KAMSSA SENIOR SIX SELF STUDY WORK

PHYSICS PAPER 2

DAY 1

TOPIC: WAVES

A wave/wave motion is a means of transferring energy from one point to another without there being any transfer of matter between the points.

To and fro movements of a body describe an oscillation e.g. S.H.M where a body oscillates about a fixed point. An oscillation can be mechanical (there is constant exchange of potential and kinetic energy) or electromagnetic (there is constant exchange of energy stored in electric and magnetic fields)

Mechanical waves

These are waves produced by a disturbance in a material medium and are transferred by the particles of the medium oscillating to and fro. E.g water waves, waves produced by musical instruments, sound waves etc. Such waves need a material medium for their transmission.

Electromagnetic waves

These are waves consisting of a disturbance in form of varying electric and magnetic fields. E.g radio waves, light waves, x – rays etc.

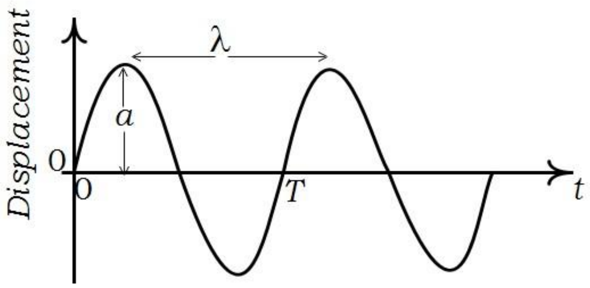
Differences between mechanical and electromagnetic waves

Mechanical waves	Electromagnetic waves
1. Need a medium for their transmission	1. Can pass through the vacuum
2. Moves with low speed	2. Move with high speed
3. Have longer wavelength	3. Have shorter wavelength
4. Are due to oscillations or vibrations of the particles of the transmitting medium	4. Are due to vibrations in electric and magnetic fields

Uses of waves

Uses of waves include; communication industry (radio, T.V waves, telephones etc.), cooking (microwaves), production of electricity (water waves), ultra-sounding in hospitals (sound waves) etc.

Common terms used



1. An oscillation or cycle: This is a complete to and fro motion of a vibrating particle about the mean position
2. Displacement: This is the distance moved by the vibrating particle from the mean position

3. Amplitude (a) : This is the maximum displacement of any vibrating particle from the mean position. It is measured in metres.
4. Period (T): This refers to the time taken by any vibrating particle to complete one cycle. It is measured in seconds (s).
5. Frequency(f): This the number of complete cycles made in one second. It is measured in hertz (Hz). A hertz is defined as one cycle per second.
6. Wavelength (λ): This is the distance between two successive oscillating particles that are in phase. Two particles are said to be in phase if they are at similar positions and moving in the same direction.

Relationship between V, f and λ

Consider a wave moving with velocity V. It covers a distance λ in time T

Distance = velocity × time

$\lambda = V \times T \Rightarrow V = \frac{\lambda}{T} = \lambda \times \frac{1}{T}$

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

$\Rightarrow V = \frac{\lambda}{T}$

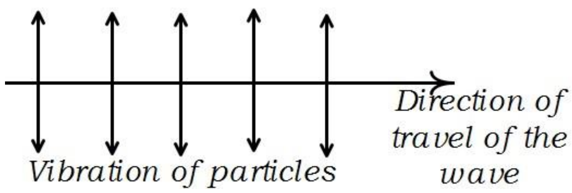
PROGRESSIVE WAVES

A progressive wave is a wave that transfers energy from one point to another without any net transfer of matter. There are two types of progressive waves; transverse and longitudinal.

Transverse waves

These are waves where particles vibrate in a direction perpendicular to the direction of the wave travel. E.g water waves and electromagnetic waves.

In transverse



waves, the distance between two successive crests or troughs equal to one wavelength.

Longitudinal waves

These are waves where particles vibrate in a direction parallel to that of the wave travel. E.g sound waves, compression waves in springs etc

In longitudinal waves, the distance between two successive compressions or rarefactions equal one wavelength.

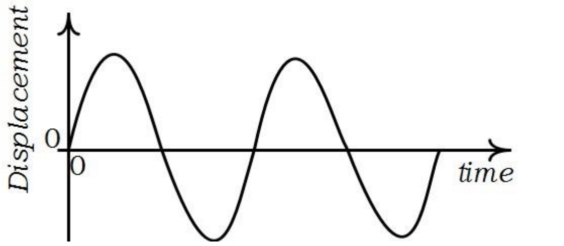
Differences between longitudinal and transverse waves

Transverse waves	Longitudinal waves
1. Particles vibrate perpendicular to the direction of wave travel	Particles vibrate parallel to the direction of wave travel
2. Can undergo polarisation	No polarization can be obtained
3. Form crests and troughs	Form compressions and rarefactions

4. Wavelength equals distance between two successive crests or troughs	Wavelength equals distance between two successive compressions or rarefactions

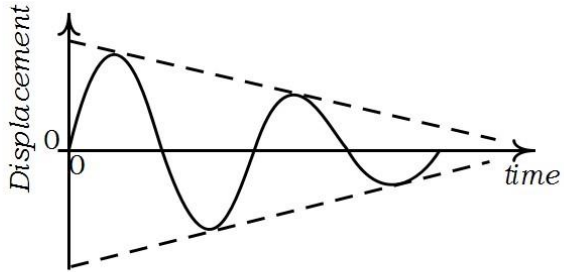
TYPES OF OSCILLATIONS (a) Free oscillations

This is where there is no loss in total energy of the oscillating system and the amplitude of oscillation remains constant. It also means that the total energy at any time is constant.

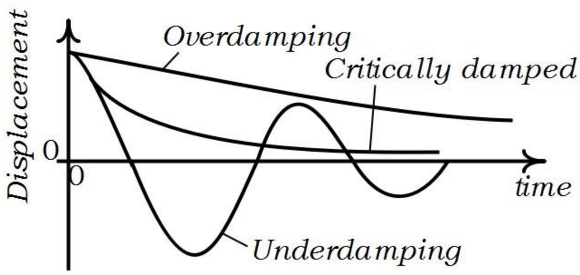


(b) Damped oscillations

This is where energy is continuously taken away from system and the amplitude of oscillation reduces with time. E.g pendulum bob oscillating in air.



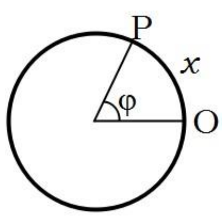
(c) Underdamped, overdamped and critically damped



In underdamped, the amplitude of the vibration progressively becomes smaller until it becomes zero.

In both critically and overdamped, no oscillations occur and the system returns very slowly to its equilibrium positions. When the time taken for the displacement to be zero is a minimum, the system is said to be critically damped.

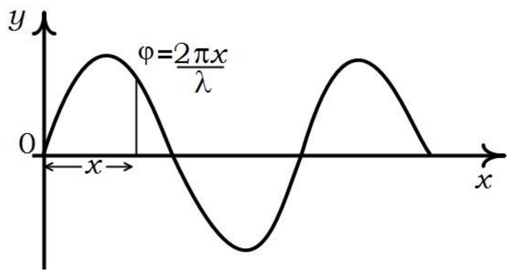
Progressive wave equation



$\frac{\varphi\lambda}{2\pi} = x$

$\varphi = \frac{2\pi x}{\lambda}$

φ is the phase angle or phase difference



Consider a particle at point P a distance x from O to the right. The displacement of the particle from O is given by

$y = a\sin(\omega t - \phi)$

$y = a\sin\left(\omega t - \frac{2\pi x}{\lambda}\right)$ ……………………………. (1)

But $\omega = 2\pi f$

$y = a\sin(2\pi f t - \frac{2\pi x}{\lambda})$

$y = a\sin 2\pi(ft - \frac{x}{\lambda})$ ……………………………. (2)

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

$y = a\sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$ ……………………………. (3)

Recall $f = \frac{V}{\lambda}$ in equation (2)

$y = a\sin\frac{2\pi}{\lambda}(Vt - x)$ ……………………………. (4)

Equations (3) and (4) represent a plane progressive wave equation of a wave moving from left to right. If the direction of the travel changes, the sign changes from negative to positive.

Examples

1. A plane progressive wave is represented by the equation $y = a\sin\left(200\pi t - \frac{\pi x}{17}\right)$ where t is in seconds and x is in cm.
   Calculate the
   (i) frequency
   (ii) wavelength
   (iii) period and
   (iv) velocity

   $y = a\sin\left(200\pi t - \frac{\pi x}{17}\right)$

   comparing with $y = a\sin\left(2\pi f t - \frac{2\pi x}{\lambda}\right)$

   $2\pi f = 200\pi$

   $f = 100\ Hz$

   $\frac{2\pi x}{\lambda} = \frac{\pi x}{17}$

   $\frac{2}{\lambda} = \frac{1}{17}$

   $\lambda = 34$cm or $\lambda = 0.34$m

   $T = \frac{1}{f} = \frac{1}{1000} = 0.001$ seconds

   $V = \lambda f = 1000 \times 0.34 = 340\ ms^{-1}$

2. The displacement y in metres in a progressive wave is given by

$y = 0.2 \sin 2\pi\ (12t - 5x)$. Find the

(i) frequency

(ii) wavelength

(iii) velocity

$y = 0.2 \sin 2\pi\ (12t - 5x) = 0.2\sin\ (24\pi t - 10\pi x)$

Comparing with $y = a \sin\left(2\pi f t - \frac{2\pi x}{\lambda}\right)$

$2\pi f = 24\pi\ f = 12\ Hz$

$\frac{2\pi x}{\lambda} = 10\pi x$

$\frac{2}{\lambda} = 10$

$\lambda = 0.2\text{m}$

$V = \lambda f = 12 \times 0.2 = 2.4\ ms^{-1}$

ACTIVITY 1

1. A plane progressive wave is represented by the equation $y = 0.1\sin\left(200\pi t - \frac{20}{17}\pi x\right)$ where t is in seconds and x in metres.

Calculate the

(iv) frequency

(v) wavelength

(vi) velocity of the wave

(vii) phase difference in radians between the points 0.25 m and 1.10 m from the origin.

(viii) equations of the wave with triple amplitude and triple frequency travelling in the same direction.

2. A progressive wave and a stationary wave each has a frequency of 240Hz and a speed of 80ms^{-1}. Calculate the

(ix) phase difference between two vibrating points in the progressive wave which are 6 cm apart.

(x) distance between nodes in the stationary wave

3. The displacement of a particle in a progressive wave is given by $y = a \sin 2\pi \left(\frac{t}{0.1} - \frac{x}{2.0}\right)$m. Find the

(i) wavelength

(ii) frequency

(iii) velocity of the wave

(iv) period

4. The displacement of a [article in a progressive wave is given by $y = 2 \sin 2\pi\ (0.25x - 100t)$ where x and y are in cm and t in seconds. Calculate the

(i) wavelength

(ii) velocity of the propagation of the wave

5. A wave of magnitude 0.2 m, wavelength 2.0cm and frequency 50Hz propagates in the positive x −direction. If the initial displacement is zero at a point x = 0,

(i) write the expression for the displacement of the wave at any time t

(ii) find the speed of the wave

6. Two waves of frequencies 256 Hz and 280 Hz respectively travel with a speed of 340ms^{-1} through a medium. Find the phase difference at a point 2.0 m from where they were initially in phase.

DAY 2

THE PRINCIPLE OF SUPERPOSITION

This states that whenever two waves are travelling in the same region the total displacement at any point is equal to the vector sum of their individual displacements at that point.

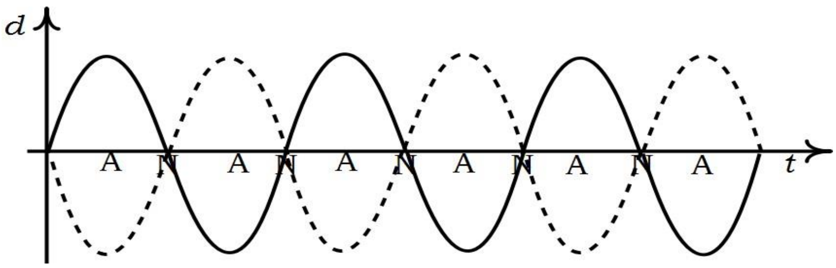
Stationary/standing waves

A stationary wave is formed when two progressive waves which are travelling in opposite directions with the same speed and frequency and approximately equal amplitudes are superposed.

Stationary waves can be produced in narrow stretched strings which are fixed at one end and are continuously set into vibrations.

An increase in frequency can cause increased number of loops of large amplitudes.

N.B



1. Points marked N are called nodes. A node is a point of zero disturbance
2. Points marked A are called antinodes. An antinode is a point of maximum displacement
3. The distance between two successive node or antinodes equals half wavelength $\left(\frac{1}{2}\lambda\right)$
4. Wavelength is equal to the distance between alternate nodes or antinodes.

Differences between progressive waves and stationary waves

Progressive waves	Stationary waves
1. There is continuous transfer of energy through the medium	There is no energy transfer
2. All particles vibrate with maximum amplitude at some point or the other	Only some particles with maximum amplitude at some point vibrate

3. Crests and troughs (transverse) or compressions and rarefactions (longitudinal) are formed	Nodes and antinodes are formed
4. A single wave moves in one direction	Two identical waves travelling in opposite directions superpose
5. Wavelength is equal to the distance between two successive crests or troughs (transverse) or distance between two successive compressions or rarefactions (longitudinal)	Wavelength is equal to the distance between alternate nodes or antinodes
6. Pressure variation is the same at every point in a medium	Pressure is maximum at nodes and zero at the antinodes

The stationary wave equation

Consider two waves of the same amplitude and frequency travelling in opposite directions.

$y_1 = a\sin(\omega t + kx)$ to the left $k = \frac{2\pi}{\lambda}$

$y_2 = a\sin(\omega t - kx)$ to the right

By principle of superposition, $y = y_1 + y_2$ where y is the resultant wave equation

$$y = a\sin(\omega t + kx) + a\sin(\omega t - kx)$$
$$= 2a\sin\left(\frac{\omega t + kx + \omega t - kx}{2}\right)\cos\left(\frac{\omega t + kx - \omega t + kx}{2}\right)$$
$$= 2a\sin\omega t\cos kx$$
$$= 2a\cos kx\sin\omega t$$

Therefore, $y = 2a\cos kx\sin\omega t$ is the equation of the stationary wave.

It can be rewritten as $y = A\sin\omega t$ where $A = 2a\cos kx$ is the amplitude of the stationary wave

<u>Example</u>

1. A plane progressive wave is given by $y = a\sin\left(100\pi t - \frac{10}{9}\pi x\right)$ where x and y are metres and t in seconds
   (i) Write the equation of the progressive wave which would give rise to a stationary wave if superposed on the one above
   (ii) Find the equation of the stationary wave and hence determine its amplitude
   (iii) (iii) Determine the frequency of the stationary wave

$$y = a\sin\left(100\pi t + \frac{10}{9}\pi x\right) + a\sin\left(100\pi t - \frac{10}{9}\pi x\right)$$
$$= 2a\sin 100\pi t\cos\frac{10}{9}\pi x$$
$$= 2a\cos\frac{10}{9}\pi x\sin 100\pi t$$

Amplitude $= 2a\cos\frac{10}{9}\pi x$

$y = 2a\cos\frac{10}{9}\pi x \sin 100\pi t$

$2\pi f = 100\pi$

$f = 50Hz$ compare with $y = A\sin 2\pi ft$

2. A plane progressive wave is given by $y = a\sin(\omega t - kx)$ is reflected at a barrier to interfere with the incoming wave. Show that the resultant wave is a stationary one

$y_1 = a\sin(\omega t - kx)$

$y_2 = a\sin(\omega t + kx)$

$y = y_1 + y_2$

$y = a\sin(\omega t + kx) + a\sin(\omega t - kx)$

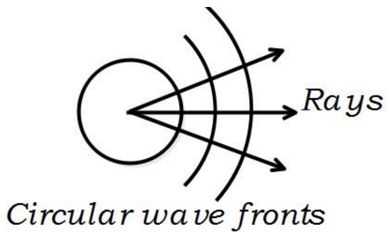
$= 2a\sin\left(\frac{\omega t+kx+\omega t-kx}{2}\right)\cos\left(\frac{\omega t+kx-\omega t+kx}{2}\right)$

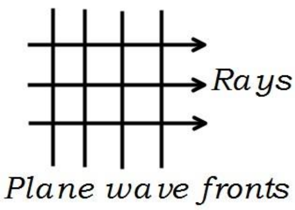
$= 2a\sin\omega t\cos kx$

$= 2a\cos kx\sin\omega t$ hence a stationary wave.

HUYGENS' PRINCIPLE

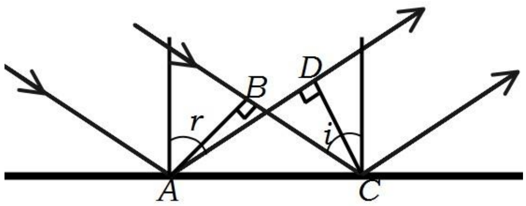
A wave front is a line or surface in the path of a wave motion on which the disturbances at every point have the same phase.





A ray is a line at right angles to a wave front which shows its direction of travel

Huygens' principle states that every point on a wave front may be regarded as a source of secondary spherical wavelets which spread out with the same velocity and the new wave front is the surface which touches all of these secondary wavelets (envelops).



Incident wave front AB is reflected on the plane surface to form a reflected wave front CD. In time t that wave strain from B reaches C the same strain from A arrives at D.

Thus BC = AD and $\angle ABC = \angle ADC = 90°$

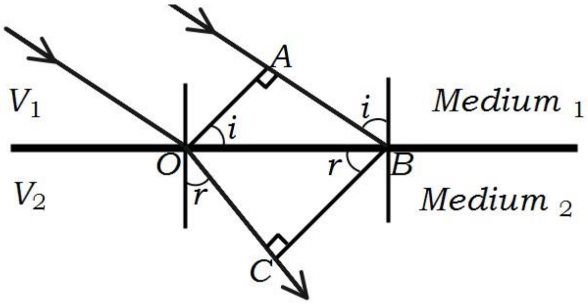
Triangles ABC and ADC have a common line AC hence they are similar

Thus $\angle CAD = \angle ACB$

$90° - r = 90° - i$

Therefore $\angle r = \angle i$

Huygens' Principle as applied to refraction



Consider a wave front OA incident on a plane boundary between two media of refractive indices n_1 and n_2 respectively.

During time t when A reaches B, wave fronts from O will have reached C.

If V_1 and V_2 is the speed of light in medium 1 and medium 2 respectively,

$AB = V_1 t$ and $OC = V_2 t$

${}_1n_2 = \frac{\sin i}{\sin r}$ where $\sin i = \frac{AB}{OB}$ and $\sin r = \frac{OC}{OB}$

${}_1n_2 = \frac{AB}{OB} \times \frac{OB}{OC} = \frac{AB}{OC}$

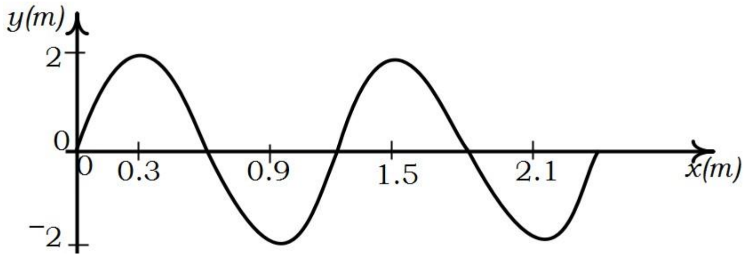
${}_1n_2 = \frac{AB}{OC} = \frac{V_1 t}{V_2 t} = \frac{V_1}{V_2}$

Since V_1 and V_2 are constants $\frac{\sin i}{\sin r} =$constant

ACTIVITY 2

1. A plane progressive wave is represented by $y = a\sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$ is reflected back along the same path. Show that the overlap of the two waves may give rise to a stationary wave.

2.



The figure above shows a wave travelling in positive x −direction away from the origin with a velocity of 9ms^{-1}.

(i) What is the period of the wave?

(ii) Show that the displacement equation for the wave is given by $y = 2\sin\frac{5}{3}\pi(at - x)$

3. (a) State Huygens' Principle

(b) Monochromatic light propagating in air is incident obliquely onto a plane boundary with a dielectric material of refractive index n. Use Huygens' Principle to show that the speed V of light in the dielectric is given by $V = \frac{c}{n}$ where c is the speed of light in air.

4.a) Define the following terms as applied to waves

i) Stationary wave

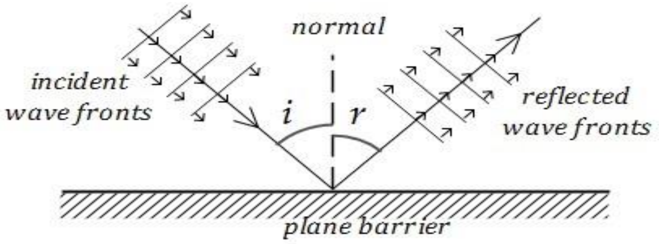
ii) Progressive waves

b) State the difference between Stationary and Progressive waves.

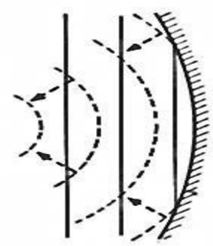
DAY 3

Refraction of waves

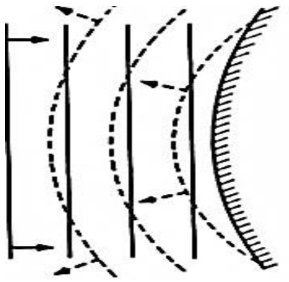
(a)Plane wave fronts on a plane reflector



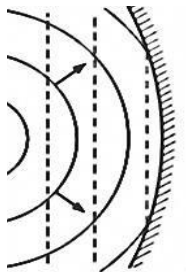
(b) Plane wave fronts on a concave reflector



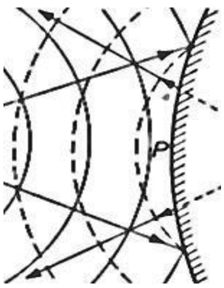
(c)Plane wave fronts on a convex reflector



(d) Circular wave fronts on a concave reflector



(e) Circular wave fronts on a convex reflector



Interference of light waves

Interference is the superposition of two waves from coherent sources leading to alternate regions of maximum and minimum intensity.

Interference effects can be observed with all types of waves, for example, light, radio, acoustic, surface water waves, gravity waves or matter waves.

Conditions for two sources of light to produce observable interference

1. The two interfering sources must be coherent (same frequency approximately equal amplitude and constant phase difference). If the condition is not satisfied, the phase difference varies continuously and the resulting intensity at any point will vary with time.
2. The interfering waves should have approximately equal amplitudes otherwise the minimum intensity will not be zero and the pattern lacks contrast i.e those will be a general illumination.
3. The separation between the two sources must be as small as possible otherwise the fringes of maximum and minimum intensity will be so close together that the fringes will not be separately visible.
4. The two sources must be narrow. If the sources are wide like car head lamps, the two sources are not coherent and can't produce interference patterns. This is because a light beam is emitted by millions of atoms radiating independently so that phase difference between waves from such sources fluctuates randomly many times per second. The interference changes rapidly that the impression is one of uniform illumination.

Constructive and destructive interference Constructive interference

This is the reinforcement of intensities from two coherent sources to give maximum intensity when the two waves superpose.

N.B

1. Amplitude is double that of either wave
2. Frequency is the same as that of either wave
3. Constructive interference occurs when the path difference is an integral multiple of the wavelength i.e path difference = $n\lambda$

Destructive interference

This is the cancellation of intensities from two coherent sources to give minimum intensity when the two waves superpose.

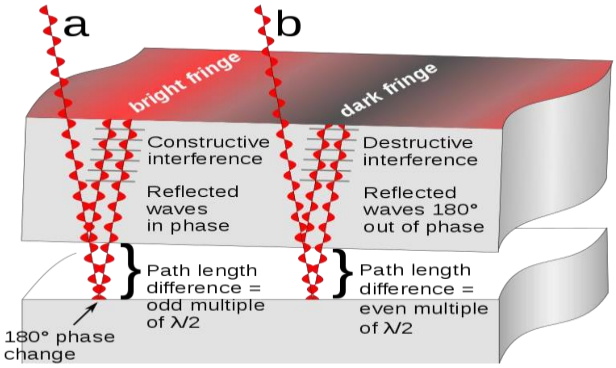
It occurs when the path difference is an odd multiple of half wavelength i.e path difference $= \left(n + \frac{1}{2}\right)\lambda$

How interference patterns are formed

When two waves from coherent sources cross, they superpose. When the path difference is an odd multiple of half wavelength, cancellation occurs resulting in minimum intensity. When the path difference is a multiple of a full wavelength, reinforcement occurs resulting into maximum intensity. This leads to formation of alternate permanent regions of maximum and minimum intensity called interference patterns.

Further information

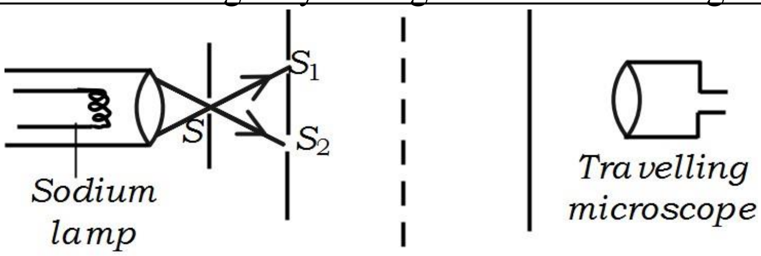
Creation of interference fringes by an optical flat on a reflective surface



Light rays from a monochromatic source pass through the glass and reflect off both the bottom surface of the flat and the supporting surface. The tiny gap between the surfaces means the two reflected rays have different path lengths. In addition, the ray reflected from the bottom plate undergoes a 180° phase reversal. As a result, at locations **(a)** where the path difference is an odd multiple of $\frac{\lambda}{2}$, the waves reinforce.

At locations **(b)** where the path difference is an even multiple of $\frac{\lambda}{2}$ the waves cancel. Since the gap between the surfaces varies slightly in width at different points, a series of alternating bright and dark bands, called interference fringes, are seen.

Measurement of wavelength by Young's interference fringes (bands)



The experiment is set up as shown in the diagram.
Light from a sodium lamp is made to illuminate the two slits S_1 and S_2 equally. Bright and dark fringes are observed on the screen using a travelling microscope.
The distance D from the double slits to the screen is measured using a metre rule in mm.
The fringe separation y is obtained by measuring the distance between fringes using a travelling microscope and dividing it by the number of fringe spacings. The distance a between the slits is measured using a travelling microscope. The wavelength λ is calculated from $\lambda = \frac{ay}{D}$

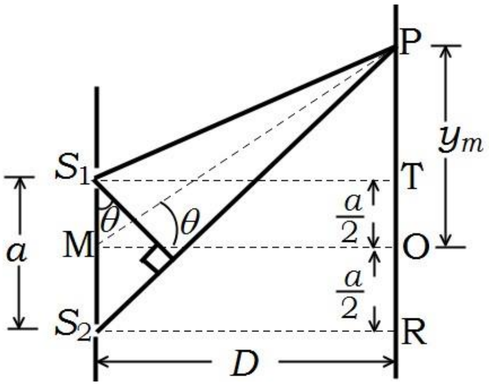
N.B

1. If the source S is moved nearer to the double slits, the separation of the fringes is not affected but their intensity increases. ($D = \frac{ay}{\lambda}$; D and a are constants)
2. If the slit separation is decreased keeping the source fixed, the separation of the fringes increases. $\left(\frac{\lambda D}{a} = y\right)$
3. If any of the slits (S, S_1 or S_2) is widened, the fringes eventually disappear. Widening slits is equivalent to a large number of slits, each producing its own fringe system at different places. The bright and dark fringes of different systems therefore overlap giving rise to uniform illumination.

4. If one of the slits is closed, the fringes disappear.
5. If white light is used, the central band is white and the bands either side are coloured. Blue is the colour near the central fringe while red is further away. This is because the wavelength of red is longer than that of blue. The path difference to a central point on the perpendicular bisector of the two slits S_1 and S_2 is zero for all colours and therefore has a white band at the centre.
6. If the slit separation is increased, the fringe separation reduces until a point where there are no fringes observed.

N.B

When comparing wavelength of different colours, different colour filters are placed one at a time between the slits and the screen.



Proof of $\lambda = \frac{ay}{D}$

Consider two coherent sources of light waves S_1 and S_2 a distance a apart that produce a fringe of width y_m on a screen a distance D from the slits.

From triangle S^{1}PT, $\overline{S_1P}^2 = D^2 + \left(y_m - \frac{a}{2}\right)^2$

$\overline{S_1P}^2 = D^2 + {y_m}^2 - ay_m + \frac{a^2}{4} \ldots\ldots\ldots\ldots\ldots (1)$

From triangle S^{2}PR, $\overline{S_2P}^2 = D^2 + \left(y_m + \frac{a}{2}\right)^2$

$\overline{S_2P}^2 = D^2 + {y_m}^2 + ay_m + \frac{a^2}{4} \ldots\ldots\ldots\ldots\ldots (2)$

Equation (2) − (1)

$\overline{S_2P}2 - \overline{S_1P}2 = 2ay_m$

$(\overline{S2P} - \overline{S1P})\ (\overline{S2P} + \overline{S1P}) = 2aym$

Since $a \ll D$, $\overline{S_2P} \approx \overline{S_1P} \approx MO = D$ such that $\overline{S_2P} + \overline{S_1P} = 2D$

$(\overline{S_2P} - \overline{S_1P})2D = 2ay_m$

$(\overline{S2P} - \overline{S1P})\ D = aym$

For a bright fringe, $\overline{S_2P} - \overline{S_1P} = m\lambda$

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

$m\lambda D = ay_m$

$y_m = \frac{m\lambda D}{a}$

For the next bright fringe, $(m + 1)$

$y_{m+1} = \frac{(m+1)\lambda D}{a}$

Fringe separation $y = y_{m+1} - y_m$

$$y = \frac{(m+1)\lambda D}{a} - \frac{m\lambda D}{a}$$

$$= \frac{m\lambda D}{a} + \frac{\lambda D}{a} - \frac{m\lambda D}{a}$$

$$= \frac{\lambda D}{a}$$ Therefore $y = \frac{\lambda D}{a}$

N.B

(a) For bright fringes, the path difference is equal to the whole number of wavelength

$\therefore y = \frac{m\lambda D}{a}$

(b) For dark fringes, the path difference is equal to the odd number of half wavelength

$\therefore y = \frac{\left(m-\frac{1}{2}\right)\lambda D}{a}$

(c) $\tan\theta \approx \theta = \frac{y_m}{D}$

Examples

1. In Young's double slit experiment, the 8^{th} bright fringe is formed 5 mm away from the centre of the fringe system when the wavelength used is 6.2×10^{-7}m.
   calculate the separation of the slits if the distance from the slits to the screen is 80 cm.

   $y = \frac{m\lambda D}{a}$

   $m = 8, y = 5mm = 5 \times 10^{-3}m, \lambda = 6.2 \times 10^{-7}m, D = 80cm = 8.0 \times 10^{-2}m$

   Then $a = \frac{m\lambda D}{y} = \frac{8\times6.2\times10^{-7}\times8.0\times10^{-2}}{5\times10^{-3}} = 7.936 \times 10^{-4}$ m

2. Two slits 2.5 mm apart are placed at a distance of 1 m from the screen. The slits are illuminated with light of wavelength 550 nm. Calculate the distance between the fourth and second bright fringes.

   $y = \frac{m\lambda D}{a}$

   $a = 2.5mm = 2.5 \times 10^{-3}m, \lambda = 550 \times 10^{-9}m, D = 1m$

   Then $y_4 - y_2 = \frac{4\lambda D}{a} - \frac{2\lambda D}{a} = \frac{2\lambda D}{a}$

   $= \frac{550\times10^{-9}\times1}{2.5\times10^{-3}} = 4.4 \times 10^{-4}$ m

ACTIVITY 3

1. In Young's double slit experiment, an interference pattern in which the 10^{th} bright fringe 3.4 cm from the centre of the pattern was obtained. The distance between the slits and the screen was 2.0 m while the slit separation was 0.34 mm. Find the wavelength of the light source.
2. In Young's double slit experiment, the distance between the centre of the interference pattern and the 10^{th} bright fringe on either side is 3.44 cm and the distance between the slits and the screen is 2.0 cm. If the wavelength of light used is 5.89×10^{-7}m, determine the slit separation.
3. In Young's double slit experiment, the separation of the slits is 0.42 mm and the perpendicular distance from the line S_1S_2 to the screen is 75 cm. P marks the centre of the 3^{rd} bright fringe from O. If light of wavelength 6×10^{-7}m is used, calculate the

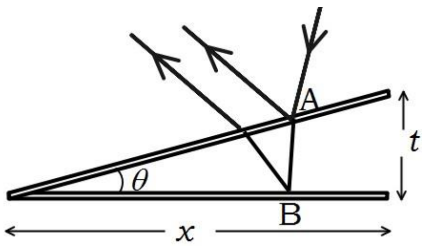
(i) distance OP

(ii) distance $S_2P - S_1P$

4. Two slits 5×10^{-5}m apart are placed a distance of 0.3 m from the screen. The slits are illuminated with light of wavelength 5.46×10^{-7}m. Calculate the angular position for the first dark fringe.

DAY 4

THE AIR WEDGE



Note

There is a path difference of $2t$ between waves reflected from A and those from B.

An air wedge is a wedge shaped film of air. Monochromatic light is incident normally on the air-wedge. Some light is reflected from the lower surface of the upper plate while the other is transmitted and finally reflected from the upper surface of the lower plate.

Light reflected from the upper surface of the lower plate suffers a phase change of 180^0 (a trough is reflected as a crest and a crest is reflected as a trough).

Waves reflected from the lower surface of the upper plate and those reflected from the upper surface of the lower plate are coherent and when superposed, interference occurs and interference bands are formed.

When the path difference is an integral multiple of full wavelength, a dark fringe is formed and when it is an odd multiple of half wavelength, a bright fringe is formed. i.e dark fringes occur when $2t = m\lambda$ and bright fringe occur when $2t = \left(m - \frac{1}{2}\right)\lambda$

Appearance of fringes when white light is used

When white light is used, coloured fringes are obtained. The blue fringe is nearest the edge and the red fringe is furthest. After the first red fringe, the coloured fringes overlap. At large distances from the edge, the fringes are so much out of phase which results in white illumination i.e no fringes are formed.

Definitions

1. Optical path: This is the distance in vacuum that would contain the same number of wavelengths as the actual path taken by a ray of light travelling through a medium. Or It is the product of the geometric path length and refractive index of the medium through which light propagates.
2. Division of wave fronts: This is the production of two coherent sources from a single source e.g Young's double slit experiment, Lloyd's mirror etc.
3. Division of amplitude: This is where two waves that interfere originate at the same point on the wave front produced by the source and each having part of the amplitude of the original e.g air-wedge, Newton's rings.
4. Path difference: This is the difference is the difference in the optical paths of two waves travelling from one point to another.

NEWTON'S RINGS
A biconvex lens of large radius of curvature is placed on a flat glass plate.
A sodium lamp S is placed at the principal focus of a convex lens L.
Monochromatic light from S is incident onto the lens L. L produces a parallel beam and directs it onto the glass plate G. The beam splitter reflects the beam to fall normally on the air film between the convex lens and the flat glass plate. Interference occurs between light reflected from the lower surface of the lens and that reflected from the upper surface of the flat glass plate. A series of dark and bright fringes are seen through a travelling microscope. These interference patterns are called Newton's rings.

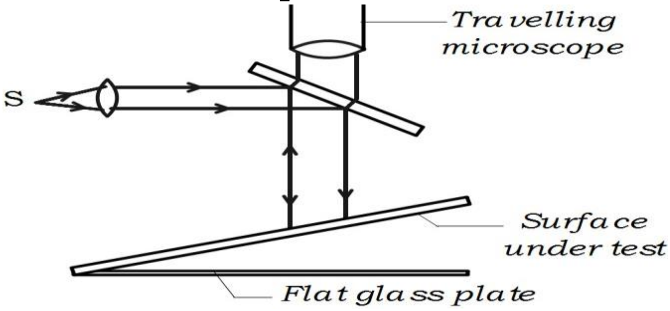
Qualitative explanation of how Newton's rings are formed.

At the lower surface of a concave lens, some light waves are reflected whole others are transmitted and finally reflected at the upper surface of the flat glass plate.
Interference occurs between light reflected from the lower surface of the lens and that reflected from the upper surface of the flat glass plate. A series of dark and bright fringes is seen through glass plate G, when a travelling microscope is focused on the air film.
At the centre of the fringe system, there is a dark spot due to 180^0 phase change. A dark fringe is formed when $2t = n\lambda$ and a broght fringe is formed when
$2t = \left(n + \frac{1}{2}\right)\lambda$
where t is the thickness of the air film.
N.B:
If water is placed between the lens and the flat glass plate, it reduces the wavelength of light. Since the ring radius is proportional to the wavelength, the Newton's rings are observed.

Measurement of wavelength using Newton's rings

Monochromatic light from a sodium lamp S is reflected by the glass plate G so that it falls normally on the convex lens. A series of bright fringes is seen through glass plate G using a travelling microscope.
Using the travelling microscope, the diameter d_n of the n^{th} dark fringe is measured. The experiment is repeated for other dark fringes. The values are tabulated including value of ${d_n}^2$. A graph of ${d_n}^2$ against n is plotted. The slope S of the graph calculated. Wavelength λ is obtained from $\lambda = \frac{S}{4R}$ where R is the radius of curvature of the lens surface in contact with the flat glass plate.

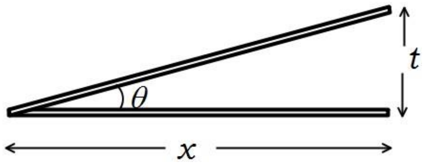
Testing the flatness of a simple surface



The surface under test is made to form an air-wedge with a plate glass surface of standard smoothness (flat glass plate). Monochromatic light is made incident normally on the air-wedge.

The light reflected from the air wedge is observed using a microscope and an interference pattern is observed.
If the surface is flat straight, parallel and equally spaced bands are seen. If uneven fringe pattern is seen, the surface is not flat.

Calculations of the fringe separation



For dark fringes, $2t = m\lambda \quad m = 0,1,2,3 \ldots \ldots$

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

$t = 0, \frac{\lambda}{2}, \frac{2\lambda}{2}, \frac{3\lambda}{2} \ldots \ldots \ldots (1)$

$\tan\theta = \frac{t}{x} \quad \Rightarrow x = \frac{t}{\tan\theta}$

From equation (1)

$x = 0, \frac{\lambda}{2\tan\theta}, \frac{2\lambda}{2\tan\theta}, \frac{3\lambda}{2\tan\theta}, \ldots \ldots$.

Hence the fringes are equally spaced.

The separation of the adjacent fringes $x_{n+1} - x_n = \frac{\lambda}{2\tan\theta}$ Or $\tan\theta = \frac{\lambda}{2(x_{n+1} - x_n)}$

For bright fringes $2t = \left(m - \frac{1}{2}\right)\lambda\,; m = 1,2,3 \ldots$.

$2t = \frac{1}{2}\lambda, \frac{3}{2}\lambda, \frac{5}{2}\lambda$

$t = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}$

$\tan\theta = \frac{t}{x} \Rightarrow x = \frac{t}{\tan\theta}$

$x = \frac{\lambda}{4\tan\theta}, \frac{3\lambda}{4\tan\theta}, \frac{5\lambda}{4\tan\theta}, \ldots \ldots$.

Hence the fringes are equally spaced.

The separation of the adjacent fringes $x_{n+1} - x_n = \frac{\lambda}{2\tan\theta}$ Or $\tan\theta = \frac{\lambda}{2(x_{n+1} - x_n)}$ <u>**Example**</u>

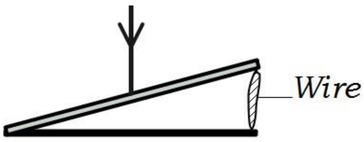
1. A piece of wire of diameter 0.050 m and two thin glass strips are available to produce the air-wedge. If a total of 200 fringes are produced, what is the wavelength of light used?

   $t = 0.05\ m, m = 200, \lambda = ?$

   $2t = m\lambda$

   $\lambda = \frac{2t}{m} = \frac{2 \times 0.05}{200} = 5.0 \times 10^{-4}\ m$

2. An air-wedge is formed by placing two glass slides of length 5.0 cm in contact at one end and a wire at the other end as shown below

   Viewing from above vertically, 10 dark fringes are observed to occupy a distance of 2.5 mm when illuminated with light of wavelength 500nm. Determine the diameter of the wire.

$t = ?, x = 5.0 \times 10^{-2} m, \lambda = 500 \times 10^{-9} m$

$x_{n+1} - x_n = \frac{2.5 \times 10^{-3}}{10} = 2.5 \times 10^{-4} m$

also $\tan\theta = \frac{\lambda}{2(x_{n+1}-x_n)}$ $\frac{t}{x} = \tan\theta$

$\frac{t}{x} = \frac{\lambda}{2(x_{n+1}-x_n)}$

$t = \frac{x\lambda}{2(x_{n+1}-x_n)} = \frac{5.0\times10^{-2}\times500\times10^{-9}}{2\times2.5\times10^{-4}} = 5\times10^{-5}m$

The diameter of the wire is $5\times10^{-5}m$

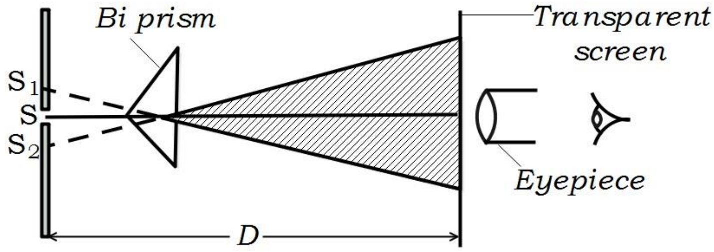
ACTIVITY 4

3. Two plates 12.0cm long are in contact at one end and separated at the other end by a piece of metal foil 2.5×10^{-3} cm thick. When the plates are illuminated normally by light of wavelength 500nm, a system of fringes is observed. Find the
   (i) fringe separation
   (ii) number of fringes formed
4. Two glass slides in contact at one end are separated by a metal foil 12.5 cm from the line of contact to form an air-wedge. When the air-wed is illuminated normally with light of wavelength 5.4×10^{-7}m, interference fringes of separation 1.5 mm are formed. Find the thickness of the metal foil.
5. Two glass plates 4 cm long touch at one end and are separated by a piece of paper 0.02 mm thick at the other end. The wedge formed is illuminated normally by bright light of wavelength 589nm.
   Calculate the
   (i) separation of the bright bands produced
   (ii) number of bright bands observed

DAY 5

PRODUCTION OF INTERFERENCE FRINGES USING A SINGLE SLIT

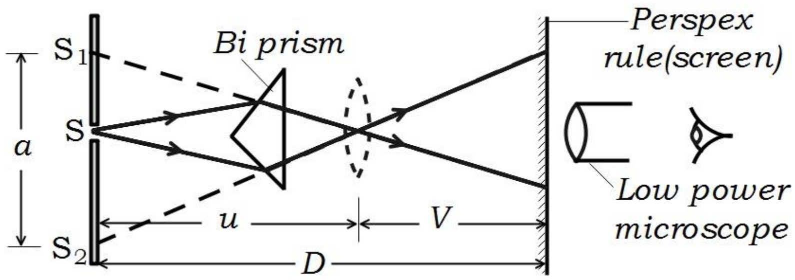
(a) Bi prism



The experiment is arranged as seen in the diagram. Light from a monochromatic source S is incident at the two halves of the bi prism. The light emerging after refraction from the two halves of the bi prism appear to be coming from S_1 and S_2. Therefore, S_1 and S_2 are virtual images of S and are coherent sources which are close together.

Waves which appear to be coming from S_1 and those which appear to be coming from S_2 overlap and interference fringes are observed using a microscope.

Measurement of wavelength using a bi prism



Monochromatic light from the slit S falls on the bi prism and alternate bright and dark bands are observed through the low power microscope.

A Perspex rule is placed in front of the microscope and moved until the graduations are clearly seen.

The average distance y between the bands is then measured on the Perspex rule. The distance D between the slit and the Perspex rule is measured using a metre rule in mm.

A convex lens is placed between the bi prism and the Perspex rule adjusted until the images of S_1 and S_2 are clearly seen on the Perspex rule.

The separation of the images x is measured. Distances u and V are also measured.

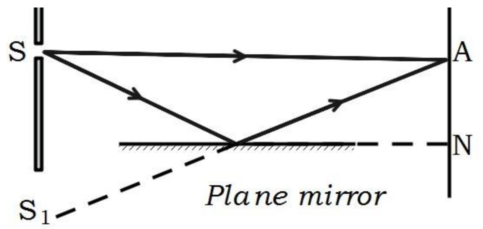
The shift separation a is obtained from $a = \frac{u}{V}x$

Wavelength is then given by $\lambda = \frac{ay}{D}$

N.B

A bi prism is preferred over Young's double slit experiment in determination of wavelength because in a bi prism, the fringes are much brighter than those produced by Young's slits. This is because much greater amount of light can pass through the bi prism compared with that passing through the double slits.

(b) Lloyd's mirror



The experiment is arranged as seen in the diagram. Light from S falls on a mirror at a very small glancing angle and a virtual image S_1 of S is formed by reflection at the surface of the mirror.

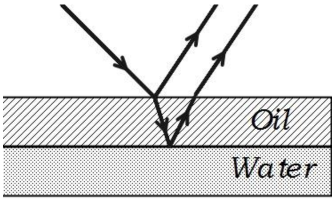
The reflected beam and the directed beam are coherent. When they overlap, a series of alternate bright and dark bands are formed.

The zeroth fringe at N will be dark due to 180^0 phase change.

In the directions where the path difference is a whole number of wavelength, dark fringes are formed. If it is an odd number of half wavelengths, bright fringes are formed.

Effects of interference (every day example)

(a) Colours of oil film on water



When monochromatic light falls on the oil some light is reflected from the surface of the oil while the other is refracted into the oil film and finally reflected at the oil-water surface. The beams of light reflected from the surface of the oil and that reflected from the oil-water surface are coherent. When they overlap, a series of alternate bright and dark fringes are formed.

When the path difference gives a constructive interference for light of one wavelength, the corresponding colour is seen in the film.

N.B

Interference patterns are not observed in thick films because in thick films, the path differences are many and therefore there are many wavelengths. This makes the spread in wavelength of light used to become significant. When one component produces a bright fringe, the other produces a dark fringe and vice versa as a result interference patterns are not observed.

(b) Pulsing of the picture on a television receiver

This occurs when an aircraft passes low overhead. The signals travelling directly from the transmitting aerial to the receiving aerial and those reflected from the aircraft interfere. Because the waves reflected from the aircraft are weaker, the interference is never completely destructive.

DIFFRACTION OF LIGHT WAVES

Diffraction is the spreading of light beyond its geometrical shadows thus leading to interference pattern on the edges of the shadow.

For diffraction to occur the dimensions of the obstacle must be of the same order as the wavelength of the light used.

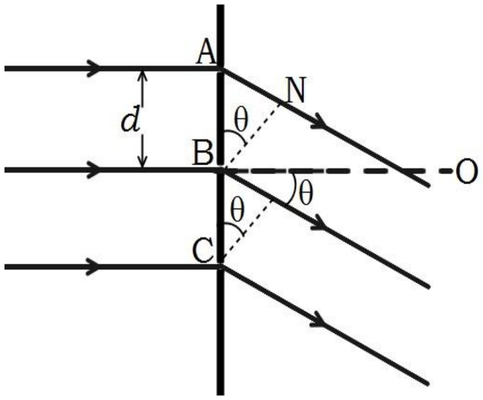
Differences between diffraction and interferences

Diffraction	Interference
Is the spreading of light beyond its geometrical shadows thus leading to interference pattern on the edges of the shadow	Is the superposition of light waves from coherent sources leading to alternate regions of maximum and minimum intensities
Involves superposition of waves from different parts of the same wave front	Involves superposition of waves two different wave fronts

The diffraction grating

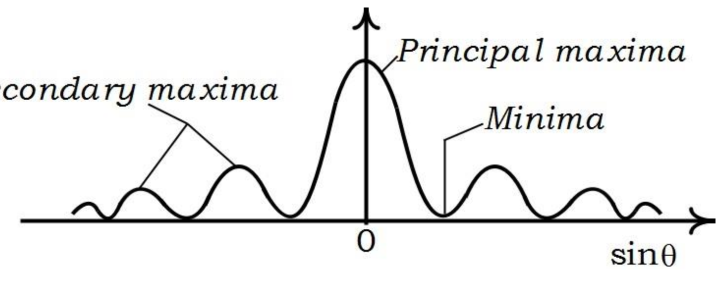
A diffraction grating is the arrangement of identical equally spaced diffracting elements Or A diffraction grating is a large number of close parallel slits, ruled on glass or metal.

Diffraction at single slit

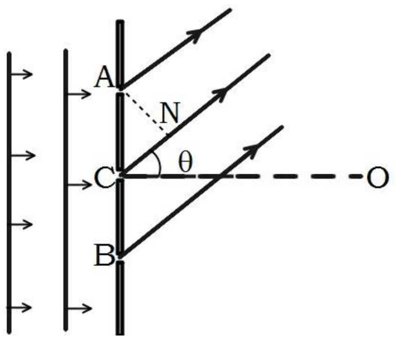


The figure represents a section of a diffraction grating which is being illuminated normally by light of wavelength λ. Each of the clear spaces A, B, C act like a very small narrow slit and diffracts the incident light to an appreciable extent in all the forward directions.
Consider that light which is diffracted at some angle θ to the normal.
The slits are equally spaced and if θ is such that light from A is in phase with that at B and C, then light from each slit is in phase with that from every other.
This happens when $AN = n\lambda$ where $n = 0,1,2,3, \ldots$ ...
n is called the diffraction order.
But $AN = d \sin\theta$
Therefore, $d \sin\theta = n\lambda$ this is called diffraction maxima.
Principal maximum is obtained when $n = 0$ Grating spacing $d = \frac{1}{e}$
where e is the number of lines per metre

N.B
If the screen is placed beyond the grating, the intensity distribution will consist of diffraction maxima of equal intensity.
<u>Variation of intensity with angular position for a single slit diffraction</u>



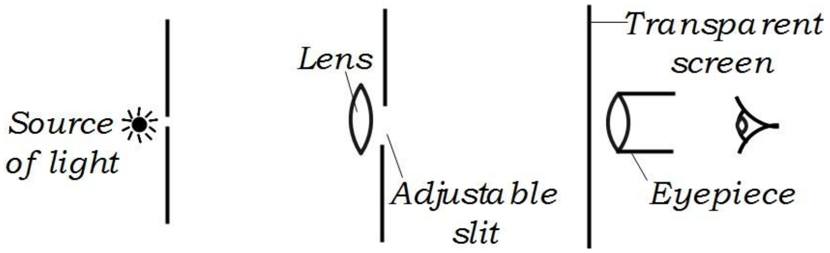
<u>Explaining the formation of the single slit diffraction pattern</u>



- Every point on AB is imagined to be a source of secondary spherical wavelet

- At O, all wavelets from each point on AB arrive in phase, constructive interference takes place and therefore there is a bright band, forming the central maximum.
- If C is the mid-point of the slits, the first dark bands on either side of the central band are formed. In the direction θ, if the path difference for wavelets from A and C is $\frac{\lambda}{2}$, there is distinctive interference and the first minima is formed. Between two minima there is a subsidiary maximum.

An experiment to observe diffraction of light



The slit is opened wide and the lens is moved to give a sharp image of light on the screen.
Observing through the eyepiece, the slit width is gradually reduced until a white central band having dark bands on either side fringed with colour is obtained.

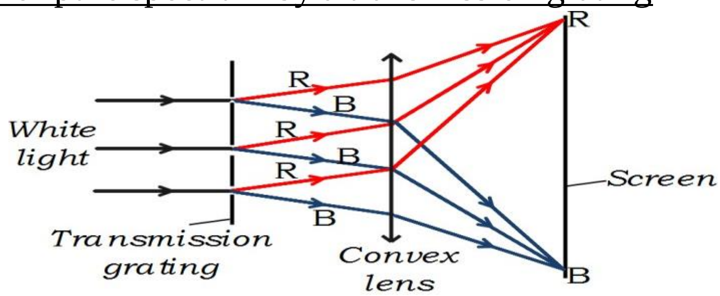
Effect on the diffraction pattern of using a grating with a large number of lines

A large number of slits produces what can be considered to be completely destructive interference in all directions other those produced by d sin $\theta = n\lambda$ and therefore gives rise to very sharp principal maxima.

Why the sky appears blue on a clear day

Sunlight consists of many wavelengths extending from red to violet. When it passes through the atmosphere, the shorter wavelength blue is scattered more than other longer wavelength in the atmosphere. The blue scattered short wavelength light is what makes the sky appear blue.

Formation of pure spectrum by a transmission grating



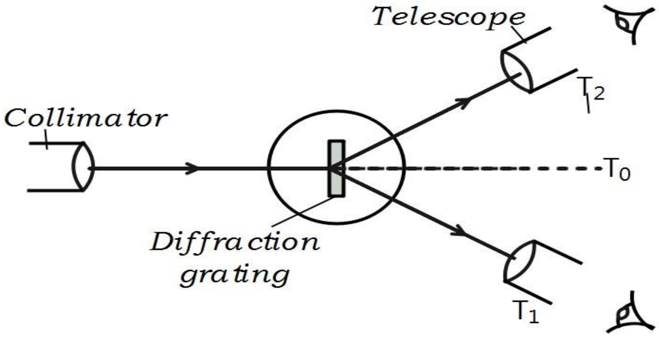
White light is made incident on a diffraction grating. A convex lens is then placed in front of the grating and a screen is placed in the focal plane of the lens. Different wavelengths are deviated by different amounts and hence travel in different directions.
The lens focuses all the corresponding colour image at the same point. A pure spectrum is then formed on the screen.

Uses of diffraction of light

- Determination of wavelength
- Determining the structure of crystals

- Holography (production of 3-dimensional images)

Measurement of wavelength using a diffraction grating



- The collimator is adjusted to produce a parallel beam of light.
- The telescope is adjusted to receive a parallel beam of light from the collimator.
- The table is levelled.
- The diffraction grating is fixed on the table such that light from the collimator is incident on it normally.
- The telescope is adjusted to receive light directly from the collimator (zero order image). Position T_0 is noted on the scale.
- The telescope is turned to one side to observe the first image. The position T_1 of the telescope is noted on the scale.
- The telescope is moved back to position T_0 and then rotated in opposite direction to observe the first order image.
- The position T_2 of the telescope is noted on the scale.
- The angle θ between the two positions T_1 and T_2 is determined.
- Wavelength is calculated from $\lambda = d\sin\left(\frac{\theta}{2}\right)$ where d is the grating spacing.

Advantages of transmission grating over glass prisms in determining wavelength

- A transmission grating leads to direct determination of wavelength while use of a prism requires a complicated formula.
- By using diffraction orders, an average wavelength can be determined while the prism method yields only one value hence the transmission grating gives a more accurate value of wavelength.

Examples

1. Light of wavelength 6.0×10^{-7} m is incident on a diffraction grating with 500 lines per centimeter. Find the diffraction angle for the first order image.

$d\sin\theta = n\lambda$

$e = \frac{500}{cm} = 500 \times 100$ lines per metre, $n = 1$, $\lambda = 6.0 \times 10^{-7}$m

$d = \frac{1}{e} = \frac{1}{500\times100}$

$\frac{1}{500\times100}\sin\theta = 6.0 \times 10^{-7}$

$\sin\theta = 6.0 \times 10^{-7} \times 500 \times 100$

$\theta = 1.72°$

2. A transmission grating of 5×10^5 lines per metre is illuminated with light of wavelength 580 nm and 590 nm in turn. Calculate the
   (i) highest order spectrum observable
   (ii) angular separation of the two wavelengths in the second order spectrum

(iii) respectively orders for the two wavelengths to overlap

$e = 5 \times 10^5$ lines per metre,
$d = \frac{1}{e} = \frac{1}{5\times10^5}$
$\lambda_1 = 580 \times 10^{-9}m$ and
$\lambda_2 = 590 \times 10^{-9}m$ $d \sin\theta$ n For
n_{max}, $\sin\theta = 1$
$d = n_{max}\lambda$
$n_{max} = \frac{d}{\lambda} = \frac{1}{5\times10^5} \times \frac{1}{580\times10^{-9}} = 3$
For $\lambda_2 = 590 \times 10^{-9}m$
$n_{max} = \frac{d}{\lambda} = \frac{1}{5\times10^5} \times \frac{1}{590\times10^{-9}} = 3$
(ii) $d\sin\theta_1 = n\lambda_1$
$\frac{1}{5\times10^5}\sin\theta_1 = 2 \times 580 \times 10^{-9}$
$\sin\theta_1 = 2 \times 580 \times 10^{-9} \times 5 \times 10^5$
$\theta_1 = 35.45°$
$d\sin\theta_2 = n\lambda_2$
$\frac{1}{5\times10^5}\sin\theta_2 = 2 \times 590 \times 10^{-9}$
$\sin\theta_2 = 2 \times 590 \times 10^{-9} \times 5 \times 10^5$
$\theta_2 = 36.16°$

Angular separation
$\theta_2 - \theta_1 = 36.16° - 35.45° = 0.71°$
(iii) Overlap occurs when
$n_1\lambda_1 = n_2\lambda_2$
$580n_1 = 590n_2$
$58n_1 = 59n_2$
Therefore 58th and 59th are the nodes

ACTIVITY 4

1. Light consisting of two wavelengths which differ by 160 nm passes through a diffraction grating with 2.5×10^5 lines per metre. In the diffraction light, the 3rd order of one wavelength coincides with the 4th order of the other. What are the two wavelengths and at what angle of diffraction does the coincidence occur?

3. A rectangular piece of glass 2cm × 3cm has 18000 evenly spaced lines ruled across its surface parallel to the shorter side, to form a diffraction grating. Parallel rays of light of wavelength 5×10^{-7} cm fall normally on the grating.
   a i) Find the highest order of spectrum in the transmitted light.
   ii) What is the minimum diameter of a camera lens which can accept all the light of this wavelength in this order which leaves the grating on one side of the normal?
   b) A light source emits two wavelengths of 450 nm and 650 nm. The light is incident normally on a phase diffraction grating of 600 lines per mm.
   Find the
   (**i**) angular separation of these lines in the second order diffraction
   (ii) the respectively orders for the two wavelengths to overlap.

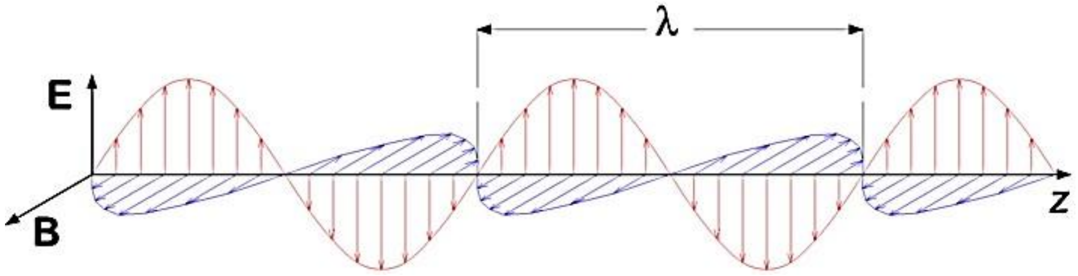
4 a) Describe how interference fringes can be produced using a single slit
  b) State difference between diffraction and interference

DAY 5

PRODUCTION OF POLARIZED LIGHT

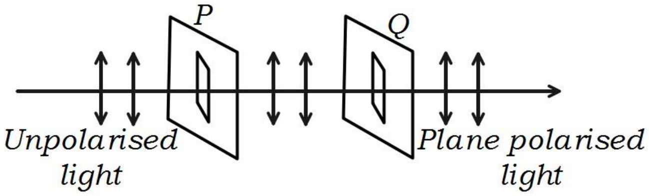
Unpolarised light is one in which vibrations exist in every plane perpendicular to the directions of the travel of the wave.
Polarisation is the production of light whose vibration of the electric vector is in only one plane.

Plane polarised light is the light whose electric field vector oscillates in one particular plane perpendicular to the direction of propagation.



<u>PRODUCTION OF POLARIZED LIGHT</u>

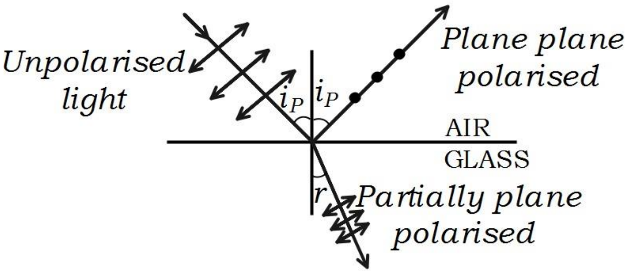
1. Selective absorption



Two Polaroid sheets P and Q are placed one behind the other in front of a source of light. With axes of P and Q parallel, light of maximum intensity is observed beyond Q. When Q is rotated about the direction of propagation, the intensity of light that emerges from it decreases. When its axis is perpendicular to that of P, light is cut off. When Q is rotated further, light reappears becoming bright again when axes of P and Q are parallel. The light emerging from P and Q is now plane polarised or linearly polarised.

Or A Polaroid is an artificial crystalline material which can be made in thin sheets which allow only light waves due to vibrations in a particular plane to pass through them.

2. Production of plane polarised light by reflection



Ordinary light is made incident on glass at an angle of about 57°. The reflected light is then viewed through a polaroid. The polaroid is rotated about the line of vision until light disappears at one position of the polaroid. This happens when the reflected ray is perpendicular to the refracted ray. The reflected light is then plane polarised.

Note

When the refracted ray is not at right angles to the reflected ray, the vibrations of incident light with a component which is perpendicular to the direction of propagation of the reflected ray can contribute to it and produce a reflected ray which is partially plane polarised.

If n is the refractive index of the glass, $n = \frac{\sin i}{\sin r}$

But $iP + 90° + r = 180°$

$r = 90° - i_P$

$\sin r = \sin(90° - i_P) = \cos i_P$

$n = \frac{\sin i_P}{\cos i_P}$

$n = \tan i_P$ [Brewster's law]

i_P is called the angle of polarisation/polarizing angle.

It is defined as the angle of incidence at which the reflected ray is completely plane polarised.

From $n = \tan i_P$ and since n varies with the colour of light, white light can not be completely plane polarised by reflection.

<u>Example</u>

1. The polarizing angle for light in air incident on a glass plate is 57.5°. What is the refractive index of glass?

   $n = \tan i_P$

   $n = \tan 57.5° = 1.57$

2. The refractive index of diamond for sodium light is 2.417. Find the angle of incidence for which the light reflected from diamond is completely plane polarised.

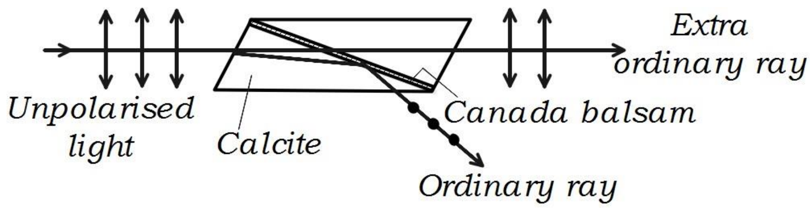
   $n = \tan i$

   $2.417 = \tan i$

   $i = \tan^{-1}(2.417)$

   $i = 67.5°$

3. Polarisation by double refraction using Nicol prism

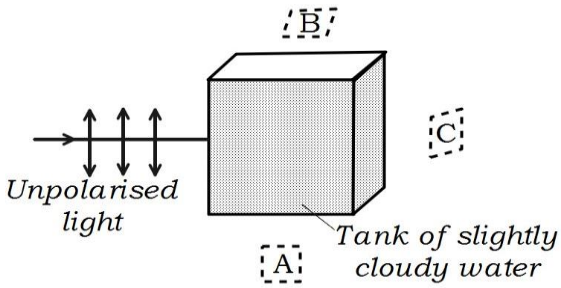


A narrow beam of ordinary light is made incident on one side of a Nicol prism and is observed from the opposite side through an analyser.

The angle of incidence i is varied by rotating the prism and for each angle; the analyser is rotated about the line of vision.

Beyond some angle of incidence, the intensity of light seen through the prism varies and finally at one position of the prism, light disappears. The emergent light is then plane polarised.

4.



Polarisation by scattering

A beam of ordinary light is passed through tank water in which a drop of milk has been added. Light is seen through a polaroid placed at different positions A, B and C. when the polaroid is rotated about the line of vision, light disappears at one position. The light is then plane polarised.

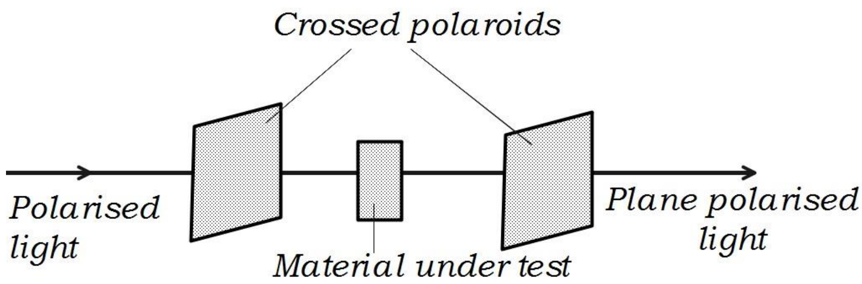
Application of polarisation

1. Reducing glare

Glare caused by light is reflected from smooth surfaces can be reduced by using polaroid discs suitably oriented in sunglasses.

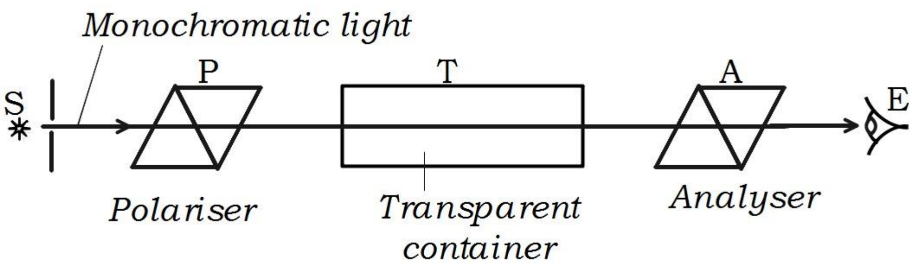
Polaroid discs are also used in cameras as filters to enable the camera to see details that would otherwise be hidden by glare.

2. Photo elasticity (stress analysis)



A material under stress becomes doubly refracting and if viewed in white light between two crossed polaroids, coloured fringes are seen round regions of strain.

3. Saccharimetry (measurement of concentration of sugars in sugar solutions)



Polarised light from a polariser, P, is made incident onto an empty transparent container and observed through the analyser A. A is rotated about the line of vision until light is cut off.

A liquid under test is put in the container, the liquid rotates the plane of vibration of polarised light passing through and light is then observed at E.

The analyser is rotated again until light is cut off. The angle of rotation is measured and is proportional to the concentration of the solution

4. In liquid crystal displays (L.C.Ds)

ACTIVITY 5

1 a i) define the terms amplitude and intensity as applied to waves.

ii) Briefly describe an experiment to show that a wire under tension can vibrate with more than one frequency.

b) A uniform wire of length 1.0m and mass 2.0×10^{-2}kg is stretched between two fixed points. The tension in the wire is 200N. The wire is plucked in the middle and released.

i)Show that fn=nf_o where f_n is the frequency of the nth note and f_o is the fundamental frequency

i) Calculate the Frequency of the fundamental note

2. (i) describe an experiment to determine the beat frequency of a note.

(ii) Derive an expression for the beat frequency.

3.(a) (i) Define the term ***interference*** of light waves.

(ii) Explain with the aid of a diagram how interference occurs in an air-wedge.

c) An air-wedge film formed by placing an Aluminium foil between two glass slides at a distance of 75 mm from the line of contact of the slides. When the air wedge is illuminated normally, by light of wave length 5.60×10^{-7} m, parallel interference fringes of separation 1.20 mm are produced. Calculate the;

(i) angle between the slides.

(ii) thickness of the Aluminium foil.

d) (i) What is ***plane polarized light?***

(ii) Describe with the aid of a labelled diagram, one application of plane polarized light.

e) (i) Describe an experiment to determine the wavelength of light waves used in a diffraction grating.

(ii) A parallel beam of sodium light of wavelength 5.89×10^{-7} m is incident normally on a diffraction grating having 6000 lines per cm. Find the angle for which the second order image will be seen.

DAY 6

BEATS

Beats are the periodic rise and fall in the intensity of sound.

Beats are formed when two sounds of nearly equal frequencies but similar amplitudes are sounded together. When the two sounds arrive at the ear in phase, a loud sound is heard. When the two sounds arrive at the ear when they are 180^0 out of phase, a minimum sound is heard.

Beat frequency

Beat frequency is the number of intense sounds heard in one second if two notes f nearly equal frequencies are sounded together.

Consider two notes A and B whose frequencies are f_1 and f_2 respectively.

In some time, T, A completes f_1T cycles and B completes f_2T cycles.

If T is such that A completes one more cycle than B, then

$f_1T - f_2T = 1$

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

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

$f_1 - f_2 = f$

Example

1. Tuning forks x and y are sounded together to produce beats of frequency 8Hz. Fork x has a frequency of 512 Hz. When y is loaded with plasticine, beats of frequency 2Hz are head when the two tuning forks are sounded together. Find the difference in frequencies of y when loaded and when unloaded.

Solution

Since beats decrease when y is loaded, then $f_y > f_x$

$f_y - f_x = 8$

$f_y - 512 = 8$

$f_y = 520$ Hz

$f'_y - f_x = 2$

$f'_y - 512 = 2$

$f'_y = 514$

Difference $= 520 - 514 = 6$Hz

2. A tuning fork of frequency 312 Hz is sounded with a fork of unknown frequency f, 4 beats per second are heard. When a little plasticine is added to the prongs of the fork, the beats decrease in number. Find the value of f.

Solution

Let $f_1 = 312$Hz

Since on adding plasticine beats decrease,

$f > f_1$

$f - f_1 = 4$

$f - 312 = 4$

$f = 316$ Hz

Demonstration of beats

Two tuning forks of the same frequency are used. A little plasticine is stuck on one prong of one the tuning fork to lower its frequency slightly.

The two tuning forks are then struck simultaneously and the stems pressed against the bench top.

Uses of beats

1. Measuring frequency of a note by use of another note of known frequency The note of unknown frequency f_1 is made to produce beats with a note of known frequency f_2 as long as f_1 and f_2 are almost the same.

The number of beats in t seconds, n, are counted and the beat frequency $f_b = \frac{n}{t}$ calculated.
One of the frequencies is changed slightly and the experiment repeated.
The new beat frequency $f_b{}'$ is determined.
If $f_b > f_b{}'$, the frequency of the test note is calculated from $f_1 = f_2 - f_b$
If $f_b < f_b{}'$, the frequency of the test note is calculated from $f_1 = f_2 + f_b$

2. Tuning of musical instruments to a given note

The musical note is sounded together with a tuning fork of known frequency f_1. The number of beats in t seconds, n, are counted and the beat frequency $f_b = \frac{n}{t}$ calculated. One of prong of the tuning fork is loaded with a piece of plasticine and the experiment is repeated.

The new beat frequency f_b' is determined.
If $f_b > f_b'$, then the frequency of the test note f_n is calculated from $f_n = f_1 - f_b$
If $f_b < f_b'$, the frequency of the test note f_n is calculated from $f_n = f_1 + f_b$

Conditions necessary for the formation of audible beats

- Notes of nearly equal frequencies are sounded together
- The notes sounded together should have the same amplitudes
- Sound waves from the two sources must overlap.

DOPPLER EFFECT

Doppler Effect is the apparent change in frequency of a wave motion when there is a relative motion between the observer and the source.

Uses of Doppler effect

- Determination of direction of motion of stars
- Determination of plasma temperature
- Estimation of speed of cars using speed guns
- Estimation of speed of stars
- Measurement of speed of rotation of the sun

(a) Used by police to estimate the speed of the car using speed guns

The speed of a car can be found by measuring the shift in frequency by the microwaves reflected by it. If a car is moving with a speed V towards stationary microwaves of frequency f, the car acts as observer moving towards a stationary source.

The speed of the car is calculated from $V = \frac{c\Delta f}{f}$ where Δf is the beat frequency

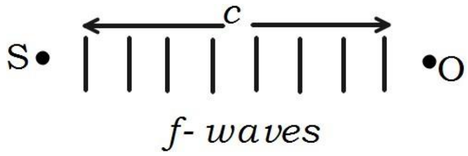
(b) Estimating the speeds of distant stars

The photo graph of a star is taken. The position of a particular spectral line and its wavelength λ' are noted. The spectral photograph of a spark is taken in a laboratory.
The spectral line and its wavelength λ corresponding to an element known to be in the star is compared with one above.
If $\lambda' > f$ (red shift), the star is moving away from the earth.
If $\lambda' < f$ (blue shift), the star is moving away towards the earth.
The speed of the star is calculated from $V = \frac{c\Delta\lambda}{\lambda}$ where $\Delta\lambda$ is the wavelength shift

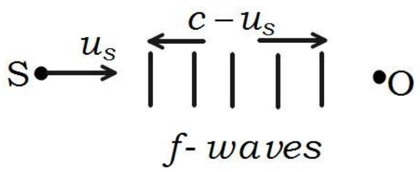
(c) Calculation of apparent frequency Let u_s be the speed of the source of sound
u_0 be the speed of an observer
f be the true frequency of the source
c be the speed of sound in air

1. Source moving towards a stationary observer

If the source was stationary, f −waves would occupy a distance c in one second



If the source
moves with a speed u_s towards a stationary observer in one second, f −waves will occupy a distance $c - u_s$.



Apparent wavelength $\lambda' = \frac{c-u_s}{f}$

Apparent frequency $f' = \frac{c}{\lambda'}$

$f' = \left(\frac{c}{c-u_s}\right) f$

Since $c - u_s$ is less than c, f' is greater than f and so the apparent frequency increases as the source moves towards the observer.

<u>Example</u>

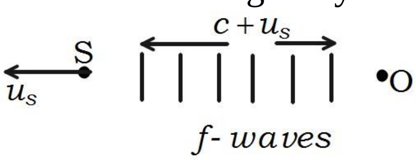
1.A police car travelling at a speed of 50 ms^{-1} sounds a siren of 1000 Hz as it approaches a stationary observer. Find the apparent frequency as heard by the observer if the speed of sound in air is 340 ms^{-1}.

Apparent wavelength $\lambda' = \frac{c-u_s}{f}$ Apparent frequency $f' = \frac{c}{\lambda'}$

$f' = \left(\frac{c}{c-u_s}\right) f$

$f' = \left(\frac{340}{340-50}\right) \times 1000 = 117.4$ Hz

2. Source moving away from a stationary observer



In one second, f −waves will occupy a distance $c + u_s$

Apparent wavelength $\lambda' = \frac{c+u_s}{f}$ Apparent frequency $f' = \frac{c}{\lambda'}$

$f' = \left(\frac{c}{c+u_s}\right) f$

Since $c + u_s$ is greater than c, f' is less than f and so the apparent frequency decreases as the source moves towards the observer.

<u>Example 2</u>

A car travelling at 72 kmh^{-1} has a siren which produces sound of frequency 500 Hz. Calculate the difference between the frequencies of sound heard by the observer by the roadside as the car approaches and recedes the observer. Speed of sound in air is 320ms^{-1}.

72 $\text{kmh}^{-1} = \frac{72\times1000}{3600} = 20\ \text{ms}^{-1}$

Case 1: Approaching

Apparent wavelength $\lambda' = \frac{c-u_s}{f}$

Apparent frequency $f' = \frac{c}{\lambda'}$

$f' = \left(\frac{c}{c-u_s}\right) f$

$f' = \left(\frac{320}{320-20}\right) \times 500 = 533.33$ Hz

Case 1: Receding

Apparent wavelength $\lambda' = \frac{c+u_s}{f}$ Apparent frequency $f' = \frac{c}{\lambda'}$

$f' = \left(\frac{c}{c+u_s}\right) f$

$f' = \left(\frac{320}{320+20}\right) \times 500 = 470.58$ Hz

Difference = 533.33 − 470.58 = 62.75 Hz

N.B

1.Observer moving towards a stationary source In this case the wavelength does not change. In one second, f −waves occupy a distance c

Wavelength $\lambda = \frac{c}{f}$

The velocity of the waves relative to the observer $V' = c + u_0$

Apparent frequency $f' = \frac{relative\ velocity\ of\ the\ waves}{wavelenght}$

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

$f' = \left(\frac{c+u_0}{c}\right) f$

2.Observer moving away from a stationary source In one second, f −waves occupy a distance c

Wavelength $\lambda = \frac{c}{f}$

Velocity of the waves relative to the observer $V' = c - u_0$

Apparent frequency $f' = \frac{relative\ velocity\ of\ the\ waves}{wavelenght}$

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

$f' = \left(\frac{c-u_0}{c}\right) f$

3.Observer and source moving toward each other

Apparent wavelength $\lambda' = \frac{c-u_s}{f}$

Velocity of the waves relative to the observer $V' = c + u_0$

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

$f' = \left(\frac{c+u_0}{c-u_s}\right) f$

4.Observer and source moving away from each other

Apparent wavelength $\lambda' = \frac{c+u_s}{f}$

Velocity of the waves relative to the observer $V' = c - u_0$

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

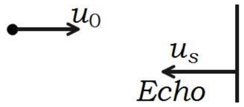
$f' = \left(\frac{c-u_0}{c+u_s}\right) f$

Example 1

A car traveling normally towards a cliff at a speed of 30ms^{-1} sounds its horn which emits a note of frequency 100 Hz. What is the apparent frequency of echo as heard by the driver? Speed of sound in air is 330 ms^{-1}.

Velocity of the waves relative to the observer $V' = c + u_0$

Apparent wavelength $\lambda' = \frac{c-u_s}{f}$



Apparent frequency $f' = \frac{V\prime}{\lambda}$

$f' = \left(\frac{c+u_0}{c-u_s}\right) f$

$f' = \left(\frac{330+30}{330-30}\right) \times 100 = 120$ Hz

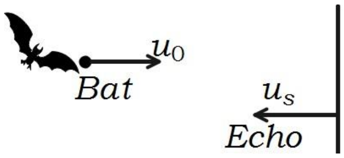
Apparent frequency of the echo is 120Hz

Example 2

One species of bats locates obstacles by emitting high frequency sound waves and detecting reflected waves. A bat flying at a steady speed of 5 ms^{-1} emits sound of frequency 78 kHz and is reflected back to it. Calculate the frequency of sound received by the bat.
Speed of sound in air is 340 ms^{-1}.

Velocity of the waves relative to the observer $V' = c + u_0$

Apparent wavelength $\lambda' = \frac{c-u_s}{f}$ Apparent frequency $f' = \frac{V\prime}{\lambda}$



$f' = \left(\frac{c+u_0}{c-u_s}\right) f$

$f' = \left(\frac{340+5}{340-5}\right) \times 78000 = 80328$ Hz

Frequency received by the bat is 80328Hz

ACTIVITY 6

1._A whistle of frequency 1000 Hz is sounded on a car travelling towards a cliff with a speed of 18 ms^{-1}, normal to the cliff. Find the apparent frequency of echo as heard by the driver. Speed of sound in air is 330 ms^{-1}.

2._A source of sound waves generates waves of frequency 500 Hz. If the speed of sound in air is 340 ms^{-1} find the

(i) wavelength of the waves detected by the observer when the source is moving away from the observer at a speed of 30 ms^{-1}

(ii) apparent frequency when the source is moving towards the observer and the observer is moving away at a speed of 20 ms^{-1}.

(i) Apparent wavelength

(ii) Apparent wavelength

3.(a) (i) Define wave length and phase difference

(ii) Using parallel wave fronts, explain why convex lenses converge light

(b)The speed of sound in a medium is given by

Speed = $\frac{\sqrt{elastic\ modulus\ of\ a\ medium}}{density\ of\ the\ medium}$

(c) Explain the effect of humidity on the Speed of sound in air

4.(a) A wire of diameter 0.04cm and made of steel of density 8000kgm-3 is under constant tension of 80N. When a fixed length of 50cm is plucked in the middle, it resonates with an open tube of length 32cm sounding its fundamental note.

Find the

(i) End correction of the tube

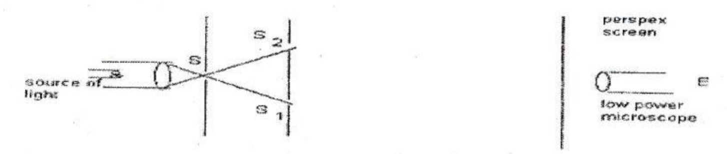
(ii) Frequency of the beats produced with the tube when only 40cm of the wire is used**.**

(b) (i) Explain what is meant by beats. (ii) Describe how the frequency of a note can be determined using beats.

5.(a) List three differences between mechanical and electromagnetic waves.

(b) (i) What are the conditions for production of observable interference of light

(iii) Describe how interference patterns are produced in Young's double slit experiment.



(c) The above set up is used to produce interference patterns on the Perspex screen.

(i) Describe how you would use the above set up to compare the wave lengths of green and red lights.

(ii) Explain what would be observed when the double slits S_1 and S_2 are moved farther away from the primary slit S.

DAY 7

MUSICAL SOUNDS

Sound is any mechanical vibration whose frequency lies within the audible range.

How sound waves propagate from one point to another

When a medium is set into vibration, the molecules vibrate to and from about their mean positions. The vibrating molecules pass on energy to the neighbouring molecules. These molecules vibrate and on energy. Compressions and rarefactions are then formed and sound is propagated.

Music and noise

A sound of regular frequency is called a tome or a musical note. Music is a combination of such sounds.

Noise is a sound which is not wanted or unpleasant to the ear.

Musical intervals

The ratio of frequencies between two notes is called a musical interval

Characteristics of sound notes (differences between musical sounds)

(a) Pitch

A pitch is a characteristic of a note which enables one to differentiate between a high note and a low note.

It depends on

- frequency of sound produced
- relative motion between the source and the observer

(b) Intensity and loudness

Intensity of a sound wave is the rate of flow of energy through an area of 1 m^2 perpendicular to the direction of flow of the sound wave.

It depends on

ii) amplitude of vibrating body i.e intensity is directly proportional to the square of the amplitude

iii) distance from the vibrating body i.e intensity is inversely proportional to the square of the distance from the vibrating body.

iiii) Area of the vibrating surface i.e intensity is directly proportional to the surface area of the vibrating body

iiv) density of the medium i.e intensity is directly proportional to the density of the medium in which it vibrates

iv) motion of the medium i.e if the wind blows in the direction in which sound travel, the intensity increases if the wind blows in opposite direction, intensity decreases

Loudness

Loudness is the sensation of a note in the mind of an individual. It depends on

a. sound intensity of the sound reaching the person concerned and on the person
b. sensitivity of the ear to the different frequencies
c. variation of pressure exerted on the ear drum by the nerves

(c) Quality/timbre

This is a characteristic of a musical note which enables us to distinguish a note produced by one instrument from another of the same pitch and intensity.

Similarities between sound and light waves

Both can be reflected and refracted

- Both can be diffracted and undergo interference

Differences between sound waves and light waves

Light waves	Sound waves

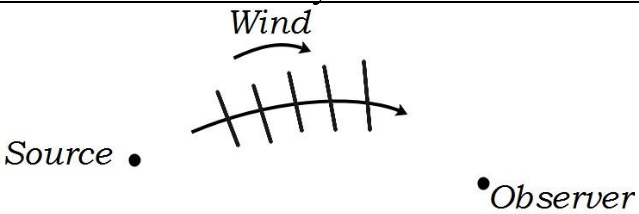
Do not need a material medium for propagation	Need a material medium for propagation
Are transverse in nature	Are longitudinal in nature
Can undergo plane polarisation	Cannot undergo plane polarisation
Travel much faster in air	Travel slower in air

<u>Sound is easily heard at night than during the day</u>

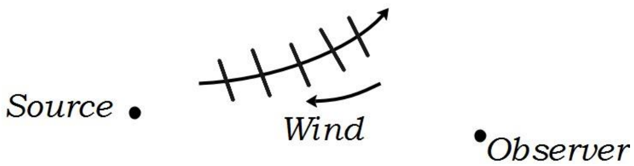
During the day, the air near the earth is warmer than air higher up. As sound wave moves upwards, its speed reduces and sound is refracted away from the earth hence sound intensity reduces.

At night the air near the earth is colder than air higher up. As sound wave moves upwards, its speed increases and sound is refracted towards the earth hence sound intensity increases.

<u>Sound is heard clearly when the wind blows in the direction in which sound travels</u>



When wind is blowing towards the observer the bottom of the sound wave front is moving more slowly than the upper part. The wave fronts turn towards the observer who therefore, hears sound easily.



When wind is blowing in opposite direction, the bottom of the sound wave front is moving faster than the upper part. The wave fronts turn upwards away from the observer. The intensity of sound reduces.

<u>Factors that determine the speed of sound in air</u>

- Temperature of the air
- Percentage of humidity in the air

(a) Temperature

The speed of sound is proportional to the square root of tits kelvin temperature.

Increase in temperature of air increases its volume in accordance to Charles' law. This therefore makes air less dense since $V \propto \frac{P}{\rho}$.

Decrease in density increases the speed of the sound in air hence sound travels faster in hotter air than in cold air.

(b) Humidity

Humid air is less dense. At a given pressure, the ratio of pressure to density increases with humidity. Since $V \propto \frac{P}{\rho}$, sound travels faster in humid air than dry air.

Reverberation

Reverberation occurs when the sound produced at one instant by a source is closely followed by its echo. This is due to the reflecting surface being very close. The observer fails to distinguish the original sound from the echo and gets an impression that the original sound has been prolonged.

Implications of reverberation in concert halls

In large halls, clothes, cushions and human skin absorbs the sound instead of reflecting it and consequently the music and speech appear to be weaker and in such cases reverberation of a small degree enhances audibility

Excess reverberation, however, makes the speech or music to sound indistinct and confused.

Minimizing reverberation

Reverberation is minimised by covering the wall of walls with soft materials so that there is reduced reflection of sound as most of the incident sound is absorbed by the soft materials.

The amplitude of a wave decreases as the distance from the source increases This is because as the distance from the source increases, there is a decrease in the intensity of the sound wave caused by

- loss of energy of the wave to the transmitting medium
- the wave energy spreading over a wide area to a point, a distance d from the source

Intensity $\propto \frac{1}{d^2}$ also Intensity $\propto a^2$

$a^2 \propto \frac{1}{d^2}$

$a \propto \frac{1}{d}$

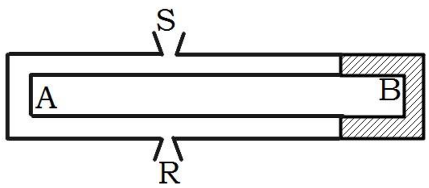
Therefore, the amplitude is inversely proportional to the distance of the wave from the source and so should decrease as the distance decreases.

Resonance

Resonance is said to occur when a system is set to vibrate at its natural frequency due to impulses received from a nearby system vibrating at the same frequency.

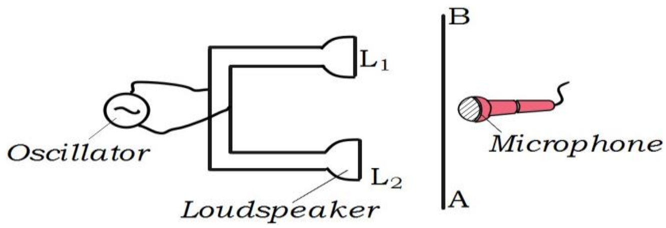
Experiment to demonstrate interference of sound waves

(a)



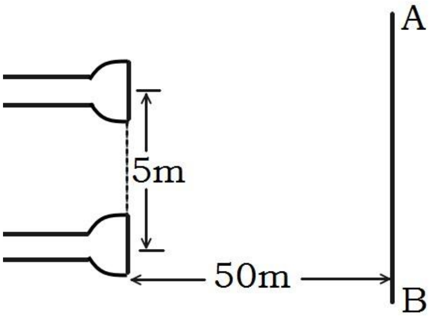
Sound from the source S is admitted into the tube as seen above. The tube is pulled outwards slowly. One wave follows a constant path SAR and the other follows a variable path SBR. As the sliding tube is pulled, a series of maximum and minimum intensities are obtained.

(b)



Two loudspeakers L_1 and L_2 are connected in parallel to an audio-frequency oscillator. A sensitive sound detector e.g. microphone is moved along line AB, parallel to the line joining the two loud speakers.
Alternate loud and soft sounds are heard.
Loud sound is heard where there is constructive interference i.e where sound waves from L_1 and L_2 arrive in phase.
Soft sound is heard where there is destructive interference i.e where sound waves from L_1 and L_2 arrive out of phase.

Example



Two loudspeakers which emit sound of the same frequency are placed as shown in the figure. A microphone moved along the line AB detects intensity maxima at regular intervals of 3.4m. Find the frequency of the sound waves emitted if the speed of sound in air is 340 ms^{-1}.

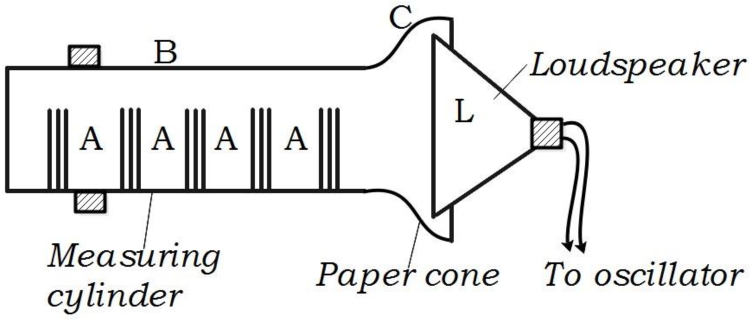
a = 5m D = 50m y = 3.4 m

$\lambda = \frac{ay}{D} = \frac{5\times3.4}{50} = 0.34$ m

$f = \frac{V}{\lambda} = \frac{340}{0.34} = 1000$ Hz

Therefore, frequency of sound waves is 1000 Hz

Determining the value of sound by dust tube method



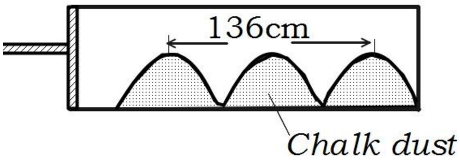
A measuring cylinder B is placed on its side lying horizontally on smooth supports. The inside of the cylinder is coated with lycopodium powder or chalk dust along its length. A paper cone C attached to a loudspeaker L is fitted over the open end of B.
L is connected to a suitable oscillator and sound waves are produced which travel to the closed end of B and are reflected to form a stationary wave.
The frequency of the oscillator is varied until the lycopodium powder settles into regularly spaced heaps in the cylinder. These are nodes N. The average distance between successive nodes is obtained and is equal to half wavelength $\left(\frac{\lambda}{2}\right)$.

The velocity of sound in air is calculated from $V = f\lambda$ where f is the frequency of the oscillator.

<u>Disadvantages of using dust tube method</u>

- The sound waves are damped by the sides of the tube and therefore the method does not give the speed of sound in free air
- The distance between successive nodes can not be measured to a high degree of accuracy
- The dust and the tune must be dry which may not be the case.

<u>Example 1</u>

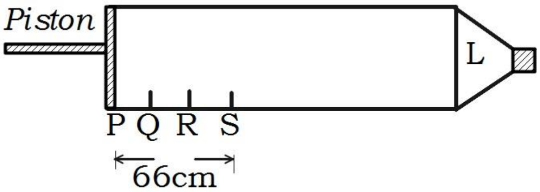


In an experiment to determine the speed of sound in air in a tube, chalk dust settles in heaps as shown in figure above. If the frequency of the vibrating rod is 250 Hz and the distance between three consecutive heaps is 136 cm, calculate the speed of sound in air.

$\lambda = 1.36$m $f = 250$ Hz $V = f\lambda = 250 \times 1.36$

$= 340$ ms^{-1}

<u>Example 2</u>



A tube T has a tight fitting piston at one end and a small loudspeaker L at the other end. Nodes are detected in air at Q, R and S where PS = 66cm. If the frequency of sound from L is 800Hz, determine the speed of sound in air.

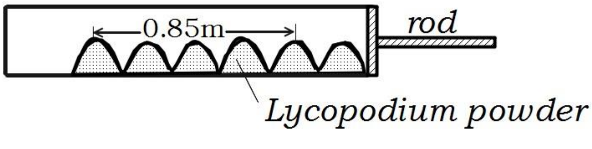
$\frac{3}{2}\lambda = 0.66$m $\lambda = \frac{2}{3} \times 0.66 = 0.44$m

$f = 800$ Hz

$V = f\lambda = 800 \times 0.44 = 352$ ms^{-1}

ACTIVITY 8

1.



In an experiment to the velocity of sound in air, lycopodium powder settles in heaps as shown in figure above. If the frequency of the vibrating rod is 800 Hz and the distance between five consecutive heaps is 0.85 m, calculate the speed of sound in air.

2.(a)Two glass slides in contact at one end are separated by a sheet of paper placed 15cm from the line of contact to form an air wedge. When the aid wedge is illuminated normally by light of wave length 5.8×10^{-7}m interference fringes of separation 1.7mm are found in reflection. Find the thickness of the paper.

(**b**)What is the effect of increasing the thickness of the sheet separating the glass slides and using light of longer wave length, on fringe separation?

(**c**) What is the effect of increasing the thickness of the sheet separating the glass slides and using light of longer waves length, on fringe separation.

3.(a)State the differences and similarities between sound and light waves.

(**b**) Using an experiment demonstrate the interference of sound waves.

4.A car sounds its horn as it travels at a speed of 15 ms^{-1} along a straight road between two stationary observers A and B. Observer A hears a frequency of 538 Hz while B hears a lower frequency. Calculate the frequency heard by B. Speed of sound in air is 340 ms^{-1}.

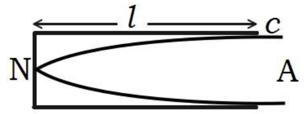
5. Calculate the frequency of beats (beat frequency) heard by a stationary observer when a source of sound of frequency 100 Hz moves directly away from him with a speed of 10 ms^{-1} towards a vertical wall.

DAY 9

PIPES

(a) Closed pipes

A closed pipe is the one which has one end closed and the other open.



The air column at A vibrates with maximum amplitude. This is the position of the antinode. The amplitude of vibration decreases from end A (maximum) to N (zero). N is the position of the node.

The length of the air column corresponds to the position of the antinode A. this position does not coincide with the end of the pipe but slightly above.

The difference between the end of the pipe and the position of the antinode is called the end correction, e.

The end correction is the length of a vibrating air column beyond the end of the resonance tube.

End correction increases the length of air in a pipe. This reduces the frequency of a note produced by the pipe. Since the pitch of a note depends on its frequency, end correction reduces the pitch of a note.

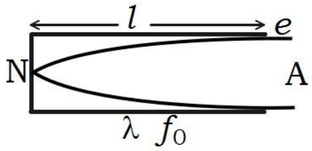
The fundamental frequency is lowest frequency that a vibrating string or pipe can produce.

A harmonic is a note whose frequency is an integral multiple of the fundamental note.

A fundamental note is note is a note of lowest frequency that a vibrating string or pipe can produce.

Overtones are notes of higher frequencies which are produced with the fundamental note.

Resonance in a closed pipe



For fundamental note, the length of the air column is equal to $\frac{\lambda}{4}$.

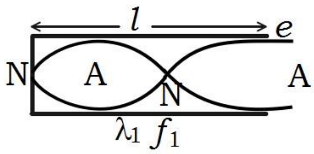
$l = \frac{\lambda}{4}$

$\lambda = 4l$

If f_0 is the fundamental frequency, (1st harmonic), $f_0 = \frac{V}{\lambda} = \frac{V}{4l}$ where V is the velocity of sound in air.

Overtones: First overtone (3rd harmonic)

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



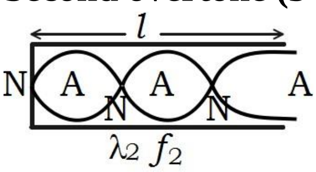
$\lambda_1 = \frac{4}{3}l$

$f_1 = \frac{V}{\lambda_1} = \frac{3V}{4l} = 3\frac{V}{4l}$

But $\frac{V}{4l} = f_0$

$f_1 = 3f_0$ this is the why it is called the 3rd harmonic.

Second overtone (5th harmonic)



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

$\lambda_2 = \frac{4}{5}l$

$f_2 = \frac{V}{\lambda_2} = \frac{5V}{4l} = 5\frac{V}{4l}$

But $\frac{V}{4l} = f_0$

$f_2 = 5f_0$ this is the why it is called the 5th harmonic.

Therefore, in closed pipes, only odd harmonics are possible. i.e f_0, $3f_0$, $5f_0$, $7f_0$, ….

Pressure variation in a closed pipe

At the closed end of the pipe, the displacement of air is minimum thus pressure is maximum. At the open end, air is free. The pressure is minimum (constant and equal to the atmospheric pressure).

Example 1

A cylindrical pipe of length 29 cm is closed at one end. The air column in the pipe resonates with a tuning fork of frequency 860 Hz sounded near the open end of the pipe. Determine the mode of vibration and find the end correction. Speed of sound in air is 340ms^{-1}.

$l = 29cm = 0.29m$ Observable frequency = 860 Hz

Observable wavelength $\lambda = \frac{V}{f} = \frac{340}{860} = 0.395\ m$

Comparing wavelength;

1st harmonic; $\lambda = 4l = 4 \times 0.29 = 1.16\ m$ Thus mode is not 1st harmonic

3rd harmonic; $\lambda_1 = \frac{4}{3}l = \frac{4}{3} \times 0.29 = 0.387\ m$

Since 0.387 m is comparable to 0.397 m, the mode is the 3rd harmonic.

Or comparing frequencies;

Observable frequency is 860 Hz 1st harmonic;

$f = \frac{V}{4l} = \frac{340}{4\times0.29} = 293.10\ Hz$

3rd harmonic; $f_1 = 3f_0 = 3 \times 293.10 = 879.31\ Hz$

Since 879.31Hz is comparable 860Hz, the mode is the 3rd harmonic.

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

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

$e = \frac{3}{4} \times 0.395 - 0.29 = 6.25 \times 10^{-3}m$

Example 2

A small loudspeaker, activated by a variable frequency oscillator is sounded continuously over the open end of a vertical tube 40cm long and closed at its lower end. At what frequency of the note emitted by the loudspeaker is increases from 200Hz to 1200Hz. Velocity of sound in air is $3.44 \times 10^4 cms^{-1}$.

For closed pipes, only odd harmonics are possible

i.e $f_0, 3f_0, 5f_0, 7f_0, \ldots.$

$V = 3.44 \times 10^4 cms^{-1} = 344ms^{-1}, l = 0.40m$

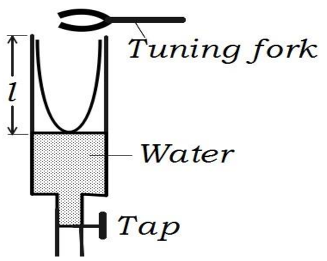
$f_0 = \frac{V}{4l} = \frac{344}{4\times0.4} = 215\ Hz$

$f_1 = 3f_0 = 3 \times 215 = 645\ Hz$

$f_2 = 5f_0 = 5 \times 215 = 1{,}075\ Hz$

Measurement of speed of sound in air using a resonance tube

A glass tube with a

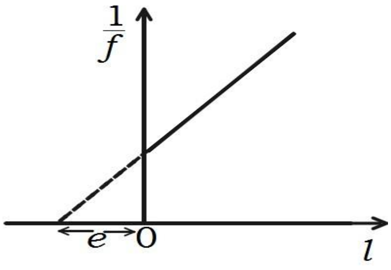


tap at the bottom is filled with water. A tuning fork of known frequency, f, is sounded over the mouth of the tube as water is gradually ran out of the tube until a loud sound is heard.

The tap is closed and the length l of the air column is measured and noted. The experiment is repeated with other tuning forks of different frequencies and their corresponding lengths of air column recorded.

The values of are put in a table including values of $\frac{1}{f}$.

A graph of $\frac{1}{f}$ against l is plotted.

The slope S, 

of the graph is calculated. The velocity of sound in air is calculated from $V = \frac{4}{S}$.

<u>Side work</u>

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

$\lambda = 4l$

$V = \lambda f$

$\frac{1}{f} = \frac{4}{V} l$

Measurement of end correction using a resonance tube Same diagram and same procedure as previous method A graph of $\frac{1}{f}$ against l is plotted.

The intercept e on the l-axis is recorded.

The value of $-e$ is the end correction of the tube.

<u>Side work</u>

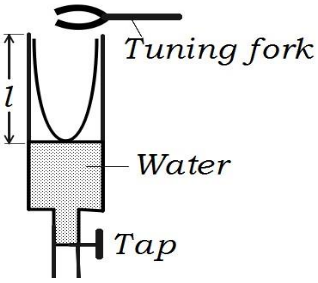
$l + e = \frac{\lambda}{4}$

$\lambda = 4(l + e)$

$V = \lambda f$ $V = 4f(l + e)$

$\frac{1}{f} = \frac{4}{V}(l + e)$ when $\frac{1}{f} = 0, l = -e$

Measurement of speed of sound in air using resonance tube when only one tuning fork is available



A glass tube with a tap at the bottom is filled with water. A tuning fork of known frequency, f, is sounded over the mouth of the tube as water is gradually ran out of the tube until a loud sound is heard.

The tap is closed and the length l_1 of the air column is measured and noted. The tap is again opened and water is gradually run out of the tube until a second loud sound is heard.

The tap is closed and the length l_2 of the air column is measured and noted.

The velocity of sound in air is obtained from $V = 2f(l_2 - l_1)$.

<u>Side work</u>

For 1st loud sound, $l_1 = \frac{\lambda}{4}$

For 2nd loud sound, $l_2 = \frac{3\lambda}{4}$

$l_2 - l_1 = \frac{3\lambda}{4} - \frac{\lambda}{4}$

$l_2 - l_1 = \frac{\lambda}{2}$

$\lambda = 2(l_2 - l_1)$

$V = \lambda f$ $V = 2f\ (l_2 - l_1)$

Measurement of end correction using resonance tube when only one fork is available

Same diagram and procedure as previous experiment

Only change l_1 to $l_1 + e$ and l_2 to $l_2 + e$

End correction is obtained from $e = \frac{1}{2}(l_2 - 3l_1)$

<u>Side work</u>

For 1st loud sound, $l_1 + e = \frac{\lambda}{4}$

$3l_1 + 3e = \frac{3\lambda}{4}$

For 2nd loud sound, $l_2 + e = \frac{3\lambda}{4}$

$l_2 + e = 3l_1 + 3e$

$l_2 = 3l_1 + 2e$

$e = \frac{1}{2}(l_2 - 3l_1)$

<u>Example 1</u>

A uniform tube 50cm long is filled with water and a vibrating tuning fork of frequency 512Hz is sounded and held above it. When the level of water is gradually lowered, the air column resonates with a tuning fork when its length is 12cm and again 43.3cm. Estimate the lowest frequency to which the air in the tube could resonate if the tube was empty.

$V = 2f(l_2 - l_1)$

$V = 2 \times 512(0.433 - 0.12) = 320ms^{-1}$

$f_0 = \frac{V}{4l} = \frac{320}{4\times0.5} = 160Hz$

The lowest frequency is $160Hz$

<u>Example 2</u>

A resonance tube is filled with water and a vibrating tuning fork of frequency 600Hz is sounded above it as water is gradually ran out of the tube.

The first loud sound is heard when the length of air column is 0.13m and the third loud sound is heard when the length of the air column is 0.698m. Determine the speed of sound in air and the end correction of the tube.

$l_1 + e = \frac{\lambda}{4} \ldots (1)$

$l_2 + e = \frac{3\lambda}{4} \ldots . (2)$

$l_3 + e = \frac{5\lambda}{4} \ldots .. (3)$

$(2) - (1)$

$l_2 - l_1 = \frac{\lambda}{2} \ldots . (4)$

$(3) - (2)$

$l_3 - l_2 = \frac{\lambda}{2} \ldots .. (4)$

$l_2 - l_1 = l_3 - l_2$

$l_2 = \frac{l_3 + l_1}{2}$

$V = 2f(l_2 - l_1)$

$V = 2f\left(\frac{l_3 + l_1}{2} - l_1\right)$

$\frac{l_3 + l_1 - 2l_1}{2} = \frac{\lambda}{2}$

$\lambda = l_3 - l_1$

$V = 2f\left(\frac{l_3 - l_1}{2}\right)$

$V = f(l_3 - l_1)$

$V = 600(0.698 - 0.13) = 340.8Hz$

Using (4)

Put in (1)

$l_1 + e = \frac{\lambda}{4}$

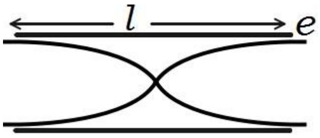
$l_1 + e = \frac{l_3 - l_1}{4}$

$e = \frac{l_3 - l_1}{4} - l_1$

$e = \frac{l_3 - 3l_1}{4} = \frac{0.698 - 0.65}{2} = 0.012m$

(b) Open pipes

(i) **Fundamental note (1st harmonic)**

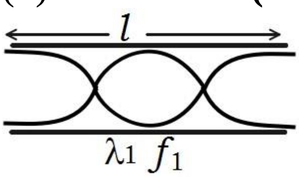


$l = \frac{\lambda}{2}$

$\lambda = 2l$

$f_0 = \frac{V}{\lambda} = \frac{V}{2l}$

(ii) **1st overtone (2nd harmonic)**

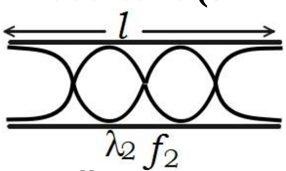


$l = \lambda_1$

$f_1 = \frac{V}{\lambda_1} = \frac{V}{l}$

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

(iii) **2nd overtone (3rd harmonic)**



But $\frac{V}{2l} = f_0$

$f_1 = 2f_0$ this is why it is called 2nd harmonic

$l = \frac{3}{2}\lambda_2$

$\lambda_2 = \frac{2}{3}l$

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

But $\frac{V}{2l} = f_0$

$f_2 = 3f_0$ this is why it is called

$f_2 = \frac{3v}{2l}$ 3rd harmonic

$f_2 = 3\frac{V}{2l}$

Note

1. For open pipes all harmonics are possible
2. The fundamental frequency of an open pipe is twice that of a closed pipe.
   For closed pipe $f_0 = \frac{V}{4l}$ and for open pipe $f_0 = \frac{V}{2l}$
3. The notes from an open pipe are richer than those from closed pipes because of extra overtones.

Closed pipes; f_0, $3f_0$, $5f_0$, $7f_0$,……………….

Open pipes; f_0, $2f_0$, $3f_0$, $4f_0$, $5f_0$, $6f_0$, $7f_0$,……………….

Because of the above, open pipes are preferred to closed one as the musical instruments.

ACTIVITY 9

1.Calculate the frequency of the 3rd harmonic of a sound note set in a pipe of length 0.5m, when the pipe is

(i) closed at one end

(ii) open at both ends

Speed of sound in air is 340 ms^{-1}.

2. Two open pipes of lengths 92cm and 93cm are found to give beat frequencies of 3Hz when each is sounding in its fundamental note. If the end corrections are 1.5cm and 1.8cm respectively, calculate the

(i) velocity of sound in air

(ii) frequency of each note.

3. A uniform tube 50cm long stands vertically with its lower end dipped in water. The tube resonates with a vibrating tuning fork of frequency 256Hz when its length above the water is 12cm and again when it is 39.6cm.

(iii) Estimate the lowest frequency to which the tube resonates when it is open at both ends. (ii) Find the end correctio