WAVE OPTICS

Nature of Light

I. Corpuscular theory:

According to Newton light consist of stream of particles called corpuscles which are shot out at high speed by a luminous object and light has greater speed in denser medium than rarer medium. This theory can explain the phenomena like

i) Reflection

ii) Refraction

iii) Rectilinear propagation

II. Huygen's Wave Theory:

According to him light travels in the form of longitudinal waves and propagate through a hypothetical medium called 'ether'.

This theory can explain the phenomena like

i) Reflection

ii) Refraction

iii) Diffraction

iv) Interference

III. Electromagnetic Wave Theory:

According to maxwell light propagate as electric and magnetic field oscillations, these are called electro magnetic wave, transverse in nature and which require no material medium for propagation.

IV. Quantum theory or Photon theory

According to max planck light propagate in the form of small packets of energy called quanta or photons and $E = h\upsilon$

This theory can explain the phenomena like

i) Origin of spectra

ii) Photoelectric effect

iii) Black body radiation

V. Dual Nature:

According to Debroglie light has particle as well as wave characteristics.

Eddington named light as Wavicle (Wave + particle)

Points to remember

- ✶ Light is non mechanical transverse wave
- ✶ When a transverse wave reflected from denser medium (rigid boundary), there is a phase reversal of 180^o $(\pi \,\text{radian})$
- ✶ **Optical path**

Let light travels D distance through a medium of refractive index μ with speed v for a time 't'.

$V = \frac{D}{t}$ also $\mu = \frac{C}{V}$

$\frac{C}{V} = \frac{C}{D/t} = \mu$ or ct = light travels through vacuum for same interval 't' = optical path

$$\boxed{\text{optical path} = \mu D}$$

✶ **Relation between phase difference $(\Delta\phi)$ and path difference (Δx)**

Let two particle are located at positions x, and x_2 at an instant. Then $\phi_1 = 2\pi\left(\frac{t}{T} - \frac{x_1}{\lambda}\right)$ and $\phi_2 = 2\pi\left(\frac{t}{T} - \frac{x_2}{\lambda}\right)$

$\therefore$ phase difference, $\Delta\phi = \phi_1 - \phi_2 = \frac{2\pi}{\lambda}(x_2 - x_1)$

$$\boxed{\Delta\phi = \frac{2\pi}{\lambda}\Delta x = k\Delta x = \frac{\omega}{V}\Delta x}$$

✶ **Intensity**

Intensity (I) $= \frac{\text{Energy}}{\text{Area} \times \text{time}}; Wm^{-2}$

✶ **Intensity of a Wave**

$$I = \frac{1}{2}\rho\omega^2 A^2 V$$

$$I \,\alpha\, A^2$$

WAVE FRONT

Consider a wave spreading out on the surface of water after a stone is thrown in. Every point on the surface oscillates. At any time, a photograph of the surface would show circular rings on which the disturbance is maximum. Clearly, all points on such a circle are oscillating in phase because they are at the same distance from the source. Such a locus of points which oscillates in phase is an example of a wavefront.

Wave front:

It is the continuous locus of all particles of medium which are vibrating in the same phase at any instant.

Characteristics of wavefront

i) All the particles on a wavefront are in same phase.

ii) The phases of consecutive wavefronts are different.

iii) Wavefronts separated by a particular distance, known as the wavelength of wave are also in same phase.

iv) The speed with which the wavefront moves outward from the source is called the phase speed.

v) Wave always propagates in medium in a direction perpendicular to the wavefront.

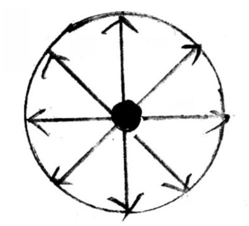
vi) Shape of wavefront varies with the nature of source.

vii) Two wavefronts never cross each other. If they intersect, then there will be two rays or two directions of propagation of energy. It is not possible.

TYPES OF WAVEFRONT

1. Spherical wavefront

In case of waves travelling in all directions from a point source, the wavefronts are spherical shape.



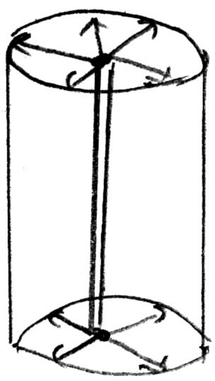
Intensity $\alpha \frac{1}{\text{distance}^2}$

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

$\therefore A \alpha \frac{1}{r}$

2. Cylindrical Wavefront

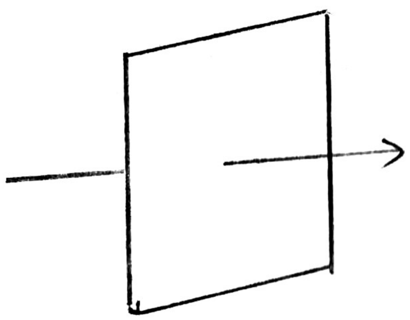
When the source of light is linear such as rectangular slit, the wavefront is cylindrical.



$I \alpha \frac{1}{r}; \quad A \alpha \frac{1}{\sqrt{r}}$

3. Plane Wavefront

As spherical or cylindrical wave advances, its curvature decreases progressively. So a small portions of such a wavefront at a large distance from source will be planar.

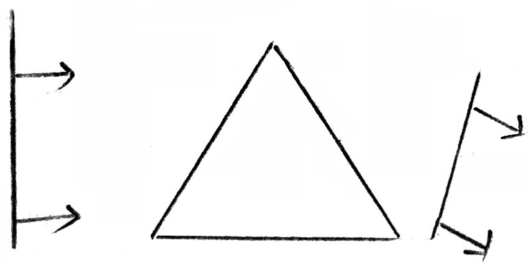


$I \ \alpha \ r^{o} \qquad A \ \alpha \ r^{o}$

BEHAVIOUR OF PLANE WAVEFRONT ON REFLECTION AND REFRACTION

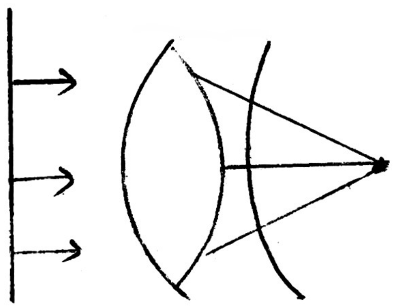
a) Refraction of a plane wavefront by a thin prism

Consider a plane wavefront passing through thin prism. Clearly the portion of the incoming wavefront which travels through the greatest thickness of glass has been delayed the most, since light travels more slowly in glass. So emerging wavefront is planar with a tilt.

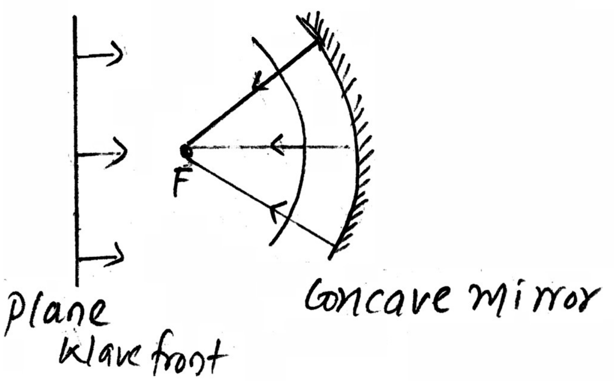


b) **Refraction of plane wavefront by a lens**

Consider a plane wavefront incident on a convex lens. The central part of incident plane wave travels the thickest portion of convex lens and is delayed most. The emerging wavefront has a depression at the centre and is spherical and converges to a focus.



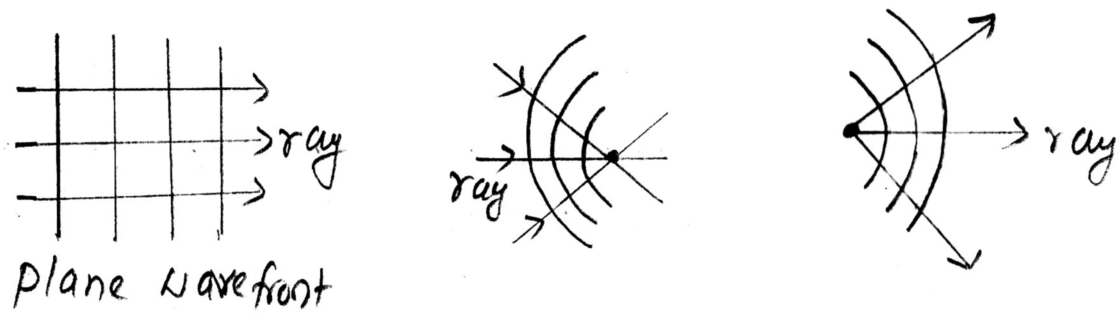
c) A concave mirror, concave lens and convex mirror produces similar effect. The emerging or reflecting wavefronts are converging spherical.



Ray of light

- ✶ It is an arrow drawn perpendicular to wavefront in the direction of propagation.
- ✶ It represent the path along which light travels.
- ✶ The time taken for light to travel from one wavefront to another is the same along any ray.

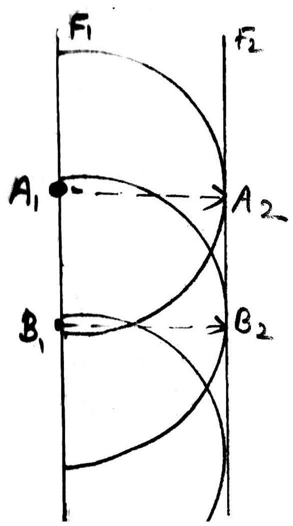
In case of spherical wavefront, the rays either converge to a point or diverge from a point.



HUYGEN'S PRINCIPLE

1. Each point on a wavefront act as a fresh source of new disturbance called secondary waves or wavelets.
2. The wavelets are spherical and spread out in all directions with the speed of light in the given medium.
3. The new wavefront at any later time is given by the forward envelope (tangential surface in forward direction) of the secondary wavelets at that time.

✶ Huygen's principle illustrated in simple cases of a plane wave.



i) At t = 0, we have a wavefront F_1, F_1 separates those parts of the medium which are undisturbed from those where the wave has already reached.

ii) Each point on F_1 acts like a new source and sends out a spherical wave. After a time, t = t each of these will have radius r = Vt. These spheres are the secondary wavelets.

iii) After a time 't', the disturbance would now have reached all points with in the region covered by all these secondary waves. The boundary of this region is the new wavefront F_2. Notice that F_2 is surface tangent to all the spheres. It is called the forward envelope of these secondary wavelets.

Principle of superposition of waves

When a number of waves travelling through a medium, superpose each other, the resultant displacement at any point at a given instant is equal to the vector sum of displacements due to individual waves at that point.

$$\vec{y} = \vec{y}_1 + \vec{y}_2 + ...$$

INTERFERENCE

✶ When light waves of same frequency and having zero or constant phase difference travelling in same direction superpose each other, the intensity in the region of superposition get redistributed becoming maximum at some points (constructive interference) and minimum at others (destructive interference)

Constructive interference

When crest of one wave falls over crest of another, or trough of one wave falls over trough of another, resultant intensity is maximum.

Destructive interference

When crest of one wave falls over trough of another, resultant intensity is minimum.

Examples for interference

i) Colour of soap bubbles

ii) Colour of thin films

iii) Irridescence of morpho butterfly

iv) Holography

v) Coloured pattern of wings of peacock

vi) Shift in coloured pattern of security thread in currencies

Sustained interference

- In interference pattern, in which the positions of maximum and minimum intensity of light remain fixed all along the screen. Then interference is said to be sustained.

Condition for sustained interference

i) The two sources should emit continuously waves of same frequency or wavelength.

ii) The amplitude of the two waves should be either or nearly equal

iii) The two sources should be narrow

iv) The sources should be close to each other

v) The two sources should be coherent one [This is the necessary condition for interference]

vi) They are in same state of polarisation

vii) They (waves) travel along same direction.

viii) The distance between sources should be small and distance between source and screen is large.

COHERENT SOURCE

- Sources are said to be coherent, if they emit light waves continuously of same frequency or wavelength with zero or constant phase difference between them.
- LASER is highly monochromatic and highly coherent.
- Incoherent sources are those which does not emit light waves continuously with constant phase difference.
- Single criterion for coherence is constant phase difference.

Two independent sources can't be coherent

Light is emitted by individual atoms and not by the bulk matter acting as a whole.

Even an atom emits an unbroken wave of about 10^{-8}s due to its transition from a higher energy state to lower energy state. Thus phase difference can remain constant for about 10^{-8}s only ie phase changes (position of bright and dark bands) 10^{8} times in one second. Such rapid change in position of maxima and minima can't be detected by our eye. The interference pattern is lost and almost a uniform illumination is seen on screen.

TWO COHERENT SOURCES CAN BE OBTAINED FROM A SINGLE PARENT SOURCE

1. In Young's double slit experiment

$$\left.\begin{array}{ll} 2. & \text{Fresnel's biprism method (refraction)} \\ 3. & \text{In Lloyd's mirror mehtod} \\ 4. & \text{In Billet's split lens} \\ 5. & \text{In Michleson's interferometer} \end{array}\right\} \text{Beyond our scope}$$

CONDITION FOR OBTAINING TWO COHERENT SOURCES

I) The two sources of light must be obtained from a single source.

ii) The two sources must give monochromatic light.

iii) The path difference between the waves arriving on the screen from the two sources must not be large.

METHOD OF PRODUCING COHERENT SOURCES

1. By division of wavefront (eg: YDSE)
2. By division of amplitude (eg: thin films, soap bubbles)

CONDITION FOR CONSTRUCTIVE & DESTRUCTIVE INTERFERENCE

Consider two waves of amplitudes a_1 and a_2 travelling along same direction with constant phase difference (ϕ), superpose

$$y_1 = a_1 \sin \omega t$$

$$y_2 = a_2 \sin(\omega t + \phi)$$

Resultant displacement, $y = y_1 + y_2$

$$y = a_1 \sin \omega t + a_2 \sin(\omega t + \phi)$$

$$= a_1 \sin \omega t + a_2 \sin \omega t \cos \phi + a_2 \cos \omega t \sin \phi$$

$$= (a_1 + a_2 \cos \phi) \sin \omega t + a_2 \sin \phi \cos \omega t$$

Put $a_1 + a_2 \cos \phi = A \cos \theta ----(1)$

$$a_2 \sin \phi = A \sin \theta ----(2)$$

$$(1)^2 + (2)^2 \Rightarrow A^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos \phi$$

Resultant amplitude, $A = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos \phi}$ and $I \alpha A^2$

Resultant intensity $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$; $2\sqrt{I_1 I_2} \cos \phi$ is known as interference term.

For constructive interference

Intensity should be maximum, for this $\cos \phi = +1$ ie $\phi = 0, 2\pi, 4\pi, ...$

$$\boxed{\phi = 2n\pi}$$

$$\therefore I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2} \quad ------(1)$$

$$= \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$$

$$= \left(a_1 + a_2\right)^2$$

Path difference, $\Delta x = \frac{\lambda}{2\pi}\Delta\phi$

$$= \frac{\lambda}{2\pi}2n\pi$$

$$\boxed{\Delta x = n\lambda}$$

For destructive interference

Intensity should be minimum, for this $\cos\phi = -1$ ie $\phi = \pi, 3\pi, 5\pi, ...$

$$\boxed{\phi = \left(2n - 1\right)\pi}$$

$$\Delta x = \frac{\lambda}{2\pi}\Delta\phi = \frac{\lambda}{2\pi}\left(2n-1\right)\pi$$

$$\boxed{\Delta x = \left(2n-1\right)\frac{\lambda}{2}}$$

$$I_{min} = I_1 + I_2 - 2\sqrt{I_1 I_2} \quad ------(2)$$

$$= \left(\sqrt{I_1} - \sqrt{I_2}\right)^2 \qquad = \left(a_1 - a_2\right)^2$$

$$\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{\frac{I_1}{I_2}} + 1}{\sqrt{\frac{I_1}{I_2}} - 1}\right)^2$$

Note:

i) If intensities of two interfering beams are equal ie $I_1 = I_2 = I_0$

$$I_{max} = \left(\sqrt{I_0} + \sqrt{I_0}\right)^2 = 4I_0$$

$$I_{min} = \left(\sqrt{I_0} - \sqrt{I_0}\right)^2 = 0$$

$$I_R = I_0 + I_0 + 2\sqrt{I_0 I_0}\cos\phi$$

$$= 2I_0(1+\cos\phi) \qquad = 4I_0\cos^2\frac{\phi}{2}$$

$$I_R = I_{max}\cos^2\frac{\phi}{2}$$

ii) From equations (1) and (2) it is clear that in interference energy is conserved but redistributed.
ie Interference is the modification in energy distribution as a result of superposition of two waves.

iii) For incoherent source interference term $2\sqrt{I_1 I_2}\cos\phi = 0$

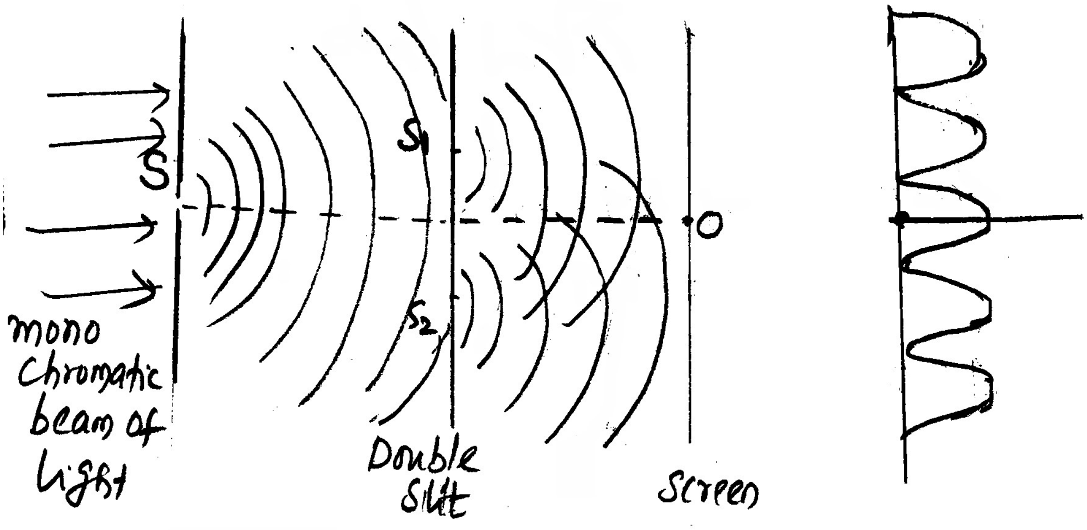
$$\therefore \; I_{incoherent} = I_1 + I_2$$

if $I_1 = I_2 = I_0$; $\qquad I_{max} = 2I_0$

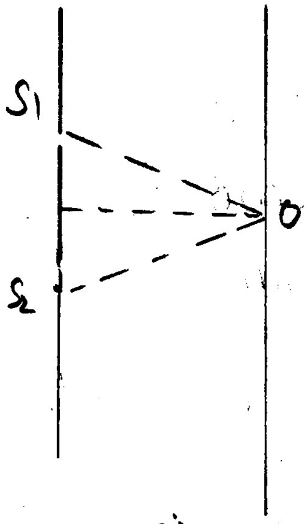
iv) If I_{avg} is the average intensity of two interfering beams of intensities I_1 and I_2

$$I_{avg} = \frac{I_{max} + I_{min}}{2} = I_1 + I_2 = A_1^2 + A_2^2$$

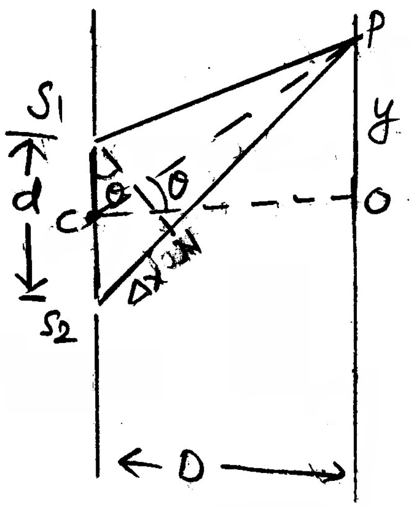
YOUNG'S DOUBLE SLIT EXPERIMENT (YDSE)



(i)



(ii)



(iii)

Figure (i) shows arrangement of Young's experiment, in which monochromatic light passes through a single narrow source slit (s) and falls on two closely spaced narrow slits s_1 and s_2. These two slits act as coherent sources of light waves that interfere constructively and destructively at different points on the screen to produce a pattern of alternate bright and dark fringes.

Since point O, the centre of screen is equidistant as shown in figure (ii) from s_1 and s_2, path difference $\Delta x = 0$ for wave fronts coming out of s_1 and s_2. They add constructively thus producing bright fringe at centre.

<u>From fig (iii)</u>

Path difference, $\Delta x = s_2p - s_1p$ $= s_2N$

Form $\Delta s_1 s_2 N; \sin\theta = \dfrac{\Delta x}{d}$

$$\boxed{\Delta x = d\sin\theta}$$

and from $\Delta COP, \tan\theta = \dfrac{y}{D}$

Since θ is very small, $\sin\theta \sim \tan\theta$

$\boxed{\dfrac{\Delta x}{d} = \dfrac{y}{D}} \Rightarrow$ for 'd' is very small

Position of nth bright fringe from central bright fringe

From $\dfrac{\Delta x}{d} = \dfrac{y}{D}$

$$y_n = \frac{\Delta x\, D}{d}$$

For constructive interference, $\Delta x = n\lambda$

$$\therefore \boxed{y_n = \frac{n\lambda D}{d}}$$

Position of nth dark fringe from central bright fringe

For destructive interference $\Delta x = (2n-1)\dfrac{\lambda}{2}$

$$\boxed{\therefore\ y_n = (2n-1)\frac{\lambda D}{2d}}$$

Fringe width or Band width (β)

It is the distance between two successive bright fringes or two successive dark fringes.

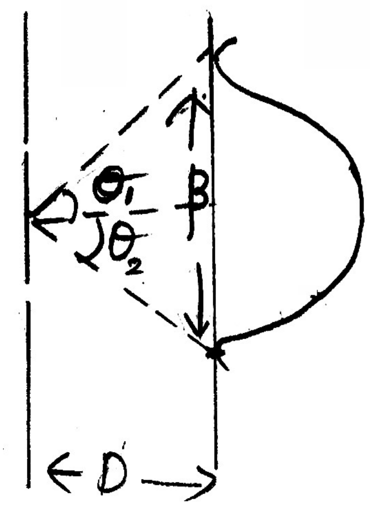
$$\beta = y_{n+1} - y_n = (n+1)\frac{\lambda D}{d} - \frac{n\lambda D}{d}$$

$$\boxed{\beta = \frac{\lambda D}{d}}$$

✶ In the interference pattern, the fringe width is constant for all the fringes, because fringe width is independent of order of fringes(n)

✶ All bright fringes are of same intensity.

Angular fringe width



$$\theta = \theta_1 + \theta_2 \qquad \theta_1 = \theta_2$$

$$= \frac{\beta}{2D} + \frac{\beta}{2D}$$

$$\theta = \frac{\beta}{D}$$

$$\theta = \frac{\lambda D}{dD}$$

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

Angular position of n^{th} bright fringe, $\theta_n = \frac{n\lambda}{d}$

Angular position of n^{th} dark fringe, $\theta_n = (2n-1)\frac{\lambda}{2d}$

Note

1. Fringe visibility (V): It quantifies the contrast of interference in any system

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \qquad = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}$$

✶ The two individual wave should have equal amplitude for best visibility

2. If W_1 and W_2 be the width of two slits in YDSE then $\frac{W_1}{W_2} = \frac{I_1}{I_2} = \frac{a_1^2}{a_2^2}$

3. If entire arrangement of YDSE is immersed in a medium of refractive index μ without any change in experimental setup. Then

   Fringe width decreases by μ times

   $\beta \alpha \lambda$

   $\beta_{med} \,\alpha\, \lambda_{med}$ $\qquad \frac{\beta}{\beta_m} = \frac{\lambda}{\lambda_m} = \frac{\lambda}{\lambda/\mu}$

   $\mu = \frac{\lambda}{\lambda_{med}}$ $\qquad$ ie $\beta_m = \frac{\beta}{\mu}$ also $\theta_m = \frac{\theta}{\mu}$

4. If any one of the slit in YDSE is closed. Then

   i) Interference pattern is replaced by diffraction pattern

   ii) Intensity at central maximum (at any point) become $\frac{I_0}{4}$ because amplitude halved.

5. Intensity interms of fringe width

   $$I_R = I_{max} \cos^2 \phi / 2$$

   $$\frac{\Delta x}{d} = \frac{y}{D}; \ \Delta\phi = \frac{2\pi}{\lambda}\Delta x = \frac{2\pi}{\lambda}\frac{yd}{D}$$

   $$I_R = I_{max} \cos^2 \frac{\pi}{\lambda}\frac{yd}{D} \qquad = I_{max} \cos^2\left(\frac{\pi y}{\beta}\right)$$

   and also $\Delta x = d\sin\theta; \ \Delta\phi = \frac{2\pi}{\lambda} d\sin\theta$

   $$\therefore I_R = I_{max} \cos^2\left(\frac{\pi}{\lambda} d\sin\theta\right)$$

6. **Shape of fringes**

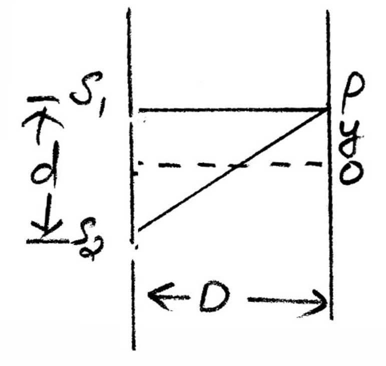
   a) Fringes are usually hyperbolic shape.

   b) When double slit plane and screen are mutually perpendicular, fringes are concentric circles.

   c) When distance between double slit plane (D) is very large compared to separation between slits (d), fringes are straight lines.

7. **Expression for missing wavelength**

At a point on the screen directly infront of one of the slits.



For missing wavelength, intensity will be minimum

$$\Delta x = (2n-1)\frac{\lambda}{2}$$

$$y = \frac{\Delta x D}{d}$$

$$\frac{d}{2} = (2n-1)\frac{\lambda D}{2d}$$

$\therefore \lambda = \dfrac{d^2}{(2n-1)D}$ for n = 1,2,3, ... $\lambda_{missing} = \dfrac{d^2}{D}, \dfrac{d^2}{3D}, ...$

8. **If one of the slit in YDSE is covered by transparent sheet of thickness t and refractive index** μ

i) Fringe width remains same

ii) The path difference at centre will not be zero. It is $\Delta x = (\mu - 1)t$

iii) The entire fringe pattern will shift upward if sheet is placed before the upper slit, and if the sheet is placed before the lower slit, the fringe pattern gets shifted downwards.

Fringe shift $y_0 = \dfrac{\Delta x D}{d} = (\mu - 1)t\dfrac{D}{d}$

$$= \frac{\beta}{\lambda}(\mu - 1)t$$

iv) number of fringes shifted, $n = \dfrac{\text{shift}}{\text{fringe width}}$

$$n = \frac{\beta}{\lambda}\frac{(\mu-1)t}{\beta} = (\mu-1)\frac{t}{\lambda}$$

v) The intensity of light from the covered slit will decrease due to absorption. Hence intensity of bright fringe decreases and dark fringes have some finite intensity. Hence fringe pattern will become less distinct.

9. **If the beam of light has two wavelengths λ_1 and λ_2 (Bichromatic)**

i) their maxima will coincide if $y_1 = y_2$

ie $n_1\lambda_1\frac{D}{d} = n_2\lambda_2\frac{D}{d}$

$$\boxed{n_1\lambda_1 = n_2\lambda_2}$$

DIFFRACTION

✶ It is the phenomenon of bending of light around the corners of small obstacles or apertures and its consequent spreading into the regions of geometrical shadow.

eg: 1) Appearance of a shining circle around the section of sun just before sun rise is due to diffraction.

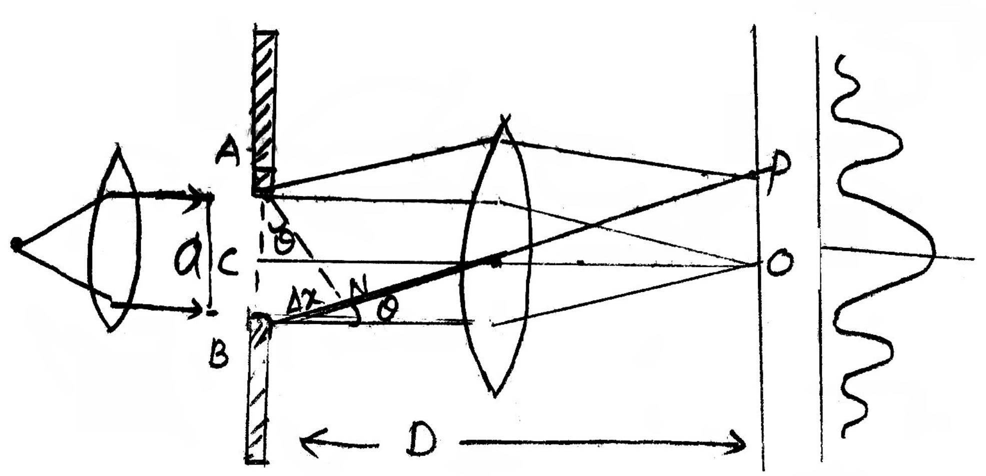
2) Colour of CD

3) Sun light filtering through leaves of trees forms circular patches on ground.

Condition for diffraction

✶ The diffraction effect is more pronounced if the size of the aperture or the obstacle is of the order of wavelength of light used.

DIFFRACTION DUE TO SINGLE SLIT



Let a plane wavefront falling on a single narrow slit AB of width ‘a’. According to Huygen’s principles, each point on the plane wavefront falling on AB gives rise to secondary wavelets which are initially in the same phase. These wavelets spread out in all directions, thus causing diffraction.

Central maximum

All secondary wavelets going straight across the slit AB are focussed at centre O. The wavelets from any two corresponding points of the two halves of the slit reach the point O in same phase, they add constructively to produce a central bright fringe.

From ΔABN

$$\sin\theta = \frac{\Delta x}{a}; \qquad \therefore \Delta x = a\sin\theta$$

Position of minima

Let the point P be so located on the screen that the path difference $\Delta x = \lambda$. Now divide the slit AB into two halves AC and CB. Then path difference between wavelet from A and C will be $\frac{\lambda}{2}$. Similarly corresponding to every point on the upper half AC, there is a point in lower half CB for which $\Delta x = \frac{\lambda}{2}$. Hence they reach at point P in opposite phase. They add destructively producing first minimum. Proceeding the same way, it can be shown that the condition for n^{th} minima.

$$\Delta x = n\lambda \quad = a\sin\theta_n$$

$$\sin\theta_n = \frac{n\lambda}{a}$$

If angle is very small, then $\theta_n = \frac{n\lambda}{a}$

Position of maxima

Let point P on the screen be situated such that the path difference $\Delta x = \frac{3\lambda}{2}$

Now consider the slit width to be divided into three equal parts so that the path difference between the wavelets from the first two parts will again be $\frac{\lambda}{2}$. These wavelets will interfere destructively and cancel each other's effect.

The wavelet from the third part will remain uncancelled. Since all of them are in the same phase, they reinforce each other and thus produce the first secondary maximum.

Proceeding in the same way, it can be shown that the condition for n^{th} secondary maximum is

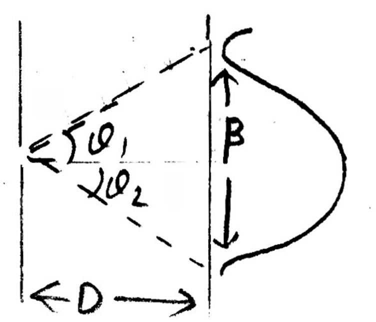
$$\Delta x = (2n+1)\frac{\lambda}{2}$$

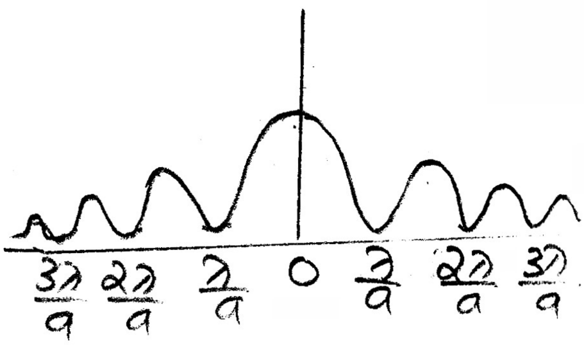
$$a\sin\theta_n = (2n+1)\frac{\lambda}{2}$$

$$\sin\theta_n = (2n+1)\frac{\lambda}{2a}$$

For small angle $\theta_n = (2n+1)\frac{\lambda}{2a}$

Angular width of central maximum and secondary maximum





The angular width of the central maximum is the angular separation between the directions of first minima on the two sides of the central maximum. The directions of first minima on either side of central maximum are given by $\theta = \frac{\lambda}{a}$. This angle is called half angular width of central maximum.

$\therefore$ Angular width of central maximum $= \frac{2\lambda}{a}$

✶ Linear width of central maximum, $\theta_1 + \theta_2 = \frac{\beta}{2D} + \frac{\beta}{2D}$

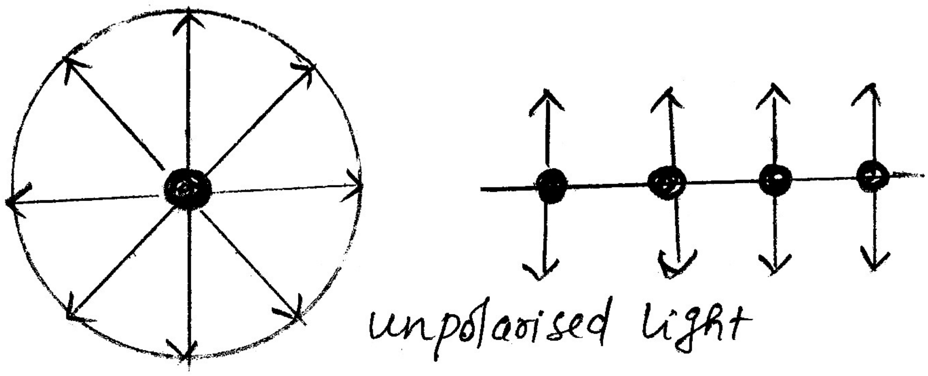
$$\frac{\beta}{D} = \frac{2\lambda}{a}$$

$\therefore \beta = \frac{2\lambda D}{a}$ Since convex lens is placed very close to the slit, then $D \approx f$

$$\therefore \beta = \frac{2\lambda f}{a}$$

POLARISATION

✶ A light which has vibration in all directions in a plane perpendicular to the direction of propagation is called unpolarised light.



* Polarization is the phenomenon of restricting the electric field vibration of light in a particular direction perpendicular to the direction of propagation of wave while passing through certain crystals called polarisers.

  Examples for polariser

  1. Tourmaline crystal
  2. Herapathite crystals
  3. Quartz crystal
  4. Calcite crystal
  5. Nicol prism

* If the EF vector of light wave vibrates just in one direction perpendicular to the direction of propagation is called linearly polarised.

  Since linearly polarised wave, the vibration at all points, at all times, lies in the same plane is called plane polarised.

* In case of linearly polarised light, the magnitude of electric field vector varies periodically with time.
* Polarisation is a characteristics of transverse waves only.

  Examples for polarisation

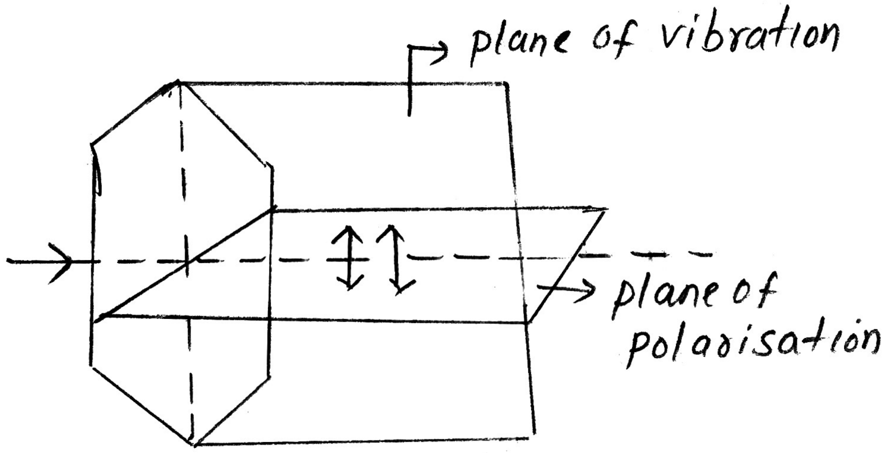
  1. Golden view of sea shell
  2. The wave emitted by radio transmitters are linearly polarised.

  Plane of vibration

* It is the plane with in which the vibrations of polarised light are confined.

Plane of polarisation

✶ It is a plane right angles to the plane of vibration and passing through the direction of propagation of light.

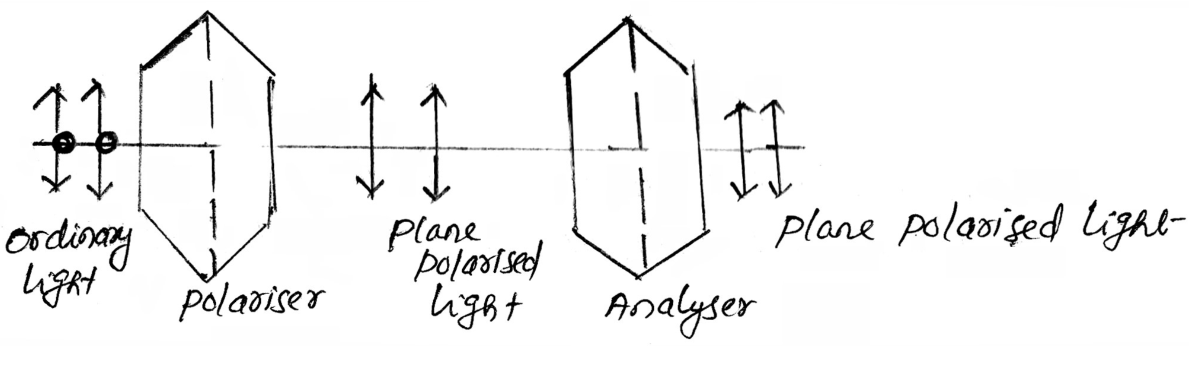


DETECTING PLANE POLARISED LIGHT

✶ We can't make distinction between the unpolarised light and the plane polarised light with the polariser alone. Another such crystal required to analyse the nature of light is called analyser.

A tourmaline crystal or a Nicol prism used to produce plane polarised light is called polariser. If the polariser is rotated in the path of the ordinary light, the intensity of light transmitted from the polariser remains unchanged. It is because, in each orientation of the polariser, the plane polarised light is obtained, which has vibrations in a direction parallel to the axis of the crystal in that orientation.

If we rotate the analyser in the path of the light transmitted from the polariser, so that the axes of the polariser and analyser are parallel to each other, then the intensity of light found to remain unaffected (maximum).



But when the axis of the polariser and analyser are perpendicular to each other, the intensity of light becomes minimum.

MALUS'S LAW

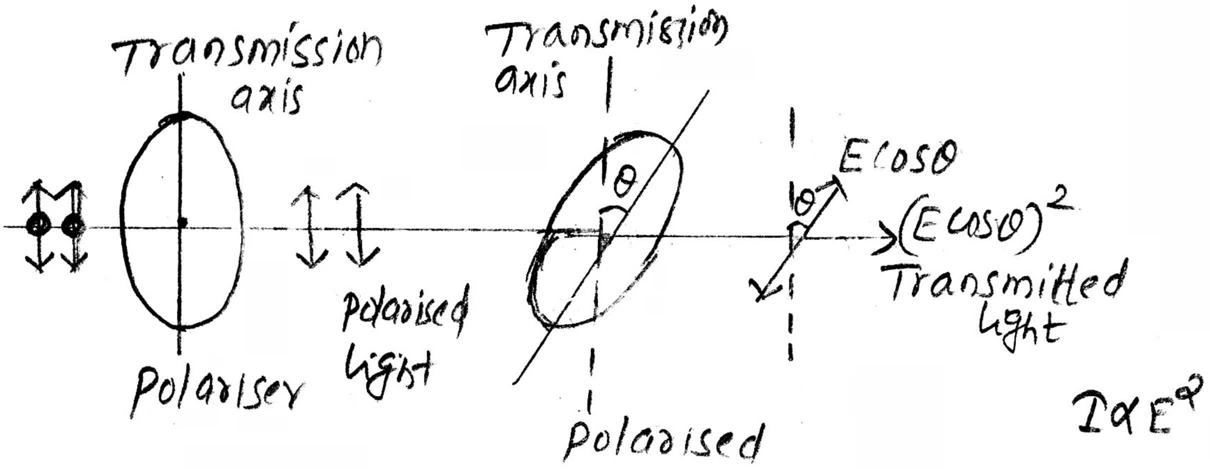
✶ The dependence of intensity of transmitted light on the angle between the analyser and polariser was investigated by E.I. Malus.

- It states that when a beam of completely plane polarised light passed through analyser, the intensity I of transmitted light from analyser varies directly as square of cosine of angle between transmission direction of polariser and analyser.

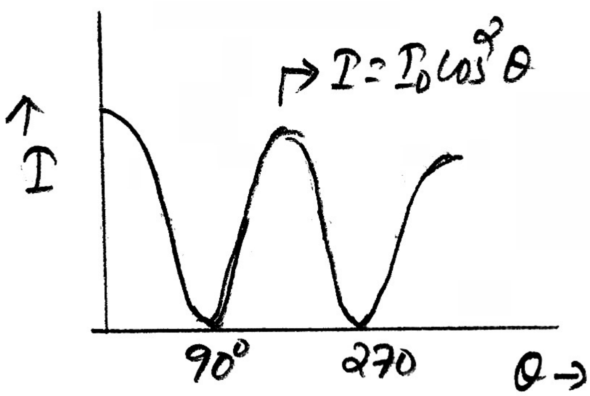
  ie $I \alpha \cos^2 \theta$

  $I = I_0 \cos^2 \theta$

  Here I_0 is the intensity of plane polarised light and is equal to half the intensity of unpolarised light.



Intensity curve:

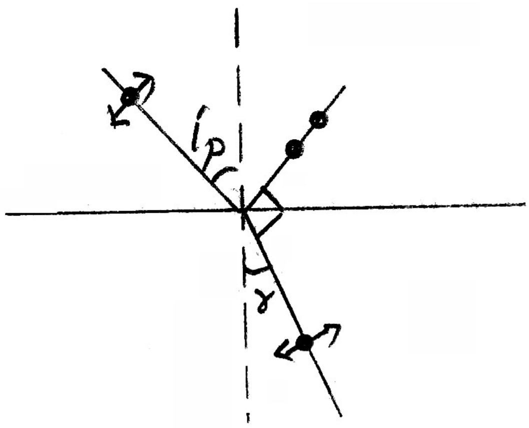


- On one complete rotation of analyser, intensity becomes twice maximum and twice minimum.

METHODS OF PRODUCING PLANE POLARISED LIGHT

1. Polarisation by reflection: Brewster's law

✶ When unpolarised light is incident on an interface separating two media, reflected and refracted light are partically polarised. When angle of incidence gradually increases, for a particular value of angle of incidence called polarising angle or Brewster's angle, reflected light is completely polarised. At this stage reflected ray and refracted ray are mutually perpendicular.



When $i = i_p, r = 90 - i_p$

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin i_p}{\sin(90 - i_p)} = \frac{\sin i_p}{\cos i_p}$$

$\mu = \tan i_p \Rightarrow$ Brewster' law

From Snell's rule, $\mu = \dfrac{\sin i_p}{\sin r}$

From Brewster's law, $\mu = \tan i_p = \dfrac{\sin i_p}{\cos i_p}$

$$\frac{\sin i_p}{\sin r} = \frac{\sin i_p}{\sin(90 - i_p)}$$

$$\sin r = \sin(90 - i_p)$$

$r = 90 - i_p$

$r + i_p = 90^\circ$

2. Polarisation by scattering

✶ Since light waves are EM in nature they will vibrate the electrons of air molecules perpendicular to the direction in which they are travelling. The electrons then produce radiation that is polarised perpendicular to the direction of the ray.

However there is no polarisation parallel to the original direction of incident light. The light perpendicular to original ray is completely plane polarised and in all other direction, the light scattered by air molecules partially polarised.