Optics

(Lec-5)

Abdul Barik
Lecturer
Department of Science & Humanities
Military Institute of Science and Technology (MIST)

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OUTLINES

- Interference in thin films
- Newton's ring
- Fresnel biprism
- Interferometry

Interference in Thin Films

Thin-film interference is the phenomenon that is a result of light wave being reflected off two surfaces that are at a distance comparable to its wavelength. When light waves that reflect off the top and bottom surfaces interfere with one another we see different colored patterns. During this, the light reaches the boundary between two media and part of it gets reflected and some part gets transmitted.

Interference due to reflected light from a plane parallel thin Films

Fig. 27.14 shows a thin transparent film of uniform thickness t and refractive index μ, bounded by two parallel surfaces MN and PQ. A ray AB of monochromatic light is incident on the upper (Fig. 27.14) surface at the point B. A part of it is reflected along BC and a part is refracted along BD. The refracted beam is again partly reflected at the point D back into the medium along DE and the rest refracts into the surrounding medium along DL. The ray along DE suffers both reflection and refraction at point E on the upper surface MN. The refracted ray goes along EF. Similar reflections and refractions will produce a number of parallel rays in the surrounding medium both above and below the thin film.

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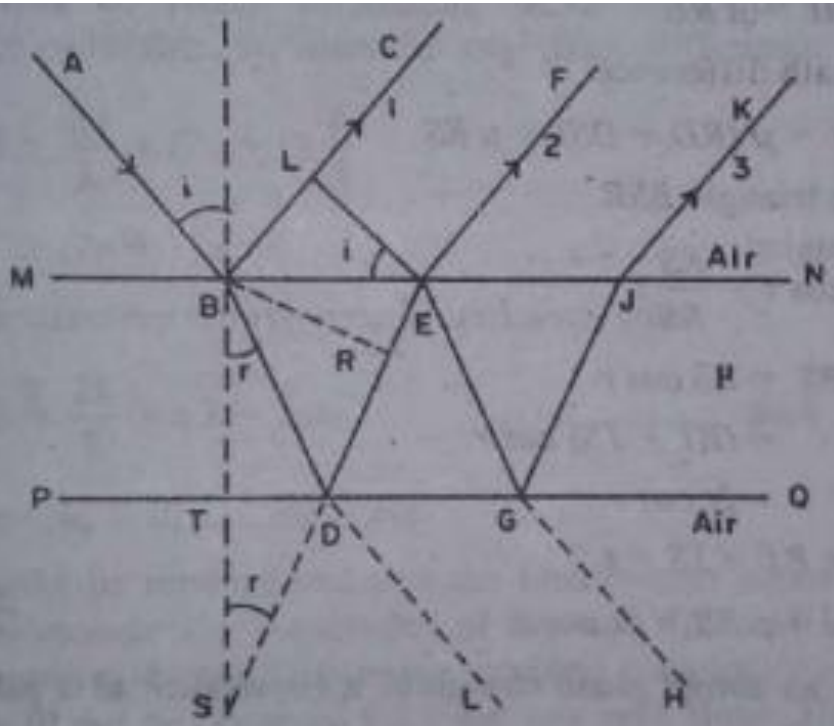


Fig. 27.14

Consider the rays *BC* and *BDEF*. They are both derived from the single beam *AB* and hence satisfy the condition for producing interference (coherent source). Whether they (when collected by a lens or an eye) will interfere constructively or destructively *i.e.*, produce brightness or darkness, will depend on their path difference. To determine this path difference, draw *EL* normal to *BC* and *BR* normal to *DE*. Also produce *ED* to meet *BT* produced at S. Let the angle of incidence and refraction be *i* and *r* respectively.

It is obvious that from the points L and E onwards, the two waves and rays travel equal distances. Since the path $(BD + DE)$ within the film is equivalent to a path $\mu (BD + DE)$ in air, the difference in optical path of the two rays is

$$x = \mu (BD + DE) - BL$$

$$= \mu (BD + DR + RE) - BL$$

Also $BD = DE$.

and $$\mu = \frac{\sin i}{\sin r} = \frac{BL/BE}{RE/BE} = \frac{BL}{RE}$$

or, $BL = \mu RE$

The path difference

$$x = \mu (RD + DS) = \mu RS$$

In the triangle BSR

$$\cos r = \frac{RS}{BS};$$

or, $RS = BS \cos r$

$$= (BT + TS) \cos r$$

$$= 2t \cos r$$

where $BT = TS = t$

$$\therefore \quad x = \mu SR = 2t \cos r \qquad (27.37)$$

Since an abrupt phase change of π (equivalent to a path diffence of $\frac{\lambda}{2}$) is introduced whenever a ray is reflected from a surface backed by a denser medium (Art. 27.17), eqn. 27.37 does not represent the total path difference between BC and BDEF. Taking into account this additional path difference of $\frac{\lambda}{2}$ for reflection suffered at the point D the total path difference will be

$$x = 2\mu t \cos r \pm \frac{\lambda}{2}$$

Therefore, for constructive interference or brightness

$$2\mu t \cos r \pm \frac{\lambda}{2} = n\lambda$$

or, $2\mu \cos r = (2n \pm 1)\frac{\lambda}{2}$ ..... bright

and for destructive interference or darkness

$$2\mu t \cos r \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$$

or, $2\mu t \cos r = n\lambda$ ..... dark

In terms of phase difference, there will be constructive interference or brightness, when the total phase difference

$$\delta = \frac{2\pi}{\lambda} \times (2n \pm 1)\frac{\lambda}{2}$$

$= (2n \pm 1)\pi$ ..... bright

and destructive interference or darkness, when

$$\delta = \frac{2\pi}{\lambda} \times n\lambda = 2\pi n$$ ..... dark

$n = 0, 1, 2, 3, \ldots\ldots$ etc.

Theory of Newton's rings:

Newton's rings are a noteworthy illustration of the interference of light waves reflected from the opposite surfaces of a thin film variable thickness.

Let us consider a ray of monochromatic light AB from an extended source to be incident at the point B on the upper surface of the film (Fig. 1). One portion of the ray is reflected from point B on the glass air boundary and goes upwards along BC. The other part refracts into the air film along BD. At point D, a part of light is again reflected along DEF. The two reflected waves BC and BDEF are derived from the same source and are coherent.

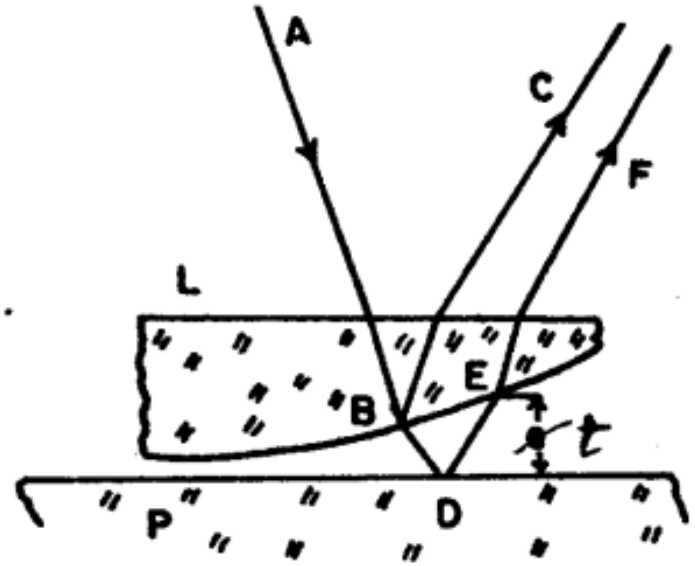


Fig. 1

They will produce constructive or destructive interference depending on their path difference. Let t be the thickness of the film at the point E. Then the optical path difference between the two rays is given by 2μt cos (θ + r) where θ is the angle which the tangent to the convex surface at the point E makes with the horizontal, r is the angle of refraction at the point B and μ is the refractive index of the film with respect to air.

In Fig.1 the point B is backed by a rarer medium (air) while the point D is backed by a denser medium (glass). Thus, there will be an additional path difference of $\frac{\lambda}{2}$, the rays BC and BDEF corresponding to this phase difference of π. Then the total optical path difference between the two rays is

$$2\mu t \cos\ (\theta + r) \pm \frac{\lambda}{2}$$

The two rays will interfere constructively when

$$2\mu t \cos\ (\theta + r) \pm \frac{\lambda}{2} = n\lambda$$

$$2\mu t \cos\ (\theta + r) = (2n - 1)\frac{\lambda}{2} \quad \ldots\ldots\ldots\ldots (1)$$

The minus sign has been chosen purposely since n cannot have a value of zero for bright fringes seen in reflected light. The rays will interfere destructively when

$$2\mu t \cos\ (\theta + r) \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$$

Or, $$2\mu t \cos\ (\theta + r) = n\lambda \quad \ldots\ldots\ldots\ldots (2)$$

Where, λ is the wavelength of light in air.

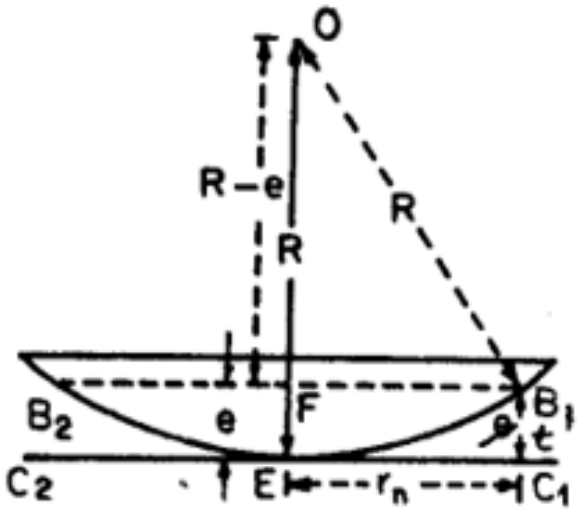


Fig. 2

In practice, a thin lens of extremely small curvature is used in order to keep the film enclosed between the lens and the plane glass plate extremely thin. As a consequence, the angle θ becomes negligibly small as compared to r. Furthermore, the experimental arrangement is so designed that the light is incident almost normally on the film and is viewed from nearly normal directions by reflected light so that cosr = 1. Accordingly eqns. (1) and (2) reduce to

$$2\mu t = (2n - 1)\frac{\lambda}{2} \quad \text{..... Bright}$$

And

$$2\mu t = n\lambda \quad \text{..... Dark}$$

Let R be the radius of curvature of the convex surface which rests on the plane glass surface (Fig.2). From the right-angled triangle OFB_1, we get the relation

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

or

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

where r_n is the radius of the circular ring. As outlined above, the condition of the experiment makes t extremely small. So, to a sufficient degree of accuracy, t^2 may be neglected compared to 2Rt. Then, $t = r_n^2 / 2R$

Substituting the value of t in the expressions for bright and dark fringes, we have

$$r_n^2 = (2n - 1)\frac{\lambda R}{\mu} \quad \text{..... Bright}$$

$$r_n^2 = \frac{n\lambda R}{2\mu} \quad \text{..... Dark}$$

The corresponding expressions for the squares of the diameter are

$$D_n^2 = 2(2n-1)\frac{\lambda R}{\mu} \quad \ldots\ldots\ldots \text{ bright}$$

And, $$D_n^2 = \frac{4n\lambda R}{\mu} \quad \ldots\ldots\ldots \text{ dark}$$

In the laboratory, the diameters of the Newton's rings can be measured with a travelling microscope. Usually, a little away from the center, a bright (or dark) ring is chosen which is clearly visible and its diameter measured. Let it be the n^{th} order ring. For an air film μ =1. Then we have

$$D_n^2 = 2(2n-1)\lambda R \ldots\ldots (3) \ldots. \text{ bright}$$

And, $$D_n^2 = 4n\lambda R \quad \ldots\ldots\ldots(4)\ldots. \text{ dark}$$

The wavelength of the monochromatic light employed to illuminate the film can be computed from either of the above equations, provided R is known.

However, in actual practice, another ring, p ring from this ring onwards is selected. The diameter of this $(n+p)^{th}$ ring is also measured. Then we have

$$D_{n+p}^2 = 2(2n+2p-1)\lambda R \quad \ldots\ldots\ldots \text{ bright}$$

And, $$D_{n+p}^2 = 4(n+p)\lambda R \quad \ldots\ldots\ldots\ldots \text{ dark}$$

Subtracting D_n^2 from D_{n+p}^2, we have

$$D_{n+p}^2 - D_n^2 = 4p\lambda R \quad \ldots\ldots\ldots\ldots (5)$$

for either bright or dark ring.

$$R = \frac{Dn+p2 - Dn2}{4p\lambda} \ldots\ldots\ldots\ldots (6)$$

Fresnel biprism

A bi-prism is essentially two prisms, each of very small refracting angle placed base to base. In reality, the bi-prism is constructed from a single plate of glass by suitably grinding and polishing it. The obtuse angle of the prism is only slightly less than 180^0 and the other angles are equal. In a very thin bi-prism, the obtuse angle may be $179^0 20'$, the other two angles being 20' each.

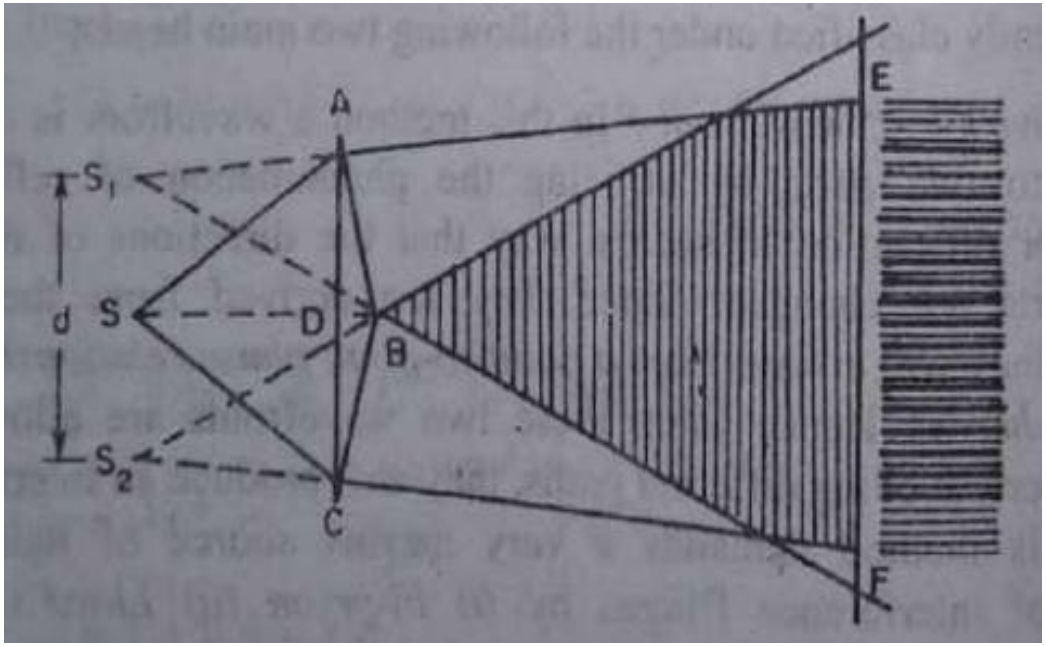


Fig.1

In the experimental arrangement the bi-prism is placed with its refracting edge accurately parallel to the slit S which is illuminated by a source of monochromatic light of wavelength λ. When light is allowed to fall symmetrically on the bi-prism, the refracting edge divides the incident wavefront into two parts. Firstly, the one which in passing through the upper half ABD if the bi-prism is deviated through a small angle towards the lower half of the diagram and appears to diverge from the virtual source S_1. Secondly, the one which passes through the lower half is deviated through a small angle towards the upper half and appears to diverse from the virtual source S_2. S_1 and S_2 being the image of the slit S, obviously function as coherent sources in this experiment.

Moreover, the two emergent wavefronts intersect at small angles and hence the fundamental condition of interference is satisfied. If a screen is placed on the right of the bi-prism, interference fringes of equal widths are produced in the overlapping region between E and F the two emergent beams. Beyond E and F fringes of large width are produced which are due to diffraction. In reality diffraction bands are present over the whole region but equally spaced interference fringes are observed superposed on them in portion between E and F.

Determination of the wavelength of light:

The bi-prism arrangement can be used to determine the wavelength of monochromatic light or almost monochromatic light like the one coming from a sodium lamp. Light from the sodium lamp illuminates the slit S and resulting interference fringes can be viewed through the eye-piece. By employing the formula

$$\lambda = \frac{dX}{D} \quad \left[X = \frac{\lambda D}{d} \right]$$

λ can be determined once the values of X, the fringe-width, d, the distance of separation of the virtual sources S_1 and S_2 and D, the normal distance of the plane of observation of the fringes from the slit, are measured with the help of the bi-prism experiment.

Interferometry

The phenomenon of interference has been used to measure the wavelength of light and the thickness of very thin plate to test the plane of surfaces to determine refractive indices of substances and also to determine whether a given so supply is an automatic or otherwise instruments based on the principle of interference of light are known as interferometer.

Some of these interferometers can be used in conjunction with a large extended source. Of those the Michelson interferometer has been important in the past and steel is. The instrument, designed by Prof. Albert Michelson, is used to determine the wavelength of light, to measure the thickness of thin strips, for the resolution of spectral line and also for the standardization of the meter.