Unit-3

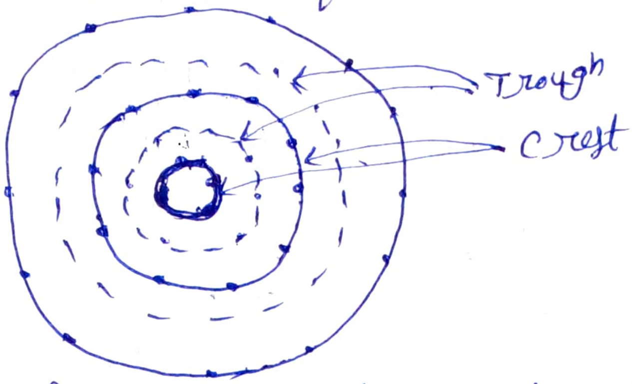
Interference of light:→ When two light waves having same frequency, approximately same direction of propagation and have constant phase difference with time superimpose in space then the resultant intensity of light is not distributed uniformly in space. The non-uniform distribution of light intensity due to the superposition of two light waves is called 'Interference'.

At some points the intensity is maximum, so the interference at these points is known as Constructive Interference. At other points the intensity is minimum, so the Interference at these points is called Destructive Interference.

Due to the superposition of light waves, we get alternate dark and bright bands of regular or irregular shape. These bands are known as Interference fringes.

Wavefront ⇒ Locus of particles vibrating in same phase is known as wavefront.

In water waves, the wavefront is shown as-



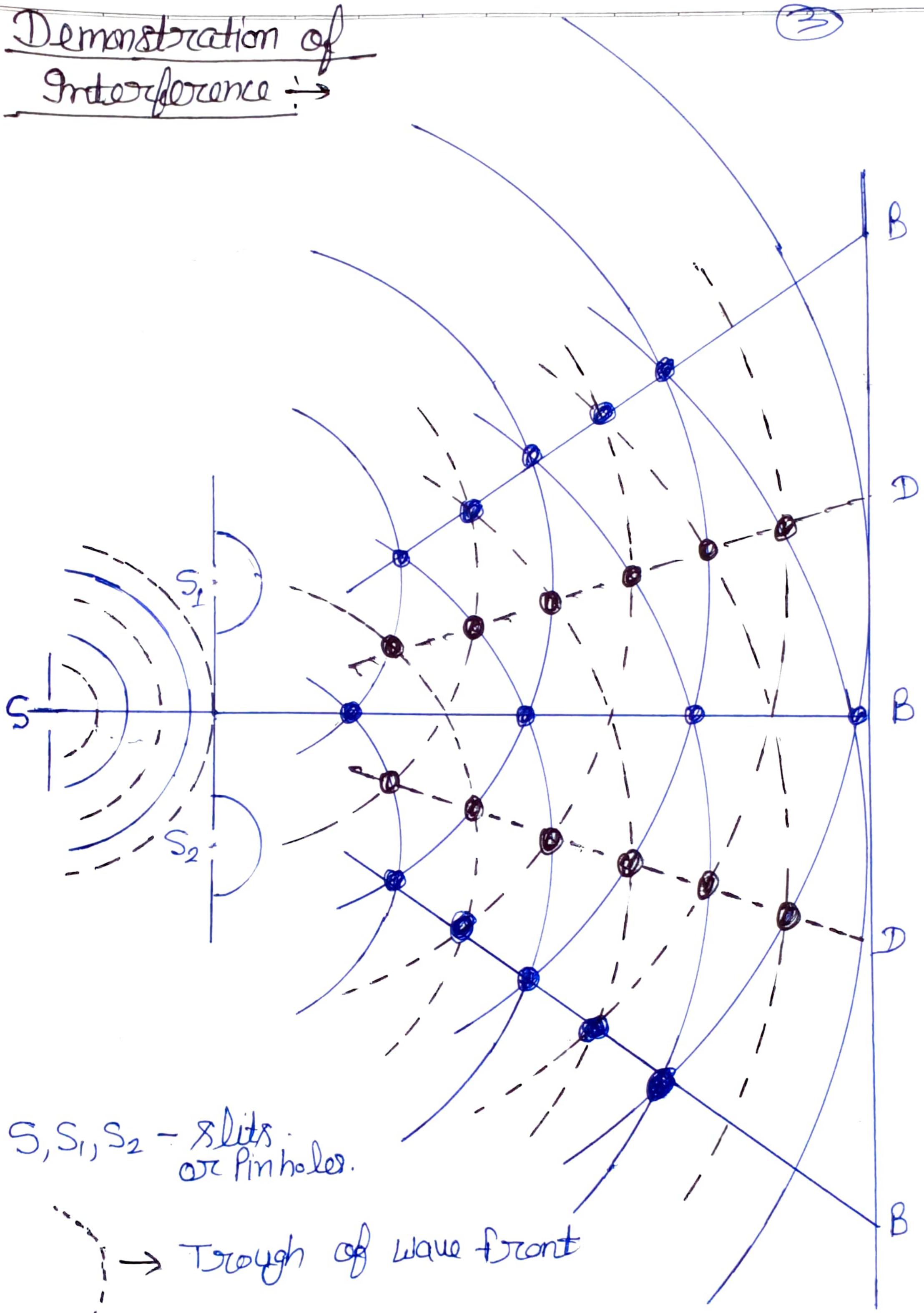
Wavefront has crest and trough. the crest is shown by solid line and the trough is shown by dotted line.

Interference by Division of wave front:

Young's double slit Experiment ⇒

Thomas Young demonstrated the phenomenon of interference of light. The experimental arrangement of Thomas young experiment is shown in figure

Demonstration of Interference :→



S, S_1, S_2 – Slits or Pinholes.

→ Trough of wave front

→ crest of wave front

– – – – – → loci of minimum intensity i.e. nodal line

———— → loci of maximum " " antinodal line.

B → Position of bright fringe

D → Position of dark fringe

Sunlight was first allowed to pass through a pin hole S and then through two Pin holes S_1 & S_2 placed at a considerable distance from S, Finally the light was received on a screen. Coloured fringes of varying intensity were seen on the screen

This original arrangement is improved as the Pinholes S_1 & S_2 are replaced by narrow slits and sunlight is replaced by monochromatic light. In this improved arrangement a number of alternate bright and dark fringes are observed on the screen.

Explanation → The formation of bright and dark fringes on the screen can be explained on the basis of wave theory of light. The wave front starting from S falls on S_1 and S_2.

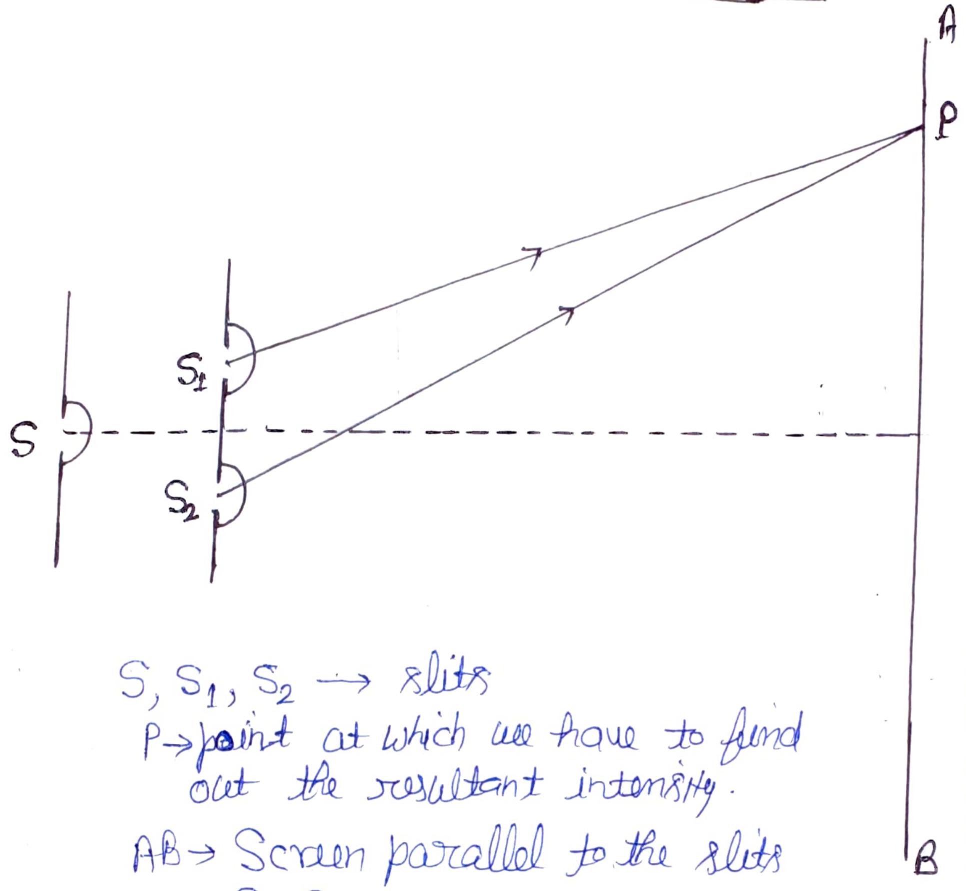
According to the Huygen's principle S_1 and S_2 becomes the centre of secondary wavelets, thus two new wavefronts are produced, one from S_1 and other from S_2. Their radii increase as they move away and away from S_1 and S_2, so that they super--impose more and more on each other. At points where a crest (or trough) due to one falls on a crest (or trough) due to other, the resultant amplitude is sum of the amplitudes due to each wave seperately. The intensity, which is proportional to the square of the amplitude, at these points is therefore maximum. This is the case of constructive inference.

At points where a crest due to one wave falls on trough due to other, the resultant amplitude is difference of the amplitudes due to separate waves and the resultant intensity is a minimum. This is the case of destructive interference.

In figure the solid arcs represent the crests while the dotted arcs indicate the troughs. The solid lines are the loci of the points of maximum intensity while the dotted lines are the loci of the points of minimum intensity. The solid lines are known as antinodel lines while dotted lines are known as nodal lines. In three dimensional space the antinodal lines and nodal lines describe the planes of maximum intensity and minimum intensity respectively and called antinodel and nodal planes.

The intersections of these lines on the screen at point B and D respectively give the positions of bright and dark fringes respectively.
The bright and dark fringes occur alternately at equal distances.

Expression for Intensity: Expression for Constructive and destructive Interference:→



$S, S_1, S_2 \rightarrow$ slits

$P \rightarrow$ point at which we have to find out the resultant intensity.

$AB \rightarrow$ Screen parallel to the slits S_1, S_2

Let S be a narrow slit illuminated by a monochromatic source and S_1, S_2 are equidistant from S. Suppose the waves from S reach S_1 and S_2 in the same phase. Then beyond S_1 and S_2, the waves proceed as if they started from S_1 and S_2.

Now we have to find the resultant intensity of light at point P on a screen. Let a_1 and a_2 be the amplitudes of the waves from S_1 and S_2 respectively. The waves arrive at P, having different paths S_1P and S_2P. Hence they are superposed at P with a phase difference δ, i.e.

Phase difference(δ) = $\frac{2\pi}{\lambda}$ × path difference

$$\delta = \frac{2\pi}{\lambda} \times (S_2P - S_1P)$$

λ - wavelength.

The displacement at P due to the simple harmonic waves from S_1 and S_2 may be represented by -

$$y_1 = a_1 \sin \omega t$$
$$y_2 = a_2 \sin(\omega t + \delta)$$

where ω - common frequency of the two waves.

According to the Principle of Super-position, the resultant displacement at point P,

$$y = y_1 + y_2$$

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

$$y = a_1 \sin\omega t + a_2 \sin\omega t \cos\delta + a_2 \cos\omega t \sin\delta$$

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

Let, $a_1 + a_2\cos\delta = R\cos\theta$ —(i)

$a_2 \sin\delta = R\sin\theta$ ——(ii)

$$y = \sin\omega t \, R\cos\theta + \cos\omega t \, R\sin\theta$$

$$y = R(\sin\omega t\cos\theta + \cos\omega t \sin\theta)$$

$$y = R\sin(\omega t + \theta)$$

It shows that the resultant displacement at P is simple harmonic and of amplitude R.

Squaring and adding eq(i) and (ii), we get

$$(a_1 + a_2\cos\delta)^2 + (a_2\sin\delta)^2 = R^2\cos^2\theta + R^2\sin^2\theta$$

$$a_1^2 + a_2^2\cos^2\delta + 2a_1a_2\cos\delta + a_2^2\sin^2\delta = R^2(\cos^2\theta + \sin^2\theta)$$

$$a_1^2 + a_2^2(\cos^2\delta + \sin^2\delta) + 2a_1a_2\cos\delta = R^2$$

$$[\because \cos^2\theta + \sin^2\theta = 1]$$

$$R^2 = (a_1^2 + a_2^2 + 2a_1a_2\cos\delta)$$

Intensity $(I) \propto [\text{Amplitude}(R)]^2$

So, $\boxed{I = (a_1^2 + a_2^2 + 2a_1a_2\cos\delta)}$ — (iii)

This is the expression for Intensity (I) at point P.

<u>Condition of Maxima (Constructive Interference)</u>

The intensity (I) is given by,

$$I = a_1^2 + a_2^2 + 2a_1a_2\cos\delta$$

The Intensity (I) is maximum,
when $\cos\delta = +1$

$\cos\delta = \cos 2n\pi$, where $n = 0, 1, 2$ - etc

$$\delta = 2n\pi$$

So, $I_{max} = a_1^2 + a_2^2 + 2a_1a_2 \times 1$

$$\boxed{I_{max} = (a_1 + a_2)^2}$$

It shows that the maximum intensity is greater than the sum of two seperate intensities $(a_1^2 + a_2^2)$.

Condition of Minima (Destructive Interference) →

The resultant Intensity (I) is given by,

$$I = a_1^2 + a_2^2 + 2a_1a_2 \cos\delta$$

The Intensity (I) is minimum,

when $\cos\delta = -1$

$\cos\delta = \cos(2n-1)\pi$, $n = 1, 2, 3$ — etc

$$\delta = (2n-1)\pi$$

So, $I_{min} = a_1^2 + a_2^2 + 2a_1a_2(-1)$

$$I_{min} = (a_1^2 + a_2^2 - 2a_1a_2)$$

$$\boxed{I_{min} = (a_1 - a_2)^2}$$

The minimum intensity is less than the sum of the two seperate intensities $(a_1^2 + a_2^2)$.

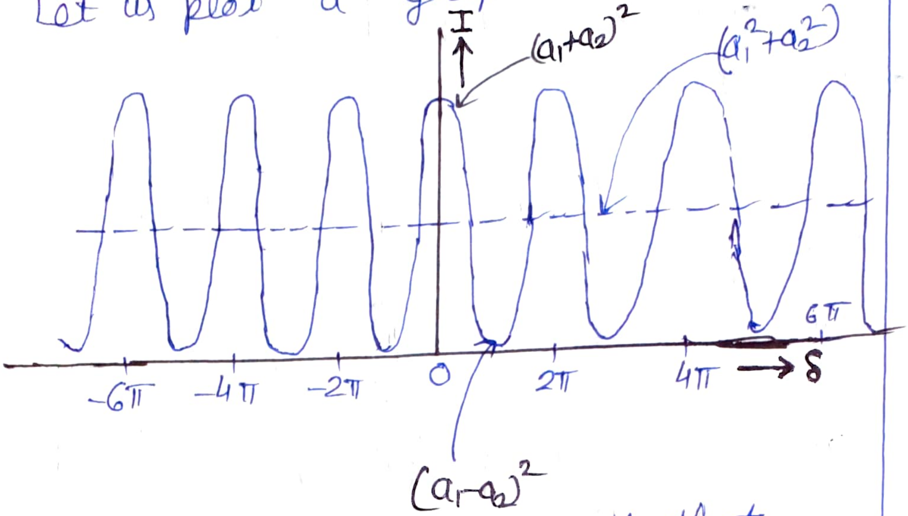
So, As we move on the screen, the path difference between two waves gradually changes and there is a variation in the intensity of light, being alternately maximum and minimum. This is called the 'Interference pattern'.

Interference and conservation of Energy ⇒

The resultant Intensity at any point in the interference pattern is given by.

$$I = a_1^2 + a_2^2 + 2a_1a_2\cos\delta$$

Let us plot a graph between I & δ



It is clear from the graph that It is a periodic curve. If $\delta = 2n\pi$, $n = 0, 1, 2$ -

then, $I = I_{max} = a_1^2 + a_2^2 + 2a_1a_2 \times 1$

$$\boxed{I_{max} = (a_1+a_2)^2}$$

If $\delta = (2n-1)\pi$, $n = 1, 2, 3$ —

$$I = I_{min} = (a_1^2 + a_2^2 - 2a_1a_2)$$

$$\boxed{I_{min} = (a_1-a_2)^2}$$

$$I_{average} = \frac{\int_0^{2\pi} I\,d\delta}{\int_0^{2\pi} d\delta} = \frac{\int_0^{2\pi}(a_1^2+a_2^2+2a_1a_2\cos\delta)}{[\delta]_0^{2\pi}}$$

$$= \frac{[a_1^2\delta + a_2^2\delta + 2a_1a_2\sin\delta]_0^{2\pi}}{[\delta]_0^{2\pi}} = \frac{[a_1^2+a_2^2]\cancel{2\pi}}{\cancel{2\pi}}$$

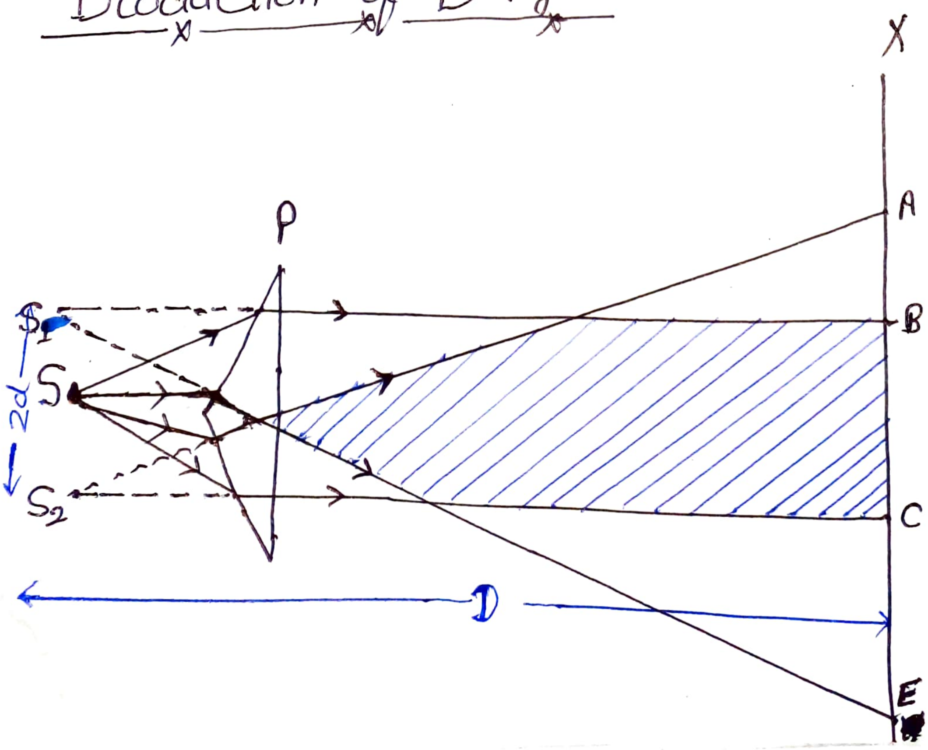
$\boxed{I_{average} = (a_1^2+a_2^2)}$, It means average energy is equal to the sum of separate intensities i.e. whatever energy apparently disappears at the minima is actually present at maxima. So there is no violation of conservation of energy in Interference.

Fresnel's Biprism→ It is a device, which is used to obtain two coherent sources to produce interference pattern.

Construction→ It is a combination of two prisms of very small refracting angles, placed base to base. In practice,

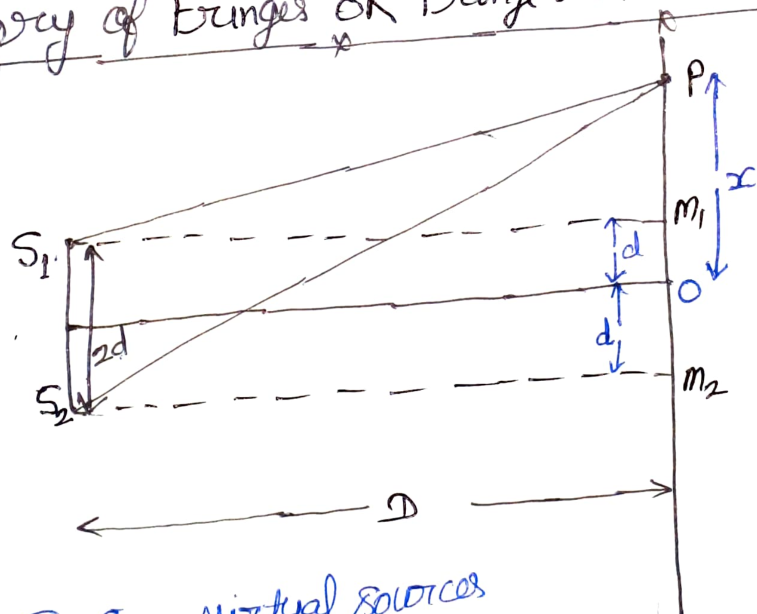
the biprism is made from a single plate by grinding and polishing, so that it is a single prism with one of its angles about 179° and the other two about 30'.

Production of Fringes:→



S is a narrow vertical slit illuminated by monochromatic light. The light from S is allowed to fall symmetrically on the bi-prism P. The light beams emerging from the upper and lower halves of the prism appear to start from two virtual images of S_1 and S_2, which act as coherent sources. The cones of light BS_1E and AS_2C, diverging from S_1 and S_2 are superposed and the interference fringes are obtained in the overlapping region of BC. These fringes are non localised and may be obtained on a screen or seen through an eye piece.

Theory of Fringes OR Fringe width formula →



S_1, S_2 – virtual sources

XY – screen

D → distance between slits and screen

2d → distance between two slits

P → the point at which two beams are meeting.

(15)

The illumination or intensity at ~~any~~ point P can be obtained by calculating the path difference $S_2P - S_1P$, so:-

from $\Delta S_2 M_2 P$,

$$(S_2P)^2 = (S_2M_2)^2 + (PM_2)^2$$
$$= D^2 + (x+d)^2$$
$$= D^2\left[1 + \frac{(x+d)^2}{D^2}\right]$$
$$S_2P = D\left[1 + \frac{(x+d)^2}{D^2}\right]^{1/2}$$

As $(x+d) << D$

$$S_2P = D\left[1 + \frac{1}{2}\frac{(x+d)^2}{D^2}\right]$$
$$S_2P = D + \frac{1}{2}\frac{(x+d)^2}{D}$$

Similarly. from $\Delta S_1 M_1 P$

$$(S_1P)^2 = (S_1M_1)^2 + (PM_1)^2$$
$$(S_1P)^2 = D^2 + (x-d)^2$$
$$S_1P = D\left[1 + \frac{(x-d)^2}{D^2}\right]^{1/2}$$

As $(x-d) << D$

$$(S_1P) = D\left[1 + \frac{1}{2}\frac{(x-d)^2}{D^2}\right]$$
$$(S_1P) = D + \frac{1}{2}\frac{(x-d)^2}{D}$$
$$(S_1P) = D + \frac{1}{2}\frac{(x-d)^2}{D}$$

Now $S_2P - S_1P = \cancel{D} + \frac{1}{2}\frac{(x+d)^2}{D} - \cancel{D} - \frac{1}{2}\frac{(x-d)^2}{D}$

$$S_2P - S_1P = \frac{1}{2D}\left[\cancel{x^2} + \cancel{d^2} + 2xd - \cancel{x^2} - \cancel{d^2} + 2xd\right]$$
$$S_2P - S_1P = \frac{2 \times \cancel{2}\, x d}{\cancel{2} D} = \frac{2xd}{D}$$
$$(S_2P - S_1P) = \frac{2xd}{D}$$

$$(S_2P - S_1P) = \frac{2xd}{D} \quad — (1)$$

We know the relation b/w path difference & phase difference (δ)

$$\delta = \frac{2\pi}{\lambda} \times \text{path difference}$$

for Maximum Intensity, $\delta = 2n\pi$, where, $n = 0, 1, 2, 3$

$$\cancel{2}n\cancel{\pi} = \frac{\cancel{2\pi}}{\lambda} \times \text{path difference}$$

$$\text{path difference} = n\lambda, \quad n = 0, 1, 2, 3 \ldots \quad — (2)$$

from eq (1) & (2)

$$\frac{2xd}{D} = n\lambda$$

$$x = \frac{D}{2d}(n\lambda), \quad n = 0, 1, 2, 3$$

Let x_n & $x_{(n+1)}$ denote the distances of nth and $(n+1)$th bright fringes, then

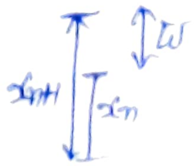
$$x_{n+1} - x_n = \frac{D}{2d}(n+1)\lambda - \frac{D}{2d}n\lambda$$

$$[x_{n+1} - x_n] = \frac{D\lambda}{2d}[\cancel{n}+1-\cancel{n}]$$

$$[x_{n+1} - x_n] = \frac{D\lambda}{2d}$$

The distance between any two consecutive bright or dark fringes is known as fringe width, it is denoted by W

$$x_{n+1} - x_n = \frac{D\lambda}{2d}$$



$$\boxed{W = \frac{D\lambda}{2d}}$$

this is the required expression for fringe width.

Determination of wavelength of light λ using Fresnel's Bi Prism →

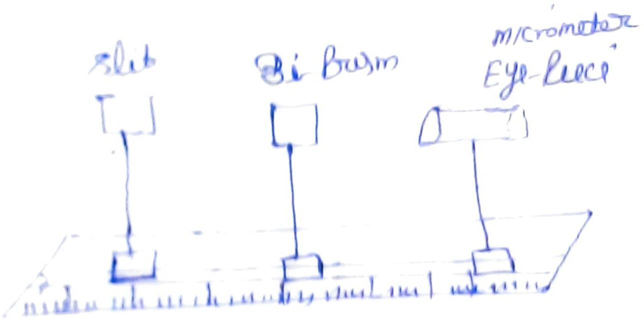
The fringe width (W) is given by

$$W = \frac{D\lambda}{2d}$$

$$\lambda = W\left(\frac{2d}{D}\right)$$

If fringe width (W), the distance between two slits (2d) and distance between screen and slits (D) are measured, then the wavelength of light (λ) can be calculated.

Experimental Arrangement and Adjustment →



It consists of optical bench with three stands. The first stand carries an adjustable slit, the second carries a biprism and third carries micrometer eyepiece.

Screws are provided to rotate the slit and Bi-prism in their own planes, and also to move the bi-prism and the eye piece at right angles to the length of optical bench. The slit is illuminated by monochromatic light ~~to get~~ whose wavelength is to be determined.

The slit, Bi-Prism and the eye piece are adjusted to get the sharp fringes (Interference pattern).

We know, the fringe width (ω) is given by,

$$W = \frac{D\lambda}{2d}$$

$$\lambda = W\left(\frac{2d}{D}\right)$$

The following measurements are now made.

(i) measurement of fringe width (W) :→

After obtaining the sharp fringes, the vertical cross-wire is set on one side of interference pattern. The reading of the micrometer is taken. then eye-piece is moved laterally so that the vertical cross-wire coincides with successive bright fringes and corresponding readings are noted. from these reading the fringe-width can be found.

(ii) <u>Measurement of D</u>→ The distance between the slit and the micrometer eye-piece is measured with the help of scale of optical bench.

(iii) <u>measurement of 2d</u> :→ To measure the distance 2d between the slits S_1 and S_2, a convex lens of short focal length is placed between the Bi-Prism and eye piece. By moving the lens along the length of the bench two positions L_1 and L_2 are obtained such that the real images of S_1 and S_2 are obtained in the eye piece.

Let d_1 and d_2 be the separations between real images in the position L_1 and L_2 respectively.
If $u \rightarrow$ distance b/w slits and lens in L_1 position
$v \rightarrow$ " " lens and eye piece in L_1 position;

then from magnification formula
In L_1 position $\rightarrow$

$$\frac{v}{u} = \frac{d_1}{2d} \quad \text{— (i)}$$

As two positions of lens are conjugate then in L_2 position

$$\frac{u}{v} = \frac{d_2}{2d} \quad \text{—(ii)}$$

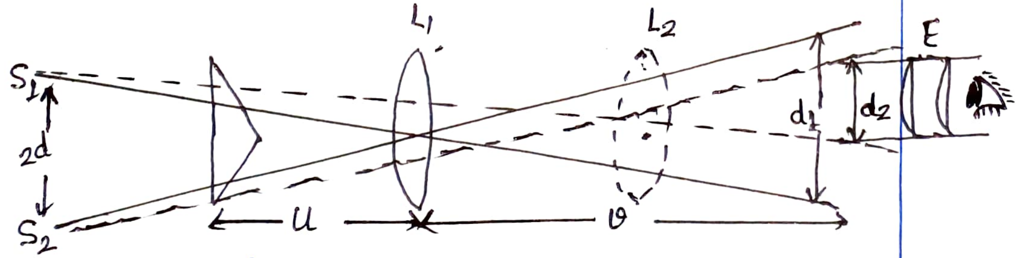
multiplying eq (1) & (2)

$$\frac{\cancel{v}}{\cancel{u}} \times \frac{\cancel{u}}{\cancel{v}} = \frac{d_1 d_2}{2d \times 2d}$$

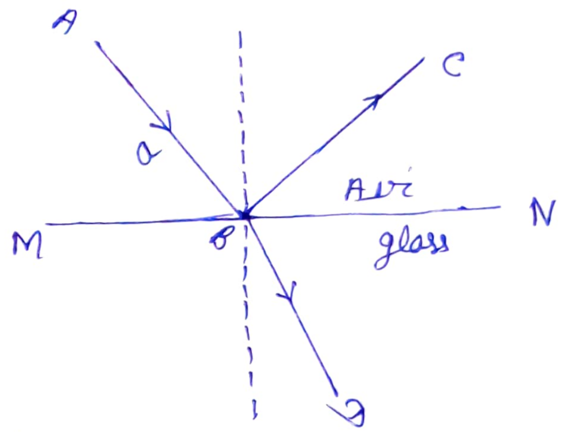
$$4d^2 = d_1 d_2$$

$$\boxed{2d = \sqrt{d_1 d_2}}$$

putting the value of W, $2d$, D
λ can be calculated from the formula, $\boxed{\lambda = W\left(\frac{2d}{D}\right)}$



Stoke's Treatment:→ (Phase change on-Reflection)



When light wave is reflected at the surface of an optically denser medium, it suffers a phase change of π.

We know

$$\text{Phase difference} = \frac{2\pi}{\lambda} \times \text{path diff}$$

$$\cancel{\pi} = \frac{2\cancel{\pi}}{\lambda} \times \text{path diff}$$

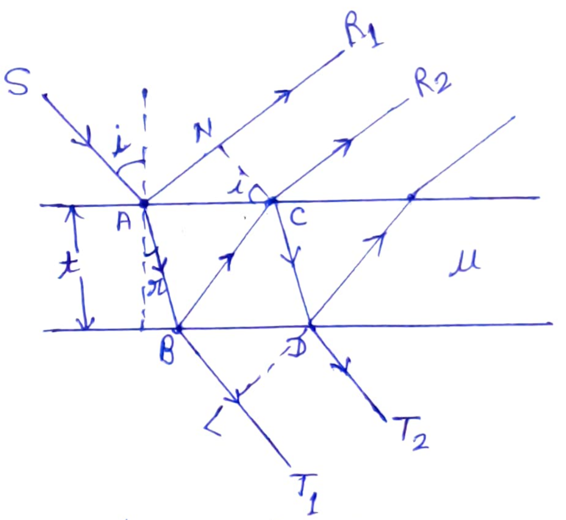
$$\text{path diff} = \frac{\lambda}{2}$$

Hence If a light wave is reflected from an optically denser medium, then it suffers a phase change of π or path change of $\lambda/2$.

Interference In thin films: Division of Amplitude :→

Thin Film → Thin film is made by spreading oil on surface of water or thin-glass plate.

Interference in Thin Films :→ When a such thin film is illuminated by light, the light waves are reflected from the upper and lower part of the thin film and the light waves are also transmitted through the thin film. So interference occurs between the reflected waves from thin film and also between the transmitted waves through the thin film. Let us consider the case of monochromatic light.



Let a monochromatic light ray SA be incident at an angle i on a parallel-sided transparent thin film of thickness t and refractive index $\mu (>1)$. At the point A, the ray is partly reflected along AR_1 and partly refracted along AB at angle r. At point B, it is again partly reflected along BC and partly refracted along BT_1.

Similarly reflections and refractions occur at points C, D --- etc as shown. So we get a set of parallel reflected rays AR_1, CR_2--- and a set of parallel transmitted rays BT_1, DT_2-- etc.

Interference in Thin films due to Reflected rays ⇒ Here, we have to see the interference in thin films due to reflected rays AR_1, CR_2---

The path difference (P) between AR_1 & CR_2 rays will be -

$$P = \text{Path ABC in film} - \text{Path AN in Air}$$

$$= \mu(AB + AC) - AN$$

$\because$ optical path $= \mu$ (path)

$$\boxed{P = 2\mu t \cos r} \quad \text{—(1)}$$

Where μ - refractive index of film
t - thickness of film
r - angle of refraction.

The ray AR_1 is reflected from denser medium, so According to Stokes treatment it will suffer a phase change of π, which is equivalent to path difference $\lambda/2$.
So, from eq(1), the Path difference b/w AR_1 & CR_2 will be

$$\boxed{P = 2\mu t \cos r \pm \frac{\lambda}{2}} \quad \text{-(2)}$$

(4)

Condition for Maxima and minima in Reflected light →

The two rays will reinforce each other if the path difference between them is an integral multiple of λ, i.e

$$2\mu t\cos r \pm \frac{\lambda}{2} = n\lambda, \quad n = 0, 1, 2 \ldots$$

taking $(-ve)$ sign -

$$2\mu t\cos r - \frac{\lambda}{2} = n\lambda$$

$$\boxed{2\mu t\cos r = (2n+1)\frac{\lambda}{2}}, \quad n = 0, 1, 2, 3 \ldots \quad (3)$$

Condition for maxima.

this is the condition for maxima, hence if this condition is satisfied, the film will appear bright in the reflected light.

The two rays will destroy each other, if the path diff between them is an odd multiple of $\lambda/2$ i.e

$$2\mu t\cos r \pm \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}, \quad n = 1, 2, 3 \ldots$$

taking $(-ve)$ sign -

$$2\mu t\cos r - \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$$

$$\boxed{2\mu t\cos r = n\lambda}, \quad n = 0, 1, 2, 3 \ldots \quad (4)$$

Condition of minima.

If this condition is satisfied, the film will appear dark in the reflected light.

Condition for Maxima and minima in Transmitted light:-

The path difference between the transmitted rays BT_1 and DT_2 is given by

$$P = \text{Path } BCD \text{ in film} - \text{Path } BL \text{ in Air}$$

$$P = \mu(BC + CD) - BL \times 1$$

$$P = 2\mu t \cos r$$

In this case, there is no phase change due to reflection at B or C because in either case the light is travelling from denser to rarer medium. Hence the effective path difference between BT_1 & DT_2 is $2\mu t \cos r$

So, the two rays will reinforce each other if the path diff between them is an integral multiple of λ ie.

$$\boxed{2\mu t \cos r = n\lambda}, \quad n = 0, 1, 2, 3 \quad \text{— (5)}$$

Condition of maxima

If this condition is satisfied, then the film will appear bright in transmitted light. The two rays will destroy each other, if path diff b/w them is an odd multiple of $\lambda/2$ ie

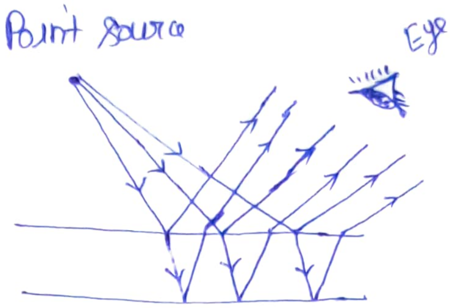
$$\boxed{2\mu t \cos r = (2n-1)\frac{\lambda}{2}}, \quad n = 1, 2, 3. \quad \text{— (6)}$$

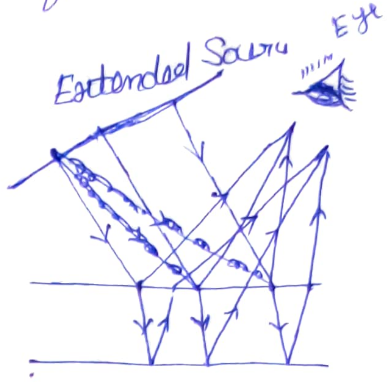
Condition of minima

If this condition is satisfied the film will appear dark in the transmitted light.

Note: A comparison of eq (3), (4), (5), (6) shows that the conditions for maxima and minima in reflected light are just reverse of those in transmitted light. Hence the film which appears bright in reflected light will appear dark in transmitted light.

<u>Need of Extended source</u>:→ An extended source is required to enable the eye to see the large area of the film simultaneously





If we take point source then we can not see the entire film simultaneously but if we take extended source we can see the entire film simultaneously as shown in figure.

Production of colours in Thin Films: → When a white light (such as sky light) is incident on the film of oil on water or soap bubble, then the film of oil or soap bubble is seen coloured observing under reflected light. It arises due to the interference between the reflected light from the top and bottom surfaces of the film.

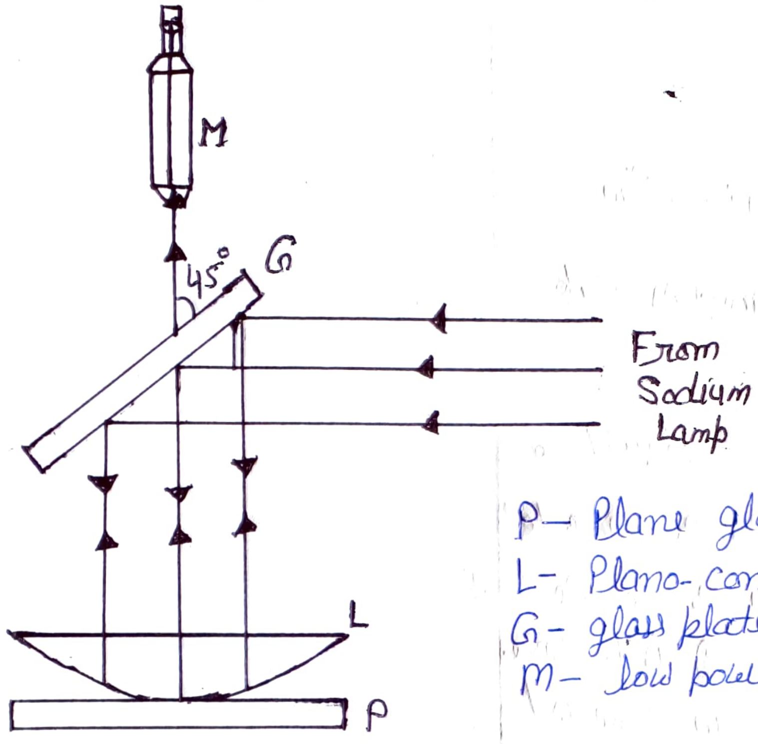
When we see the film or soap bubble, our eyes receive rays of light reflected from the upper and lower surfaces of the film. The path difference between interfering rays depends upon thickness of film t and upon r. $(2\mu t \cos r)$ White light consists of continuous range of wavelengths. At a particular point of film, only certain wavelengths of light will satisfy the condition of maxima and other wavelengths of light satisfies either less intensity maxima or minima, So coloured pattern is observed in thin film of oil or soap bubble. If thickness of film is same throughout the film and incident rays are parallel, the film of uniform colouration is seen.

Fringes of Equal Thickness :→ The path difference between two interfering rays obtained due to the reflection from the film of thickness t and refractive index μ is given by $2\mu t \cos r$, where r is the inclination of ray inside the film. If the thickness t of the film varies rapidly, then the path difference changes mainly due to the thickness t of the film and we get alternate maxima and minima due to variation of thickness t of the film. So each maxima or minima will be the locus of constant film thickness. Such types of fringes are called fringes of equal thickness. Such fringes are localised on the film itself. These fringes are observed by a microscope focussed on the film. Example of such types of film is Newton's Rings.

Fringes of Equal Inclination: (OR Haidinger's Fringes) :→ The path difference between two interfering rays obtained due to the reflection from the film of thickness t and refractive index μ is given by $2\mu t \cos r$. If the thickness of the film is uniform, then the path difference $2\mu t \cos r$ changes with the change in inclination r. In this case we take wide cone of light in our observations. Each fringe (maxima or minima) is obtained at particular value of r. Such fringes are called fringes of equal inclination. These fringes are formed at infinity. These fringes are first observed by Haidinger using telescope focussed at infinity, so these fringes are also called as Haidinger's fringes.

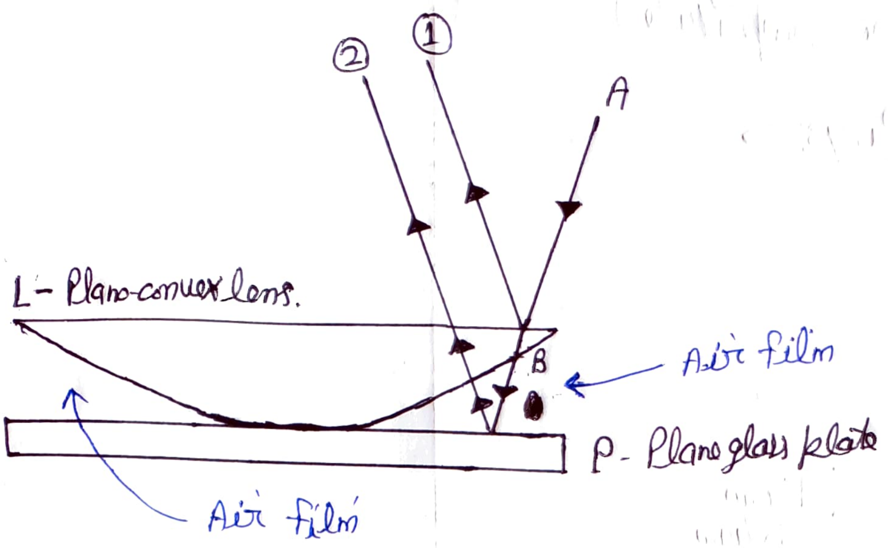
Newton's Rings
(Division of Amplitude)

Formation of Newton's Rings:→



P – Plane glass plate
L – Plano-convex lens
G – glass plate
M – low power microscope

When a plano-convex lens (L) of large radius of curvature is placed with its convex surface in contact with a plane glass plate (P), an air film is formed between the lower surface of the lens and upper surface of plate. The thickness of the film gradually increases from the point of contact outwards. If monochromatic light is allowed to fall normally on this film, a system of alternate bright and dark concentric rings with their centre dark is formed in the air film. These are called Newton's Rings. They can be seen through Low-power microscope focussed on the film.



Newton's Rings are formed as a result of interference between the light waves reflected from the upper and lower surfaces of the air film. In figure the ray 1 & 2 interfere.

Recall Interference in thin film in Reflected light, The path difference between interfering rays is, $P = 2\mu t \cos r \pm \frac{\lambda}{2}$

Here $r = 0$ (normal incidence) and t = thickness of the film at point B, so,

$$P = 2\mu t \cos 0 \pm \frac{\lambda}{2}$$

$$P = 2\mu t \pm \frac{\lambda}{2} \quad —(1)$$

At the point of contact O of the lens and the plate, $t = 0$, and here $\mu = 1$ (Air film)

$$\boxed{P = \pm \lambda/2}$$

Hence at the centre or at the point of contact, the path difference is $\lambda/2$ which is the condition of minima (because if path diff is an odd multiple of $\lambda/2$, then we get minima). So at centre we get dark spot in Newton's Rings in reflected light.

Condition for Maximum Intensity (Bright Fringe) in reflected Light →

Recall the condition of maximum Intensity in Interference in thin film in Reflected light,

$$2\mu t \cos r = (2n+1)\frac{\lambda}{2}, \quad n = 0, 1, 2, 3 \ldots$$

here $\mu = 1$ (Air film), $r = 0$ (normal incidence)

$$\boxed{2t = (2n+1)\frac{\lambda}{2}} \quad (2)$$

— this is the condition of maxima or Bright fringe.

where $n = 0, 1, 2, 3 \ldots$

Condition of minimum Intensity (Dark-Fringe) in Reflected light —

Recall the condition of minimum intensity in Interference in thin film in Reflected light

$$2\mu t \cos r = n\lambda, \quad n = 1, 2, 3 \ldots$$

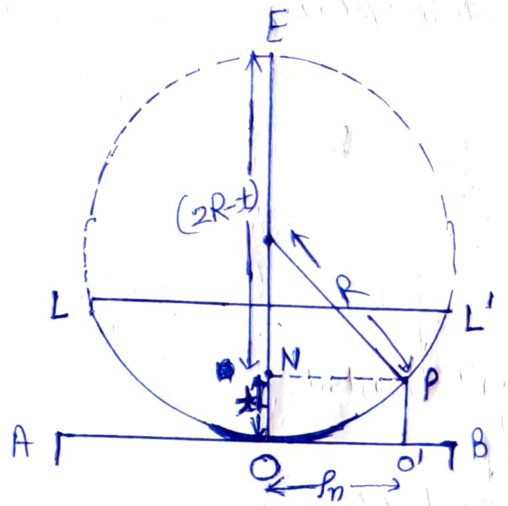
Here $\mu = 1$ (Air film), $r = 0$ (normal incidence)

$$\boxed{2t = n\lambda}, \quad n = 1, 2, 3 \ldots \quad (3)$$

This is the condition of minima or Dark fringes.

Note— The above conditions of maxima and minima are reversed in Interference in transmitted light in Newton's Rings.

Diameters of Bright and Dark Rings :→



Let us consider a plano-convex lens LOL', which is placed on glass plate AB. O is the point of contact of glass plate AB and lens. Let R be the radius of curvature of the curved surface of the lens and ρ_n be the radius of Newton's Ring corresponding to a point P, where the film thickness is t. Draw perpendicular PN. $PN = \rho_n$; $ON = t$, $NE = (2R-t)$

From the property of circle,

$$(PN)^2 = ON \times NE$$

$$\rho_n^2 = t \times (2R-t)$$

$$\rho_n^2 = 2Rt - t^2$$

t is very small, so neglecting t^2

$$\rho_n^2 = 2Rt$$

$$\rho_n^2 = 2tR \quad -④$$

Recall, the condition for Newton's Bright ring from eq②, $2t = (2n+1)\frac{\lambda}{2}$

So, $\rho_n^2 = (2n+1)\frac{\lambda}{2} R$

(5)

$$\rho_n^2 = (2n+1)\frac{\lambda R}{2}$$

If D_n be the Diameter of nth bright ring, then $D_n = 2\rho_n$, $\because \rho_n$ is the radius of nth bright ring

$$\frac{D_n^2}{4_2} = (2n+1)\frac{\lambda R}{2}$$

$$D_n^2 = 2(2n+1)\lambda R$$

$$D_n^2 = 2(2n+1)\lambda R$$

$$D_n = \sqrt{2\lambda R}\sqrt{(2n+1)}$$

$$\boxed{D_n \propto \sqrt{(2n+1)} \quad \text{where } n = 0,1,2,3\ldots}$$ $\because \sqrt{2\lambda R}$ = Constant

It represents that the diameters of bright rings are proportional to the square roots of the odd natural numbers.

The diameters of first few bright rings are in the ratio

$= 1 : \sqrt{3} : \sqrt{5} : \sqrt{7}$

$= 1 : 1.732 : 2.236 : \ldots$

the seperations between successive rings are

0.732, 0.504, 0.416, ..

hence seperation decreases as the order increases.

Diameters of Dark Rings– The condition for minimum intensity (Dark ring) is

$$2t = n\lambda$$

but we know $2tR = \rho_n^2$

$$2t = \rho_n^2/R$$

$$n\lambda = \rho_n^2/R$$

and If D_n be the diameter of nth dark ring, $\rho_n = D_n/2$

$$\frac{D_n^2}{4R} = n\lambda$$

$$D_n^2 = 4nR\lambda$$

$$D_n = \sqrt{4nR\lambda}$$

$$D_n = \sqrt{4R\lambda}\sqrt{n}$$

$$\boxed{D_n \propto \sqrt{n}}$$

Thus, the diameters of dark rings are proportional to the square-roots of natural numbers.

Applications of Newton's Ring →

(i) Determination of wavelength of monochromatic light →

Recall the diameter for n^{th} bright fringe or ring

$$D_n^2 = 2(2n-1)\lambda R$$

If D_{n+p} be the diameter for $(n+p)^{th}$ bright ring, then

$$D_{n+p}^2 = 2[2(n+p)-1]\lambda R$$

$$D_{n+p}^2 - D_n^2 = 2[2(n+p)-1]\lambda R - 2(2n-1)\lambda R$$

$$= 2[2n+2p-1]\lambda R - (4n-2)\lambda R$$

$$D_{n+p}^2 - D_n^2 = \cancel{4n\lambda R} + 4p\lambda R - 2\lambda R - \cancel{4n\lambda R} + 2\lambda R$$

$$D_{n+p}^2 - D_n^2 = 4p\lambda R$$

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}$$

$$\boxed{\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}}$$

So by measuring the the value of D_{n+p} and D_n and R, λ can be calculated.

(ii) Determination of Refractive index of liquid → ⑦

$$\boxed{\mu = \frac{(D^2_{n+p} - D_n^2)_{Air}}{(D^2_{n+p} - D^2_n)_{liquid}}}$$

By measuring the diameter of Newton's rings in Air and liquid, μ can be determined.

Localised fringes → These fringes are formed by broad sources and are restricted to a surface. these fringes are localised on the film itself and can be seen by focussing the microscope on the film.

Example – Newton's Rings.

Non-localised Fringes → These fringes are formed by point or line sources and are not restricted to any surface. These fringes fill all space between double slit and screen.

Exp – Fringes formed in double slit and biprism experiment are non-localised fringes.

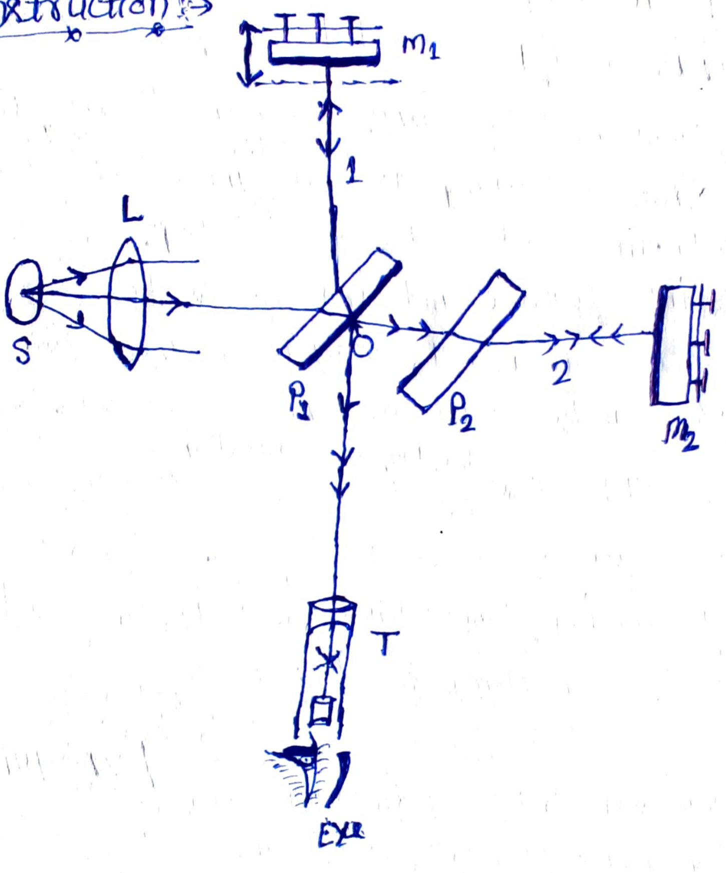
Fringes of Equal Thickness :→ The path difference between two interfering rays obtained due to the reflection from the film of thickness t and refractive index μ is given by $2\mu t \cos r$, where r is the inclination of ray inside the film. If the thickness t of the film varies rapidly, then the path difference changes mainly due to the thickness t of the film and we get alternate maxima and minima due to variation of thickness t of the film. So each maxima or minima will be the locus of constant film thickness. Such types of fringes are called fringes of equal thickness. Such fringes are localised on the film itself. These fringes are observed by a microscope focussed on the film. Example of such types of film is Newton's Rings.

Fringes of Equal Inclination:(OR Haidinger's Fringes) ⇒ The path difference between two interfering rays obtained due to the reflection from the film of thickness t and refractive index μ is given by $2\mu t \cos r$. If the thickness of the film is uniform, then the path difference $2\mu t \cos r$ changes with the change in inclination r. In this case we take wide cone of light in our observations. Each fringe (maxima or minima) is obtained at particular value of r. Such fringes are called fringes of equal inclination. These fringes are formed at infinity. These fringes are first observed by Haidinger using telescope focussed at infinity, So these fringes are also called as Haidinger's fringes.

Michelson Interferometer:→

It is a device which is used to get interference fringes of various shapes. It has number of applications in optics.

Construction:→



It consists of extended monochromatic source S, and convex lense L. Its main parts are two plane mirrors M_1 and M_2 and two similar optically plane parallel glass plates P_1, P_2. The mirrors M_1 and M_2 are silvered on their front surfaces. These mirrors M_1, M_2 are mounted vertically on two arms at right angles to each other. The planes of mirrors M_1, M_2 can be adjusted horizontally and vertically using screws. The mirror M_1 can be moved in the direction of arrows using the screws.

Working:→ Extended monochromatic source emits the light. The emitted light become parallel by lens L and falls on plate P_1. A number of rays incident on the partially silvered surface of plate P_1, but Here we take only a ray of light incident on the partially silvered surface of plate P_1. A ray of light incident on the partially silvered surface of plate P_1 is partly reflected and partly transmitted. The reflected ray 1 and transmitted ray 2 reach at m_1 and m_2 respectively. After reflection from m_1 and m_2 the two rays meet at the partially silvered surface of plate P_1 and enter the telescope T. The two rays satisfies the condition of interference and interfere because These are obtained from the same incident ray hence they are coherent. The interference fringes can be seen in the telescope.

Function of Plate P_2:→ The ray 1 passes through the glass plate P_1 twice after reflection and transmission at point O. but ray 2 does not do so. So to equalise the paths. a glass plate P_2 having same thickness as P_1, is used. glass plate P_2 is also called compensating plate.

Shapes of Fringes obtained by Michelson Interferometer → Michelson Interferometer forms different types of fringes like - circular fringes, Straight fringes and white light fringes.

Circular fringes :- When M_2 is exactly perpendicular to M_1, we obtain circular fringes localised at infinity.

Straight fringes :- When M_2 is not perpendicular to M_1, we obtain straight fringes.

White light fringes :- When M_2 is not perpendicular to M_1 and monochromatic source is replaced by white light, we obtain coloured fringes.

Applications of Michelson Interferometer (MI) →

There are various applications of Michelson Interferometer (MI) like -

(i) **Determination of wavelength of mono-chromatic light :-** Using the formula, λ can be determined,

$$\boxed{\lambda = \frac{2x}{N}}$$

Where $\lambda \rightarrow$ wavelength of mono-chromatic light

$x \rightarrow$ distance moved by mirror

N — no. of fringes shifted

(ii) Determination of Difference in Wavelengths:→ Using the formula,

$$\boxed{\Delta\lambda = \frac{\lambda_1\lambda_2}{2x} = \frac{\lambda^2}{2x}}$$

$\Delta\lambda$ or $\lambda_1 - \lambda_2$ can be determined

Where $\lambda^2 = \lambda_1\lambda_2$,

x - distance moved by mirror.

$\Delta\lambda$ is also known as width of spectral line

(iii) Determination of Refractive Index (μ) of thin plate:→

To determine the ~~thickness of~~ refractive index of a thin plate, we insert thin plate in one of the arm of MI. and using the formula.

$$\boxed{2x = 2(\mu - 1)t}$$

OR

$$\boxed{N\lambda = 2(\mu - 1)t}$$

μ can be determined,

where x - distance moved by mirror

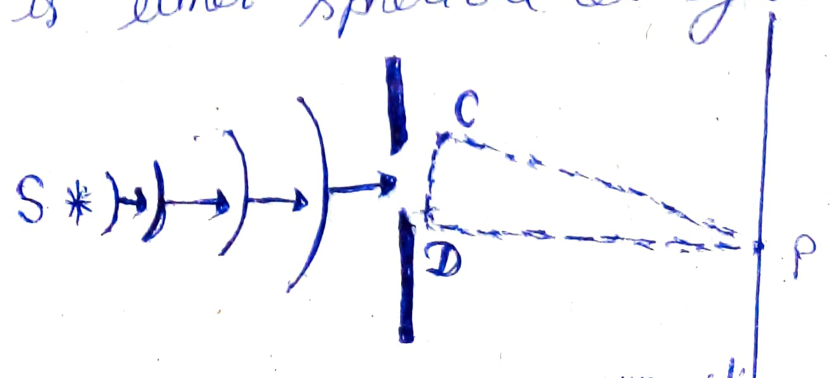
t - thickness of plate.

N - No. of fringes shift.

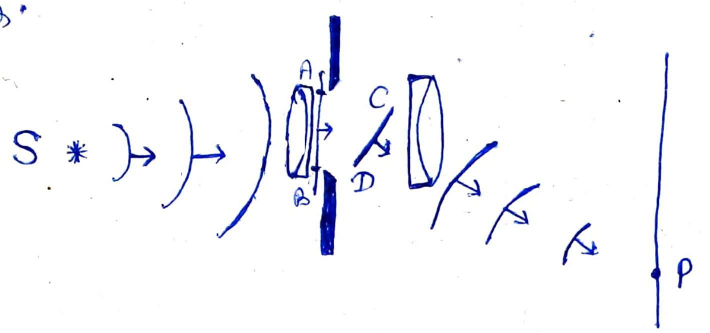
Diffraction of light:→ When an opaque obstacle is placed between the source of light and screen, a distinct shadow (or illuminated region) is obtained on the screen. This indicates that light travels in straight. but If the size of aperture or obstacle is small (comparable to the wave-length of light), then the light bends round the corner of the obstacle and enters the geometrical shadow and there is departure of from straight line propagation. This bending of light is called diffraction.

Diffraction phenomena are divided into two groups, Fresnel diffraction and Fraunhofer diffraction.

Fresnel Diffraction:→ In the Fresnel's class of diffraction the source of light or the screen or both are at finite distances from the diffracting obstacle or aperture. No lenses are used in this class of diffraction and The incident wavefront is either spherical or cylindrical.



Fraunhofer Diffraction:→ In this diffraction pattern the source of light and screen are at infinite distances from the diffracting obstacle or aperture. This condition is achieved by placing the source and screen in the focal planes of two lenses.



Fraunhofer Diffraction

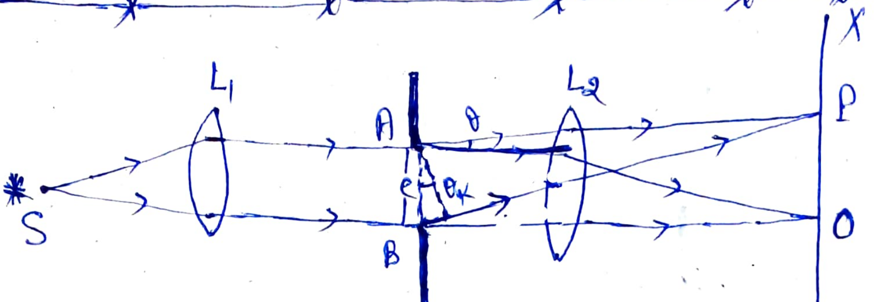
In Fraunhofer diffraction, the diffraction pattern is the image of the source of light modified by diffraction at diffracting obstacle. In Fresnel diffraction, the diffraction pattern is a shadow of diffracting obstacle or aperture modified by diffraction effects.

Difference Between Interference and Diffraction:→

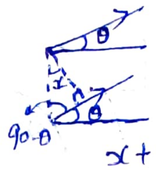
The Interference and Diffraction pattern differ in the following respect:-

1. The interference occurs between the waves starting from two (or more but finite in number) coherent sources. but in diffraction the interference occurs between the secondary wavelets starting from the different points (infinite in number) of the same wave.
2. In an interference the minima and maxima are usually almost perfectly dark and perfectly bright respectively, while in diffraction pattern they are not so.
3. The interference fringes are usually equally-spaced (but not always) but in diffraction pattern the fringes are never equally-spaced.

Fraunhofer Diffraction at a single Slit:→



Note-



$x + 90 - \theta + 90 = 180$
$x = \theta$

Experimental Set up:→ It consists of a slit having width e (AB), placed perpendicular to the plane of paper. It consists of two convex lenses L_1, L_2, monochromatic source of light S. and a screen XY.

Theory:→ A parallel beam of monochromatic light emitted from source S incident normally on slit AB. The light is diffracted from slit S and focussed on screen XY using convex lens. The diffraction pattern is obtained on the screen XY.

Explaination:→ The emitted light from the source S is made parallel using lens L_1. In terms of wave theory the Plane wave front is incident on the slit AB. According to Huygen's principle, each point on slit AB sends out secondary wavelets in all directions. The rays produced from slit AB in the same direction as the incident rays, are focussed at point PO, while the rays diffracted through an angle θ are focussed at point P. We have to find the resultant intensity at point P.

let AK is perpendicular to BK. the path difference between the wavelets from A and B in the direction θ is-

$BK = AB \sin\theta = e \sin\theta \quad (\because AB = e)$

The corresponding phase difference is

$$\frac{2\pi}{\lambda} \times \text{path difference}$$

$$= \frac{2\pi}{\lambda} \times e \sin\theta$$

The resultant intensity at P, is proportional to the square of the amplitude, is

$$I = R^2 = A^2 \frac{\sin^2\alpha}{\alpha^2} \quad \text{——} \; ①$$

Now we will find the direction of minima and maxima.

Directions of minima ⇒

we know

$$I = \frac{A^2 \sin^2\alpha}{\alpha^2}$$

I is minimum (zero), when either $A=0$ or $\frac{\sin^2\alpha}{\alpha^2}$

$A \neq 0$, so $\frac{\sin\alpha}{\alpha} = 0$

$\sin\alpha = 0$, (but $\alpha \neq 0$ If $\alpha = 0$; $\frac{\sin\alpha}{\alpha} = 1$)

$\alpha = \pm m\pi$, where m has an integral value that is $m = 1, 2, 3 \ldots$ except zero.

but $\alpha = \frac{\pi e \sin\theta}{\lambda}$,

$$\frac{\cancel{\pi} e \sin\theta}{\lambda} = \pm m\cancel{\pi}$$

$$\boxed{e \sin\theta = \pm m\lambda} \quad \text{--- (ii)}$$

This equation gives the directions of first, second, third ---- minima by putting $m = 1, 2, 3 \ldots\ldots$

Directions of maxima :→

We know, the intensity I is given by $I = \frac{A^2 \sin^2\alpha}{\alpha^2}$

To find the directions of maxima we differentiate I, and putting $\frac{dI}{d\alpha} = 0$, the value of α is determined.

$\alpha = 0, \frac{3\pi}{2}, \frac{5\pi}{2}, \frac{7\pi}{2} \ldots$

$\alpha = 0, 1.430\pi, 2.462\pi, \ldots$

using these values of α, we get the intensities of different maxima-

putting $\alpha = 0$ in eq (i)

$$I = R^2 \frac{\sin^2 0}{0} = A^2 \qquad \lim_{\alpha \to 0} \frac{\sin\alpha}{\alpha} = 1$$

$$\boxed{I_0 = R^2}$$

This is the intensity of the central (Principal) maximum.

putting $\alpha = \frac{3\pi}{2}$

$$I_1 = R^2 \frac{\sin^2 3\pi/2}{(3\pi/2)^2}$$

$$= \frac{4}{9\pi^2} A^2 = \frac{A^2}{22}$$

$$\boxed{I = A^2/22}$$

this is the intensity of the first maximum.

similarly at $\alpha = 5\pi/2$

the intensity of the second maxima.

$$I_2 = A^2 \frac{\sin^2 5\pi/2}{(5\pi/2)^2} = \frac{4A^2}{25\pi^2} = \frac{A^2}{61}$$

$$\boxed{I_2 = \frac{A^2}{61}}$$ and so on...

Thus the intensities of successive maxima are in the ratio

$$1 : \frac{4}{9\pi^2} : \frac{4}{25\pi^2} : \frac{4}{49\pi^2} : \cdots$$

$$1 : \frac{1}{22} : \frac{1}{61} : \frac{1}{121} : \cdots$$

It is clear from the above result most of the light concentrated in the principal maximum. i.e at

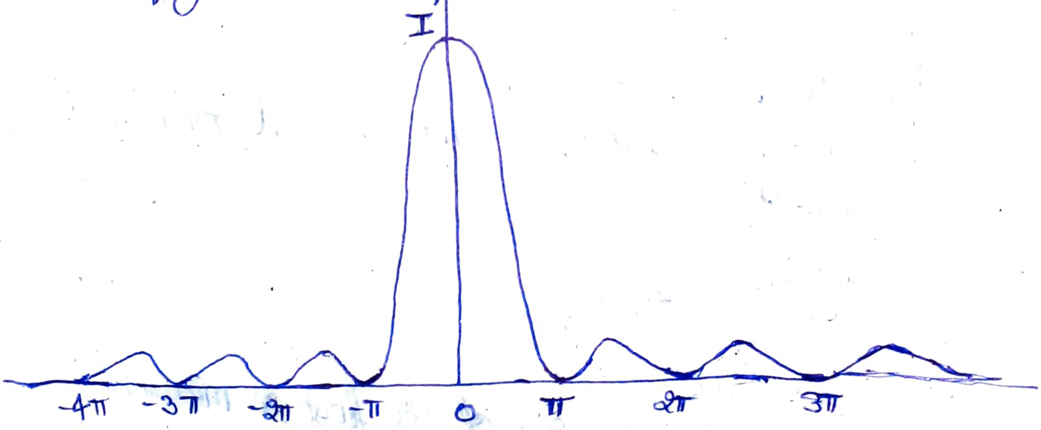
$$\alpha = 0$$

$$\frac{\pi e \sin\theta}{\lambda} = 0$$

$$\sin\theta = 0$$

$$\theta = 0.$$

It means principle maxima is in the same direction as the incident light. So diffraction pattern consists of a bright principal maximum in the direction of incident light, having alternately minima and weak subsidiary maxima of rapidly decreasing intensity of either side of it. The subsidiary maxima do not fall exactly mid way between two minima but are displaced toward the centre of the pattern by an amount which decreases with increasing order. The Diffraction pattern is shown in figure.



Note:- 1. If the slit is made narrower then from eq. $e \sin\theta = \pm\lambda$ (Direction of minima), θ increases it means the principal maximum becomes wider.

2. If width of slit is same as wavelength of incident light, then from equation $e \sin\theta = \pm\lambda$ the minima occurs at $\theta = 90^\circ$ that is principal maxima fills whole space.

Fraunhofer Diffraction at a Circular Aperture

The light emitted from the source is made parallel using convex lens. When these parallel rays are incident on circular aperture, each point of aperture emits secondary wavelets in all directions. when these secondary wavelets are focussed on a point using lens, a diffraction pattern is obtained.

The diffraction pattern consists of a central bright disc surrounded by alternately dark and bright rings of decreasing intensity. The central bright disc is also called Airy's disc. About more than 80% of incident light is obtained in Airy's disc and rest of the incident light is obtained in higher order rings.

The angular seperation θ between the centre of bright disc and the first dark ring is given by.

$$\theta = \frac{1.22\lambda}{d}$$

θ is also called The angular radius of the Airy's disc. where λ is wavelength of the incident light and d is the diameter of the circular aperture.

The above conclusion gives the limit of resolution of a telescope.

Polarisation:→ If ordinary light falls normally on the pair of parallel tourmaline crystal plates P_1 and P_2, which are cut parallel to their crystallographic axis, the emergent light indicates the variation in intensity as P_2 is rotated.

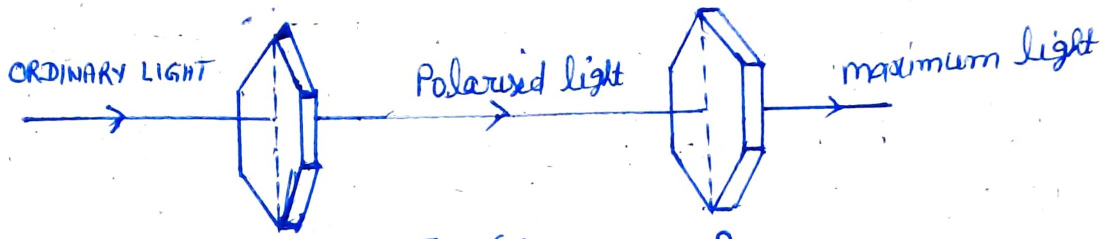


Fig 1(a)

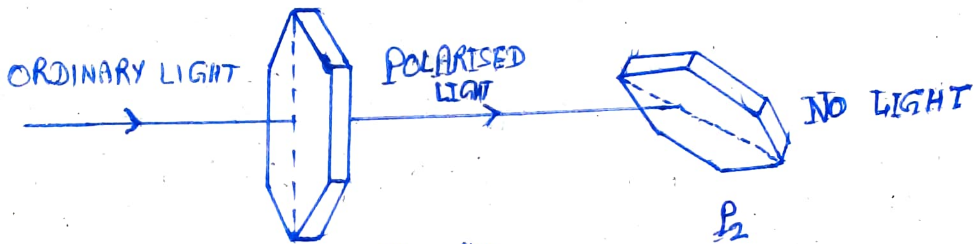
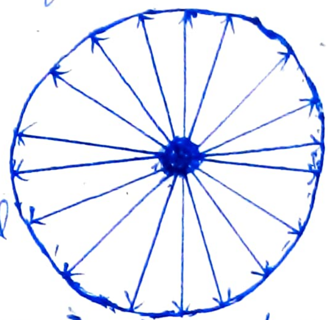


Fig 1 (b)

The intensity of emergent light is maximum Fig 1(a) when the axis of P_2 is parallel to the axis of P_1 and the intensity is minimum Fig 1(b) when the axis of P_2 is at right angles to the axis of P_1. This indicates that the light emerging from P_1 is not symmetrical about the direction of propagation of light, but its vibrations are confined in perpendicular to the direction of propagation. Such light is called plane-polarised or linearly-polarised light. This phenomenon is called polarisation.

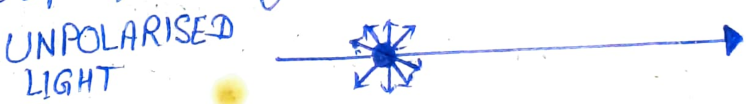
Unpolarised light:→ If ordinary light falls normally on the single rotating tourmaline crystal, there is no variation in the intensity of emergent light. It means that the ordinary light is symmetrical about its direction of propagation.



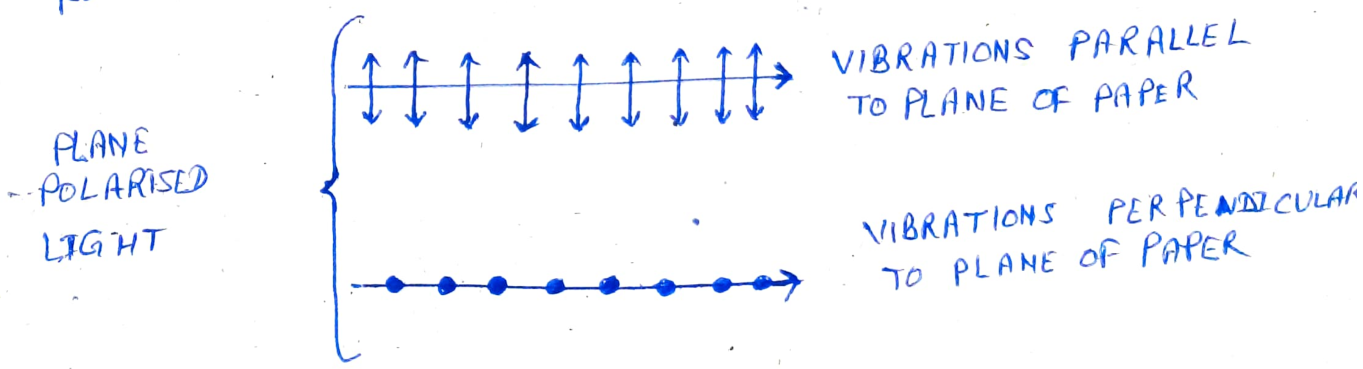
That is the light vector vibrates in all possible straight lines in a plane perpendicular to the direction of propagation of light. This light is called unpolarised light (Fig 2(a)). In other words, the unpolarised light may considered to consists of an infinite number of waves, each having its own direction of vibration. So the probability of the occurence of vibration along the axis of the crystal is same in all ~~direction~~ positions of the crystal. Hence the intensity of light emerging from the crystal plate is the same in all positions of the plate.

Representation of Polarised and Unpolarised light:→

light vectors vibrates in all possible directions perpendicular to the direction of propagation of light in unpolarised light. It is represented as-



The light vectors vibrates along a single straight line perpendicular to the direction of propagation of light in polarised light. It is represented as-



(2) **Doubly Refracting Crystals:→** When a ray of light is incident upon certain crystals, the ray is divided into two refracted rays. Such crystals are called doubly ~~r~~ refracted crystals.

Doubly refracted crystals are of two types.

(i) uniaxial crystals. (ii) Biaxial crystals.

Uniaxial crystals has one direction, called optic axis. The refracted rays travel with same velocity along the optic axis.

Examples of uniaxial crystals are calcite, tourmaline and quartz crystals.

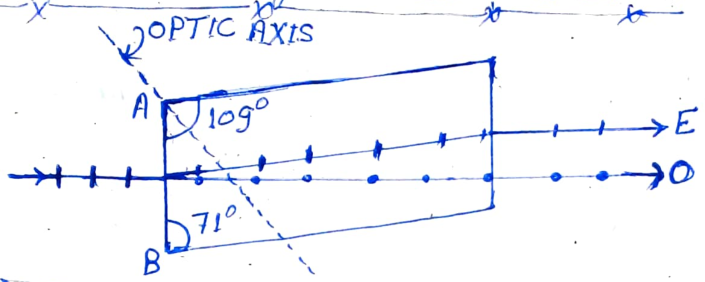
Biaxial crystals ~~are~~ has two optic axis. Examples of Biaxial crystals are topaz and aragonite (Add from page 5 something)

Optic axis of the Crystal:→ Optic axis is a line which passes through ~~a~~ any one of the blunt corners and making equal angles with the three faces which meet there. Optic axis is a direction and not a line.

Principal Section of the crystal:→ A plane containing the optic axis and perpendicular to the opposite faces of the crystal for crystal is known as principal section of the crystal for that pair of faces. So there are three principal sections passing through any point inside crystal, one corresponding to each pair of opposite faces.

Double Refraction ~~in~~ in uniaxial crystals:→ When a ray of unpolarised light is incident upon uniaxial crystal like calcite (or quartz), It is split up into two refracted rays. This phenomenon is known as Double Refraction. One of the two refracted rays obeys the law of refraction, that is it always lies in the plane of incidence and its velocity in the crystal is same in all direction. This ray is called ordinary ray (O-ray). The other refracted ray does not obey the laws of refraction. It travels in the crystal with different speeds in different directions. So it is called extra-ordinary ray (E-ray). O and E-ray have same speed along optic axis and hence the same refractive index.

Representation of Double Refraction:→



(?) → marks of which
Ans:- I think plane of incidence.

Fig 2(a)

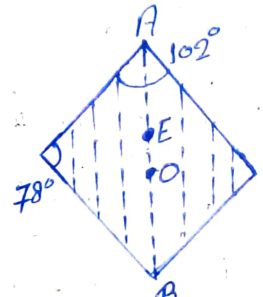


Fig 2(b)

Fig 2(a) shows the phenomenon of double refraction. When a ray of light is incident normally on the crystal, The ray is split up into two rays that is O-Ray & E-ray.

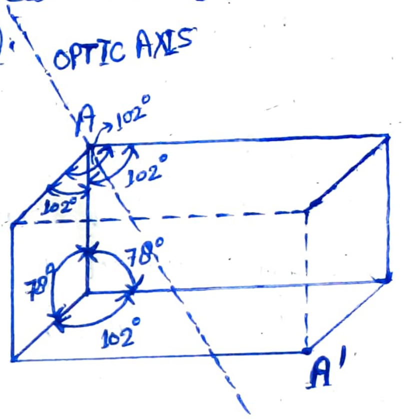
The O-ray passes through the crystal without deviated while E-ray is refracted at some angle. O-Ray always lies in the plane of incidence inside the crystal while E-ray does not. E-ray lies in the plane of incidence only when the plane of incidence is a principal section. As the opposite faces of the crystal are parallel, the emerging rays are parallel to the incident ray, but relatively displaced by a distance proportional to the thickness of the crystal.

If the face AB of the crystal is placed on a dot made on the paper then if the dot is seen through the opposite face, We see two images O and E, corresponding to O and E-rays. (fig 2(b)). The line which joins O and E is in the principal section of the crystal and either lies along the shorter diagonal AB or parallel to AB.

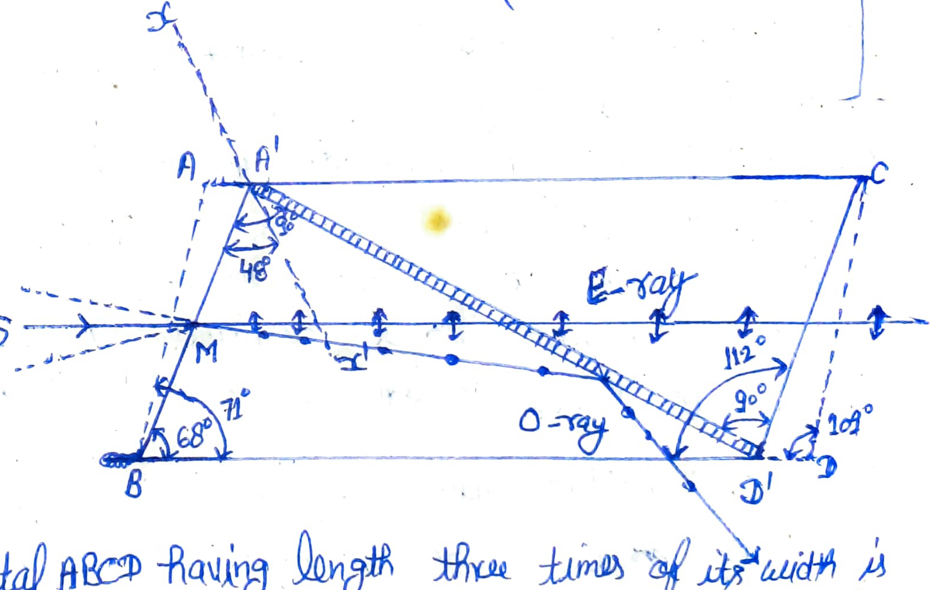
Both the O and E-rays are plane polarised by double refraction. The O-ray has the vibration ⊥ to the plane and E-ray has vibration parallel to the plane.

Nicol Prism:→ It is an optical device which is used to produce and analyse the plane-polarised light.

Calcite Crystal- Add this on page③ :- It is a colourless crystal transparent to visible as well as to ultraviolet light. It is also known as iceland spar ($CaCO_3$). It occurs in nature in various forms. All forms readily break up into simply rhombohedrons (fig.). Each face of the crystal is a parallelogram having angles 102° and 78°. Three obtuse angles meet at the diametrically opposite corners A of the crystal. One angle is obtuse and two are acute at the rest of the six corners. A and A' are called blunt corners of the crystal.



Construction:→



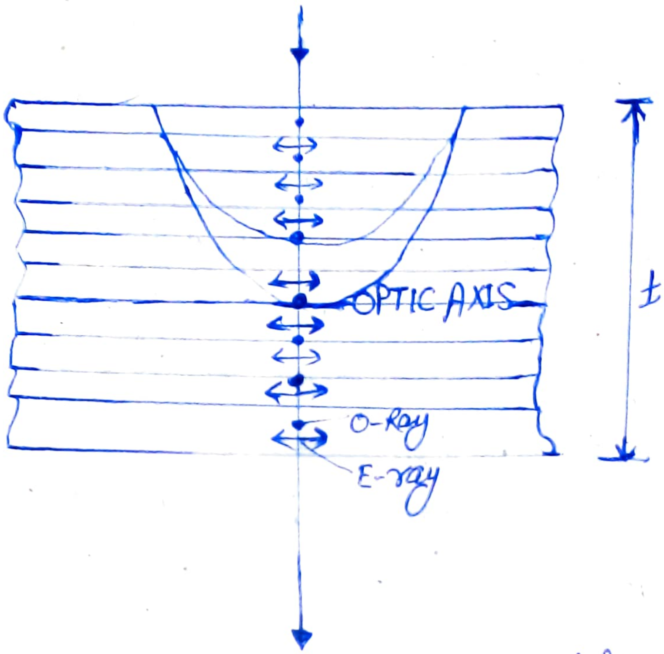
A calcite crystal ABCD having length three times of its width is taken. Its end faces AB and CD are polished such that the angles in the principal section becomes 68° and 112° instead of 71° and 109°. The crystal is then cut apart along A'D' perpendicular to both the principal section and the end faces A'B and CD'. The two cut surfaces are polished optically flat, then they are cemented by canada balsam liquid having refractive index 1.55 for sodium light. The crystal is then enclosed in a tube blackened inside

Working:→ When unpolarised light ray SM nearly parallel to BD' is incident on the surface A'B of the calcite crystal. It is split up into two plane polarised refracted rays. that is O-ray and E-ray. The refractive index of canada balsam liquid (1.55) is less than the refractive index of calcite for O-ray (1.658). But greater than the refractive index of calcite for E-ray (1.486). When O-ray strikes at the canada balsam surface, it is totally reflected because the O-ray is passing from rarer to denser medium and the angle of incidence is greater than the critical angle (69°) for the O-ray. ~~The~~ After Reflection the O-ray is absorbed by the tube containing the crystal. When E-ray strikes at the surface of the canada balsam the E-ray is transmitted through the canada balsam because the E-ray is passing ~~t~~ from rarer to the denser medium. E-ray is plane-polarised so the light emerging from the Nicol Prism is plane-polarised having vibrations parallel to the principal section. So Nicol prism is used to produce plane-polarised light.

Limitations:→ There is a limit to work for producing plane-polarised light. It works when the incident light beam is slightly divergent or convergent. If the incident beam makes angle much smaller than SMB with A'B, the O-ray will strike the Canada Balsam surface at an angle less than critical angle (69°). So the O-ray will also be transmitted and the light emerging from the Nicol prism will not be plane-polarised.

If the incident ray makes an angle much greater than SMB, then ~~the~~ ~~so~~ its refractive index will increase and become more than that of canada Balsam surface, so E-ray will be totally reflected and no light is emerged from Nicol Prism.

Quarter wave plate: Quarter wave plate is a doubly refracting crystal plate having a thickness such as ~~to~~ to produce a path difference of $\lambda/4$ or a phase difference of $\pi/2$ between the ordinary and extra ordinary waves.



Let us take a doubly refracting crystal. a plane parallel plate is cut from this crystal such that its faces are parallel to the optic axis. When a monochromatic light beam is incident normally on the plate, it is ~~broken~~ split up into O and E rays.

By Huygen's ~~Principle~~ Construction of double refraction Both the refracted rays that is O-ray and E-ray propagate along the same path perpendicular to the faces, but with different velocities (fig...)

In Negative crystal like calcite:- $\mu_O > \mu_E$

where μ_O - Principal refractive index for O-ray

μ_E - Principal refractive index for E-ray

In negative crystal E-ray travels faster than O-ray.

If t be the thickness of the plate, the optical path traversed by E and O-Ray is $\mu_e t$ & $\mu_o t$ respectively

The path difference between the O & E-ray after emerging from plate is

$$\mu_o t - \mu_e t$$
$$= (\mu_o - \mu_e) t$$

To work the plate as quarter-wave plate the path difference should be equal to $\lambda/4$

$$(\mu_o - \mu_e) t = \lambda/4$$

$$t = \frac{\lambda}{4(\mu_o - \mu_e)}$$

For uniaxial Positive crystal $\mu_e > \mu_o$

$$t = \frac{\lambda}{4(\mu_e - \mu_o)}$$

It means the plate having this thickness will work as quarter wave plate for particular wavelength.

Applications:→

1. Quarter wave plate with Nicol Prism is used to analyse all kinds of polarised light.
2. The Quarter wave plate is used for producing circularly and elliptically polarised light.

Half-wave Plate:→ ~~Quart~~ Half wave plate is a doubly refracting crystal plate having a thickness such as to produce path difference of $\lambda/2$ or phase difference π between ordinary and extra ordinary rays.

If t be the thickness of the plate, then for Negative crystal

$$t = \frac{\lambda}{2(\mu_o - \mu_e)}$$

for Positive crystal, $t = \frac{\lambda}{2(\mu_o - \mu_e)}$

So the plate having this thickness will work as Half-wave plate.

OPTICAL Rotation and optical Activity:→ When plane-polarised light is passed through certain substances, the plane of polarisation of polarised light is rotated about the direction of propagation of light through certain angle. This phenomenon is called optical rotation or rotatory polarisation. The substance is called optically active and the property of the substance to rotate plane of polarisation is called optical activity.

When the plane-polarised light received from Nicol Prism N_1 is examined through another Nicol Prism N_2, No light is obtained when the principal section of N_2 is perpendicular to that of

Specific Rotation:→ The specific rotation of a substance at a given temperature and for a given wavelength is defined as the rotation produced by the substance ~~solution~~ having 1 decimeter length ~~of the solution~~ and 1 g/cm³ concentration in solution. The specific rotation is denoted by S.

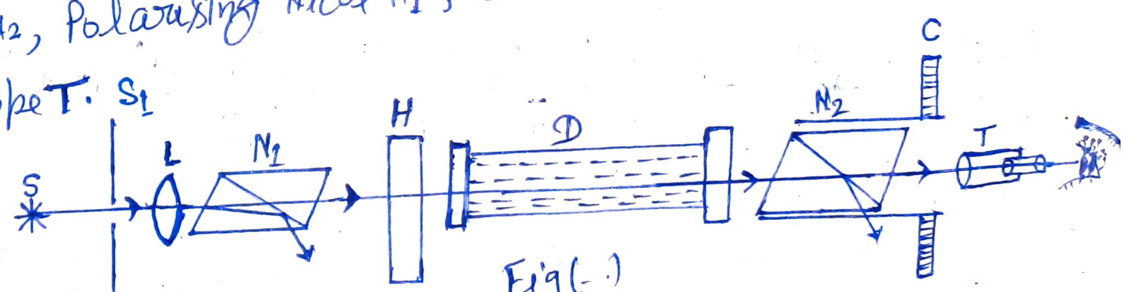
$$S = \frac{\theta}{lc}$$

where θ is the rotation in degrees.
l is the length of the solution in decimeters (for crystal in mm bcoz rotation prod by liquid is less than crystal)
c is the concentration of the solution in g/cm³.

The product of the specific rotation and molecular weight of the optically-active substance is called molecular rotation.

Laurent's Half shade Polarimeter:→ It is a device used to measure the optical rotation of certain substance.

Apparatus used:→
The experimental set up (Fig-) consists of a monochromatic sources S, slit S_1, convex lense L, half-shade device H, tube D containing the optically active solution (like- sugar solution), analysing Nicol N_2, Polarising Nicol N_1, circular degree scale C and Telescope T.



Fig(-)

The light emitted from monochromatic source S passes through slit S_1 and become parallel by lens L. The parallel light falls on Nicol N_1 and become plane-polarised. The plane polarised light falls on half-shade device H (Laurent half-plate) and then passes through tube D containing the sugar solution and then falls on the analysing Nicol N_2

The emergent light is viewed through telescope T. The analyser Nicol N_2 can be rotated about the light as axis and the rotation can be measured on a circular degree-scale C

Working:→ First of all, we assume that there is no-half shade device H in experimental set up. The position of Nicol N_2 is so adjusted ~~to get the~~ that the field of view is completely dark ~~in absence of S~~ when the tube D is empty. The reading of Nicol N_2 is noted on circular-degree scale C. The tube D is filled with the experimental solution. We observe some light in field of view. The Nicol N_2 is again so adjusted that the field of view is completely dark. The reading of Nicol N_2 is noted on circular degree-scale C. The difference of readings of Nicol N_2 ~~gives the~~ when the tube D is empty and filled gives the rotation (θ) produced in plane of plane polarised light. So the solution filled in tube D rotates the plane of plane polarised light

Half-shade Device:→ The Laurent's half shade Polarimeter with out half shade device H for measuring optical rotation is not accurate because our eye can not judge the position of complete darkness in field of view. The darkness in field of view occurs over a considerable range when N_2 is rotated.

This problem is solved using a Half-shade device H between Nicol N_1 and tube D.