General Physics I (PHYS 101)

Lecture 16

Interference (Contd.)

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Outline

1. Newton's ring
   - Determination of wave length of sodium light by Newton's ring method:
   - Determination of refractive index of transparent liquid by Newton's ring method:

Newton's ring

Suppose a monochromatic source of light S is kept at the focus of convex lens L_1 so that the light beam on passing through it becomes parallel and strikes the plane glass plate B, placed at an angle of 45^o to the horizontal as shown in figure. The beam now travels downwards and strikes the Plano-convex lens L as shown.

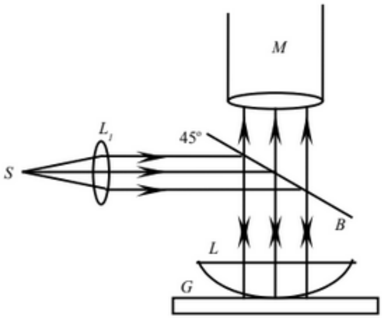


Figure 1

The Plano-convex lens is placed on a plane glass plate G with its curved surface touching the glass plate G. Since there is a thin air film

Newton's ring (contd.)

in between the lens and plane glass plate, interference takes place between the light rays reflected from the lower surface of Plano-convex lens and upper surface of plane glass plate G. The interference fringes consist of dark and bright concentric rings, known as Newton's rings and these are seen through a traveling microscope kept vertically above the lens L as shown.

Newton's ring (contd.)

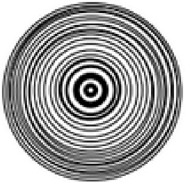


Figure 2

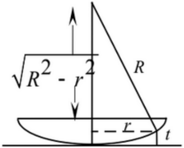


Figure 3

Let R be the radius of curvature of lens L, t be the thickness of thin air film and r be the radius of n^{th} dark or bright ring as shown in figure.

Then, from figure

$$t = R - \sqrt{R^2 - r^2}$$

$$\text{or, } t = R - R\left[1 - \left(\frac{r}{R}\right)^2\right]^{\frac{1}{2}}$$

Expanding this expression by using binomial theorem and since $r << R$, so neglecting higher powers of $\left(\frac{r}{R}\right)$ we get,

$$t = R - R\left[1 - \frac{r^2}{2R^2}\right]$$

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

$$\therefore\ 2t = \frac{r^2}{R} \tag{1}$$

Now for bright fringes, we have $2\mu t \cos\theta = (2n-1)\frac{\lambda}{2}$

Newton's ring (contd.)

For air, $\mu = 1$ and for small θ, $\cos\theta \approx 1$ so

$$2t = (2n-1)\frac{\lambda}{2} \tag{2}$$

From equations (1) and (2) we get

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

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

This relation gives the radius of n^{th} bright ring from center.

For diameter of n^{th} bright ring

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

This expression shows that diameter of n^{th} bright ring depends up on

i) $\sqrt{\frac{2n-1}{2}}$ ii) $\sqrt{\lambda}$ iii) $\sqrt{R}$

Again for dark fringes, we have $2\mu t\cos\theta = n\lambda$

For air, $\mu = 1$ and for small θ, $\cos\theta \approx 1$ so

$$2t = n\lambda \tag{3}$$

From equations (1) and (3) we get

$$\frac{r^2}{R} = n\lambda$$

$$\therefore\ r = \sqrt{n\lambda R}$$

This relation gives the radius of n^{th} dark ring from center.

For diameter of n^{th} dark ring

$$D_n = 2r = 2\sqrt{n\lambda R}$$

This expression shows that diameter of n^{th} dark ring depends up on

i) $\sqrt{n}$ ii) $\sqrt{\lambda}$ iii) $\sqrt{R}$

Newton's ring (contd.)

When $n = 0$ for diameter of dark ring, $D_n = 2\sqrt{0 \cdot \lambda \cdot R} = 0$ and this corresponds to the central dark ring. So, center of the ring system is dark in case of the reflected light.

Now diameter of n^{th} dark ring is

$$D_n = 2\sqrt{n\lambda R}$$

So, diameter of 1^{st} dark ring

$$D_1 = 2\sqrt{\lambda R}$$

Newton's ring (contd.)

And diameter of 4^{th} dark ring

$$D_4 = 2 \cdot 2\sqrt{\lambda R} = 4\sqrt{\lambda R}$$

Thus,

$$D_4 - D_1 = 4\sqrt{\lambda R} - 2\sqrt{\lambda R} = 2\sqrt{\lambda R} \tag{4}$$

Again diameter of 9^{th} dark ring

$$D_9 = 2\sqrt{9\lambda R} = 2 \cdot 3\sqrt{\lambda R} = 6\sqrt{\lambda R}$$

Newton's ring (contd.)

And diameter of 16^{th} dark ring

$$D_{16} = 2\sqrt{16\lambda R} = 2 \cdot 4\sqrt{\lambda R} = 8\sqrt{\lambda R}$$

Thus,

$$D_{16} - D_9 = 8\sqrt{\lambda R} - 6\sqrt{\lambda R} = 2\sqrt{\lambda R} \tag{5}$$

Equations (4) and (5) shows that fringe width in Newton's rings are not equally spaced and it goes on decreasing with the increasing number of fringes. That means if we go far from center, rings are found to be closely packed.

The diameter of n^{th} dark ring is given by

$$D_n = 2\sqrt{n\lambda R}$$

Squaring, we get

$$D_n^2 = 4n\lambda R \tag{6}$$

Now for m^{th} dark ring $(m > n)$

$$D_m^2 = 4m\lambda R \tag{7}$$

Newton's ring:- Determination of wave length of sodium light by Newton's ring method: (contd.)

Subtracting equation (9) from equation (10) yields

$$D_m^2 - D_n^2 = 4m\lambda R - 4n\lambda R = 4(m-n)\lambda R$$

$$\therefore\ \lambda = \frac{D_m^2 - D_n^2}{4(m-n)R}$$

This relation is used to measure the wave length of sodium light.

The experimental set up is as shown in figure. First we measure diameter of n^{th} dark ring with out liquid and then measure m^{th} dark ring $(m > n)$ with liquid.

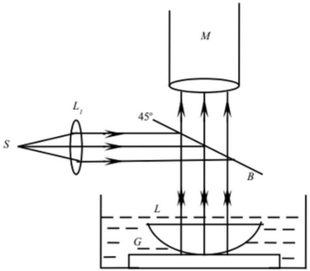


Figure 4

Now for diameter of n^{th} and m^{th} $(m > n)$ dark ring without liquid is

$$D_m^2 - D_n^2 = 4(m-n)\lambda R \tag{8}$$

Suppose liquid is poured then for n^{th} dark ring we must have

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

For small θ, $\cos\theta \approx 1$, So $2\mu t = n\lambda$ again we know that

$$2t = \frac{r'^2}{R}$$

Thus, $\mu\frac{r'^2}{R} = n\lambda \Rightarrow r' = \sqrt{\frac{n\lambda R}{\mu}}$

So the diameter is $D_n^{'} = 2r' = 2\sqrt{\frac{n\lambda R}{\mu}}$

Now for diameter of n^{th} and m^{th} $(m > n)$ dark ring with liquid is

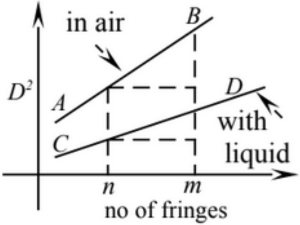
$$D_m'^2 - D_n'^2 = \frac{4(m-n)\lambda R}{\mu} \tag{9}$$

From equation (8) and equation (9)

$$D_m'^2 - D_n'^2 = \frac{D_m^2 - D_n^2}{\mu}$$

$$\therefore\ \mu = \frac{D_m^2 - D_n^2}{D_m'^2 - D_n'^2}$$

This is the required relation for the measurement of refractive index of given transparent liquid.



To determine refractive index graphically, we plot the graph between square of diameter and number of fringes with square of diameter along Y-axis and number of fringes along X-axis as shown in figure. The ratio of slopes of these graphs gives the refractive index of the given liquid. As refractive index is given by

$$\mu = \frac{D_m^2 - D_n^2}{D_m'^2 - D_n'^2}$$

From figure,

$$\mu = \frac{\text{slope of line } AB}{\text{slope of line } CD}$$

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