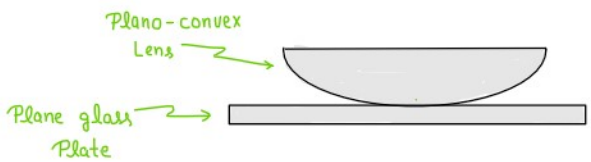
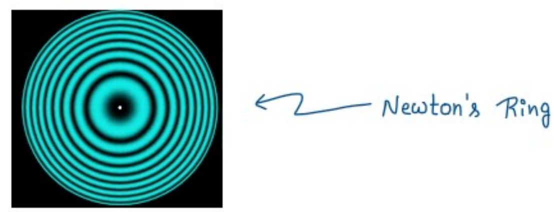
Newton's Ring

06 October 2023 18:31

#Newton's Ring :-

When a plano-convex lens of large focal length is placed with its convex surface in contact with a plane glass plate, a thin wedge shaped film of air enclosed between the lower surface of lens and the upper surface of the plate. The thickness of the air film is almost zero at the point of contact and gradually increases from the point of contact outwards. When viewed by

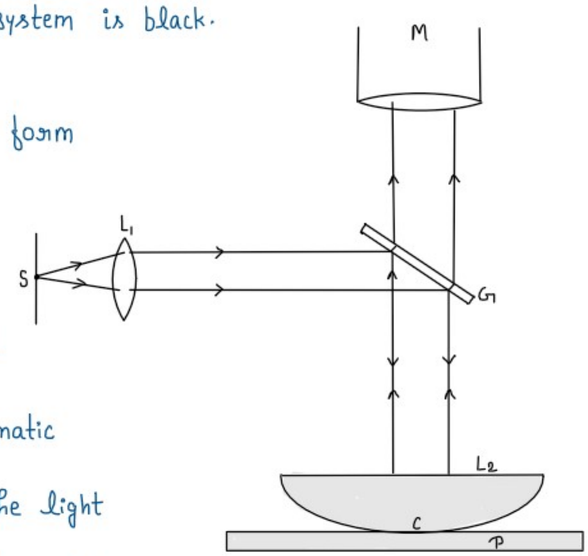




reflected monochromatic light, a system of concentric bright and dark fringes is observed in thin film. These are called Newton's Ring.

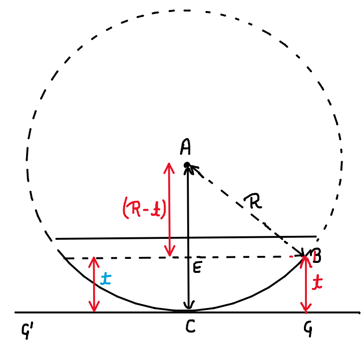
Newton's ring are the example of interference fringes of constant thickness of air film remains const. along a circle with its centre at the point of contact, the fringes are in the form of concentric circles. If the contact is perfect, the centre of the system is black.

Experimental Arrangement :- An experimental setup to form Newton's ring shown in figure. L_2 is a plano-convex lens of large radius of curvature. It is placed on an optically plane glass plate P. The lens makes contact with the plate at point C. The light from a monochromatic source S is rendered parallel by a convex lens L_1. The light is incident on a glass plate G inclined at an angle of 45° to



the incident beam. The light is reflected by this glass plate vertically downwards. A part of the incident energy is reflected by the curved surface of the lens L_2 and the part transmitted from the lens is reflected back from the plane surface of glass plate. This two reflected rays incident energy is reflected by the curved surface of the lens L_2 and the part transmitted from the lens is reflected back from the plane surface of glass plate. This two reflected rays interfere and give rise to an interference pattern in the form of circular rings. These rings are localised in the air film. Therefore, a long focus microscope is focused at C to see the pattern.

Diameter of dark and bright rings in reflected light :



As shown in figure, R is the radius of curvature of the lens and A is its centre of curvature. Let t be the thickness of the air film at a point where the radius $CG = r_n$, the radius of n^{th} ring. The distance $AE = R - t$.

From ΔAEB, we have :-

$$R^2 = r_n^2 + (R-t)^2$$

$$R^2 = r_n^2 + R^2 + t^2 - 2Rt$$

$$r_n^2 = 2Rt - t^2 \approx 2Rt$$

where t^2 is neglected as compared to $2Rt$ because film is quite thin.

$$t = \frac{r_n^2}{2R} \quad \text{—— (1)}$$

Now for a wedge shaped film, the optical path difference is given by relation :-

$$\Delta = 2\mu t \cos(r+\alpha) \quad \text{—— (2)}$$

where α is the angle of wedge and r is the angle of refraction.

But since the experimental setup is adjusted so that $r=0$ for normal incidence and α is also very small. Therefore $\cos(r+\alpha) = 1$. Hence,

$$\Delta = 2\mu t \quad \text{—— (3)}$$

The condition of maxima is given by the following relation :-

$$\Delta = 2\mu t = (2n+1)\frac{\lambda}{2} \quad \text{—— (4)}$$

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

Thickness of n^{th} ring is given by eq^n (1) :-

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

$$\boxed{r_n^2 = (2n+1)\frac{\lambda R}{2\mu}} \quad \text{——— (5)}$$

Similarly, knowing the condition for minima, we have :-

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

Again substituting value of t from eqⁿ (1), the radius of n^{th} dark ring is given by :-

$$\boxed{r_n^2 = \frac{Rn\lambda}{\mu}} \quad \text{——— (6)}$$

Relations (5) and (6) give the radii of n^{th} bright and dark ring respectively.

Therefore, the diameters of bright and dark rings are given by putting $r_n = \frac{D_n}{2}$

Hence,

$$\boxed{D_n^2 = 2(2n+1)\frac{\lambda R}{\mu}} \quad \text{——— (7)} \qquad \text{(For Bright ring)}$$

$$\boxed{D_n^2 = \frac{4n\lambda R}{\mu}} \quad \text{——— (8)} \qquad \text{(For Dark ring)}$$

For Bright rings :-

From eqⁿ (7), $\mu = 1$ for air film :-

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

$$\boxed{D_n^2 \propto (2n+1)} \quad \text{——— (9)} \qquad \text{where } n = 0, 1, 2, \text{-----}$$

where $n = 0, 1, 2, ---$ etc is an integer. Therefore $(2n+1)$ is an odd number. Thus the diameters of bright rings are proportional to the square roots of odd numbers.

The diameter of the first few bright rings is in the ratio

$$D_1 : D_2 : D_3 : D_4 = 1 : \sqrt{3} : \sqrt{5}$$

$$= 1 : 1.1732 : 2.236 : 2.646$$

The seperation between succesive bright rings are in the ratio

$$0.732 : 0.504 : 0.410$$

Thus the fringes get closer with increase in their order.

For Dark rings :-

From eq^n 8, $\mu=1$ for air film :-

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

$$\boxed{D_n^2 \propto \sqrt{n}} \qquad \text{——— (9)} \qquad \text{where } n=0,1,2,\text{-----}$$

When $n=0$, the diameter of the dark ring is zero. Therefore the centre is dark. However, while counting the order of the dark rings, the central ring is not counted and we take $n=1,2,3,$ ---- etc. Thus the diameters of dark rings are proportional to the square roots of natural numbers.

The seperation of first few dark rings in the ratio.

$$D_1 : D_2 : D_3 : D_4 = 1 : \sqrt{2} : \sqrt{3}$$

$$= 1 : 1.414 : 1.732 : 2.0$$

The seperation between successive dark rings are in the ratio

$$0.414 : 0.318 : 0.268$$

Thus the spacing between consecutive dark fringes also decreases with increase in their order.

Determination of wavelength of Sodium Light and referactive index of a Liquid by Newton's Rings :

Diameter of the n^{th} dark ring in Newton's ring experiment is given by :-

$$D_n^2 = \frac{4n\lambda R}{\mu} \qquad \text{——— (1)}$$

For a film of air enclosed between the plate and lens, $\mu=1$

$$D_n^2 = 4n\lambda R \qquad \text{——— (2)}$$

Similarly, the diameter of $(n+p)^{th}$ ring is given by :-

$$D_{n+p}^2 = 4(n+p)\lambda R \qquad \text{——— (3)}$$

Difference of eq^n 3 and 2 gives :-

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

$$\boxed{\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}} \quad \text{——} \quad (4)$$

However, the same result shall be obtained by using relation giving the diameter of n^{th} bright fringe.

If medium of the wedge film between the lens and plate has refractive index μ, then the value of λ is given by the following relation :-

$$\lambda = \frac{(D'^2_{n+p} - D'^2_n)\mu}{4pR} \quad \text{——} \quad (5)$$

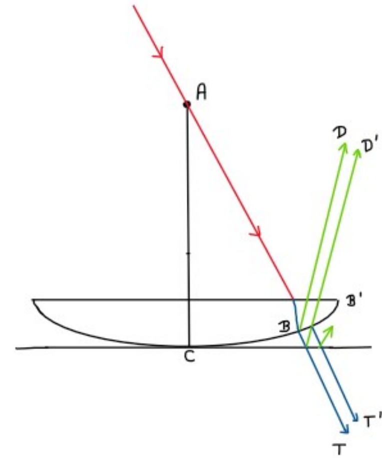
where D'_{n+p} and D'_n are the diameters of $(n+p)^{th}$ and n^{th} rings with the film of the medium of refractive index μ. However, if the wavelength of the light and the experimental setup is same then dividing eq^n (4) by (5), we get :

$$\boxed{\mu = \frac{D_{n+p}^2 - D_n^2}{D'^2_{n+p} - D'^2_n}}$$

Newton's ring by white light :-

The expressions for the diameters of the rings show that the squares of diameters are proportional to the wavelength. We know that the wavelength of red λ_r is the largest and that of violet λ_v is the smallest. Therefore the diameter of violet ring of the same order will be smallest and that of the red will be the largest. The diameters of the same order for other colors shall occupy the intermediate positions. Thus the Newton's ring system with reflected white light will have centre black enriched by mixed colours from violet to red. Ultimately it leads to uniform illumination due to overlapping of colours. The overlapping of colours occurs for thick films.

Newton's ring by transmitted light :



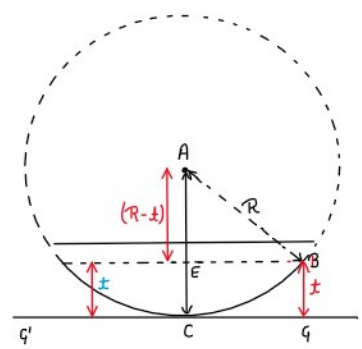
While discussing the formation of Newton's rings by reflection, we see that T, T' are the transmitted rays. These rays interfere to give Newton's ring pattern by transmitted light. In this case since no reflection takes place from the denser medium, hence no additional path change of $\lambda/2$ or phase change of π takes place. Evidently, as already mentioned, the conditions for maxima and minima shall be reverse in this case of reflection. The path difference for maxima is as follows :

$$\Delta = 2\mu t = n\lambda \qquad \text{(For maxima)}$$

$$\Delta = 2\mu t = (2n+1)\frac{\lambda}{2} \qquad \text{(For minima)}$$

where the terms have the usual meaning. These conditions show that at the point of contact of the lens and plate, a bright ring is formed as $\Delta = 0$ for $t = 0$ at this point and it satisfies the condition of a maxima. In this way we note that the reflected and transmitted ring patterns are complementary. The parts which are bright in reflected pattern are dark in the transmitted one and vice versa. The wavelength can be determined in the same way as in case of reflection pattern but it is not common and convenient, because the rings in transmitted light are poorer in contrast.

Diameter of dark and bright rings in transmitted light :-



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

Thickness of n^{th} ring is given by eq^n (1) :-

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From eqⁿ (7), $\mu = 1$ for air film :-

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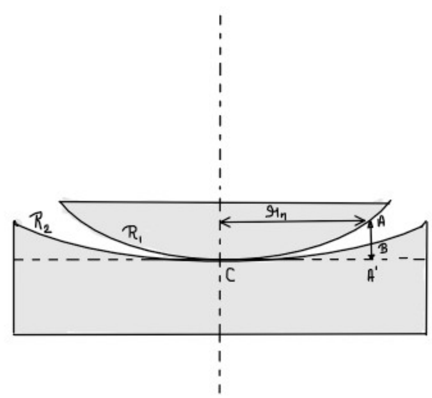
Thus the spacing between consecutive bright fringes also decreases with increase in their order.

Newton's Rings with both surfaces curved :-

Case-I :- Lower surface concave :-

Let us consider two curved surfaces of radii of curvature R_1 and R_2 in contact at point C. A thin air film is enclosed between the surfaces. The bright and dark rings are formed and can be viewed with a travelling microscope. Consider a Newton's ring of radius r_n where the film thickness is t at point B is :



$$AB = t = AA' - A'B$$

From geometry ;

$$AA' = \frac{r_n^2}{2R_1} \quad \text{and} \quad A'B = \frac{r_n^2}{2R_2}$$

then ;

$$t = \left[\frac{r_n^2}{2R_1} - \frac{r_n^2}{2R_2}\right] \qquad \text{——— (1)}$$

For normal incidence and thin film, the path difference reduces to the following form after substituting the value of t from eq^n (1) :

$$\Delta = 2\mu t = 2\mu\left[\frac{r_n^2}{2R_1} - \frac{r_n^2}{2R_2}\right]$$

$$\Delta = \mu\left[\frac{r_n^2}{R_1} - \frac{r_n^2}{R_2}\right] \qquad \text{——— (2)}$$

For maxima in reflected patterns,

We know that the path difference given above should satisfy the condition

$$\mu r_n^2\left[\frac{1}{R_1}-\frac{1}{R_2}\right] = \frac{(2n+1)\lambda}{2}$$

$$r_n^2 = \frac{(2n+1)\lambda}{2\mu\left[\frac{1}{R_1}-\frac{1}{R_2}\right]}$$

In terms of diameter $D_n = 2r_n \Rightarrow r_n = \frac{D_n}{2}$, we have :-

$$\frac{D_n^2}{4} = \frac{(2n+1)\lambda}{2\mu\left[\frac{1}{R_1}-\frac{1}{R_2}\right]}$$

$$D_n^2 = \frac{2(2n+1)\lambda}{\mu\left[\frac{1}{R_1}-\frac{1}{R_2}\right]}$$

$$\boxed{D_n^2 = \frac{2(2n+1)\lambda R_1R_2}{\mu(R_2-R_1)}}$$

For minima in reflected patterns,

We know that the path difference given above should satisfy the condition

$$\mu r_n^2\left[\frac{1}{R_1}-\frac{1}{R_2}\right] = n\lambda$$

$$r_n^2 = \frac{n\lambda}{\mu\left[\frac{1}{R_1}-\frac{1}{R_2}\right]}$$

In terms of diameter $D_n = 2r_n \Rightarrow r_n = \frac{D_n}{2}$, we have :-

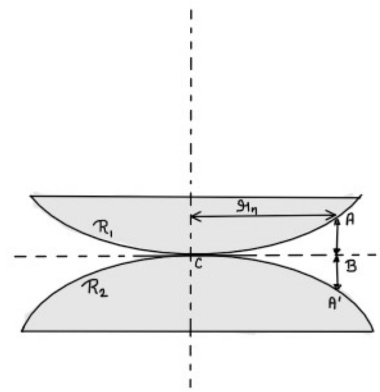
$$\frac{D_n^2}{4} = \frac{n\lambda}{\mu\left[\frac{1}{R_1}-\frac{1}{R_2}\right]}$$

$$D_n^2 = \frac{4n\lambda}{\mu\left[\frac{1}{R_1}-\frac{1}{R_2}\right]}$$

$$\boxed{D_n^2 = \frac{4n\lambda R_1R_2}{\mu(R_2-R_1)}}$$

Case-I :- Lower surface convex :-

Let us consider two curved surfaces of radii of curvature R_1 and R_2 in contact at point C. A thin air film is enclosed between the surfaces. The bright and dark rings are formed and can be viewed with a travelling microscope. Consider a Newton's ring of radius r_n where the film thickness is t at point B is :



$$AB = t = AB + BA'$$

From geometry ;

$$AB = \frac{r_n^2}{2R_1} \qquad \text{and} \qquad BA' = \frac{r_n^2}{2R_2}$$

then ;

$$t = \left[\frac{r_n^2}{2R_1} + \frac{r_n^2}{2R_2}\right] \qquad \text{——— (1)}$$

For normal incidence and thin film, the path difference reduces to the following form after substituting the value of t from eq^n (1) :

$$\Delta = 2\mu t = 2\mu\left[\frac{r_n^2}{2R_1} + \frac{r_n^2}{2R_2}\right]$$

$$\Delta = \mu\left[\frac{r_n^2}{R_1} + \frac{r_n^2}{R_2}\right] \qquad \text{——— (2)}$$

For maxima in reflected patterns,

We know that the path difference given above should satisfy the condition

$$\mu r_n^2\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = \frac{(2n+1)\lambda}{2}$$

$$r_n^2 = \frac{(2n+1)\lambda}{2\mu\left[\frac{1}{R_1} + \frac{1}{R_2}\right]}$$

In terms of diameter $D_n = 2r_n \Rightarrow r_n = \frac{D_n}{2}$, we have :-

$$\frac{D_n^2}{4} = \frac{(2n+1)\lambda}{2\mu\left[\frac{1}{R_1} + \frac{1}{R_2}\right]}$$

$$\frac{D_n^2}{4} = \frac{(2n+1)\lambda}{2\mu\left[\frac{1}{R_1}+\frac{1}{R_2}\right]}$$

$$D_n^2 = \frac{2(2n+1)\lambda}{\mu\left[\frac{1}{R_1}+\frac{1}{R_2}\right]}$$

$$\boxed{D_n^2 = \frac{2(2n+1)\lambda R_1 R_2}{\mu(R_2+R_1)}}$$

For minima in reflected patterns,

We know that the path difference given above should satisfy the condition

$$\mu r_n^2\left[\frac{1}{R_1}+\frac{1}{R_2}\right] = n\lambda$$

$$r_n^2 = \frac{n\lambda}{\mu\left[\frac{1}{R_1}+\frac{1}{R_2}\right]}$$

In terms of diameter $D_n = 2r_n \Rightarrow r_n = \frac{D_n}{2}$, we have :-

$$\frac{D_n^2}{4} = \frac{n\lambda}{\mu\left[\frac{1}{R_1}+\frac{1}{R_2}\right]}$$

$$D_n^2 = \frac{4n\lambda}{\mu\left[\frac{1}{R_1}+\frac{1}{R_2}\right]}$$

$$\boxed{D_n^2 = \frac{4n\lambda R_1 R_2}{\mu(R_2+R_1)}}$$

Ex. 23. *In Newton's rings experiment the diameters of the n^{th} and $(n + 14)^{th}$ rings are 4.2 mm and 7.0 mm respectively. Radius of curvature of plano-convex lens is 1 m. Calculate wavelength of light.*

Formula:

$$\lambda = \frac{D_{n+14}^2 - D_n^2}{4PR}$$

$$\boxed{\lambda = \quad}$$

Given Data:-

$D_{n+14} = 7 \times 10^{-3}$ m

$D_n = 4.2 \times 10^{-3}$ m

$P = 14$

$R = 1$ m

Ex. 24. *A convex lens of 350 cm placed on a flat plate and illuminated by monochromatic light gave the 6^{th} bright ring of diameter 0.68 cm. Calculate the wavelength of light used.*

<u>Soln.</u>

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

$$\boxed{\lambda = \quad}$$

<u>Given Data :-</u>

$R = 350$ cm

$n = 6$

$D_n = 0.68$ cm

Ex. 25. *A Newton's rings arrangement is used with a source emitting two wavelengths $\lambda_1 = 6 \times 10^{-7}$ m and $\lambda_2 = 4.8 \times 10^{-7}$ m and it is found that n^{th} dark ring of λ_1 coincides with $(n+1)^{th}$ dark ring of λ_2. If radius of curvature of lens is 0.6 m; then find the common diameter of these two rings.*

$$D_n^2 = \frac{4n\lambda R}{\mu} \qquad \mu = 1$$

$$D_n^2 = D_{n+1}^2$$

$$4n\lambda_1\cancel{R} = 4(n+1)\lambda_2\cancel{R}$$

$$\boxed{n = 4}$$

<u>Given :-</u>

$\lambda_1 = 6 \times 10^{-7}$ m

$\lambda_2 = 4.8 \times 10^{-7}$ m

$R = 0.6$ m

$$D_n^2 = 4n\lambda_1 R = 4 \times 4 \times (6 \times 10^{-7}) \times (0.6)$$

$$D_{n+1}^2 = 4(n+1)\lambda_2 R = 4 \times 5 \times (4.8 \times 10^{-7}) \times 0.6$$

$$\rightarrow 57.6 \times 10^{-7} \text{ m}^2$$

$$\Rightarrow D_n = \sqrt{57.6 \times 10^{-7}} \text{ m} = 2.4 \times 10^{-3} \text{ m}$$

$$= 2.4 \text{ mm}$$

Ex. 26. *In a Newton's ring experiment, the diameter of 5^{th} dark ring is reduced to half of its value on introducing a liquid below the convex surface. Calculate the refractive index of liquid.*

$$D_n^2 = 4n\lambda R \quad \text{— (1)} \qquad n = 5$$

$$D_n'^2 = \frac{4n\lambda R}{\mu} \quad \text{— (2)}$$

$$\mu = \left(\frac{D_n}{D_n'}\right)^2 = \left(\frac{D_n}{D_n/2}\right)^2 = 4$$

Ex. 28. *In Newton's ring experiment, the diameters of the 4^th and 12^th dark rings are 0.400 cm and 0.700 cm. respectively. Find the diameter of the 20^th dark ring.*

$n+P = 12$

$\hookrightarrow 4$

$P = 8$

$$d = \frac{D_{n+P}^2 - D_n^2}{4PR}$$

$$d = \frac{(0.700)^2 - (0.400)^2}{4 \times 8 \times R}$$

$$d = \frac{0.01031}{R} \text{ cm}^2$$

$$D_{20}^2 = 4(20)\,d\,R$$

$$D_{20}^2 = 4(20)\left\{\frac{0.01031}{\cancel{R}}\right\}\cancel{R}$$

$$D_{20} = \sqrt{0.824} \text{ cm}$$

$$D_{20} = 0.9 \text{ cm}$$

Ex. 29. *When Newton's rings are formed with a wavelength 6×10^{-5} cm in air, the difference between the diameters of the successive rings is found to be 0.125 cm². Discuss the changes when (a) the wavelength of light is changed to 4.5×10^{-5} cm, (b) a liquid of $\mu = 1.33$ (water) is introduced between the lens and the plate, (c) the radius of curvature of the lens is doubled and halved.*

$$D_{n+1}^2 - D_n^2 = 4dR = 0.125 \quad \text{—— (1)}$$

Given

$d = 6 \times 10^{-5}$ cm

$d' = 4.5 \times 10^{-5}$ cm

$$D_{n+1}'^2 - D_n^2 = 4d'R \quad \text{—— (2)}$$

$$\frac{0.125}{D_{n+1}'^2 - D_n'} = \frac{d}{d'}$$

$\boxed{0.094 \text{ cm}^2}$

Solⁿ (b)

$$D_{n+1}^2 - D_n^2 = 4dR = 0.125 \quad \text{—— (1)}$$

Divide

$$4\left(D_{n+1}' - D_n'\right) = 4dR \quad \text{—— (2)}$$

$\boxed{0.094 \text{ cm}^2}$

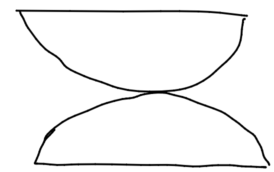
Sol^n :-

Ex. 30. *Two plano-convex lenses, each of radius of curvature 100 cm, are placed with their curved surfaces in contact with each other. Newton's rings are formed by using a light of wavelength 6×10^{-5} cm. Find the distance between 10^{th} and 20^{th} rings.*

$$r_n = \sqrt{\frac{n \lambda R_1 R_2}{(R_1 + R_2)}}$$

$\lambda = 6 \times 10^{-5}$ cm

$R_1 = R_2 = 100$ cm



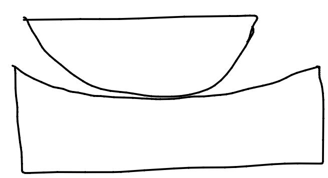
$$r_{10} = \sqrt{\frac{10 \times 6 \times 10^{-5} (100)^2}{200}}$$

$$r_{20} = \sqrt{\frac{20 \times 6 \times 10^{-5} (100)^2}{200}}$$

$$\boxed{r_{20} - r_{10} =}$$

Ex. 31. *A convex surface of radius of curvature 1 m. rests on a concave surface of radius of curvature of 2 m. Find difference in squares of diameters of successive (a) bright and (b) dark rings for wavelength 6.0×10^{-7} cm.*

$$D_{n+1}^2 - D_n^2 = ?$$



→ for Bright

→

Ex. 32. *In Newton's ring experiment, the diameter of the third dark ring is 3.2 mm, when a light of wavelength 589 nm is used. Determine the radius of the surface of the lens.* **(Amity B. Tech. 2004)**

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

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

Ex. 33. *In a Newton's ring arrangement, if a drop of water* $\left(\mu = \frac{4}{3}\right)$ *be placed in between the lens and the plate, the diameter of the 10th ring is found to be 0.6 cm. Obtain the radius of curvature of the face of the lens in contact with the plate. The wavelength of light used is 6000 Å.* ***(Amity B. Tech. 2005)***

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

Ex. 34. *In Newton's rings experiment, the diameter of the 15th ring was found to be 0.617 cm and that of the 5th ring was 0.341 cm. If the radius of curvature of the plano-convex lens is 100 cm, compute the wavelength of light used.* ***(Amity B. Tech. 2007)***

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

$p = 10$