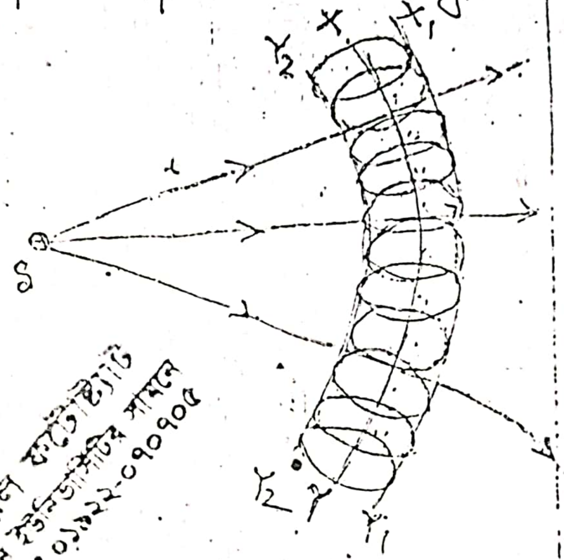
Optics Physics - 1105

OPtics

* Theories of light

* Huygen's principle and construction:

To explain the propagation of light waves through a hypothetical (Imaginary) medium called ether Huygen proposed a principle called Huygen's principle. According to Huygen, a source of light sends out waves in all directions through ether. In figure, S is the source of light. After any instant of time 't', all the particles on the surface XY will be vibrating in phase. Thus XY is a proportion of a sphere (গোলক) of radius vt, v is the velocity of propagation. XY is called the primary wavefront.



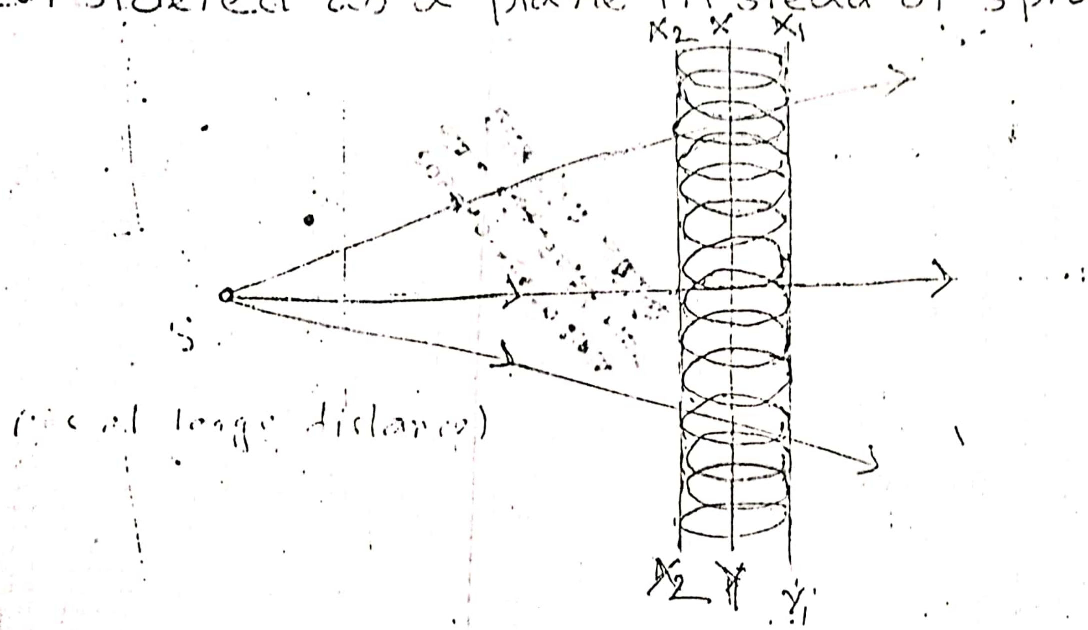
* Wavefront:

It is a locus of all points which are vibrating in all directions in phase and are also displaced at the same time. Here X_1Y_1 is forward and X_2Y_2 is backward wavefront on the basis of XY wavefront.

According to Huygen, the secondary wavefront is confined only to the forward wavefront X_1Y_1 and not the backward wavefront X_2Y_2.

However, no explanation to the absence of backward wavefront was given by Huygen. So, it is not a satisfactory principle.

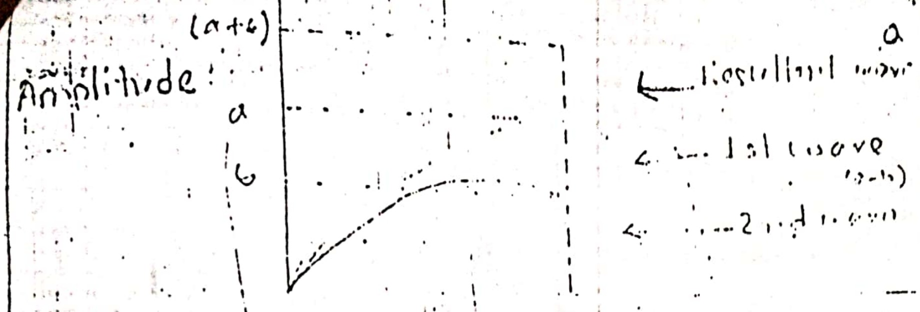
When the source is at large distance, then the small portion of the wavefront can be considered as a plane instead of sphere.



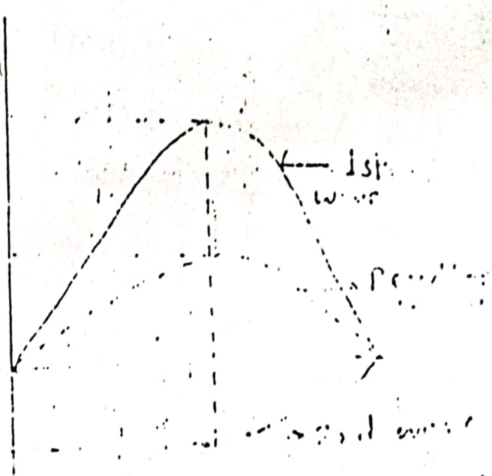
(আলোক তরঙ্গের উপরিপাতন)

* Superposition of Light waves:

The principle of superposition wave motion was first given by Thomas Young in 1801, states, when a medium.



Constructive interference



Constructive interference

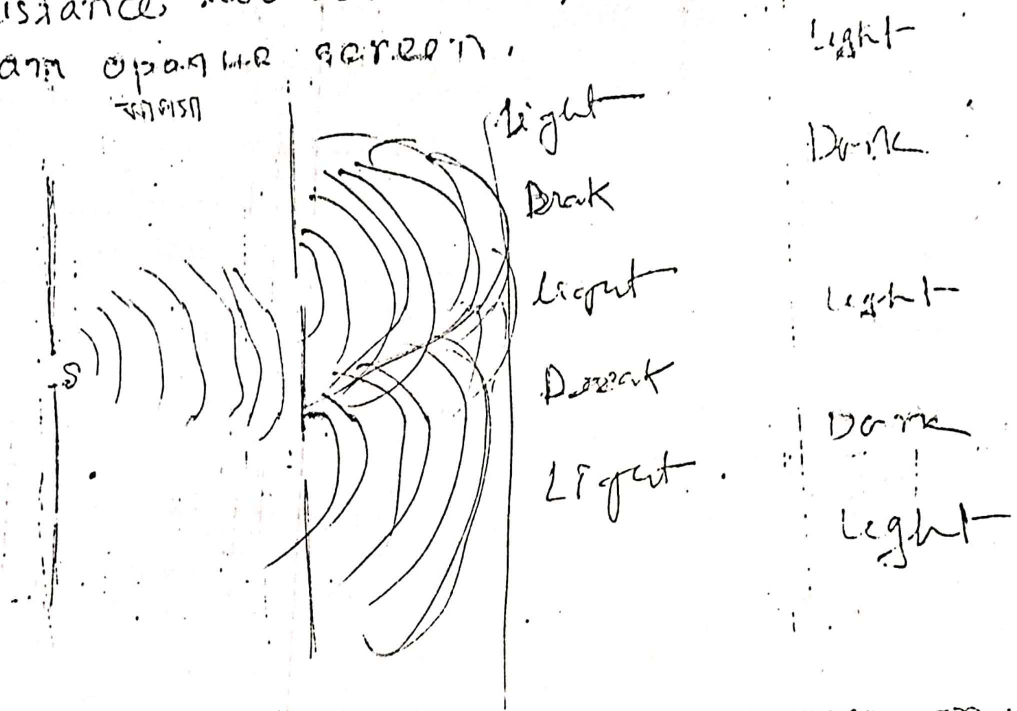
সমসাময়িক

When a medium is disturbed simultaneously by more than one wave, the resultant displacement of the medium at every point is the algebric sum of the displacement. If the two individual displacements are in same directions, the resultant displacement will be enhanced, if the are opposite directions, the resultant displacement will be diminished.

Suppose, two trains cross each other at a certain point and let y_1 be the displacement of the point produced by the first wave in the absense of the second wave. i.e. if the first wave was present alone. If y_2 is the displacement of the same point produced by the second wave in the absence of the first wave, then the resultant displacement y of the point due to the two waves acting together is expressed by,

$$y = y_1 + y_2.$$

(ii) Young's experiment: Thomas Young, in 1801, allowed to passed sunlight through a pinhole, S. then at same distance, two sufficiently close pinholes S_1 and S_2 in an opaque screen.



Finally he was received on a screen on which he observed an unevent distribution of light intensity consisting of many alternate dark and bright sparkle.

Conditions for interference:
The conditions for interference are:

* The two sources of light should emit continuous waves of same wavelength, same time period i.e. the source should have same coherence.

* The two source of light should be very close to each other.

* The waves emitted by two sources should either have zero phase difference or no phase difference.

* Condition for constructive interference:

The path difference = $n\lambda$ where, $n = 0, \pm1, \pm2, \pm3 \dots$

* Condition for destructive interference:

The path difference = $(2n+1)\frac{\lambda}{2}$ where $n = 0, \pm1, \pm2, \dots$

[* For a path difference λ, the phase difference = 2π

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

∴ Phase difference = $\frac{2\pi}{\lambda} \times$ Path difference]

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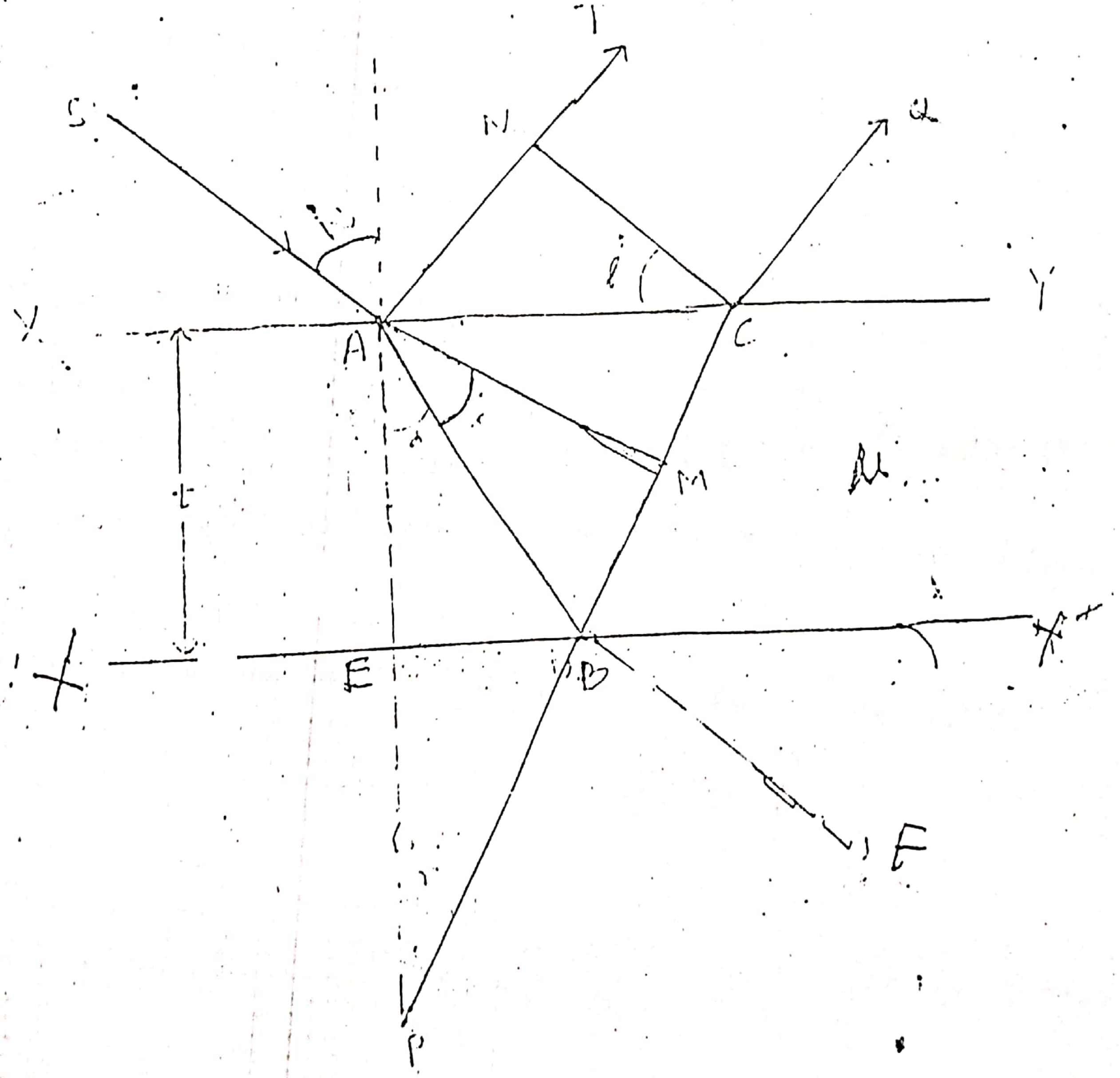
(iii) Interference due to multiple reflections:

It has been observed that the interference in the case of thin film takes place due to -

(i) reflected light.
(ii) transmitted light.

(i) Interference due to reflected light:



The figure shows a thin transparent film of uniform thickness t and refractive index μ, bounded by two parallel surfaces ~~MN and~~ XY and X'Y'. ~~S ray~~ A ray SA of monochromatic light is incident on the ~~up~~ upper surface at the point A. A part of it is reflected along AT and a part is ~~reflected~~ refracted along AB. The refracted beam is again partly reflected at the point B back into the medium along BC, and the rest refracts into the surrounding medium along BF. The ray along BC suffers refraction at the point C on the upper surface XY. The refracted rays goes along CQ. Similar refractions and reflections will produce a number of parallel rays in the surrounding medium ~~both~~ above the thin film.

Consider the rays AT and ABCQ. They are both derived from the single beam SA and hence satisfy the condition for producing interference (coherent source). Whether they (when collected by a lens or an eye) will interfere constructively or destructively i.e. produce brightness or darkness, will depend on their path difference. To determine this path difference we draw CN normal to AT and AM normal to BC. Also produce CB to meet AE produced at P. Let the angle of incidence and refraction be i and r respectively.

It is obvious that from the points N and C onwords, the two waves and rays travel ~~same~~ equal distance. Since the path (AB + BC) within the film is equivalent to a path μ(AB + BC) in air, the difference in optical path of the two rays is,

$$x = \mu(AB + BC) - AN$$

We know,

$$\mu = \frac{\sin i}{\sin r} = \frac{AN}{CM}$$

$$\Rightarrow AN = \mu \cdot CM$$

Then,

$$x = \mu(AB + BC - CM)$$

$$= \mu(PC - CM)$$

$$= \mu \cdot PM.$$

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Considering $\triangle APM$,

$$\cos r = \frac{PM}{AP}$$

$$\Rightarrow PM = AP \cdot \cos r$$

$$= (AE + EP) \cos r$$

$$= 2t \cos r$$

$$\therefore x = 2\mu t \cos r$$

This is the equation of path difference.

→ Actual path difference,

$$x' = 2\mu t \cos r - \frac{\lambda}{2}.$$

Now, → Conditions for constructive interference:

For constructive interference,

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

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

For, destructive interference,

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

$$\Rightarrow 2\mu t \cos r = (n+1)\frac{\lambda}{\cancel{2}}$$ $n+1 = n'$

$$\therefore 2\mu t \cos r = n'\lambda$$

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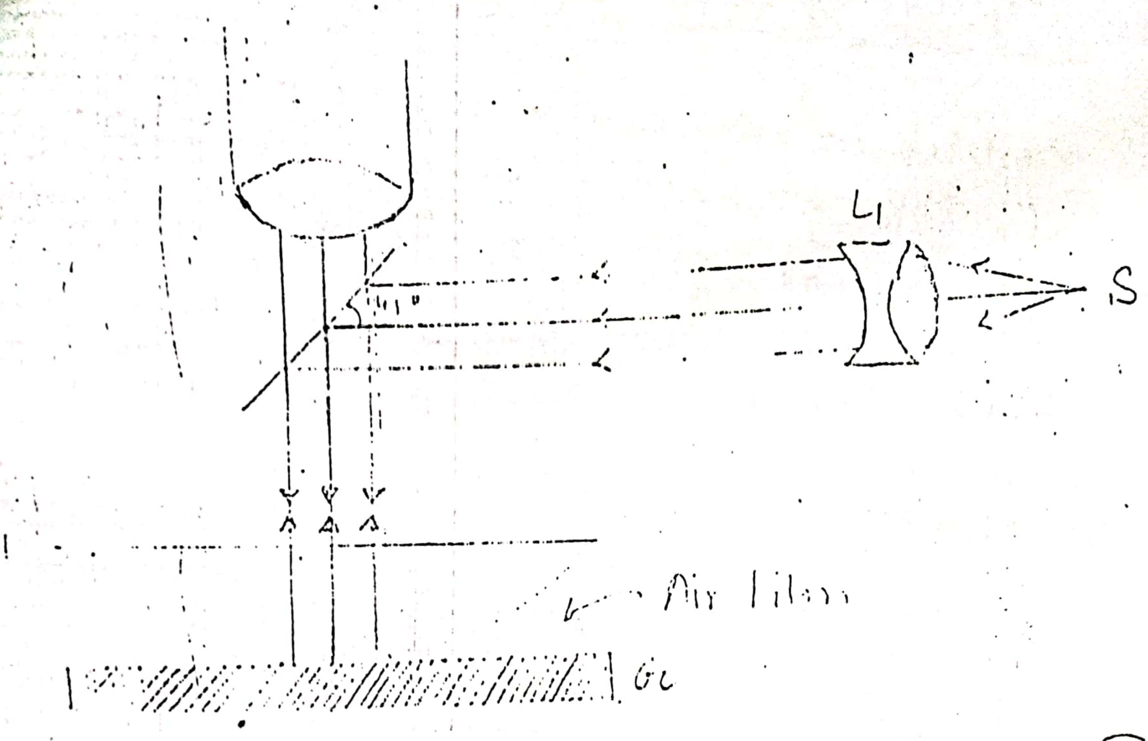
(iii) Newton's Ring: When a plano-convex lens of long focal length is placed on a plane glass plate, a thin film of air is closed between the lower surface of the lens and the upper surface of the plate. This thickness of the air film is very small at the point of contact and gradually increases from the centre outwards. The fringes produced with monochromatic light are circular. The fringes are concentric circles, uniform in thickness and with the point of contact at the centre. When viewed with white light, the fringes are coloured. With monochromatic light, bright and dark circular fringes are produced in the air film.

S is a source of monochromatic light at the focus of the lens L_1. A horizontal beam of light falls on the glass plate B at 45°. The glass plate reflects a part of the incident light towards the air film enclosed by the ns=L

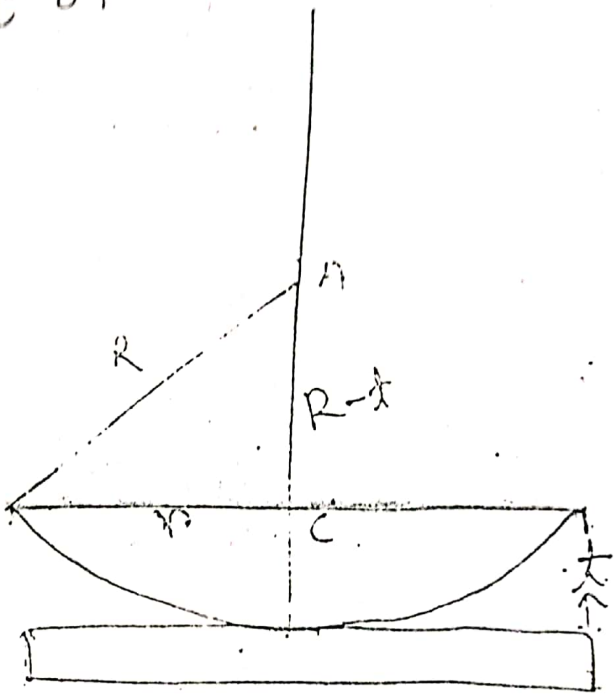


lens L and the plane glass plate G. The reflected beam from the air film is viewed with a microscope. Interference takes place and dark and ~~white~~ bright circular fringes are produced. This is due to the interference between the light reflected from the lower surface of the lens and the upper surface of the ~~gas~~ glass plate G.

(ii) Newton's rings by reflected light:

Suppose

Let, the radius of curvature of the lens is R and the air film of thickness t is at a distance of BC = r, from the point of contact C.



Here, interference is due to reflected. Therefore, for the bright fringe occour, when,

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

[n = 0, 1, 2, 3 ...]

Dark fringe occur when,

$$2\mu t \cos r = n\lambda \quad \text{--- (2)}$$

[n = 0, 1, 2, 3]

Here, r is very small and for air $\mu = 1$,

Now, from (1), $2t = (2n+1)\frac{\lambda}{2} \longrightarrow (3)$

from (2) $\Rightarrow 2t = n\lambda \longrightarrow (4)$

From ΔABC,

$$r^2 = R^2 - (R-t)^2$$

$$\therefore r^2 = 2Rt - t^2$$

$R \gg t$

So, $r^2 = 2Rt$

$$t = \frac{r^2}{2R} \longrightarrow (5) \quad \Rightarrow 2t = \frac{r^2}{R}$$

Putting the value of t in (3) and (4),

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

For light,

$$r = \sqrt{\frac{(2n+1)\lambda R}{2}} \longrightarrow (6) \quad r = \sqrt{\frac{(2n+1)\lambda R}{2}}$$

For dark,

$$r = \sqrt{n\lambda R} \longrightarrow (7)$$

when, $n = 0$, then,

Bright, $r = \sqrt{\frac{\lambda R}{2}}$

dark, $r = 0$.

which means the central ring is dark.

Determination of R/λ:

Let, the diameter of the nth Ring is D_n.

Radius, $r_n = \frac{D_n}{2}$

$$r_n = \sqrt{n\lambda R}$$

$$r_n^2 = n\lambda R$$

$$\therefore D_n^2 = 4n\lambda R \longrightarrow (8)$$

For, $(n+s)$th ring,

$$D_{n+s}^2 = 4(n+s)\lambda R \longrightarrow (9)$$

From (9) − (8),

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

$$\Rightarrow \boxed{R = \frac{D_{n+s}^2 - D_n^2}{4s\lambda}}$$

Refractive index of a liquid where $\mu \neq 1$:

For dark,

$$\cancel{2\mu t = co}$$

$$2\mu t \cos r = n\lambda$$

$$\Rightarrow 2\mu t = n\lambda \quad [\because r \text{ is very small}]$$

$$\Rightarrow r^2 = \frac{n\lambda R}{\mu} \quad \left[\because t = \frac{r^2}{2R}\right]$$

Now,

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

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

$\Rightarrow D_{n+s}^2 = \frac{4(n+s)\lambda R}{\mu}$

$D_{n+s}^2 - D_n^2 = \frac{4s\lambda R}{\mu}$

$$\boxed{\therefore \mu = \frac{4s\lambda R}{D_{n+s}^2 - D_n^2}}$$

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Problem: 1

Green light of wavelength 5100 A° from a narrow slit is incident on a double slit. If the overall separation of 10 fringes on a screen 200 cm away is 2 cm, find the slit separation.

Soln: Here,

$\lambda = 5100 \times 10^{-8}$ cm

$D = 200$ cm

$10\beta = 2$ cm

$\therefore \beta = 0.2$ cm

$d = ?$

$10\beta = 2$ cm

$\beta = 0.2$ cm.

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

We know, $\beta = \frac{\lambda D}{d}$

$\Rightarrow d = \frac{5100 \times 10^{-8} \times 200}{0.2}$

$= 0.051$ cm. Ans

Problem: 2

Two coherent sources are 0.18 mm apart and the fringes are observed on a screen 80 cm away. It is found that with a certain monochromatic source of light, the fourth bright fringe is situated at a distance of 10.8 mm from the central fringe. Calculate the wavelength of light.

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Ans: Here,

$D = 80 cm$

$d = 0.18 mm = 0.018 cm$.

$n = 4$

$x = 10.8 mm = 1.08 cm$.

$\lambda = ?$

We know, $x = \frac{nD\lambda}{d}$

$$\therefore \lambda = \frac{xd}{nD} = \frac{1.08 \times 0.018}{4 \times 80} = 6075 \times 10^{-8} cm$$

$= 6075$ A° Ans

Problem: 3

A biprism is placed 5 cm from a slit illuminated by sodium light ($\lambda = 5890$ A°). The width of the fringes obtained on a screen 75 cm from the biprism is 9.424×10^{-2} cm. What is the distance between the two coherent sources.

Ans: Here, $\lambda = 5890 \times 10^{-8} cm$.

$\beta = 9.424 \times 10^{-2} cm$.

$D = 5+75 = 80 cm$.

$d = ?$

We know $d = \frac{\lambda D}{\beta} = \frac{5890 \times 10^{-8} \times 80}{9.424 \times 10^{-2}}$

$= 0.05$ cm. Ans

Problem : 4

A parallel beam of light ($\lambda = 5890 \times 10^{-8}$ cm) is incident on a thin glass plate ($\mu = 1.5$) such that the angle of refraction into the plate is $60°$. Calculate the smallest thickness of the glass plate which will appear dark by reflection.

Soln: Here, $\lambda = 5890 \times 10^{-8}$ cm

$r = 60°$

$\therefore \cos r = 0.5$

$n = 1$

$\mu = 1.5$

We know, $2\mu t \cos r = n\lambda$

$$\therefore t = \frac{n\lambda}{2\mu \cos r} = \frac{1 \times 5890 \times 10^{-8}}{2 \times 1.5 \times 0.5}$$

$$= 3.926 \times 10^{-5} \text{ cm. Ans}$$

Problem : 5

A soap film 5×10^{-5} cm thick is viewed at an angle of $35°$ to the normal. Find the wavelength of light in the visible spectrum which will be absent from the reflected light ($\mu = 1.33$).

Soln:

Let i be the angle of incidence and r the angle of refraction.

Then, $\mu = \frac{\sin i}{\sin r} \Rightarrow 1.33 = \frac{\sin 35}{\sin r}$

$\therefore r = 25.55^\circ \Rightarrow \cos r = 0.90$.

Applying the relation: $2\mu t \cos r = n\lambda$

$t = 5\times10^{-5}$ cm.

(I) For the first order, $n = 1$.

$\therefore \lambda_1 = 2\times1.33\times5\times10^{-5}\times0.90$

$= 12.0\times10^{-5}$ cm.

which lies in the infra-red region which is invisible.

(II) For the second order, $n = 2$.

$\therefore 2\lambda_2 = 2\times1.33\times5\times10^{-5}\times0.90$

$\therefore \lambda_2 = 6.0\times10^{-5}$ cm.

which lies in the visible region.

(III) Similarly, taking $n = 3$.

$\lambda_3 = 4.0\times10^{-5}$

which lies also lies in the visible region.

(IV) If $n = 4$

$\lambda_4 = 3.0\times10^{-5}$ cm.

which lies in the ultra-violet (invisible) region.

Hence absent wavelengths in the reflected light are 6.0×10^{-5} cm and 4.0×10^{-5} cm.

Problem : 6

A beam of parallel rays is incident at an angle of 30° with the normal on a plane parallel film of thickness 4×10^{-5} cm and refractive index 1.50. Show that the reflected light whose wavelength is 7.539×10^{-5} cm will be strengthened by reinforcement.

Soln: Here, $t = 4\times10^{-5}$ cm

$\lambda = 7.539\times10^{-5}$ cm.

$\mu = 1.50$

$i = 30^\circ$

For the film to appear bright by reflection,

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

Here, n must be odd,

$$n = \frac{4\mu t \cos r}{\lambda}$$

Again, $$\mu = \frac{\sin i}{\sin r}$$

$$\therefore \sin r = \frac{0.5}{1.5} = 0.333$$

$$\therefore \cos r = 0.9432.$$

Now,
$$n = \frac{4 \times 1.5 \times 4 \times 10^{-5} \times 0.0432}{2.540 \times 10^{-5}}$$

$= 3.002 \approx 3$

$\therefore n = 3$.

Or, As n is odd the film appears bright by reflected light.

Problem: 7

A plano-convex lens of radius 300 cm is placed on an optically flat glass plate and is illuminated by monochromatic light. The diameter of the 8th dark ring in the transmitted system is 0.72 cm. Calculate the wave length of light used.

Soln: For the transmitted system

$$r^2 = \frac{(2n-1)\lambda R}{2}$$

Here, $n = 8$; $D = 0.72$ cm; $\therefore r = 0.36$ cm

$R = 300$ cm.

$\lambda = ?$

$$\therefore \lambda = \frac{2r^2}{(2n-1)R} = \frac{2 \times (0.36)^2}{(16-1) \times 300}$$

$= 5760 \times 10^{-8}$ cm

$= 5760$ A°. A

Problem : 8

In a Newton's ring experiment the diameter of the 15th ring was found to be 0.590 cm and that of 5th ring was 0.336 cm. If the radius of the plano-convex lens is 100 cm, calculate the wave-length of light used.

Soln: Here,

$D_5 = 0.336$ cm

$D_{15} = 0.590$ cm

$R = 100$ cm

$n+p$... $p = 10$

$\lambda = ?$

We know,

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

$$= \frac{0.590^2 - 0.336^2}{4 \times 10 \times 100}$$

$$= 5880 \times 10^{-8} \text{ cm}$$

$$= 5880 \, A^\circ \quad A$$

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

Problem : 9

In a Newton's rings experiment, find the radius of curvature of the lens surface in contact with the glass plate when with a light of wavelength 5890 A°, the diameter of the third dark ring is 3.2 mm. The light is falling at such an angle that it passes through the air film at an angle of zero degree to the normal.

Soln: Here, $r = \frac{3.2}{2} = 1.6mm = 0.16 cm.$

$n = 3$

$\lambda = 5890 \times 10^{-8} cm.$

$R = ?$

We know, for dark rings,

$r^2 = n\lambda R$

$$\therefore R = \frac{0.16^2}{3 \times 5890 \times 10^{-8}}$$

$= 144.9 cm.$ A=

Problem: 10

In a Newton's rings arrangement, if a drop of water ($\mu = 4/3$) be placed in between the lens and the plate, the diameter of the 10th ring is found to be 0.6cm. Obtain the radius of curvature of the face of the lens in contact with the plate. The wavelength of light used is 6000 A°.

Soln: Here, $\mu = 4/3$

$D_{10} = 0.6 cm$

$n = 10$

$\lambda = 6000 \times 10^{-8} cm.$

$R = ?$

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We know that,

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

$$\therefore R = \frac{\mu D_n^2}{4n\lambda} = \frac{4/3 \times 0.6^2}{4 \times 10 \times 6000 \times 10^{-8}}$$

$= 200$ cm. Ans

Problem 11.

Newton's rings are formed by the reflected light of wavelength 5895 A° with a liquid between the plane and curved surfaces. If the diameter of the 5th bright ring is 3mm and the radius of curvature of the curved surface is 100 cm, calculate the refractive index of the liquid.

Sol: Here, $n = 5$

$D_n = 3$mm

$r_n = 0.15$ cm

$\lambda = 5895 \times 10^{-8}$ cm.

$R = 100$ cm

$\mu = ?$

For the nth bright ring,

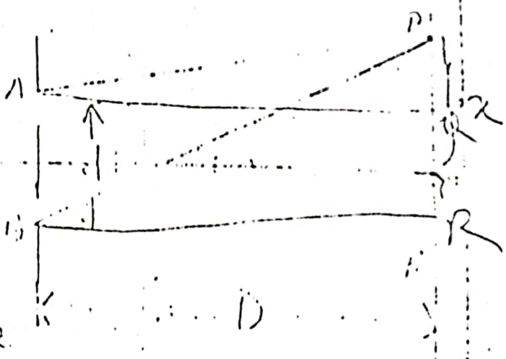
$$\mu = \frac{(2n-1)\lambda R}{2r^2}$$

$$= \frac{(10-1) \times 5895 \times 10^{-8} \times 100}{2 \times 0.15^2} = 1.179.$$

Ans

Theory of interference fringes:

Let us consider a narrow monochromatic source, S and two pinholes A and B. A and B actes as two coherent sources separated by a distance, d.



Let, a screen be placed at a distance distance, D, from coherent sources. The point C on the screen is equidistant from A and B. So the path difference between them is zero. Thus C has a maximum intensity. Consider, a point P at a distance x from C.

According to the figure,

$$PQ = x - \frac{d}{2} \quad \text{and} \quad PR = x + \frac{d}{2}$$

Now, $BP^2 = BR^2 + PR^2$

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

and $AP^2 = AQ^2 + PQ^2$

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

Now, $BP^2 - AP^2 = D^2 + \left(x + \frac{d}{2}\right)^2 - D^2 - \left(x - \frac{d}{2}\right)^2$

$$= 2xd$$

$$\Rightarrow BP + AP = \frac{2xd}{BP + AP} \quad \cdots\cdots (1)$$

$$BP - AP = \frac{2xd}{2D}$$

* Dark fringes occur when,

$$\frac{xd}{D} = (2n+1)\frac{\lambda}{2} \quad [n = 1, 2, 3, \ldots]$$

$$\Rightarrow x = \frac{(2n+1)\lambda D}{2d} \longrightarrow (6)$$

For $n = 1$ and 2,

$$x_1 = \frac{3\lambda D}{2d}$$

$$x_2 = \frac{5\lambda D}{2d}$$

Therefore, the distance between any two consequitive dark fringes,

$$x_2 - x_1 = \frac{5\lambda D}{2d} - \frac{3\lambda D}{2d} = \frac{\lambda D}{d} \longrightarrow (7)$$

The distance between any two consequitive dark or bright fringes is known as fringes with, β

$$\text{So, } \beta = \frac{\lambda D}{d} \longrightarrow (8)$$

It is clear from equations (5) and (6) (7), the width of the bright fringes is equal to the width of dark fringes.

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All the fringes are equal in width and dependent of the order number of the fringe.

From the equation, we can say that,

$\beta \propto \lambda$

$\beta \propto D$

and $\beta \propto \frac{1}{d}$.

Intensity:

If the displacement of two waves are y_1 and y_2.

$y_1 = a \sin \omega t$

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

$\therefore y = y_1 + y_2 = a \sin \omega t + a \sin (\omega t + \delta)$

$= a \sin \omega t (1 + \cos \delta) + a \cos \omega t \sin \delta$

Taking, $a (1 + \cos \delta) = R \cos \theta \longrightarrow (9)$

$a \sin \delta = R \sin \theta \longrightarrow (10)$

$\therefore y = R \sin (\omega t + \theta) \longrightarrow (11)$

Squaring and adding equations (9) and (10),

$R^2 = 2a^2 + 2a^2 \cos^2 \delta$

$= 2a^2 (1 + \cos^2 \delta)$

$= 2a^2 \times 2 \cos^2 \frac{\delta}{2}$

$$\therefore R^2 = 4a^2 \cos^2 \frac{\delta}{2}$$

Intensity is the square of amplitude, R

$$\therefore I = R^2 = 4a^2 \cos^2 \frac{\delta}{2} \longrightarrow (13)$$

For Bright fringe,

$\delta = 0, 2\pi, 2(2\pi), 3(2\pi) \ldots\ldots$

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

then, $I = 4a^2$

For dark fringe,

$\delta = \pi, 3\pi, 5\pi, \ldots\ldots$

$x = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2} \ldots\ldots$

Then, $I = 0$

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