $$f_1 = \frac{V}{2L} \quad \ldots (2)$$

put value of v from eq (i) in eq (ii), we get.

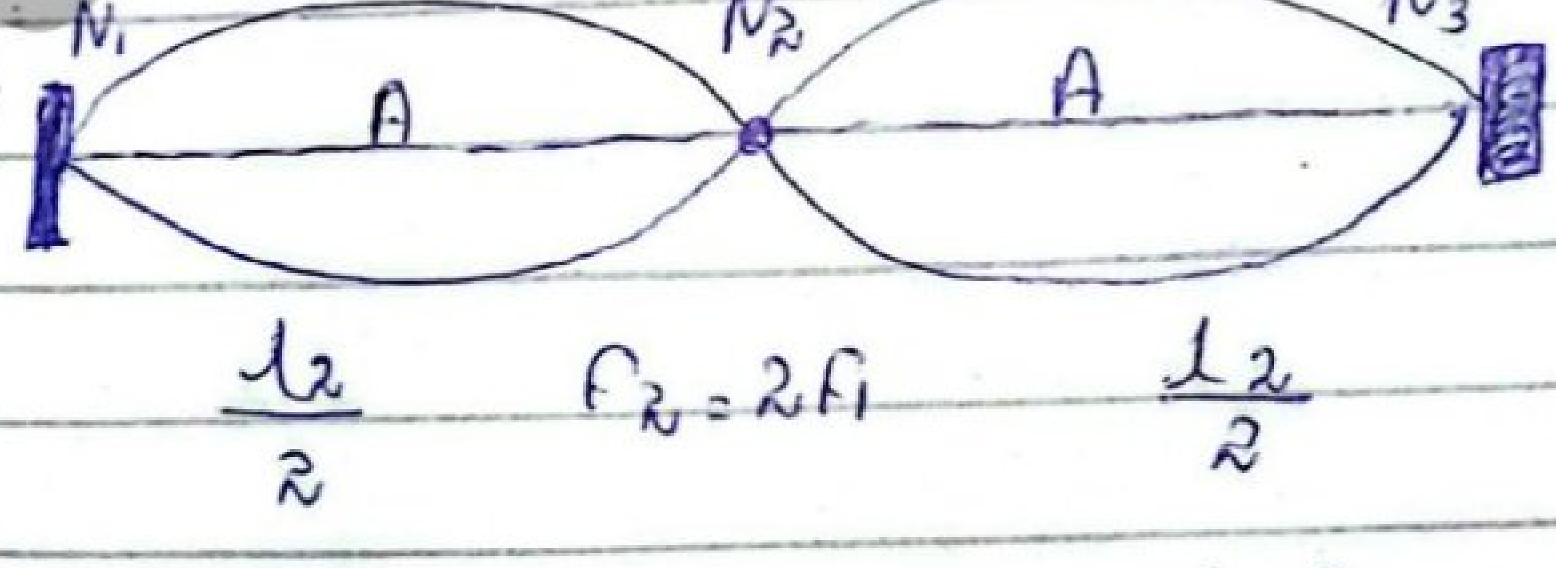
$$F_1 = \frac{1}{2L}\sqrt{\frac{T \times L}{M}}$$

If m is the mass per unit length of string i.e $m = \frac{M}{L}$ the eq (iii) can be written as

$$f_1 = \frac{1}{2L}\sqrt{\frac{T}{m}}$$

Second Mode of Vibration:-

If the string is plucked from one-quarter (1/4) of its length, it vibrates in two loops. There is one extra node in the middle. The length of string now contains one complete wavelength.



→ If λ_2 be the wavelength and f_2 is the frequency then,

$$L = \frac{\lambda_2}{2} + \frac{\lambda_2}{2}$$

$$L = \frac{2\lambda_2}{2} \quad , \text{ OR } \quad \lambda_2 = \frac{2L}{2}$$

→ The speed of wave v is $v = f_2 \lambda_2$

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

→ putting value of λ_2, we get $f_2 = \frac{v}{2L/2}$

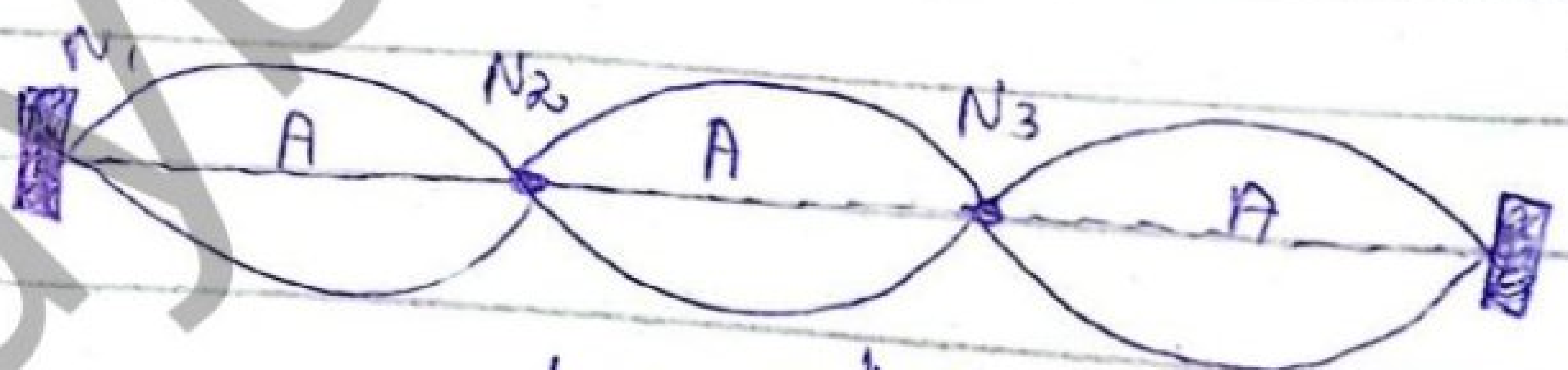
$$\text{(OR)} \quad F_2 = 2\left(\frac{v}{2L}\right)$$

So, $F_2 = 2F_1$ ∴ since $\frac{v}{2L} = F_1$

→ f_2 is called second harmonic.

Third Mode of vibration:-

when the string vibrates in three loops, there are two interior nodes and three antinodes. In this mode.



$$L = \frac{3\lambda_3}{2}$$

$$\lambda_3 = \frac{2L}{3}$$

The frequency is,

$$f_3 = \frac{v}{\lambda_3} = \frac{3v}{2L}$$

$$\Rightarrow f_3 = 3f_1$$

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

this is known as the third harmonic.

⇒ So, the stationary wave have a discrete set of frequencies $f_1, 2f_1, 3f_1, \cdots nf_1$, which is known as harmonic series.

Quantization of frequences:

__Harmonics__; Such oscillations in which each frequency is integeral multiple of fundamental frequency is called harmonics.

In stretched string only harmonics produced have frequences $f_1, 2f_1, 3f_1, 4f_1 \cdots nf_1$

→ The frequency f_1 is known as fundamental frequency.

→ This phenomenon is known as quantization of frequency.

Stationary Waves In Air Column:-

Defination:-

- When Sound waves travel in a tube and reflect back, they overlap with the incident waves.
- Due to this superposition, a wave pattern is formed that looks fixed in space.
- Such waves are called __stationary waves__
- Nodes; zero displacement
- Antinodes; Maximum displacement.

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Organ pipe

- An organ pipe is a hollow tube in which sound is produced by a vibrating air column.
- e.g;- flute, clarient, trombone, etc
- There are two types of organ pipe;-
  → open pipe (both ends open).
  → Closed pipe (one end close)
- open end behaves as antinode (free movement of air).
- Closed end behaves as node (air cannot move).

Open Organ Pipe:-

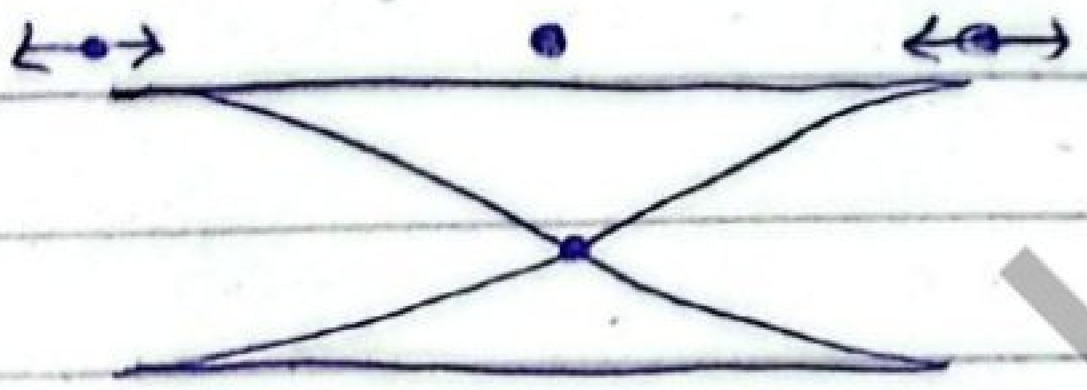
- Both ends are antinodes.
- A tuning fork sends a sound wave into the pipe.
- The wave reflects from the ends and forms stationary waves in the air column.
- Diff patterns of nodes and antinodes give diff modes of vibration.

1:- Fundamental mode of vibration:-

- In this case there is only one node at the middle of the pipe.
- There are two antinodes at both the open ends.

- If λ_1 is the wavelength of sound $L = \frac{\lambda_1}{4} + \frac{\lambda_1}{4}$

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



$$\lambda_1 = 2L$$

$$L = \frac{\lambda}{2}, \quad f_1 = \frac{v}{2L}$$

$$v = f_1 \lambda_1$$

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

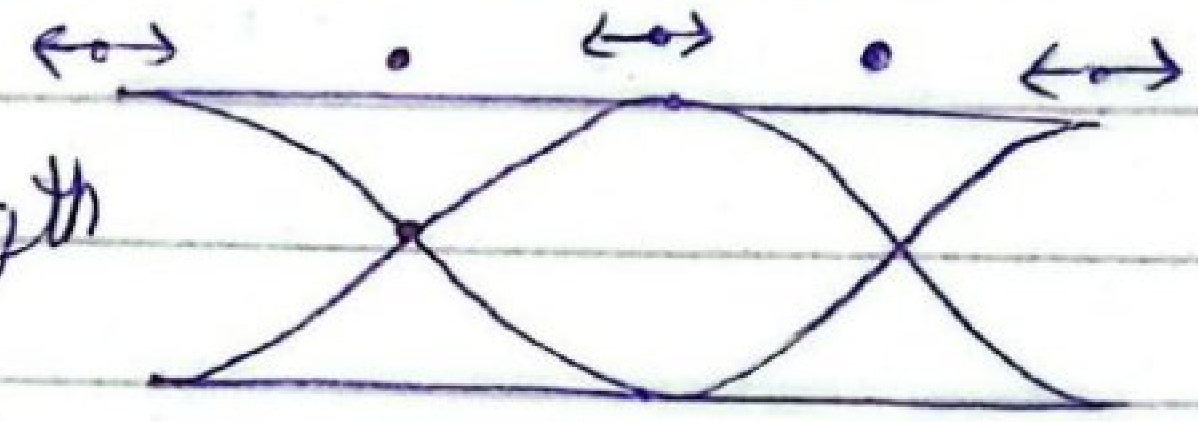
put value of $\lambda_1 = 2L$

$$f_1 = \frac{v}{2L} \quad (i)$$

- This frequency is called fundamental frequency of first harmonic.

2 Second Mode of vibration:-

- In this case, there are three antinodes and two nodes.



- If λ_2 is the wavelength of sound then

$$L = \frac{\lambda_2}{4} + \frac{\lambda_2}{2} + \frac{\lambda_2}{4} \quad L = 2(\lambda/2), \quad f_2 = \frac{v}{L}$$

$$L = \left(\frac{1+2+1}{4}\right), \quad \lambda_2 = \frac{2\lambda_2}{2}$$

$$\lambda_2 = \frac{2L}{2}.$$

If f_2 is the frequency of sound, then speed becomes, $v = f_2 \lambda_2$

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$$F_2 = \frac{V}{\lambda_2} \quad \text{put value of } \lambda_2 = L$$

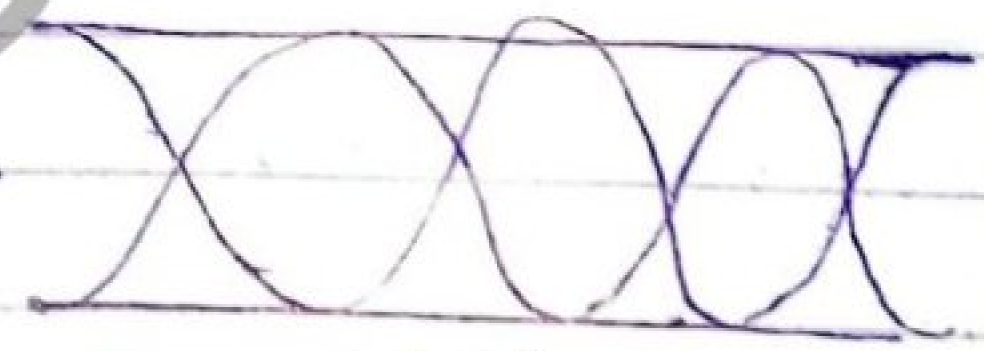
$$F_2 = \frac{V}{L}$$

$$F_2 = 2\left(\frac{V}{2L}\right), \text{ so, } F_2 = 2f_1$$

- F_2 = is 2nd harmonic.

3- Third Mode of vibration:

- For three loops, there are four antinodes and three nodes.
- If λ_3 is the wavelength of sound, then length of the pipe is



$$L = \frac{\lambda_3}{4} + \frac{\lambda_3}{2} + \frac{\lambda_3}{2} + \frac{\lambda_3}{4}$$

$$L = \left[\frac{1+2+2+1}{4}\right]\lambda_3$$

$$L = \frac{3\lambda_3}{2}$$

$$\lambda_3 = \frac{2L}{3}.$$

$L = 3(\lambda/2)$,
$F_3 = 3(V/2L)$

So, the speed becomes, $V = F_3\lambda_3$

$$F_3 = \frac{V}{\lambda_3} \quad \text{put value of } \lambda_3 = \frac{2L}{3}$$

$$F_3 = 3\left(\frac{V}{2L}\right)$$

$$F_3 = 3f_1 \quad \left[\because \frac{V}{2L} = f_1\right]$$

- The frequency f_3 is called third harmonic.

- So, the longitudinal stationary waves have a discrete set of frequencies $f_1, 2f_1, 3f_1 \cdots nf_1$ are know as harmonic series-
- And wavelength is $\lambda_n = \frac{2L}{n}$.

-> where $n = 1, 2, 3, 4, 5, \ldots$

Closed Organ Pipe:-

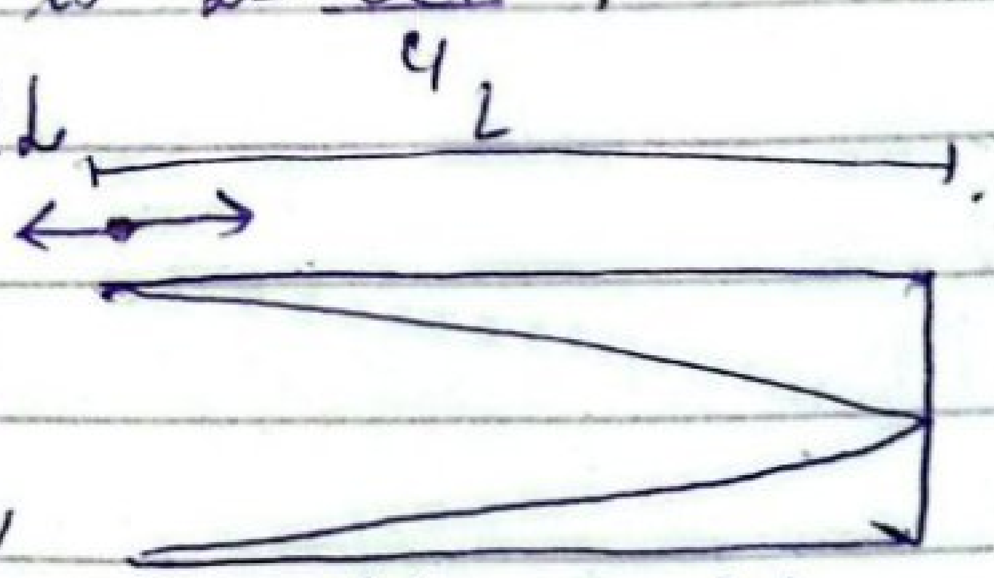
- Let us consider an organ pipe of length "L" which is closed at ~~both~~ one end.
- At the closed end we get node while at the open end we get antinode.

1- First Mode of vibration:-

- First mode or fundamental mode of vibration has one node and antinode.
- If λ_1 is the wavelength of fundamental mode, then length of the pipe is $L = \frac{\lambda_1}{4}$.

$\lambda_1 = 4L$

L



$v = f_1 \lambda_1$

$f_1 = \frac{v}{\lambda_1}$ put value of λ_1

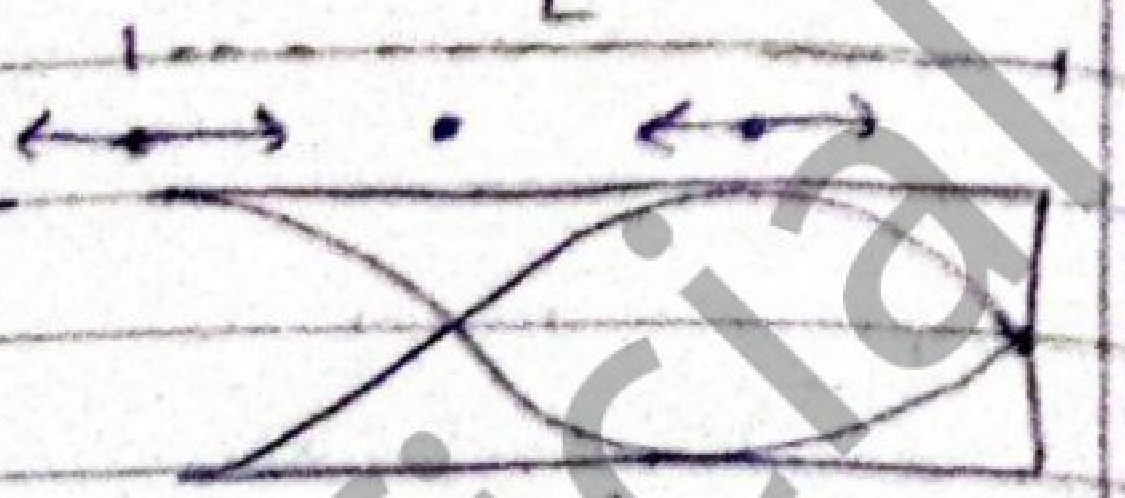
$f_1 = \frac{v}{4L}$ —•

$L = \lambda/4, \; f_1 = v/4L$

- The frequency of f_1 is called fundamental frequency.

2- Second Mode of vibration:-

- Second mode of vibration contains two nodes and two antinodes.
- If λ_2 is the wavelength, then length of the pipe is.



$$L = \frac{\lambda_2}{2} + \frac{\lambda_2}{4}$$

$$L = \frac{3\lambda_2}{4}$$

$$\lambda_2 = \frac{4L}{3}.$$

$$f_2 = \frac{v}{\lambda_2} \quad \text{put value of } \lambda_2.$$

$$f_2 = \frac{v}{4L/3}$$

$$f_2 = 3\left(\frac{v}{4L}\right) \quad \left(\because f_1 = v/4L\right)$$

$$f_2 = 3f_1.$$

- This is called second harmonic.

3- Third Mode of vibration:-

- Third Mode of vibration contains three nodes and three antinodes.
- If λ_3 is the wavelength, the length of the pipe is

$$L = \frac{\lambda_3}{4} + \frac{\lambda_3}{2} + \frac{\lambda_3}{2}.$$

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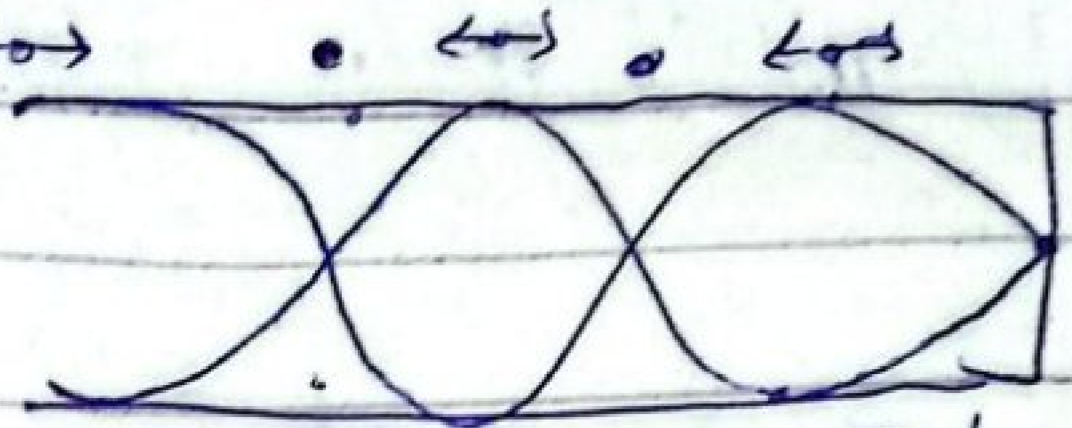
$$L = \left(\frac{1+2+2}{4}\right)\lambda_3$$



$l = 5\left(\lambda/4\right)$, $f_3 = 5v/4L$

$$L = \frac{5}{4}\lambda_3$$

$$\lambda_3 = \frac{4L}{5}$$

$$v = f_3 \lambda_3$$

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

put value of $\lambda_3 = \frac{4L}{5}$

$$f_3 = \frac{v}{4L/5}$$

$$f_3 = 5\left(\frac{v}{4L}\right)$$

$$f_3 = 5f_1 \quad \left[\because \frac{v}{4L} = f_1\right]$$

Which is the frequency of third harmonic.

n^{th} mode of vibration:-

- If air coulomn vibrates in n loops, then

$$f_n = (2n-1)\frac{v}{4L}$$

$$f_n = (2n-1)f_1$$

$$\lambda_n = \frac{4L}{2n-1}$$

- In closed pipe only odd harmonics are present.

Demonstrate Stationary Waves:-

1- A vibrating tuning fork is held over a glass tube partly filled with water.

2- Water level is lowered to changed the length of the air column

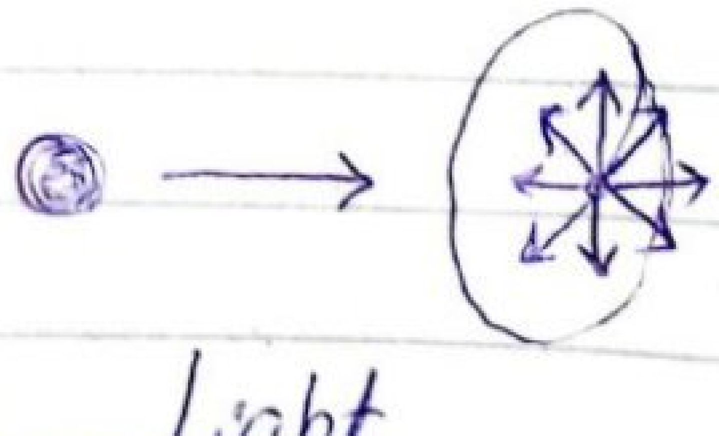
3- At certain lengths, loud sound is heard due to resonance.

4- This resonance shows that stationary waves are formed in the air column.

Polarization of Light:-

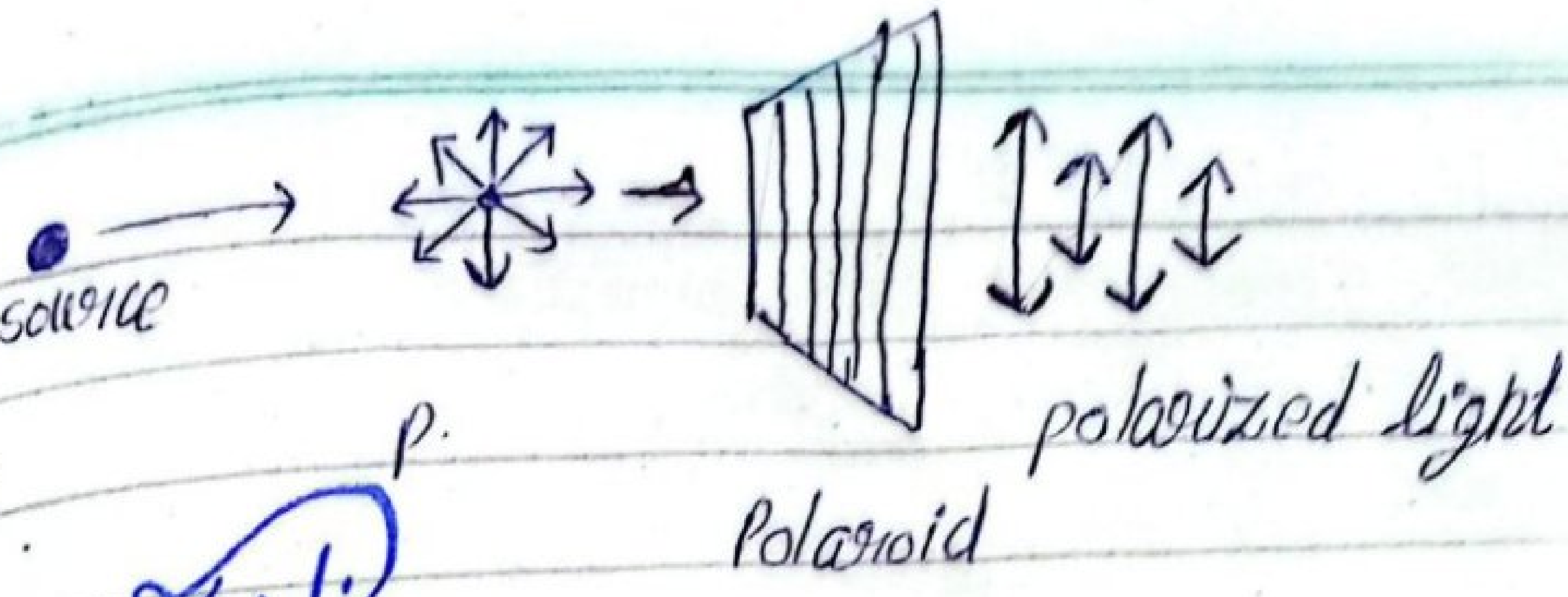
UnPolarized Light:-

A ray of light in which waves of light are vibrating in all directions in a plane perpendicular to the direction of propagation of light.



Polarized Light

A ray of light in which electric field vectors of light wave are vibrating in only one plane/direction is called polarized light.



Polarization:-

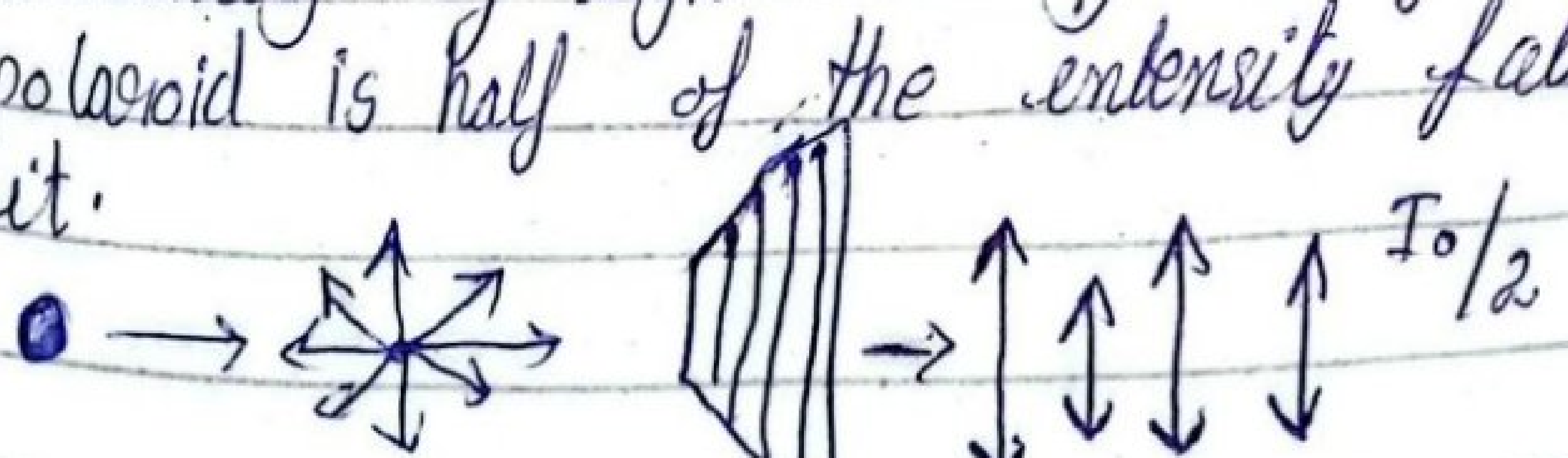
An optical process in which unpolarized light is converted into polarized light is called polarization. Device used to make unpolarized light into polarized light is called polaroid filter.

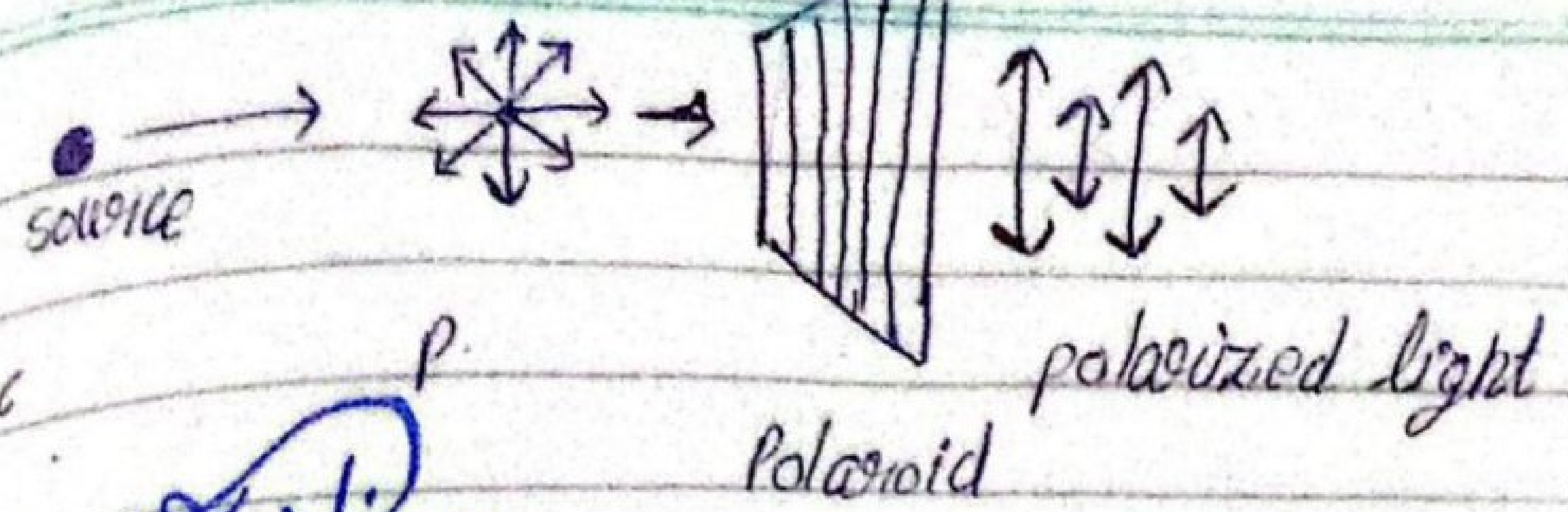
Methods of Polarization:-

There are two methods of polarization of light.
- → Polarization using polaroids.
- → Polarization by reflection.

Polarization by polaroid:-

Polaroid is a substance that converts unpolaroid light into polarized light. This is because, the chemical composition of the polaroid is such that it allows vibrations of only one direction and absorbs that electric field vibrations of remaining directions. Intensity of light coming out of the polaroid is half of the intensity falling on it.





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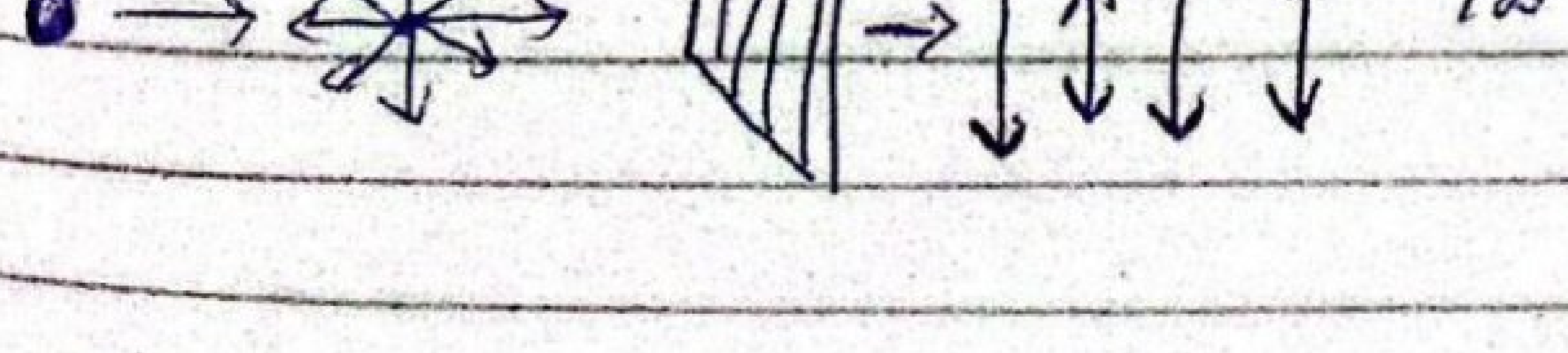
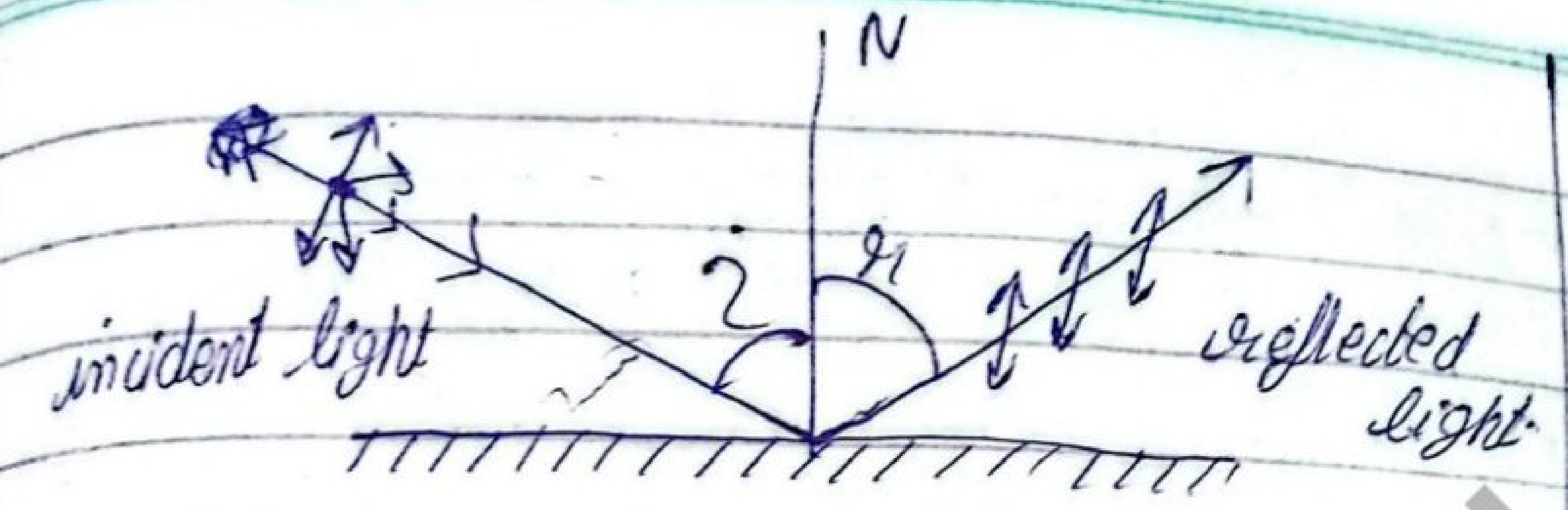




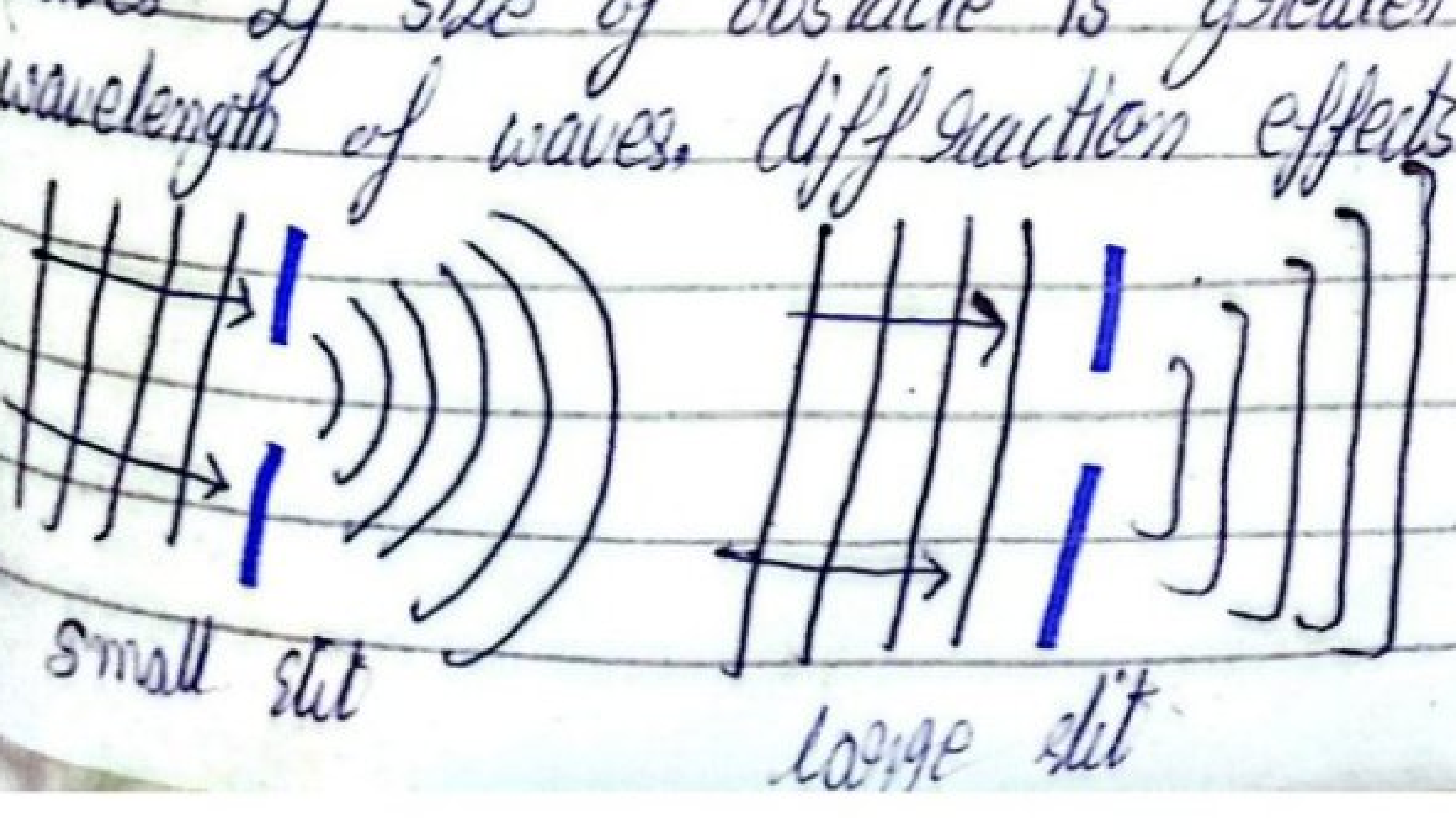
Use of Polaroids:-

1. sky photography :- Reduce glare and give clearer photos.
2. stress Analysis :- show coloured bands in plastics to locate stressed regions.
3. 3D movies :- Used in glasses to give separate images to each eye and create 3-D effect.

Diffraction of waves:-

The bending or spreading of waves around the corners of an obstacles while passing through it is called diffraction of waves. This phenomenon is shown by all kinds of waves.

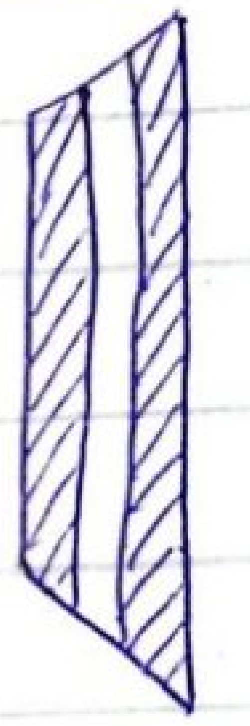
Condition for prominent diffraction:-
Diffraction of waves is maximum when size of obstacle is comparable to the wavelength of diffracting waves. If size of obstacle is greater than the wavelength of waves, diffraction effects are negligible



Diffraction of Light:-

- Light bends around edges when passing through a narrow slit - this is <u>diffraction</u>.
- A bright central spot (<u>central maximum</u>) appears on the screen.
- Other fringes on both sides are smaller and less bright.

<u>Diagram:-</u>



By: Mohd Khan MD-54.