Syllabus : UNIT I : WAVE OPTICS: Huygen's wave theory of light; Huygen's principle, construction Huygen's wave front, Laws of reflection and refraction using spherical wave front at a plane surface (derivation of image distance = object distance using Huygen's construction, derivation of Snell's law and ${}_1n_2 = \frac{v_1}{v_2}$).

INTERFERENCE : Coherent sources and their production; Conditions for observing interference (mention); Conditions for constructive and destructive interference (mention)

Coherent sources by division of wavefront : Biprism-theory and working, experiment to determine wavelength; Effect of thin film in the path of one of the beams; Calculation of thickness of the film

Coherent sources by division of amplitude: Interference at thin films - reflected and transmitted light, Colours of thin films; Theory of air wedge; Theory of Newton's rings (Only reflected System). Determination of refractive index of liquid.

Introduction : Geometrical optics

Introduction : Geometrical optics deals with the properties of light like Reflection, Refraction, Dispersion etc.. on the basis of Rectilinear propagation of light (Ray of light – light travelling along a Straight line). Also optical instruments are based on this property.

Physical optics deals with the nature of light. Light is a form energy which is transferred from a source to eye, either by the motion of material particles or by means of wave disturbance travelling through the medium.

Thus following theories of light were proposed: (i) Newton's Corpuscular theory of light (1665) (ii) Huygens' wave theory of light (1678) (iii) Maxwell's electromagnetic theory of light (or radiation) (1873) (iv) Planck's quantum theory of radiation (1900)

Theories of light

(1) Newton's corpuscular theory: says light propagates as a stream of tiny invisible particles called corpuscles. They start from the source and travel in all directions along a straight line with very high speed. When they strike the eye they produce the sensation of vision. Newton attributed different colours of light to different sized particles.

Success: With this theory Newton was able to explain rectilinear propagation of light and laws of reflection.

Drawback: (1) According to this theory light travels faster in denser medium compared to that in rarer medium. This contradicts the experimental results.

(2) It fails to explain interference, diffraction and polarization. Hence the theory was discarded.

(2) Huygens' wave theory: says each point in a light source sends out waves in all directions through a hypothetical medium called ether. i.e. light is a periodic disturbance transmitted in the form of mechanical longitudinal waves with constant speed with ether pervading all space. This theory uses the concept of wavefront based on Huygens' Principle.

Success: This theory was able to explain rectilinear propagation, reflection, refraction, interference and diffraction.

Drawback: (1) It fails to explain polarization of light as it requires light to be transverse in nature. This difficulty was overcome by Fresnel who assumed the propagation of light to be transverse in nature. Though the Huygens' wave theory was modified by Fresnel, yet it had many drawbacks. It necessitated the adoption of a hypothetical medium called ether possessing an extraordinary property of elastic solid. The velocity of transverse wave in a solid medium is given by $v = \sqrt{\frac{\eta}{\rho}}$ η is the modulus rigidity and ρ the density of the medium. Hence, to account high velocity of light, ether must possess high rigidity and low density – the elasticity of ether must be many times, greater than that of steel and its density many times less than that of the best vacuum which is not possible.

(2) The presence of ether could not be proved experimentally. Michelson – Morley experiment failed to establish the presence of ether.

[Maxwell's electromagnetic theory: According to this theory proposed by Maxwell, light waves are oscillations of electric and magnetic field vectors transmitted in space. The directions of electric and magnetic field vectors are at right angles to each other and also right angles to the direction of wave propagation. Thus light is a transverse electromagnetic wave.

Success: (1) This theory explains the properties of light like rectilinear propagation, reflection, refraction, interference, diffraction and polarization.

(2) It also shows how light can travel in free space also. (3) This theory unifies electricity, magnetism and optics. (4) This theory gives the expression for the velocity of light in free space as $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

where μ_0 is the permeability in free space and its value is $4\pi \times 10^{-7}$Hm^{-1} and ε_0 is the permittivity in free space and its value is 8.854×10^{-12} Fm^{-1}. Substituting for the constants in the above equation, the value of c is 3×10^8ms^{-1}.

Drawback: This theory fails to explain the energy distribution in black body radiation spectrum and photoelectric effect.

Planck's quantum theory: According to this theory, the emission and absorption of radiation does not take place continuously as explained by Maxwell's theory. But it takes place in discrete packets of energy called photons and the amount of energy contained in each packet is called quanta. The energy of each photon equal to hν, where h is the Planck 's constant whose value is 6.625×10^{-34} Js and ν is the frequency of the emitted radiation. **Success:** This theory explains black body radiation spectrum. Einstein explained photoelectric effect using this theory. This theory also explains Compton effect.

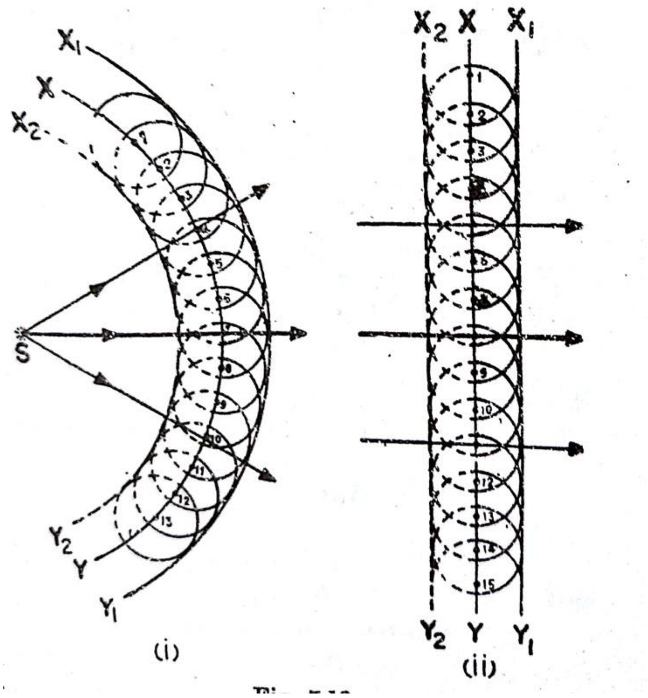
Drawback: This theory cannot explain the properties of light like interference, diffraction and polarization which are based on wave nature of light.

Dual nature of light: The properties of light such as reflection, refraction, interference, diffraction and polarization are explained by considering light to travel in the form of waves. The properties of light like photoelectric effect or processes of emission, absorption and scattering of light can be explained by assuming light to behave like particles only. Thus a single theory cannot explain all the properties of light. Hence the conclusion is that light has **dual nature** i.e., particle and wave nature.]

Huygens' Wavefront According to Huygens' theory a point source of light placed in a isotropic medium emits light waves in all directions. Tese waves spresd out in theform of concentric spheres with the velocity of $3 \times 10^8\ ms^{-1}$. The disturbance will reach simultaneously to all particles lying on the surface of s sphere with the point source as the centre.Such a sphere is called as a wavefront. **The locus of all the particles in the medium which are disturbed at the same instant of time and are in the same phase or same state of vibration is called a wavefront**

The shape of the wavefront depends on the shape of the source of light. 1. Spherical wavefront – This is due to a point source of light. 2. Cylindrical wavefront – This is due to a linear source of light. 3. Plane wavefront – When a point source of a linear source is placed at a large distance, then the part of the spherical or cylindrical wavefront can be considered as a plane wavefront.

Huygens' Principle



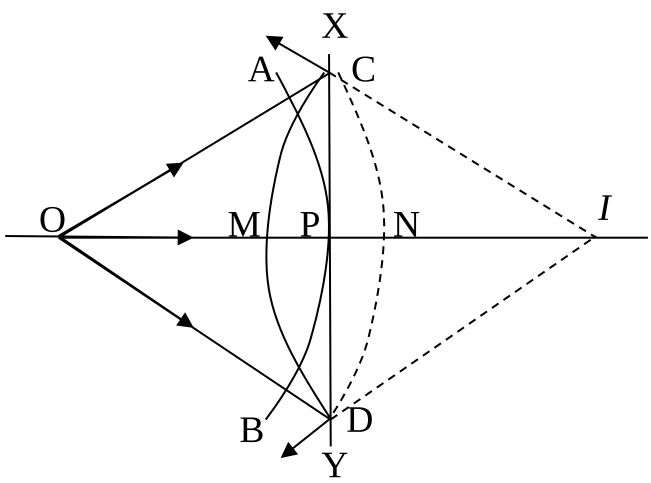
S is the source of light sending out light waves in all directions. After any given interval of time (t) all the particles of the medium on a surface XY will be vibrating in phase. Thus XY is a portion of the sphere of radius vt and centre S. v is the velocity of propagation of waves. XY is called primary wavefront.
According to Huygens' principle, all points on the primary wavefront (1, 2, 3…….) are sources of secondary disturbance. The secondary waves from these sources travel with the same velocity as the original wave and the envelop of all the secondary wavelets after any given interval of time gives rise to secondary wavfront. In the diagram shown XY is the primary wavefront. After an interval of time t' the secondary waves travel a distance vt'. With the points 1,2,3… as centres spheres of radii vt' are drawn. The envelop X_1Y_1 is the secondary wavefront. The backward wavefront X_2Y_2 is not considered in the Huygens'principle.
Based on Huygens wave theory and Huygens principle, by constructing wavefronts, reflection and refraction of light can be explained.

Reflection of a spherical wavefront at a plane surface

Consider a plane reflecting surface XY (a mirror) The waves from the point source of light O (as object) strikes the mirror and gets reflected as shown. APB is the incident spherical wavefront and CMD is the reflected spherical wavefront. In the absence of the mirror the rays would have travelled further and CND will be the incident wavefront.

Thus by the time the secondary waves from A reach C and waves from B reach D, the reflected rays would have reached M from P . Thus AC = BD = PM. In the absence of mirror, the waves would have moved to N from P. Thus PM = PN. I would be the virtual image of the object O. Also $OP = u$, the object distance and $IP = v$, the image distance. Further the curvature of the incident spherical wavfront is same as the reflected spherical wavefront.

From Sagitta's theorem, for the curvature CND with O as centre and CD as cord, $PN = \frac{(CP)^2}{2\,ON}$



As N is close to P, ON = OP. Thus $PN = \frac{(CP)^2}{2\,OP}$ ……(1)

For the curvature CMD with I as centre and CD as cord, $PM = \frac{(CP)^2}{2\,IN}$

As M is close to P, $IM = IP$. Thus $PM = \frac{(CP)^2}{2\,IP}$ ……..(2)

As $PM = PN$ Comparing (1) and (2)

$$\frac{(CP)^2}{2\,OP} = \frac{(CP)^2}{2\,IP}$$

We get $\boldsymbol{OP = IP}$ **or $= v$. Thus object distance = Image distance. i.e. image is formed as far behind the mirror as the object is in front of it.**

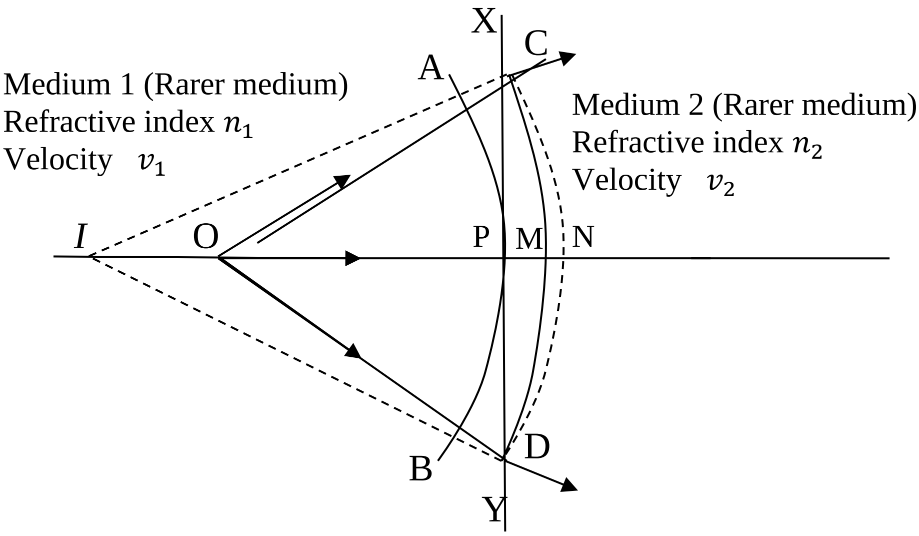
Refraction of a spherical wavefront at a plane surface

Consider a point source of light O (object) placed in a rarer medium of refractive index n_1. The waves from the source of light travelling with a speed v_1 strikes the surface XY of the denser medium along the normal as shown. APB is the incident spherical wavefront.

The secondary waves of light undergo refraction at XY and travels in the denser medium of refractive index n_2 with a velocity v_2 . CMD represents refracted spherical wavefront. By the time t, light waves travel from point A to C or from B to D. the refracted waves travel from P to M with velocity v_2 . In the absence of refracting medium, the waves travel to N with velocity v_1 and CND as the wavefront. Thus AC = BD = PN.

Also $PN = v_1 t$ ……(1) and $PM = v_2 t$ ……(2)

Dividing (2) by (1), we get $\frac{PM}{PN} = \frac{v_2 t}{v_1 t}$ or $\frac{PM}{PN} = \frac{v_2}{v_1}$ …..(3)



For the wavefront CND, O is the centre. With CD as the cord, from Sagitta's theorem $PN = \frac{(CP)^2}{2\,ON}$

As N is close to P, ON = OP. Thus $PN = \frac{(CP)^2}{2\,OP}$ ……(4)

For the curvature CMD with I as centre and CD as cord, $PM = \frac{(CP)^2}{2\,IN}$

As M is close to P, $IM = IP$. Thus $PM = \frac{(CP)^2}{2\,IP}$ ……..(5)

Substituting for PN and PM from (4) and (5) in (3), we get $\frac{(CP)^2}{2\,IP} \times \frac{2\,OP}{(CP)^2} = \frac{v_2}{v_1}$

or $\frac{OP}{IP} = \frac{v_2}{v_1}$ …..(6) By definition $n_1 = \frac{c}{v_1}$ and $n_2 = \frac{c}{v_2}$ where c is the speed of light in vacuum, $\frac{n_1}{n_2} = \frac{v_2}{v_1}$ ………(7)

Comparing equations (6) and (7) $\frac{OP}{IP} = \frac{n_1}{n_2}$

As $OP = object\ distance$ and $IP = image\ distance$, $\frac{\boldsymbol{object\ distance}}{\boldsymbol{image\ distance}} = \frac{\boldsymbol{n_1}}{\boldsymbol{n_2}} = \frac{\boldsymbol{1}}{\boldsymbol{{}_1n_2}}$

(since ${}_1n_2 = \frac{n_2}{n_1}$)

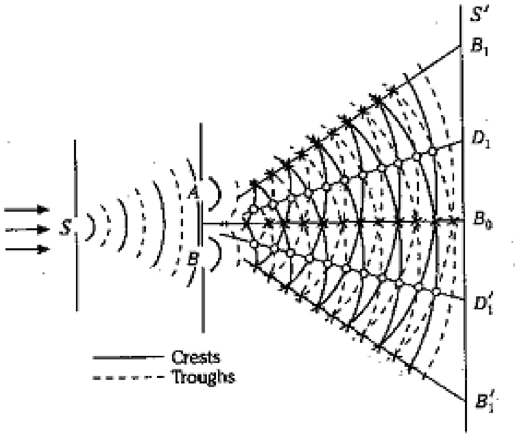
Interference of light

The phenomenon of interference has proved the validiiy of wave theory of light. Thomas Young successfully demonstrated the interference of light from his experiment.

Young's double slit experiment: Light from a monochromatic source is directed on to a fine vertical slit S. A fine beam of light from S is made to fall on two parallel and equally distinct fine slits A and B separated by a small distance.

The two slits act as two sources of light From these two slits, waves spread out in all directions. These waves superpose on each other and produce interference pattern on a screen placed at a distance from the slits.

The interference pattern consists of alternate bright and dark bands. The two light waves arriving in phase at a point on the screen interfere constructively giving rise to a bright band. This is due to overlapping of crest of one wave on the crest of the other or trough of one falling on the trough of the other.



The two light waves arriving out of phase at a point on the screen interfere destructively giving rise to a **dark** band. This is due to overlapping of a crest of one wave on the trough of the other or vice versa. Thus the phenomenon of interference is defined as folloss,

The modification in the intensity of light energy, when two or more light waves superpose on each other is called interference.

This phenomenon is based on the **principle of superposition**. According to this principle, when two or more light waves travel through a point in a medium simultaneously, the net effect at that point is the algebraic sum of the effects produced due to individual waves. At any instant, the resultant displacement is equal to the vector sum of the individual displacements produced by each wave.

It is not possible to show interference due to two independent sources of light. This is because, the two sources may have different amplitudes, different wavelengths and the phases of two may vary. Hence there is a requirement of coherent sources.

Coherent sources: The two light sources that are responsible for producing interference must be coherent sources.

The two light sources are said to be coherent if the two light waves are in the same phase or have constant phase difference.

Also the wavelengths or the frequencies of the two sources must be sam and also they must have nearly same amplitude.
In practice the two independent sources cannot be coherent. But for experimental purposes, the two virtual sources formed from a single source can act as coherent sources. There are two methods of obtaining these sources.

(1) Division of wavefront – For experimental purposes two virtual sources formed due to a single source can act as coherent sources. It is also possible to achieve coherence between a real source and a virtual source. In these cases a wavefront coming from a source is divided into two parts. For example in case of Young's double slit experiment, the primary wavefront incident on the double slit is divided to two parts. Other example is the Fresnel's biprism in which a biprism divides the wavefront into two parts and forms two virtual coherent sources toproduce interference.

(2) Division of amplitude – Here the amplitude of wave emitted by a source of light is divided into two parts where one part is reflected and the other part is transmitted. These reflected or transmitted rays superpose and produce interference. In case of thin film, the incident light is partly reflected at the top surface of the film and the other part is refracted. The refracted light is again reflected at the bottom surface of the film and comes out of the film parallel to the first reflected ray. These tao rays are coherent and they superpose to produce interference. Other examples are Newton's rings, Michelson's interferometer, colors in thin films etc.

Phase difference and path difference

If the path difference between the two waves is λ, the phase difference is equal to 2π.
Suppose for a path difference x, the phase difference is δ.
Then phase difference $\delta = \frac{2\pi}{\lambda} \times x$
Thus $Phase\ difference = \frac{2\pi}{\lambda} \times path\ difference$
Also path difference is $x = \frac{\lambda}{2\pi} \times \delta$ Thus $Path\ difference = \frac{\lambda}{2\pi} \times phase\ difference$

Analytical treatment of interference:

Consider two light waves of same amplitude 'a' and same frequency traveling in a medium in the same direction. The displacement of any particle in the medium due to these waves at an instant of time t is given by

$y_1 = a \sin\omega t$ .....(1)

and $y_2 = a \sin(\omega t+\delta)$ .....(2)

where ω is the angular frequency and δ is the phase difference between the two waves.

From the principle of superposition, the resultant displacement of the particle is,

$y = y_1 + y_2 = a \sin\omega t + a \sin(\omega t + \delta) = a \sin\omega t + a(\sin\omega t \cos\delta + \cos\omega t \sin\delta)$

$= a \sin\omega t + a \sin\omega t \cos\delta + a \cos\omega t \sin\delta$

$= a \sin\omega t\,(1 + \cos\delta) + a \cos\omega t \sin\delta$

Let $a(1 + \cos\delta) = R\cos\theta$ ...... (3) and $a\sin\delta = R\sin\theta$ ......(4)

Then, $y = R\sin\omega t\cos\theta + R\cos\omega t\sin\theta = R(\sin\omega t\cos\theta + \cos\omega t\sin\theta)$

or $y = R\sin(\omega t + \theta)$ ......(5)

Equation (5) represents the resultant wave that is also simple harmonic of the same frequency. **R is the amplitude of the resultant wave** and 'θ' is the phase difference between the resultant wave and the first wave.

Squaring and adding equations (3) and (4)

$R^2 = a^2 + 2a^2\cos\delta + a^2\cos^2\delta + a^2\sin^2\delta$ Thus $R^2 = a^2 + a^2 + 2a^2\cos\delta$

or $R^2 = 2a^2 + 2a^2\cos\delta$ ......(6)

$$\boldsymbol{R^2 = 2a^2(1 + \cos\delta)} \quad \text{or} \quad \boldsymbol{R^2 = 2a^2\, 2\cos^2\frac{\delta}{2}}$$

ir $$\boldsymbol{R^2 = 4a^2\cos^2\frac{\delta}{2}}$$

As the intensity of light is $I \propto R^2$, thus the resultant intensity of light due to superposition of waves is given by $\boldsymbol{I = 4a^2\cos^2\frac{\delta}{2}}$ **....(7)**

Conditions for constructive interference

The interference is said to be constructive, when the net amplitude is maximum and resulting intensity of light is also maximum due to superposition of two waves. Since $I \propto R^2$, I will be maximum at the points in the region of interference where R is maximum.

The intensity of light due to interference is given by $I = 4a^2\cos^2\frac{\delta}{2}$. The intensity will be maximum if the **phase difference is $\delta = 2m\pi$ when m = 0, 1, 2, 3....**

Thus I is maximum when the phase difference between the two waves is δ = 0, 2π, 4π ..... that is even multiples of π.

Path difference x between the waves is given by, $x = \frac{\lambda}{2\pi} \times \delta = \frac{\lambda}{2\pi} \times 2m\pi$.

Thus the condition for **path difference between the two interfering waves to get maximum intensity of light is given by $x = m\lambda$ where m = 0, 1,2 ,3 .....**

The condition for constructive interference is that the phase difference between two light waves must be even multiples of π or the path difference must be integral multiples of λ. **The maximum value of intensity is given by $I_{max} = 4a^2$.**

Conditions for destructive interference

The interference is said to be destructive, when the net amplitude is minimum and resulting intensity of light is also minimum due to superposition of two waves. Since $I \propto R^2$, I will be minimum at the points in the region of interference where R is minimum.

The intensity of light due to interference is given by $I = 4a^2\cos^2\frac{\delta}{2}$. The intensity will be minimum if the **phase difference is $\delta = (2m+1)\pi$ where m = 0, 1, 2, 3....**

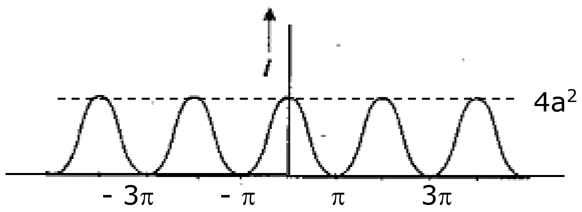
Thus I is minimum when the phase difference between the two waves is δ = π, 3π, 5π ..... that is odd multiples of π.

Path difference x between the waves is given by, $x = \frac{\lambda}{2\pi} \times \delta = \frac{\lambda}{2\pi} \times (2m+1)\pi$.

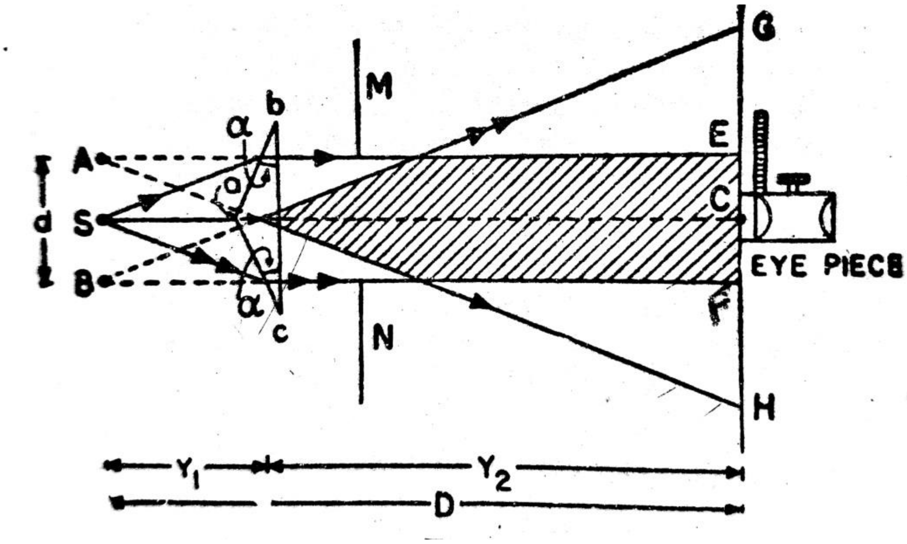
Thus the condition for **path difference between the two interfering waves to get minimum intensity of light is given by $x = (2m+1)\frac{\lambda}{2}$ where m = 0, 1,2 ,3 .....**

The condition for destructive interference is that the phase difference between two light waves must be equal to odd multiples of π or the path difference must be odd integral multiples of λ/2. **The minimum value of intensity is given by $I_{min} = 0$.**

Intensity distribution curve: The variation of intensity of interference fringes with phase or the path difference is as shown. The intensity at the dark region is zero. The intensity at the bright region is directly proportional to $4a^2$. Thus due to interference the energy is transferred from the regions of minimum intensity to regions of maximum intensity. It varies from zero to $4a^2$ and the average value is $(4a^2 + 0)/2 = 2a^2$ as shown. If net intensity is taken due to the two waves without interference, then it turns out be proportional to $2a^2$. ($a^2 + a^2 = 2a^2$). **Thus interference phenomenon is in accordance with law of conservation of energy**.



Fresnel's Biprism



Fresnel used a biprim to demonstrate the phenomenon of interference. The biprism abc consists of two acute angled prisms placed base to base.

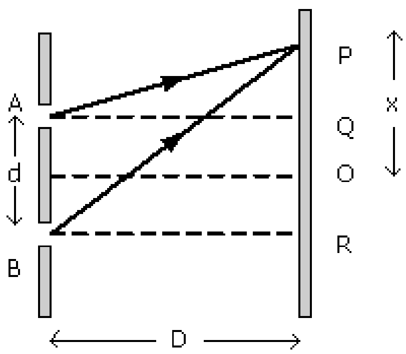
It is constructed as a single prism of obtuse angle of about 179^0. The other two angles are acute angles of 30' each. The light from a monochromatic source is incident on a slit S. The light from S falls on the biprism as shown in the diagram. The light falling on the lower part ac of the prism is bent upwards and appears to come from the point B.

Similarly the light falling on the upper part ab of the prism is bent downwards and appear to come from point A. Hence A and B act as coherent sources which are virtual sources in nature. Let the distance between the virtual sources be d. If a screen is placed at C, then interference fringes are formed between E and F. An eyepiece is placed at the position of the screen then bright and dark fringes are seen in the field of view.

Thus biprism is used to divide the incident wavefront into two parts to produce coherent sources. The light from these coherent sources interfere to produce fringes.

Theory of Biprism

Expression for the fringe width in the interference pattern :



Light from a monochromatic source is directed on to a slit S. The biprsim splits the waves into two parts producing two coherent sources A and B separated by a small distance d. The screen is placed at a large distance D from the sources and parallel to it.

Consider a point O on the screen which is equidistant from both the slits such that AO = BO. Thus the path difference between the light waves from the slits reaching the point O is zero resulting in a bright fringe at O called the **central bright fringe**.

Consider a point P on the screen at a distance x from point O. The path difference between the light waves reaching point P is given by

Path difference = BP – AP (from the diagram)

From Δ BRP, $(BP)^2 = (BR)^2 + (RP)^2$

Thus $BP^2 = D^2 + \left(x + \frac{d}{2}\right)^2$ ....(1) (OQ = d/2)

From Δ AQP, $(AP)^2 = (AQ)^2 + (QP)^2$

Thus $AP^2 = D^2 + \left(x - \frac{d}{2}\right)^2$ ....(2)

$(BP)^2 - (AP)^2 = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(x - \frac{d}{2}\right)^2\right]$

$(BP)^2 - (AP)^2 = \left(x + \frac{d}{2}\right)^2 - \left(x - \frac{d}{2}\right)^2$

or (BP + AP) (BP – AP) $= \left(x^2 + \frac{2xd}{2} + \frac{d^2}{4}\right) - \left(x^2 - \frac{2xd}{2} + \frac{d^2}{4}\right)$ = 2xd

As d is very small compared to D, BP ≅ AP. ≅ D. Thus BP + AP = 2D

From the above equation 2D (BP – AP) = 2xd

or BP – AP = $\frac{xd}{D}$

To get a bright fringe at point P, the path difference = m λ

Thus $\frac{xd}{D}$ = m λ or $x = \frac{m\lambda D}{d}$

The distance of the mth bright fringe from the centre O is $x_m = \frac{m\lambda D}{d}$ … (3)

The distance of the (n - 1) th bright fringe O is $x_{m-1} = \frac{(m-1)\lambda D}{d}$ … (4)

The distance between two consecutive bright fringes is $x_m - x_{m-1} = \frac{\lambda D}{d}$

To get a dark fringe at point P, the path difference = $(2m + 1)\frac{\lambda}{2}$

Thus $\frac{xd}{D} = (2m + 1)\frac{\lambda}{2}$ or $x = \frac{(2m+1)\lambda D}{2d}$

The distance of the mth dark fringe from the centre O is $x_m = \frac{(2m+1)\lambda D}{2d}$

The distance of the (m - 1)th dark fringe O is $x_{m-1} = \frac{(2(m-1)+1)\lambda D}{2d}$

The distance between two consecutive dark fringes is $x_m - x_{m-1} = \frac{\lambda D}{d}$

Thus the distance between any two consecutive bright or dark fringes called **fringe width** is $\boldsymbol{\beta = \frac{\lambda D}{d}}$

Characteristics of interference pattern

(1) The widths of all bright and dark fringes are the same.

(2) The fringe width depends on
   (a) the distance between the coherent sources (d) ,
   (b) the wavelength (λ) of the monochromatic source used
   (c) the distance between the coherent sources and the screen (D).

(3) The fringe width can be increased by
   (a) decreasing the distance between the coherent sources,
   (b) increasing the distance between the coherent sources and the screen.
   (c) Using light of higher wavelength

(4) If white light is used as the source then central bright band is white with colored bands on either side of the central bright band.

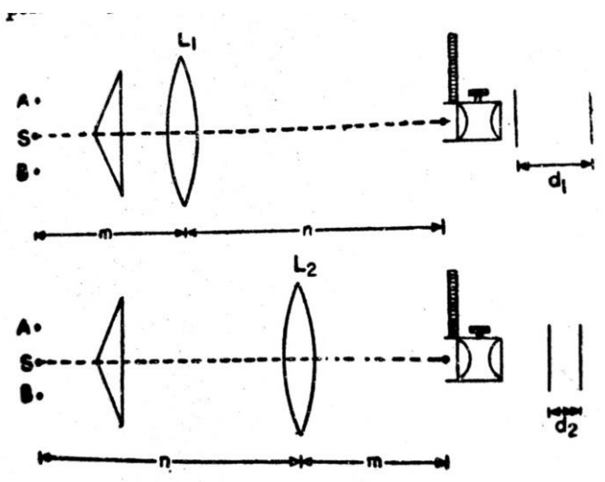
Determination of wavelength of light using biprism

A monochromatic light is made to incident on a vertical slit S placed close to a biprism in such a way that the slit is parallel to the refracting edge of the biprism. This arrangement is done on a optical bench. A micrometer eyepiece is placed at a distance from the prism so that interference fringes can be viewed.

Let D be the distance between the slit S and the eyepiece and d be the distance between the two virtual sources A and B. The eye piece is moved horizontally perpendicular to optical bench to find the fringe width. Let l be the distance moved for 20 fringes. Then the fringe width $\beta = \frac{l}{20}$. But the fringe width is given by $\beta = \frac{\lambda D}{d}$. By knowing D, d and , the wavelength of light λ can be determined.

Determination of distance between the two virtual sources (d) :

The displacement method is used to determine d. A convex lens is placed between biprism and eye piece (say at L_1). The images of the virtual sources are seen in the field of view in the eye piece. The distance between the two sources is determined. Let it be d_1.



From the diagram, we can write $\frac{d_1}{d} = \frac{v}{u} = \frac{n}{m}$ ....(1)

The lens is now moved close to eye piece (L_2) to get the clear images again. Let the distance be d_2.. Again the relation can be expressed as $\frac{d_2}{d} = \frac{v}{u} = \frac{m}{n}$ ....(2)

From equations (1) and (2), we see that $\frac{d_1 d_2}{d^2} = 1$ or $d = \sqrt{d_1 d_2}$.

Using the value of d, D and β the wavelength of light λ can be calculated.

Conditions for sustained interference pattern:

1. The two sources of light used must be monochromatic i.e. having same wavelength or same frequency.
2. The amplitudes of the two superposing waves should be equal or nearly equal. The two waves must be traveling in the same direction with the same velocity
3. The two sources producing interference must be coherent i.e. two superposing waves must be in phase or must have a constant phase difference.
4. The distance between the two coherent sources must be as small as possible.
5. The two slits used as coherent sources must be very narrow.
6. If the two interfering waves are polarized, then the plane of polarization of the two must be same.

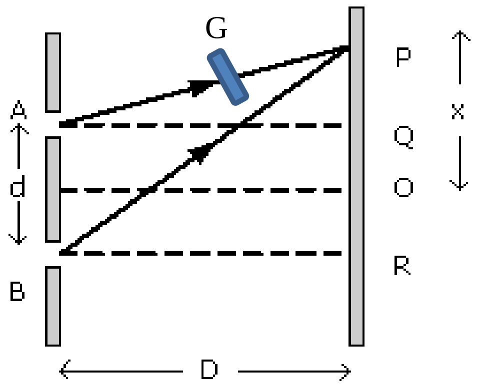
Note : The intensity of the coherent sources depends on the width of the two slits. If x_1 and x_2 are the widths of the two slits and I_1 and I_2 are the corresponding intensities, then $\frac{I_1}{I_2}=\frac{x_1}{x_2}$

Also if a and b are the amplitudes of the light waves from the two sources then $\frac{I_1}{I_2}=\frac{a^2}{b^2}$ or $\frac{a}{b}=\sqrt{\frac{I_1}{I_2}}$ Also $\frac{I_{max}}{I_{min}}=\frac{(a+b)^2}{(a-b)^2}$.

Determination of thickness of a thin sheet of transparent material

Biprism experiment is used to determine thickness of a given thin sheet of a transparent material like glass or a mica sheet.

Consider A and B as virtual coherent sources. The point O is equidistant from A and B. When a transparent sheet G of thickness 't' and refractive index 'n' is introduced in the path of one of the beams as shown, the fringe which was originally at O will be shifted to point P.



The time taken by the wave to travel from B to P in air issame as the time taken by the wave to travel from A to P partly through air and partly through the film or the plate.

Suppose v_0 is the velocity of light in air and v is the velocity of light in the medium of the film,

then $\frac{BP}{v_0}=\frac{AP-t}{v_0}+\frac{t}{v}$

or $BP = AP - t + \frac{v_0}{v}t$

But $\frac{v_0}{v}=n$, the refractive index of the material of the film, then $BP - AP = \frac{v_0}{v}t + \ t$ or $BP - AP = nt + \ t = t(n-1)$.

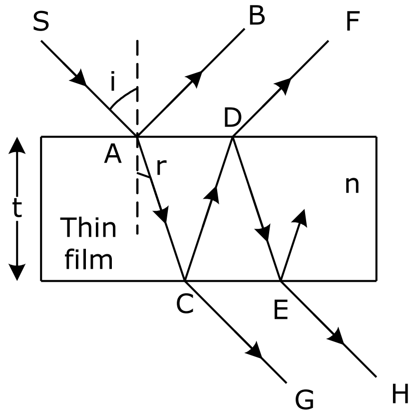
If P is the point originally occupied by the mth fringe, then the path difference is $BP - AP = m\lambda$. Thus $\boldsymbol{t(n-1) = m\lambda}$ or $\boldsymbol{t = \frac{m\lambda}{n-1}}$.

The distance through which the fringe is shifted is given by $x = \frac{m\lambda D}{d}$

Also $m\lambda = \frac{xd}{D}$ Thus $t(n-1) = \frac{xd}{D}$

Thus knowing x i.e. the distance through which the central fringe is shifted, D, d and n, the thickness of the transparent film 't' can be determined.

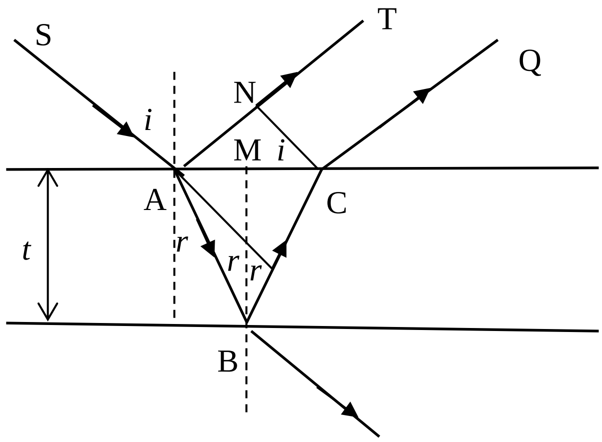
Interference at thin films



A film of transparent refracting material of very small thickness is called a **thin film.**

Examples of interference due to thin films are, colours produced by a thin film of oil on the surface of water and also by the thin film of a soap bubble. Young was ableto explain the phenomenon on the basis of interference between light reflected from the top and bottom surface of a thin film. It is observed that the interference in thin films take place due to (1) reflected light and (2) transmitted light. Thus this is based on the division of amplitude.

Interference due to reflected light by a thin film



Consider a transparent film of thickness t and of refractive index n. A ray SA incident on the upper surface of the film is partly reflected along AT and partly refracted along AB. At B part of it is reflected along BC and finally emerges out along CQ.

It is required to find the path difference between the two reflected rays AT and CQ. A normal CN is drawn to AT and normal AM to BC is drawn. Let the angle of incidence be i and the angle of refraction be r.

The reflected ray along AT is a reflected ray from a denser medium. Thus when light is reflected from the surface of an optically denser medium (air- medium interface) a phase change π equivalent to a path difference $\frac{\lambda}{2}$ occurs.

The ray CQ has travelled a longer path thanthat along AT due to refraction and reflection inside the film. But here no phase change occurs. From the diagram, the path difference = path traversed in the film ABC – path traversed in air AN

The optical path difference is $x = n(AB + BC) - AN$ ....(1)
From the triangle ANC, $AN = AC \sin i$
Also, from the diagram $AC = AM + MC$ Thus $AN = (AM + MC)\sin i$
or $AN = (t\tan r + t\tan r)\sin i$
(Since from triangle, AMB and BMC, AM = t tan r and MC = t tan r)
Thus $AN = 2t\tan r \times \sin i = 2t\,\frac{\sin r}{\cos r} \times \sin i$ ....(2)
From snell's law $= \frac{\sin i}{\sin r}$, thus $\sin i = n\, sin\, r$
Equation (2) now can be written as $AN = 2t\,\frac{\sin r}{\cos r} \times n\, sin\, r = 2nt\,\frac{sin^2 r}{\cos r}$
Thus $AN = 2nt\,\frac{sin^2 r}{\cos r}$ .....(3)
Also from the triangle ABM, $AB = \frac{t}{\cos r}$ ......(4)
and from triangle BMC, $BC = \frac{t}{\cos r}$ .....(5)
substituting for respective terms from (3), (4) and (5) in (1), we get
$x = n(AB + BC) - AN = \frac{2nt}{\cos r} - 2nt\,\frac{sin^2 r}{\cos r}$
Thus, path difference $x = \frac{2nt}{\cos r}(1 - sin^2 r) = \frac{2nt}{\cos r}\, cos^2 r$
Thus $x = 2nt\,\cos r$
The total path difference $\boldsymbol{x = 2nt\, cosr - \frac{\lambda}{2}}$ ....(6) (as reflection at surface of denser medium a path change of $\frac{\lambda}{2}$ occurs)

Condition for maxima and minima

(1) If the path difference $x = m\lambda$, where m = 0, 1, 2, 3, ..., constructive interference takes place and the film appears bright. Thus $m\lambda = 2\,nt\cos r - \frac{\lambda}{2}$

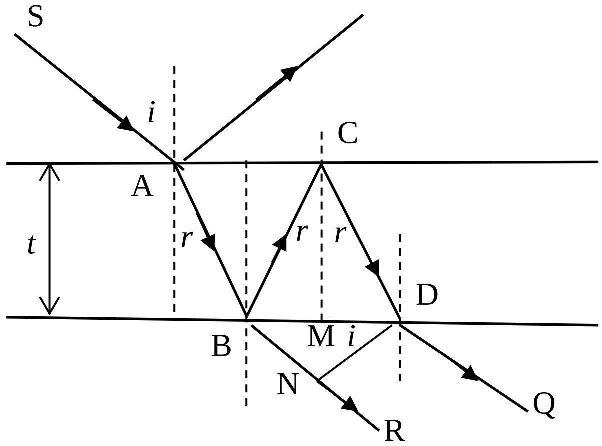
or $\boldsymbol{2\,nt\cos r = (2m + 1)\frac{\lambda}{2}}$ ....(7)

(2) If the path difference is $= (2m + 1)\frac{\lambda}{2}$, where m = 0, 1, 2, 3, ..., destructive interference takes place and the film appears dark.

Therefore $(2m + 1)\frac{\lambda}{2} = 2\,nt\cos r - \frac{\lambda}{2}$

or $\boldsymbol{2\,nt\cos r = (m + 1)\lambda}$ Here m is an integer only. Thus (m + 1) is also an integer and can be taken as k. Thus $\boldsymbol{2\,nt\cos r = k\,\lambda}$ .....(8) where k = 0, 1, 2, 3, ...

Interference due to transmitted light by a thin film



Consider a transparent film of thickness t and of refractive index n. A ray SA incident on the upper surface of the film is refracted along AB. At B, the ray is partly reflected along BC and partly refracted along BR. At C, the ray gets reflected along CD and refracted along DQ. It is required to find the path difference between the two transmitted rays BR and DQ. A normal DN is drawn to BR. Let the angle of incidence be i and the angle of refraction be r.

The transmitted ray along BR is a refracted ray from a denser medium. Thus when light is refracted from the denser to rarer medium, no additional path difference occurs.

The ray DQ has travelled a longer path than that along BR due to refraction and reflection inside the film. But here no phase change occurs. From the diagram, the path difference = path traversed in the film BCD – path traversed in air BN.

The optical path difference is $x = n(BC + CD) - BN$ ....(1)

From the triangle BND, $BN = BD \sin i$

Also, from the diagram BD = $BM + MD$ Thus B$N = (BM + MD) \sin i$

or $BN = (t \tan r + t \tan r) \sin i$

(Since from triangle, BCM and MCD, BM = t tan r and MD = t tan r)

Thus $BN = 2t \tan r \times \sin i = 2t \frac{\sin r}{\cos r} \times \sin i$ ....(2)

From snell's law = $\frac{\sin i}{\sin r}$, thus $\sin i = n \, sin \, r$

Equation (2) now can be written as B$N = 2t \frac{\sin r}{\cos r} \times n \, sin \, r = 2nt \frac{sin^2 r}{\cos r}$

Thus $BN = 2nt \frac{sin^2 r}{\cos r}$ .....(3)

Also from B the triangle BMC, BC= $\frac{t}{\cos r}$ ......(4)

and from triangle MCD, CD= $\frac{t}{\cos r}$ .....(5)

substituting for respective terms from (3), (4) and (5) in (1), we get

$x = n(BC + CD) - BN = \frac{2nt}{\cos r} - 2nt \frac{sin^2 r}{\cos r}$

Thus, path difference $x = \frac{2nt}{\cos r}(1 - sin^2 r) = \frac{2nt}{\cos r} cos^2 r$

Thus $x = 2nt \cos r$

The total path difference $\boldsymbol{x = 2nt \, cosr}$ ....(6)

Condition for maxima and minima

The path difference is ` $\boldsymbol{x = 2 \, nt \cos r}$ ....(2)

(1) If the path difference $x = m\lambda$, where m = 0, 1, 2, 3, ..., constructive interference takes place and the film appears bright.

Thus $\mathbf{2\,nt\cos r = m\lambda}$ ....(3)

(2) If the path difference is $= (2m+1)\frac{\lambda}{2}$, where m = 0, 1, 2, 3, ..., destructive interference takes place and the film appears dark.

Therefore $(2m+1)\frac{\lambda}{2} = 2\,nt\cos r$

or $\mathbf{2\,nt\cos r = (2m+1)\frac{\lambda}{2}}$ .....(4) where m = 0, 1, 2, 3, ...

Colors of thin films:

When a thin film is illuminated by white light, the film appears colored in the reflected light due to interference. Only those colors are visible in the reflected light which satisfies the conditions for constructive interference.

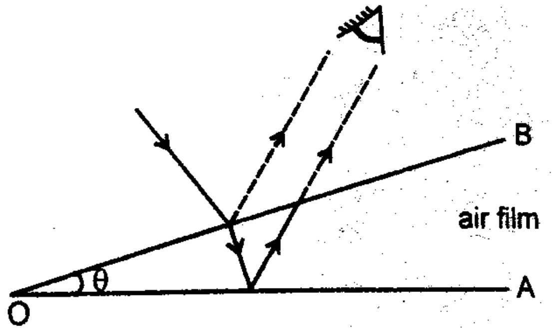
The color depends on the angle of incidence and the thickness of the film. Further since the path difference depends on the angle of refraction and hence on the angle of incidence, different colors can be seen from different angles.

Colors are observed in the transmitted beam also. However those colors which are seen in the reflected system will be missing in the transmitted system and vice-versa.

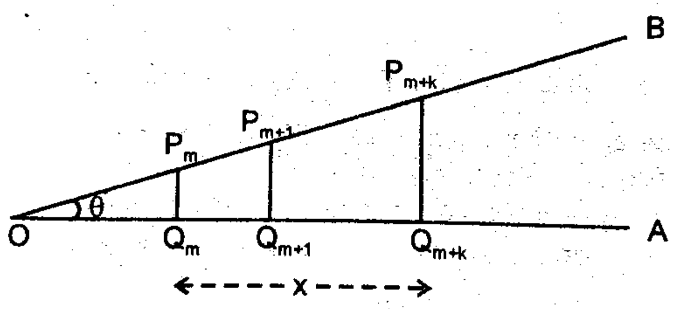
The colours which we see on a soap bubble and on a film of oil on the surface of water are examples of interference at thin films.

Wedge shaped thin film – Air wedge

Consider two optically flat transparent glass plates OA and OB inclined at an angle θ as shown in the diagram. Such an arrangement encloses a wedge shaped air film.



The thickness of the air film increases from O to A. When such an air film is viewed with reflected monochromatic light, interference fringes of equal bright and dark regions are observed which are parallel to the line of intersection of the two surfaces. The interference occurs due to superposition of light waves reflected from the air film based on division of amplitude of light.



Suppose the m^{th}bright fringe occurs at a point P_m (as shown in the diagram). The thickness of the air film at P_m is equal to $t = P_mQ_m$. As the angle of incidence is small, $\cos r = 1$.

The condition for a bright fringe in case of a thin film is , $2\,nt\cos r = (2m+1)\frac{\lambda}{2}$

As the thin film is air, the refractive index n = 1 and as $\cos r = 1$, the above equation can be written as $2t = (2m+1)\frac{\lambda}{2}$ or $2\,P_mQ_m = (2m+1)\frac{\lambda}{2}$ ....(1)

The next bright fringe $(m+1)$ will occur at p_{m+1} , such that

$$2\,P_{m+1}Q_{m+1} = (2(m+1)+1)\frac{\lambda}{2} \quad \text{or} \quad 2\,P_{m+1}Q_{m+1} = (2m+3)\frac{\lambda}{2} \quad ....(2)$$

Subtracting (1) from (2) $P_{m+1}Q_{m+1} - P_mQ_m = \frac{\lambda}{2}$ ...(3)

Thus, the next bright fringe will occur at the point when the thickness of the air film increases by $\frac{\lambda}{2}$. Suppose the $(m+k)th$ bright fringe is at P_{m+k}. Then, there will be k bright fringes between P_m and P_{m+k} such that $P_{m+k}Q_{m+k} - P_mQ_m = \frac{k\lambda}{2}$ ......(4)

If the distance $Q_{m+k}Q_m = x$

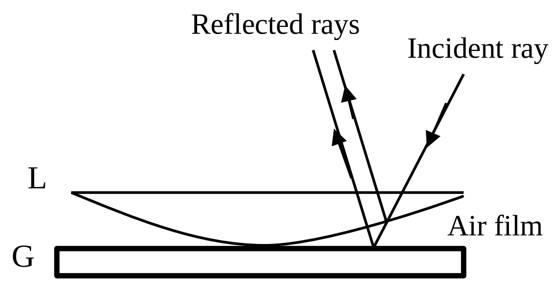
The angle $\theta = \frac{P_{m+k}Q_{m+k} - P_mQ_m}{Q_{m+k}Q_m} = \frac{\frac{k\lambda}{2}}{x} = \frac{k\lambda}{2x}$ ...(5) or $x = \frac{k\lambda}{2\theta}$ .....(6)

The angle of inclination is the angle between the surfaces OA and OB. Here x is the distance corresponding to k fringes.

Thus the fringe width $\boldsymbol{\beta} = \frac{x}{k} = \frac{\lambda}{2\theta}$ .....(7)

If a thin wire of thickness d is placed between the plates OA and OB to form a wedge shaped air film and l is the length of the air film, then $\theta = \frac{d}{l}$, thus the above equation is $\frac{d}{l} = \frac{\lambda}{2\beta}$ *or* $\boldsymbol{d} = \frac{\lambda\,l}{2\beta}$.

Newton's rings

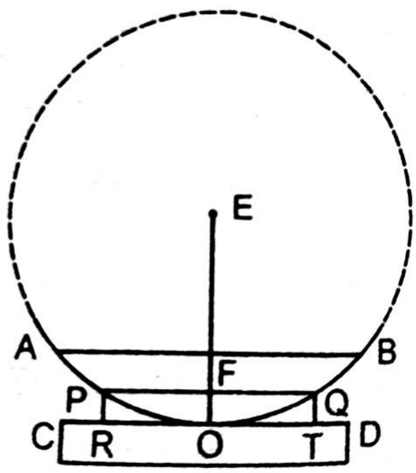


When a plano convex lens of large focal length with its convex surface is placed on a plane glass plate, a thin film of air of increasing thickness is formed.

The interference fringes formed are circular bright and dark rings. This formation is due to division of amplitude wherein the superposition of reflected or transmitted waves from the air film occurs. When viewed with white light, the fringes are coloured.

Theory of Newton's rings by Reflected light

Consider a plano convex of radius of curvature R and let t be the thickness of the air film at a distance of OT = r from the point of contact O. Here, interference is due to reflected light. Therefore, for the bright ring



$2\,nt\cos r = (2m+1)\frac{\lambda}{2}$ .....(1) where m = 0, 1, 2, 3,......

As θ is small, cos r =1, and for air n = 1

Thus $2\,t = (2m+1)\frac{\lambda}{2}$ ....(2)

For the dark ring $2\,nt\cos r = m\lambda$ where m = 0,1 2, 3,.....

or $2\,t = m\lambda$ .... (3)

In the diagram, $PF \times FQ = OF \times (2R - OF)$ .....(4) (Sagitta's theorem)

But, $PF = FQ = r,\ OF = TQ = t$ and $2R - t = 2R$ (approximately)

Thus equation (4) becomes $r^2 = 2R\,t$ or $t = \frac{r^2}{2R}$

Substituting the value of t in equations (2) and (3) we have

For bright fringe $2\,\frac{r^2}{2R} = (2m+1)\frac{\lambda}{2}$ or $r^2 = (2m+1)\frac{\lambda R}{2}$

or $\boldsymbol{r = \sqrt{\frac{(2m+1)\lambda R}{2}}}$ .....(5)

For dark rings, $2\,t = m\lambda$ or $2\,\frac{r^2}{2R} = m\lambda$ or $\boldsymbol{r = \sqrt{m\lambda R}}$ .....(6)

When m = 0, the radius of the dark ring is zero and the radius of the bright ring is $\boldsymbol{r = \sqrt{\frac{\lambda R}{2}}}$. Therefore the centre is dark and alternately dark and bright rings are formed.

Result : The radius of the dark ring is proportional to $\sqrt{m}$, $\sqrt{\lambda}$ and $\sqrt{R}$. Also the radius of the bright ring is proportional to $\sqrt{2m+1}$, $\sqrt{\lambda}$ and $\sqrt{R}$.

The diameter of a dark ring is $D = 2r = 2\sqrt{m\lambda R}$. Thus, the diameter of central dark ring is zero. The diameter of the first dark ring is $D_1 = 2\sqrt{\lambda R}$. Similarly for the second, third etc.. are $D_2 = 2\sqrt{2\lambda R}$, $D_3 = 2\sqrt{3\lambda R}$.

The difference in diameters of 16th and the 9th rings are $D_{16} - D_9 = 2\sqrt{16\lambda R} - 2\sqrt{9\lambda R}$

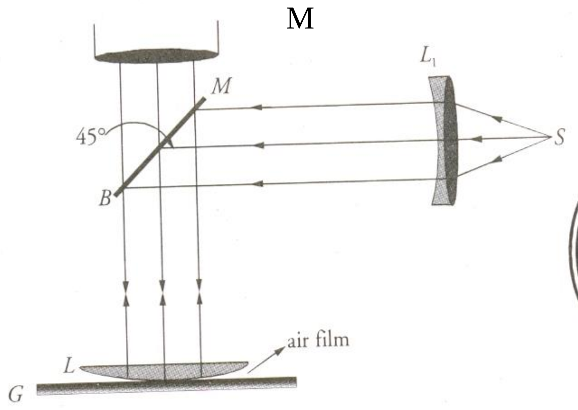
Thus $D_{16} - D_9 = 2\sqrt{\lambda R}$. Similarly $D_4 - D_1 = 2\sqrt{\lambda R}$.

Therefore the fringe width decreases with the order of the fringe and the fringes get closer with increase in their order.

In general, $D_m^2 - D_n^2 = 4(m-n)\lambda R$. The radius of curvature of the convex lens can be determined using the relation $\boldsymbol{R = \frac{D_m^2 - D_n^2}{4(m-n)\lambda}}$.

The Newton's rings apparatus consists of a Plano-convex lens of large radius of curvature (L) placed on an optically flat glass plate (G), so that the convex surface is in contact with the glass plate as shown. Light from source S is incident on a glass plate (B) inclined at 45° with the direction of incident rays.

A part of light is incident on L after reflection from B. The light falls on a thin air film formed between lens and glass plate G. Interference pattern is observed through a microscope (M). The pattern consists of circular alternate bright and dark rings with centre as a dark spot.



Newton's

The wavelength of light can be determined using the relation, $= \frac{D_m^2 - D_n^2}{4(m-n)R}$.

Refractive index of water using Newton's rings

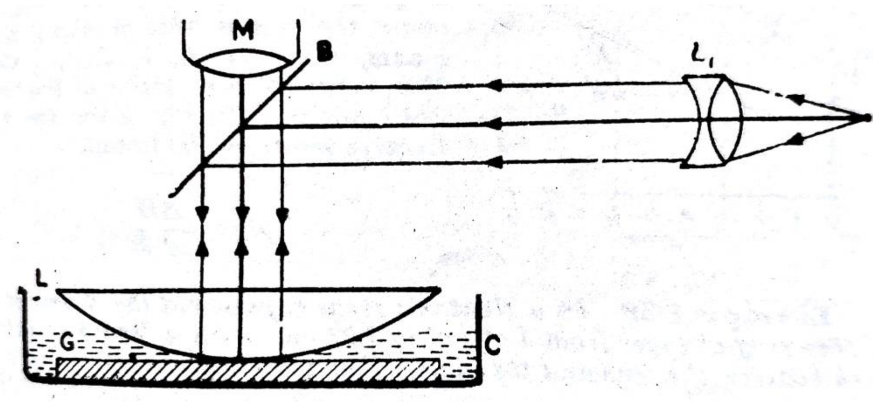
The experiment is performed when there is air between the plano convex lens and the glass plate. The lens arrangement is placed in a metal container C as shown. The diameters of the mth and (m + k)th dark rings are measuredwith the help of the travelling microscope.

For air the diameter of the mth dark ring $D_m^2 = 4\, m\lambda R$

and for(m + k)th dark ring $D_{m+k}^2 = 4(m + k)\lambda R$

Thus $D_{m+k}^2 - D_m^2 = 4(m + k)\lambda R - 4\, m\lambda R$

or $D_{m+k}^2 - D_m^2 = 4\, k\lambda R$ .....(1)



The liquid whose refractive index is to be determined is poured into the container without disturbing the arrangement. Now the liquid replaces the lower surface of the lens and upper surface of the glass plate. The diameters of the mth and (m+k)th rings are determined using the travelling microscope.

The condition for the dark ring in the presence of the liquid of refractive index n is

$2\, nt \cos r = m\lambda$ or $2\, nt = m\lambda$

But $t = \frac{r^2}{2R}$ Thus $2\, n \frac{r^2}{2R} = m\lambda$ or $r^2 = \frac{m\lambda R}{n}$.

As $r = \frac{D}{2}$ Thus $D^2 = \frac{4m\lambda R}{n}$

If D'_m and D'_{m+k} are the diameters of the mth and (m + k)th dark rings in the presence of liquid, then

For liquid the diameter of the mth dark ring $D'^{2}_m = \frac{4\,m\lambda R}{n}$

and for(m + k)th dark ring $D'^{2}_{m+k} = \frac{4(m+k)\lambda R}{n}$

Thus $D'^{2}_{m+k} - D'^{2}_m = \frac{4(m+k)\lambda R}{n} - \frac{4\,m\lambda R}{n}$

or $D'^{2}_{m+k} - D'^{2}_m = \frac{4\,k\lambda R}{n}$

The refractive index of the liquid is calculated as $\boldsymbol{n = \frac{4\,k\lambda R}{D'^{2}_{m+k} - D'^{2}_m}}$ .... (2)

Also n can be determined by dividing (2) by (1), i.e. $\boldsymbol{n = \frac{D^{2}_{m+k} - D^{2}_m}{D'^{2}_{m+k} - D'^{2}_m}}$

Part A : Eight mark Questions

1 (a) Explain Huygens' wave theory.
   (b) Verify the law of refraction for a spherical wavefront incident on a plane surface using Huygens' wave theory.

2 (a) Explain Huygens' principle.
   (b) Verify the law of reflection for a spherical wavefront incident on a plane surface using Huygens' wave theory.

3 (a) What is interference of light? Explain
   (b) Mention the conditions required for constructive and destructive interference of light.

5 (a) Explain how interference fringes are produced using biprism.
   (b) Describe Fresnel's biprism method for the determination of wavelength of light.

6 (a) State and explain Huygens' principle
   (b) Obtain an expression for band width of interference fringes produced by biprism.

7 Discuss the effect of introducing a thin transparent plate in the path of the interfering beams in a biprism. Deduce an expression for the displacement of the fringes. Briefly explain how thin can be used to determine the thickness of a mica sheet.

8 (a) State the conditions for the sustained interference
   (b) Write a note on production colours in thin films

9 (a) Explain any two methods of obtaining coherent sources.
   (b) Describe with theory the formation of bright and dark interference fringes in the light reflected from a thin film.

10 (a) What are the methods used to get coherent sources.
   (b) Describe with theory the formation of bright and dark interference fringes in the light transmitted from a thin film.

11 (a) What are Newton's rings?

(b) Show that the radii of the dark rings are in the ratio of square root of natural numbers.

12 Describe an experiment to determine the refractive index of water using Newton's rings.

13 (a) Explain with a diagram and necessary theory the interference in a wedge shaped thin film. Derive an expression for the fringe width.

(b) Why does the centre of Newton's ring pattern appear dark in reflected light?

Part B : Numerical problems

1 The distance between the two coherent sources of lightis 0.16 mm. Interference fringes are obtained on a screen placed at a distance of 1.2 m from the sources. It is found that for a certain monochromatic source of light the second bright fringe is at a distance of 9.6 mm from the central fringe. What is the wavelength of the source?

[Hint : $x_m = \frac{m\,\lambda\,D}{d}$, $here\ m = 2,\ \lambda = 6.4\ \times 10^{-7}\ m$]

2 The distance between two coherent sources is 1 mm and the screen is 1 m away from the sources. The second dark band is 0.1 cm from the central bright fringe. Find the wavelength and the distance of the second bright band from the central bright band.

[Hint : $x_m = \frac{(2m+1)\,\lambda\,D}{2d}$, $here\ for\ second\ dark\ m = 1,\ \lambda = 6.667\ \times 10^{-7}\ m$

For second bright fringe m = 2, $x_m = \frac{m\,\lambda\,D}{d} = 1.33\ \times 10^{-3}\ m$]

3 A beam of light consisting of two wavelengths 650 nm and 520 nm is used to obtain interference fringes in a Young's double slit experiment. (a) Find the distance of the third bright fringe on the screen from the central maximum for the wavelength 650 nm, (b) What is the least distance from the central maximum when the bright fringes due to both the wavelengths coincide. Assume d = 2 mm, D = 1.2 m. [Hint : $x_m = \frac{m\,\lambda\,D}{d}$, $here\ m = 3,\ x_3 = 0.177\ \times 10^{-2}\ m,$ $\frac{m\,\lambda_1\,D}{d} = \frac{(m+1)\,\lambda_2\,D}{d}$, $thus\ \ m = 4,\ x = \frac{m\,\lambda_1 D}{d} = 0.156\ \times 10^{-2}\ m$

4 In a biprism experiment interference fringes are obtained in the focal plane of an eye-piece at a distance of 1m from slit. The separation between the images for conjugate positions of a convex lens are 3.17mm and 1.75 mm. If the width of the fringes is 0.025 cm, find the wavelength of light used.

[Hint : $d = \sqrt{d_1 d_2},\ \ where\ d_1 = 3.17mm, d_2 = 1.75mm,\ \ \beta = \frac{\lambda\,D}{d}$, $Hence\ \lambda = \frac{\beta\,d}{D} = 5.888\ \times 10^{-7}\ m$]

5. In a biprism experiment fringes of width 0.02 cm are observed at a distance of 1m from the slit. Distance between coherent sources is 3mm. Find the wavelength of light. On placing a thin transparent sheet of refractive index 1.5 in the path of

one of the interfering beams the central bright fringe was found to be shifted through a distance equal to width of 10 fringes. Calculate the thickness of the sheet.

[Hint : $\beta = \frac{\lambda D}{d}$, $\lambda = 6 \times 10^{-7}\, m$, $t = \frac{m\lambda}{n-1}$, here m = 10, $t = 1.2 \times 10^{-5}\, m$]

6 Interference fringes at an air wedge are formed by using sodium light of wavelength 589.3nm. While viewing normally 10 fringes are observed in a distance of 1cm. calculate the angle of wedge.

[Hint : $\beta = \frac{x}{k} = \frac{0.01}{10}$, $\beta = \frac{\lambda}{2\theta}$, $\theta = 2.94 \times 10^{-4}\, radian$]

7. An air wedge of angle 0.01 radian is illuminated by light of wavelength 600nm falling normally on it. At what distance from the edge of the wedge, will the 10th dark fringe be observed by the reflected light.

[Hint : $2t = m\lambda$ $(dark\ fringe)$, $\theta = \frac{t}{l}$, $or\ t = l\,\theta$, $thus\ 2l\theta = m\lambda$, $l = \frac{m\lambda}{2\theta} = 0.3\ cm$]

8. In a biprism experiment, with sodium light bands of width 0.02 cm are observed at 1m from the slit. On introducing a convex lens 0.3m away from the slit, two images of the slit are seen at 0.7×10^{-2}m apart at one metre distance from the slit .Calculate the wave length of light.

[Hint : $\frac{size\ of\ image}{size\ of\ object=} = \frac{v}{u}$, $\frac{0.7 \times 10^{-2}}{d} = \frac{0.7}{0.3}$, $d = 0.3 \times 10^{-2}$, $here\ u + v = 1$, $i.e.$ $0.3 + v = 1$, $\beta = \frac{\lambda D}{d}$, $\lambda = 600\ nm$]

9 A biprism is placed 0.05m from a slit illuminated by sodium light (λ=589nm). The width of the fringes obtained on a screen placed 0.75m from the biprism is 9.424×10^{-2}cm. What is the distance between the two coherent sources?

[Hint : $\beta = \frac{\lambda D}{d}$ $Here\ D = 0.05 + 0.75$, $d = 5 \times 10^{-4}\, m$]

10 Interference fringes are observed with a biprism of refracting angle of 1^0 and refractive index 1.5 on a screen 1 m away from it. If the distance between the source and the biprism is 0.1m ,calculate the fringe width when the wavelength of light used is 590nm.

[Hint : $\beta = \frac{\lambda D}{d}$, $d = 2(n-1)\alpha y_1 = 2\,(1.5-1)1 \times \frac{180}{\pi} \times 0.1$, $D = y_1 + y_2 = 0.1 + 1$, $\beta = 3.7 \times 10^{-4} m$]

11 In a biprism experiment the eyepiece was placed at a distance of 1.2m from the source. The distance between the two virtual sources was found to be 0.075cm. Find the wavelength of light of the source if the eyepiece has to be moved through a distance 1.883cm for 20 fringes to cross the field of view.

[Hint : $\beta = \frac{0.01883}{20}$, $\beta = \frac{\lambda D}{d}$, $\lambda = 588.4\, nm$]

12 When a thin sheet of a transparent material of refractive index 1.52 is introduced in the path of one of the interfering beams the central fringe shifts to a position occupied by the sixth bright fringe. If the wavelength of the light used is 546.1nm, calculate the thickness of the material.

[Hint : $t = \frac{m\lambda}{n-1}$, here m = 6, $t = 6.3 \times 10^{-6}\, m$]

13 A transparent plate of thickness 10μm is placed in the path of one of the interfering beams of a biprism experiment using light of wavelength 500nm. If the central fringe shifts by a distance equal to the width of ten fringes, calculate the refractive index of the material of the plate

[Hint : $t = \frac{m\lambda}{n-1}$, $n = 1.5$]

14 A parallel beam of sodium light of wavelength 589.3nm is incident on a thin glass plate of refractive index 1.5 at an angle 60^0. Calculate the smallest thickness of the plate which makes it dark by reflection.

[Hint : $2\,nt\cos r = m\,\lambda,\quad t = \frac{m\,\lambda}{2\,n\cos r},\quad here\ n = 1,\quad t = 3.92\times 10^{-7}\,m$

15 Interference fringes are produced by monochromatic light falling normally ona wedge shaped film of cellophane of refractive index 1.4. If the angle of wedge is 20 seconds of an arc and the distance between successive fringes is 0.25 cm, calculate the wavelength of light.

[Hint : $\theta = 20\times\frac{\pi}{180}\times\frac{1}{60\times60}\ radian,\ \beta = \frac{\lambda}{2\theta n}$, $(n = 1.4),\quad \lambda = 679\ nm$]

16 Newton's ring arrangement is used with a source emitting the wavelengths λ_1=600nm λ_2=450nm . It is found that the mth dark ring due to λ_1 coincides with the (m+1)th dark ring due to λ_2. Find the diameter of mth dark ring for the wavelength λ_1. Radius of curvature of the lens is 0.9m. [Hint :$D_m^2 = 4\,m\lambda_1 R\quad and\quad D_{m+1}^2 = 4\,(m+1)\lambda_2 R,\quad 4\,m\lambda_1 R = 4\,(m+1)\lambda_2 R,\quad m = 3,\ D_m^2 = 4\,m\lambda_1 R\ ,\quad D_m = 2.5\,mm$

17 The diameter of the third dark ring from the light of wavelength 589nm in a Newton's ring experiment is 3.2mm. Calculate the radius of curvature of the lens. What will be the radius of the ring if the air gap is filled with few drops of water (R.I of Water=1.3) Ans R=1.45m , r_3 =1.2x10^{-2}m.

[Hint : $D^2 = \frac{4m\lambda R}{n},\ (here\ \ m = 3,\quad n = 1), thus\quad R = 1.45\,m,\quad r^2 = \frac{m\lambda R}{n} = 1.2\times10^{-2}\,m\ \ (here\ n = 1.3)$]

18 In Newton's rings experiment, the diameters of third and ninth rings are 0.3 cm and 0.5 cm respectively. Calculate the diameter of the 15^{th} ring.

[Hint : $D_m^2 - D_n^2 = 4(m-n)\lambda R,\ D_9^2 - D_3^2 = 4(9-3)\lambda R,\quad D_{15}^2 - D_3^2 = 4(15-3)\lambda R$

Dividing above two equations, $D_{15} = 0.64\,m$]

19 Two glass plates enclose a wedge shaped air film touching at one edge and are separated by a thin wire of 0.06 mm diameter at a distance of 0.18 m from the edge. Calculate the fringe width if wavelength is 600 nm.

[Hint : $\theta = \frac{t}{l} = \frac{0.06\times10^{-3}}{0.18}$, $\beta = \frac{\lambda}{2\theta} = 9\times10^{-4}\,m$]

20 A soap film of 0.4 μm thick is observed at 50^0 to the normal. Find the wavelengths of light in the visible spectrum which will be absent from the reflected light. n = 1.33.

[Hint : $n = \frac{\sin i}{\sin r}$, $r = 35^0 4'\,,\cos r = 0.8185,\ 2nt\cos r = m\lambda,\ \ for\ \ m = 1,\ \lambda_1 = 8.7\times10^{-7}m\,,\ \ for\ \ m = 2\,,\ \ \lambda_2 = 4.35\times10^{-7}m,\ \ for\ m = 3,\ \lambda_3 = 2.97\times10^{-7}m$]

21 Newton's rings are formed by light of wavelength 589.3 nm between a convex lens and a plane glass plate with a liquid between them. The diameter of the 5th and the 15th rings in the reflected system are 2.18 mm and 4.51 mm respectively. If the radius of curvature of the lens is 0.9 m, calculate the refractive index of the lens.

[Hint : $r_k^2 - r_m^2 = \frac{4(k-m)\lambda R}{n}$, $n = 1.361$]

22 On placing a sheet of mica of refractive index 1.5 in the path of one of the interfering beams in a biprism arrangement, it is found that the central bright fringe shifts a distance equal to the width of a bright fringe. Calculate the thickness of the mica sheet (wavelength of light = 600 nm).

[Hint : $t = \frac{m\lambda}{n-1}$. $here\ m = 1, \quad t = 1.2 \times 10^{-6}\ m$]

PART C : Two Mark Questions

1 Can interference be obtained by using two independent sources? Explain.

Ans : No, The two independent sources of light may emit light of different amplitudes, wavelengths and the phase difference between the two sources may vary with time. Thus interference of light cannot be obtained by two independent sources of light.

2 Does the phenomenon of interference obey the law of conservation of energy? Explain.

Ans : Yes, In interference there is only transfer of energy from points of minimum intensity to the points of maximum intensity. At maxima, the intensity due to two waves is $4a^2$ instead of $2a^2$. The intensity varies from 0 to $4a^2$ but the average is still $2a^2$ which is equal to uniform intensity $2a^2$ when there is no interference. Thus formation of interference fringes is in accordance to the law of conservation of energy.

3 Why are Newton's Rings circular and the fringes due to air wedge straight?

Ans : Interference in wedge shaped film is due to interference of light from reflected rays from two surfaces of the film of increasing thickness in a specific direction as the two glass plates touch each other at one of the edges.Thus fringes are straight. But in case of Newton's rings, the point of contact between the lens and glass plate is at the centre and thickness of the film increases in all directions and thus fringes are circular.

4 The interference pattern of the reflected rays and transmitted rays are complimentary Explain.

Ans : The condition for maxima and minima found in case of transmitted pattern are opposite to those found in case of reflected pattern. Under the same condition the film looks dark in the reflected pattern and bright in transmitted pattern. In case of white light, the colours found due to reflected pattern is absent in *transmitted pattern and vice versa. Thus the fringes in the two patterns are complementary.*

5 What will happen in Newton's ring experiment if few drops of water are introduced between the lens and the plate?

Ans : The diameter of a dark ring is given by $D^2 = \frac{4m\lambda R}{n}$. *By introducing a liquid in between the lens and the glass plate will decrease the diameter of the ring. This will bring the rings closer.*

6 The centre of Newton's ring pattern in the reflected system is dark. Explain.

Ans : In case of interference due to reflected pattern, the light is getting reflected at the surface of denser medium and undergoes a phase change of 180^0. *Thus the interfering at the centre are opposite in phase. Thus the centre appears dark.*

7. A thin film illuminated by monochromatic light appears bright in the transmitted system. Explain

Ans : In case of interference due to transmitted pattern, the light getting refracted at the surface of denser medium to rarer medium and does not undergo any phase change. Thus the interfering at the centre are in same phase. Thus the centre appears bright.

8. What happens to Newton's ring pattern if a monochromatic source of light is replaced by white light?

Ans: When white light which is the combination of different colours, is used the fringes are coloured.

9. A thin film of oil on the surface of water appears coloured. Explain.

Ans : A film of oil is a thin film and the light getting reflected from the lower and upper surface of the film superpose on each other resulting in interference. As light incident on it white light, the pattern appears coloured.

10. Why do the fringes in Young's double-slit experiment become indistinct if one of the slits is covered with a cellophane?

Ans : When of the slits is covered by cellophane, the intensity of light coming from that slit will decrease. The bright fringe which is constructive interference will not be that bright and the dark fringe will not be very dark. No constras in fringes is found and the fringes become indistinct.

11 What type of fringes are observed in a double slit experiment with a white source?

Ans : When white light is used, the fringe pattern is coloured. Only those colours are visible that satisfy the condition for constructive interference.

12 Is laser an example for coherence? Explain.

Ans : Yes, It arises from the stimulated emission process which provides amplification. The emitted photons have a definite phase relation to each other.

13 What happens to the fringe width in double slit experiment if the distance between the coherent sources is reduced to half and distance between the sources and screen is doubled?

Ans :From the relation $\beta = \frac{\lambda D}{d}$, *d is reduced to half and D is doubled, then the fringe width becomes four times the original width.*

14 What happens to the fringe system if a thin transparent film is placed in the path of one of the interfering beams?

Ans : The fringe system gets shifted. This can be observed as the central fringe which is white gets shifted.

15 In the biprism experiment, what happens to the fringe width if a monochromatic light of shorter wavelength is used?

Ans : *From the relation* $\beta = \frac{\lambda D}{d}$ *it is observed that by using light of shorter wavelength, the fringe width decreases as the fringe width is directly proportional to the wavelength of light.*

16 Explain why the fringes formed by a biprism disappear when the slit is made wide?

Ans : To observe interference fringes, it is required to have two coherent sources. In biprism, two virtual sources formed by the biprism act as coherent sources. When the slit is widened, it is not possible to get two narrow coherent sources which could broaden, Thus the fringes disappear.

17 What is the principle at interference due to thin films?

Ans : It is based on division of amplitude where there is partial reflection and partial refraction resulting in formation of two coherent source. The light from these sources superpose and produce interference.

18 On what factors colours observed on a soap bubble depend?

Ans : The colours on a soap bubble depend on the angle of refraction and the thickness of the film.