Interference.

- **Monocromatic sources of light:** Two sources of light are said to be monocromatic only when they emit light waves of same wavelength, i.e; same frequency, amplitude.

- **Coherent sources:** Two sources are said to be coherent if there always exists a constant phase difference between the waves emitted by these sources.

  In practice, it is not possible that two independent sources which are coherent. But, for experimental purpose, two virtual sources formed from a single source which act as coherent source.

- **Slit:** A rectangular hole which width is more smaller than its length is called a slit.

- **Interference:** When two waves of light of equal wavelength proceed in the same direction from the very narrow sources and superimpose at a point in a medium, at the instant of superposition according as the waves meet at the point in the same or opposite phase. This phenomenon is called interference.

  When two waves meet in the same phase they produce brightness and in the opposite phase they produce darkness.

  For example- a soap bubble with different colours like that of a rainbow, light reflecting from oil floating on water.

Interference
- Constructive interference.
- Destructive interference.

Constructive interference: When two light waves of same frequency meet at a point in the same phase with each other, then the interference is called constructive interference.

At this point intensity is maximum, this point is called bright point.

➜ Destructive interference: When two light waves of same frequency meet at a point in the opposite phase with each other, then the interference is called destructive interference.

At this point intensity is minimum, this point is called dark point.

Conditions of interference:

When waves come together they can interfere constructively or destructively. To set up a stable and clear interference pattern, these conditions must be met:-

1. The two sources of wave should be coherent, which means they emit identical waves with a constant phase difference.
2. The amplitude must be same. (and frequency)
3. The fringe wide should be as large as possible
4. The original source must be monocromatic. They should be of a single wavelength.
5. The propagation direction should be same.

Principle of superposition: The principle of superposition states that, when two waves of same kind meet at a point in space, the resultant displacement of that point is the vector sum of the displacements that two wave would separately produce at that point.

Q. What are coherent sources? Why are coherent sources required to produce interference of light?

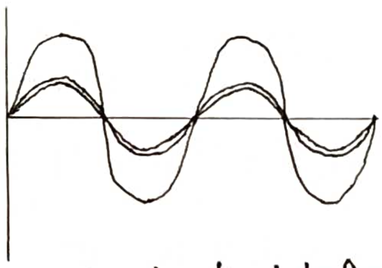
Two sources are said to be coherent if they emit light wave of the same wavelength, frequency, amplitude and a constant phase difference between each other.

Coherent sources are required to produce sustained interference pattern. Because then only we will have constant maximum and minimum intensity of light on screen, otherwise there will be a continuous fluctuation of intensity on screen, hence the intensity pattern will be lost.

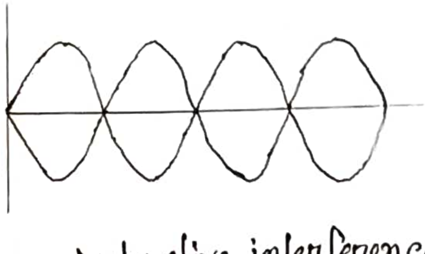
For example: A thin film of oil spread on water shows beautiful colours due to interference of light.

Theory of interference:

Interference is the combination of two or more waves to form a composite wave, based on such principle of superposition. The idea of the superposition principle is shown in Fig.1



Constructive interference



Destructive interference.

Let us consider two waves,

$$E_1(x,t) = E_{01}\sin\{\omega t - (kx_1 + \varphi_1)\}$$

$$E_2(x,t) = E_{02}\sin\{\omega t - (kx_2 + \varphi_2)\}$$

The principle of superposition of the two waves, the resultant wave is given by,

$$E = E_1(x,t) + E_2(x,t)$$

The interference is constructive if the amplitude of $E(x,t)$ is greater than the individual ones and the interference is destructive if the amplitude of $E(x,t)$ is smaller than the individual ones.

Again we know the wave equation in the form,

$$E(x,t) = E_0\sin\{\omega t - (kx + \varphi)\} \qquad (1)$$

Where, E_0 is the amplitude of harmonic wave disturbance propagated along the positive axis.

Let,

$$\alpha(x,\varphi) = -(kx + \varphi)$$

From equation (1) we can write,

$$E(x,t) = E_0\sin\{\omega t + \alpha(x,\varphi)\} \qquad (2)$$

Now we can write two wave equations such as,

$$E_1 = E_{01}\sin(\omega t+\alpha_1)$$
$$E_2 = E_{02}\sin(\omega t+\alpha_2)$$

Frequency and speed of the two waves have same and overlaping in space. The resultant disturbance is the linear superposition of these two waves. So,

$$E = E_1+E_2$$
$$= E_{01}\sin(\omega t+\alpha_1) + E_{02}\sin(\omega t+\alpha_2)$$
$$= E_{01}(\cancel{\sin\omega t}\ \sin\omega t\cos\alpha_1 + \cos\omega t\sin\alpha_1) + E_{02}(\sin\omega t\cos\alpha_2 + \cos\omega t\sin\alpha_2).$$
$$= (E_{01}\cos\alpha_1 + E_{02}\cos\alpha_2)\sin\omega t + (E_{01}\sin\alpha_1 + E_{02}\sin\alpha_2)\cos\omega t.$$

Since the bracket quantities are constant in time. So,

Let, $E_0\cos\alpha = E_{01}\cos\alpha_1 + E_{02}\cos\alpha_2$ ———— (3)

$E_0\sin\alpha = E_{01}\sin\alpha_1 + E_{02}\sin\alpha_2$ ———— (4)

Squaring and adding equations (3) and (4) we get,

$$E_0^2\cos^2\alpha + E_0^2\sin^2\alpha = \cancel{E_{01}^2(\cos^2\alpha_1+\sin^2\alpha_1)+E_{02}^2(\cos^2\alpha_2+\sin^2\alpha_2)}$$
$$E_{01}^2\cos^2\alpha_1 + E_{02}^2\cos^2\alpha_2 + 2E_{01}E_{02}\cos\alpha_1\cos\alpha_2$$
$$+E_{01}^2\sin^2\alpha_1 + E_{02}^2\sin^2\alpha_2 + 2E_{01}E_{02}\sin\alpha_1\cdot\sin\alpha_2$$

$$\Rightarrow E_0^2(\cos^2\alpha+\sin^2\alpha) = E_{01}^2(\cos^2\alpha_1+\sin^2\alpha_1) + E_{02}^2(\cos^2\alpha_2+\sin^2\alpha_2) + 2E_{01}E_{02}\cos(\alpha_2-\alpha_1)$$

$$\therefore E_0^2 = E_{01}^2 + E_{02}^2 + 2E_{01}E_{02}\cos(\alpha_2-\alpha_1) \quad \text{———— (5)}$$

And dividing equation (4) by (3), we get,

$$\tan\alpha = \frac{E_{01}\sin\alpha_1 + E_{02}\sin\alpha_2}{E_{01}\cos\alpha_1 + E_{02}\cos\alpha_2} \quad \text{———— (6)}$$

The equation (5) and (6) provided that they are satisfied for E_0 and α.
The total disturbance,

$$E = E_0\cos\alpha\sin\omega t + E_0\sin\alpha\cos\omega t$$
$$\Rightarrow E = E_0\sin(\omega t+\alpha) \quad \text{———— (7)}$$

The equation (7) is the resultant wave of two waves.

This is the single disturbance resultant from the superposition of the two sinusoidal waves E_1 and E_2. The composite wave (7) is the harmonic wave of the same frequency as the constituents although its amplitude and phase are different.

From equ. (5)(7) the term $2E_{0_1}E_{0_2}\cos(\alpha_2-\alpha_1)$ is known as interference term and the difference in phase between two interfearing waves E_1 and E_2 is $(\alpha_2-\alpha_1)$.

Let, phase difference, $\delta = \alpha_2 - \alpha_1$.

When, $\delta = 0, \pm 2\pi, \pm 4\pi, \dots\dots, 2n\pi$;

the resultant amplitude is maximum.

When, $\delta = \pm\pi, \pm 3\pi, \dots\dots, (2n+1)\pi$;

the resultant amplitude is minimum.

The waves are said to be inphase when crest overlaps crest. The waves are said to be outphase when trough overlaps crest.

Now, the phase difference,

$$\delta = (kx_1+\varphi_1) - (kx_2+\varphi_2)$$

$$\Rightarrow \delta = k(x_1-x_2) + (\varphi_1-\varphi_2)$$

$$\Rightarrow \delta = \frac{2\pi}{\lambda}(x_1-x_2) + (\varphi_1-\varphi_2) \quad \text{------------ (8)}$$

Where, $k=\frac{2\pi}{\lambda}$ is wave vector.

Here, x_1 and x_2 are the distance from the source of the two waves to the point of observation and λ is the wavelength of the provaiding.

If the waves are inphase $\varphi_1 = \varphi_2$;

$$\therefore \delta = \frac{2\pi}{\lambda}(x_1-x_2) \quad \text{------------ (9)}$$

We know,

$$n = \frac{c}{v} = \frac{\lambda_0}{\lambda}$$

$$\Rightarrow \frac{n}{\lambda_0} = \frac{1}{\lambda}$$

Now, from equ. (9) we get,

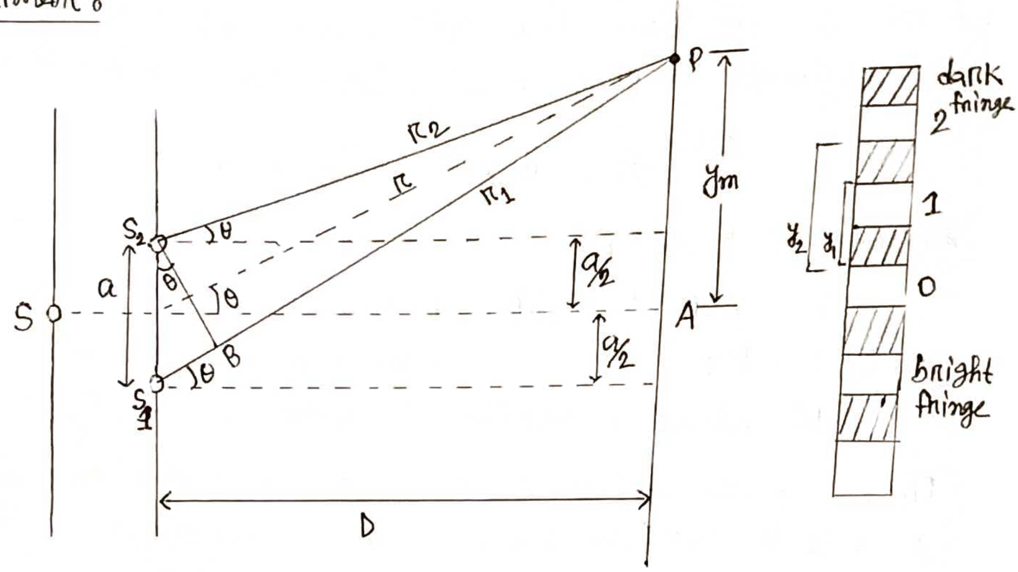
$$\delta = \frac{2\pi}{\lambda_0} n(x_1-x_2).$$

The quantity $n(x_1-x_2)$ is known as optical path difference and representing OPD or Δ.

$$\therefore \delta = K_0 \Delta$$

Where, K_0 is the wave vector in vaccum.

Young's experiment:



Let us consider a monochromatic source of light S emitting waves of wavelength λ and two narrow pin holes S_1 and S_2 which is shown in fig. and S_1 and S_2 are equidistance from the source S. Here, S_1 and S_2 act as a coherent sources separated by the distance a. Let a screen be placed at a distance D from the coherent source. The point A on the screen is equidistance from S_1 and S_2.

The light rays comes at the point A from the coherent source S_1 and S_2. Here, $S_1A = S_2A$, therefore, the path difference between the two wave which are comes from S_1 and S_2 is zero. Thus the point A has the maximum intensity is known as central maxima or the central fringe.

Consider a another point P at a distance y_m from the central fringe A. The waves reached at the point P from the coherent sources S_1 and S_2. So, the path difference between the rays along S_1P and S_2P is;

$$S_1B = S_1P - S_2P$$

$$\Rightarrow S_1B = r_1 - r_2 \quad \text{———} \quad (1)$$

$$\sin\theta = \frac{S_1B}{a}$$
$$\Rightarrow S_1B = a\sin\theta.$$

From the fig. we can write,

$$S_1B = a\sin\theta \quad \text{——— (2)}$$

From equ (1) and (2) we have,

$$a\sin\theta = r_1 - r_2 \quad \text{——— (3)}$$

Now,
$$r_1^2 = D^2 + \left(y_m + \frac{a}{2}\right)^2$$
$$r_2^2 = D^2 + \left(y_m - a/2\right)^2$$

Using these two equations, we can write

$$\therefore r_1^2 - r_2^2 = \left(y_m + a/2\right)^2 - \left(y_m - a/2\right)^2$$
$$\Rightarrow (r_1 - r_2)(r_1 + r_2) = \left(y_m + \cancel{a/2} + y_m - \cancel{a/2}\right)\left(\cancel{y_m} + a/2 - \cancel{y_m} + a/2\right)$$
$$= 2y_m \cdot 2 \cdot a/2$$
$$= 4 \cdot y_m \cdot a/2 \quad \text{——— (4)}$$

Since the distance to the screen is much greater than the distance between the two source S_1 and S_2, the sum of r_1 and r_2 may be approximately by,

$$r_1 + r_2 = 2r = 2D.$$

So, from the equation (4);

$$(r_1 - r_2) \cdot 2D = 2y_m a$$
$$\Rightarrow r_1 - r_2 = \frac{y_m a}{D} \quad \text{——— (5)}$$

From (3) and (5) we have,

$$a\sin\theta = \frac{y_m a}{D} \quad \text{——— (6)}$$

(*) <u>For constructive interference (bright fringes):</u>

i.e; $a\sin\theta = m\lambda$ where, $m = 1, 2, 3, \dots$, m is called the order number.

So, the equation becomes,

$$\frac{y_m a}{D} = m\lambda$$
$$\Rightarrow y_m = \frac{m\lambda D}{a} \quad \text{——— (7)}$$

This equation gives the position of the m^{th} bright fringe on the screen.

The distance for m^{th} bright fringe, $y_m = m\frac{\lambda D}{a}$

The distance for $(m+1)^{th}$ bright fringe, $y_{m+1} = (m+1)\frac{\lambda D}{a}$.

The difference in the position of two constructive maxima is;

$$\Delta y = y_{m+1} - y_m$$
$$\therefore \Delta y = \frac{D\lambda}{a} \quad \text{——— (8)}$$

(*) For destructive interference (dark fringes):

i.e; $a \sin\theta = (m+\frac{1}{2})\lambda$ where, $m = 1, 2, 3, \ldots$, m is called the order number.

So, $\frac{y_m a}{D} = (m+\frac{1}{2})\lambda$

$$\Rightarrow y_m = (m+1/2)\frac{\lambda D}{a} \quad \text{——— (9)}$$

This equation gives the position of the mth dark fringe on the screen.

The distance for mth dark fringe $y_m = (m+1/2)\frac{\lambda D}{a}$.

The distance for $(m+1)^{th}$ dark fringe, $y_{m+1} = (m+1/2+1)\frac{\lambda D}{a}$.

So, the difference in the position of the two destructive,

$$\Delta y = y_{m+1} - y_m$$

$$\Delta y = \frac{\lambda D}{a} \quad \text{——— (10)}$$

(*) Band width (β): The distance between any two consecutive bright or dark band's is called band width.

$$\Delta y = \frac{\lambda D}{a}$$

$$\therefore \beta = \frac{\lambda D}{a}.$$

Since, bright and dark fringe's are of same width, they are equi-spaced on either side of central maxima.

(*) Math: An Young's double slit experiment the separation of the slit is 1.9 mm and the fringe's spacing is 0.31 mm at a distance of 1m from the slit. Calculate the wavelength of light.

Here,

$D = 1m = 1000\,mm$

$a = 1.9\,mm$.

$\Delta y/\beta = 0.31\,mm$

$\lambda = ?$

We know that,

$$\Delta y/\beta = \frac{\lambda D}{a}$$

$$\Rightarrow \lambda = \frac{\beta . a}{D}$$

$$= \frac{0.31 \times 1.9}{1000}$$

$$= 5.89 \times 10^{-4}\,mm$$

$$= 5890\,A^{\circ}$$

Ans.

Math: Green light of wavelength 5100 A° from a narrow slit is incident on a double slit. If the overall separation of 10 fringes on a screen 200 cm away is 2m, find the slit separation.

Here, $\lambda = 5100 A^\circ$
$= 5100 \times 10^{-8}$ cm
$D = 200$ cm
$\beta = \frac{2}{10}$ cm
$= 1/5$ cm.
$a = ?$

We know that,
$$\beta = \frac{\lambda D}{a}$$
$$\Rightarrow a = \frac{\lambda D}{\beta}$$
$$= \frac{5100 \times 10^{-8} \times 200}{1/5}$$
$$= 0.051 \text{ cm}$$
Ans.

The coherent sources are 0.18 mm apart and the fringes are observed on a screen 80 cm away. It is found that with a certain monochromatic source of light, the fourth bright fringe is situated at a distance of 10.8 mm from the central fringe. Calculate the wavelength of light.

Here,
The distance of the mth fringe from the central fringe is, $y_m = 10.8$ mm
$= \frac{10.8}{10}$ cm
$= 1.08$ cm.

$D = 80$ cm
$a = 0.18$ mm
$= \frac{0.18}{10}$ cm
$= 0.018$ cm
$m = 4$
$\lambda = ?$

We know that,
$$y_m = \frac{m\lambda D}{a}$$
$$\Rightarrow \lambda = \frac{y_m \cdot a}{m \cdot D}$$
$$= \frac{1.08 \times 0.018}{4 \times 80}$$
$$= 6.075 \times 10^{-5} \text{ cm}$$
$$= \frac{6.075 \times 10^{-5}}{10^{-8}} A^\circ$$
$$= 6075 A^\circ$$
Ans.

Answer to the question no: 01 (a)

আলোক রশ্মি এক বিন্দু থেকে প্রতিফলন বা প্রতিসরণের পর আরেক বিন্দুতে যেতে সেই পথ অনুসরণ করে যেই পথে অন্যান্য পথের তুলনায় কম সময় লাগে।

Fermat's principle :

According to Fermat's-principle, "path followed by a ray of light moving from one point to another point after any number of reflections or refractions, would always be stationary and will be same for all the rays and will take the least time to travel the path.

As a straight line is the path of least distance between two points, therefore, the time taken by the ray of light along a straight line is minimum, as compared to some other path which may be curved. Fermat's principle shows that light rays travel along straight line paths in a homogeneous medium.

ঘন মাধ্যমে আলোর বেগ কম

- **Newton's rings:** Newton's ring's is interference of light waves reflected from the opposite surfaces of a thin film of variable thickness.

OR, Newton's rings is a phenomenon in which an interference pattern is created by the reflection of light between two surfaces: a spherical surface and an adjacent touching flat surface. It is named after Isaac Newton.

- **Formation of Newton's rings:**

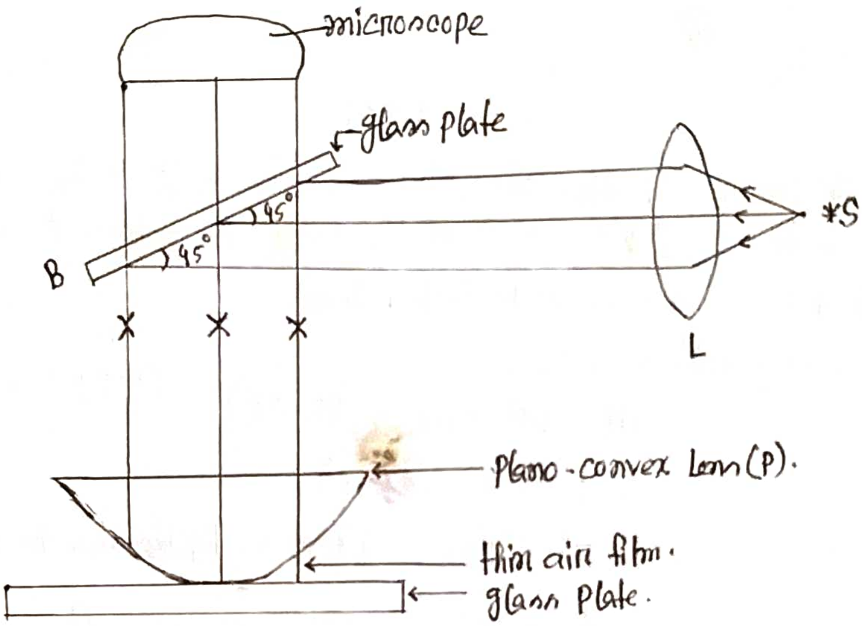
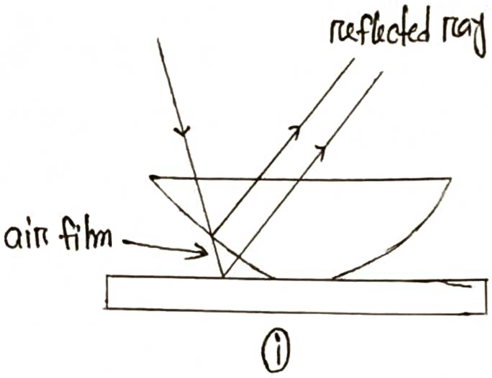


Fig. Experimental arrangement for producing Newton's rings.

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 upper surface of the glass plate. The thickness of air film is very small at the point of contact and gradually increases from the centre outwards. The fringes produced with monocromatic light are circular.

Let S be a source of monocromatic light at the focus of lens, L. A horizontal beam of light falls on the glass plate B at 45°. The glassplate reflects a part of incident light towards the air film enclosed by the lens P and the glassplate. Interference takes place and dark and bright circular fringes are produced and viewed with a microscope. This is due to interference between the light reflected from the lower surface of lens and the upper surface of the glassplate.

7. Interference due to reflected light:



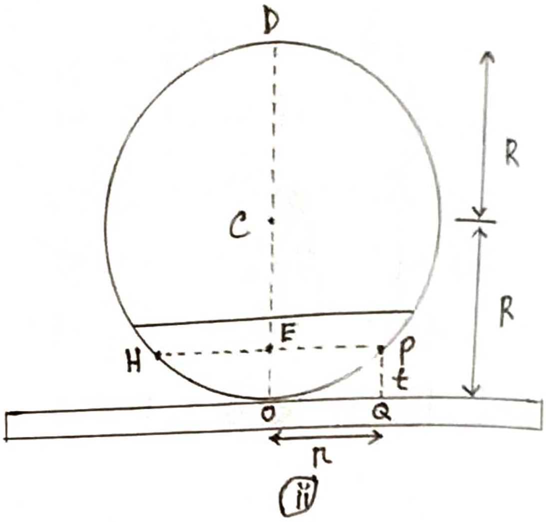


Fig. 01

Suppose, the radius of the curvature of lens, R and the air film of thickness 't' at a distance of OQ = r from the point of contact O as shown in Fig. 1(ii). Here, interference is due to reflected light.

From Fig. 1(ii) we have;

$$HE \times EP = OE \times (2R - OE) \quad [\because ED = 2R - OE]$$

$$\Rightarrow r^2 = t \times (2R - t)$$

$$\Rightarrow r^2 = 2Rt \quad [t \text{ is negligible w.r.to } 2R].$$

$$\therefore t = \frac{r^2}{2R} \qquad \text{--------- (1)}$$

(*) For bright rings;

$$2\mu t \cos\theta = (2n+1)\lambda/2 \;; \text{ Where, } n = 1, 2, 3, \ldots$$

For air; $\mu = 1$

As θ is very small; $\cos\theta = 1$

$$\Rightarrow 2t = (2n+1)\lambda/2 \qquad \text{--------- (2)}$$

$$\Rightarrow 2 \cdot \frac{r^2}{2R} = (2n+1)\lambda/2 \quad \left[\because t = \frac{r^2}{2R}\right]$$

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

$$\therefore r = \sqrt{(2n+1)\frac{\lambda R}{2}} \qquad \text{--------- (3)}$$

This is the radius for the bright rings.

(*) For dark Rings; $2\mu t \cos\theta = n\lambda$; Where, $n = 0, 1, 2, 3, \ldots$

$$\Rightarrow 2t = n\lambda \quad \left[\begin{matrix}\mu = 1 \\ \cos\theta = 1\end{matrix}\right] \qquad \text{--------- (4)}$$

$$\Rightarrow \frac{r^2}{R} = n\lambda \quad \left[\because t = \frac{r^2}{2R}\right]$$

$$\Rightarrow r = \sqrt{n\lambda R} \qquad \text{--------- (5)}$$

This is the radius for the dark rings.

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 of the Newton's rings is dark and alternately dark and bright rings are produced.

Wavelength of a monocromatic light source by Newton's rings method:

Suppose, the diameter of the nth dark ring is D_n and the diameter of the the $(n+m)$th dark ring D_{n+m}.

For nth dark ring,

$$r_n = \sqrt{n\lambda R}$$

$$\Rightarrow r_n^2 = n\lambda R$$

$$\Rightarrow (2r_n)^2 = 4n\lambda R \quad [D_n = 2r_n]$$

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

For $(n+m)$th dark ring,

$$r_{n+m} = \sqrt{(n+m)\lambda R}$$

$$\Rightarrow r_{n+m}^2 = (n+m)\lambda R$$

$$\Rightarrow \left(\frac{D_{n+m}}{2}\right)^2 = (n+m)\lambda R \quad \left[r_{n+m} = \frac{D_{n+m}}{2}\right]$$

$$\Rightarrow D_{n+m}^2 = 4(n+m)\lambda R \quad \text{--------- (2)}$$

Subtracting equ.(2) by equ(1), we get,

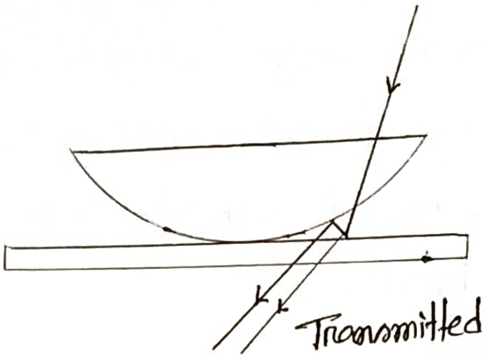
$$D_{n+m}^2 - D_n^2 = 4n\lambda R + 4m\lambda R - 4n\lambda R$$

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

$$\therefore \lambda = \frac{D_{n+m}^2 - D_n^2}{4mR} \quad \text{--------- (3)}$$

Here, wavelength λ can be calculated from this equation.

Newton's rings in transmitted light:



Newton's rings due to the transmitted light may be observed with the arrangement made as in Fig. The Condition for;

Maxima or bright rings is,

$$2\mu t\cos r = m\lambda$$

$$\Rightarrow 2t = m\lambda \quad \left[\begin{array}{l}\mu = 1 \text{ for air,} \\ r = 0 \text{ for normal observation}\end{array}\right]$$

$$\Rightarrow \frac{r^2}{R} = m\lambda \quad \left[t = \frac{r^2}{2R}\right]$$

$$\Rightarrow r^2 = m\lambda R$$

$$\therefore r = \sqrt{m\lambda R} \quad \text{——— (1)}$$

Minima or dark rings is,

$$2\mu t\cos r = (2m+1)\lambda/2$$

$$\Rightarrow 2t = (2m+1)\lambda/2$$

$$\Rightarrow \frac{r^2}{R} = (2m+1)\frac{\lambda}{2}$$

$$\Rightarrow r = \sqrt{(2m+1)\frac{\lambda R}{2}} \quad \text{——— (2)}$$

The radius of the bright rings given by; $r = \sqrt{m\lambda R}$

The radius of the dark rings given by; $r = \sqrt{(2m+1)\frac{\lambda R}{2}}$

Refractive index of a liquid : (for reflected light)

The liquid, whose refractive index is to be determined, is filled in the gap between the lens and plane glass plate. Now the liquid film substitutes the air film.

For ~~bright~~ dark rings,

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

$$\Rightarrow 2\mu t = n\lambda \quad [\text{as } \theta \text{ is very small}, \cos\theta = 1]$$

$$\Rightarrow 2\mu \cdot \frac{r^2}{2R} = n\lambda \quad \left[t = \frac{r^2}{2R}\right]$$

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

$$\Rightarrow D^2 = \frac{4n\lambda R}{\mu} \quad [r = D/2]$$

The diameter of the ~~m~~ n^{th} ring,

$$[D_n^2]_L = \frac{4n\lambda R}{\mu} \quad \text{------ (1)}$$

The diameter of the $(n+m)^{th}$ ring,

$$[D_{n+m}^2]_L = \frac{4(n+m)\lambda R}{\mu} \quad \text{------ (2)}$$

Subtracting equ. (1) from equ. (2);

$$[D_{n+m}^2]_L - [D_n^2]_L = \frac{4n\lambda R}{\mu} + \frac{4m\lambda R}{\mu} - \frac{4n\lambda R}{\mu}$$

$$\Rightarrow [D_{n+m}^2]_L - [D_n^2]_L = \frac{4m\lambda R}{\mu} \quad \text{------ (3)}$$

From equ. (3) wavelength λ can be calculated.

But we know that,

$$[D_{n+m}^2]_{air} - [D_n^2]_{air} = 4m\lambda R \quad \text{------ (4)}$$

Dividing equ. (4) by equ. (3) we get,

$$\mu = \frac{[D_{n+m}^2]_{air} - [D_n^2]_{air}}{[D_{n+m}^2]_L - [D_n^2]_L} \quad \text{------ (5)}$$

Why are Newton's rings circular?

⇨ The thickness of the air film at the point of contact is zero and gradually increases from the centre outwards. The locus of points where the air film has the same thickness then fall on a circle whose center is the point of contact. That mean's Newton's rings are circular because of the constant thickness of the air film on the locus of the circle from a fixed point.

Why center of Newton's ring is dark?

⇨ The thickness of the air film at the point of contact is zero compared to the wavelength of light. Hence path difference is zero. The wave reflected from the plane surface of the air film ~~surface~~ suffers a phase change of π while they reflected from the spherical surface of the air film does not suffer such change. Thus the two interfering waves at the centre are opposite in phase and produced dark ring which centre is dark.

We know; For bright rings; $r = \sqrt{(2n+1)\frac{\lambda R}{2}}$.

For dark rings; $r = \sqrt{n\lambda R}$.

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 center is dark and alternately dark and bright rings are produced.

Applications of Newton's rings:

1. We can determine the wavelength (λ) of monochromatic light.
2. Determine the refractive index of liquid by placing liquid instead of air between two surfaces.
3. We can determine the radius of curvature (R) of curved surface of the planoconvex lens.
4. We can measure the thickness (t) of thin film formed between lens and glass plate.

What will happens in Newton's rings if we use white light instead of monochromatic light?

⇨ Monochromatic light is light of a single wavelength, or at least very narrow bandwidth. This makes for very sharply defined interference bands, and the interference pattern is stable.

We can also use white light but it will be difficult to see fringe pattern with a white light. When ~~the~~ we use monochromatic light the centre of the Newton's ring is dark because at these points, destructive interference of light takes place. On the other hand, white light consists of ~~a~~ seven colours of wavelength ranging from 400-700 nm. Then every light of different wavelength will make a dark circle of different radius. This will result in overlapping of fringes and no clear fringe can be observed.

Newton's rings are observed in reflected light of $\lambda = 5.9 \times 10^{-5}$ cm. The diameter of the 10th dark ring is 0.5cm. Find the radius of curvature and the thickness of the air film.

Soln: Here,

$\lambda = 5.9 \times 10^{-5}$ cm

$= 5.9 \times 10^{-5}$ m

$n = 10$.

$D = 0.5$cm

$r = D/2 = 0.25$cm

$R = ?$

$t = ?$

We know that,

$$r^2 = n\lambda R$$

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

$$= \frac{(0.25)^2}{10 \times 5.9 \times 10^{-5}}$$

$$= 106 \text{ cm}$$

$$= 1.06 \text{ m}.$$

Again, $2t = n\lambda$

$$\Rightarrow t = \frac{n\lambda}{2} = \frac{10 \times 5.9 \times 10^{-5}}{2} = 2.95 \text{ lcm}.$$

In a Newton's ring experiment the diameter of 15th ring was found to be 0.59 cm and that of the 5th ring was 0.336 cm. If the radius of the plano-convex lens is ~~400~~ 100 cm, calculate the wavelength of light used.

$D_{n+m} = 0.59$

$D_n = 0.336$

$R = 100$ cm

We know,

$$\lambda = \frac{D_{n+m}^2 - D_n^2}{4mR} = \frac{D_{5+10}^2 - D_5^2}{4 \times 10 \times 100}$$

$$= \frac{(0.59^2 - 0.336^2)}{4 \times 10 \times 100} \quad \cancel{= 1.6129 \times 10^{-5} \text{cm}}$$

$$= 5.8801 \times 10^{-5} \text{cm}$$

$$= \frac{5.8801 \times 10^{-5}}{10^{-8}} A^{0}$$

$$= 5880.1\ A^{0}.$$

In a Newton's rings experiment, the diameter of 10th dark rings due to wavelength 6000 A° in air is 0.5 cm. Find the radius of curvature of the lens.

Soln:

$D = 0.5\ cm$

$n = 10$

$\lambda = 6000\ A^{0}$

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

We know that,

$$\lambda = \frac{D^2}{4nR}$$

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

$$= \frac{(0.5)^2}{4 \times 10 \times 6 \times 10^{-5}}$$

$$= 104.167\ cm$$

$$= 1.04\ m.$$

In a Newton's ring experiment the diameter of the 10th ring changes from 1.40 to 1.27 cm when a drop of liquid is introduced between the lens and the glass plate. Calculate the refractive index of the liquid.

Soln:

$D^2_{10_{air}} = 1.40\ cm$

$D^2_{10_{liq}} = 1.27\ cm$

We know that,

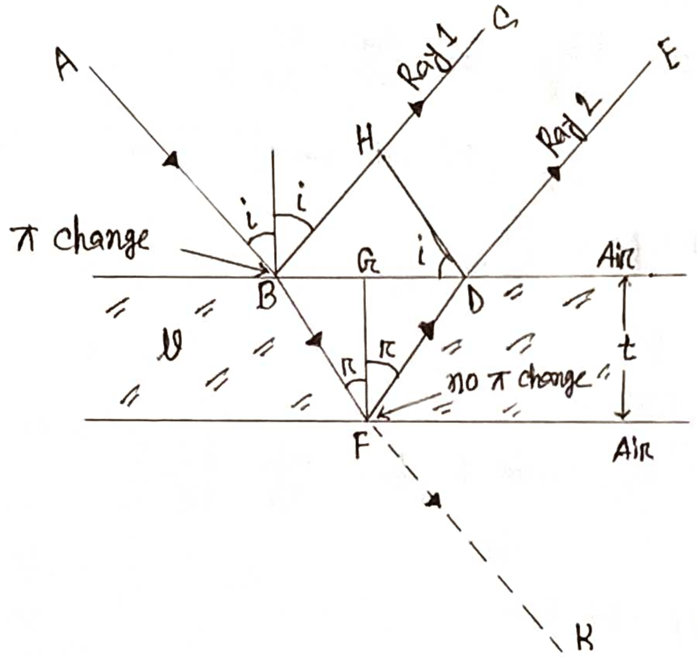
$$\mu = \frac{(D_m^2)_{air}}{(D_m^2)_{liq.}}$$

$$= \frac{(1.40)^2}{(1.27)^2}$$

$$= 1.215\ \text{Ans.}$$

Thin film: An optical medium is called a thin film when it's thickness is about the order of 1 wavelength of light in visible region. The thickness range 0.5 – 10 μm may be considered as a thin film.
For example, soap bubble with colourful light patterns is a thin film interference and thin film of oil floating on water. Because, it is the interference of light waves reflecting off the top surface of a film with the waves reflecting from the bottom surface.

Interference in thin film due to reflected light:



Let us consider a transparent film of uniform thickness 't' and the refractive index of the material be μ.

Let us consider plane waves from a monochromatic source falling on the thin film at an angle of incidence 'i'. Part of a ray such as AB is reflected along BC, and part of it is transmitted into the film along BF. The transmitted ray BF makes an angle 'r' with the normal to the surface at the point G. The ray BF is in turn partly reflected back into the film along FD while a major part refracts into the surrounding medium along FK Part of the reflected ray FD is transmitted at the upper surface and travels along DE. Since the film boundaries are parallel, the reflected rays BC and DE will be parallel to each other. The waves travelling along the paths BC and BFDE are derived from a single incident wave AB. Therefore they are coherent and can produce interference if they are made to overlap by a considering lens or the eye.

Optical path difference:

Optical path difference, Δ.

$$\Delta = \mu(BF+FD) - BH \quad \text{———— (1)}$$

In the ΔBFD;

$$\angle BFG = \angle GFD = \angle r$$

$$BF = FD.$$

$$BF = \frac{FG}{\cos r} \quad \left[\cos r = \frac{\text{ভূমি}}{\text{অতিভুজ}} = \frac{FG}{BF}\right]$$

$$= \frac{t}{\cos r} \quad [FG = \text{thickness}, t]$$

$$\therefore BF + FD = \frac{2t}{\cos r} \quad \text{———— (2)}$$

Also; $BG = GD$

$$BD = 2BG$$

$$\therefore BG = FG \tan r \quad \left[\tan r = \frac{\text{লম্ব}}{\text{ভূমি}} = \frac{BG}{FG}\right]$$

$$= t.\tan r$$

$$\therefore BD = 2t.\tan r$$

In the Δ BHD;

$$\angle HBD = (90-i)$$

$$\angle BHD = 90^\circ$$

$$\angle BDH = i.$$

$$\therefore BH = BD \sin i \quad \left[\sin i = \frac{\text{লম্ব}}{\text{অতিভুজ}} = \frac{BH}{BD}\right]$$

$$\Rightarrow BH = 2t.\tan r.\sin i \quad [BD = 2t.\tan r] \quad \text{———— (3)}$$

From Snell's law,

$$\sin i = \mu \sin r$$

$\therefore$ From eqn. (3) we can write,

$$BH = 2t.\tan r.\mu \sin r$$

$$= \frac{2\mu t.\sin^2 r}{\cos r} \quad \left[\tan r = \frac{\sin r}{\cos r}\right] \quad \text{———— (4)}$$

Using the equations (2) and (4) into equ. (1) we get,

$$\Delta = \mu\left[\frac{2t}{\cos r}\right] - \left[\frac{2\mu t \sin^2 r}{\cos r}\right]$$

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

$$= \frac{2\mu t}{\cos r} \cdot \cos^2 r$$

$$= 2\mu t \cdot \cos r$$

Correction on account of phase change at reflection:

When a ray is reflected at the boundary of a rarer to denser medium, a path change of $\lambda/2$ occurs for the ray BC. There is no path difference due to transmission at D. Including the change in path difference due to reflection,

the true path difference, $\Delta_t = 2\mu t \cos r - \lambda/2$.

Conditions for maxima (brightness):

Maxima occur when the optical path difference $\Delta = m\lambda$ where $m = 1, 2, 3, \ldots$

$$\therefore 2\mu t \cos r - \lambda/2 = m\lambda$$

$$\Rightarrow 2\mu t \cos r = m\lambda + \lambda/2$$

$$\therefore 2\mu t \cos r = (2m+1)\lambda/2.$$

Condition for minima (darkness):

Minima occur when the optical path difference is $\Delta = (2m+1)\lambda/2$ where, $m = 0, 1, 2, 3, \ldots$

$$2\mu t \cos r - \lambda/2 = (2m+1)\lambda/2$$

$$\Rightarrow 2\mu t \cos r = (2m+1)\lambda/2 + \lambda/2$$

$$= (m+1)\lambda$$

Therefore, $(m+1)\lambda$ can be replaced by $m\lambda$ for simplicity in the expression.

Thus, $2\mu t \cos r = m\lambda$.

Interferometer: An interferometer is an instrument in which the phenomenon of interference is used to make precise measurements of wavelengths or distances.
Example: Twyman-Green interferometer, Mach-Zehnder interferometer.

Construction of Michelson's interferometer:

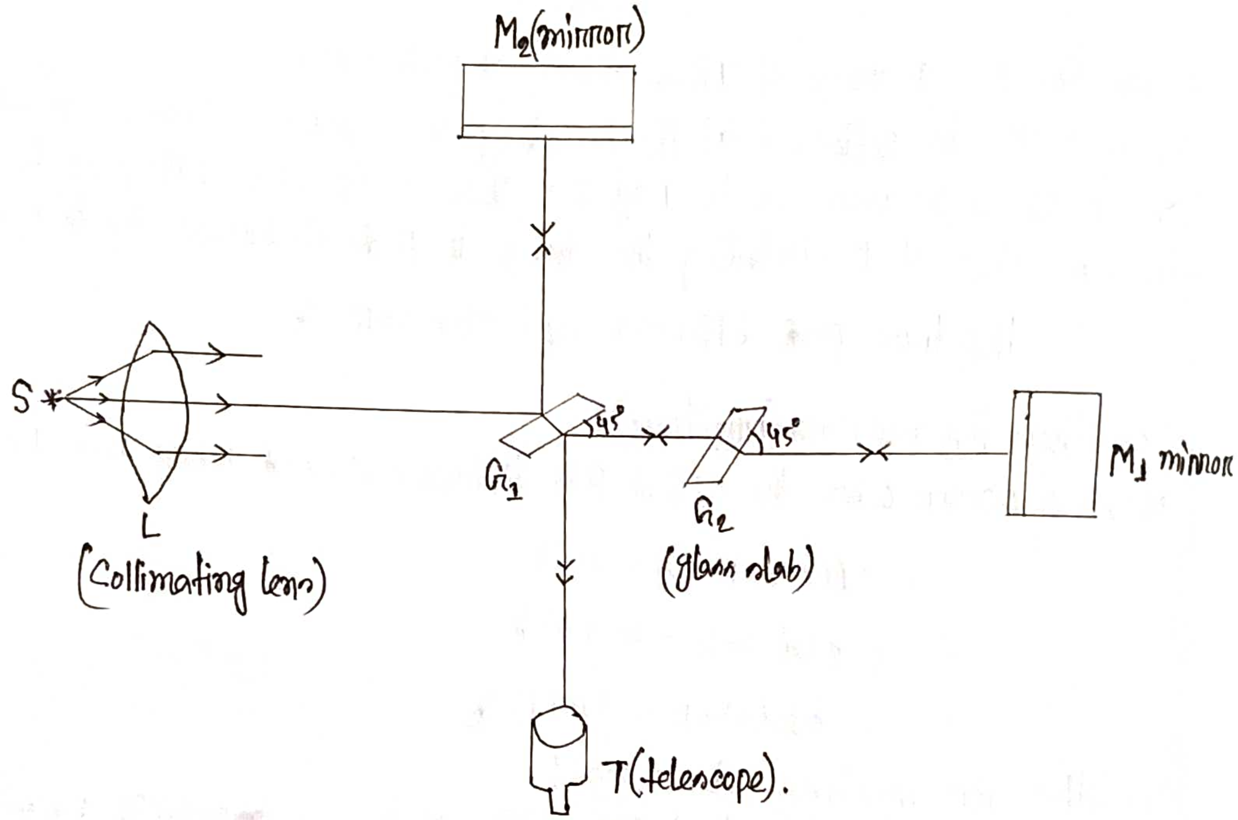


Fig. Michelson interferometer.

This instrument is constructed by two highly polished plane mirrors and two glass plate G_1 and G_2. These glass plates are of same thickness and are kept in the same angle i.e; they are always in a parallel direction. The glass plate, placed at first in the path of the light beam coming from the source, is kept half silvered to make a reflected and transmitted beam of the same intensity.

Both the plates are placed at 45° to both the mirrors and these mirror's are mutually perpendicular to each other. There are provided with screws on the backside of these mirror's so that they can be adjusted to be exactly perpendicular. The mirror placed on the top and can be move exactly parallel to itself with a micrometer screw. The screw is filled with a graduated drum which can read a displacement of approximately 10^{-5} cm. The interference bands can be observed with the help of a telescope placed at the bottom in the image.

Applications of the Michelson interferometer:

Michelson interferometer is used to determine;

1. the wavelength of a monochromatic source.
2. The difference between the two neighbouring wavelengths or resolution of the spectral lines.
3. refractive index and thickness of various thin transparent materials.
4. For measurement of the standard metre in terms of the wavelength of light.

Types of fringes:

(i) Circular fringes.
(ii) Localized fringes.
(iii) White light fringes.

Circular fringes: Circular fringes are produced with monochromatic light when the mirrors M_1 and M_2 are exactly perpendicular to each other.

Localized fringes: When the two mirrors are tilted, they are not exactly perpendicular to each other. In this case, the air path between them is wedge-shaped and the fringes appear to be straight.

White light fringes: Instead of a monochromatic source, if a white light source is used, a few colour fringes with a central dark fringe can be observed.

Different types of interferometer:

1. The Michelson interferometer.
2. The Febry-Perot interferometer.
3. Polarization interferometer.
4. Grading interferometer.
5. Schematic interferometer.
6. Fresnel interferometer.

☐ **Steady interference Pattern:** An interference pattern in which the intensity of light at any given point remains constant, is called steady or Constant interference Pattern.

☐ **Interference pattern:** The change in intensity of light due to interference is obtained on screen, then alternative bright and dark bands or rings are obtained. This Pattern is known as the interference Pattern.

☐ **Condition for obtaining clear and broad interference bands:**

1. The screen should be Placed as far as possible from the source.
2. The wavelength of light used must be larger.
3. The two coherent sources must be close as possible.

Coherence and coherence source:

Coherence: The two wave sources are perfectly coherent if they have a constant phase difference and the same frequency and the same waveform is called coherence.

Coherence source: The source of light wave are said to be coherence if they emit waves having the same wavelength (or frequency), the same amplitude and a constant phase relation between them.

Types of interference and their conditions:

Constructive interference: When two light waves of same frequency meet at a point in the same phase with each other, then the interference is called constructive interference.

At this point intensity is maximum, this point is called bright point.

Condition for constructive interference:

Assuming the initial phase difference is zero, then necessary conditions for constructive interference.

1. Phase difference $\delta = 2\pi n$, where, $n = 1, 2, 3, \ldots$
2. Path difference $x = n\lambda$, where, $n = 1, 2, 3, \ldots$

Thus the intensity is maximum when the phase difference is an even number multiple of π.

If the intensity is maximum then the constructive interference occur and the point will be bright.

Destructive interference: When two light waves of same frequency meet at a point in the opposite phase with each other, then the interference is called destructive interference.

Condition for destructive interference:

1. Phase difference $\delta = (2n+1)\pi$, where $n = 1, 2, 3, \ldots$
2. Path difference $x = (2n+1)\lambda/2$; where $n = 1, 2, 3, \ldots$

If the intensity is minimum then the destructive interference occur and the point will be dark.

Interference due to transmitted light:

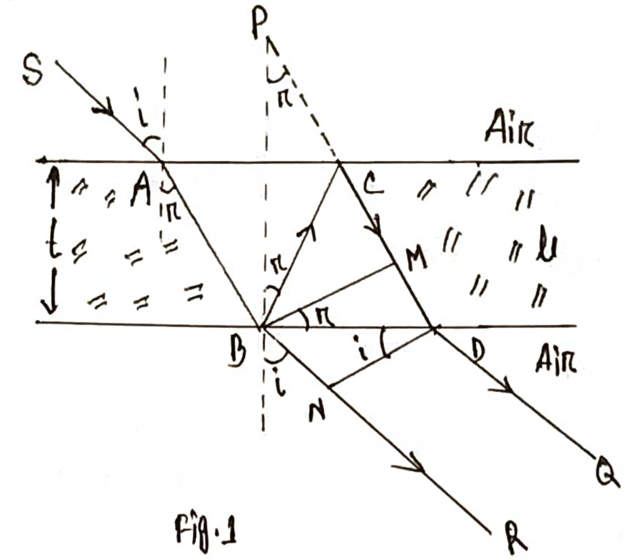


Fig.1

Consider a thin transparent film of thickness t and refractive index μ. A ray SA after refraction goes along AB. At B it is partly reflected along BC and partly reflected along BR. The ray BC, after reflection at C, finally emerges along DQ. Here at B and C reflection takes place at the rarer medium. Therefore, no phase change occurs. Draw BM normal to CD and DN normal to BR. The optical path difference between DQ and BR is given by,

$$\Delta = \mu(BC + CD) - BN$$

Also, $\mu = \dfrac{\sin i}{\sin r} = \dfrac{BN}{MD}$ or, $BN = \mu \cdot MD$

$\angle BPC = r$ and, $CP = BC = CD$

$BC + CD = PD$

$$\therefore \Delta = \mu(PD) - \mu(MD)$$
$$= \mu(PD - MD) = \mu \cdot PM$$

In $\triangle BPM$, $\cos r = \dfrac{PM}{BP}$ or, $PM = BP \cdot \cos r$

$BP = 2t$

$PM = 2t \cdot \cos r$

$$\Delta = \mu \cdot PM = 2\mu t \cos r.$$

Bright fringes: When the optical path difference $\Delta = m\lambda$, bright fringes occurs.

$$2\mu t\cos r = m\lambda \quad \text{where; } m = 0, 1, 2, 3, \ldots$$

Dark fringes: When the optical path difference $\Delta = (2m+1)\lambda/2$ dark fringe occurs,

$$\therefore 2\mu t\cos r = \left(\frac{2m+1}{2}\right)\lambda \quad \text{where; } m = 0, 1, 2, 3, \ldots$$

In case of transmitted light, the fringes are less distinct because the difference in amplitudes of BR and DQ is very large.

However, when the angle of incident is nearly 45° the fringes are more distinct.