Interference part-4

5.8 NEWTON'S RINGS

Newton's rings in a special case of wedge shaped film in which an air film is formed between a glass plate and a convex surface of lens. The thickness of air film is zero at the center and increases gradually towards the outside.

When a plano-convex lens of large focal length is placed on a plane glass plate, a thin air film is formed between the lower surface of plano-convex lens and upper surface of glass plate. When a monochromatic light falls on this film the light reflected from upper and lower surfaces of air film, and after interference of these rays, we get an inner dark spot surrounded by alternate bright and dark rings called Newton's rings. These rings are first observed by Newton and hence called Newton's rings.

5.8.1 Experimental Arrangement for Reflected Light

The experimental arrangement for Newton's rings experiment is shown in Figure 5.7. A beam of light from a monochromatic source S is made parallel by using a convex lens L. The parallel beam of light falls on a partially polished glass plate inclined at an angle of 45^0. The light falls on glass plate is partially reflected and partially transmitted. The reflected light normally falls on the plano-convex lens placed on plane glass plate.

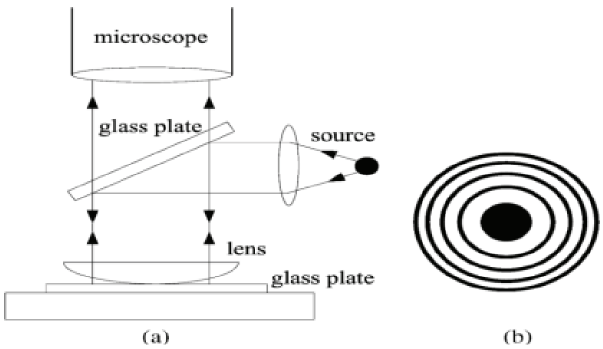

Fig. 5.7

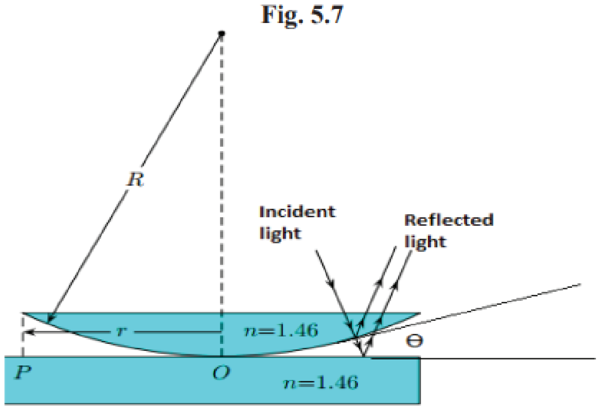

Fig 5.8

This light reflected from upper and lower surface of the air film form between plane glass plate and plno-convex lens. These rays interfere and rings are observed in the field of view. The figure 5.8 shows the reflection of light form upper and lower surfaces of air film which are responsible for interference.

5.8.2 Formation of Bright and Dark Rings

As we know the interference occurs due to light reflected from upper and lower surface of air film form between glass plate and plano-convex lens. The air film can be considered as a special case of wedge shaped film. In this case, angle wedge is the angle made between the plan glass plate and tangent from line of contact to curved surface of plano convex lens as shown in figure. 5.8.

The path difference between two interfering rays reflected by air film

$$\Delta = 2\mu t \cos(r + \Theta) - \frac{\lambda}{2} \qquad \text{....... (5.14)}$$

where μ is the refractive index of the air film, t is the thickness of air film at the point of reflection (say point P) r is angle of refraction and Θ is angle of wedge.

In this case the light normally falls on the plane convex lens for the angle of refraction r = 0. Further, as we use a lens of large focal length the angle of wedge Θ is very small. So $\cos(r+\Theta) = \cos\Theta = \cos 0^0 = 1$ and thus the path difference

$$\Delta = 2\mu t - \frac{\lambda}{2} \qquad \text{....... (5.15)}$$

At point of contact t = 0, therefore, $\Delta = \frac{\lambda}{2}$

Which is the condition of minima. Hence at centre or at point of contact there is a dark spot.

Condition of Bright Rings or Maxima

The condition for bright rings is path difference Δ = n λ therefore

$$\Delta = 2\mu t - \frac{\lambda}{2} = n\lambda \text{ where } n = 0, 1, 2, 3\ldots\ldots\ldots$$

or $$2\mu t = \left(\frac{2n+1}{2}\right)\lambda$$

or $$2\mu t = \left(\frac{2n-1}{2}\right)\lambda \qquad \text{....... (5.16)}$$

Where n = 1, 2, 3………

Condition of Dark Ring or Minima

In case of dark rings, the path difference, $\Delta = \left(\frac{2n-1}{2}\right)\lambda$

Where n= 1, 2, 3………

Therefore $$\Delta = 2\mu t - \frac{\lambda}{2} = \left(\frac{2n-1}{2}\right)\lambda$$

or $$2\mu t = n\lambda \qquad \text{....... (5.17)}$$

Thus corresponding to n = 1, 2, 3….. we observe first, second third…..etc. bright or dark rings. In Newton's rings experiment the locus of points of constant thickness is a circle therefore the fringes are circular rings.

5.8.3 Diameter of Bright and Dark Rings

In figure 5.9 the plano-convex lens BOPF is place on glass plate G and O is the point of contact. Suppose, C is the centre of the sphere OBFP from which the plano-convex lens is constructed. P is point on the air film at which the thickness of air film is t. At point P, the light is incident and reflected form the upper and lower surface of air film, and rings are formed. AP is the radius of ring passes through point P. According to property of circle

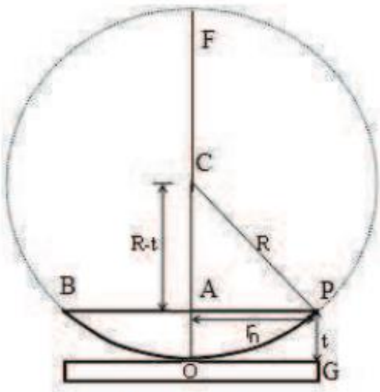

Figure 5.9

$$AP \times AB = AO \times AL$$

$$r^2 = t \times (2R - t) \quad \because AL=OL-OA$$

Where R is the radius of curvature of lens.

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

Since R is very large and t is very small, we can write

$$r^2 = 2Rt \qquad \text{or} \qquad t = \frac{r^2}{2R}$$

Substituting this value of t in equation (5.16), we get,

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

or

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

This expression contains n, *i.e.*, r is a function of n. Thus it is better to use r_n in place of r. If D_n is the diameter of nth bright ring then we have $r = r_n = D_n / 2$ and can write

$$\frac{{D_n}^2}{4} = \frac{\left(\frac{2n-1}{2}\right)\lambda R}{\mu}$$

or

$${D_n}^2 = \frac{2(2n-1)\lambda R}{\mu} \qquad \text{....... (5.18)}$$

Where n= 1, 2, 3……. Similarly for dark rings

$$2\mu t = n\lambda \qquad \text{or} \qquad 2\mu \frac{r^2}{2R} = n\lambda \qquad \text{or} \qquad r^2 = \frac{n\lambda R}{\mu}.$$

If D_n is diameter of nth dark ring then

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

or $$D_n{}^2 = \frac{4n\lambda R}{\mu} \qquad \text{....... (5.19)}$$

Where n = 1, 2, 3……

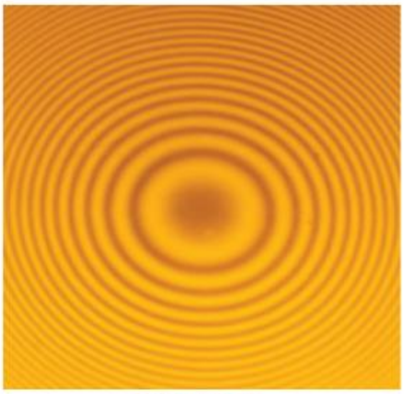

Figure 5.10

The alternate bright and dark rings are formed as shown in figure 5.10. The spacing between two consecutive rings can be given as

$r_{n+1}^2 - r_n^2 = (\sqrt{n+1} - \sqrt{n})\, \lambda R$ (in case of air film μ =1)

Spacing between 1st and 2nd rings = $(\sqrt{2} - \sqrt{1})\, \lambda R = 0.4142\, \lambda R$

Spacing between 2nd and 3rd rings = $(\sqrt{3} - \sqrt{2})\, \lambda R = 0.3178\, \lambda R$

Spacing between 4th and 3rd rings = $(\sqrt{4} - \sqrt{3})\, \lambda R = 0.21\, \lambda R$

Thus it is clear that the spacing between successive rings decreases with increase in order.

5.8.4 Determination of Wave Length of a Monochromatic Light Source

In Newton's experiment if we use a light source of unknown wave length (say sodium lamp) then we can determine the wavelength of light source by measuring the diameters of Newton's ring.

If D_n is diameter of nth dark ring formed due to air film then

$$D_n^2 = 4n\lambda R$$

Where n is any integer number.

Similarly if $D_{(n+p)}$ is the diameter of $(n+p)^{th}$ ring

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

Using this equation, we can write

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

or $$\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR} \qquad \text{....... (5.20)}$$

Where p is any integer number and R is radius of curvature of plano-convex lens.

5.8.5. Determination of Refractive Index of a Liquid by Newton's Rings Experiment

In Newton's rings experiment the diameter of n^{th} dark ring in case air film is

$$D_n^2 = 4n\lambda R \qquad (\because \mu = 1)$$

The diameter of $(n+p)^{th}$ ring

$$D^2_{n+p} = 4(n+p)\lambda R$$

If a liquid of refractive index μ is filled between the plane glass plate and convex lens then

$$D^2_n = \frac{4n\lambda R}{\mu} \quad \text{and} \quad D^2_{n+p} = \frac{4(n+p)\lambda R}{\mu}$$

Thus we can write

$$\frac{[D^2_{n+p} - D^2_n]air}{[D^2_{n+p} - D^2_n]liquid} = \frac{4p\,\lambda R}{\frac{4p\,\lambda R}{\mu}} = \mu$$

or

$$\mu = \frac{[D^2_{n+p} - D^2_n]air}{[D^2_{n+p} - D^2_n]liquid} \qquad \text{....... (5.21)}$$

Example 5.7: In Newton's rings experiment if the radius of curvature of plano-convex lens in 200 cm and wavelength of the light used is 5890 Å, calculate the diameter of 10^{th} bright ring.

Solution: The diameter of n^{th} bright ring is given as (μ=1 for air film) is given by

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

or

$$D_{10}^2 = 2 \times (20\text{-}1) \times 5890 \times 10^{-8} \times 200\ \text{cm}^2 = 6.69\text{mm}$$

The diameter of 10^{th} bright ring is 6.69 mm.

Example 5.8: In a Newton's ring experiment the diameter of 15^{th} dark ring and 5^{th} dark ring are 0.59 cm and 0.33cm respectively. If the radius of curvature of the convex lens is 100cm calculate the wave length of light used.

Solution: The wave length of unknown light source is Newton's rings experiment is given as

$$\lambda = \frac{[D^2_{n+p} - D^2_n]}{4pR}$$

Here $D_{n+p} = D_{15} = 0.59$ cm, $D_n = D_5 = 0.33$cm, $p = 10$, R = 100cm

$$\lambda = \frac{(0.59)^2 - (0.33)^2}{4 \times 10 \times 100} = 5980\ \text{Å}$$

Example 5.9: Newton's rings are formed by using a monochromatic light of 6000Å. When a liquid is introduced between the convex lens and plane glass plate the diameter of 6^{th} bright ring becomes 3.1mm. If the radius of curvature of lens is 1mt, calculate the refractive index of liquid.

Solution: Given that, n= 6, D_n = 3.1mm = 3.1 $\times 10^{-3}$ m, λ = 6000Å = 6×10^{-7} m, R = 1m

$$\mu = \frac{2(2n-1)\lambda R}{D_n^2} = \frac{2\times11\times6\times10^{-7}\times1}{(3.1\times10^{-3})^2} = 1.37$$

Example 5.10: In Newton's ring experiment two light sources of wavelength 6000Å and 4500Å are used to form rings. It is observed that n^{th} dark ring due to 6000Å light coinside with $(n+1)^{th}$ dark ring due to 4500Å. If the radius of curvature of the plano convex lens is 100cm, calculate the diameter of n^{th} dark ring due to λ_1 and λ_2.

Solution: For n^{th} dark ring due to λ_1, $D^2_n = 4n\,\lambda_1 R$

Similarly for $(n+1)^{th}$ dark ring due to λ_2, $D^2_{n+1} = 4\,(n+1)\,\lambda_2 R$

Since n^{th} dark ring due to λ_1 co-inside with $(n+1)^{th}$ dark ring due to λ_2 therefore.

$4n\lambda_1 R = 4(n+1)\,\lambda_2 R$ or $n\lambda_1 = (n+1)\,\lambda_2$ or $n\lambda_1 - n\lambda_2 = \lambda_2$ or $n = \frac{\lambda_2}{\lambda_1 - \lambda_2}$

Here $\lambda_1 = 6000$Å, $\lambda_2 = 4500$Å

$$\therefore \qquad n = \frac{4500}{6000-4500} = 3$$

Now the diameter of $n=3^{rd}$ dark ring due to λ_1

$$D_3^2 = 4n\lambda_1 R = 4\times3\times6000\times10^{-10}\times1 \text{ m}$$

Or $D_3 = 2.68$ mm.

Similarly diameter of $n=3^{rd}$ dark ring due to λ_2

$$D_3^2 = 4n\lambda_2 R = 4\times3\times4500\times10^{-10}\times1 \text{ m}$$

or $D_3 = 2.32$ mm.

Same relation can also be obtained for bright rings.

5.8.6 Newton's Rings in Case of Transmitted Light

The Newton's rings can also be formed in case of interference due to transmitted light as shown in figure 5.11. In this case the transmitted rays 1 and 2 interfere, and we can observe the rings in the field of view. In this case the net path difference between the rays is $\Delta = 2\mu t$. since we will not consider the path difference arises due to reflection from denser medium. Therefore this is net path difference.

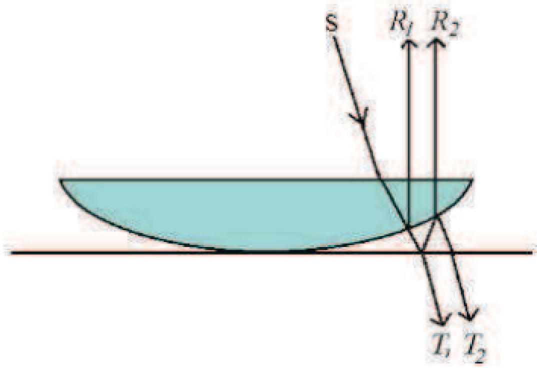

Figure 5.11

The condition for maxima (bright rings) is given by

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

And we know that in case of reflected light, $t = \frac{r^2}{2R}$

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

Now if D_n is the diameter of nth bright ring then, $\frac{D_n}{2} = r$ and thus

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

In case of air film, $Dn^2 = 4n\lambda R$

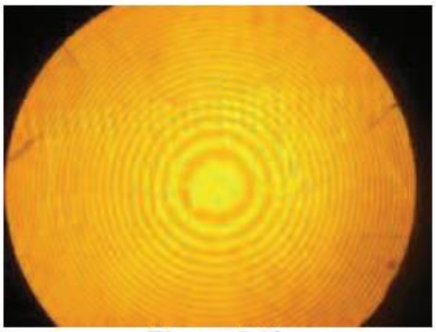

Figure 5.12

Similarly in case of minima (dark ring) the diameter nth dark ring is given by

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

We can see that, this is an opposite case of reflected light. In case at point of contact the path difference is zero which is condition corresponding to bright fringe thus the centre point is bright. The rings system in this case is shown in figure 5.12.