PHYSICAL OPTICS

Theories of light:

The theories to describe the nature of light are as follows—

(I) Newton's corpuscular theory
(II) Huygen's wave theory
(III) Electromagnetic theory of Maxwell
(IV) Einstein's quantum theory.

Interference of light:

Due to the superposition of two light waves emitted from coherent sources intensity of light increases at some points and decreases at other points. As a result alternate bright and dark state is produced on a plane. The alternate variation of intensity of light from point to point on a plane is called the interference of light.

Coherent sources: Two sources are said to be coherent if they emit light of same wave length having no phase difference or if there is any phase difference it is maintained all along during propagation.

Young's Double-Slit Experiment:

Thomas Young demonstrated optical interference by his double slit experiment. The experiment established wave theory firmly. The experimental arrangement has been shown in the fig-1.

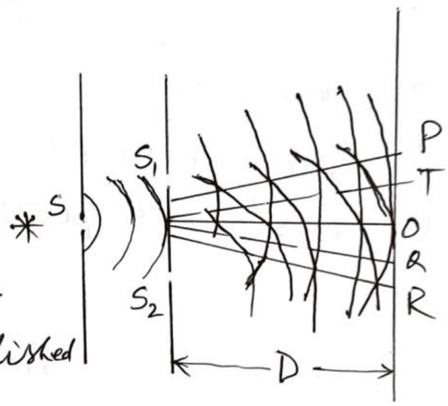


fig-1.

Experiment: A slit S has been kept perpendicularly with the plane of paper. Two other slits S_1 and S_2 very near to each other kept parallel to the slit S. Allowing white light through the slit S coloured interference fringe are observed on the screen kept at the position PR. If monochromatic light instead of white light is taken then the alternate bright and dark fringes are observed. If we ~~are~~ close either slit S_1 or S_2 then no interference

fringe would be observed. In this way
Young first demonstraated by experiment
the interference of light and proved the
wave nature of light.

<u>Explanation:</u> The interference of light demons-
trated by young in this double slit experi-
ment can be explained by Huygens' principle.
The slit S sends spherical wave front.
Since the slits S_1 and S_2 are equidistant
from S, so the same wave front will reach
S_1 and S_2. The points S_1 and S_2 on this
wave front emitt secondary wave those
are in phase with each other. So the
secondary waves emitted from the slits
S_1 and S_2 are coherent as their frequency
and amplitude are same. Now the superposi-
tion of two waves emitted from S_1 and S_2
produces interference. In fig-1. constructive
interference takes place along the solid
lines and bright fringes are seen at
P, O, R etc. ~~place~~ places. On the other
hand destructive interference takes
place along the dotted line and dark
fringes are seen at T and Q points.

Relation between phase difference and path difference:

Let, at any instant if the displacement of light wave at P coming from S_1 is y_1 and from S_2 is y_2 then

$$y_1 = a \sin \frac{2\pi}{\lambda}(ct - x_1)$$
$$y_2 = a \sin \frac{2\pi}{\lambda}(ct - x_2)$$

Therefore, at P (fig-1) the phase difference of the two waves,

$$\delta = \frac{2\pi}{\lambda}(ct - x_2) - \frac{2\pi}{\lambda}(ct - x_1)$$
$$= \frac{2\pi}{\lambda}(x_2 - x_1)$$
$$\delta = \frac{2\pi}{\lambda}(PS_2 - PS_1)$$

$\therefore$ Phase difference $= \frac{2\pi}{\lambda} \times$ path difference.

Derive conditions ~~fro~~ for constructive and destructive interference:

Let us consider two waves emitted from the sources are as -

$$y_1 = a \sin \frac{2\pi}{\lambda}(ct - x_1)$$
$$y_2 = a \sin \frac{2\pi}{\lambda}(ct - x_2)$$

According to the principle of superposition

$$Y = y_1 + y_2$$

$$= a\left[\sin\frac{2\pi}{\lambda}(ct - x_1) + \sin\frac{2\pi}{\lambda}(ct - x_2)\right]$$

$$= 2a \cdot \sin\frac{2\pi}{\lambda}\left(\frac{ct - x_1 + ct - x_2}{2}\right) \cdot \cos\frac{2\pi}{\lambda}\left(\frac{\cancel{ct} - x_1 - \cancel{ct} + x_2}{2}\right)$$

$$= 2a\cos\frac{\pi}{\lambda}(x_2 - x_1)\,\sin\frac{2\pi}{\lambda}\left(ct - \frac{x_1 + x_2}{2}\right)$$

$$Y = A\sin\frac{2\pi}{\lambda}\left(ct - \frac{x_1 + x_2}{2}\right) \quad \text{--- (1)}$$

Eqn (1) indicates the resultant equation of a wave whose amplitude is

$$A = 2a\cos\frac{\pi}{\lambda}(x_2 - x_1)$$

<u>condition for constructive interference:</u>

The amplitude of the resultant wave becomes maximum as a result bright fringe is formed or constructive interference is produced. The value of A will be maximum when

$$\cos\frac{\pi}{\lambda}(x_2 - x_1) = \pm 1 = \cos 0, \cos\pi, \cos 2\pi, \ldots$$

or, $\cos\frac{\pi}{\lambda}(x_2 - x_1) = \cos n\pi$

or, $\frac{\pi}{\lambda}(x_2 - x_1) = n\pi$

or, $x_2 - x_1 = n\lambda$

or, $x_2 - x_1 = n\lambda = 2n \cdot \frac{\lambda}{2}$ (when $n = 0, 1, 2, 3 \ldots$

So for constructive interference the optical path difference will be zero or even multiple of $\frac{\lambda}{2}$.

Condition for destructive interference:

The amplitude of the resultant wave becomes ~~become~~ zero as a result destructive interference occurs dark fringes. The value of A will be zero when –

$$\cos\frac{\pi}{\lambda}(x_2 - x_1) = 0 = \cos\frac{\pi}{2}, \cos\frac{3\pi}{2}, \cos\frac{5\pi}{2}, \ldots$$

or, $\cos\frac{\pi}{\lambda}(x_2 - x_1) = \cos(2n+1)\frac{\pi}{2}$

or, $\frac{\cancel{\pi}}{\lambda}(x_2 - x_1) = (2n+1)\frac{\cancel{\pi}}{2}$

or, $x_2 - x_1 = (2n+1)\frac{\lambda}{2}$

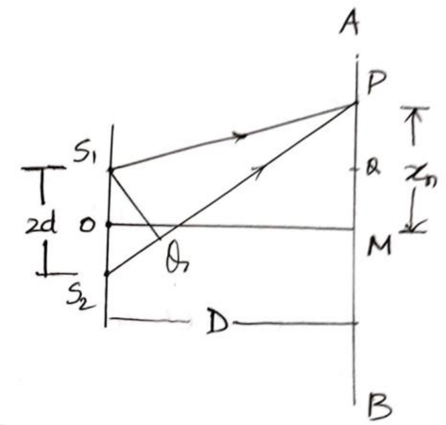
So for destructive interference the optical path difference is odd multiple of $\frac{\lambda}{2}$.

Determination of distance between two consecutive centres of the dark or bright bands and width of the bands.

In the fig.

x_n = The distance between two consecutive bright or dark fringes.

2d = Distance between two slits.



We get —

$$S_1P^2 = D^2 + (x_n - d)^2$$

$$S_1P^2 = D^2 + x_n^2 - 2x_nd + d^2 \quad \text{--- (1)}$$

and $S_2P^2 = D^2 + x_n^2 + 2x_nd + d^2$ — (2)

Now (2) − (1)

$$S_2P^2 - S_1P^2 = 2x_nd + 2x_nd$$

or, $(S_2P + S_1P)(S_2P - S_1P) = 4x_nd$

Point P is very closed to M ; so $S_1P \simeq S_2P \simeq D$

$$\therefore \quad S_2P - S_1P = \frac{4x_nd}{2D} = \frac{2x_nd}{D}$$

So, the path difference between two waves (S_1P and S_2P)

$$\delta = S_2P - S_1P = \frac{2x_nd}{D} \quad \text{--- (3)}$$

or, ~~$x_n = \frac{D.\delta}{2d}$ — (3)~~

From eqn (3) we know that, for n-th bright fringe the path difference will be $n\lambda$.

$$\therefore \frac{2x_n d}{D} = n\lambda \quad \text{Hence, } n = 0, 1, 2, 3 \ldots$$

$$\text{or, } x_n = \frac{nD\lambda}{2d}$$

Similarly, for $(n+1)$th bright fringe from point M

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

$\therefore$ The distance between two consecutive bright or dark fringes —

$$\beta = x_{n+1} - x_n$$

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

$$= \cancel{\frac{nD\lambda}{2d}} + \frac{D\lambda}{2d} - \cancel{\frac{nD\lambda}{2d}}$$

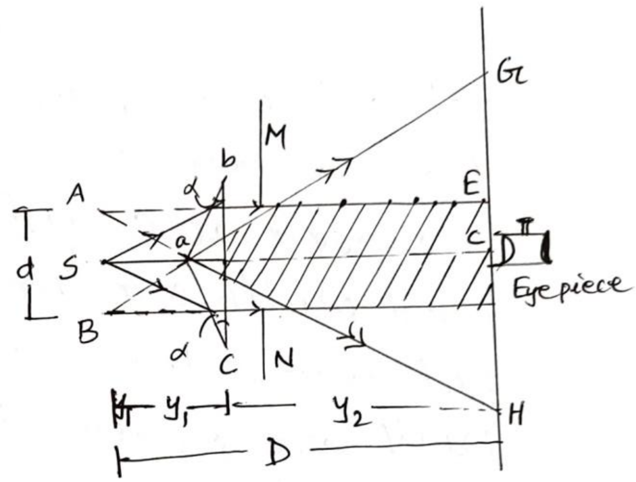
$$\boxed{\beta = \frac{D\lambda}{2d}}$$

~~A~~ And the width of a bright or dark fringe is -

$$y = \frac{\beta}{2} = \frac{D\lambda}{2 \times 2d}$$

$$\boxed{y = \frac{D\lambda}{2 \times 2d}}$$

Describe Fresnel's Biprism and determine its theory.



Fresnel used a biprism to show interference phenomenon. The biprism abc consists of two acute angled prisms ~~placed~~ base to base. Actually it is constructed as a single prism of obtuse angle of about 179° (fig:). The acute angle α on both sides is about 30'. The prism is placed with its refracting edge parallel to the line source S (slit) such that Sa is normal to the face bc of the prism. When light falls from S on the lower portion of the biprism it is bent upwards and appears to come from the virtual source B. Similarly light falling from

S on the upper portion of the prism is bent downwards and appears to come from the virtual source A. Therefore A and B act as two coherent sources. Suppose the distance between A and B = d. If a screen is placed at C, interference fringes of equal width are produced between E and F but beyond E and F fringes of large width are produced which are due to diffraction. MN is a stop to limit the rays. To observe the fringes, the screen can be replaced by an eye- piece or a low power microscope and fringes are seen in the field of view. If the point C is at the principal focus of the eyepiece, the fringes are observed in the field of view.

Theory:

~~For complete theory~~ The point C is equidistant from A and B. Therefore, it has maximum intensity. On both sides of C, alternately bright and dark fringes are produced. The width of the bright fringe or dark fringe, $\beta = \frac{\lambda D}{d}$. Moreover, any point on the screen will be at the centre of a bright fringe if its distance from c is $\beta = \frac{n\lambda D}{d}$, where $n = 0, 1, 2, 3$ etc. The point will be at the centre of a dark fringe if its distance from c is

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

where $n = 0, 1, 2, 3$ etc.

Why Newton's rings are formed? Establish the theory of Newton's rings.

When a plano-convex lens of long focal length is placed on a plane glass plate, a thin film of air is enclosed between the lower surface of the lens and the upper surface of the plate. The 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 as the centre. With monochromatic light, bright and dark circular fringes are produced in the air film.

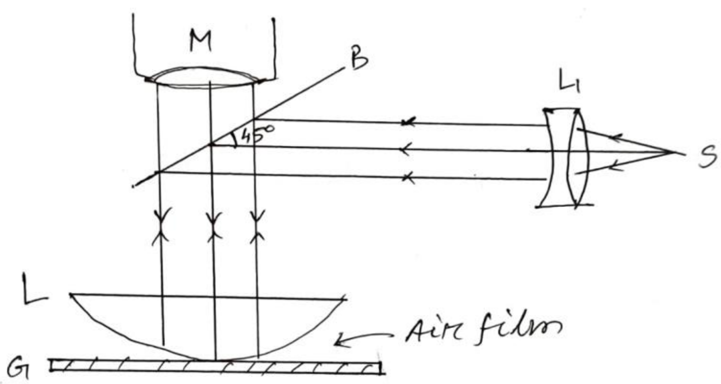


fig-1

S is source of monochromatic light at the focus of the lens L_1 (fig-1). A horizontal beam of light falls on the glass plate B at 45°. The glass plate B reflects a part of the incident light towards the air film enclosed by the lens L and the ~~plate~~ glass plate G. The reflected beam from the air film is viewed with a microscope. Interference takes place and dark and 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 glass plate G.

Theory: (Newton's rings by reflected light)

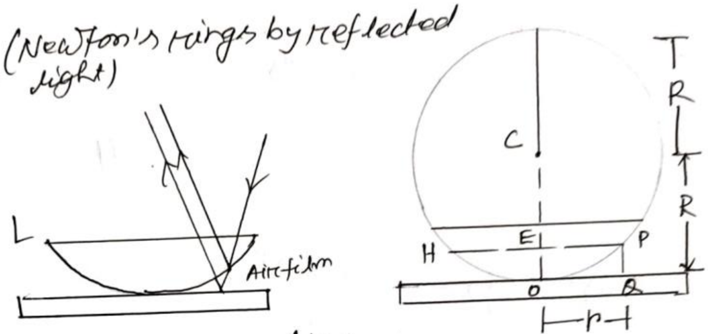


fig-2

Suppose the radius of curvature of the lens is R and the air film is of thickness t at a distance of $OQ = r$, from the point of contact O.

Here, interference is due to reflected light. Therefore, for the bright rings

$$2\mu t\cos\theta = (2n-1)\frac{\lambda}{2} \quad \text{—} \ (1) \quad n = 1,2,3 \cdots \text{etc}$$

Here θ is small, therefore $\cos\theta = 1$; for air $\mu = 1$.

$$\therefore 2t = (2n-1)\frac{\lambda}{2} \quad \text{—} \ (2)$$

For dark rings, $2\mu t\cos\theta = n\lambda$

$$\text{or,} \quad 2t = n\lambda \ (3) \ ; \quad n = 0,1,2,3 \cdots$$

From the fig-2 $\quad EP \times HE = OE \times (2R - OE)$

But, $\quad EP = HE = r$, $OE = PQ = t$

and $\quad 2R - t = 2R$ (approximately)

$$r^2 = 2R.t$$

$$or,\ t = \frac{r^2}{2R}$$

Substituting the value of t in eqn (2) and (3)

for bright ~~fringes~~,

$$r^2 = \frac{(2n-1)\lambda R}{2} \quad \text{--- (4)}$$

$$or,\ r = \sqrt{\frac{(2n-1)\lambda R}{2}} \quad \text{--- (5)}$$

For dark rings, $r^2 = n\lambda R$

$$\therefore\ r = \sqrt{n\lambda R} \quad \text{--- (6)}$$

When $n=0$, the radius of the dark ring is zero. and the radius of the bright ring is $\sqrt{\frac{\lambda R}{2}}$. Therefore, the centre is dark. Alternately dark and bright rings are produced.