(1)

Study Material - Physics / Sem. 2 / Interference / Dr. T. Kar / Class 3

Newton's Rings

Newton's rings are a particular example of interference fringes formed by thin films. A plano-convex lens of large radius of curvature is placed on a glass plate due to which a thin air film of progressively increasing

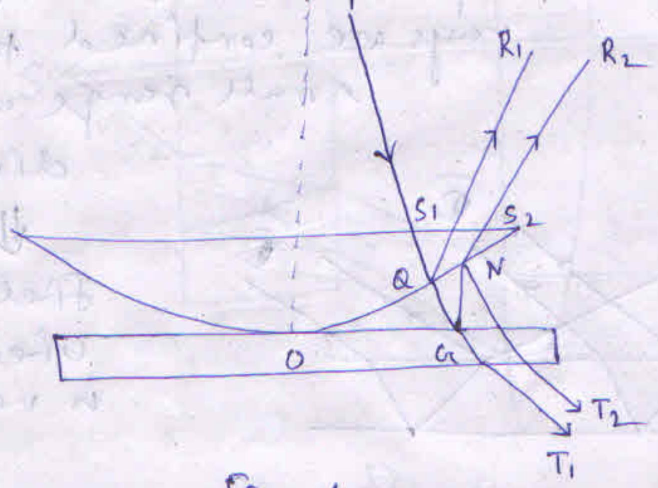


Fig. 1.

thickness from the point of contact 'O' is formed. If this set up is illuminated by a monochromatic light, interference fringes in the form of concentric circular fringes are formed. These fringes are the loci of points of equal film thickness. These rings are localized in the air film.

Newton's rings with reflected light (2)

The rings are formed due to interference of light waves reflected from the lower convex surface of the plano-convex lens and the flat upper surface of the glass plate. As the plano-convex lens has large radius of curvature, the air film thickness is very small. The experimental arrangement is so designed that the light falls on the air film almost normally. Hence the optical path difference is $\left(2\mu d \pm \frac{\lambda}{2}\right)$, where, d = thickness of air film at N. As the r.i. of film is less than above and lower medium, there is an abrupt phase change of π or path diff. of $\lambda/2$ due to reflection at 'G'.

Therefore, for constructive interference,

$$2\mu d \pm \frac{\lambda}{2} = \text{even multiple of} \left(\frac{\lambda}{2}\right)$$

or, $2\mu d$ = odd multiple of $\left(\frac{\lambda}{2}\right)$

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

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

For destructive interference,

$$2\mu d \pm \lambda/2 = \text{odd multiple of } \frac{\lambda}{2}$$

or, $2\mu d = 2n\frac{\lambda}{2} \longrightarrow (2)$

(3)

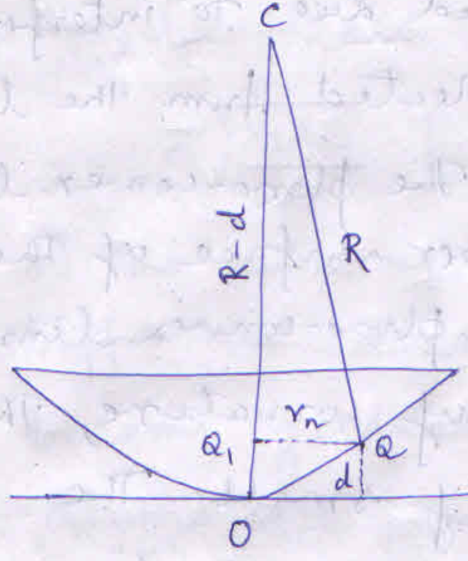


Fig. 2

The fringe of a given order 'n' will be along the loci of points of equal film thickness 'd' and hence the fringes will be circular.

If the point 'Q' fulfills the condition of brightness (or darkness), then all points on the circumference of a circle of radius Q_1Q will be bright (or dark).

Let $Q_1Q = r_n$ be the radius of the 'n'th ring (bright or dark).

Then,
$$R^2 = r_n^2 + (R-d)^2$$
$$= r_n^2 + R^2 - 2Rd + d^2$$
$$\simeq r_n^2 + R^2 - 2Rd \quad \text{as } R >> d$$
$$\text{or, } R = \frac{r_n^2}{2d} \text{ or, } r_n^2 = 2Rd \longrightarrow (3)$$

Therefore, radius of n th. bright ring is,
$$2\mu d = (2n+1)\frac{\lambda}{2}$$
$$\text{or, } 2\mu\left(\frac{r_n^2}{2R}\right) = (2n+1)\frac{\lambda}{2}$$

(4)

$$r_n^2 = \frac{(2n+1)\lambda R}{2\mu} \longrightarrow (4) \Rightarrow (r_n)_{bright} \propto \sqrt{2n+1}$$

Thus, Radius of n th dark ring is —

$$2\mu d = 2n\left(\frac{\lambda}{2}\right)$$

$$\text{or, } 2\mu\left(\frac{r_n^2}{2R}\right) = \frac{2n\lambda}{2}$$

$$\text{or, } r_n^2 = \frac{2n\lambda R}{2\mu} \longrightarrow (5) \Rightarrow (r_n)_{dark} \propto \sqrt{n}$$

Now, Diameter of bright ring is —

$$(D_n^2)_{bright} = \frac{2(2n+1)\lambda R}{\mu} \longrightarrow (6)$$

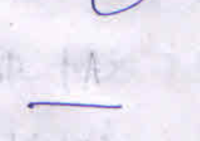
and diameter of dark ring is —

$$(D_n^2)_{dark} = \frac{4n\lambda R}{\mu} \longrightarrow (7)$$

Now, $(D_{n+1}^2)_{dark} - (D_n^2)_{dark} = \frac{4\lambda R}{\mu}$

$$\text{or, } (D_{n+1} + D_n)(D_{n+1} - D_n) = \frac{4\lambda R}{\mu}$$

$$\text{or, } D_{n+1} - D_n = \frac{4\lambda R}{\mu(D_{n+1} + D_n)}$$



β → fringe width

$$\text{or, } 2\beta \simeq \frac{4\lambda R}{2D_n\mu}$$

$$\text{or, } \beta = \frac{\lambda R}{\mu D_n} \longrightarrow (8)$$

$\therefore \beta \propto \frac{1}{D_n} \Rightarrow$ fringe width decreases as diameter of ring increases.

Now, $(D_{n+1})_{dark} - (D_n)_{dark}$

$$= \sqrt{\frac{4\lambda R}{\mu}} \left[\sqrt{n+1} - \sqrt{n}\right] \rightarrow (9)$$

As the value of 'n' increases, the above difference decreases ⇒ The rings become gradually narrower as diameter increases ⇒ fringe width decreases as order no. of rings or diameter of rings increases. (which we also get from eq-(8)).

At the point of contact of the plano-convex lens and glass plate, $d = 0$ ⇒ condition of destructive interference is satisfied ⇒ The central spot is dark.

If white light is used instead of monochromatic light, the central spot remains dark which will be surrounded by a few coloured rings beyond which there will be general illumination due to overlapping of different coloured rings.

Uses

1. Measurement of wavelength of monochromatic light

Diameter of n Th. dark ring ⇒

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

and Diameter of (n+p) Th. dark ring

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

$$\therefore D_{n+p}^2 - D_n^2 = \frac{4\lambda R}{\mu}(n+p-n)$$

$$= \frac{4\lambda R p}{\mu}$$

$$\therefore \lambda = \frac{(D_{n+p}^2 - D_n^2)\mu}{4pR} \rightarrow (10)$$

for air film, $\mu = 1$, Then,

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR} \rightarrow (11)$$

[You can use the diameter of bright ring also]

2. Measurement of refractive index of a liquid

At first, diameters of n Th. and (n+p) Th. dark / bright rings are measured with air film. Then experimental liquid

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is introduced between plano-convex lens and glass plate. Then diameters of nth and $(n+p)$th dark/bright ~~rings~~ rings are measured again. Introduction of liquid decreases the diameters of the rings.

For air film,

$$\left(D_{n+p}^2 - D_n^2\right)_{air} = 4p\lambda R \longrightarrow (12)$$

For liquid film,

$$\left(D_{n+p}^2 - D_n^2\right)_{liquid} = \frac{4p\lambda R}{\mu} \longrightarrow (13)$$

$$\therefore \left(D_{n+p}^2 - D_n^2\right)_{liquid} = \frac{\left(D_{n+p}^2 - D_n^2\right)_{air}}{\mu}$$

or, $$\mu = \frac{\left(D_{n+p}^2 - D_n^2\right)_{air}}{\left(D_{n+p}^2 - D_n^2\right)_{liquid}} \longrightarrow (14)$$

Newton's rings with transmitted light

The transmitted ray suffers only refraction or refraction plus even number of reflections each introducing a phase change of π. So, the net path difference is $2\mu d$. For normal incidence,

For maximum : $2\mu d = 2n\frac{\lambda}{2} \rightarrow$ (1.5)

For minimum : $2\mu d = (2n+1)\frac{\lambda}{2} \rightarrow$ (1.6)

For central spot ($n=0$ & $d=0$), The condition of maxima is satisfied. Hence is central spot is bright in case of transmitted light. Fringes produced by transmitted light are not as distinct as produced by reflected light. Newton's rings are usually observed by reflected light.

Difference: Biprism Fringes & Newton's Rings

i. In biprism, fringes are produced by interference of light from two virtual coherent sources produced by division of wavefront. To maintain spatial coherence, narrow source is essential in biprism experiment.

In case of Newton's rings, fringes of equal Thickness are produced by division of amplitude of the incident beam of light. Broad light source is employed to produce brighter fringes.

ii. In biprism, fringes are straight lines having equal fringe width, whereas in Newton's rings, fringes are concentric circles and fringe width decreases as the diameter of the rings increases.

iii. In biprism, the central fringe is bright. In Newton's rings, central fringe is either dark or bright if the rings are produced by reflected or transmitted lights respectively.