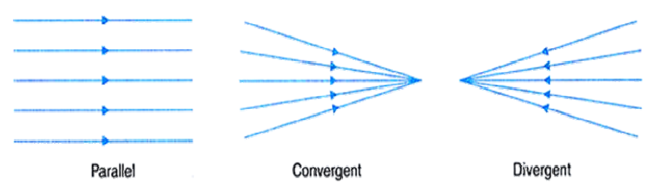
Light:

Light is something that stimulates our sense of vision and makes us see objects. Light travels in the form of electromagnetic waves and hence posses energy and exert pressure.

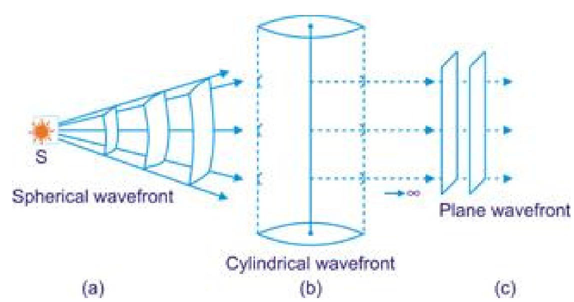
Source of light→ Radiation from excited atom. Whenever an atom of the light source gets excited its energy increases. When the atom returns to the ground state it emits the extra energy in form of electromagnetic radiations. If the wavelength of this radiation falls within the visible range, light is emitted.

Light ray→ Direction of propagation of light from a source.

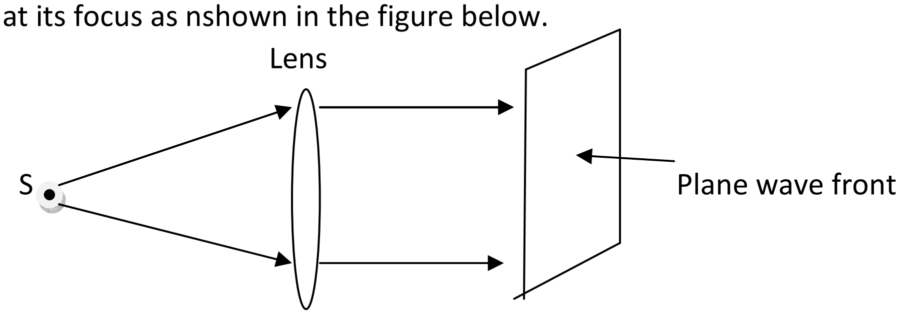
Light beam→ Collection of rays in a particular direction.



Wave front→ A hypothetical surface perpendicular to the rays of light. Every point on this surface is at equal phase.



(1) Light rays diverges from a point source, has **spherical wave front**.
(2) A linearly distributed source has **cylindrical wave front**.
(3) For parallel rays **wave front is plane**. When a source is at large distance, observed light rays are assumed parallel and the distant source (Like Sun rays) should have **plane wavefront**. In laboratory, we can produce it with the help of a convex lens with the source at its focus as nshown in the figure below.



Properties of wavefront

1. A wave front is the continuous locus of all the particles which are vibrating in the same phase at same instant.
2. A wave front at any position of space is perpendicular to the direction of wave propagation at that region.

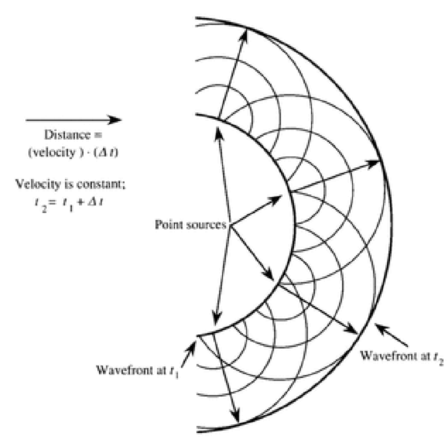
Isotropic and anisotropic medium→ In an isotropic medium optical parameters are same in all directions, so light travels with same velocity in all the directions.
In anisotropic medium optical parameters are different in different directions, so velocity of light is different in different directions.
In isotropic medium wave front has specific geometric shape depending on the nature of source, While in anisotropic medium shape of wave front is irregular.

Huygens' principle: This principle predicts the future position of the wave front from its present position. The principle states that:

1. Every point on a wave front can behave as a point source of secondary waves

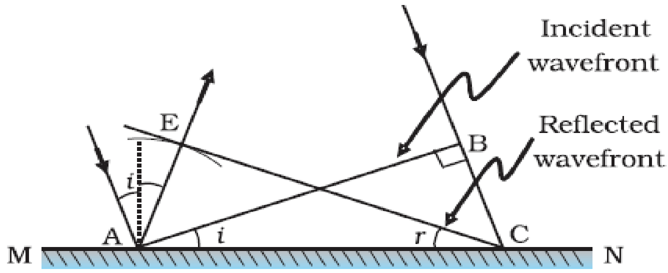
2. These secondary wavelets generate waves of spherical wave front of radius 'ct' in a time 't', c being the velocity of light in the concerned medium.

3. The surface of tangency to the secondary to the secondary waves give the position of the wave front after time 't'



It is used to explain the observed phenomena of reflection, refraction, interference, diffraction and other wave properties of light.

Application of Huygen's principle to prove reflection at a plane surface.



Reflection of a plane wave AB by the reflecting surface MN.
AB and CE represent incident and reflected wavefronts.

We can see a ray of light incident on the surface MN at A and another ray which is parallel to this ray is also incident on this surface at C. As these rays are incident on the surface, so we call them incident rays. If we draw a perpendicular from point 'A' to the point B on the other incident ray, then the line AB is called the incident wavefront. . The incident wave front is inclined at an angle ' i ' to the reflecting surface MN, 'i' being the angle of incidence. Since the wave reaches all points on the wave front simultaneously hence it can be said that when one ray reaches the surface MN at A the other ray is yet to reach it. It is at B. If 't' be the additional time taken by the second wave to reach B, along BC hence:

BC = ct, ...(1.1) c being the velocity of light in the concerned medium.

But within this time 't' the wave at A will be reflected from the surface. According to Huygens principle It will generate a spherical wave front of radius 'ct'. The tangent CE drawn on this spherical wave front from C gives the reflected wave front. The reflected wave front is inclined at an angle ' r ' to the reflecting surface MN, 'r' being the angle of reflection. AE is the reflected ray.

AE = ct ....(1.2)

If we now consider the triangles EAC and BCA

AC is the common side

$\angle$ AEC = $\angle$ABC = 90^0

AE = BC = ct

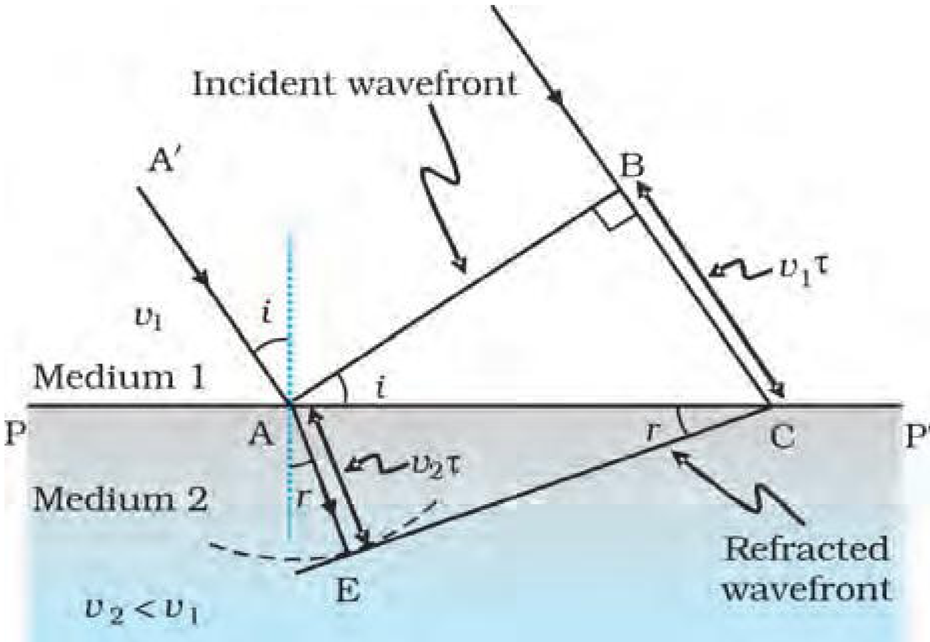
So the triangles are congruent by RHS rule.

Hence $\angle$ECA = $\angle$BAC

Or i = r

This proves that in reflection at a plane surface the angle of incidence is equal to the angle of reflection.

Application of Huygen's principle to prove refraction at a plane surface.



The figure shows a surface $PP^{/}$ separating two media (1) and (2). The velocity of light in medium (1) is 'v_1' and that in medium (2) is 'v_2'. It is assumed that medium (2) is optically denser than medium (1) So $v_2 < v_1$. A ray of light is incident on the surface $PP^{/}$ at A and another ray which is parallel to this ray is also incident on this surface at C. As these rays are incident on the surface, so we call them incident rays. If we draw a perpendicular from point 'A' to the point B on the other incident ray, then the line AB is called the incident wave front. . The incident wave front is inclined at an angle ' i ' to the reflecting surface $PP^{/}$, 'i' being the angle of incidence. Since the wave reaches all points on the wave front simultaneously hence it can be said that when one ray reaches the surface $PP^{/}$ at A theother ray is yet to reach it. It is at B. If 't' be the additional time taken by the second wave to reach B, along BC hence:

$BC = c_1t$, ...(1.3) c being the velocity of light in the concerned medium (1).

But within this time 't' the wave at A will be refracted through the surface $PP^{/}$ to the second medium (2). According to Huygens principle it will generate a spherical wave front of radius 'c_2t'. The tangent CE drawn on this spherical wave front from C gives the refracted wave front. The refracted wave front is inclined at an angle ' r ' to the reflecting surface $PP^{/}$, 'r' being the angle of refraction. AE is the refracted ray.

$AE = c_2t$ ....(1.4)

In the right angled triangle ABC: $\text{Sin}(i) = \frac{BC}{AC} = \frac{c_1 t}{AC}$...(1.5)

In the right angled triangle AEC: $\text{Sin}(r) = \frac{EC}{AC} = \frac{c_2 t}{AC}$...(1.6)

From equations (1.5) amd (1.6)

$$\frac{Sin(i)}{Sin(r)} = \frac{c_1 t}{c_2 t} = \frac{c_1}{c_2}$$ = constant = ${}_1\mu_2$ = refractive index of the second medium with respect to the first. This proves Snell's law of refraction.

Equation of light wave:

Y= a Sin(ωt-kx)
a→ amplitude of light wave,
(ωt-kx) → phase of light wave. If a light wave traverses a distance Δx through a medium, the phase difference acquired by it is $\Delta\phi = k\Delta x = (2\pi/\lambda)\Delta x$
Relation between geometrical path and optical Path: If a light traverses a distance Δx in a medium of refractive index μ, the optical path traversed by light will be μΔx.

Intensity of a wave is proportional to the square of its amplitude.

$$I = fa^2 \quad \text{………………………………………….(1.7)}$$ f is a proportionality constant

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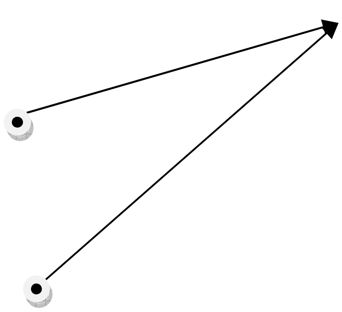
INTERFERENCE OF LIGHT

When light from two sources with same frequency and wave length, travelling in same direction with same state of polarization superpose on each other at some region of space, the distribution of intensity or energy of light of individual beam gets modified to form a pattern of energy distribution at that region with alternate dark and bright fringes. This is termed as interference.

Mathematical treatment of interference:



The figure shows light from two sources travelling almost in same direction with same frequency and wavelength. They will interfere according to the principle of superposition. Let the equation of the two interfering light waves be:

$$\left.\begin{aligned} \Psi_1 &= a_1 Sin(\omega t - kx) \\ \Psi_2 &= a_2 Sin(\omega t - kx + \delta) \end{aligned}\right\} \text{…………………………….(1.8)}$$

a_1 and a_2 are the amplitudes of Ψ_1 and Ψ_2 and δ is the phase difference between them. From equation (1.7) the resultant wave is given by:

$$\Psi = \Psi_1 + \Psi_2$$

$= a_1 \text{Sin}(\omega t - kx) + a_2 \text{Sin}(\omega t - kx + \delta)$

$= a_1 \text{Sin}(\omega t - kx) + a_2 \text{Sin}(\omega t - kx)\text{Cos}\delta + a_2 \text{Cos}(\omega t - kx)\text{Sin}\delta$

$= (a_1 + a_2 \text{Cos}\delta)\,\text{Sin}(\omega t - kx) + a_2 \text{Sin}\delta \text{Cos}(\omega t - kx)$ ……………………………….(1.9)

Let $\left.\begin{aligned} a_1 + a_2\text{Cos}\delta &= R\cos\theta \\ a_2\text{Sin}\delta &= R\sin\theta \end{aligned}\right\}$ ……………………………………………(1.10)

Substituting (1.10) in (1.9)

$\Psi = R\text{Sin}((\omega t - kx + \theta)$ ……………………………………(1.11)

R is the amplitude of the resultant wave. From equation (1.10):

$R^2 = (a_1 + a_2\text{Cos}\delta)^2 + (a_2\text{Sin}\delta)^2$

Or $R^2 = a_1^2 + a_2^2 + 2a_1a_2\text{Cos}\delta$ ……………………………..(1.12)

Since intensity is proportional to the square of the amplitude, The expression for resultant intensity becomes:

$I = I_1 + I_2 + 2I_1I_2\text{Cos}\delta$ ……………………………………(1.13)

Equation (1.12) shows that intensity varies with variation of phase difference δ.

Condition for constructive interference or maxima:

Equation (1.13) shows that resultant intensity is maximum when $\text{Cos}\delta$ takes its maximum possible value i.e. $\text{Cos}\delta = 1$. So the condition for maxima is:

$\delta = 2n\pi$ ……………………….(1.14) $n = 0, \pm1, \pm2, \pm3$……….

and the maximum intensity is

$I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$ ……………………………………(1.15)

Condition for destructive interference or minima:

Equation (1.13) shows that resultant intensity is minimum when $\text{Cos}\delta$ takes its minimum possible value i.e. $\text{Cos}\delta = -1$. So the condition for maxima is:

$\delta = (2n + 1)\frac{\pi}{2}$ ……………………….(1.14) $n = 0, \pm1, \pm2, \pm3$……….

and the maximum intensity is

$I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$ ……………………………………(1.15)

Hence if a screen is placed in the path of the interfering beams, it will show maximum brightness at some positions and minimum brightness at some other positions. Thus a pattern is formed on the screen. **This pattern is called interference pattern or interference fringes.**

Conditions for obtaining a distinct pattern.

If the two interfering waves have widely different intensities, the $\left(\sqrt{I_1} + \sqrt{I_2}\right)^2$ will not differ much from $\left(\sqrt{I_1} - \sqrt{I_2}\right)^2$. So it will be difficult to distinguish I_{max} from I_{min}. But if the two light waves are equally intense i.e. $I_1 = I_2 = I_0$ then:

$$\left.\begin{array}{l} I_{max} = 4I_0 \\ I_{min} = 0 \end{array}\right\} \quad \text{..(1.16)}$$

Due to zero intensity the minimas indicate complete extinction of light and thus are completely dark. Hence the dark minimas are easily distinguishable against bright maximas. **Hence to observe a distinct interference pattern the teo interfering light waves should have equal intensity.** The resultant intensity is thus given by:

$$I = I_0 + I_0 + 2I_0\text{Cos}\delta$$

Or $\quad I = 2I_0(1 + \text{Cos}\delta)$

Or $\quad I = 4I_0\text{Sin}^2\frac{\delta}{2}$ ....(1.16)

However the conditions for maxima and minima remain same.

Sustained Interference and coherence.

If the interference pattern formed on the screen remains constant with time the interference is said to be sustained. For sustained interference to occur, the phase difference between the interfering light waves at a particular point on the screen should remain constant with time. Such light waves are said to be **coherent.** If the phase difference changes with time the pattern on the screen will go on changing and it will not be possible to observe the pattern

Coherent light sources:

The light sources from which the emitted lights always maintain constant phase relation between them are **coherent sources**.

Light beam from two independent light sources, viz., two candles cannot maintain constant phase relation at any point in space, so they are **incoherent sources**. So even if they interfere they will not produce sustained interference.

Conditions for obtaining distinct sustained interference pattern

(1) The superposing light beams must be coherent, means they should maintain constant phase difference between them.
(2) They should propagate almost in the same direction.
(3) They must be monochromatic and have same frequency. If light is polychromatic, the interference fringe of one colour may falls over the higher order interference fringe of other colour to degrade visibility.
(4) They should have same state of polarization.
(5) They should have almost same amplitude or intensity.

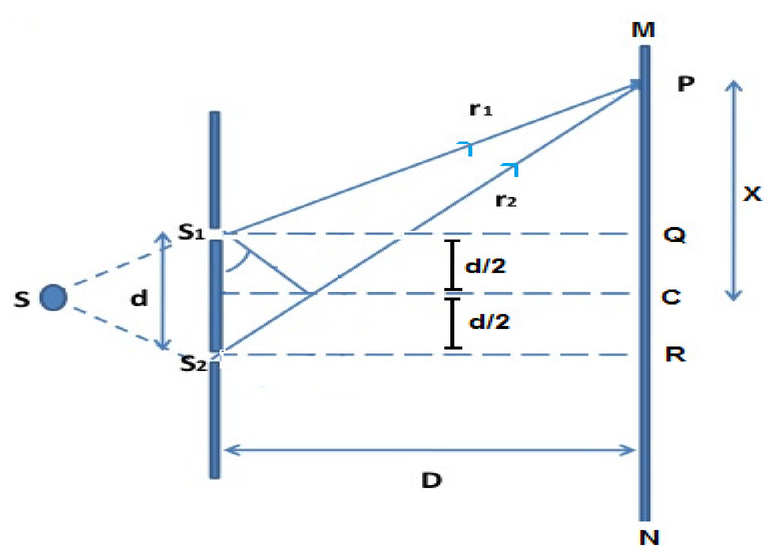
Production of coherent light sources:

Coherent light waves can be produced by splitting a single wave from a single source in two parts. There are two methods for spliiting a light wave.

1. Division of wave front→ Wave front of light from a narrow source is divided into two parts by reflection, refraction or by using slits to split the wave front to generate two coherent sources as in (a) Young's double slit experiment, (b) Fresnel's biprism experiment, (c) Lloyd's mirror experiment.

Division of amplitude→ Amplitude of light from a source is divided to get two coherent sources by means of partial reflection and refraction as in (a) Thin film experiment (b) Newton's ring experiment.

<u>**YOUNG'S DOUBLE SLIT EXPERIMENT**</u>



Let S be a monochromatic source of light. S_1 and S_2 are two narrow slits placed at equal distance from S, i.e. $S_1P = S_2P$. The point C is equidistance from S_1 and S_2. Therefore, path difference at C is zero. Let D is the distance between the slits and screen and d is the distance between two slits. Let us consider a point P on the screen at distance x from C. The path difference between two waves arriving at P is given by:

Path difference = $S_2P - S_1P$

By using simple geometrical laws, we can have the following relations:

$$PQ = x - \frac{d}{2} \quad \text{and} \quad PR = x + \frac{d}{2} \qquad \text{......................................(1.17)}$$

Path difference between the interfering waves is:

$$\Delta x = S_1P - S_2P \qquad \text{...(1.18)}$$

$$\left.\begin{aligned} (S_1P)^2 &= (S_1Q)^2 + (PQ)^2 = D^2 + \left(x - \frac{d}{2}\right)^2 \\ (S_2P)^2 &= (S_2R)^2 + (PR)^2 = D^2 + \left(x + \frac{d}{2}\right)^2 \end{aligned}\right\} \qquad \text{.......................................(1.19)}$$

$$(S_2P)^2 - (S_1P)^2 = D^2 + \left(x + \frac{d}{2}\right)^2 - D^2 + \left(x - \frac{d}{2}\right)^2 = 2xd$$

Or $(S_1P + S_2P)(S_1P - S_2P) = 2xd$

Or $(S_1P + S_2P)\Delta x = 2xd$ ....(1.20)

Since the point P lies very close to C,

$$S_2P \approx S_1P \approx D$$

So $S_1P + S_2P = D + D = 2D$ ....(1.21)

Substituting equation (1.21) in (1.20)

$$2D.\Delta x = 2xd$$

Or $\Delta x = \frac{xd}{D}$ ....(1.22)

Equation (1.22) gives the expression for path difference between the interfering waves at P. The corresponding phase difference at P is:

$$\delta = \left(\frac{2\pi}{\lambda}\right)\Delta x \qquad \text{..(1.23)}$$

Condition for maxima:

$$\delta = 2n\pi$$

Or $\quad (\frac{2\pi}{\lambda})\Delta x = 2n\pi$

Or $\quad (\frac{2\pi}{\lambda})\frac{xd}{D} = 2n\pi$

Or $\quad \boxed{x = \frac{n\lambda D}{d}}$ ………………………………………………………..(1.24)

Condition for maxima:

$$\delta = (2n+1)\pi$$

Or $\quad (\frac{2\pi}{\lambda})\Delta x = (2n+1)\pi$

Or $\quad (\frac{2\pi}{\lambda})\frac{xd}{D} = (2n+1)\pi$

Or $\quad \boxed{x = \frac{n\lambda D}{d}}$ ………………………………………………………..(1.25)

Fringe width.

Fringe width 'β' is the separation between two successive maxima or two successive minima on the screen, i.e. the difference between the values of 'x' between successive maxima orsuccessive minima.

For Maxima : $x = \frac{n\lambda D}{d}$

Differentiating: $\quad \Delta x = \frac{\Delta n\lambda D}{d}$ ………………………………………………(1.26)

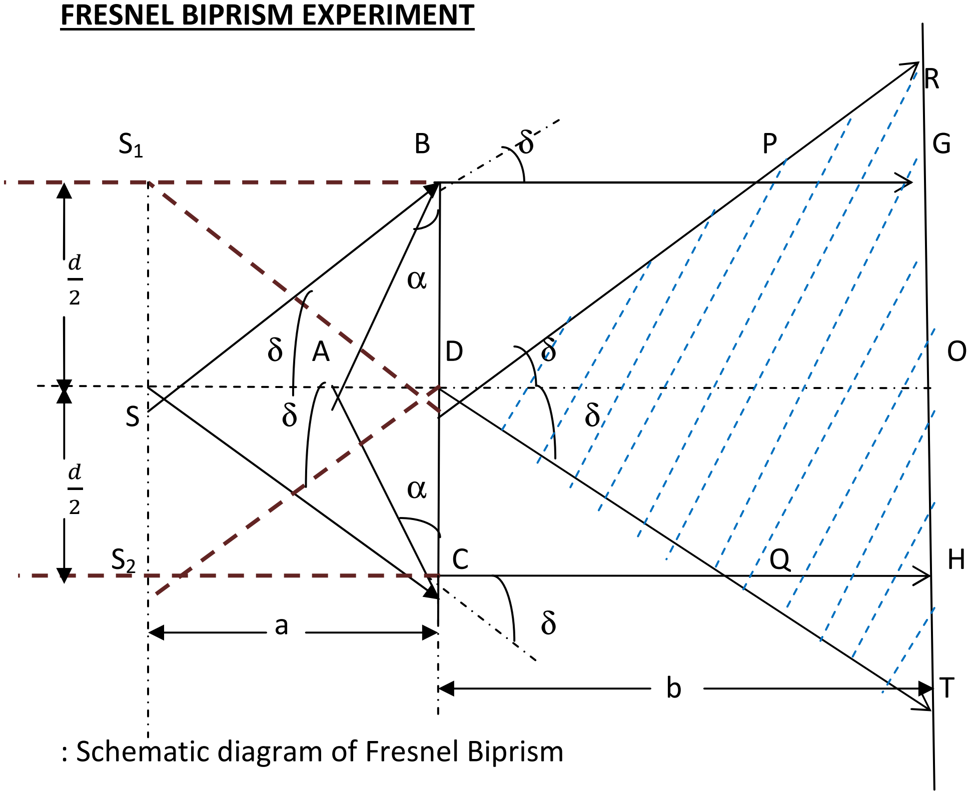
For two consecutive orders $\Delta n = 1$. Fringe width 'β' $= (\Delta x)_{\Delta n=1}$. Substituting $\Delta n = 1$ in (1.26)

Fringe width : $\quad \boxed{\beta = \frac{\lambda D}{d}}$ ………………………………………………………….(1.27)

For polychromatic light (white light)

Polychromatic light has a number of colours corresponding to a number of wavelengths. As path difference 'Δx' and fringe width 'β' is wavelength dependent, so the positions of maximas and minimas are different for different colours. Hence it is expected that each maxima will exhibit a spectrum. But at higher orders it may so happen that maxima of red for one order falls on the maxima of violet of some other order or may fall on minimas of other orders. So instead of distinct fringes the screen will show an uniform illumination at higher orders. However for zero order maxima the value of order 'n' is zero. So path difference is zero, whatever be the value of wave length. So, all colours will form zero order maxima at the same position. So if the incident light is white light, the zero order maxima is also white. This fringe is known as the **achromatic fringe.** Hence only for white light we can didentify the position of zero order. For monochromatic light all the maximas appear alike and equally intense. So the zero order cannot be identified.

FRESNEL BIPRISM EXPERIMENT



: Schematic diagram of Fresnel Biprism

In Fresnel's biprism interference occurs by division of wave front. The biprism BAC is a prism with the obtuse angle of prism A ≈ 179^0. It can be considered to be a combination of two thin prisms ABD and ACD of very small angles with their bases facing each other and joined together.

S → A narrow source slit placed with its length parallel to the edge of the biprism, the edge being the line of intersection of the two faces represented by AB and AC.

The incident wavefront is divided in two parts and suffer separate reflections from upper and lower prisms. The refracted beams being coherent interfere with each other and the resultant pattern is obtained on a screen. A beam of light SD incident normally on the biprism gets refracted along DQ due to the upper prism ABD and along DP due to the lower prism ACD after suffering a deviation δ. Another two beams of light SB and SC get refracted along DR and DT due to the upper and lower prism respectively after suffering a deviation = δ. The light beams within the cone GS_1T seem to diverge from S_1 and those within the cone RS_2H seem to diverge from S_2. So S_1 and S_2 are the virtual images of S which serve as coherent sources of light. Apart from the refraction mechanism, the scheme of interference is same as Young's double slit experiment and fringes of same shape will be formed.

Determination of wavelength from biprism experiment

$\alpha \rightarrow$ Angle of each thin prism - $\angle ABD = \angle ACD$, where α is very small.

a $\rightarrow$ distance of S from biprism,

b $\rightarrow$ distance of screen from biprism

$\delta \rightarrow$ angle of minimum deviation for each thin prism.

$\frac{d}{2}$ = Distance between S_1 and S = Distance between S_2 and S

So d = Distance between S_1 and S_2

Comparing with Young's double slit experiment, here:

D = a + b = distance between source and screen which is analogous to distance between double slit and screen.

The distance between the coherent sources is = d

If λ be the wavelength of light used then the fringe width β is given by

$$\beta = \frac{D\lambda}{d} = \beta = \frac{(a+b)\lambda}{d} \quad \text{.................................(1.28)}$$

β can be measured by taking readings. 'a' and 'b' can be measured by mounting the screen and source on an optical bench. Hence if 'd' is known, then the unknown wavelength 'λ' of the light used can be calculated from equation (2.4). But 'd' being the distance between virtual sources cannot be directly measured. It has to be measured using suitable experimental arrangements.

Determination of wavelength of light by Fresnel biprism

When a beam monochromatic light from a source is allowed to fall on the Fresnel's biprism after passing through a thin slit, two virtual sources are formed after refraction. These two images act as coherent sources and interference fringes are formed. The corresponding fringe width 'β' is given by: $\beta = \frac{D\lambda}{d}$

Or $$\lambda = \frac{d\beta}{D} \quad \text{...(1.29)}$$

D can be measured by mounting the apparatus on an optical bench and noting the distance between the source slit and the screen. Fringe width β can be noted by shifting the eye piece attached with the screen along the fringes and taking the readings from a micrometer scale arrangement. The main problem is the determination of 'd', the distance between the virtual sources.

Measurement of d

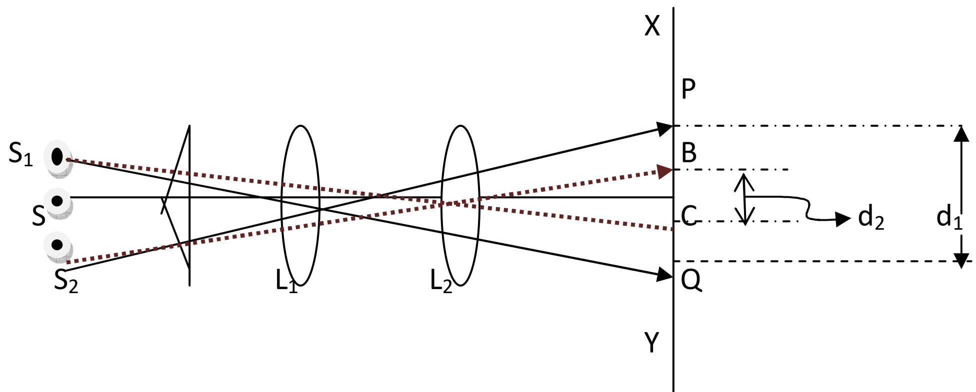


Fig. 3.4. Experimental determination of β

XY is the focal plane of an eye piece. The source, biprism and an eye piece are mounted on an optical bench. A lens is placed between the biprism and eye piece, whose focal length is less than one fourth of the distance between them. The lens is moved parallel to the optical bench. There are two positions between the biprism and eye piece, where if the lens is placed real images of S_1 and S_2 are formed on XY. For position L_1, the image of S_1 is at Q and that of S_2 is at P. Similarly for position L_2, the image of S_1 is at C and that of S_2 is at B.

d_1 = distance between P and Q

d_2 = distance between B and C

Since the images are real hence d_1 and d_2 can be measured. The distance between S_1 and S_2 is given by $d = \sqrt{d_1 d_2}$ ....(1.30)

The value of 'd' thus obtained is substituted in equation (1.29) to calculate the value of λ.

Determination of acute angle of biprism

The angle of minimum deviation δ being very small we can write

$$\delta = \tan\delta = \frac{\frac{d}{2}}{a} = \frac{d}{2a} \quad \text{......................(1.31) From the fig .}$$

So $\quad d = 2a\delta$ ....(1.32)

If μ is the refractive index of the prism, then the expression for minimum deviation is given by:

$\delta = (\mu - 1)\alpha$, α being the angle of prism.

Substituting this expression of δ in equation (1.31) we have

$d = 2a(\mu - 1)\alpha$

Or $\alpha = \dfrac{d}{2a(\mu - 1)}$ ....(1.33)

'd' can be determined experimentally. 'a' can be measured. So with known value of μ, the acute angle of biprism (α) can be calculated. **Equation (1.33) can also be used to find the refractive index 'μ' if the value of δ is known.**

PHASE CHANGE ON REFLECTION: STOKES TREATMENT

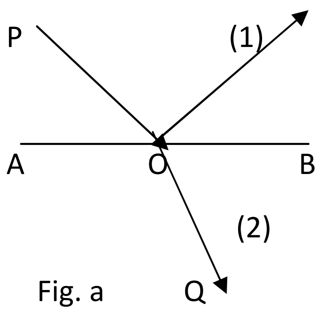


Fig. a

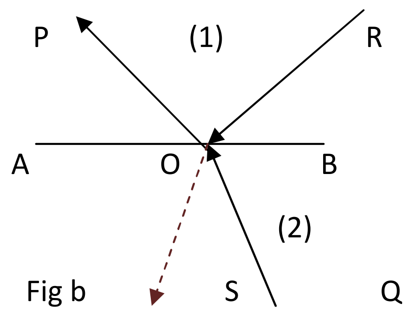


Fig b

Fig (a) shows an absorption less surface AB separating two media (1) and (2) It is assumed that medium (i) is optically rarer that medium (2) i.e. $\mu_1 < \mu_2$, where . μ_1 and μ_2 are the refractive indices of (1) and (2)

r = reflection coefficient of the surface of AB facing (1)

t = transmission coefficient from (1) to (2)

$r^{/}$ = reflection coefficient of the surface of AB facing (2)

$t^{/}$ = transmission coefficient from (2) to (1)

A wave of amplitude 'a' is incident along PO at the point O on AB. OR is the reflected wave and OQ is the transmitted wave.

ar = amplitude of OR

at = amplitude of OQ

Now keeping the point of incidence O on AB fixed let it be assumed that the directions of the waves OR and OQ are reversed along RO and QO respectively (Fig. b). Now, the principle of reversibility of light demands that their resultant effect should the incident light with same amplitude but reversed in direction i.e. along OP.

Now RO is reflected along OP and transmitted along OS

ar^2 = amplitude of the reflected part of RO along OP

art = amplitude of the transmitted part of RO along OS

atr' = amplitude of the reflected part of QO along OS

att' = amplitude of the transmitted part of QO along OP

So the net amplitude along OP is = $ar^2 + att'$.

According to our argument this amplitude should be 'a'

Hence : $a = ar^2 + att'$.

Or $r^2 + tt' = 1$ ……………………..(1.34)

Also the net amplitude along OS is = $art + atr'$.

Since initially there was no wave along OS or SO , So OS will be non- existent. Consequently the amplitude of OS should be zero.

Hence: $art + atr' = 0$

Or $r + r' = 0$

Or $r' = -r$ ……………………………………..(1.35)

This shows that if one of the reflection coefficients is positive the other must be negative and vice versa. **A negative refractive index denotes a phase change of π of the wave on reflection. Hence a phase change of π occurs on reflection either from rarer to denser medium or from denser to rarer medium, but from Stokes treatment it cannot be predicted which one.**

The actual fact is revealed experimentally in Lloyd's mirror experiment, where interference occurs by the process of division of amplitude between waves direct from the source and waves reflected from an optically denser medium. It was found that the central fringe corresponding to zero path difference is dark instead of bright. This is possible only if light waves reflected from the surface of a denser medium undergoes a phase change of π. **Thus a phase change of π occurs when light coming from a rarer medium gets reflected at the surface of a denser medium.**

LLOYD'S MIRROR

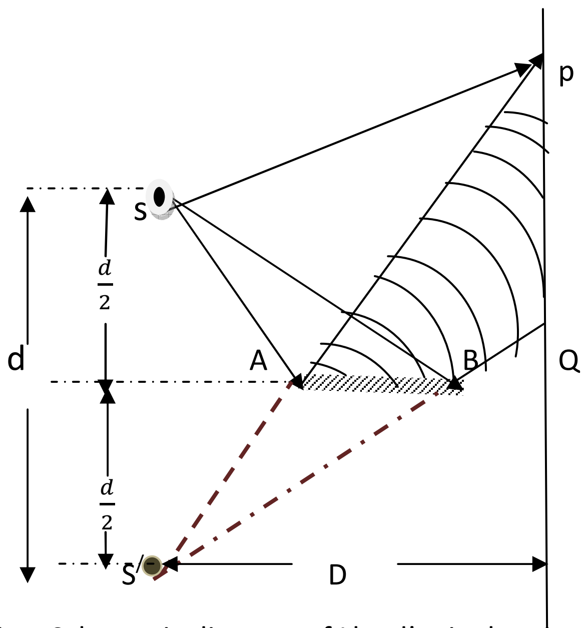


Fig:. Schematic diagram of Lloyd's single mirror experiment.

AB is a plane mirror. S is a source of light. A beam of light SA strikes the mirror at A and gets reflected along AP. Another beam of light SB strikes the mirror at B and gets reflected along BQ. Interference occurs at P between the direct light from S and the reflected light and interference fringes are obtained on a **screen separated from the source by a distance 'D'**. AP and BQ appear to diverge from $S^{/}$, which is the virtual image of S. It seems that S and $S^{/}$ are the two coherent sources of light. **So out of the two coherent sources one is real and the other is virtual**. Apart from the reflection mechanism, the scheme of interference is same as Young's double slit experiment and fringes of same shape will be formed. In the given fig. the point of zero path difference is outside the zone of interference. So, less than one half of the fringes, will be obtained within the region PQ. In order to observe the zero path difference fringe the screen has to be moved to the point B. At B the light waves SB and $S^{/}B$ have zero path difference and zero order fringe will be formed there. The zero order fringe was found to be a dark fringe. This indicates that even if the path difference is zero an additional phase difference of π must have crept in from somewhere. SP being a direct beam from S has no scope of phase change. So the only option is that the phase change must have occurred in the reflected ray. Here the incident ray SA after coming from a rarer medium (air) gets reflected at the mirror surface which is a denser medium. This clearly points out that when light is reflected at the surface of a denser medium it undergoes a phase change of π, and the corresponding reflection coefficient is negative. Hence the reflection coefficient corresponding to reflection from a rarer surface is positive and in that case no phase change occurs.

Determination of wavelength from Lloyd's mirror experiment

Comparing with Young's double slit experiment, here:

D = distance between source and screen which is analogous to distance between double slit and screen.

$\frac{d}{2}$ = distance of real source S from the mirror.

Since for reflection in a plane surface object distance is equal to the image distance hence:

$\frac{d}{2}$ = distance of virtual source $S^{/}$ from the mirror.

So the distance between the coherent sources is =d

If λ be the wavelength of light used then :

Fringe width = $\beta = \frac{D\lambda}{d}$ ....(1.36)

β can be measured by taking readings. 'D' can be measured by mounting the screen and source on an optical bench. 'd' can also be measured. Using these values λ can be calculated from equation (2.3).

Comparisn between biprism and Lloyds mirror

Serial no.	Biprism fringes	Lloyd's mirror fringes.
1	In biprism the complete pattern of fringes is obtained with zero order fringe and higher orders on either side of zero order.	Less than half of the fringe pattern is obtained. The zero order is not obtained unless the screen is in contact with one end of mirror
2	Zero order fringe is bright	Zero order fringe is dark
3	The Zero order fringe is not very sharp	The Zero order fringe if present is sharp
4	The two coherent sources producing interference fringes are virtual.	One of the two coherent sources producing interference fringes are real and the other one is virtual.

INTERFERENCE IN THIN FILMS

I: INTERFERENCE BY A PARALLEL SIDED THIN FILM

When a thin film of some transparent material is exposed to light, circular patterns of brilliant colours can be seen for e.g. colours seen in a soap bubble, or formation of coloured rings on a wet road on which car oil has been spilled. This is due to interference of light reflected from upper and lower surface of the film via the method of division of amplitude.

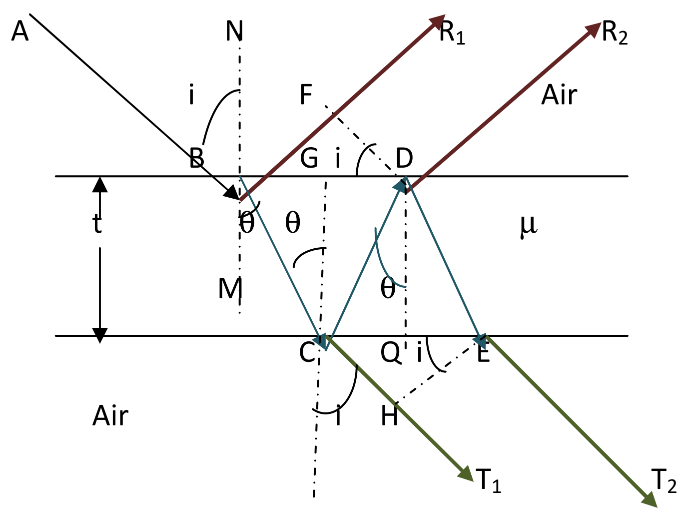


Fig. 5.1. Interference of light by parallel sided thin film.

Let a parallel sided thin film of refractive index μ and thickness, 't' be considered within an air medium. It is assumed surfaces of the film have a high reflection coefficient

AB $\rightarrow$ A beam of light of amplitude 'a' incident on the upper surface of the film.

BR_1 $\rightarrow$ Light reflected from the upper surface of the film.

BC $\rightarrow$ Light transmitted into the film through the upper surface.

CD $\rightarrow$ Light reflected from the lower surface of the film.

CT_1 $\rightarrow$ Light transmitted outside the film through the lower surface

DR_2 $\rightarrow$ Light transmitted outside the film through the upper surface

DE $\rightarrow$ Light re-reflected into the film at the point D

ET_2 $\rightarrow$ Corresponding transmitted light.

The reflection coefficient of the film surfaces being high it can be assumed that the amplitude becomes insignificant after two reflections and hence other subsequent reflections inside the film can be ignored.

FD and EH are perpendiculars drawn from D and E on BR_1 and CT_1 respectively

CG is the perpendicular drawn from C on BD.

$\angle ABN = i$ = Angle of incidence = $\angle FDB = \angle CEH$ from the geometry of the fig. (5.1)

$\angle MBC = \theta$ = Angle of refraction = $\angle GCB = \angle CDQ$ from the geometry of the fig. (5.1)

The reflected beams BR_1 and DR_2 are parts of the same wave obtained by division of amplitude. So they are coherent and will interfere. Also the transmitted beams CT_1 and ET_2 are parts of the same wave obtained by division of amplitude. So they are coherent and will interfere. Hence both for reflected beams and transmitted beams interference fringes will be formed. Since the reflected beams are parallel, the interfering beams superpose at infinity. Hence the fringes are formed at infinity. The same thing holds for transmitted beam. So to observe the fringes a convex lens is required to focus the parallel beams at its focal plane.

Path difference and conditions of maxima and minima for reflected beams

The beam DR_2 travels through the thin film twice before emerging from it. So it travels an extra optical path: $\mu(BC + CD)$ as compared to BR_1. On the other hand BR_1 travels an extra path BF in air as compared to DR_2. So the net optical path difference between the beams BR_1 and DR_2 is:

$$\Delta x = \mu(BC + CD) - BF$$

Now, from the geometry of the Fig. (5.1) BC = CD, which gives

$$\Delta x = 2\mu BC - BF$$

G is the midpoint of BD and CG is perpendicular to BD. CG = t. This gives

$$\Delta x = 2\mu.CG.Sec\theta - BD.Sin(i)$$

From Snell's law of refraction $Sin(i) = \mu Sin\theta$

$\therefore \quad \Delta x = 2\mu.CG.Sec\theta - \mu.BD.\ Sin\theta$

Or $\quad \Delta x = 2\mu.CG.Sec\theta - 2\mu BG.Sin\theta \qquad$ as BD = 2BG

Or $\quad \Delta x = 2\mu.CG.Sec\theta - 2\mu CG.tan\theta.Sin\theta$

Or $\quad \Delta x = 2\mu.t.Sec\theta - 2\mu t.Sin^2\theta.Sec\theta$

Or $\quad \Delta x = 2\mu.t.Sec\theta.(1 - Sin^2\theta)$

Or $\quad \Delta x = 2\mu.t.Sec\theta.Cos^2\theta$

Or $\boxed{\Delta x = 2\mu t.\text{Cos}\theta}$ ……………………………………….(1.37)

Equation (5.1) gives the path difference between the reflected interfering beams BR_1 and DR_2

BR_1 is reflected at the surface of a denser medium. So it suffers a phase change of π, while the beam DR_2 comes via reflection at C i.e. at the surface of a rarer medium and hence suffers no phase change. Hence between the beams BR_1 and DR_2 an extra phase of π occurs other than that due to the path difference. So net phase difference between the two reflected beams is:

$$\Delta\phi = \frac{2\pi}{\lambda}.\ 2\mu t\text{Cos}\theta - \pi \qquad \text{(Note: } +\pi \text{ can also be used)}$$

Condition for maxima

$$\Delta\phi = 2n\pi$$

Or $\frac{2\pi}{\lambda}.2\mu t\text{Cos}\theta - \pi = 2n\pi$ where n = 0, 1, 2,…….

Or $\boxed{2\mu t\text{Cos}\theta = (2n+1)\frac{\lambda}{2}}$ ……………………………………….(1.38)

Condition for minima

$$\Delta\phi = (2n - 1)\pi$$

Or $\frac{2\pi}{\lambda}.2\mu t\text{Cos}\theta - \pi = (2n - 1)\pi$ where n = 1, 2, 3…..

Or $\boxed{2\mu t\text{Cos}\theta = n\lambda}$ ……………………………………………(1.39)

For transmitted beams: The value of the path difference is same as for reflected beams but there is no phase change of π on reflection. So –

Condition for maxima

$$\Delta\phi = 2n\pi$$

Or $\frac{2\pi}{\lambda}.2\mu t\text{Cos}\theta = 2n\pi$ where n = 0, 1, 2,…….

Or $\boxed{2\mu t\text{Cos}\theta = n\lambda}$ ……………………………………….(1.40)

Condition for minima

$\Delta\phi = (2n - 1)\pi$, where n = 1,2,3 Note: + sign can also be used but for that case n = 0,1,2 ….)

Or $\frac{2\pi}{\lambda}.2\mu t Cos\theta = (2n-1)\pi$

Or $$\boxed{2\mu t Cos\theta = (2n - 1)\frac{\lambda}{2}}$$ ………………………………………….(1.41)

So it is seen, that the condition for maxima in reflected beams is same as the condition for minima in transmitted beams and vice versa. So reflected and transmitted fringes, are complementary to each other. θ decreases with increase of order. So the order of fringe decreases outwards.

Nature of the fringes

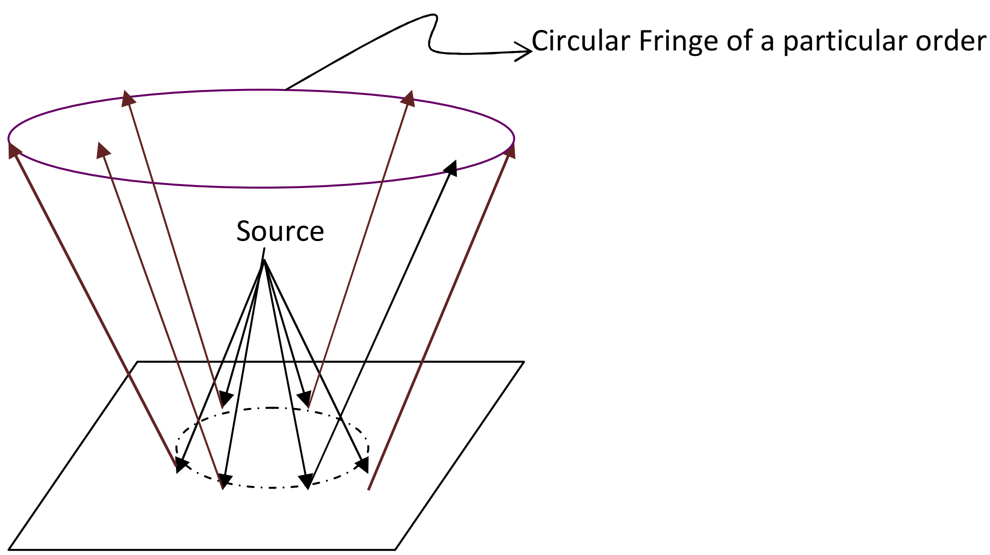


Fig. Shape of the fringes in a parallel sided thin film.

In the expression of path difference, for both reflected and transmitted beams, thickness of the film 't' is constant for a parallel sided film. So for a given λ, the fringe order 'n' depends directly on Cosθ, and hence on 'θ' So fringe of a particular order is the locus of all points having the same value of 'θ'. Now, 'θ' is the angle of refraction. So for 'θ' to remain fixed, the angle of incidence should also remain fixed. The locus of all points on the surface of the film, at which angle of incidence of the beams coming from a single source, is constant, is the point of intersection of a cone of semi vertical angle 'i' with the film surface and hence is a circle on the film surface. If all the corresponding reflected beams are collected corresponding to a fixed angle of incidence a circular fringe will be obtained. The fringe pattern for different angles of incidence will be series of concentric bright and dark circles as shown in Fig. below. The same thing holds for transmitted beams also**.** These fringes are called **fringes of equal inclination or Haidinger fringes.**

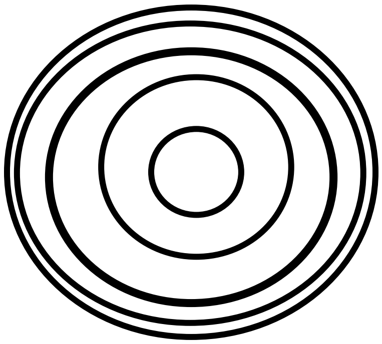


Fig. The nature of fringes with fringe width and order decreasing outwards.

For a polychromatic light source

- The refractive index ‘μ’ and thickness, ‘t’ is constant. So, for a particular order, ‘θ’ changes with wave length λ’. Hence for each wavelength of a polychromatic light a circular pattern will be obtained for a given order. Hence corresponding to one order, a number of circular fringes of different colours will be obtained as shown in Fig. below.

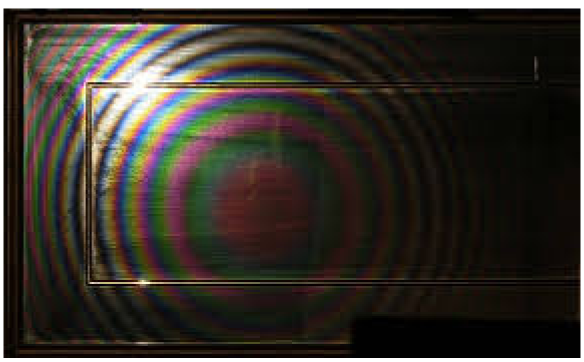


Fig. Appearance of the fringes with polychromatic light

Zero order fringe

For zero order corresponds to zero path difference. The path difference $2\mu t\text{Cos}\theta$ will be zero only if $\text{Cos}\theta$ is equal to zero, i.e. $\theta = 90^0$

When light coming from a rarer medium is incident on the surface of a denser medium the angle of refraction is always less than the angle of incidence. The maximum possible value of angle of incidence can be 90^0. So the maximum possible angle of refraction is less than 90^0. Hence it is never possible for $\text{Cos}\theta$ to be zero thereby making zero order fringe impossible.

When light coming from a denser medium is incident on the surface of a rarer medium the angle of refraction is always greater than the angle of incidence. So for an angle of incidence less than 90^0 (critical angle)the angle of refraction can be equal to 90^0. So it is possible for $\text{Cos}\theta$ to be zero thereby making zero order fringe possible. **For reflected fringes the zero order fringe**

is a dark fringe, while for transmitted fringes the zero order fringe is a bright fringe as is evident from the maxima and minima conditions

For an Ultrathin film

For an ultrathin film, the thickness of the film is negligible compared to the wave length of light. So as ‘t’ $\rightarrow$ 0, the path difference $\Delta x = 2\mu t \cos\theta$ can practically taken to be zero as compared to wave length for all values of θ. So $\Delta x = 0$ corresponds to a zero order minima for reflected fringes for all ‘θ. Hence instead of a fringe pattern, a uniform darkness will be obtained throughout the field of view. This explains the darkening of a thin soap bubble just before it explodes.

The transmitted fringes being complementary to the reflected fringes, it will exhibit an uniform brightness throughout the field of view, indicating that the energy absent in reflected light is fully present in transmitted light.

Difference between Reflected and transmitted fringes for a parallel sided thin film

Serial no.	Reflected fringes	Transmitted fringes
1.	Condition for maxima is $2\mu t\cos\theta = (2n + 1)\frac{\lambda}{2}$	Condition for maxima is : $2\mu t\cos\theta = n\lambda$
2	Condition for minima is : $2\mu t\cos\theta = n\lambda$	Condition for mniima is $2\mu t\cos\theta = (2n + 1)\frac{\lambda}{2}$
3	The zero order fringe if present is a dark fringe.	The zero order fringe if present is a bright fringe.

II. INTERFERENCE BY A WEDGE SHAPED FILM

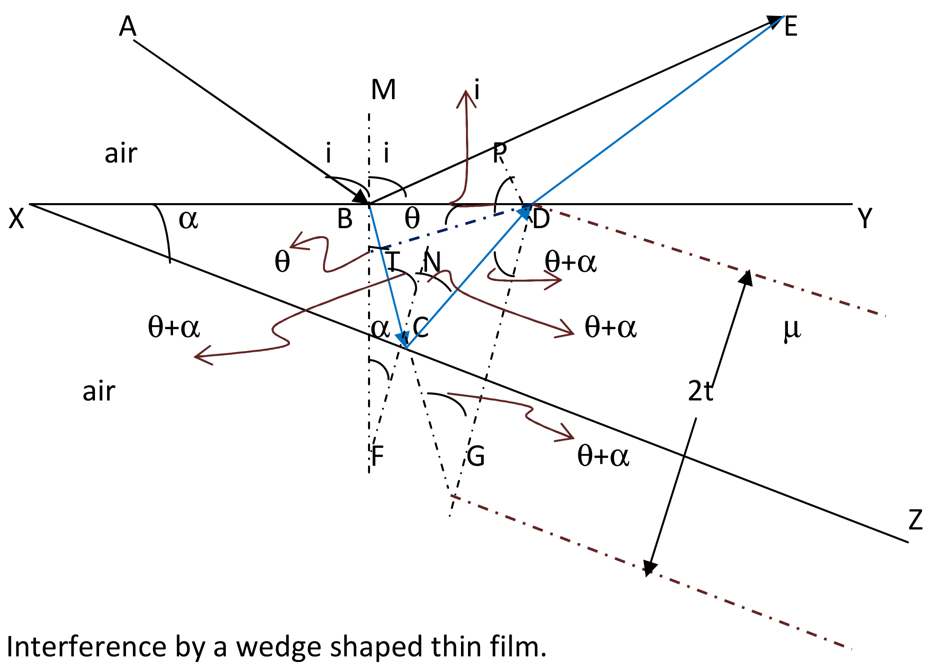


Fig. 5.5 . Interference by a wedge shaped thin film.

When a wedge shaped thin film of some transparent material is exposed to light, straight line patterns of brilliant colours can be seen for This is due to interference of light reflected from upper and lower surface of the film via the method of division of amplitude.

Let wedge shaped thin film YXZ **of refractive index μ and angle of wedge '**α' be considered within an air medium. It is assumed surfaces of the film have a high reflection coefficient

AB ⟶ A beam of light of amplitude 'a' incident on the upper surface of the film.

BE ⟶ Light reflected from the upper surface of the film.

BC ⟶ Light transmitted into the film through the upper surface.

CD ⟶ Light reflected from the lower surface of the film.

DE ⟶ Light transmitted outside the film through the upper surface

MF ⟶ Normal to XY

NF, DG ⟶ Normal to XZ

∠MFN ⟶ angles between the normals to the two surfaces of the wedge = α

BC produced meets the normal DG at G

DG $\rightarrow$ Twice the thickness of the film at point D = 2t

t $\rightarrow$ Thickness of the film at point D

i = angle of incidence = $\angle$ABM = $\angle$BME = Angle of reflection

DP $\rightarrow$ perpendicular to BE

DT $\rightarrow$ Perpendicular to BC

$\theta \rightarrow \angle$FBC = Angle of refraction

From the geometry of the Fig. (5.5)

$$\left.\begin{array}{l}\angle PDB = i, \quad \angle BDT = \theta, \quad \angle BCN = \angle NCD = \angle CDG = \angle DGC = \theta+\alpha\end{array}\right\} \quad \ldots\ldots\ldots\ldots(1.42)$$

Hence CD = CG ……………………………….(1.43)

The beam DE travels through the thin film twice before emerging from it. So it travels an extra optical path: μ(BC + CD) as compared to BE. On the other hand BE travels an extra path BF in air as compared to DR_2. So the net optical path difference between the beams BE and DE is:

$$\Delta x = \mu(BC + CD) - BP$$

Or $\Delta x = \mu(BC + CG) - BP$ from (1.43)

Or $\Delta x = \mu.BG - BP$

Or $\Delta x = \mu.(BT + TG) - BD.Sin(i)$ ……………….from the fig.

Or $\Delta x = \mu\{BD.Sin\theta + DG.Cos(\theta+\alpha)\} - \mu BD.Sin\theta$

Or $\Delta x = \mu BD.Sin\theta + \mu\, DG.Cos(\theta+\alpha) - \mu BD.Sin\theta$

Or $\Delta x = \mu\, DG.Cos(\theta+\alpha)$

Or $\boxed{\Delta x = 2\mu t Cos(\theta+\alpha)}$ ……………………………………………….(1.44)

Assuming light to be incident normally on the wedge shaped film angle 'θ' is zero. Also for the wedge shaped film to be thin the angle 'α' should tend to zero. This gives the expression for path difference as:

$\boxed{\Delta x = 2\mu t}$ ……………………………………………………….(1.45)

BE is reflected at the surface of a denser medium. So it suffers a phase change of π, while the beam DE comes via reflection at C i.e. at the surface of a rarer medium and hence suffers no phase change. Hence between the beams BE and DE an extra phase of π occurs other than that due to the path difference. So net phase difference between the two reflected

$$\Delta\phi = \frac{2\pi}{\lambda} \cdot 2\mu t - \pi \quad \text{.......................(1.46)} \quad \text{(Note: } +\pi \text{ can also be used)}$$

Condition for maxima

$\Delta\phi = 2n\pi$

Or $\quad \frac{2\pi}{\lambda} \cdot 2\mu t - \pi = 2n\pi \quad$ where n = 0, 1, 2,.......

Or $\quad \boxed{2\mu t = (2n+1)\frac{\lambda}{2}} \quad$ ....(1.47)

Condition for minima

$$\Delta\phi = (2n - 1)\pi$$

Or $\quad \frac{2\pi}{\lambda} \cdot 2\mu t - \pi = (2n - 1)\pi \quad$ where n = 1, 2, 3.....

Or $\quad \boxed{2\mu t \text{Cos} = n\lambda} \quad$ ....(1.48)

Nature of the fringes

In the expression for path difference it is seen that the thickness ‘t’ of the film varies from point to point. The expressions of maxima and minima, shows that the order of the fringe, is directly proportional to the thickness at the concerned point. Hence fringe of a particular order will be the locus of points having constant thickness. This locus is a straight line parallel to the edge of the wedge. So fringes will be alternate bright and dark straight lines parallel to the edge of the wedge as shown in Fig. (5.6). The fringes are **localized fringes** since the interfering occurs at the exit surface of the film. **These fringes are called fringes are called fringes of equal thickness or Fizeau fringes**

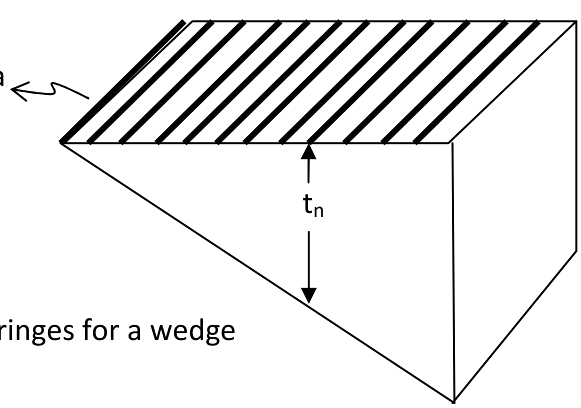


Fig. Interference fringes for a wedge shaped thin film

Zero order fringe

The zero order fringe will occur at the positions where thickness of the film is zero. This position is the edge of the wedge. Due to the phase change of π due to reflection the zero order will be a dark fringe. So the zero order dark fringe will be formed at the edge of the wedge as shown in Fig. (5.6).

Determination of fringe width

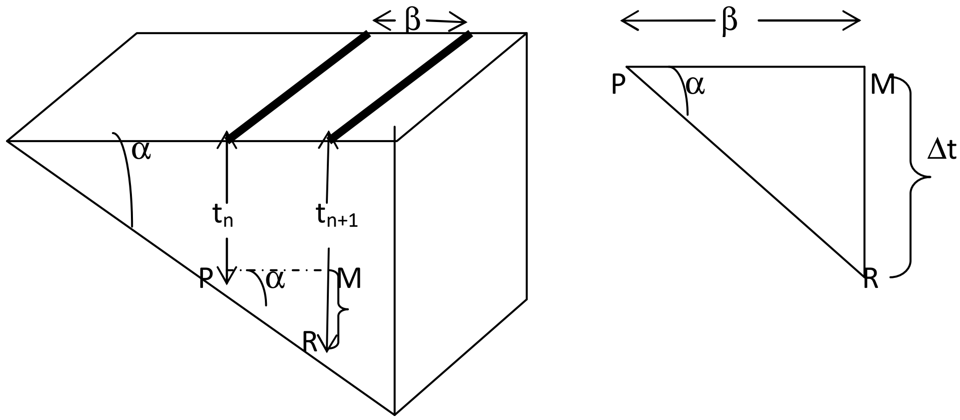


Fig. Diagram for calculation of fringe width β

Fringe width is the separation between two consecutive maximas or two consecutive minimas. As a fringe of a particular order is the locus of points with constant thickness, hence the separation (β) corresponding to the difference of thickness (Δt) between two consecutive maximas or two consecutive minimas gives the fringe width.

Condition for minima: $2\mu t = n\lambda$

Differentiating: $2\mu.\Delta t = \Delta n\lambda$

For consecutive orders $\Delta n = 1$, which gives

$$\Delta t = \frac{\lambda}{2\mu Cos} \quad \text{...(1.49)}$$

Now from the Fig. above : $\Delta t = \beta.\tan\alpha$ ....(5.15)where β is the fringe width.

Assuming α to be very small for a thin wedge, $\tan\alpha = \alpha$, which gives

$$\Delta t = \beta.\alpha \quad \text{...(1.50)}$$

From equations (1.49) and (1.50) the value of fringe width is

$$\boxed{\beta = \frac{\lambda}{2\mu\alpha}} \quad \text{..................................(1.51)}$$

Since μ, θ and α are constants, hence the fringe width is constant for monochromatic light. So the straight line fringes are equidistant

For normal incidence i= θ = 0 and the expression for fringe width becomes

$$\Delta t = \frac{\lambda}{2\mu} \quad \text{.............. ....(1.52)}$$

Which gives :

$$\boxed{\beta = \frac{\lambda}{2\mu\alpha}} \quad \text{..(1.53)}$$

Since μ and α are constants, hence the fringe width is constant for monochromatic light. So the straight line fringes are equidistant.

For a polychromatic light source

The refractive index 'μ' and angle of wedge 'α' is constant. So, for a particular order, 't' changes with wave length λ'. Hence for each wavelength of a polychromatic light a straight line pattern will be obtained for a given order. Hence corresponding to one order, a number of straight line fringes of different colours will be obtained as shown in Fig. (5.7).

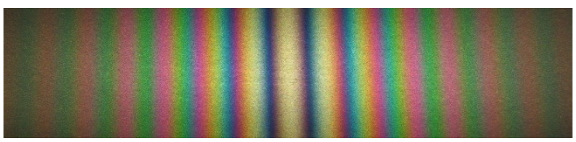


Fig. 5.8. Straight line coloured fringed formed by white light in wedge shaped film.

Need of an extended source

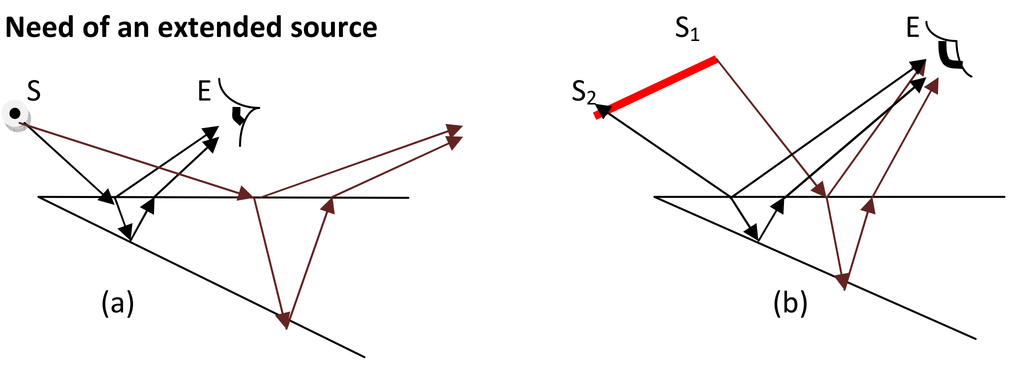


Fig. Diagram demonstrating the need of extended source.

Let S be a narrow or point source of light as shown in Fig. (5.9a) A beam of light from S enters the eye E after one reflection from the upper surface of the film and one from lower surface. Another ray of light from S is incident at a different angle After the two reflections at the two surfaces of the film it cannot enter the eye as shown in Fig. (5.9a). So only a limited portion of the film become visible. To observe the whole film, the eye has to be continuously shifted from one position to the other.

If however an extended source S_1S_2 is used (fig. 5.9b) the light reflected from a large section of the film enters the eye, placed in a suitable position. Thus the entire film can be viewed simultaneously without moving the eye, as shown in (fig. 5.9b). Hence an extended source is required to view the film

Difference between fringes formed by Fizeau fringes and Haidinger fringes

Serial no.	Fizeau fringes	Haidinger fringes
1	These fringes are formed by interference due to a wedge shaped thin film.	These fringes are formed by interference due to a parallel sided to a thin film.
2	Fringes are loci of points of equal thickness.	Fringes are loci of points of equal inclination.
3	The fringes are straight lines parallel to the edge of the wedge.	The fringes are concentric circles
4	The fringes are localized.	The fringes are formed at infiniy
5	The zero order fringe is always present and is formed at the edge of the wedge whatever be the nature of the film and the medium on either side of it.	The zero order fringe is possible only if the medium on either side of the fringe is optically denser that the material of the film.
6	The fringe width is constant.	The angular fringe width decreases with decrease of order.
7	The fringe width is finite even for an ultra thin film and so the fringe pattern is present with different orders.	For an ultra thin film the angular fringe width tends to infinity and the zero order fringe fills up the entire field of view.

III. NEWTONS' RINGS.

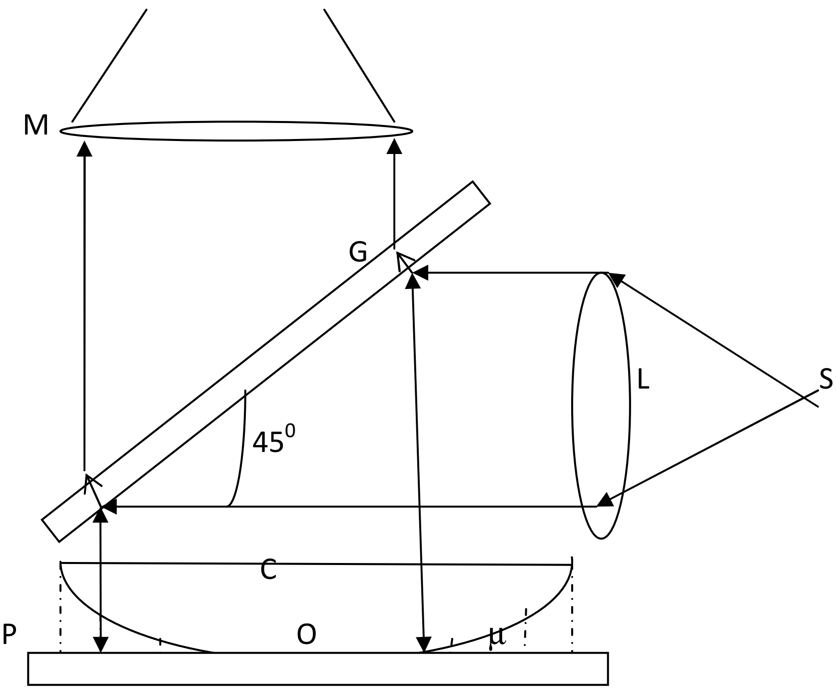


Fig. 5.11. The arrangement for formation of Newton's rings.

P $\rightarrow$ A plane glass plate

C $\rightarrow$ A plano convex lens of large radius of curvature placed on P

O $\rightarrow$ point where C touches P

C being of large radius of curvature it encloses a wedge shaped thin film of refractive index μ between itself and P. It is assumed that μ is less than the refractive index of P.

S $\rightarrow$ Source of light

L $\rightarrow$ A collimating lens.

G $\rightarrow$ A half silvered glass plate inclined at an angle of 45^0 to the horizontal

M$\rightarrow$ a microscope

Beams of light from S are rendered parallel by l and allowed to be incident on G. Being a half silvered plate G will reflect half of the incident light and transmit the remaining. As G is inclined at angle of 45^0 to the horizontal, hence the incident light will suffer 90^0 deviation on reflection and fall on C normally. As C has a large radius of curvature, it can be assumed that the light travels through C and is incident on the thin film normally. Consequently this light will be reflected from C and rereflected from P and finally gets transmitted through G to reach M. The light reflected from the upper and lower surfaces of the film, being coherent, interfere on superposition. Fringes of equal thickness are formed at the focal plane of M. Since the upper surface of the thin film is circular (concave) so the corresponding to a particular order the locus of points having constant thickness will be circular. Hence the fringes will be a set of bright and dark concentric circles with O as centre. These concentric circles or rings are called **Newton's rings.** At the point of contact, O the thickness of the film is zero. This corresponds to zero path difference and a zero order fringe. But due to reflection at the surface of denser medium, a phase change of π occurs, which leads the central fringe to be a dark fringe (Fig. 5.12). **Newtons' rings are also localized fringes as they are formed on the exit surface of the film.**

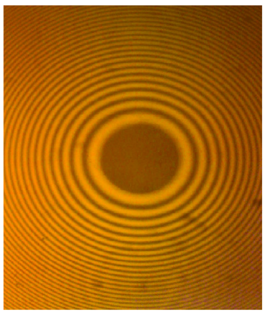


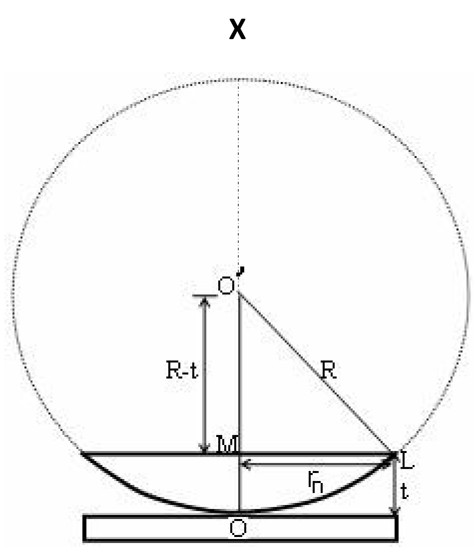
Fig. Photograph of Newton's rings.

Conditions for maxima and minima.

The film concerned here is a wedge shaped thin film. The conditions of maxima and minima are given by:

$$\left.\begin{aligned} 2\mu t &= (2n+1)\frac{\lambda}{2} \quad \text{for maxima} \\ &= n\lambda \quad \text{for minima} \end{aligned}\right\} \qquad \text{..........(1.54)}$$

Calculation of radius of a Newton's rings



O' $\rightarrow$ centre of the circle of which the convex surface of the plano convex lens is a part.

$O'L = O'O = R$ $\rightarrow$ Radius of curvature of the convex surface of the plano convex lens.

$XO = 2R$ $\rightarrow$ diameter of curvature of the convex surface of the plano convex lens.

$ML = r_n$ $\rightarrow$ Radius of the n^{th} order ring.

O $\rightarrow$ Point where the plano conves lens touched the glass plate

$MO = t$ $\rightarrow$ thickness of film corresponding to order ring.

$O'M = R - t$

From the geometry of the figure.

$$XM.MO = ML^2$$

Or $$(2R - t).t = r_n^2$$

The film is a thin film and radius of curvature of the convex surface of the plano convex lens is high. So : $t << 2R$, which gives:

$$\mathbf{2Rt = r_n^2} \quad \text{...(1.55)}$$

So $$r_n = \sqrt{2Rt} \quad \text{..(1.56)}$$

To show that order of a fringe is directly proportional to the square of the radius

Substituting the expression of thickness 't' from equation to (1.55) to (1.54):

$$\left.\begin{aligned} \frac{\mu r_n^2}{R} &= (2n+1)\frac{\lambda}{2} \quad \text{for maxima} \\ &= n\lambda \text{ for minima} \end{aligned}\right\} \quad \text{..(1.57)}$$

Equation (1.58) shows that the order of the fringe is directly proportional to the square of its radius.

In terms of diameter D_n of the n^{th} fringe equation (1.57) becomes

$$\left.\begin{aligned} \frac{\mu D_n^2}{4R} &= (2n+1)\frac{\lambda}{2} \quad \text{for maxima} \\ &= n\lambda \text{ for minima} \end{aligned}\right\} \quad \text{..(1.58)}$$

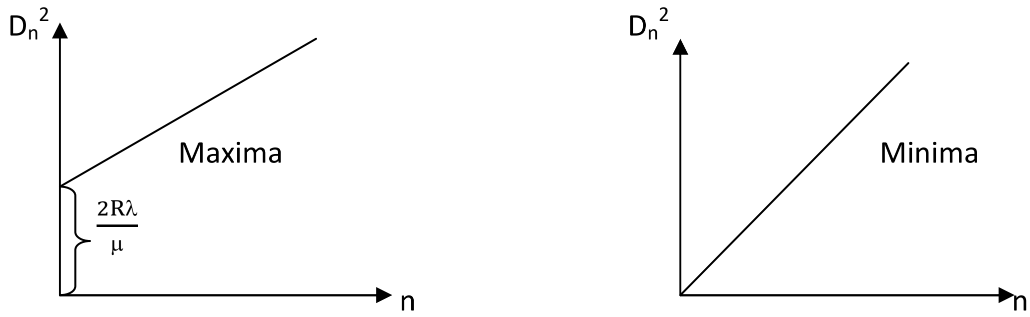


Fig. 5.14. Graph of D_n^2 vs. n.

If a graph of D_n^2 is plotted against order number 'n' then it is found that both for maxima and minima the slope of the graph is:

$$m' = \frac{4R\lambda}{\mu} \quad \text{...(1.59)}$$

For maxima the Y intercept of the graph is

$$Y_0 = \frac{2R\lambda}{\mu} \quad \text{...(1.60)}$$

The graph for minima passes through the origin.

Fringe width

Fringe width is the se[aration betweem successive maxima or successive minima. Hence fringe width 'β' will be the difference of radius betweem successive maxima or successive minima.

$$\beta = r_{m+1} - r_m \quad \text{..(1.61)}$$

Let r_m and r_{m+1} be the radii of the m^{th} and $(m+1)^{th}$ ring respectively. The corresponding diameters are Dm and $D_{m+1.}$ Using equation (1.57)

$$\frac{\mu r_p^2}{R} = m\lambda \qquad \text{for } m^{th} \text{ minima}$$

$$\frac{\mu r_{m+1}^2}{R} = (m+1)\lambda \qquad \text{for } (p+m)^{th} \text{ minima}$$

Subtracting one from the other

$$\frac{\mu(r_{m+1}^2 - r_m^2)}{R} = \lambda$$

Or $$\frac{\mu(r_{m+1} - r_m)(r_{m+1} + r_m)}{R} = \lambda$$

As the m^{th} and $(m+1)^{th}$ fringes are very close to each other hence: $r_{m+1} + r_m \approx 2r_m = D_m$

This gives $\frac{\mu(r_{m+1} - r_m)D_m}{R} = \lambda$

Or $r_{m+1} - r_m = \frac{R\lambda}{\mu D_m}$

Or $\beta = \frac{R\lambda}{\mu D_m}$ …………………………………………(1.62)

The expression for fringe width shows that fringe width inversely proportional to the fringe diameter. So the fringe width decreases as ring diameter increases.

Measurement of unknown wavelength of light using Newton's rings.

The experimental arrangement shown in Fig. for formation of newtom's ring is used with air film for which refractive index μ = 1. The microscope M is focussed to visualise the Newton's rings. The microscope has a micrometer scale attached with it. By shifting the position of the microscope along the rings, the diameters D_p and D_{p+m} of the p^{th} and $(p+m)^{th}$ dark rings respectively are measured using the readings taken from the micrometer scale.

For p^{th} ring: $\frac{D_p^2}{4R} = p\lambda$ ………………………………(1.63)

For $(p+m)^{th}$ ring: $\frac{D_{p+m}^2}{4R} = (p+m)\lambda$ …………………………..(1.64)

Substracting equation (5.29) from (5.30)

$$\frac{D_{p+m}^2 - D_p^2}{4R} = m\lambda$$

Or $\lambda = \frac{D_{p+m}^2 - D_p^2}{4Rm}$ ……………………………(1.65)

'm' can be obtained by counting the fringes. The radius of curvature 'R' of the plano convex lens can be measured by using a spherometer. Substituting all of them in equation (1.65) the value of wavelength 'λ' can be calculated.

Graphical method: The values of D_n for different values of 'n' are measured. D_n^2 is plotted against 'n' The slope of the graph '$m^/$' is calculated

$m^/ = \frac{4R\lambda}{\mu} = 4R\lambda$ for air film

Or $\lambda = \frac{m^/}{4R}$. ……………………………………(1.66)

The radius of curvature 'R' of the plano convex lens can be measured by using a spherometer, which on substitution in equation (1.66) gives the value of λ. Use of bright fringes also gives the same result.

If the wave length of light 'λ'used is known the radius of curvature of the plano convex lens can be determined from equation (1.65) or (1.66)

Measurement of refractive index of a liquid using Newton's rings.

The Newton's ring experiment is first performed with air film between the plano convex lens and glass plate. The microscope M is focussed to visualise the Newton's rings. The microscope has a micrometer scale attached with it. By shifting the position of the microscope along the rings, the diameters D_p and D_{p+m} of the p^{th} and $(p+m)^{th}$ dark rings respectively are measured using the readings taken from the micrometer scale. As before we get

$$\frac{D_{p+m}^2 - D_p^2}{4R} = m\lambda$$

Or $$D_{p+m}^2 - D_p^2 = 4Rm\lambda \quad \text{...} (5.33)$$

The experiment is again performed in a similar manner, after filling the space between the plano convex lens and glass plate with the liquid whose refractive index is to be measured. The film will now have a refractive index 'μ' Let the diameters of the p^{th} and $(p+m)^{th}$ ring be measured as before. Let D'_p and D'_{p+m} be the corresponding diameters. Hence

$$\frac{D'^2_{p+m} - D'^2_p}{4\mu R} = m\lambda$$

Or $$D'^2_{p+m} - D'^2_p = 4\mu Rm\lambda \quad \text{...} (5.34)$$

From equation (5.33) and (5.34)

$$\mu = \frac{D'^2_{p+m} - D'^2_p}{D_{p+m}^2 - D_p^2} \quad \text{...} (5.33)$$

However if λ is known one can use equation (5.34) to calculate μ