(a) **Reflected System:** For the thin film in air the ray BG suffers reflection at air-medium (rare to denser) boundary, it undergoes a phase change of π and a path change of $\lambda/2$, while the ray DF does not, as it is reflected at D, the medium-air (denser to rare) boundary. Hence the net path difference between the two rays BG and DF

$$\Delta = 2nd\cos\theta' - \frac{\lambda}{2}$$

(i) When the film is quite *thin* as compared to the wavelength of light, $2nd\cos\theta'$ can be neglected and the net path difference is $\lambda/2$. *The two rays will produce destructive interference and the film will appear **dark**.*

(ii) When the thickness is increased so that $2nd\cos\theta'$ cannot be neglected, the film will appear ***bright*** if the path difference is

$$2nd\cos\theta' - \frac{\lambda}{2} = m\lambda \qquad \text{where m= 0, 1, 2, ...}$$

or, $$2nd\cos\theta' = \left(m + \tfrac{1}{2}\right)\lambda$$ **condition for constructive interference**

(iii) The film will appear dark if the path difference is

$$2nd\cos\theta' - \frac{\lambda}{2} = \left(m + \tfrac{1}{2}\right)\lambda \qquad \text{where m= 0, 1, 2, ...}$$

or, $$2nd\cos\theta' = (m+1)\lambda$$

as m or m+1 both are just integer, therefore m+1 can be replaced by m, so

$$2nd\cos\theta' = m\lambda$$ **condition for destructive interference**

(b) **Transmitted System**: The path difference between the transmitted rays DI and EH can be obtained similarly and it is equal to

$$\Delta = n(DF + FE) - DI$$

$$\Delta = 2nd\cos\theta'$$

In this case, there is no phase change due to reflection at D or E because the light is coming from denser to rare medium. Hence, the net path difference between the two rays DI and FE is

$$\Delta = 2nd\cos\theta'$$

(i) When the film is quite *thin* as compared to the wavelength of light, $2nd\cos\theta'$ can be neglected and the net path difference is *zero*. *The two rays will produce constructive interference and the film will appear **bright**.*

(ii) When the thickness is increased so that $2nd\cos\theta'$ cannot be neglected, the film will appear ***bright*** if the path difference is

$$2nd\cos\theta' = m\lambda$$ **condition for constructive interference**

(iii) The film will appear dark if the path difference is

$$2nd\cos\theta' = \left(m + \tfrac{1}{2}\right)\lambda$$ **condition for destructive interference**

Therefore the condition for maxima and minima in the reflected light are just the reverse of those in the transmitted light. Hence the film, which appears bright in reflected light, would appear dark in transmitted light, and *vice-versa*. Hence we can say that *the reflected and transmitted systems are complementary to each other*.

1.3.1 Production of colours in thin film with white light: When white light incident upon any thin film like soap bubble or oil film on water, a beautiful system of different colours are seen through eye. This beautiful natural effect is produced by interference occurring between two waves – one reflected from the surface of the bubble or oil film and other from bubble-water/oil-water boundary. When the path difference Δ is such that it gives constructive interference for light of any one wavelength, the colour corresponding to the wavelength is seen in the film. The path difference Δ varies with the thickness d of the film and the angle of viewing (which is equal to angle of incidence θ), thus both of which affect the colour produced at any one part of the film. That's the reason why in soap bubble or oil film, different part (having different thickness d) of it shows a very different colour pattern when the viewing angle is fixed. Simultaneously, if we move the eye for changing the viewing angle again the colour of the same part (for which thickness d is constant) of film change correspondingly.

1.4 NEWTON'S RING

(a) **Principle:** If we place a plano-convex lens on a plane glass plate of the lens (ABC) and the plane glass plate (DBE) – see Figure 6. The thickness of the air film is zero at the point of contact B and increases as one move away from the point of contact. If we allow monochromatic light to fall on the surface of the lens, then the light reflected from the surface DBE. Both reflected waves have arisen from the same incoming beam of light (by division of amplitude), therefore they are coherent and when brought together by travelling microscope they can interfere. Due to interference, a series of bright and dark rings is seen through beam splitter G, when a travelling microscope is focused on the air film. The rings are ***fringes of equal thickness***, *localized* in the air film and as their radii increases, the separation between two rings decreases.

(b) **Arrangement:** Suppose S is a broad source of monochromatic light placed at the focus of lens L (Figure 6). The lights emitted from S are made parallel by the lens L. These horizontal parallel rays fall on a glass plate G at 45°, and are partially reflected from it. These reflected rays falls normally on the plano-convex lens of large focal length placed on the glass plate. Interference occurs between the rays reflected from the upper and lower surface of the film trapped between plano-convex lens and glass plate. The interference rings are viewed through a travelling microscope focused on the air film where the rings are formed.

(c) **Theory:** If d is the thickness of the air film at P then, for normal incidence (Figure 7), the path difference between the rays at P is $2d$. When the beam in the air film is reflected at the upper surface DBE of the glass plate, i.e. at a denser medium a π phase change ($\lambda/2$ path change will occurs. Thus, a bright fringe is formed at P if,

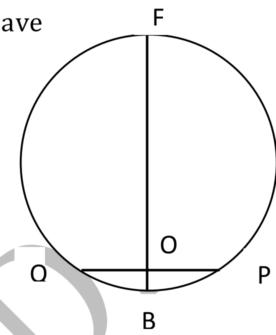
$$2d = \left(m + \tfrac{1}{2}\right)\lambda \qquad \textbf{condition for constructive interference}$$

and a dark fringe is formed at P if

$$2d = m\lambda \qquad \textbf{condition for destructive interference}$$

Since the convex side of the lens is spherical surface, the thickness of the air film will be constant over a circle (whose centre will be at B) and we obtain concentric dark and bright rings. These rings are known as **Newton's rings**.

(d) **Radius of rings:** the radius of various rings can be easily calculated. If R is the radius of curvature of the lower surface ABC of the lens. Let r_m be the radius OP=OQ of the ring at P, where the thickness PP' of the film is d. If BO is extended to meet the circle at F then BOF is a diameter. By the theorem of intersecting chords, we have



$$QO.OP = FO.OB$$

$$r_m . r_m = (2R - d). d$$

$$r_m^2 = 2Rd - d^2$$

$$r_m^2 \cong 2Rd$$

because d^2 is very small compared with $2Rd$, since R is large.
Thus, if a dark ring is formed at P then, from the condition of destructive interference, we can write

$$r_m^2 = mR\lambda \qquad \textbf{Dark rings}$$

This implies that the radii of the rings vary as square root of natural numbers. Thus, the rings will become close to each other as the radius increases. Thus at B, where $m = 0$ gives the central dark spot, $m = 1$ gives the first dark ring and so on. Between two dark rings there will be a bright ring. If a bright ring is formed at P, then from the condition for constructive interference, the radius is given by

$$r_m^2 = \left(m + \tfrac{1}{2}\right)R\lambda \qquad \textbf{Bright rings}$$

This implies that the radii of the rings vary as square root of half of natural numbers. When $m = 0$, it gives the first bright ring; for $m = 1$ gives the second and so on.

(e) **Determination of wavelength of light:** It is better to measure the diameter of rings rather than radii because of the uncertainty in locating the centre of the rings system. Hence, if D_m and D_{m+p} are the diameter of the m^{th} and $(m+p)^{th}$ dark rings, respectively. Then, we have

$$D_m^2 = 4mR\lambda$$

and, $$D_{m+p}^2 = 4(m+p)R\lambda$$

on subtraction, $D_{m+p}^2 - D_m^2 = 4pR\lambda$

and wavelength, $$\lambda = \frac{D_{m+p}^2 - D_m^2}{4pR}$$

However, the same result can be obtained by using diameter of bright rings. A traveling microscope is used to measure diameters and radius of curvature can be found by Boy's method.

1.5 MICHELSON INTERFEROMETER

(a) Arrangement: A schematic diagram of Michelson interferometer is shown in Figure 9. Light from the broad source strikes on a glass plate C, known as beam splitter, the right side of which has a thin coating of silver. Part of the light is reflected from the silvered surface at P to the mirror M_2 and back through C to the observer's eye through microscope.

The remainder of the light passes through the silvered surface and the compensator plate D and is reflected from Mirror M_1. It then return through D and is reflected from the silvered surface of C to the observer. The compensator plate D is cut from the same piece of glass plate C, so that the thickness will not differ from that of C. Both the plates should incline at an angle of 45°. Its purpose to ensure that rays 1 and 2 pass through the same thickness of glass and as ray 2 traverse the plate C thrice thus, ray 1 should also traverse the plate C once and plate D twice to compensate the path.

The whole apparatus is mounted on a heavy rigid frame and a fine, very accurate screw thread is used to move the mirror M_2. The source is placed to the left and the observer is directly in front of the handle that turns the screw.

(b) Theory: When there is partial silver coating on plate C, the phase changes due to reflection from it (from air to glass or glass to air) are also similar, each being equal to π. Thus, both the waves will suffer similar phase change on reflection because both the rays reflected twice (once by any mirror and once by plate C). Both the waves will be in their original phase because of twice reflection.

The path difference between the two rays is, therefore, only due to the different paths traversed in air before reaching the eye of observer through microscope. The two waves shall interfere constructively or destructively according to its path difference Δ, *i.e.* when

$\Delta = m\lambda$ **condition for constructive interference**

$\Delta = \left(m + \frac{1}{2}\right)\lambda$ **condition for destructive interference**

The path difference Δ can be obtained by moving the mirror M_2.

(c) Principle: When M_2 and M_1 are precisely perpendicular, the enclosed air film is planner and of thickness d, the fringe pattern consists of a series of concentric circular ***fringes of equal inclination***. These circular fringes are known as **Haidinger fringes**. When M_2 exactly overlap over M_1', the thickness d and thus path difference Δ will be zero, therefore, the central spot will be bright. As the thickness d will change by moving mirror M_2, this spot will alternatively changes from bright to dark and then dark to bright and so on so forth (see Figure 10a).

Furthermore, when M_2 and M_1' are close together and inclined with respect to each other, the contained air film is a thin wedge and the localized fringes would results. It will be perfectly straight fringe when M_2 intersect M_1' in the middle (Figure 10b). If M_2 does not intersect M_1' and are in other position. Then, the patterns are curved and are always convex towards the thin edge of the wedge (Figure 10c & d).

(d) Measurement of wavelength: Suppose that the light source is monochromatic with wavelength λ. The mirror M_2 and M_1' are intersecting in such a way that vertical straight fringes are present in the field of view of microscope. Now if mirror M_2 is moved by a distance $\lambda/2$, the effective film thickness and hence path difference will change by λ and each of the fringes will move by a distance equal to the spacing of the two consecutive similar fringes, i.e. position of any bright/dark fringe will occupied by nearest next similar bright/dark fringe. Thus, if the mirror M_2 is moved by a distance x and if p numbers of fringes cross the crosswire of eye-piece of microscope, then

$$x = p\frac{\lambda}{2}$$

or,

$$\lambda = \frac{2x}{p}$$

If p is as large as several thousand, the distance x is sufficiently great so that it can be measured with good precision and hence a precise value of the wavelength λ can be obtained.

1.6 FABRY – PEROT INTERFEROMETER

(a) **Construction:** The interferometer consists of two plane glass or quartz plates which are coated on one side with a partially reflecting metallic film of aluminum or silver of about 80% reflectivity. These two plates are kept in such a way that they enclose a plane parallel slab of air between their coated surfaces which are parallel to high degree of accuracy and the surface should be flat up to a very small fraction of wavelength ($\sim\lambda/100$). The two uncoated surfaces of each plate are made to have a slight angle (~1' to 10'') between them in order to avoid the unwanted fringes formed due to multiple reflections in the plate itself.

One of the two plates is kept fixed while the other is mounted on a carriage which can be moved to vary the separation of the two plates. In this configuration the instrument is called a *Fabry-Perot interferometer* (FPI). Sometimes both the plates are kept at a fixed separation (1-200 mm) with the help of *spacers*. The system with fixed spacing is known as *Fabry-Perot etalon* (FPE) or simply ***etalon***. Both of them employ the principle of multiple beam interference produces much sharper fringes then Michelson interferometer.

(b) Principle: If a plane wave falls on a plane parallel film lying between the inner silvered surfaces and a large number of beams of successively decreasing amplitude will emerge on both sides of the plate. These beams (on either side) interfere to produce an interference pattern at infinity.

If after multiple reflection the emerging beams on either side are brought to focus at any point by the lens. Then the fringes would be circular in the focal plane of lens. The circular fringe will be loci of points corresponds to constant θ', known as ***fringes of equal inclination***.

The condition for interference by transmitted light beam in a plane parallel air film is given by