Wave

A wave is a vibratory disturbance in a medium which carry energy from one place to another.

Time period (T) → The time required by a particle to make one complete oscilation is called time period.

Frequency (f) → the number of waves produced per unit time is called frequency.

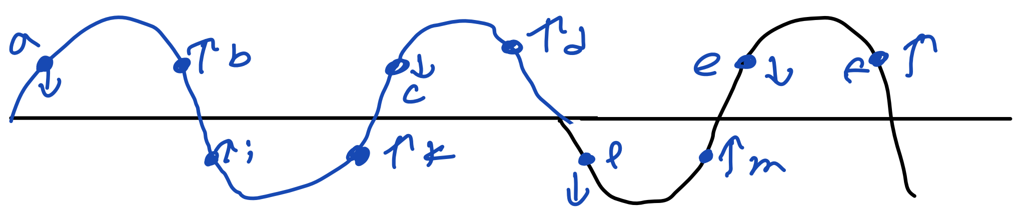
$$f = \frac{1}{T}$$

Amplitude (A) → maximum displacement from the rest / mean position.

Wave length (λ) → The shortest distance between any two points on a wave that are in phase.

Phase → State of motion of a particle in a wave is called phase.
It is denoted by angle.

Two points said to be in phase if they have same displacement and same velocity.



in phase

$a - c = 2\pi$

$a - e = 4\pi$

$a - g = 6\pi$

$2n\pi$

$n = 0, 1, 2, 3$

antiphase

$a - i \rightarrow \pi$

$a - k \rightarrow 3\pi$

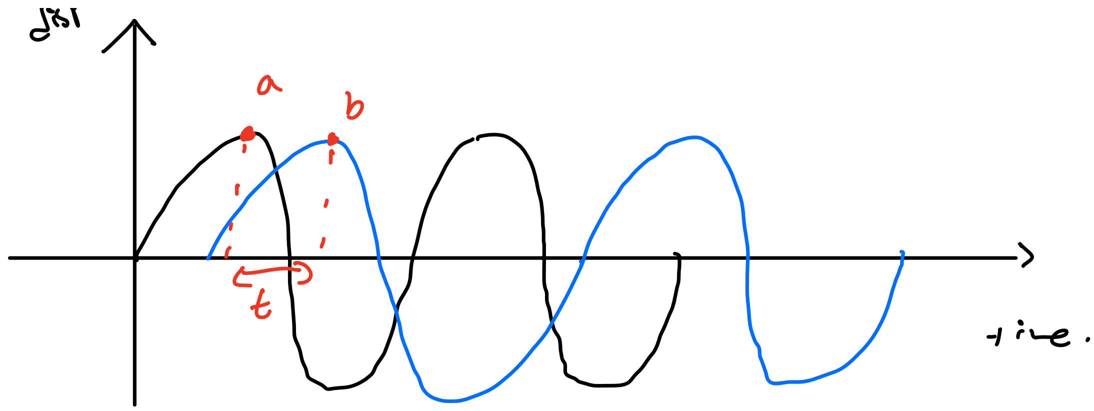
$a - m \rightarrow 5\pi$

$(2n+1)\pi$

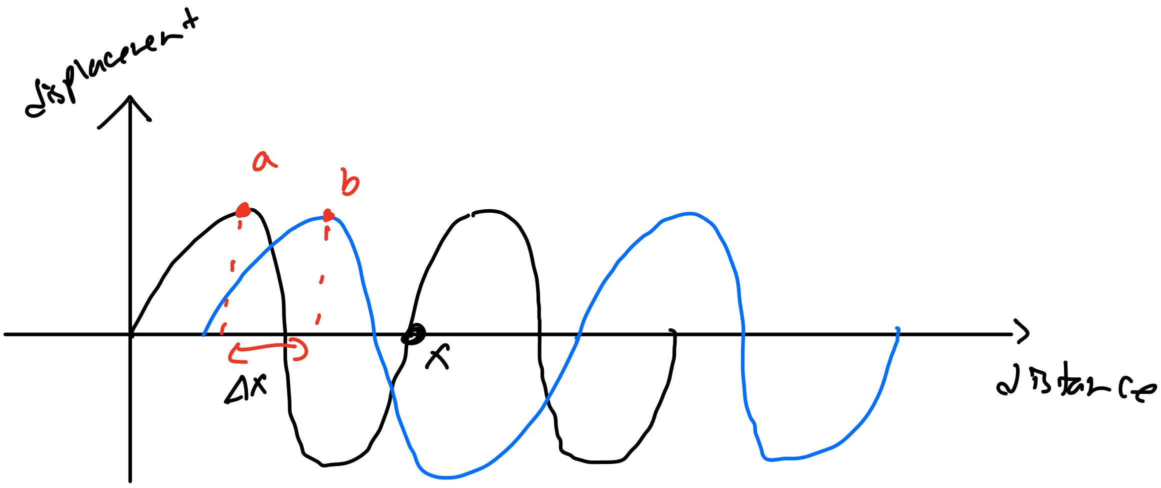
$n = 0, 1, 2, 3)$

Phase difference

placement



$$\text{phase difference} = \frac{\Delta t}{T} \times 2\pi$$



$$\frac{\Delta x}{x} \times 2\pi$$

Intensity of a wave → the amount of energy passing through unit area per unit time is called the intensity of the wave.

$$I = \frac{E}{A \times t} = \frac{P}{A} = \frac{P}{4\pi r^2}$$

$$I \propto \frac{1}{r^2}$$

$$I = k \frac{1}{r^2}$$

$$k = I r^2$$

$$I_1 r_1^2 = I_2 r_2^2$$

* $I \propto A^2$ (amplitude)

$$\frac{I_1}{A_1^2} = \frac{I_2}{A_2^2}$$

* $I \propto f^2$ (frequency)

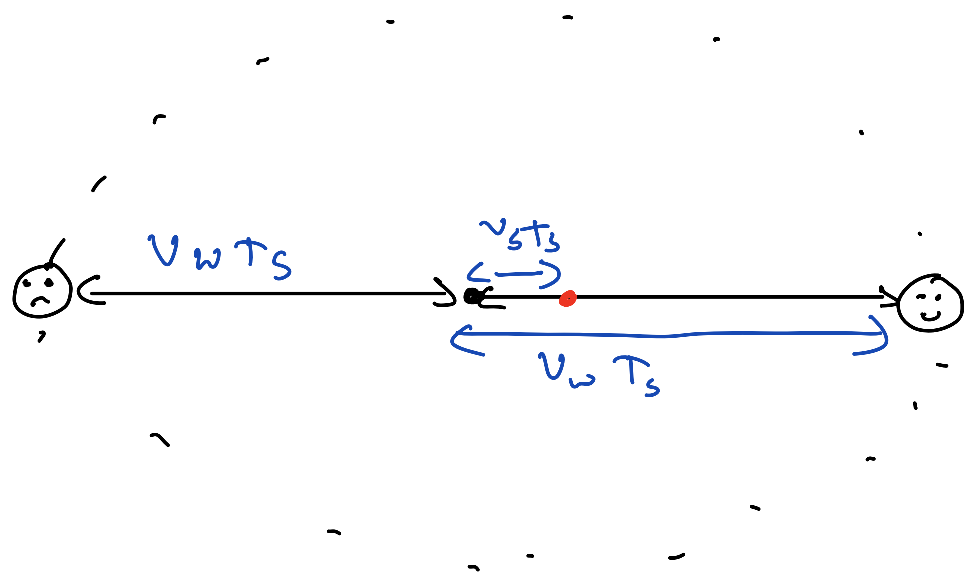
$$\frac{I_1}{f_1^2} = \frac{I_2}{f_2^2}$$

For sound, intensity is a measure of loudness.

For light, intensity is a measure of brightness.

Doppler effect

The change in observed frequency of wave due to relative speed between the source and observer is called Doppler effect.



v_w = speed of sound wave
T_s = source period
v_s = speed of source

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

Coming Close

$$T_o = \frac{v_w T_s - v_s T_s}{v_w}$$

$$T_o = T_s \left(\frac{v_w - v_s}{v_w} \right)$$

$$f_o = f_s \left(\frac{v_w}{v_w - v_s} \right)$$

Moving away

$$T_o = \frac{v_w T_s + v_s T_s}{}$$

v_w

$$f_o = f_s \left(\frac{v_w}{v_w + v_s}\right)$$

Q1. A police car travels towards a stationary observer at a speed of 15 ms⁻¹. The siren of the car emits a sound of frequency 250 Hz. Calculate the observed frequency if the speed of sound is 340 ms⁻¹.

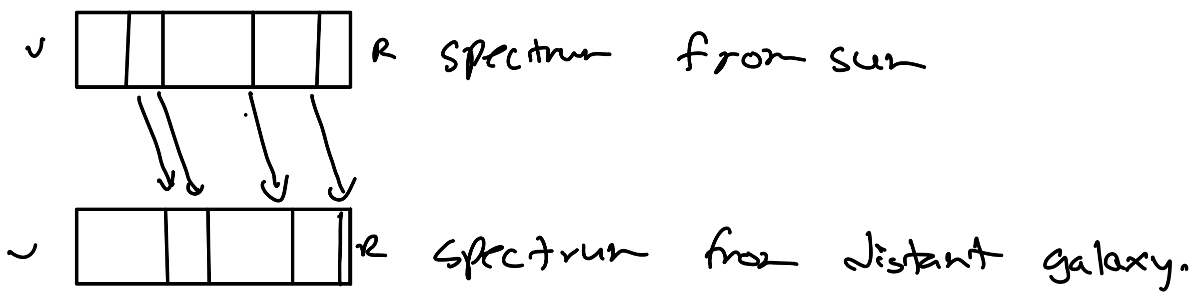
$$250 \times \left(\frac{340}{340 - 15}\right)$$

$\Rightarrow$ 260 Hz

Ans

* Doppler shift not only occurs for sound, it also occurs for light or water wave.

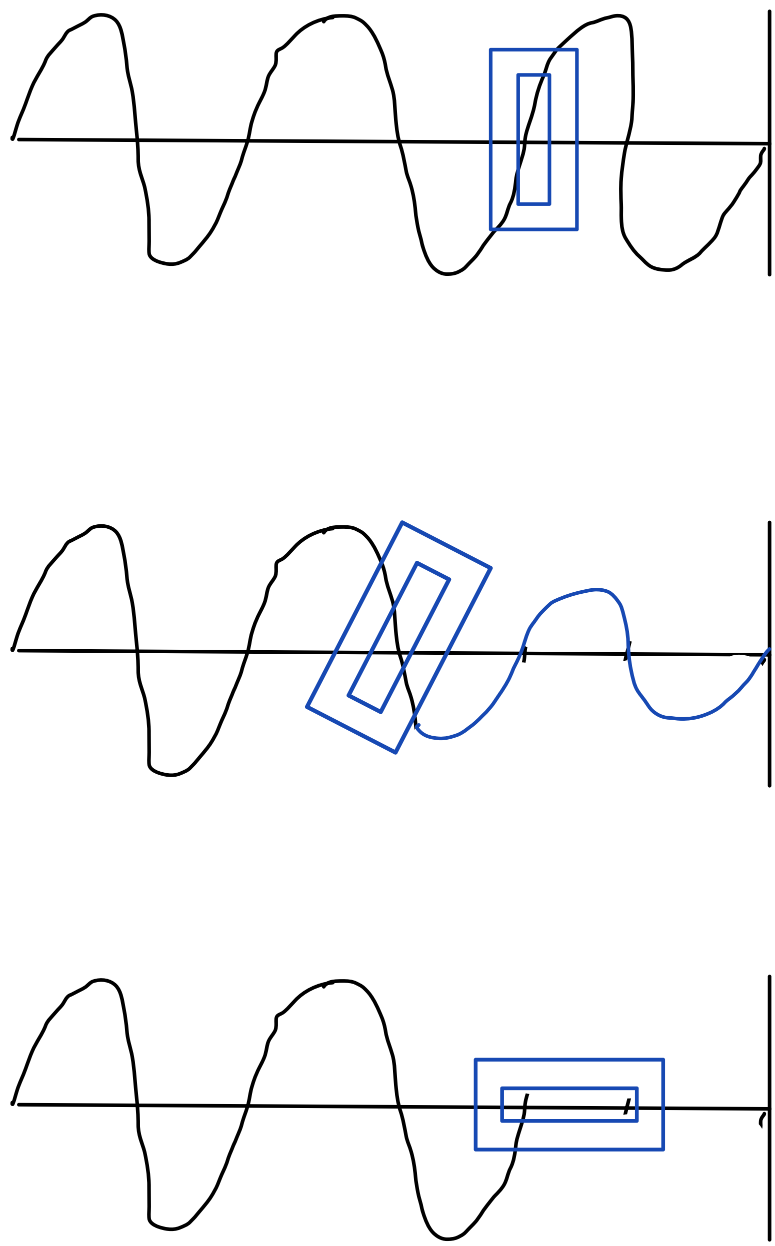
When a galaxy moves away from us or towards us, then wavelength and frequency of light is moved either towards the red red end of the visible spectrum or moves towards the blue end respectively.



Electromagnetic Spectrum

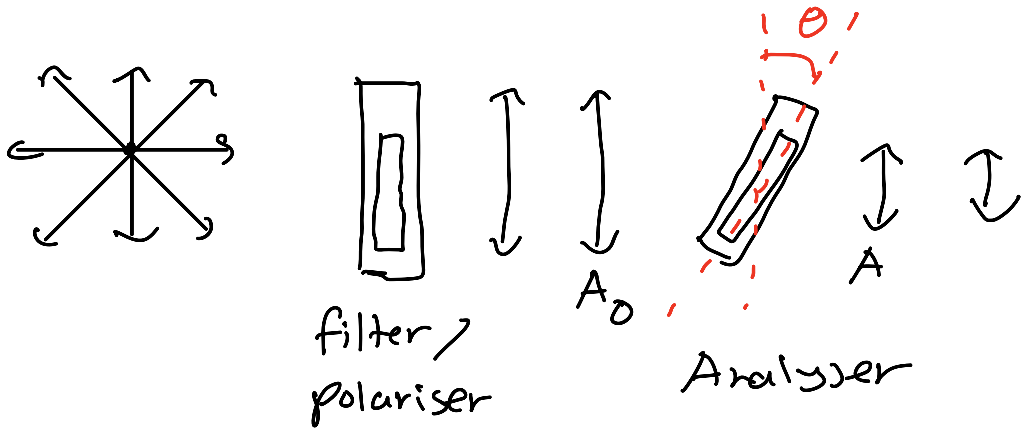
Name	Wavelength
1) Gamma	→ 10^{-12} m
2) X ray	→ 10^{-10} m
3) UV	→ 10^{-8} m
4) Visible light	→ 10^{-7} m
	red → 650 nm
	violet → 350 nm
5) Infrared	→ 10^{-4} m
6) Microwave	→ 10^{-2} m
7) Radiowave	→ 10^{-1} m to 10^{2} m

Polarisation is the restriction of a vibration of a wave in a single plane.



A wave in which the oscillation takes place in a number of planes is called unpolarised.

(only transverse waves can be polarised)



Malus's Law

$$A = A_0 \cos\theta$$

$$I \propto A^2$$

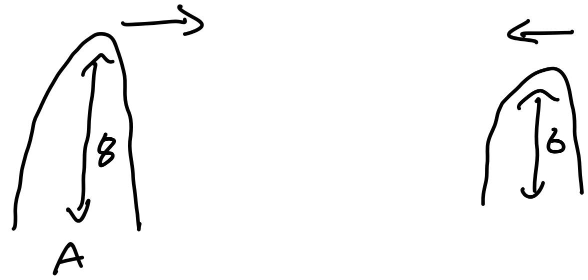
$$A^2 = A_0^2 \cos^2\theta$$

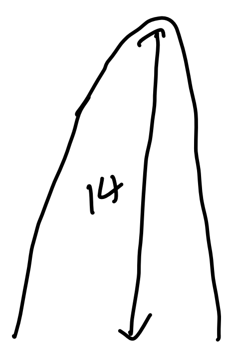
Superposition / Interference

Principal of superposition

When two or more waves meet at a point, then the resultant displacement is equal to the vector sum of displacements of individual waves.

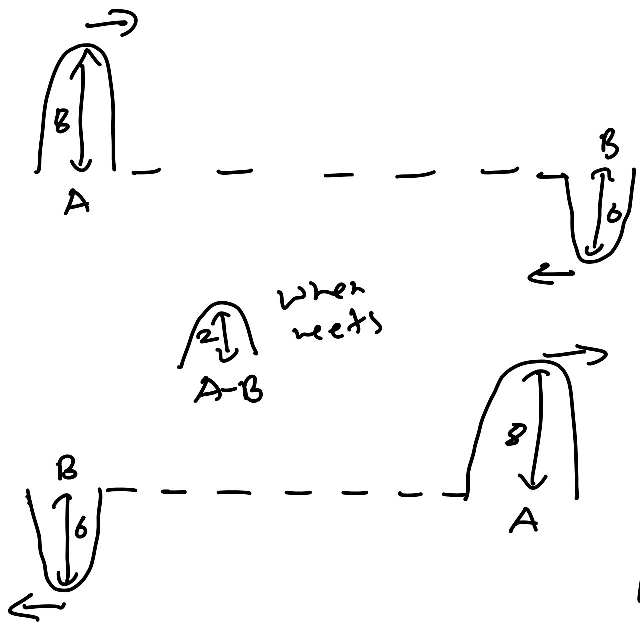
Constructive superposition





When two waves meet at a point in phase, then a resultant wave is produced with increased amplitude.

Deconstructive super position



When two waves meet at a point in phase, then a resultant wave is produced with reduced amplitude.

For constructive superposition / Interface

path difference = $0, \lambda, 2\lambda, 3\lambda \dots (n\lambda)$

Phase difference = $0, 2\pi, 4\pi, 6\pi \dots (2n\pi)$

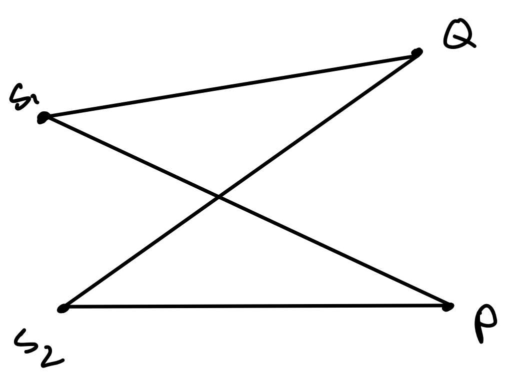
For deconstructive superposition / Interference

path difference = $\frac{\lambda}{2}, \frac{3}{2}\lambda, \frac{5}{2}\lambda \dots (2n+1)\frac{\lambda}{2}$

phase difference = $\pi, 3\pi, 5\pi \dots (2n+1)\pi$

$n = 0, 1, 2, 3 \dots$

Example



$S_1Q = 52$ cm
$S_2Q = 64$ cm
$S_1P = 49$ cm
$S_2P = 58$ cm
$\lambda = 6$ cm

Use info given to determine these two waves meet at P and Q in phase or antiphase

A7 Q

$$64 - 52 = \frac{12}{6} = 2\lambda = 4\lambda$$

constructive.

Conditions for interference / superposition

1) Both should be same type of wave
   or both should be transverse or longitudinal.

2) They must meet at a point.

3) Same direction of polarisation.

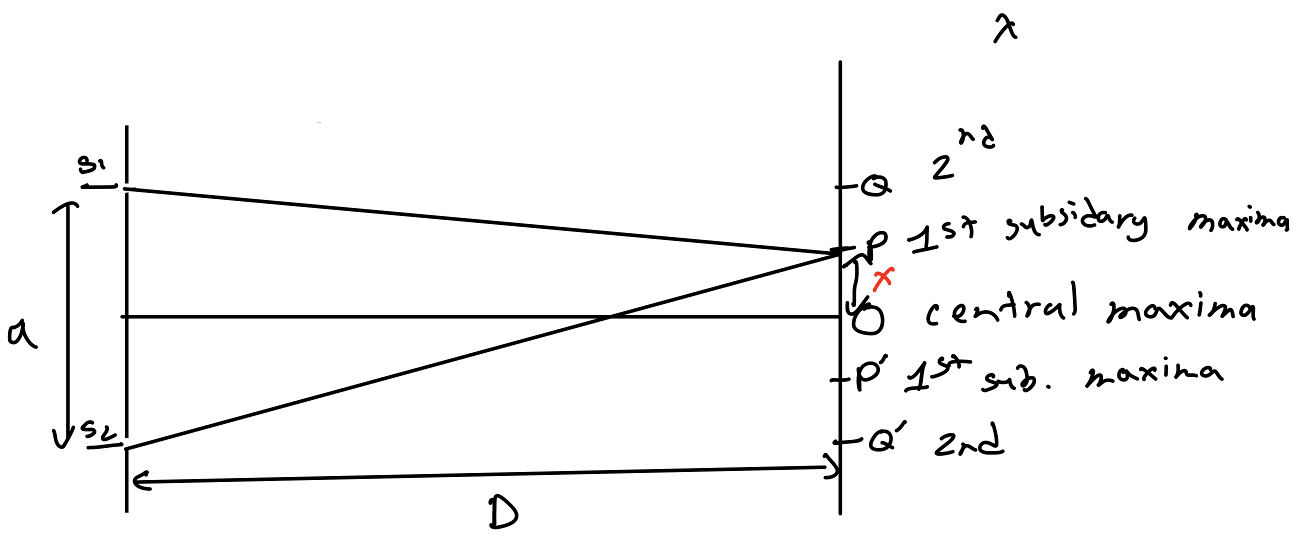
4) They must be coherent.

Coherent -> This means the waves must have the same frequency and any phase difference must be constant.

Diffraction

When wave front is incident through a gap or an edge, the waves bend into geometrical shadows.

Young's double slit experiment



$$\lambda = \frac{a x}{D}$$

x = fringe width

a = difference between two slits.

λ = wave length

D = distance from

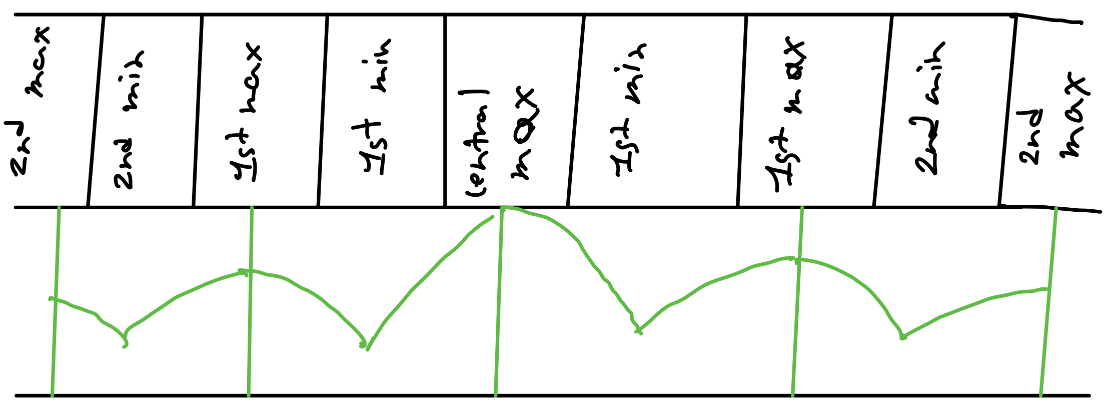
slit to screen.

Note

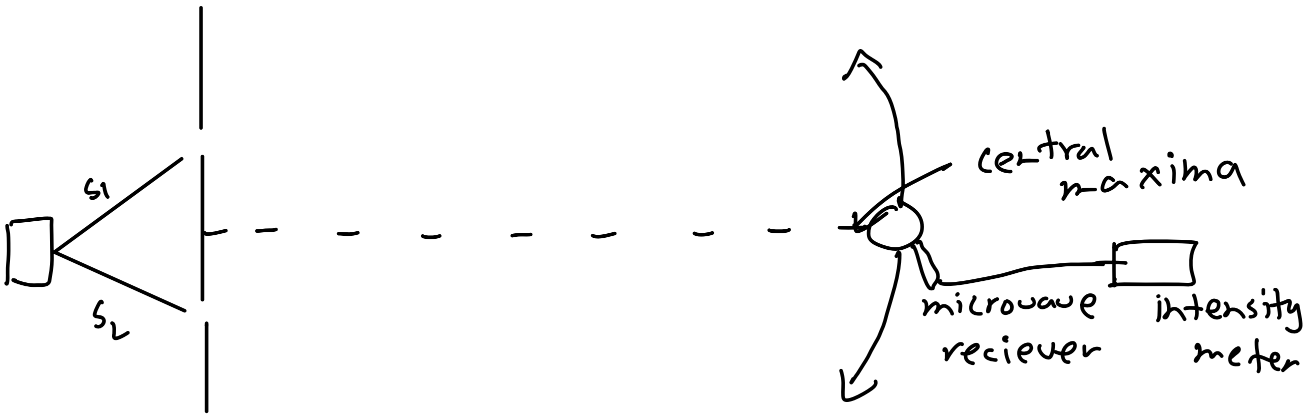
1) Increasing D, x increases but intensity decreases.

2) Decreasing a, x increases but upto a certain limit.

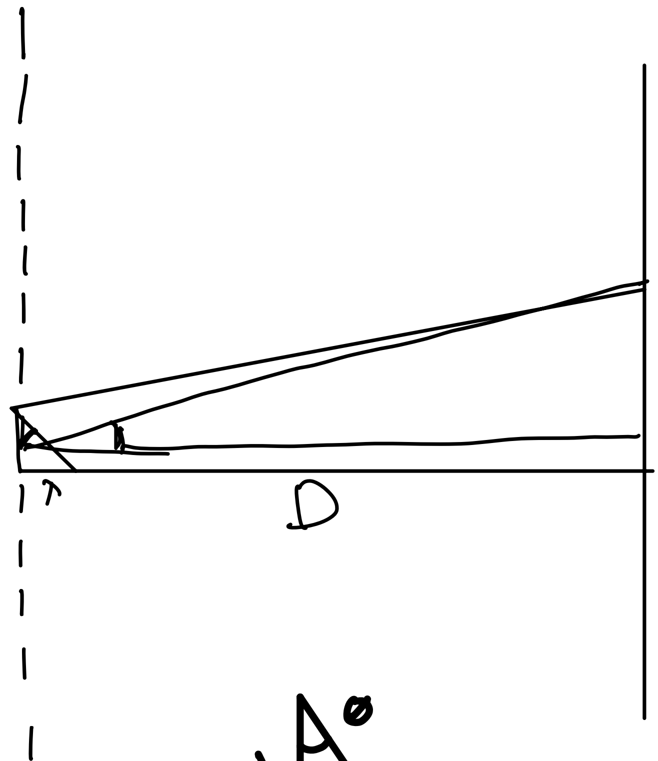
3) Increasing λ, x increases.

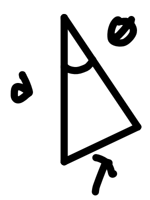


Double slit experiment using Microwaves



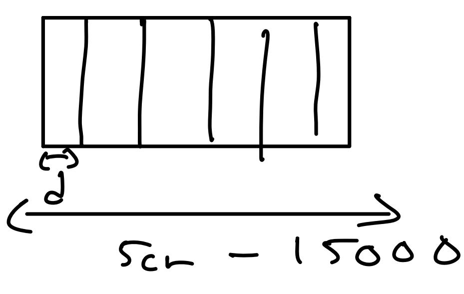
Microwave is diffracted at each slit. These two microwaves superpose infront of the screen. If the microwave reciever is moved along the arrow shown, intensity of microwaves is found to vary. On a white sheet of paper, position of different maxima (greater intensity) and different minima (reduced intensity is marked) central maxima and other subsidary maxima are identified. Direct distance of the first subsidary maxima from the centre of both slits are measured, Difference of these length is wave length.





$$\sin\theta = \frac{\lambda}{d}$$

$$d\sin\theta = \lambda$$



$$\frac{5}{15000} = 3\cdot 3 \times 10^{-4}\ \text{cm}$$

$$d = 3\cdot 3 \times 10^{-6}\ \text{m}$$

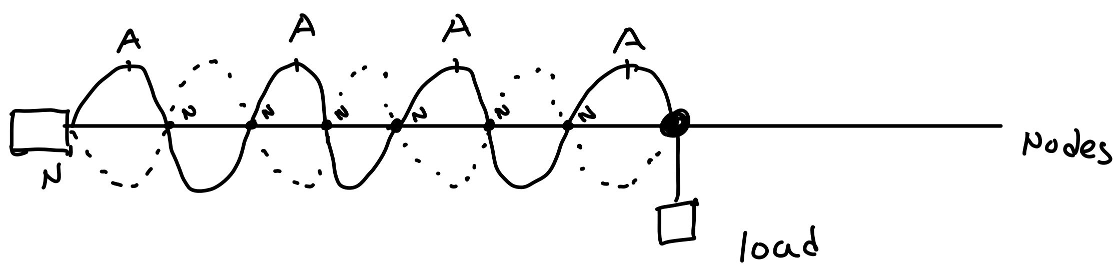
$$\boxed{d \sin\theta = n\lambda}$$

n = number of maxima

d = distance between two slits.

Stationary wave

When two waves travelling along the same line in opposite direction overlap/meet if they have same frequency and wavelength, the resultant displacement is the sum of displacements producing nodes and antinodes.

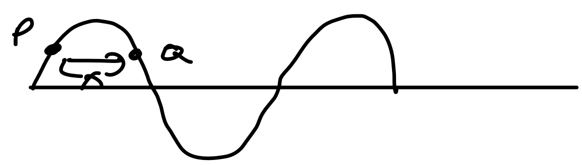


The incident wave and reflected wave are identical and are travelling in opposite directions. When superposition occurs between these two waves a stationary pattern is formed called stationary wave.

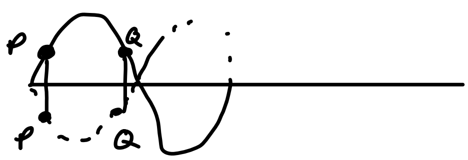
<u>Nodes (N)</u> → These are the points that remain stationary. ie. which do not undergo any vibration. At these points always destructive interference occurs because the two progressive waves always pass eachother at antiphase at

these points (Node → zero displacement)

Antinode → These points undergo maximum displacements from mean position.
At these points, constructive interference occurs because waves cross each other in phase.
(Maximum displacement from mean position)



$\frac{x}{\lambda} \times 2\pi$



For stationary wave

P and Q are in phase

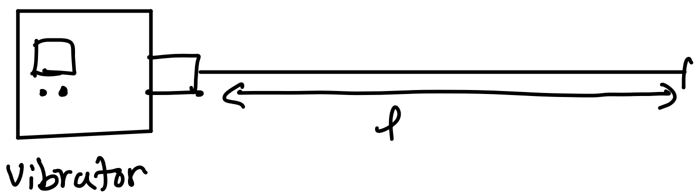
Δ phase $= 0$

Resonance

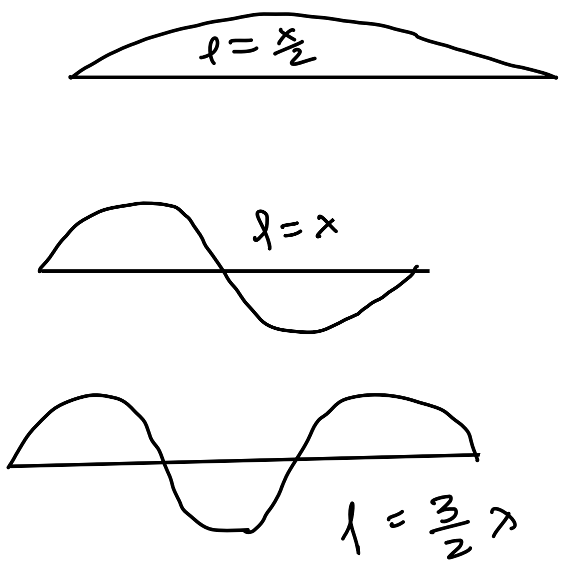
Stationary wave in a string

free vibration → Any vibrating/oscillating system has a constant frequency of vibration is called natural frequency.

Natural frequency $= f_0$



f applied $= f_0$



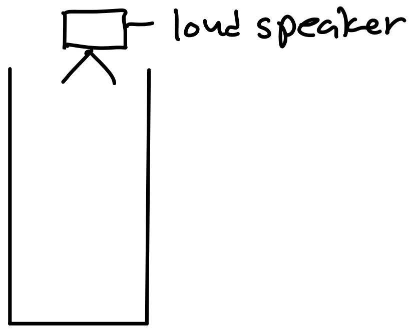
$f_a = f_0$ (1st harmonic)

$f_a = 2f_0$ (2nd harmonic)

$f_a = 3f_0$ (3rd harmonic)

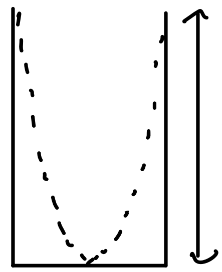
Stationary wave in resonance tube

In a one end closed pipe, resonance occurs when air is blown into it or loudspeaker sound is given which has a frequency equal to the natural frequency of air column. Air inside the tube vibrate with greater amplitude and makes louder sound.



At close ends always node is formed

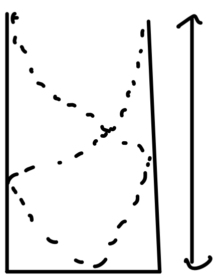
At open end antinode is formed



$l = \frac{\lambda}{4}$

$f_a = f_0$

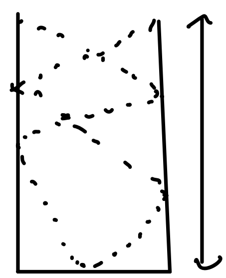
1st stationary wave



$l = \frac{3}{4}\lambda$

$f_a = 3f_0$

2nd stationary wave

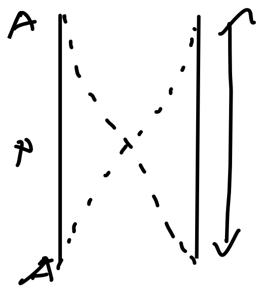


$l = \frac{5}{4}\lambda$

$f_a = 5f_0$

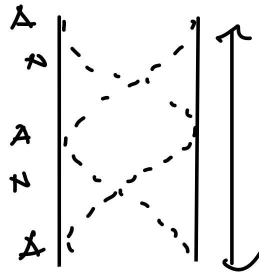
3rd stationary wave

Stationary wave pattern in both end open tube



$l = \frac{\lambda}{2}$

$f_a = f_0$



$l = \lambda$

$f_a = 2f_0$

Stroboscope