UNIT: 8
'waves'

@sochbadlobyMAK batch I (2022-23)
student: Aimen Jamil

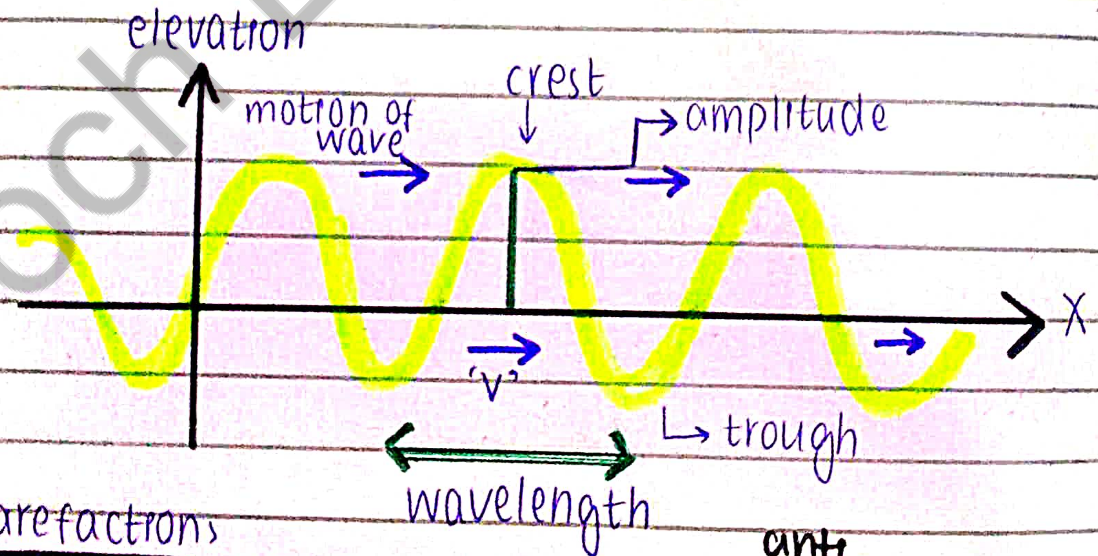
→ wave:

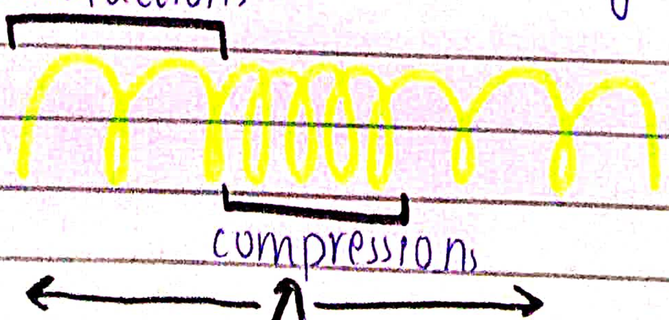
→ a wave is a disturbance in the medium that causes the particles of that medium to undergo vibratory motion about their mean position in equal intervals of time

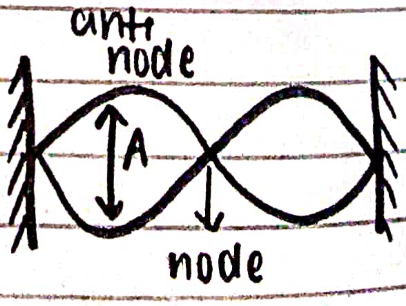
• in short:

a disturbance that travels/propagates from the place it was created.

→ a sensation produced by a vibrating body is wave.
~ sir MAK

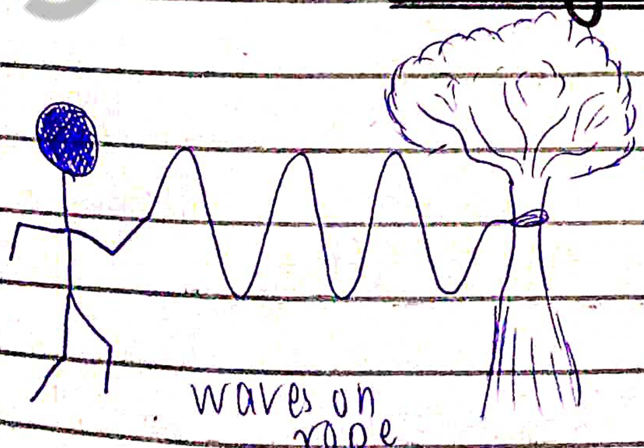




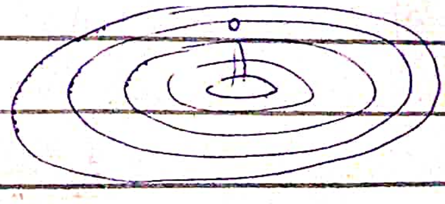


Periodic waves	Progressive Waves
definition	
A wave of continous repeating pattern	A wave that travels continously in medium in same direction, with no amplitude change.
Practical examples	
• electromagnetic vibrator • circular periodic waves on ripple tank • Oscillating mass-spring system • waves on ropes	• Stone dropping into a pond of work • vibrating tuning fork • waves on ropes • vibrating strings of instruments
Key difference	
Periodic waves do NOT transfer energy	Progressive waves DO transfer energy.

diagrams



waves on rope



water waves

→ Classification of Progressive waves

i. Transverse waves
ii. Longitudinal waves

→ Transverse Waves | Longitudinal waves

Transverse Waves	Longitudinal waves
definition	
waves in which partic-les of medium vibrate along a line perpendicular to direction of propagation of waves	waves in which particles of medium vibrate about their mean position parallel to direction of propagation of waves
composition	
Transverse waves consist of crests and troughs	Longitudinal waves consists of compressions and rarefactions
Direction	
Particles of medium vibrate at right angles	Particles of medium vibrate parallel.
Polarization	
Transverse waves can be polarized.	Longitudinal waves can NOT be polarized
Change in density	
NO change in density of medium.	There is a change in the density of medium throughout.

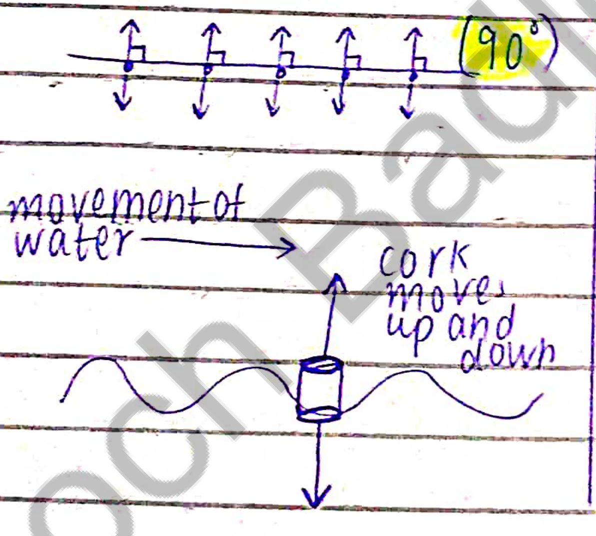
Pressure Variation

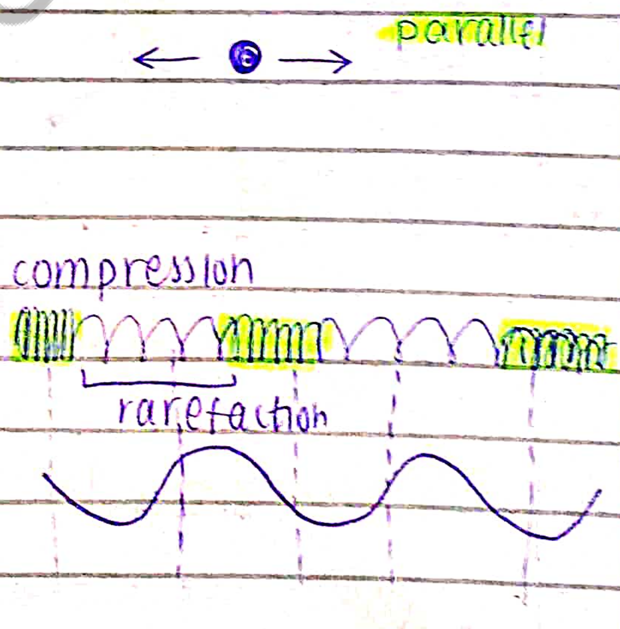
There are no pressure variations	There is a pressure variation

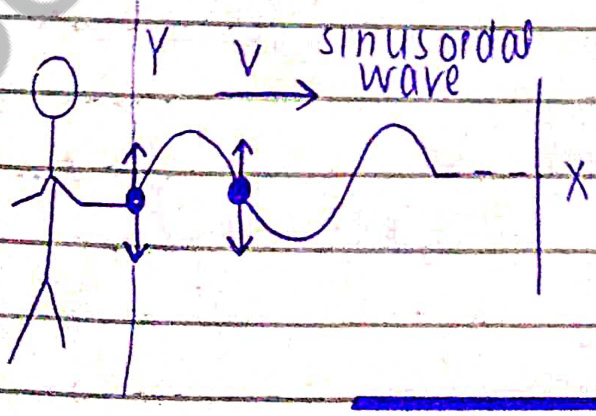
Practical examples

• Electromagnetic waves e.g radio, visible light UV rays	• sound waves
• Waves on strings and ropes.	• Ultrasound waves
	• waves on slinky spring
	• shock waves (earth quake) aka seismic waves

diagram







Speed of sound

→ **definition:**
The distance covered by sound waves per unit time is called speed of sound.

→ **nature:** sound waves are longitudinal.

→ **depends upon:**

i. Elasticity of medium (**E**)
ii. Density of medium (**ρ**)

→ **formula:**

$$V = \sqrt{\frac{E}{\rho}}$$ **(Newton's formula)**

→ **Point:**

speed of sound in:
solids **>** gases

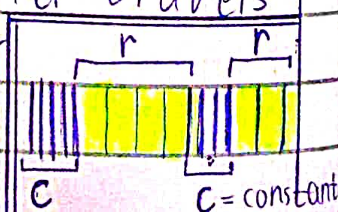
∴ **reason:**

1) Molecules are closely packed, so they respond to disturbance more quickly.
2) Gases are more compressible, having smaller modulus of elasticity.

Newton's assumption

∴ **assumption:**

→ Newton assumed that the sound travels through air / other gases under **isothermal conditions** (No change in temperature)



Calculation for Modulus of elasticity:

So from Boyle's law;

$$PV = \text{constant}$$

Pressure increases from $P \rightarrow P + \Delta P$

Volume decreases from $V \rightarrow V - \Delta V$

$$P_1 V_1 = P_2 V_2$$

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

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

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

$$0 = -P\Delta V + \Delta P V \quad (\Delta P \Delta V \text{ is neglected})$$

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

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

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

$$P = \frac{\Delta P}{\Delta V / V} = \frac{\text{volumetric stress}}{\text{volumetric strain}} = E$$

$$\boxed{P = E}$$

since,

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

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

$$V = \sqrt{\frac{\rho_m g h}{\rho}}$$

$$V = \sqrt{\frac{13.6 \times 980 \times 76}{0.001293}}$$

since $P = \rho_m g h$

values:

$\rho_m = 13.6\ g/cm^3$ (density of mercury)

$g = 980\ cm/s^2$

$h = 76\ cm$

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

→ **Drawback in Newton's formula:**

1. The experimental value of speed of sound is **332 m/s** (16% more than theoretical value)
2. During a **compression**, temperature of air doesn't remain constant but **increases**

Laplace's correction

Introduction:

→ A French mathematician Laplace explained the **discrepancy in theoretical and experimental values** of speed of sound

His conclusions:

→ Laplace's drew the following conclusion:

1. At a **compression**, the temperature of **air rises** due to **increased pressure**.
2. At a **rarefaction**, the **cooling effect** is produced. Hence, the **temperature** of air does **NOT** remain **constant**.
3. **Boyle's law** → NOT applicable, because **temperature** isn't **constant**
4. **Air** is a very **poor conductor** of heat. sound waves travel through with **greater speed**

$$P = P - \gamma P \frac{\Delta V}{V} + \Delta P \left(\gamma \Delta P \frac{\Delta V}{V} \text{ neglected coz it's small} \right)$$

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

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

$$\gamma P = \frac{\Delta P}{\Delta V / V} = \frac{\text{volumetric stress}}{\text{volumetric strain}} = E \left(\text{modulus of Elasticity}\right)$$

$$\boxed{\gamma P = E}$$

since,

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

so it becomes,

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

$$V = \sqrt{\frac{\rho_m g h}{\rho}} \qquad \therefore P = \rho_m g h$$

$$V = \sqrt{\frac{1.42 \times 13.6 \times 980 \times 76}{0.001293}}$$

$$V = 33310 \text{ cm/s}$$

$$\boxed{V = 333.10 \text{ m/s}}$$

→ wave motion:

Mechanism by which energy transfer from one point ⟶ another.

→ conditions:

i. Medium must be elastic

ii. Particles of medium should not be independent of eachother.

SUPERPOSITION: of waves

→ Principle:

"If a particle of a medium is simultaneously acted upon by **n** number of waves such that its displacement due to each of the individual **n** waves is"

$$y = y_1 + y_2 + y_3 + \cdots + y_n$$

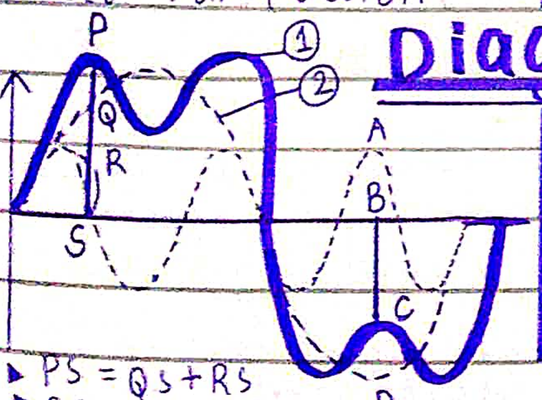
→ cases:

i. Interference	ii Beats	iii Stationary waves
→ two waves of:	two waves of:	two waves of:
• same frequency	different frequency	same frequency
• same direction	same direction	opposite direction

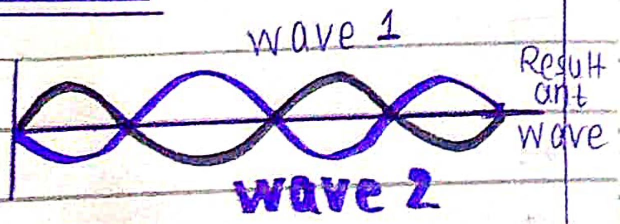
Interference:

effect produced by superposition of waves from two coherent sources, passing through same region.

Constructive interference	Destructive interference
definition	
When two waves arrive at same place, same time, in phase, they reinforce each-other.	When two waves arrive at same place, same time, out-of phase (180°), they cancel each other
resultant	
The resultant displacement = vector sum of individual displacement of each wave	The resultant wave's amplitude = difference b/w amplitudes of individual waves
resultant amplitude	
PS = QS + RS BC = BD − AB	$y = y_1 - y_2$
Transverse	
When crest meets crest & trough meets trough	When crest of one meets trough of other
Longitudinal	
When compression meets compression & rarefaction meets rarefaction	When compression of one meets rarefaction of other
Diagram	



▸ PS = QS + RS
▸ BC = BD − AB



Phase

→ In-phase | Out-of phase (180°)

Path difference

→ zero or integral multiple of λ

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

$d = m\lambda$

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

$m = 0, 1, 2 \ldots$

→ odd integral multiple of $(\lambda/2)$

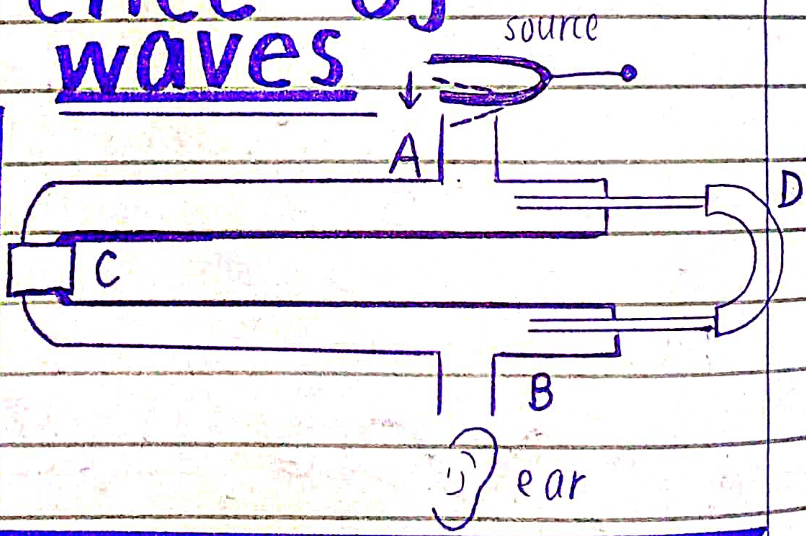
conditions :

→ Two waves:

i. Must be phase coherent.
ii. Arrive at same place & same time
iii. Travel in same direction
iv. Satisfy principle of linear superposition.

Interference of sound waves

Activity:



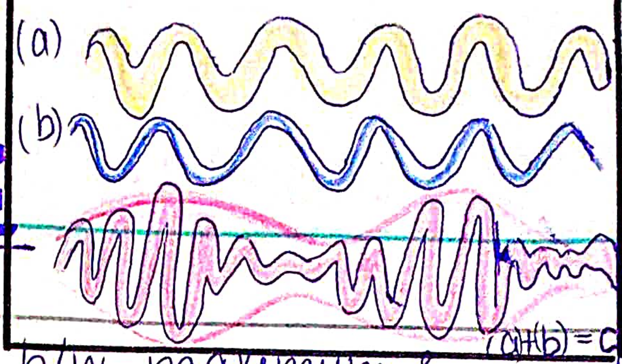
- Half intensity goes
  by ACB → B
  by ADB → B

→ reunite at B, so it can be heard by ear.

- If sliding tube is out, ADB longer than ACB
- If we pinch rubber portion of C, no sound heard at B

→ silence is due to destructive interference of 2 sound waves

BEATS:



→ **definition:**

Periodic variations b/w maximum & minimum loudness of sound waves.

→ **Beat frequency:**

The difference b/w frequencies of two waves is called beat frequency.

→ **Denoted by:** N

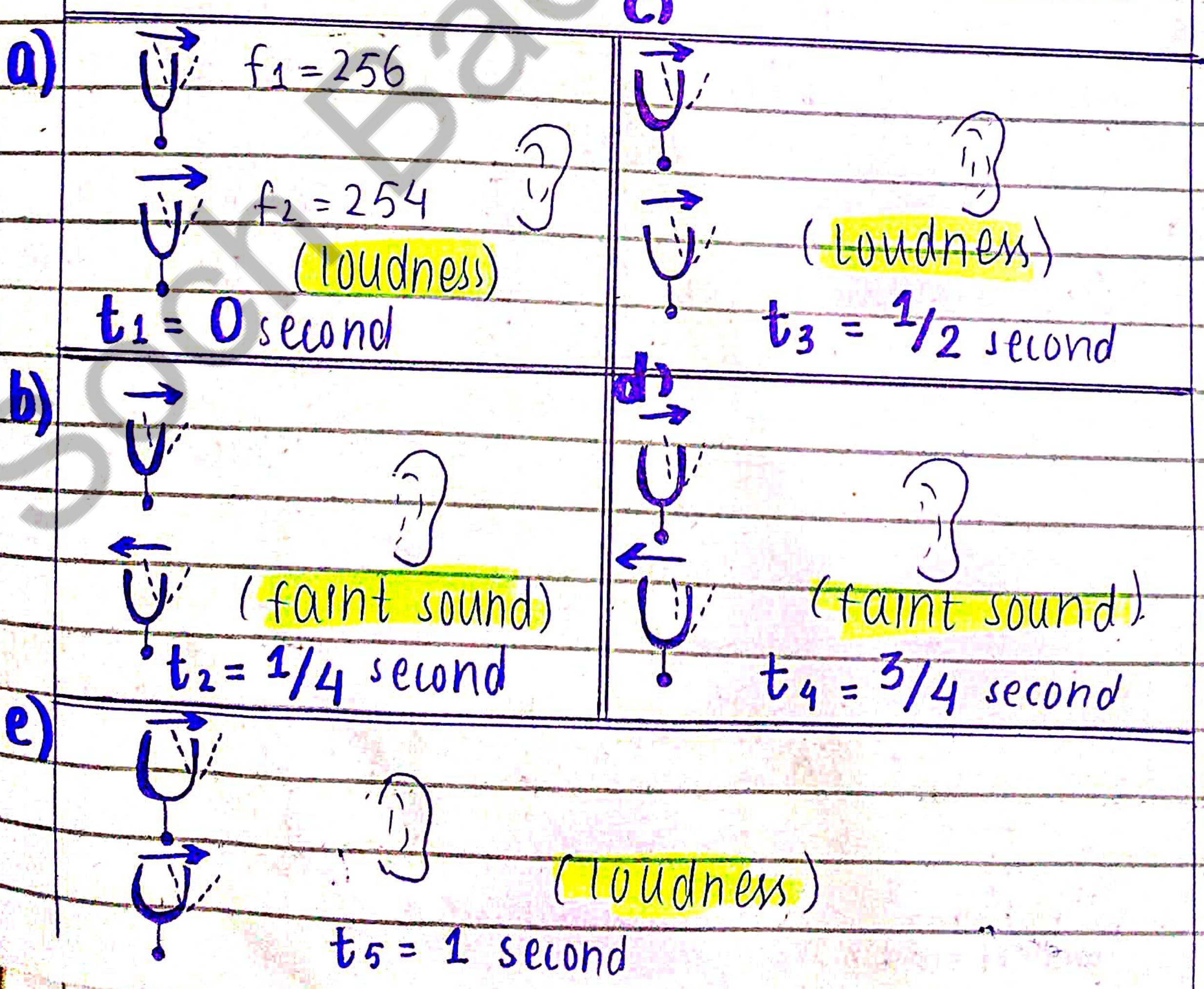
→ **Formula:** $N = f_1 - f_2$

→ **Production of beats**

∴ **experiment**

Take two forks A and B, such that after waxing one fork, its 'f' decreases

fork A → 256 Hz   fork B → 254 Hz

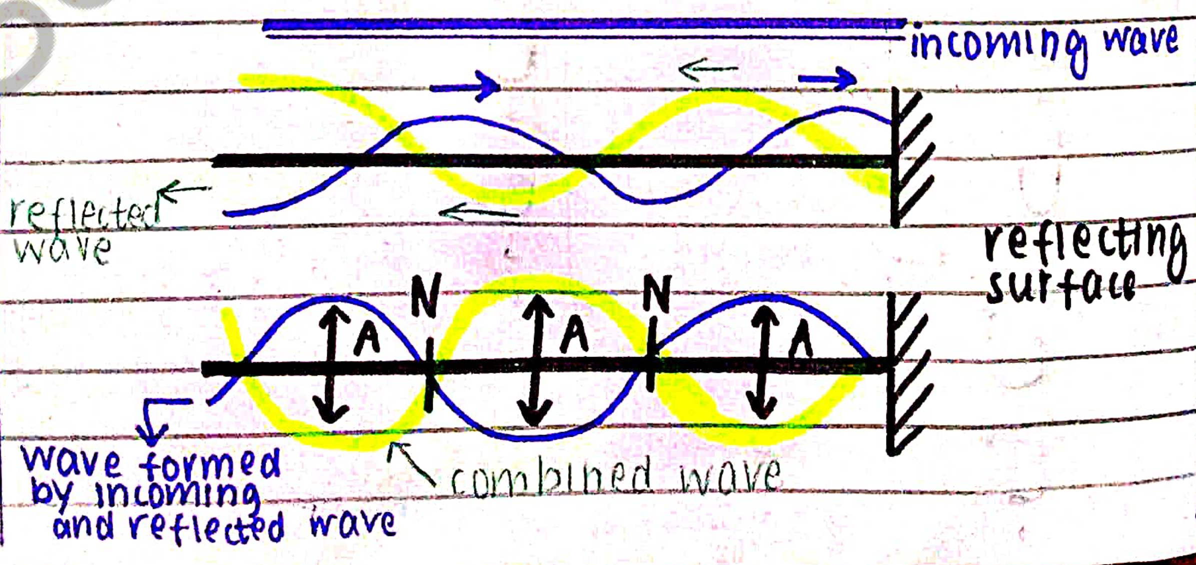


Reflection of sound waves

→ **definition:**

The bouncing back of waves from the boundary of a certain medium is called reflection of waves

ECHO	**REVERBERATION**
Phenomenon	
The reflection of an original sound from a certain object.	The reflection of sound waves along with echo
distance	
effective distance for echo is **17m**	effective distance is **less than 17m**.
time	
It is received at **0.1** seconds later.	It is received at less than **0.1** seconds.



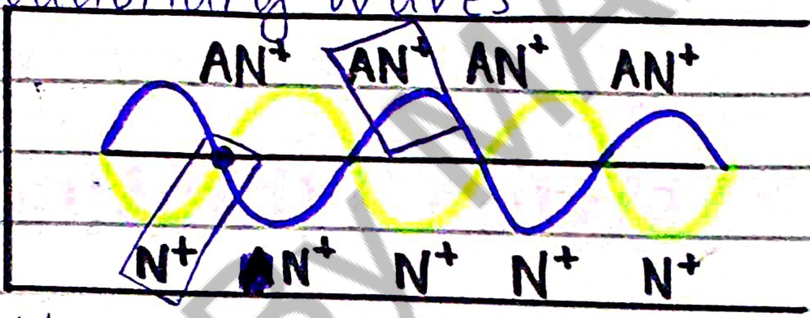
Stationary Waves

definition:

Two identical waves travelling with same speed, along same line but in opposite direction **superpose eachother** giving rise to stationary waves

components:

I. **Nodes**
ii. **Anti-nodes**



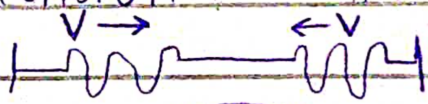
Production:

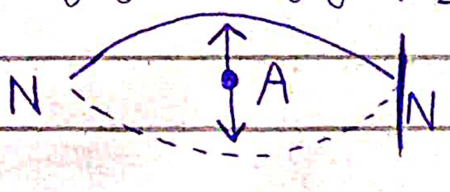
Production by the superposition of two waves moving in opposite direction

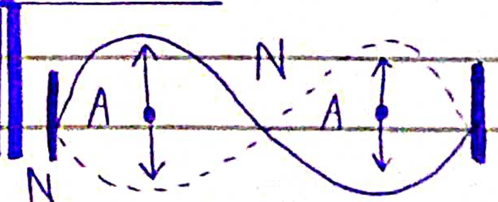
examples:

Sound produced by wind-type instrument and string type instruments

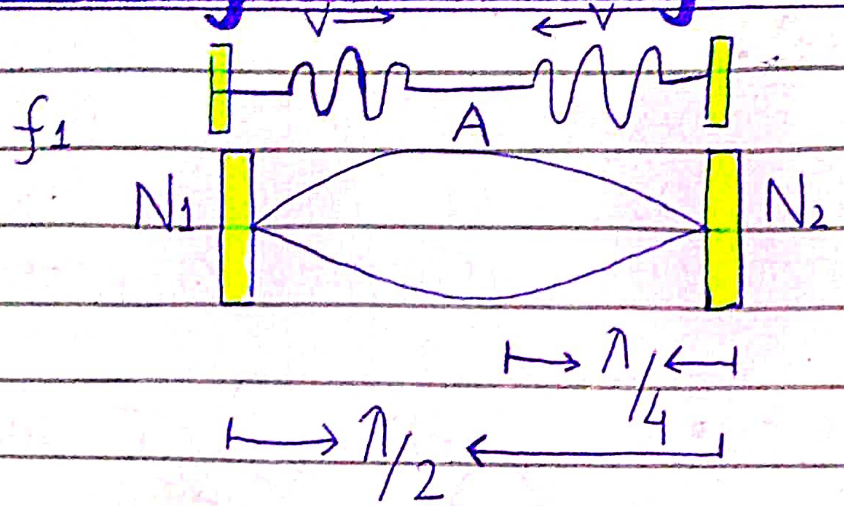
NODES	ANTINODES
→ indicated by N	→ denoted by A
displacement	
Points of zero displacement	Points of maximum displacement
motion	
Nodes are at rest	Antinodes → oscillating motion
Location	
At end of each loop	At mid of each loop.
Tension	
Tension is maximum	Tension is minimum
diagram	



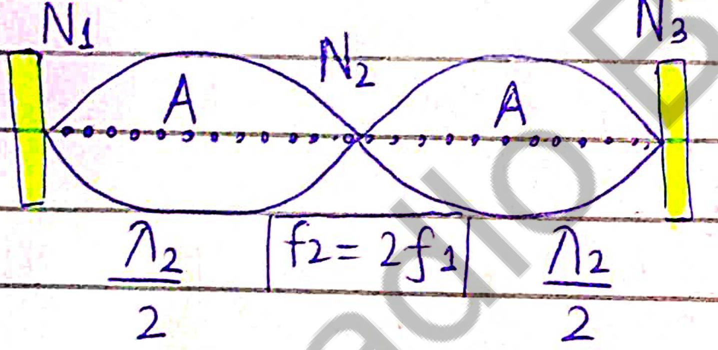




string vibrating in 1 loop:



string vibrating in 2 loops:



Transverse stationary waves in stretched string

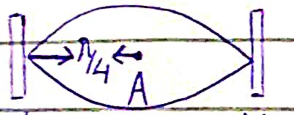
→ A standing wave obtained due to the superposition of transverse waves

→ **consideration:**

Let us consider, string of length **L**, Tension in string **T**, mass of string **M**, speed of wave **V**

→ **Plucked at its**

MIDDLE



one loop

→ distance b/w 2 consecutive node $= \lambda/2$

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

$$\boxed{\lambda_1 = 2L} \rightarrow (1)$$

since,

$$v = f\lambda$$

so,

$$v = f_1 \lambda_1$$

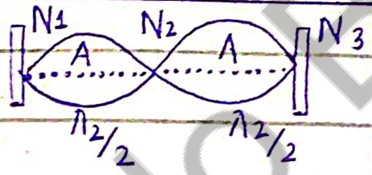
$$f_1 = \frac{v}{\lambda_1}$$

putting (1), we get

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

Putting $v = \sqrt{\frac{T \times L}{M}}$,

QUARTER



two loops

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

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

$$\boxed{\lambda_2 = \frac{2L}{2}} \rightarrow (2)$$

$$v = f_2 \lambda_2$$

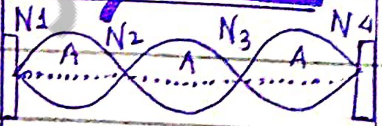
$$f_2 = \frac{v}{\lambda_2}$$

Putting (2) we get

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

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

1/6th



$$L = 3\lambda_3/2$$

three loops

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

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

$$\boxed{\lambda_3 = \frac{2L}{3}} \rightarrow (3)$$

$$v = f_3 \lambda_3$$

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

Putting (3), we get

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

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

$$f_1 = \frac{1}{2L}\sqrt{\frac{T \times L}{M}}$$; putting $\frac{M}{L} = m$, $1/m = L/M$

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

☆ Christian Johann Doppler → 1842 → frequency shift
☆ both light and sound waves

Doppler's Effect

→ **Definition:**

The apparent change in the frequency of sound, caused by relative motion of either the source of sound / listener / both.

→ **relative motion** b/w **source** & **observer**.

→ **Consideration:**

consider source of sound '**S**' emitting waves of velocity '**V**', frequency '**f**' & wavelength '**λ**'

∴ **distance** b/w listener '**L**' and source '**S**' is '**V**'

☆ speed & distance are inter-convertible

$$S = vt$$

$$S = v(1) \quad ∴ t = 1 \text{ second}$$

$$\boxed{S = v}$$

∴ since,

$$v = f\lambda$$

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

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

① source comes near
→ $\lambda \downarrow f \uparrow$, denominator +ve

source moves away
→ $\lambda \uparrow f \downarrow$, denominator −ve

☆ λ depends upon source of sound NOT listener.

→ **Derivation:**

1) **source moving, listener rest**
2) **source rest, listener moving**
3) **When both move.**

parallel direction of both → +ve
anti-parallel direction of both → −ve

1) source moving, listener rest

a) source moves TOWARDS

so, apparent wavelength, λ'

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

speed = a

$\therefore v' = v - a$

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

since,

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

so,

$$f' = \frac{v}{v-a} f$$

source moves AWAY

so apparent wavelength, λ'

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

speed = a

$\therefore v' = v + a$

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

since,

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

$$f' = \frac{v}{v+a} f$$

2) source rest, listener moving

a) listener moves TOWARDS

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

speed = b

$v' = v + b$

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

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

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

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

listener moves AWAY

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

speed = b

$v' = v - b$

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

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

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

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

3) source moves, listener moves

a) both move TOWARDS

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

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

$$f' = \frac{v+b}{v-a/f}$$

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

$\left[\frac{v+b}{v-a}\right] > 1$, $f' > f$

→ pitch increase,

both move AWAY

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

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

$$f' = \frac{v-b}{v+a/f}$$

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

$\left[\frac{v-b}{v+a}\right] < 1$, $f' < f$

→ pitch decreases

Ultrasonic waves

→ pressure wave
→ short wavelength
→ high frequency

→ The sounds of frequencies higher than **20,000** Hz

∴ **ultrasonic** → above or beyond sound

→ **Produced by** → an object vibrating at a frequency higher than **20000 Hz**

→ **range : 20 KHz → 100 KHz**

→ **ultrasonic device:** vibrates at **25 billion Hz**

→ **wavelength:**

ultrasonic → 10^{-8} m

visible light → 10^{-6} m

X-rays → 10^{-10} m

∴ shorter wavelength ↓, penetration power ↑

Uses:

i. Non-destructive testing of metals

ii. In liquids, for cleaning metal parts

iii. Killing micro-organisms in air/liquids.

iv. In processes such as cavitations, helps in degassing.

v. An ultrasonic pulse penetrating a metal when strike a flaw.

→ Generation of ultrasonic waves:

→ **condition:** object must be capable of oscillation at frequency higher than 20 KHz.

1. Applying electric current:

① By applying electric current to a special kind of of crystal aka **Piezoelectric Crystal**
↳ converts electrical energy → mechanical energy

② crystal then vibrates with **higher "f"** thus generating **ultrasonic waves.**

2. Applying magnetic field:

① By applying magnetic field to a **special crystal**, causing it to oscillate at **higher "f" than 20KHz**, thus emitting **ultrasonic waves.**

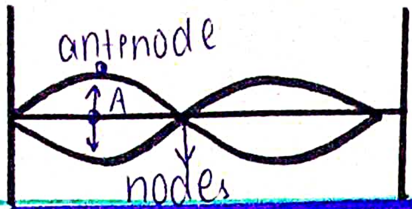
→ Detection: (when λ is not very short)

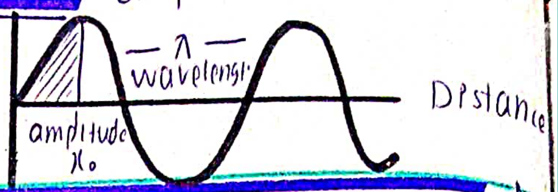
Piezoelectric	**Kundt's tube**
→ when they're allowed to fall on **quartz crystal** a certain **potential difference** is produced.	→ **Lycopodium** powder is sprinkled in the tube.
→ After difference is amplified by amplifier, waves are detected	→ When ultrasonic waves pass, the powder collects at **nodes** and blown off at **anti-nodes**

$$V = V_0 \sin \omega t$$

$$V = V_0 \sin 2\pi \omega t$$

diagram





Stationary Waves	Progressive Waves
definition	
Formed by superposition of 2 progressive waves of equal amplitude & 'f'.	Advancing wave which travels continously
also known as	
Standing waves	Travelling waves
transfer of energy	
No energy transfer	Energy transfer exists
amplitude	
varies from zero → nodes maximum → anti nodes	Is the same for all particles within the wave.
frequency	
same → anti-nodes different → Nodes	All practicles oscillate with same frequency
Phase difference	
Between nodes, all particles same phase	Between two particles same phase doesN'T exist.
vibration	
At nodes, particles never vibrate	All particles vibrate
Production	
superposition of 2 waves in opposite direction	Disturbance in a medium.