SPEED OF SOUND

The distance covered by sound wave per unit time is called speed of sound $V = S/t$

→ Sound waves are compressional, pressure and longitudinal waves in nature.

FACTORS

The speed of mechanical wave in a medium depends on 2 characteristics of medium:

1. DENSITY OF THE MEDIUM

In denser medium, the speed of sound will be less and vice versa

2. ELASTICITY OF THE MEDIUM

The more compressible medium, less will be elasticity and less will be speed of sound.

compressible mean when pressure is applied on a gas and its volume reduce.

$(V)_{solids} > (V)_{gases}$

1. compressibility of solid is less but respond is quick
   - compressibility $\propto \frac{1}{\text{elasticity}}$
   - Elasticity $\propto$ speed of sound
2. Inertia of the medium.

SPEED OF SOUND BY NEWTON

ASSUMPTIONS

1. Newton assumed that sound travel through air and other gases under **isothermal conditions** which means that sound wave travel with constant temperature. **T = constant**

2. Newton used **Boyle's Law** which states that "At constant temperature, the pressure of a fixed amount of a gas varies inversely with its volume **$[P \propto \frac{1}{V}]$**

E = P

→ Under such conditions, the modulus of elasticity is equal to the pressure of the gas.

CALCULATIONS

Let 'V' be the volume of the air at pressure 'P'

According to Boyle's Law

If pressure increases from P to $P+\Delta P$ then Volume decreases from V to $V-\Delta V$

$$PV = \text{constant}$$

$$PV = (P+\Delta P)(V-\Delta V)$$

$$PV = PV - P\Delta V + \Delta P V - \Delta P \Delta V$$

$$0 = -P\Delta V + \Delta P V - \Delta P \Delta V$$

Neglecting $\Delta P \Delta V$

$$0 = -P\Delta V + \Delta P V$$

$$P\Delta V = \Delta P V$$

$$P = \frac{\Delta P V}{\Delta V}$$

$$P = \frac{\Delta P}{\Delta V} \times V$$

$$P = \frac{\Delta P}{\frac{\Delta V}{V}}$$

$$P = \frac{\text{stress}}{\text{Volumetric strain}}$$

$$P = E$$

Now expression for speed of sound can be written as:

$$V = \sqrt{\frac{E}{\rho}}$$

$$V = \sqrt{\frac{P}{\rho}}$$

$$V = \sqrt{\frac{\rho_m . g h}{\rho}} \quad -(1) \quad (\because P = \rho_m g h)$$

ρ_m = density of mercury

g = gravitational acceleration

h = height of mercury column

$\rho_m = 13600 \ kgm^{-1}$ $g = 9.8 \ m/s^2$ $h = 0.76m$

By putting the values in eq (1)

$$V = \sqrt{\frac{13600 \times 9.8 \times 0.76}{1.28}}$$

$$\boxed{V = 281 \ m/s}$$

PERCENTAGE ERROR

$$\text{Percentage Error} = \frac{\text{Actual speed} - \text{observed speed}}{\text{Actual speed}} \times 100$$

$$= \frac{332 - 281}{332} \times 100$$

$$= 15.6 \approx 16\%$$

→ The theoretical value is 16% less than the experimental value.

LAPLACE'S CORRECTION

CORRECTION

1. Laplace said that sound waves are longitudinal waves which consists of compression and rarefactions.
2. The compressions & rarefactions are generated so rapidly that heat cannot flow from compression to rarefaction
3. At compression, the temp of air rises due to increase in pressure and at rarfaction temp falls.
4. Temperature of a gas does not remain constant **Temperature ≠ constant**
5. Boyle's law is not applicable.

ADIABATIC PROCESS

1. Air is poor conductor of heat & sound waves travel through it with great speed
2. During compression air can't lose heat & at rarefaction it can't gain heat.
3. So the propagation of sound wave is an adiabatic process in which temp varies but heat can't flow.

LAPLACE'S MATHEMATICAL EXPLANATION FOR SPEED OF SOUND

PV^{γ} = constant

P = Pressure

V = volume of the gas

γ = constant depending on nature of a gas

GAMMA

- Gamma 'γ' is a constant

$$\gamma = \frac{\text{molar specific heat at constant Pressure}}{\text{molar specific heat at constant volume}}$$

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

- As it is Ratio so it has no unit
- For diatomic gas, $\gamma = 1.4$

  For monoatomic gas, $\gamma = 1.67$

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

$$PV^{\gamma} = (P+\Delta P)\left(V - \frac{\Delta V}{V}\cdot V\right)^{\gamma}$$

$$\cancel{PV^{\gamma}} = (P+\Delta P)\cancel{V^{\gamma}}\left(1-\frac{\Delta V}{V}\right)^{\gamma}$$

$$P = (P+\Delta P)\left(1-\frac{\Delta V}{V}\right)^{\gamma} \quad \text{———} (1)$$

Applying Binomial Theorem

$$(1-x)^n = 1 - nx$$

Eq. (Y) becomes:

$$P = (P + \Delta P)\left(1 - \gamma \frac{\Delta V}{V}\right)$$

$$P = P - \gamma P \frac{\Delta V}{V} + \Delta P - \gamma \frac{\Delta P \Delta V}{V}$$

Neglecting $\frac{\gamma \Delta P \Delta V}{V}$

$$\gamma \frac{P \Delta V}{V} = \Delta P$$

$$\gamma P = \frac{\Delta P}{[\Delta V/V]}$$

$$\gamma P = \frac{\text{stress}}{\text{strain}}$$

$$\gamma P = \text{modulus of elasticity}$$

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

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

$$V = \sqrt{1.4}\ (280)$$

$$\boxed{V = 333\ m/s}$$

CONCLUSION

The theoretical value is close to experimental value (332 m/S). Therefore Laplace has corrected Newton.

EFFECTS OF VARIOUS FACTORS ON SPEED OF SOUND IN AIR

DENSITY

$$v = \sqrt{\frac{\gamma P}{\rho}} \Rightarrow v = \text{constant} \frac{1}{\sqrt{\rho}} \Rightarrow v \propto \frac{1}{\sqrt{\rho}}$$

MOISTURE

The presence of moisture in the air reduces the resultant density

$$\text{moisture} \propto \frac{1}{\rho}$$

$$\text{moisture} \propto \text{speed of sound}$$

$$(\text{velocity of sound})_{\text{damp air}} > (\text{velocity of sound})_{\text{dry air}}$$

PRESSURE

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

$$v = \sqrt{\frac{\gamma P}{(m/V)}}, \quad (\because \rho = m/V)$$

$$v = \sqrt{\frac{\gamma PV}{m}}$$

$$v = \sqrt{\frac{\gamma RT}{m}} \quad (\because PV = RT)$$

Hence, speed of sound is not affected by variation in the pressure of gas.

WIND

- The speed of a sound in the direction of wind relative to the ground is

$$V + V_w$$

(V) wind || (V) sound = speed of sound increases

- The speed of sound when direction of wind opposite

$$V - V_w$$

(V) wind ↑↓ (V) sound = speed of sound decreases

V = speed of sound
V_w = speed of wind.

TEMPERATURE

FOR SOLIDS & LIQUIDS

change in speed of sound with temperature is very small and can be neglected

FOR GASES

change in speed of sound with temperature is very large. The increase in speed of sound with temp in gas is about **0.6 m/s** for each 1°C

تاریخ ______

How does speed of sound increases with 1°C rise in temperature?

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

$$V = \sqrt{\frac{\gamma P}{m/V}}$$

$$V = \sqrt{\frac{\gamma PV}{m}}$$

$$V = \sqrt{\frac{\gamma RT}{m}}$$

$$V = \text{constant}\sqrt{T}$$

$$V \propto \sqrt{T}$$

$$T = t°C = (t+273)K$$

$$T_0 = 0°C = 273K$$

$$V = \text{constant}\sqrt{T}$$

$$V_0 = \text{constant}\sqrt{T_0}$$

$$\frac{V}{V_0} = \frac{\text{constant}\sqrt{T}}{\text{constant}\sqrt{T_0}}$$

$$\frac{V}{V_0} = \frac{\sqrt{T}}{\sqrt{T_0}}$$

$$\frac{V}{V_0} = \sqrt{\frac{T}{T_0}}$$

$$\frac{V}{V_0} = \sqrt{\frac{t+273}{273}}$$

$$\frac{V}{V_0} = \sqrt{\frac{t}{273} + \frac{273}{273}}$$

$$\frac{V}{V_0} = \sqrt{\frac{t}{273} + 1}$$

$$\frac{V}{V_0} = \left(1 + \frac{t}{273}\right)^{1/2}$$

Applying Binomial Theorem

$$(1+x)^n = 1 + nx$$

$$\frac{V}{V_0} = \left[1 + \frac{1}{2} \times \frac{t}{273}\right]$$

$$\frac{V}{V_0} = \left[1 + \frac{T}{546}\right]$$

$$v = v_0 \left[1 + \frac{t}{546} \right]$$

$$v = v_0 + \frac{v_0}{546} t$$

$$v = v_0 + \frac{332}{546} t \qquad (\because \text{At } 0°C = v_0 = 332)$$

$$\boxed{v = v_0 + 0.61\, t°C}$$

For 1°C	**For 2°C**	**For 3°C**
$v = 332 + 0.61(1)$	$v = 332 + 0.61(2)$	$v = 332 + 0.61(3)$
$v = 332 + 0.61$	$v = 332 + 1.22$	$v = 332 + 1.83$
$v = 332.61\ m/s$	$v = 333.22$	$v = 333.83$

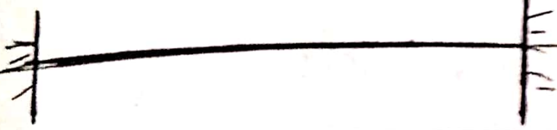
Superposition Of Waves

"When 2 waves are passing through the same region at the same time, the total displaceme at the point where they interact is equal to the vector sum of the individual displacement due to each pulse at that point"

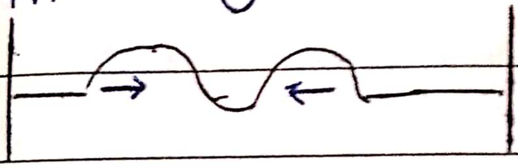
If a particle of medium is simultaneously acted upon by no. of wav them resultand displacement of the particle is the algebric sum of thei individual displacement. This is called superposition principle.

Case - 1

1. consider a string is connected to support on both sides

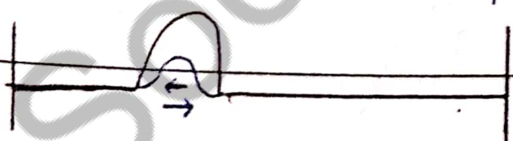


2. Two equal in phase transverse pulses on the string are approaching



3. When they cross, the pulses superpose

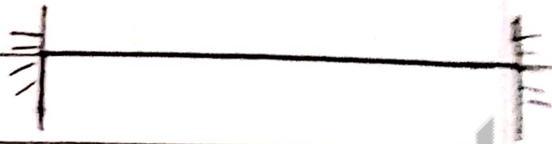
4. The resultant displacement is equal to sum of 'd' which each pulse has caused at that point



5. After crossing, each pulse travels along the spring as nothing has happened & it has its original shape & speed

Case - 2

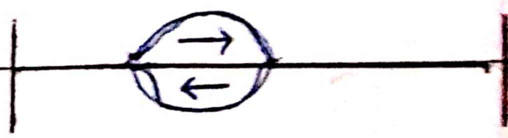
1. Consider a string is connected to support on both sides



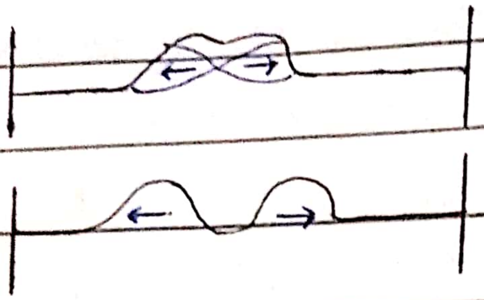
2. Two equal out of phase & opposite pulses are approaching

3. When the pulses superpose

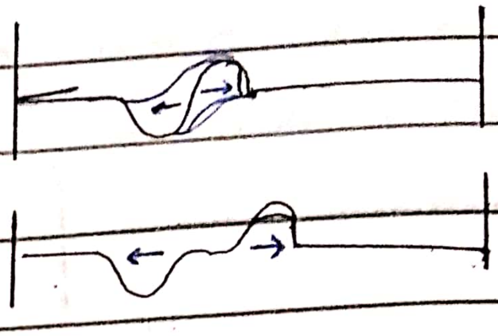
4. They cancel the effect of each other and net displacement of the string is zero



5. After cancelling the effect of each other, the pulses will move their separate ways.



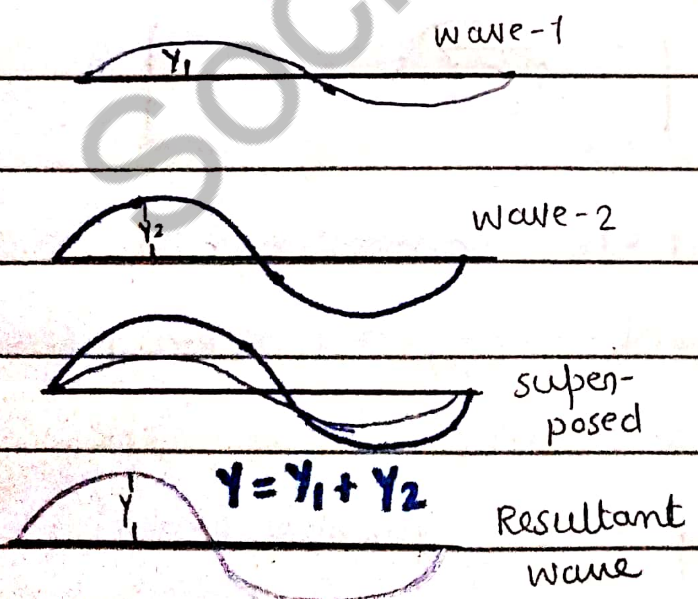
→ constructive interference occurs when 2 equal in-phase waves meet



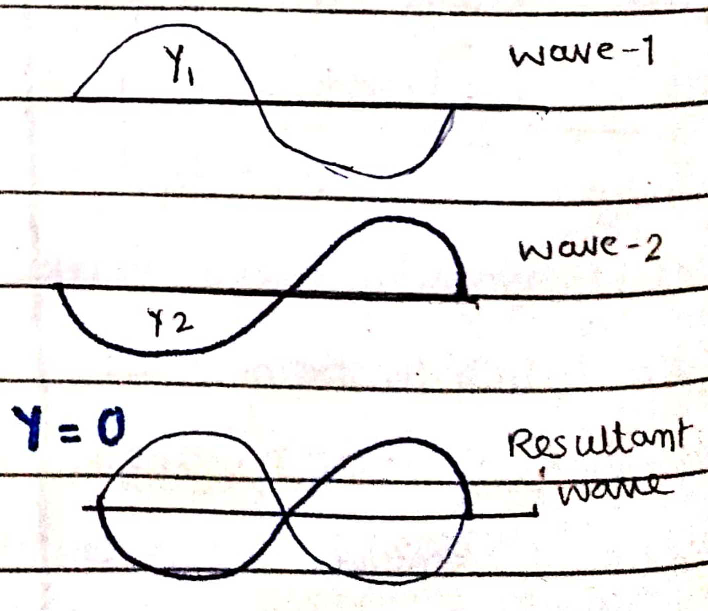
→ Destructive interference occurs when 2 equal out of phase waves meet

Thus, if particle is acted upon by n no. of waves such that the displacement is $Y_1, Y_2, \dots Y_n$. Then resultant displacement Y of the particle is $Y = Y_1 + Y_2 + Y_3 + \dots Y_n$

IN PHASE



OUT OF PHASE



PHENOMENON OF SUPERPOSITION

INTERFERENCE

2 waves having same frequency traveling in same direction $f_1 = f_2$

BEATS

slightly different frequency, same direction

$$f_1 \neq f_2$$

STATIONARY WAVE

same frequency, opposite direction

$$f_1 = f_2$$

INTERFERENCE OF WAVES

"The effect produced by the superposition from 2 coherent sources, passing through the same region is known as interference"

COHERENT SOURCES

2 sources are said be coherent if the phase difference b/w the sources is constant, which means they must have same frequency & amplitude.

PATTERN OF INTERFERENCE

In a region where wave trains from coherent sources meet, superposition occurs, giving reinforcement of the waves at some points and cancellation at the other.

TYPES OF INTERFERENCE

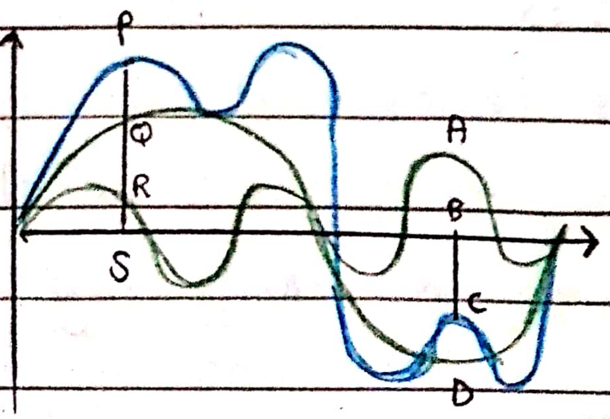
(1) constructive interference
(2) destructive interference

CONSTRUCTIVE INTERFERENCE

When 2 waves arrive at the same place at the same time in phase they reinforce each other & constructive interference occurs.

IN TRNSVERSE WAVES

When crest of one wave meets with crest of the other wave while trough of one wave meet with trough of the other



The amplitude of Resultant wave is:

(1) PS = RS + QS

(2) BC = BD − AB

IN LONGITUDINAL WAVES

when compression of one wave meets with compression of the other wave and rarefaction of one wave with rarefaction of the other

CONDITION

when path difference is equal to integral multiple of wavelength.

$d = m\lambda \qquad m = 0, \pm1, \pm2, \pm3, \ldots$

$d = 0, \lambda, 2\lambda, 3\lambda, \ldots$

DESTRUCTIVE INTERFERENCE

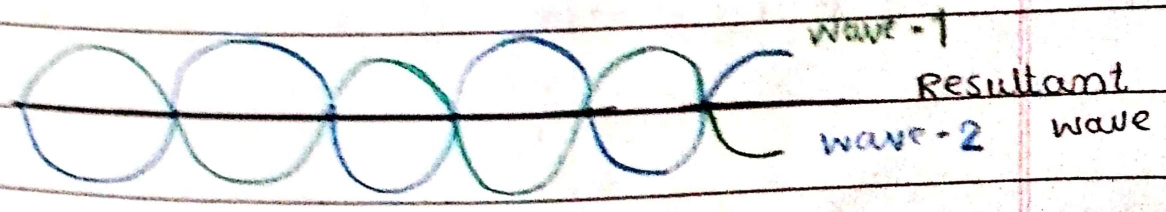
When 2 wave arrive at same place at the same time but are out of phase (180°) then destructive interference occurs.

The amplitude of resultant wave is:

$$Y = Y_1 - Y_2$$

IN TRANSVERSE WAVES

when crest of one wave meet with trough of the other wave.



IN LONGITUDINAL WAVES

when compression of one wave meets with rarefaction of other wave.

CONDITION

Path difference is equal to odd integral multiple of half of wavelength.

$$d = 2n + \frac{1}{2}$$

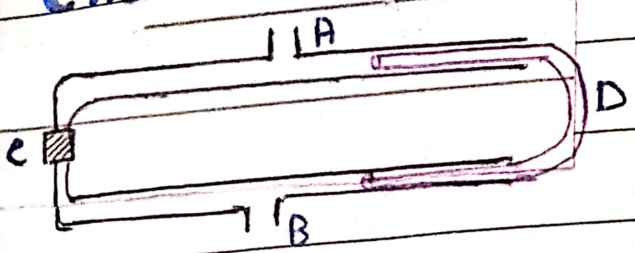
CONDITIONS FOR INTERFERENCE

1. The 2 waves must be phase coherent
2. They must arrive at the same time
3. The 2 waves must be traveling in the same direction
4. The principle of linear super position must be satisfied.
5. For constructive interference, waves must be in phase. The path difference b/w the waves must be either zero or integral multiple of λ
6. For destructive interference, the 2 waves must be out of phase (180°)

Interference Of Sound Wave

"The effect produced by superposition of sound waves from 2 coherent sources, passing through same region is known as interference of sound waves"

Case - 1



1) Path ACB = Path ADB

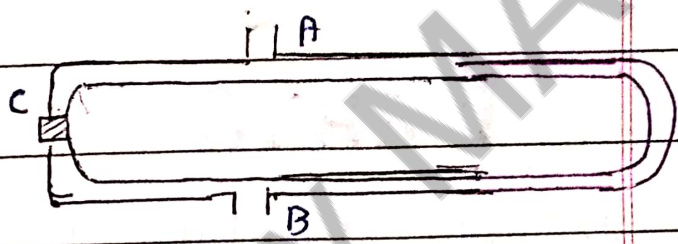
2) 2 waves arrives at B

3) $\Delta d = ADB - ACB$
$= 0\lambda$

4) The 2 waves are in phase and constructive interference will occur

5) A loud sound is heard

Case - 2



1) Path ADB > Path ACB

2) Sound waves arriving at B via C is different coming via C

3) $\Delta d = ADB - ACB = [m+\frac{1}{2}]\lambda$
let $= \frac{\lambda}{2}$

4) The 2 waves are out of phase and destructive interference takes place.

5) No sound is heard at B

CASE -3

1. The rubber portion of tube is pinched at C
2. The path ACB is closed
3. No sound wave is passed through C
4. The sound wave only will come via D
5. So the ear will hear again the sound.

BEATS

"The periodic vibration in the loudness of sound which is heard when 2 notes of nearly the same frequency are played simultaneously is called beats."

1) The waves must be of same amplitude
2) slightly different frequency
3) traveling in same direction

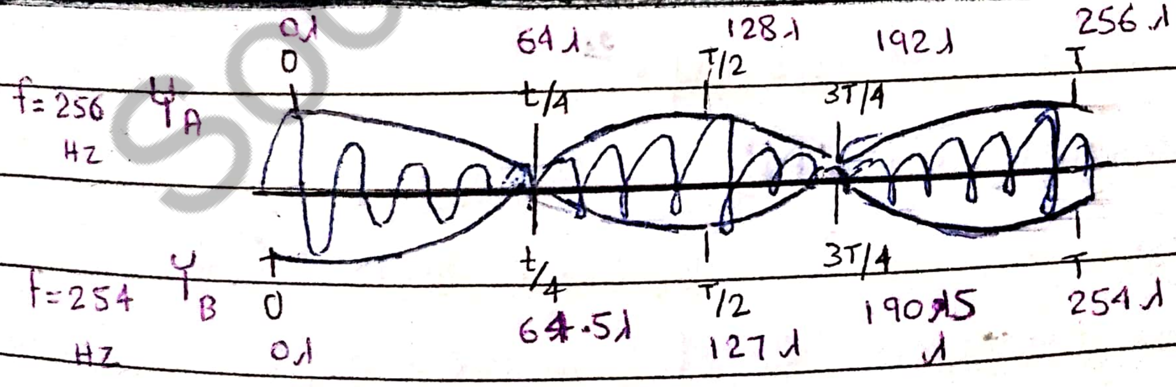
EXPLANATION

1. Take 2 tuning forks of frequency 256 Hz
2. Slightly load the freq prong of fork B with wax so its frequency become 254 Hz

$f_A = 256\,Hz$ $f_B = 254\,Hz$

3. Now they are placed at equal distance from ear and sounded simultaneously

TIME INTERVEL	COMPRESSION & RAREFACTION	INTERFERENCE	PHASE	RESULT
0	Both are sending compression	constructive	In-phase	loud sound is heard
$\frac{T}{4}$	A = compression B = Rarefaction	Destructive	out-of phase	Faint sound A = 64 vibrations B = 63.5 vibrations
$\frac{T}{2}$	Both are sending compression	constructive	In phase	loud sound A = 128 vibr B = 127 vibr
$\frac{3T}{4}$	A = compression B = Rarefaction	Destructive	out-of phase	Faint sound A = 192 vib B = 190.5 vib
T	Both are sending compression	Constructive	In-phase	loud sound A = 256 vib B = 254 vib



Thus, in one second, 2 beats are produced. The difference in frequencies of the forks is also two.

$$\Delta f = \frac{\text{No. of beats}}{\text{time}}$$

$f_A = 256 Hz$ $\quad$ $f_B = 254 Hz$

$$\Delta f = \frac{f_A - f_B}{1} = \frac{256 - 254}{1} = 2 \text{ beats}$$

No. of beats $= f_1 - f_2$

$$\boxed{N = f_1 - f_2 = \Delta f}$$

- Amplitude varies with time that give rise to vibration of loudness known as **beats**

BEAT FREQUENCY

"The difference b/w the frequencies of 2 waves is called beat frequency."

- It is denoted by 'N'

T = time interval b/w 2 successive loud sound

f_1T = No. of oscillation of 1st wave

f_2T = No. of oscillation of 2nd wave

1 = Difference in oscillation of 2 waves

$$f_1 T - f_2 T = 1$$
$$T(f_1 - f_2) = 1$$
$$f_1 - f_2 = \frac{1}{T}$$

As $f_1 - f_2 = 1$

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

$N = f$

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

f = beat frequency , T = time period of beat

USES OF BEATS

1. To find the unknown frequencies
2. To tune musical instrument.

TUNING OF INSTRUMENT

Tuning is the process in which 2 pitches are sounded together and one is adjusted to match the other.

REFERENCE PITCH

Several different devices may be used to produce the reference pith **such as** tunig forks and pianos, etc.

PROCEDURE

1. If 2 pitches are played at different frequencies it will produce beating sound called **interference beats.**

2. As the 2 notes approach a harmonic relationshi the frequency of beating **decrease**

3. To get the note in tune, you adjust the instrument until the beating slows down so much that it cannot be detected.

REFLECTION OF WAVES AND PHASE CHANGE

"The bouncing back of waves from the boundar of certain medium is called reflection of waves."

REFLECTION OF MECHANICAL WAVES

CASE-1 When reflecting surface is denser	**CASE-2 When reflecting surface is rare**
Rare $\longrightarrow$ Denser	Denser $\longrightarrow$ Rare
1. When the end of string is fixed to wall and can't move, it act as denser medium	1. When the fixed end of the string is attached to a ring which can move freely up & down, it act as Rare end

Production of transverse wave

The ~~right~~ left hand end of string is fixed at the wall and a transverse upward pulse is set in it by hand traveling towards the wall.

Reflection

When the crest strike the wall, a part of its energy is absorbed and rest is reflected

Downward Pull

Since the wall does not move up with the crest in same way as it pulls the string upward so the wall exert downward pull on the string.

Movement of Ring

When the wave pulse arrive the end, the ring moves up & ~~down~~ so the ring down an upward pulse is produced.

Phase change

No phase change because

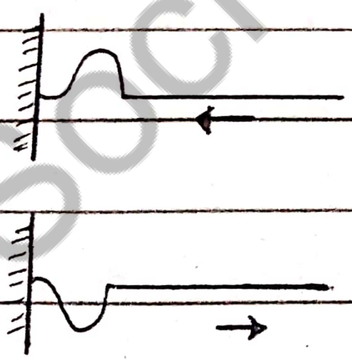
- Ring moves up with incoming crest
- No downward pull is exerted by the ring.

Phase change

A phase change of **180°** or π radians has occurred which is equal to 1/2 b/w incident & reflected pulses

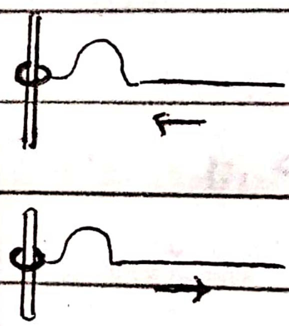
CONCLUSION

1. The reflected wave is 180° out-of phase
2. Transverse wave bounce back such that the direction of its displacement is reversed
3. An incident crest on reflection become a trough



CONCLUSION

1. The reflected wave is in-phase with no phase change
2. Transverse wave when (encounter) reflected from boundary of rare medium the direction of displacement remains same
3. An incident crest is reflected as crest



ECHO

" The reflection of an original sound from a certain object is recieved at 0.1s later than the direct sound is called echo"

speed of sound in air = 340 m/s

$$S = vt$$

$$S = 340 \times 0.1$$

$$S = 34\,m$$

$$S = 2d$$

$$34 = 2d$$

$$d = \frac{34}{2} \Rightarrow d = 17\,m.$$

REVERBERATION When echo follows so close to direct sound then they cannot be distinguishe This effect is called reverberation

EFFECTIVE DISTANCE

Reverberation occurs when reflecting surface is at a distance less than 17m away from the source of sound

EFFECT Reverberation cause general confusion of sound impression on ear.

STATIONARY WAVES

"When 2 plane waves having same amplitude and frequency, traveling with the same speed in opposite direction along a line are superposed, a wave obtained is called stationary or standing wave"

DESTRUCTIVE SUPERPOSITION

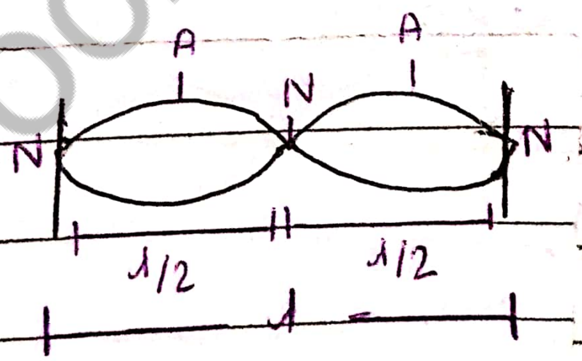
D.S of 2 waves results in cancelation of amplitudes of both waves. This forms a region of zero amplitude called node (N)

CONSTRUCTIVE SUPERPOSITION

C.S of 2 waves results in addition of amplitude of both waves. This forms a region of double amplitude called antinode (A)

RESULTANT STATIONARY WAVE

The waves forms a single wave with alternating N & A called stationary wave.



NODE

1. The points of the cord which do not vibrate at all.
2. They are formed by destructive superposition
3. demoted by **N**

ANTINODE

1. All the midpoints b/w 2 successive nodes where amplitude of oscillation is max
2. They are formed by constructive superposition
3. demoted by **A**

$\lambda/2$

The distance b/w 2 successive nodes or antinodes is equal to half of wavelength $\lambda/2$

$\lambda/4$

The distance b/w adjacent node and antinode is equal to $\lambda/4$

FIRST HARMONIC

1. Frequency at which cord vibrate with one loop
2. denoted by f_1
3. It is called fundamental f

OTHER HARMONICS

1. integral multiple of 1st harmonic
2. They are called overtone

2nd HARMONIC [1st OVERTONE]

1. Frequency at which cord vibrate in 2 loops
2. denoted as f_2
3. $f_2 = 2f_1$

3rd HARMONIC [2nd OVERTONE]

1. f at which cord vibrate in 3 loops
2. demoted as f_3
3. $f_3 = 3f_1$

n^{th} HARMONIC

$f_n = nf_1$

f at which cord vibrate in n^{th} loops

TRANSVERSE STATIONARY WAVES IN A STRETCH STRING

"A standing wave obtained due to superposition of transverse waves is called transverse stationary waves"

EXPLANATION

consider a string of length 'L' which is kept stretched by clamping its 2 ends so that the tension in the string is 'T'

As we know,

$v = \sqrt{\frac{T}{m}}$ = speed of transverse waves in stretched st

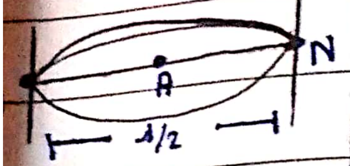
T = tension in the string

$m = \frac{M}{L}$ = mass per unit length.

→ String is plucked at different points, stationary waves are generated in the form of loops which are of different frequency.

If there are n no. of loops then nodes will be n+1 and antinodes will be equal to no. of loops

Plucked at its middle



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

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

$v = f_1 \lambda_1$

$f_1 = \frac{v}{\lambda_1}$ —(i)

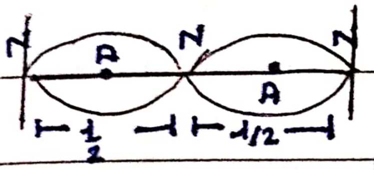
$v = \sqrt{T/m}$

utting values
 eq (i)

$= \frac{1}{\lambda_1} \times v$

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

Plucked at quarter length



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

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

$$\boxed{L = \lambda_2}$$

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

$f_2 = \frac{1}{\lambda_2} \times v$

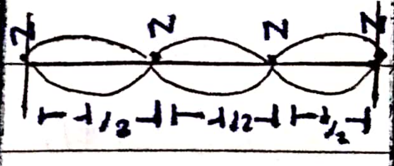
$f_2 = \frac{1}{L}\sqrt{\frac{T}{m}}$

$f_2 = \frac{2}{2L}\sqrt{T/m}$

$f_2 = 2\left[\frac{1}{2L}\sqrt{\frac{T}{m}}\right]$

$f_2 = 2f_1$

plucked at one sixth of its length



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

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

$2L = 3\lambda_3$

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

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

$f_3 = \frac{1}{\lambda_3} \times v$

$f_3 = \frac{1}{(2L/3)}\sqrt{\frac{T}{m}}$

$f_3 = \frac{3}{2L}\sqrt{\frac{T}{m}}$

$f_3 = 3\left[\frac{1}{2L}\sqrt{\frac{T}{m}}\right]$

$f_3 = 3f_1$

plucked at arbitary point

$f_1 = 1f_1$

$f_2 = 2f_1$

$f_3 = 3f_1$

$\vdots$

$$\boxed{f_n = nf_1}$$

$$\boxed{f_n = \frac{n}{2L}\sqrt{\frac{T}{m}}}$$

$\lambda_1 = 2L$

$\lambda_2 = 2L/2$

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

$\vdots$

$$\boxed{\lambda_n = \frac{2L}{n}}$$

CONCLUSION

1. String always resonate in segments or loops
2. String resonate only if it is whole number of half wavelength

$\frac{\lambda}{2}, \frac{2\lambda}{2}, \frac{3\lambda}{2}, \ldots \quad L = n\left[\lambda/2\right]$

3. As the no. of loops increase:
   - frequency increase $f \propto 1/\lambda$
   - wave-length decrease
   - speed of wave remains constant.

QUANTIZATION OF FREQUENCIES

1. The frequency f_1 is known as fundamental frequency
2. The other possible modes of vibration whose frequencies are integral multiple of a lowest frequency are called harmonics or overtone

$2f_1 \; 3f_1 \; 4f_1 \ldots \; nf_1$

3. The stationary wave on the string can be set up only with discrete set of frequencies $f_1, f_2, f_3 \ldots$
4. This phenomenon is known as quantization of frequency.

RESONANCE OF AIR COLUMN AND ORGAN PIPE

AIR COLUMN

Stationary waves can be set up in any medium with discrete set of frequency, same is the case with air column.

EXPERIMENT

1. If you hold a sounding tunig fork over the open end of a glass tube filled with water, the sound of tunig fork can be greatly amplified.
2. Lower the water surface in the tube with the help of reservoir
3. At certain height of the water level, the air column in the Tube will resonate loudly to the sound being sent into it by the Tunig fork.
4. Resonance occurs when

frequency of periodic force = fundamental frequency of air column

$$f_e = f_o$$

ORGAN PIPES

An organ pipe is the simplest example of an instrument which produces sound by means of vibrating air column.

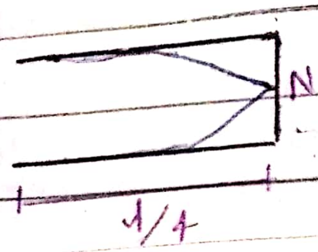
TYPES < closed organ pipe / open organ pipe

CLOSED ORGAN PIPE

A pipe whose end opposite to the whistle end is closed is called a closed organ pipe.

* A node is formed at the closed end
* Antinode is formed at the open end
* As the air molecules can easily move out into the open space there and so at that point there will be **maximum** vibration

FIRST HARMONIC



$$L = \frac{\lambda_1}{4}$$

$$\boxed{\lambda_1 = 4L}$$

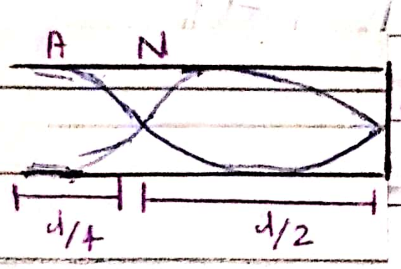
$$v = f_1 \lambda_1$$

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

$$\boxed{f_1 = \frac{v}{4L}}$$

→ Fundamental frequency

THIRD HARMONIC



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

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

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

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

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

$$f_2 = v \frac{1}{\lambda_2}$$

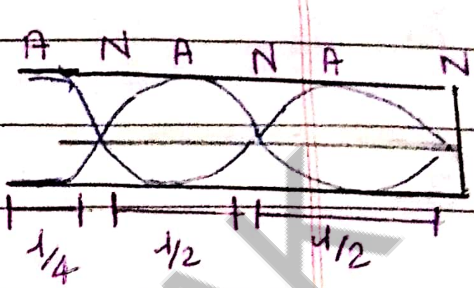
$$f_2 = v \frac{1}{4L/3}$$

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

$$f_2 = 3\,[v/4L]$$

$$\boxed{f_2 = 3f_1}$$

FIFTH HARMONIC



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

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

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

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

$$f_3 = v \frac{1}{\lambda_3}$$

$$f_3 = v \frac{1}{[4L/5]}$$

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

$$f_3 = 5\,[v/4L]$$

$$\boxed{f_3 = 5f_1}$$

GENERAL DESCRIPTION

1. only odd harmonics are generated
2. $f_n = \frac{nv}{4L}$
3. $\lambda_n = \frac{4L}{n}$
4. $f_1, f_2, f_3, \ldots$

   $f_1, 3f_1, 5f_1 \ldots$

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

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

   $n = 1, 2, 3, \ldots$

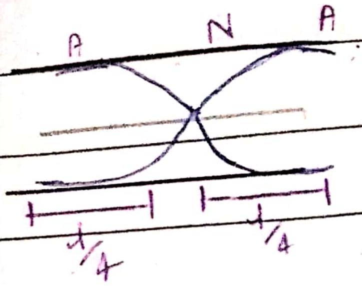
OPEN ORGAN PIPE

"A pipe whose end opposite to the blowing end is open is called open organ pipe"

* There are antinode at both ends
* There are nodes at the middle

1st HARMONIC

Fundamental Frequency



$$L = \frac{\lambda_1}{4} + \frac{\lambda_1}{4}$$

$$L = \frac{2\lambda_1}{4}$$

$$\lambda_1 = \frac{4L}{2}$$

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

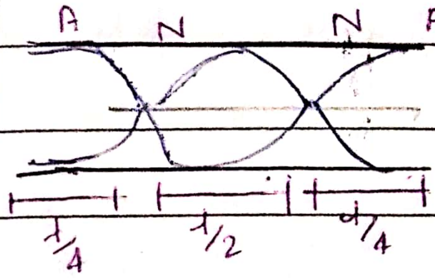
$$f_1 = \frac{v}{\lambda_1}$$

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

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

2nd HARMONIC

First overtone



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

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

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

$$L = \lambda_2$$

$$\boxed{\lambda_2 = L}$$

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

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

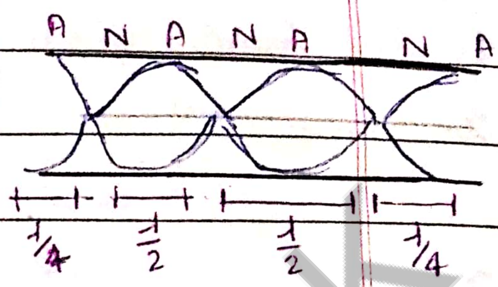
$$f_2 = \frac{2v}{2L}$$

$$f_2 = 2\left[\frac{v}{2L}\right]$$

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

3rd HARMONIC

or 2nd overtone



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

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

$$L = \frac{6\lambda_3}{4}$$

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

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

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

$$f_3 = v \times \frac{1}{\lambda_3}$$

$$f_3 = v \times \frac{1}{[2L/3]}$$

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

$$f_3 = 3\left[\frac{v}{2L}\right]$$

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

GENERAL DESCRIPTION

1. odd and even harmonics are generated
2. $f_n = \frac{nv}{2L}$
3. $\lambda_n = \frac{2L}{n}$
4. $f_1, f_2, f_3, \ldots$
   $f_1, 2f_1, 3f_1, \ldots$
5. $f_n = nf_1$

DOPPLER EFFECT

" The apparent change in frequency of sound cause by the relative motion of either the source or listener or both is called Doppler Effect "

➡ Also known as **Doppler Shift**

➡ observed in both longitudinal waves (sound) and transverse waves (light).

DIFFERENT POSSIBILITIES OF RELATIVE MOTION

SOURCE IS MOVING & LISTNER IS AT REST

- source moving toward listner
- source moving away from listner

SOURCE IS AT REST & LISTNER IS MOVING

- listner moving toward source
- listner moving away from source.

BOTH SOURCE & LISTNER ARE MOVING

- Toward each other
- away from each other

When listner moves	When source moves
• λ remains constant • f' is calculated from relative speed	• λ changes [toward ⇒ λ decrease; away ⇒ λ increase] • f' is calculated from relative λ

SOURCE IS MOVING & LISTNER AT REST

Toward listner

Let a = speed of source

$V = f'\lambda'$

$\lambda' = \frac{V}{f'} \Rightarrow \lambda' = \frac{V-a}{f}$

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

$f' = \frac{V}{\left[\frac{V-a}{f}\right]}$

$f' = \left(\frac{V}{V-a}\right) f$

$\frac{V}{V-a} > 1, \quad f' > f$

RESULT

1. Apparent frequency will be greater than real frequency
2. Pitch of sound increases

Away from listner

$V = f'\lambda'$

$\lambda' = \frac{V}{f} \Rightarrow \lambda' = \frac{V+a}{f}$

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

$f' = \frac{V}{\left[\frac{V+a}{f}\right]}$

$f' = \left[\frac{V}{V+a}\right] f$

$\frac{V}{V+a} < 1, \quad f' < f$

RESULT

Apparant frequency will be less than real f

pitch of sound decreases

LISTNER IS MOVING & SOURCE IS AT REST

toward Source

let b = speed of listner

$v'' = f''\lambda$

$v'' = v + b$

$$f'' = \frac{v+b}{\lambda}$$

$$\lambda = \frac{v}{f}$$

$$f'' = \frac{v+b}{\left[\frac{v}{f}\right]}$$

$$f'' = \left[\frac{v+b}{v}\right] f$$

$\frac{v+b}{v} > 1$, $f'' > f$

RESULT

Apparent frequency > Real f

pitch of sound increase

Away from source

$v'' = f''\lambda$

$v'' = v - b$

$$f'' = \frac{v-b}{\lambda}$$

$$\lambda = \frac{v}{f}$$

$$f'' = \frac{v-b}{[v/f]}$$

$$f'' = \left[\frac{v-b}{v}\right] f$$

$\frac{v-b}{v} < 1$, $f'' < f$

RESULT

Apparent frequency is less than Real frequency

pitch of sound decreases

BOTH LISTNER & SOURCE ARE MOVING

a = speed of source

b = speed of listner

Toward each other

Relative speed of sound & listner

$= V + b$

Relative speed of sound & source

$= V - a$

$\lambda' = \frac{V-a}{f}$, $V' = V+b$

Apparent frequency can be calculated as:

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

$f''' = \frac{V+b}{(V-a/f)}$

$f''' = \left[\frac{V+b}{V-a}\right] f$

$\frac{V+b}{V-a} > 1$

$f''' > f$

Away from each other

Relative speed of sound & listner $= V - b$

Relative speed of sound & source $= V + a$

$\lambda' = \frac{V+a}{f}$, $V' = V - b$

Apparent frequency can be calculated as:

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

$f''' = \frac{V-b}{\left[\frac{V+a}{f}\right]}$

$f''' = \left[\frac{V-b}{V+a}\right] f$

$\frac{V-b}{V+a} < 1$

$f''' < f$

APPLICATIONS OF DOPPLER EFFECT

SPEED OF STARS

BLUE SHIFT	RED SHIFT
• star moving toward the earth	• star moving away from the earth
• Short wave length	• large wave length
• high frequency	• low frequency
• more energy	• less energy
$f_{Blue} = \left[\frac{V}{V - V_B}\right] f$	$f_{Red} = \left[\frac{V}{V + V_R}\right] f$