Department of Applied Physics
KDK College of Engineering, Nagpur

Subject: Applied Physics

Unit1:Wave Optics

12 marks

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Contents of Unit I: Wave optics

Concept of Wavefront

- It is also defined as *a surface on which the wave disturbance is in same phase at all the points.*
- The direction of propagation of a wave at a point is always perpendicular to the wavefront through that point.
- Depending on source, the shape of the wavefront may be circular, spherical, cylindrical or planar.
- Point source produces spherical wavefront and linear source produces cylindrical wavefront.

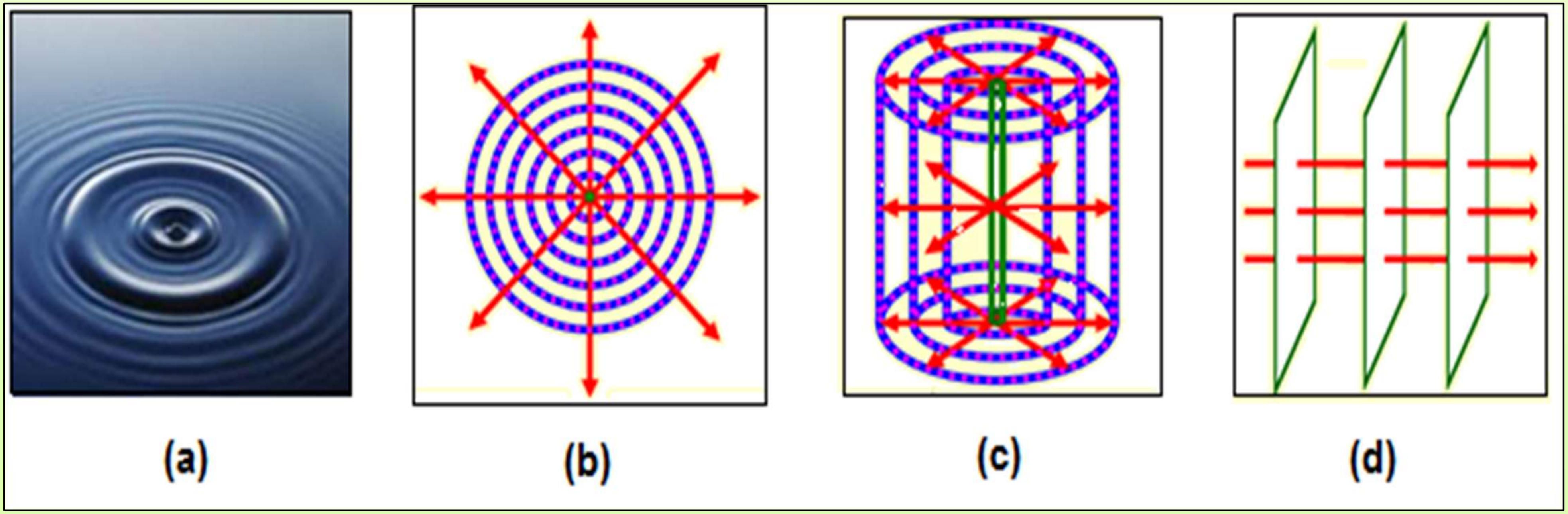


Figure1.(a) Circular (b) Spherical (c) Cylindrical (d) Plane Wavefront

HUYGENS' PRINCIPLE

- **A Dutch physicist named Christian Huygens (1629 – 1695), suggested that light may have a wave nature.**
- **Huygens' wave theory of light successfully explained Young's double slit experiment in 1801.**
- **Huygens proposed a geometrical method known as *Huygens' Principle* to find the shape and location of wavefront at some instant from the knowledge of the same at earlier instant of time**
- **Huygens' Principle states that:**
- **Each point of a wavefront is a source of a secondary disturbance and generates spherical secondary wavelets.**
- **After a certain interval of time 't', the new position of the wavefront will be that of surface tangent to these secondary wavelets.**

Christian Huygens →

Geometrical construction of wavefront

- **Each point of primary wavefront AB acts as a source of secondary disturbance coming from a point source 'S' of light as shown in fig.2(a).**
- **The secondary wavelets emerging from these points are spherical in shape, spreading in all directions at speed equal to wave's speed.**
- **Draw spheres of radius *vt* from each point on the spherical wavefront where speed of the wave is'*v*' in time 't'.**
- **Then draw a common tangent to all these spheres, we obtain the new position of the wavefront at *t*.**
- **The new wavefront is again a spherical wavefront.**
- **According to Huygens, amplitude of the secondary wavelets is maximum in the forward direction and zero in the backward direction; hence he could explain the absence of the backwave.**
- **Hence the wavelets as well as the whole wave always travel in forward direction only.**
- **Similarly, plane wavefront can be constructed as shown in fig.2(b).**

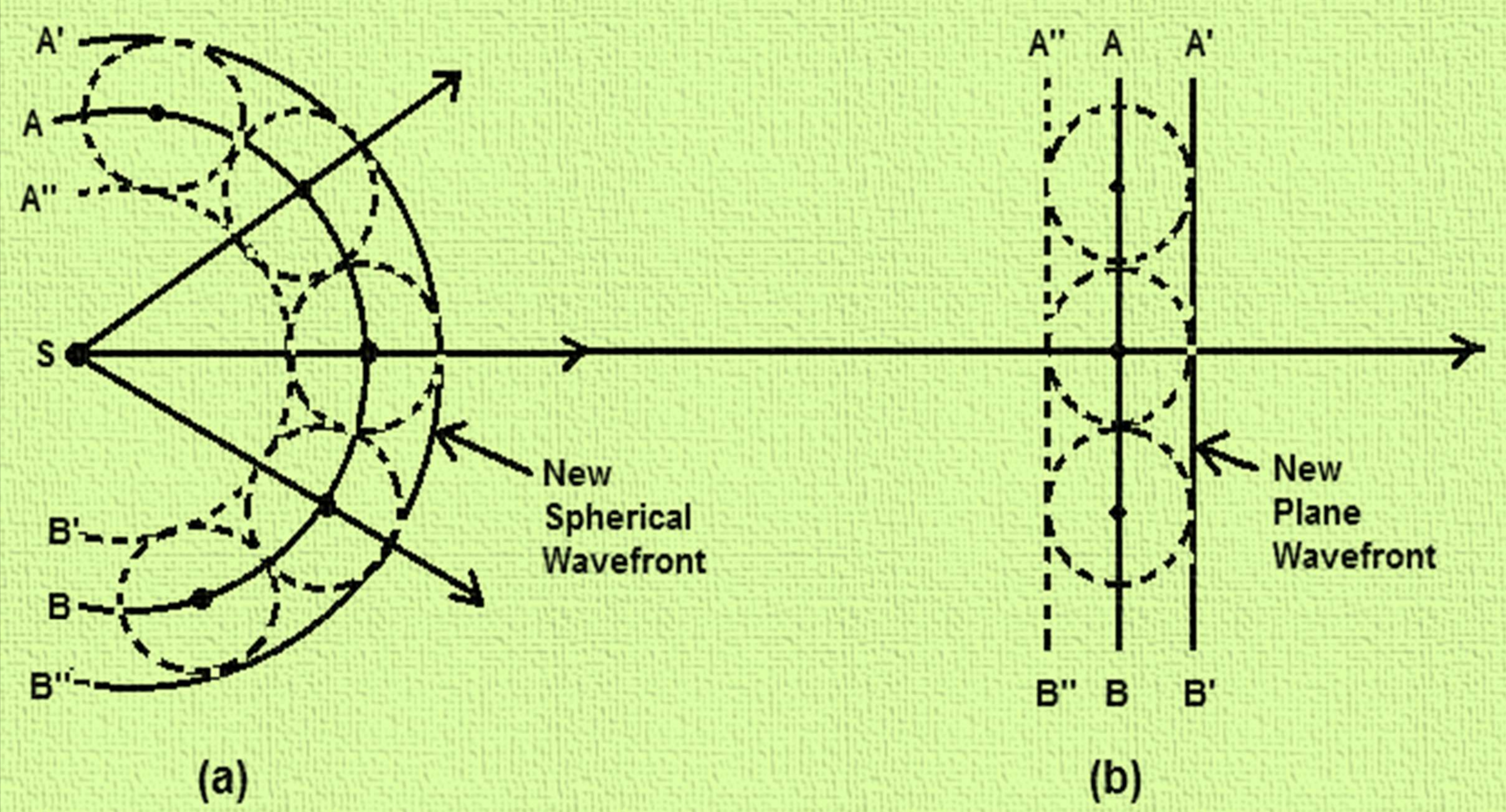


Fig.2: Geometrical construction of Huygen's Principle (a) Spherical (b) Plane wavefront

QUE: What is Huygens principle in regard to the conception of light waves ?

QUE:What is a wavefront ? How is it produced? Slide 3

QUE:State the postulates of Huygens's wave theory.

SUPERPOSITION PRINCIPLE

- **The Superposition Principle states that:** ***When two or more waves arrive at a point in a medium simultaneously, the resultant displacement at that point is the algebraic sum of their individual displacements.***
- **After the superposition, the wave trains travel as if they have not interfered at all. Each wave train retains its individual characteristics. They pass through each other without being disturbed.**
- **To understand this, as shown in fig.3, consider two waves travelling in opposite directions pass through a point in a medium.**

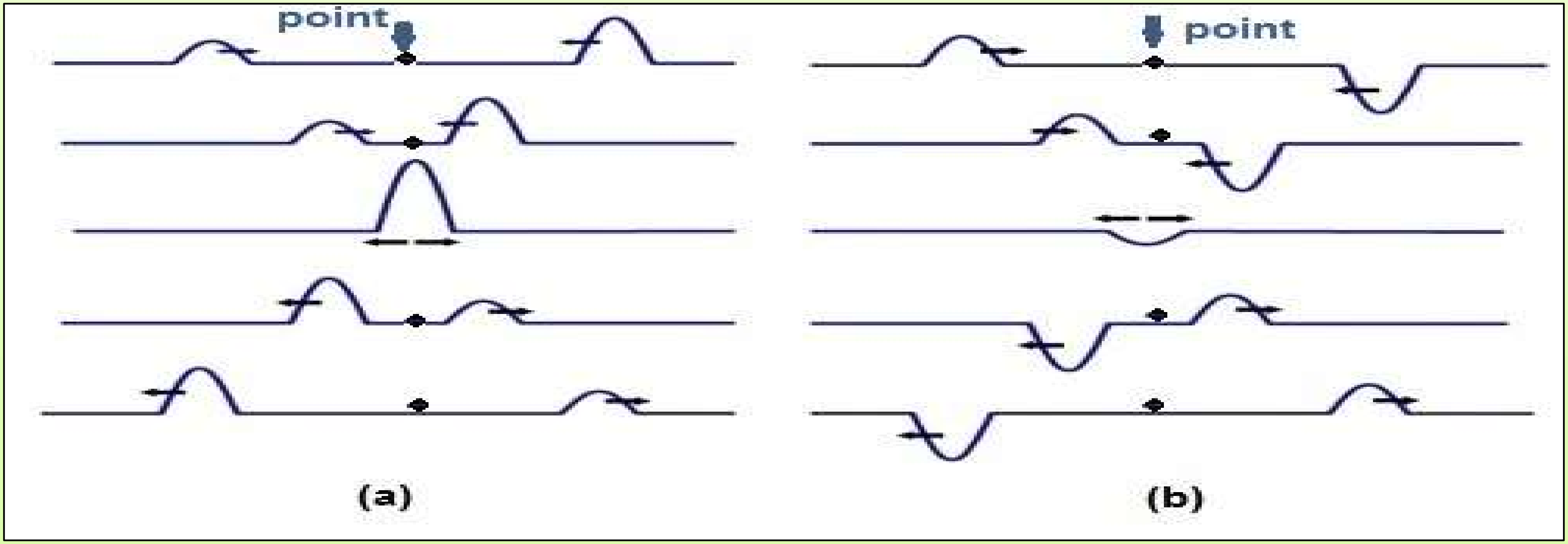


Fig.3: Superposition of two waves a) in phase b) out of phase

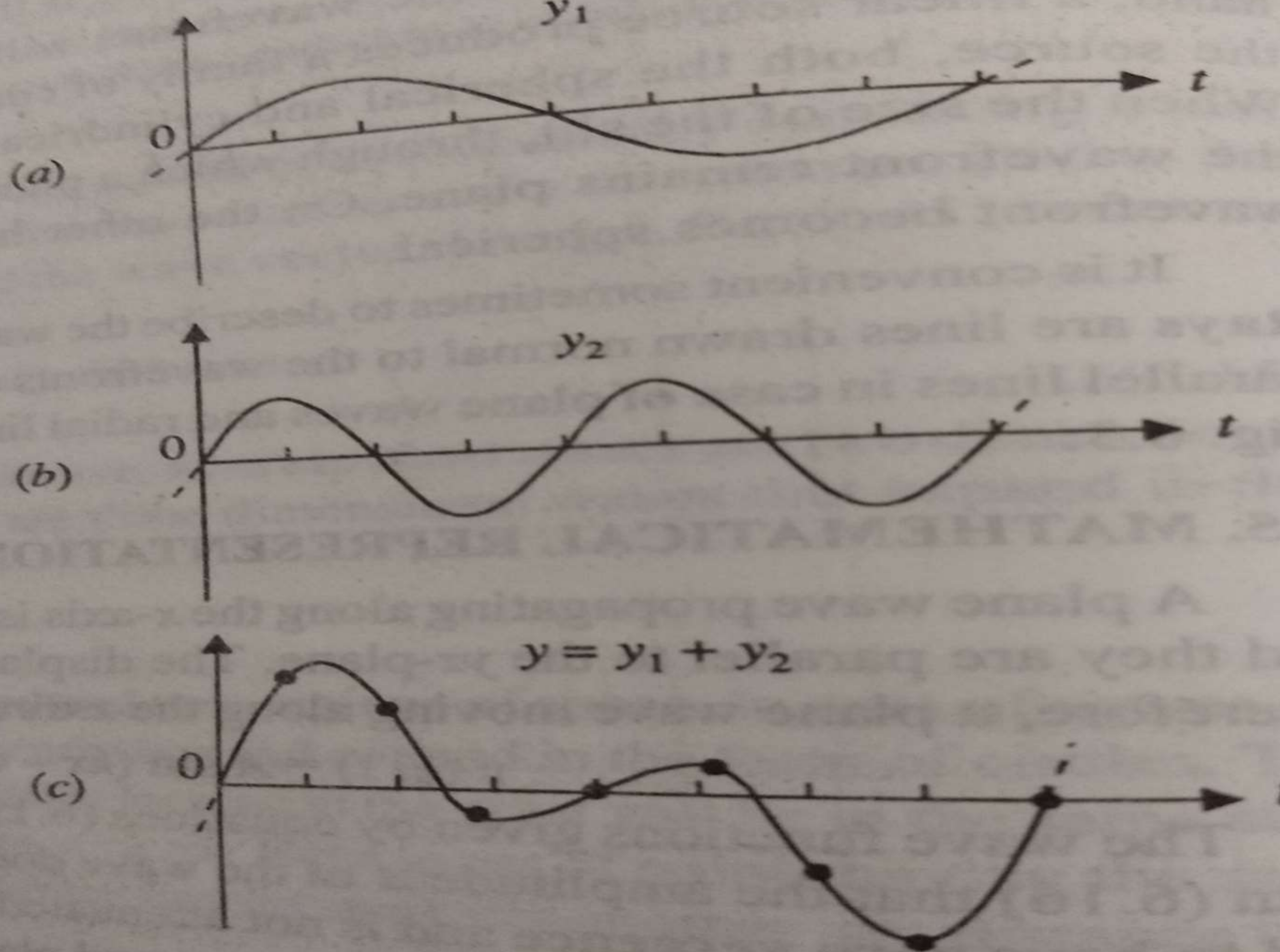
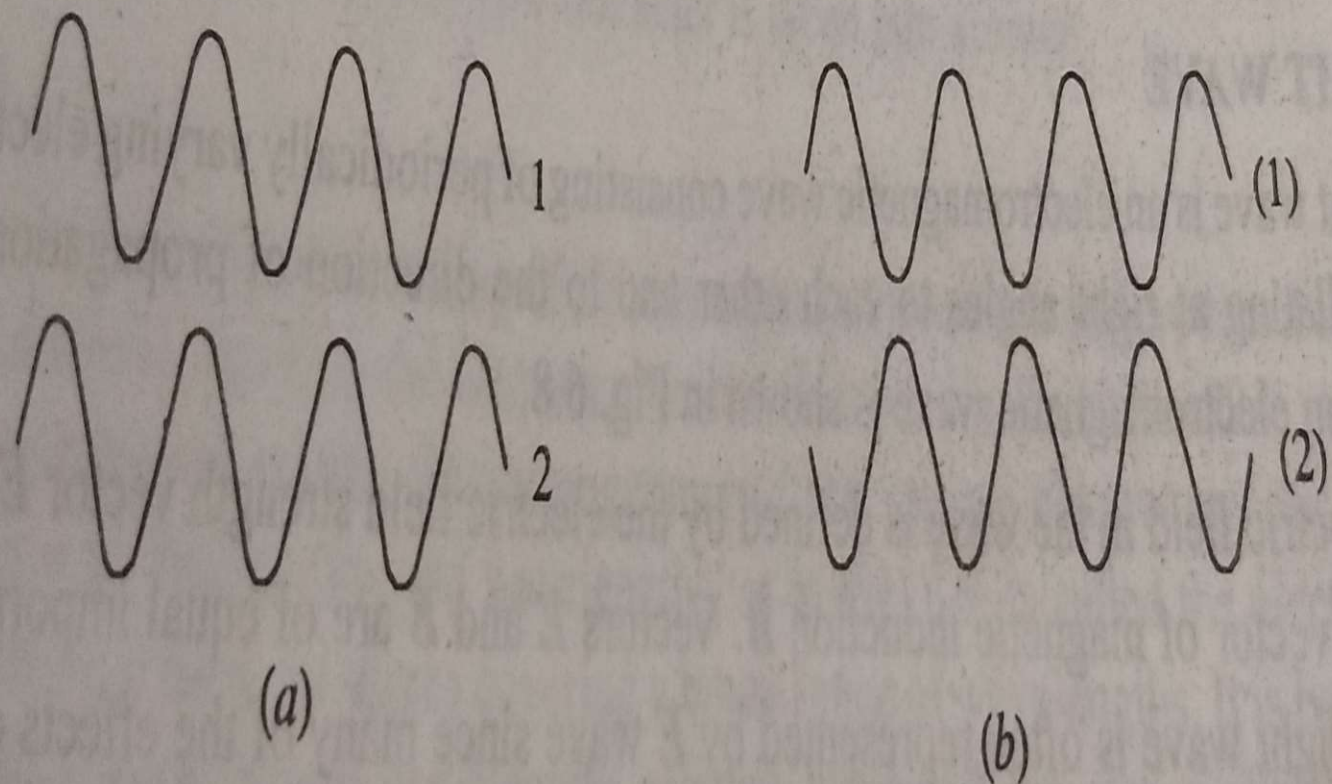


Fig. 6.5. Illustration of the principle of superposition.

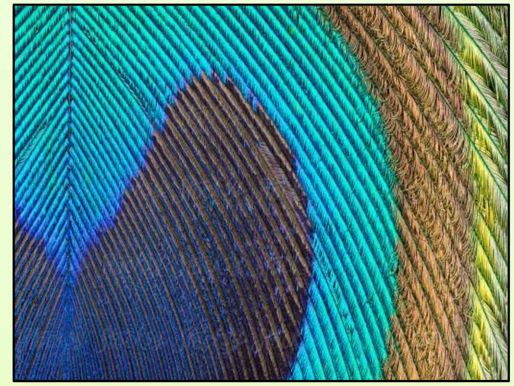
- **Interference: When *two or more coherent light waves traveling along the same direction superpose, then there is redistribution of light energy, at some points energy is maximum (constructive Interference) and at some points energy is minimum (destructive Interference). This phenomenon is called as Interference. This phenomenon is based on superposition principle.***
- ***Condition for constructive interference*: When two light waves travelling through a medium arrive at a point in phase simultaneously, the resultant light intensity at that point is maximum and the point appears bright. This is called the condition of constructive interference.**
- **The phase difference between the two waves is $0, 2\pi, 4\pi \ldots etc.$**
- **The path difference between the two waves = $n\lambda$ where n the order of fringe is 0, 1, 2, 3…..**
- ***Condition for destructive interference*: When two light waves travelling through a medium arrive at a point out of phase, the resultant light intensity at that point is minimum and the point appears dark. This is called the condition of destructive interference.**
- **The phase difference between the two waves is $\pi, 3\pi, 5\pi, \ldots etc.$**
- **The path difference between the two waves = $(2n+1)\,\lambda/2$ or $(2n-1)\,\lambda/2$ where n the order of fringe is 1, 2, 3…..**
- **Interference phenomena was observed by Newton and Robert Hooke but theory was developed by Thomas Young.**



7. Phase relationships—(*a*) Two waves of same frequency in phase. (*b*) Two waves of same frequency in opposite phase.

Interfernce in thin films:Natural thin film and related phenomena: Iridescence

Thin film: A film is said to be thin when its thickness is of the order of one wavelength of visible light ~ 5500 Å (0.55μm) or of incident light.



Iridescence caused by interference : Colours as seen due to interference phenomena on oil layer, soap bubbles, peacock feathers, beetle body, oil film on rock and morph butterfly wings, Colours on CD and DVD.

Techniques of Interference

Division of wavefront

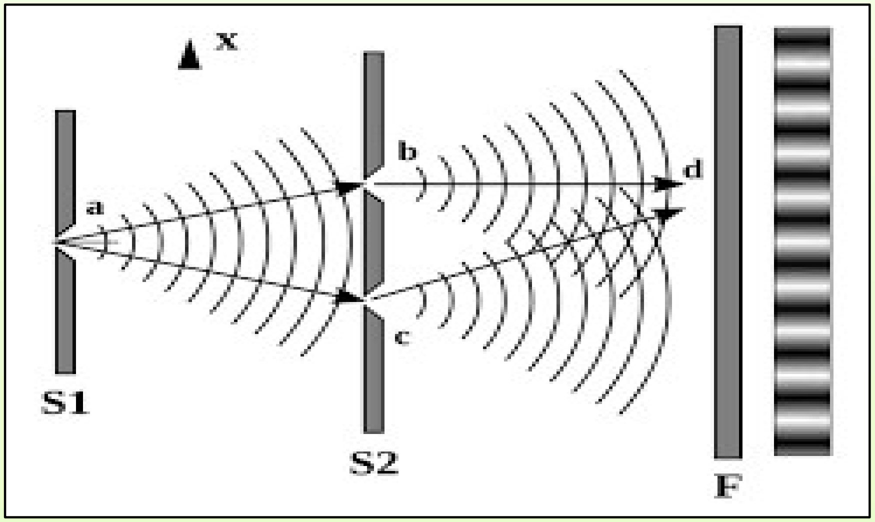


Figure 1

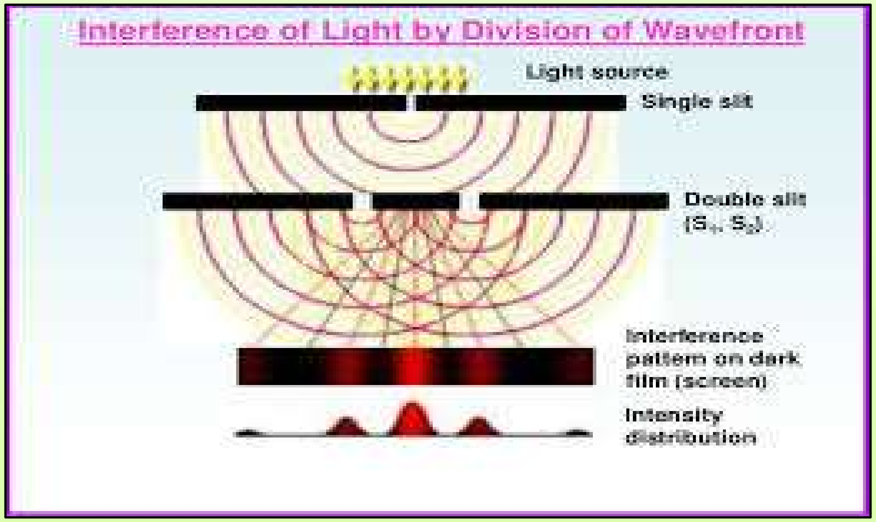


Figure 2

Division of amplitude

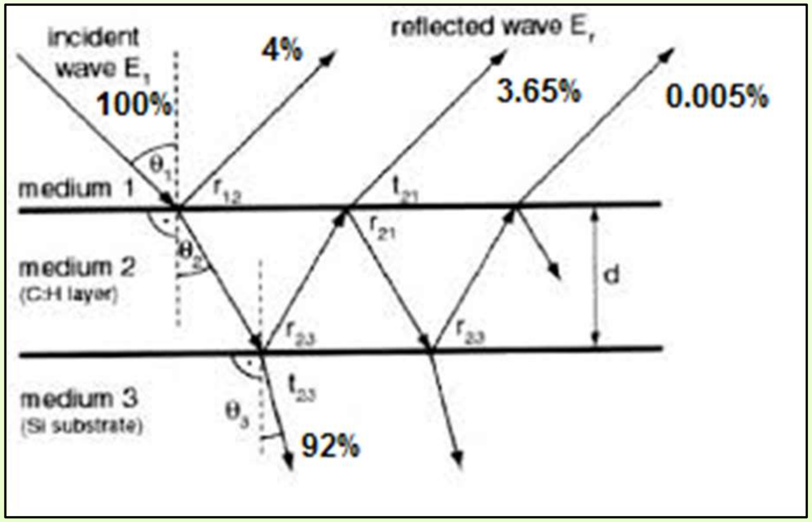


Figure 3

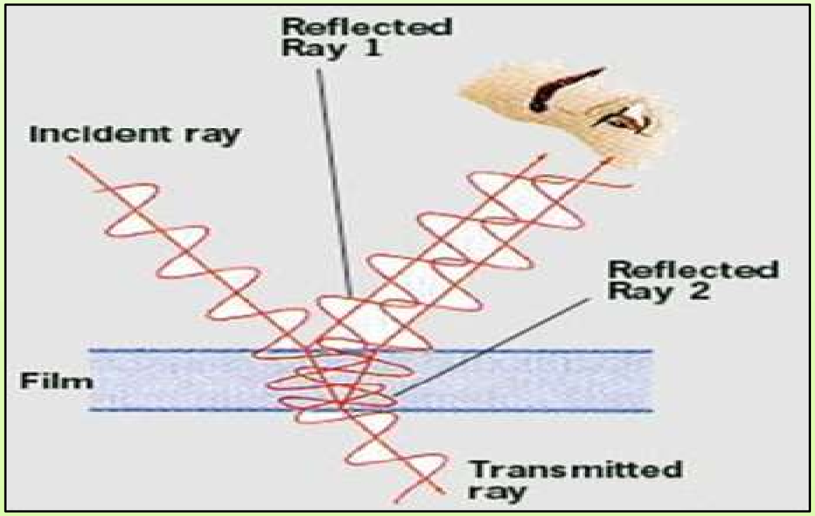


Figure 4

Important Concepts

Geometrical path

- Shortest distance between two points.
- It is same in vacuum or any other medium.

Optical path

- The path traveled by light in a medium having refractive index ‘μ’.
- Optical path = R.I × Geometrical path.
- **Optical path difference**

  The difference between optical paths of two rays travelling in different directions is called *Optical path difference*.
- **Phase difference**:

  When a wave covers a distance of one wavelength(λ),its phase changes by 2π

  Hence for a wave travelling a distance of ‘L’ in air, its phase changes by $\delta = \frac{2\pi L}{\lambda}$

Plane parallel thin film:Thin Film of uniform thickness

Derivation of Path difference and condition of constructive (maxima) and destructive (minima) interference:

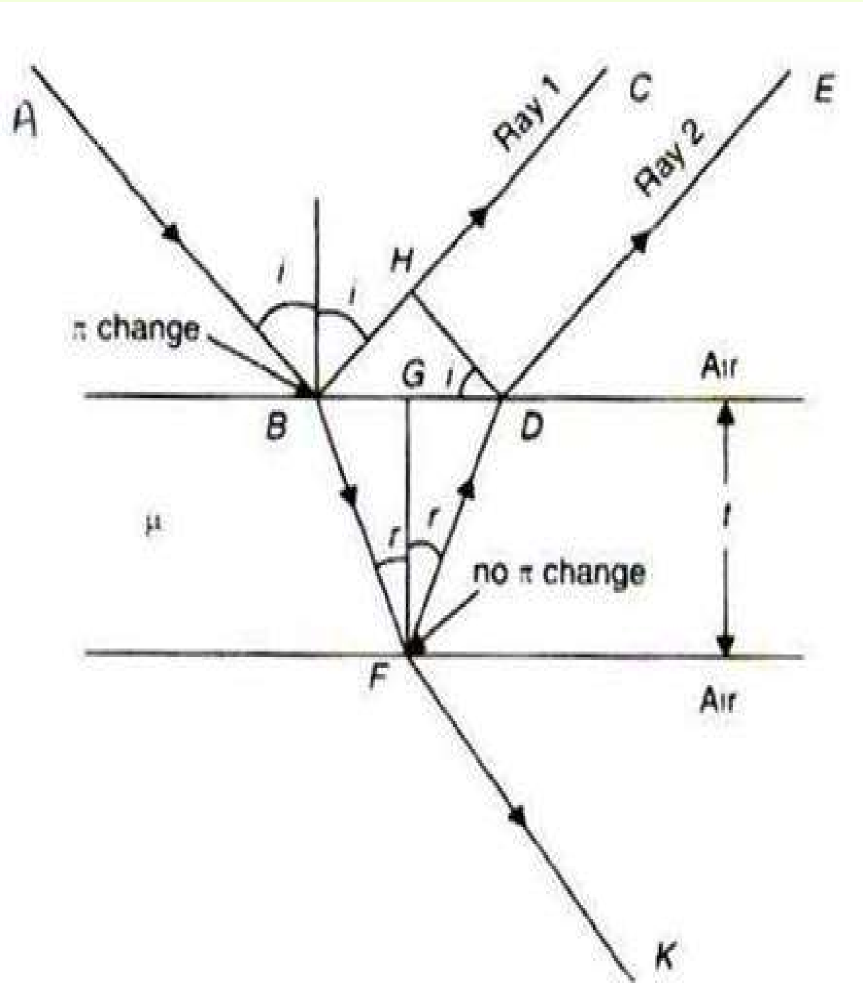


Figure5

- ❖**Consider a plane parallel thin film of uniform thickness 't' having refractive index 'μ' as shown in Figure 5. The film is surrounded by air on both the sides.**
- ❖**Let a monochromatic source of light of wavelength 'λ' is incident on the plane parallel thin film obliquely.**
- ❖**Let AB represent one of the incident rays at point B, a part of incident light at B is reflected as BC (ray 1) and partially transmitted into the film along BF.**
- ❖**The transmitted ray BF partially reflected back into the film along FD and refracts into the outer medium as DE (ray 2). Ray2 is parallel to the Ray1.**
- ❖**The interference pattern consisting of dark and bright bands is formed due to superposition of light rays reflected from top and bottom of this thin film.**

To find optical path difference between the rays 1 and 2:

Draw DH ⊥ to BC and FG ⊥ to BD.

From the geometry of the figure 5, ∠BFG = ∠ r and ∠ BDH = ∠ i.

Optical path difference between the two waves = μ (BF+FD) - BH

Since BF = FD , ∴ Optical path difference = μ(2BF) - BH----- (1)

From Δ BFG, cos r = $FG/BF = t/BF$ or BF = $t/\cos r$ ----- (2)

From Δ BDH, sin i = BH/BD Or BH= BD sin i ----- (3)

From Δ BFG, tan r = $BG/FG = BG/t$

Or BG = t tan r

But BD = 2 BG ∴ BD = 2 t tan r ----- (4)

Substituting the value of BD from equation (4) in equation (3) we get,

BH = 2 t tan r x sin i =2 t tan r x μ sin r

(using Snell's law $\mu = \sin i/\sin r$)

or BH =2 t ($\sin r \cos r$) x μ sin r =2 μ t $\sin^2 r/\cos r$ ----- (5)

Substituting the value of BH from eqn. (5) and BF from eqn. (2) in equation (1) we get,

Optical path difference $= 2\mu t/\cos r - 2\mu t \sin^2 r/\cos r$

$$= 2\mu t/\cos r \, (1 - \sin^2 r)$$

$$= 2\mu t/\cos r \, (\cos^2 r) = 2\mu t \cos r$$

When light is reflected from the surface of an optically denser medium, a phase change of π, equivalent to a path difference of λ/2 occurs.

Correct path difference $\Delta = 2\mu t \cos r - \lambda/2$.

Condition for constructive interference (Bright bands)

Path difference = nλ

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

$2 \mu t \cos r = n\lambda + \lambda/2$

$2\mu t \cos r = ((2n+1) \lambda/2$ ------ **Condition for brightness(maxima)**

Condition for destructive interference (Dark bands)

Path difference = (2n-1) λ/2

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

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

$= (2n) \lambda/2 = n\lambda$

or $2 \mu t \cos r = (n+1) \lambda = n\lambda$ ------ **Condition for darkness (minima)**

Question1:Derive an expression for path difference and conditions for constructive and destructive interference for phenomenon of interference in thin parallel film in reflected light. (4) W-15

Interpretations/Conclusions

THIN FILM EXPOSED TO WHITE LIGHT

- When white light consisting of many wavelengths (colors) is incident on thin film then all colors get reflected from the top and bottom surface.
- But all of them does not satisfy the condition of brightness (maxima).
- Hence reflected light will have only those colors which satisfy the condition of maxima.
- The colors which satisfy the condition of minima (darkness) will remain absent. Hence thin film appears colored under White light.

WHEN FILM IS VERY THIN

- When film is so thin like only a few layers of air molecules as in case of air film, then the thickness of film is very small as compared to wavelength of incident light (i.e., $t << \lambda$).
- The path difference will be nearly equal to $\lambda/2$.Hence a phase difference of 180^o will be introduced between the interfering rays .
- Therefore, the wave reflected from upper surface and bottom surface of film will interfere destructively and the film appears dark.

Interference in Wedge shape thin film :Film of varying thickness

❖A wedge shaped thin is a thin film of varying thickness having thickness zero at one end and uniformly increasing towards another end.

❖A wedge- shape thin film of air can be formed by placing two glass slides resting on each other at one edge and separated by a thin spacer at the opposite edge.

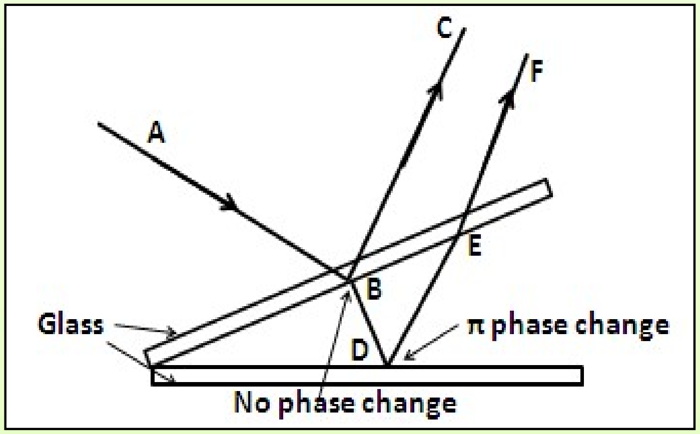


Figure 6

❖The interference pattern of wedge- shape thin film consists of alternate dark and bright bands of equal thickness called as fringes.

❖The optical path difference between two interfering rays, $\Delta = 2\mu t\cos r - \lambda/2$ as shown in figure 6.

Experimental Arrangement

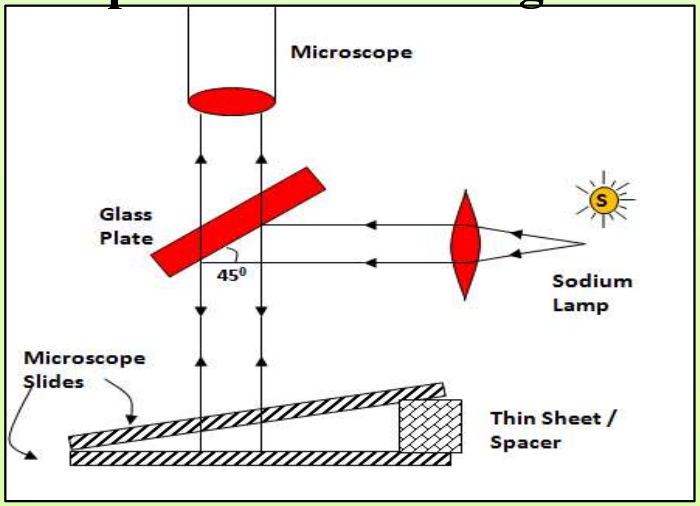
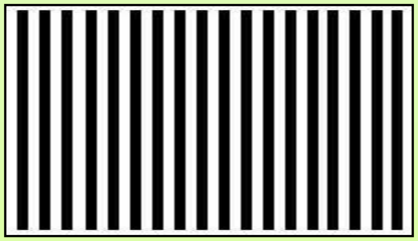


Figure 7

❖A parallel beam of monochromatic light illuminates the wedge as shown in figure 7.

❖A glass plate is kept at an angle of 45^o to make the light fall on top surface of wedge shape film at normal incidence.

❖The light reflected from top and bottom surface of wedge shape film forms an interference pattern of straight, parallel, equidistant dark and bright fringes.



Interference pattern

Derive an expression for fringe width(β) in wedge shape thin film

- Consider a wedge shape thin film of varying thickness with refractive index 'μ' and wedge angle 'θ' illuminated by a parallel beam of monochromatic light of wavelength λ.
- The rays reflected from top and bottom surfaces of the thin film form an interference pattern consisting of dark and bright, straight, parallel fringes.
- Consider two consecutive dark fringes at point A and C as shown in figure 8. The n^{th} dark band be formed at point A at a distance x_1 from the edge of contact 'O' and t_1 be the thickness of film at A.
- The $(n+1)^{th}$ dark band is formed at point C at a distance x_2 from 'O' and t_2 is the thickness of film at point C.

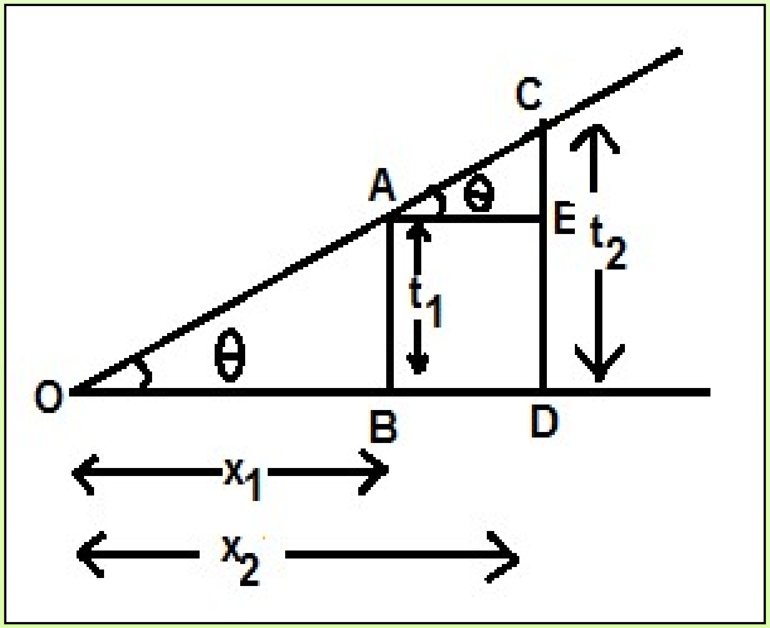


Figure 8

- For destructive interference condition,

$$2\,\mu\, t \cos r = n\,\lambda \text{ (normal incidence, } \cos r = 1)$$

For n^{th} dark fringe, $2\,\mu\, t_1 = n\lambda$ ------- (1)

- For $(n+1)^{th}$ dark fringe,

$$2\,\mu\, t_2 = (n+1)\,\lambda \text{ --------- (2)}$$

Subtracting (1) from (2) we get,

$$2\,\mu\,(t_2 - t_1) = \lambda \text{ -------- (3)}$$

- From figure, in right angled triangle AEC,

$$\tan\theta = CE/AE = t_2 - t_1/x_2 - x_1$$

Since θ is small, $\tan\theta \sim \theta, t_2 - t_1 = (x_2 - x_1)\,\theta$ ---- (4)

❖ Substituting value of t_2-t_1 in equation (3) we get

$$2\mu(x_2 - x_1)\theta = \lambda$$

Since x_2-x_1 = β = Fringe width (i.e., distance between two consecutive dark fringes).

❖ Therefore, 2 μ β θ = λ or Fringe width $\beta = \lambda/2\mu\theta$

For air film, refractive index μ =1,

$$\beta = \lambda/2\theta$$

Since λ, θ are constant, β is constant. Hence fringes are equidistant .

To find the Wedge angle 'θ'

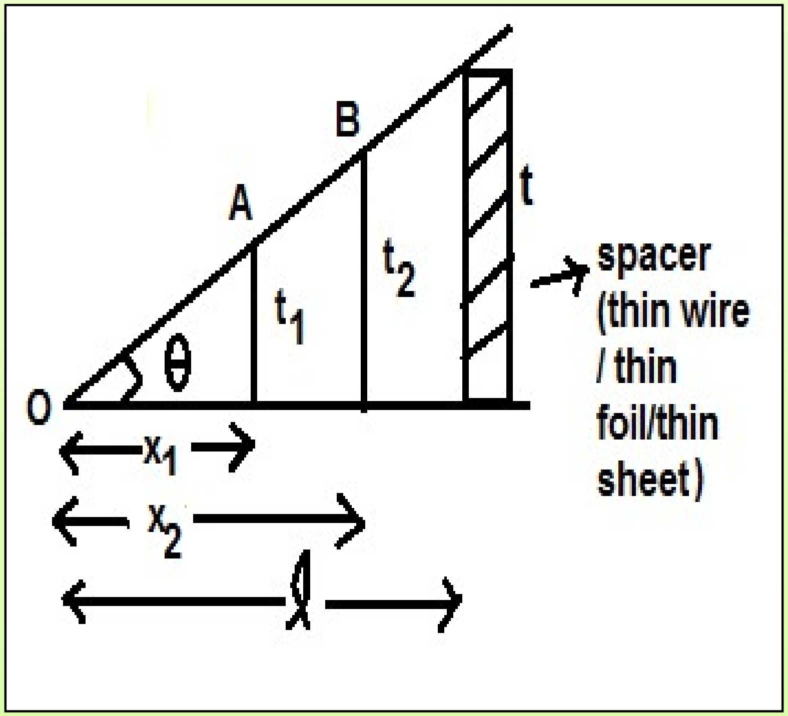


Figure 9

❖ Experimentally, we can find the wedge angle 'θ' using a travelling microscope.

❖As shown in the figure 7, consider two dark fringes formed at points A and B at a distance $x_1$and x_2 respectively from apex 'O'.

❖ Let 'N' be the number of fringes in between A and B.

❖Consider that the thickness of the film be t_1 and t_2 at A and B respectively.

At point A, $2\mu t_1 = n\lambda$

❖From the figure 9, $t_1 = x_1 \tan\theta \sim x_1\theta$

(as θ is very small)

$$\therefore 2\mu x_1\theta = n\lambda \text{ ------- } (1)$$

❖ **Similarly, at point B,**

$$2\mu\, x_2\, \theta = (n+N)\, \lambda \text{ ------- } (2)$$

Subtracting (1) from (2) we get, $2\, \mu(x_2 - x_1)\, \theta = N\lambda$

Hence $\theta = N\lambda/2\, \mu(x_2 - x_1)$

for air film, $\theta = N\lambda/2\, (x_2 - x_1)$ **---------- (3)**

The fringes at apex is dark

❖ **At the apex, the thickness of the wedge is very small compared to λ, i.e.** $t \ll \lambda$**. Therefore, thickness of film at apex is zero.**

❖ **The optical path difference becomes,** $\Delta = 2\mu t - \lambda/2 = \lambda/2$

❖ **For path difference of** $\lambda/2$**, the interfering rays will always be 180° out of phase and interfere destructively . Therefore, the fringe at the apex of the wedge is always dark.**

Question2:What is thin film? Obtain an expression for fringe width in wedge shaped thin film. (1+3) S-13,S-15,S-17,W-17,W-18

Question3: Deduce expression for fringe width and wedge angle in case of wedge -shaped thin film. (4) W-13, S-18 ,W13,W-17

Question4:Derive the expression for wedge angle in case of wedge- shaped thin film. (3) S-18

Question5: Obtain an expression for fringe width in the interference pattern of wedge- shaped film. Explain why the fringe at the apex of the wedge is always dark. (4) W-16

Question6:Derive an expression for fringe width in interference pattern obtained in wedge shaped thin film. How this phenomenon is used for testing the optically flat surface? (5) S-14

Applications of Wedge shape film

❖ **To find the thickness of spacer/sheet or diameter of wire 't'**

From figure 9, $t = l \tan\theta \sim l\,\theta$ [Slide 18]

where $\tan\theta \sim \theta$, for very small values of θ and l is the length of air wedge.

Substituting the value of θ from eqn.3 we get,

$$t = l\,\theta = l\,N\,\lambda/2\mu\,(x_2 - x_1) \text{ --------(using eqn.3)}$$

❖ **Testing of optically flatness of a surface:**

The flatness of the surface can be inspected easily by keeping an optical flat at an angle on the surface under inspection and illuminating the wedge formed with a monochromatic light.

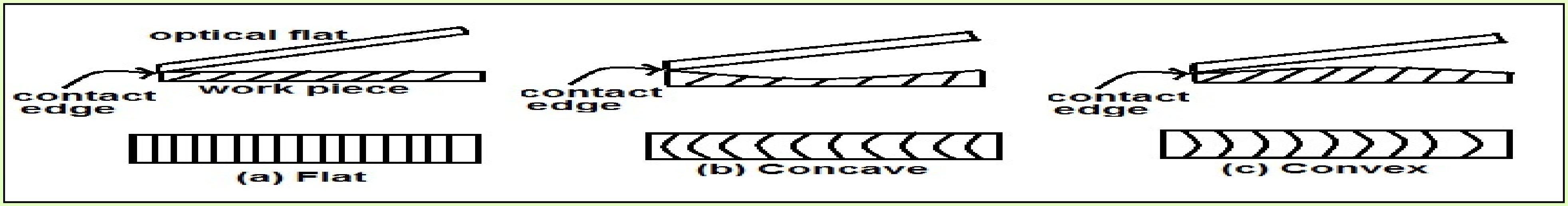


Figure10: Testing of surface finish (a) optically flat (b) concave (c) convex surface

Interpretation:

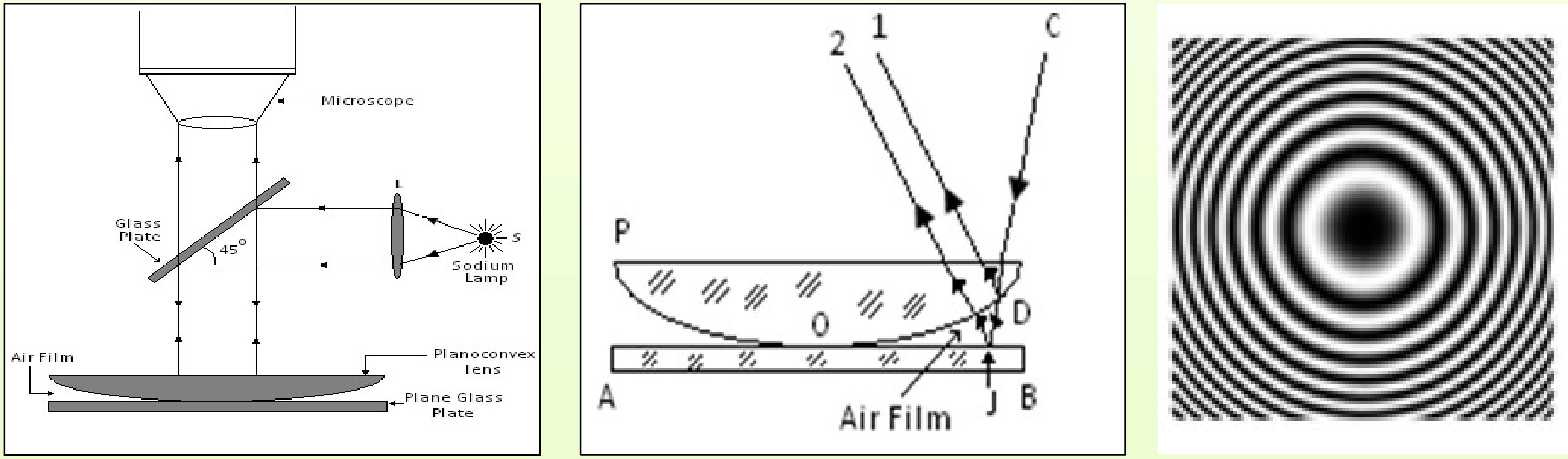
1] An air wedge will produce straight equidistant bands if surface is *flat*.

2] If the fringes are curved towards the apex then surface is *concave.*

3] If the fringes are curved away from the apex then surface is *convex.*

The surface under test is then polished and above process is repeated till straight and parallel fringes are obtained.

Newton's Rings: Fringes of equal thickness



(a) (b) (c)

Figure 11:(a) Experimental set up of Newton's rings (b) Ray diagram and (c) Fringe pattern

❖. **The phenomenon of Newton's rings, observed by Isaac Newton, is an interference pattern formed by the reflection of light from a film enclosed between a Plano-convex lens of large radius of curvature and a plane glass plate as shown in figure 11(a).**

❖ **The air film has zero thickness at the point of contact between lens and glass plate and gradually increases as we move away from the point of contact on either side as shown in Figure 11(b).**

❖**When illuminated by monochromatic source, light is reflected at point D from top surface of the air film as ray 1 and the remaining light pass through an air film, strike the plane glass plate at point J and gets reflected as ray 2 as shown in Figure 11(b).**

❖**Ray 1 and ray 2 interfere and produce interference pattern as shown in figure 11(c).**

Condition for dark and bright rings

- The condition of brightness and darkness depends on path difference between the two reflected light rays 1 and 2.
- The path difference itself depends on thickness of the air film at the point of incidence.
- For bright rings: Path difference $2\mu t \cos r - \lambda/2 = n\lambda$

  For air film, $\mu = 1$ and for normal incidence $\cos r = 1$,

  Hence $2t - \lambda/2 = n\lambda$

  or $2t = (2n+1)\lambda/2$ ------ Condition for bright fringe
- For dark rings: Path difference $2\mu t \cos r - \lambda/2 = (2n+1)\lambda/2$

  For air film, $\mu = 1$ and for normal incidence $\cos r = 1$,

  Hence $2t - \lambda/2 = (2n+1)\lambda/2$

  $2t = (2n+1)\lambda/2 + \lambda/2$

  or $2t = (n+1)\lambda = n\lambda$ ------ Condition for dark fringe
- The fringes are localized, circular and of constant thickness.

Expression for Radii of dark and bright rings

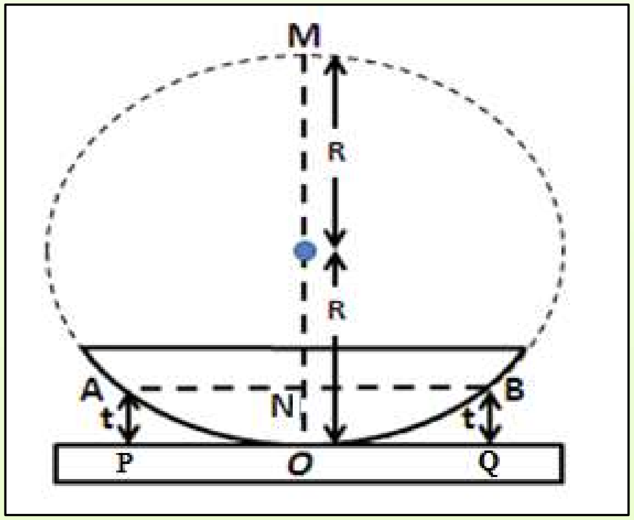


Figure12

- As shown in figure12, consider a Plano-convex lens of large radius of curvature 'R'.
- Let 't' be the thickness of film at point P.

  then AP = BQ = t = ON
- Let the radius of circular fringe at point P be 'r_n'.

  Hence PO =OQ = r_n . Also, r_n= AN=NB.
- Let 'D_n' is the diameter of n^{th} dark ring ,

  then D_n = PQ = AB.

By the theorem of intersecting chords, (MN) x (ON) = (AN) x (BN)

or (MO - ON) x (ON) = (AN) x (BN)

Hence (2R – t) x (t) = r_n x r_n

or $r^2{}_n = 2Rt - t^2$

Since R >>> t, 2Rt >>> t^2

Therefore $r^2_n \approx 2Rt$ ----------(1)

But for dark ring, 2t = nλ .Hence eqn.(1) becomes $r^2{}_n \approx n\lambda R$

Hence radius of dark ring $r_n = \sqrt{n\lambda R}$ Also diameter $D_n = 2\sqrt{n\lambda R}$

for n=1,2,3----- where 'n' represents order of rings

Hence $r_n \, \alpha \, \sqrt{n}$, $r_n \, \alpha \, \sqrt{R}$ and $r_n \, \alpha \, \sqrt{\lambda}$

❖*Hence radius as well as diameters of dark rings are proportional to square root of natural numbers.*

❖**Also, Radius as well as Diameters of dark rings are proportional to square root of wavelength(λ) of incident light and square root of radius of curvature of Plano-convex lens(R).**

❖**Similarly, for bright ring, 2*t* = (2n+1) *λ*/2 ,**

❖ **Hence radius of bright ring,** $r_n = \sqrt{\frac{(2n+1)\lambda R}{2}}$

Hence radius and Diameter of bright rings are proportional to square root of odd numbers.

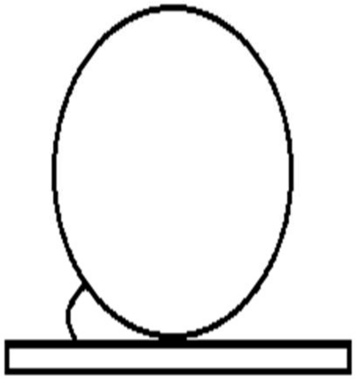
<u>Salient feautres of Newton's Rings:</u>

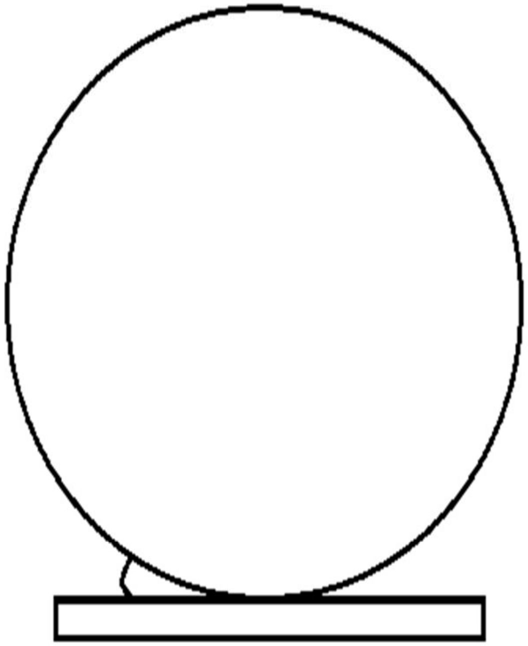
1. *<u>Plano-convex Lens of large radius of curvature is used:</u>*

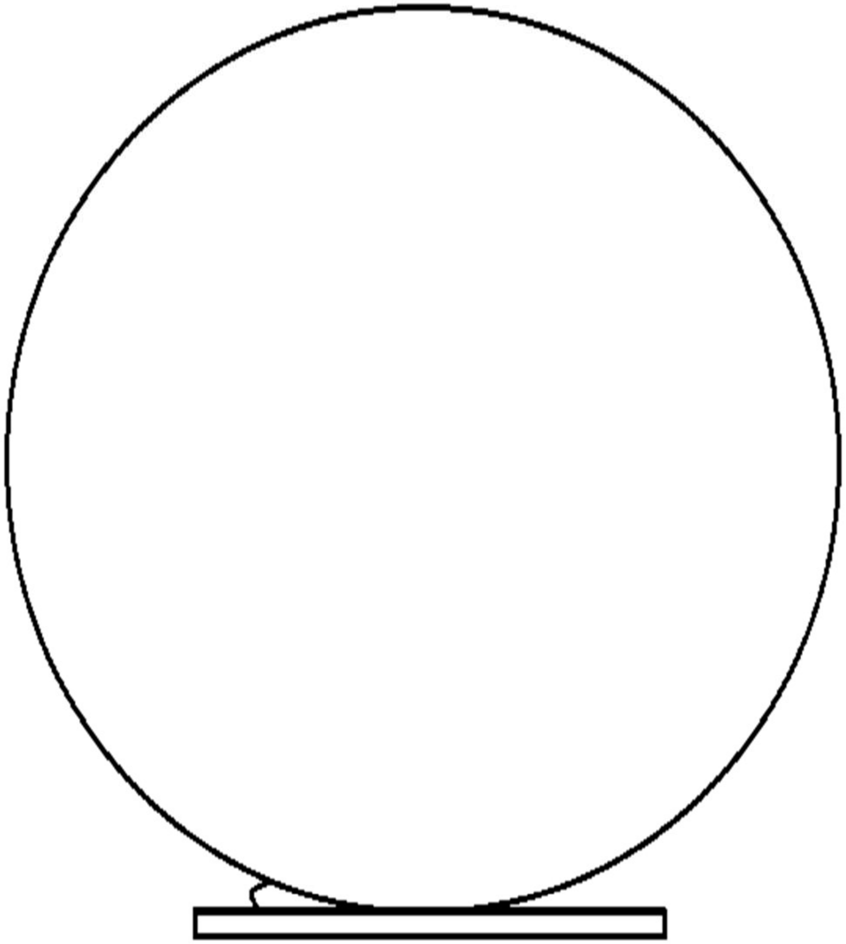
1. The radius of dark fringe $r_n \alpha \sqrt{R}$ and hence diameter $D_n \alpha \sqrt{R}$ where R is the radius of curvature of plano-convex lens. Hence, greater the radius of curvature of the lens, the larger would be the diameter of the ring.

2. Secondly if R is large, the angle enclosing the air film will become smaller and hence fringe width β will become larger.

Therefore due to these two reasons, we conclude that there will be more accuracy and less error in the measurement of diameter of rings when radius of curvature of Plano convex lens is large.





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2. *Rings get closer/crowded away from the center(rings are not equally spaced) :*

1.In Newton's rings experiment, diameter of a dark ring is directly proportional to square root of natural numbers, while the diameter of the bright ring is proportional to square root of odd numbers.

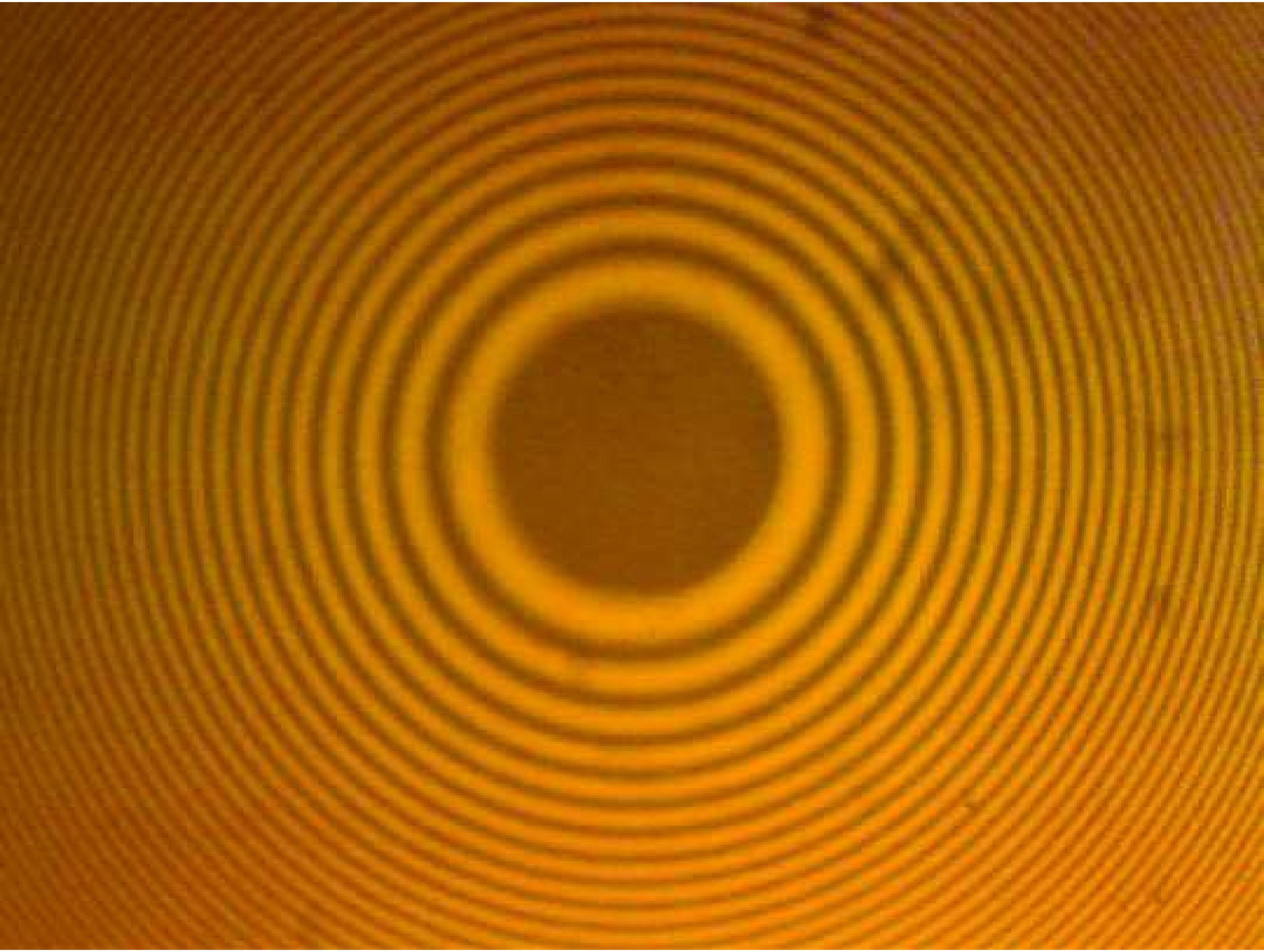
Therefore, as the order of rings (n) increases, the diameter does not increase in the same proportion.

2. Also, the wedge angle is zero at the point of contact and gradually increases as we move away from the point of contact on either side. Hence according to the relation, $\beta=\lambda/2\mu\theta$, when wedge angle θ increases, β (fringe width) decreases.

Hence due to these two reasons, we conclude that the fringes, therefore, get closer and closer with increasing radii as we move away from the centre.

3. *Central fringe is dark in reflected light :*

- **At the point of contact of the lens and glass plate the thickness of air film is negligibly small compared to wavelength of light. $\therefore t\cong 0$ $\therefore \Delta\cong\lambda/2$**
- **For path difference of $\lambda/2$, the interfering rays will always be 180° out of phase and interfere destructively with each other. Thus, the two interfering waves at the center are opposite in phase and produce a dark spot.**



4. ***Fringes are circular :***

- **In Newton's ring arrangement, a thin air film is enclosed between plano-convex lens and a glass plate.**
- **The thickness of the air film at the point of contact is zero and gradually increases as we move outward.**
- **Each dark and bright fringe is locus of film of constant thickness.**
- **The locus of points (in the air film)having the constant thickness lie on the circle whose center is the point of contact between the lens and glass plate. The fringes are, therefore, circular.**

Question6: Draw a neat diagram of experimental set up for the Newton's rings formation. Why are the rings circular? Why the rings are not evenly spaced? (4M)[S16]

Question7: In Newton's ring experiment why: i) The rings are not equally spaced? ii) The central fringe is dark? (3M)[S11]

Question8: In Newton's ring experiment why: i) Plano convex lens should have larger radius ii) Rings get closer away from center iii) Central fringe is dark in reflected light. (4M)[S15]

Question9: In Newtons ring experiment why: i)Plano convex lens should have larger radius of curvature ii) Rings gets closer away from center (3M)[S13]

Question10: Why in Newton's ring experiment the central spot is dark? (4M)[W13]

Question11: In Newton's Ring experiment, explain why i) Plano-convex lens should have larger radius ii) Rings get closer away from the center iii) Central fringe is dark in reflected light iv) Fringes are circular. (4M)[S18]

Applications of Newton's Rings:

❖ To determine the radius of curvature of plano-convex lens.

❖ To determine the wavelength of incident light.

❖ To determine refractive index of liquid.

❖ To test the surface finish of lens.

Experiment: To determine the radius of curvature of plano-convex lens:

❖ In Newton's ring arrangement, a thin film of air is enclosed between Plano convex lens and a glass plate.

❖ The thickness of the film at the point of contact is zero and gradually increases as we move outward.

❖ When the film is illuminated with monochromatic sodium light of wavelength 'λ' at normal incidence, dark and bright circular concentric fringes (rings) are obtained.

❖ The condition of constructive and destructive interference of rays is given by

For bright rings, $2t=(2n+1)\,\lambda/2$

For dark rings, $2\,t = n\,\lambda$

The radius of dark rings of n^{th} dark ring is $r_n = \sqrt{(n\lambda R)}$

The diameter is given by $D_n = 2\sqrt{(n\lambda R)}$ and

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

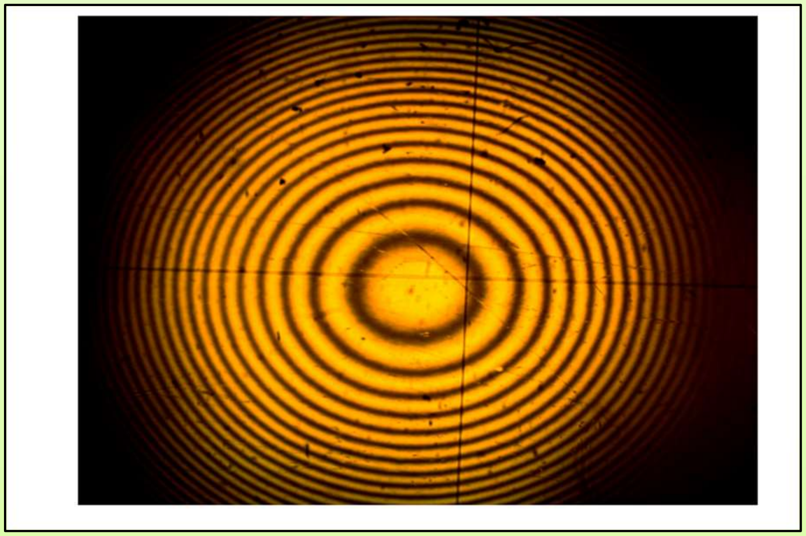
❖ For $(n+p)^{th}$ dark ring, $D_{n+p}^2 = 4(n+p)\,\lambda\,R$ --------------- (2)

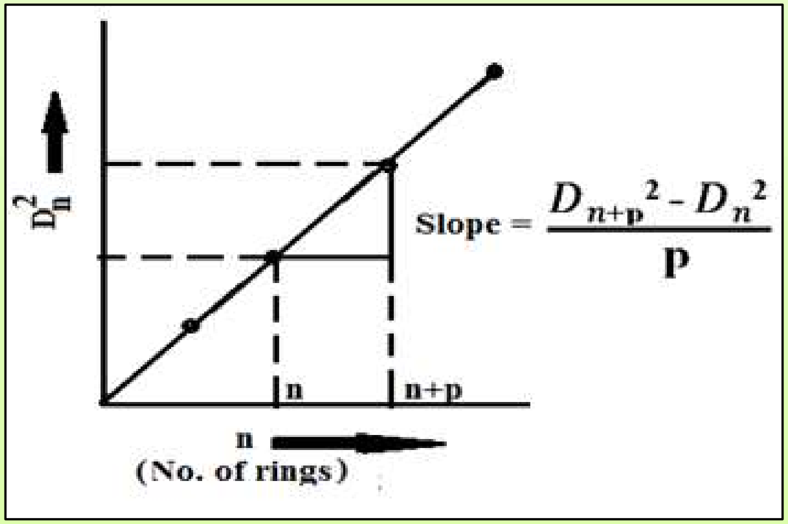
- Subtracting eqn.(1) from eqn.(2) we get

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

  Hence $R = D_{n+p}^2 - D_n^2 / 4p\lambda$ ---------- (3)

- In practice, the diameters of successive dark rings are measured using a travelling microscope (Figure 11).
- A graph is plotted between D_n^2 versus 'n' as shown in figure 14.
- The plot is a straight line passing through origin. The slope of line is calculated as $D_{n+p}^2 - D_n^2 / p$.
- Substituting value of slope, Radius of curvature of Plano-convex lens 'R' is calculated as R = slope/4 λ where the wavelength of incident monochromatic source(sodium source) is given as λ = 5893Å.
- Eqn.(3) can also be used to find wavelength of incident light provided the value of Radius of curvature of Plano-convex lens 'R' is known.





Application:To determine refractive index of liquid

- We first determine the diameters of (n+p)th and nth dark rings with air film enclosed between lens and glass plate.
- The air film is then replaced by liquid whose refractive index is to be determined. The liquid is filled between plano-convex lens and glass plate as shown in figure 15.
- The condition of interference is given by, $2\mu_L t = n\lambda$ (for dark rings) -------- (1)
- Diameter of nth dark ring is given by,

  $(D^2{}_n)_L = 4n\lambda R/\mu_L$ --------- (2)
- Similarly, diameter of (n+p)th dark ring is given by,

  $(D_{n+p}{}^2)_L = 4(n+p)\lambda R/\mu_L$ --------- (3)
- Subtracting eq. (2) from (3), we get,

  $(D_{n+p}{}^2)_L - (D^2{}_n)_L = 4p\lambda R/\mu_L$ --------- (4)

  We know for air, μ=1,

  $(D_{n+p}{}^2)_{air} - (D^2{}_n)_{air} = 4p\lambda R$ --------- (5)
- Dividing equation (5) by (4) we get,

  $\mu_L = (D_{n+p}{}^2)_{air} - (D^2{}_n)_{air} / ((D_{n+p}{}^2)_L - (D^2{}_n)_L$ --------- (6)

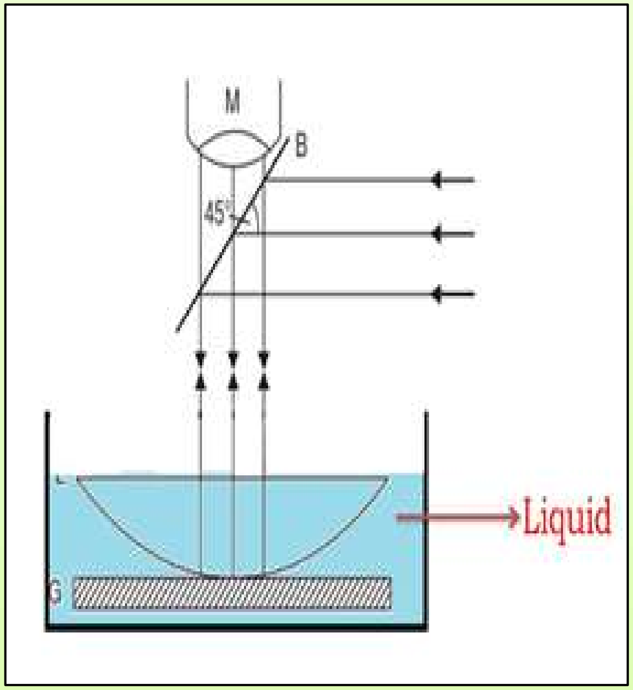


Figure15

Question12:How can Newton's ring experiment be used to determine refractive index of liquid? (4) W-14, W-18

Application: To test the surface finish of lens

- This experiment is used for testing the optical components of telescopes and other instruments. The lens surface is tested by keeping it on a master.
- If the lens is grounded perfectly, circular fringe pattern can be obtained as shown in Figure.14 (a). If not, distorted patterns can be observed as shown in Figure. 16 (b) and (c).
- Variations in the fringe pattern indicate how the lens must be grounded and polished to remove the imperfections.

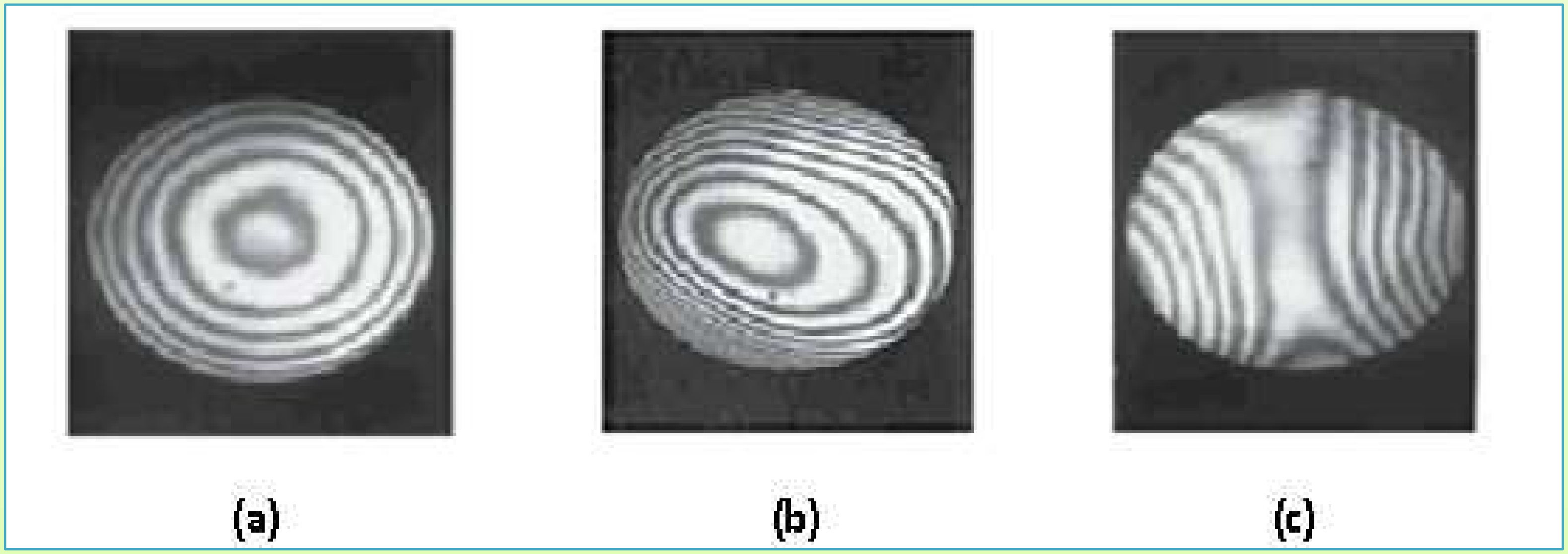


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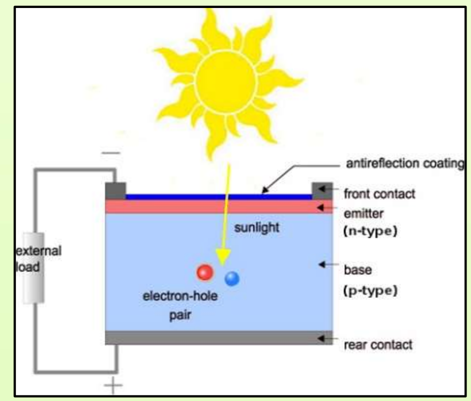
Figure16:Testing the lens surface using Newton's rings (a) circular ring pattern indicating the perfectness of the surface (b) and (c) distorted patterns indicating irregularities

Anti reflection coating(AR coating)

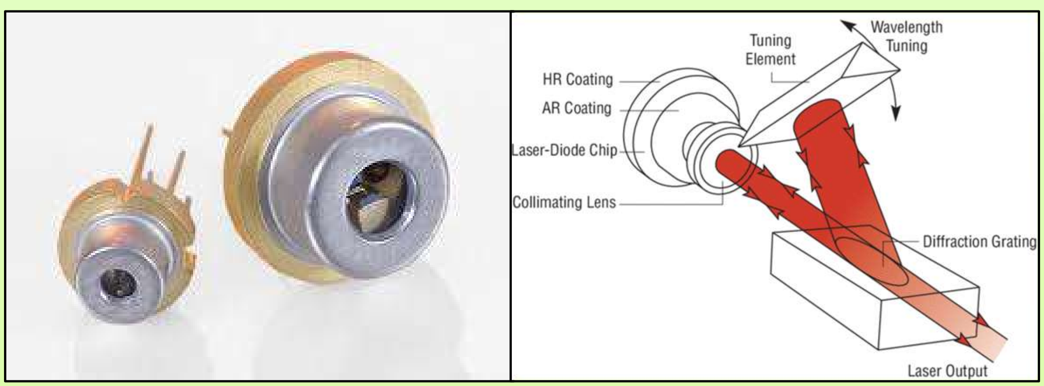
- **Anti-reflective (AR) coatings make your glasses easier to clean by preventing oil, water, and dirt from sticking to the lens.**
- **It increases visual clarity, enhances life of lenses, reduces blue light exposure and protects our eyes from UV rays.**
- **(AR) coating options that vastly improve the efficiency of the optic by increasing transmission, enhancing contrast, and eliminating ghost images.**

AR coating On Spectacles

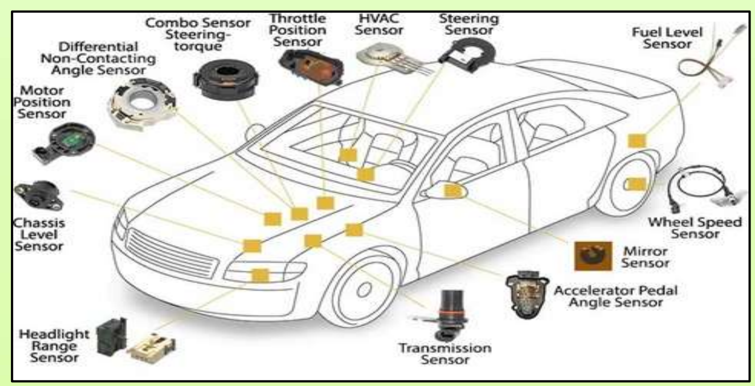
AR coating On camera lens



AR coating on Solar cells



AR coating On laser diodes



AR coating On Sensors in automobiles

Principle of Anti reflective coating

- A thin transparent film coated on a surface in order to suppress reflections from it is called an antireflection coating (AR coating).

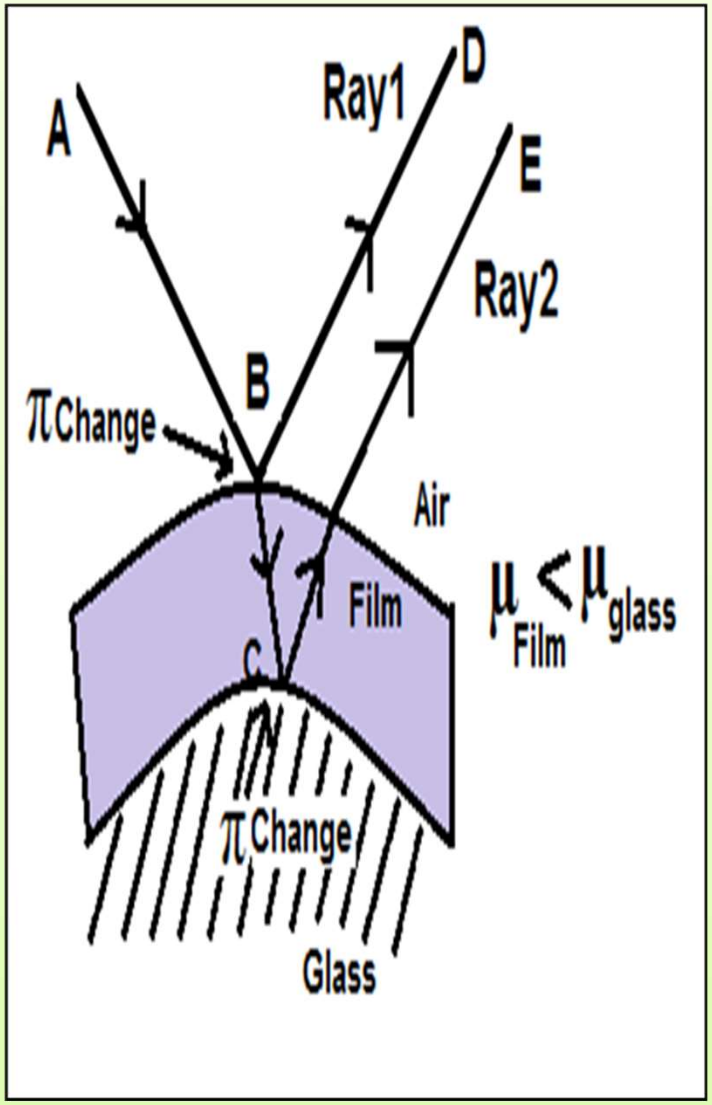


Figure17

❖ **Principle**: A thin film coating can act as an AR coating if it satisfies two conditions:

1. **Phase condition**: The waves reflected from the top and bottom surface are exactly out of phase by 180º and

(b) **Amplitude condition**: The two waves should have equal amplitude.

❖ When these two conditions are satisfied the reflected rays, Ray1 and Ray 2 undergo destructive interference as shown in figure 17.

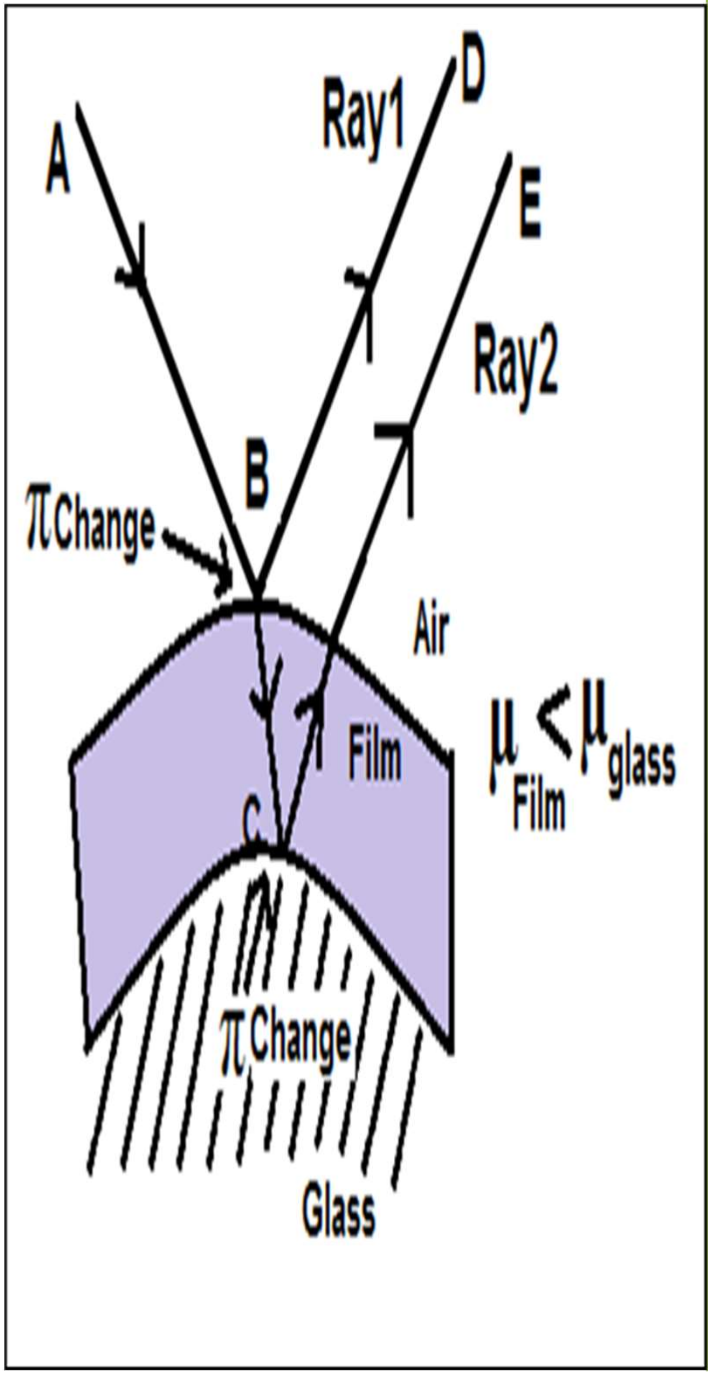
Amplitude condition

❖ To satisfy amplitude condition, the refractive index of the coating material must be nearly equal to the square root of the refractive index of the substrate material (glass).

$$\mu_{film} = \sqrt{\mu_{substrate}} = \sqrt{\mu_{\text{glass}}} \text{ --------- (1)}$$

Therefore $\mu_{film} < \sqrt{\mu_{substrate}}$

Phase condition and expression for minimum thickness of Anti-reflection coating):



- Consider a thin film coated on a glass surface such that refractive index $\mu_f < \mu_g$ as shown in figure.
- The phase condition requires that the waves reflected from top and bottom (Ray1 and Ray 2) must be exactly 180^o out of phase.
- Hence after reflection the path difference for both the ray changes by $\lambda/2$.
- Therefore, the Optical path difference between the reflected rays is given by

$$\Delta = 2\mu_f t \cos r - \lambda/2 - \lambda/2$$

- For normal incidence cos r = 1 ∴ Path difference

$$\Delta = 2\mu_f t - \lambda = 2\mu_f t$$

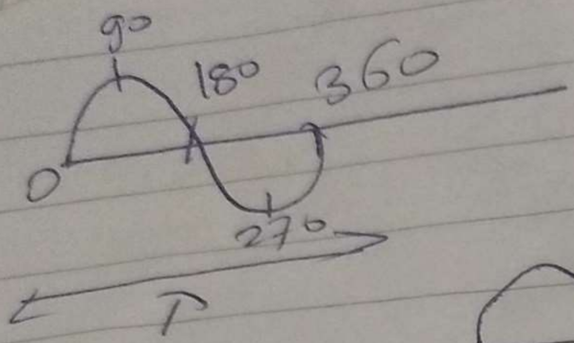
- But for destructive interference , $\Delta = (2n+1)\lambda/2$

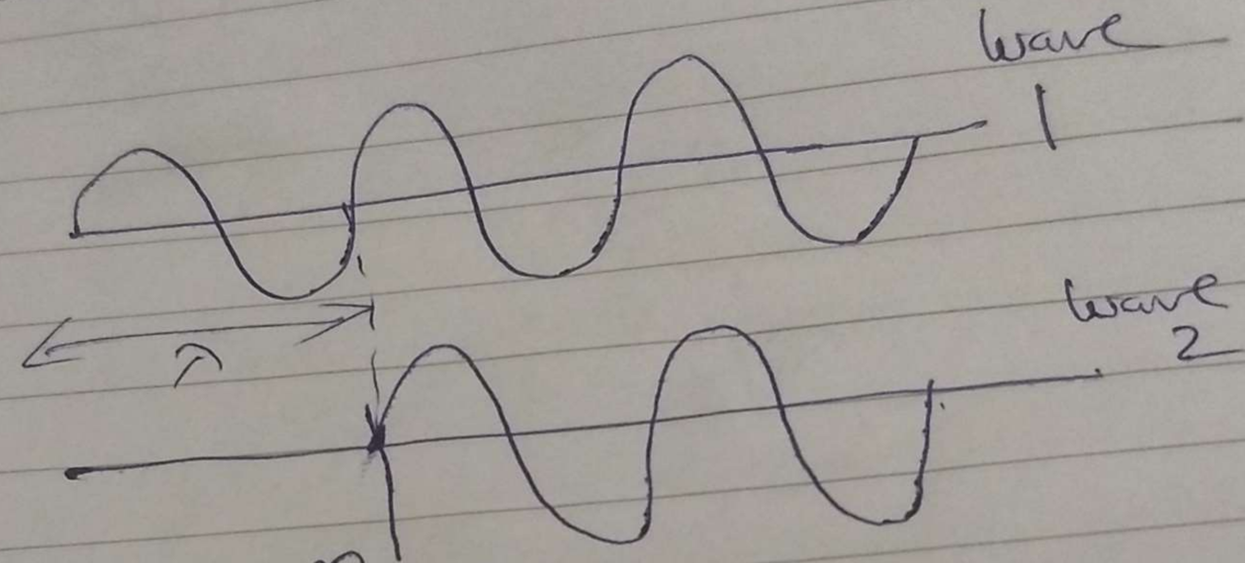
$$\therefore 2\mu_f t = (2n+1)\lambda/2$$

- When n = 0, the thickness of the film will be minimum. Thus, $\therefore 2\mu_f t_{min} = \lambda/2$

$$t_{min} = \lambda/4\mu_f \text{ --------- (2)}$$

Therefore, the optical thickness of the film ($\mu_f t$) should be equal to one- quarter wavelength.





At path difference is $+\lambda$ or $-\lambda$ there will be no path difference

$\therefore$ Path difference

$= \Delta = 2\mu t \cos r - \lambda = 2\mu t \cos r$

Similarly $\Delta = 2\mu t \cos r + \lambda = 2\mu t \cos r$

DIFFRACTION OF LIGHT: INTRODUCTION

- **Diffraction is exhibited by all types of waves, be it sound waves, light waves, water waves or matter waves.**
- **Since the wavelength of light is much smaller than the dimensions of most of the obstacles; we do not encounter diffraction effects of light in everyday observations.**
- **Also, the finite resolution of our eye or of optical instruments such as telescopes or microscopes is limited due to the phenomenon of diffraction.**
- **The first scientist who recorded accurate observations on the diffraction phenomenon was an Italian scientist Francesco Maria Grimaldi, in 1660.**
- **He coined the word "diffraction“ from the Latin word ‘*diffringere’*,meaning ‘to break into pieces', referring to light breaking up into different directions.**
- **Diffraction is defined as *the bending of light rays around the corners of an obstacle or encroachment of light within the geometrical shadow of the obstacle or aperture.***

DIFFRACTION OF LIGHT:IN REAL LIFE

- **Some examples of diffraction phenomenon in real life are formation of rainbow after rain, CD and DVD's reflecting rainbow colours, Sun appears red during sunset, bending of light at the corners of the door as shown in figure**
- **Diffraction in the atmosphere by small particles can cause a bright ring to be visible around a bright light source like the sun or the moon.**

Fig.21: Some examples of diffraction phenomenon in real life

CONDITIONS FOR DIFFRACTION OF LIGHT

- The amount of diffraction depends on the wavelength of light and the size of the opening as shown in fig.22
- If the opening is much larger than the light's wavelength (Fig.22 a), the bending will be almost unnoticeable.
- *However, if the* size of the opening *(fig.22 b) is of the order of* the wavelength of light, then *the amount of bending is considerable,i.e.the condition of diffraction.(Slit width should be of the the order of* the wavelength of light,
- An obstacle or opening will diffract shorter wavelength slightly and longer wavelengths more as shown in fig.22 (c).

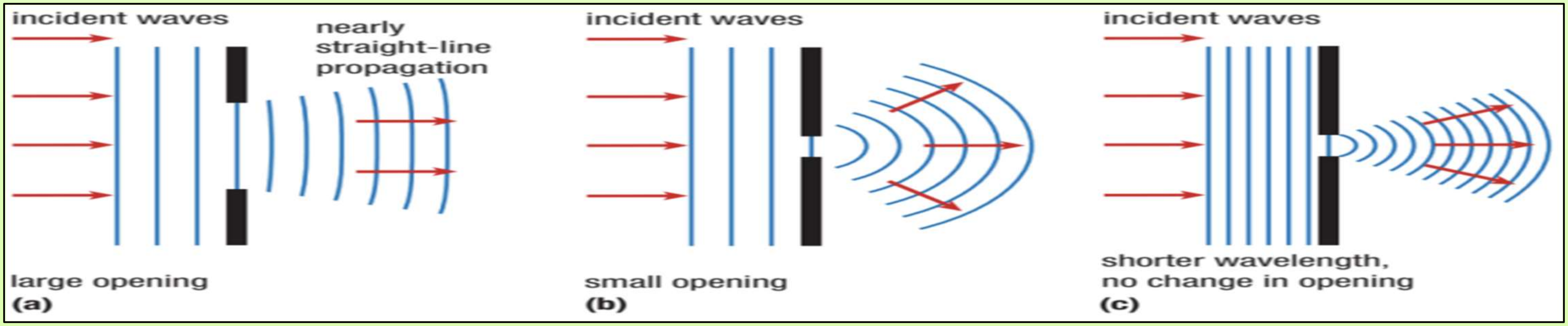


Fig.22: a) and b) As slit opening decreases, diffraction increases. c) With shorter wavelength and no change in size of opening, diffraction decreases.

TYPES OF DIFFRACTION

Types of Diffraction

Fresnel

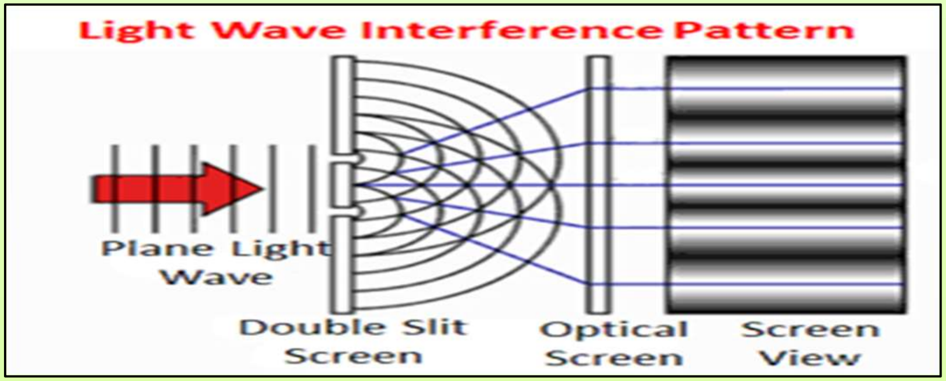
- The source or the screen or both are at finite distances from the obstacle (or aperture).
- In this case, no lenses are used to make the rays parallel or convergent.
- The incident wavefronts are either spherical or cylindrical.

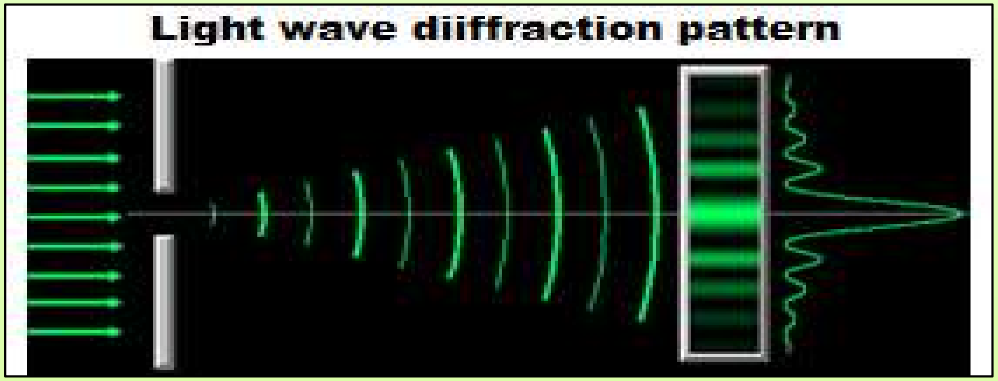
Fraunhofer

- The source and the screen or the telescope is placed at infinite distance from the obstacle.
- Lenses are used to make the rays converge.
- The incident wavefront on the aperture or obstacle and the telescope is plane wavefront.

Difference between interference and diffraction

S.No.	Interference	Diffraction
1.	Interference phenomenon is due to superposition of light waves from two separated wavefronts.	Diffraction phenomenon is due to superposition of secondary wavelets originating from different points of the exposed parts of the same wavefront.
2.	In the interference pattern, the contrast between maxima and minima is good.	In the diffraction pattern, the contrast between maxima and minima is poor.
3.	In the interference pattern, regions of minimum intensity are perfectly dark and all bright fringes are of equal intensity.	In the diffraction pattern, regions of minimum intensity are not perfectly dark and only the first maxima has maximum intensity and the intensity decreases as the order of maxima increases.





FRAUNHOFER DIFFRACTION THROUGH SINGLE SLIT

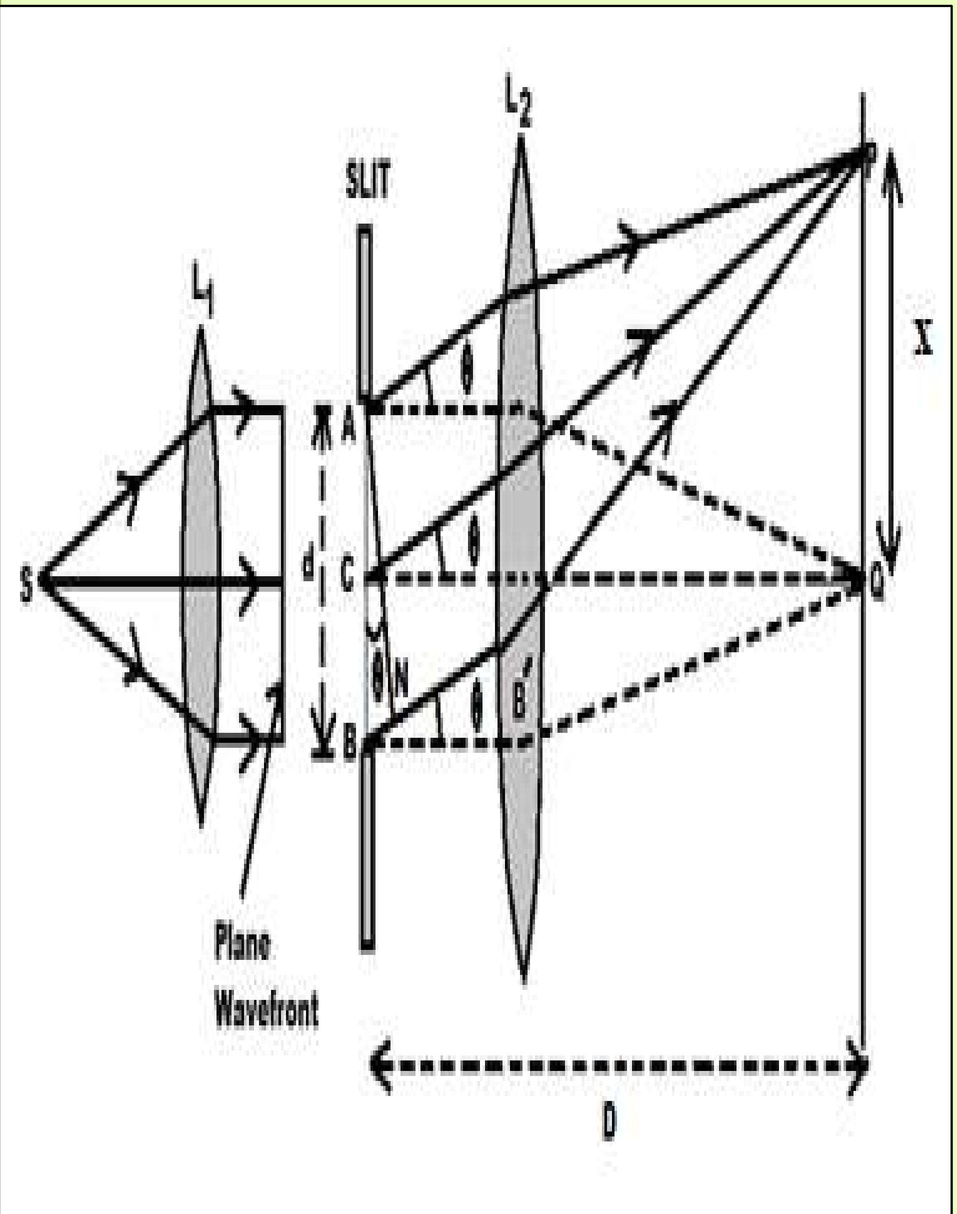
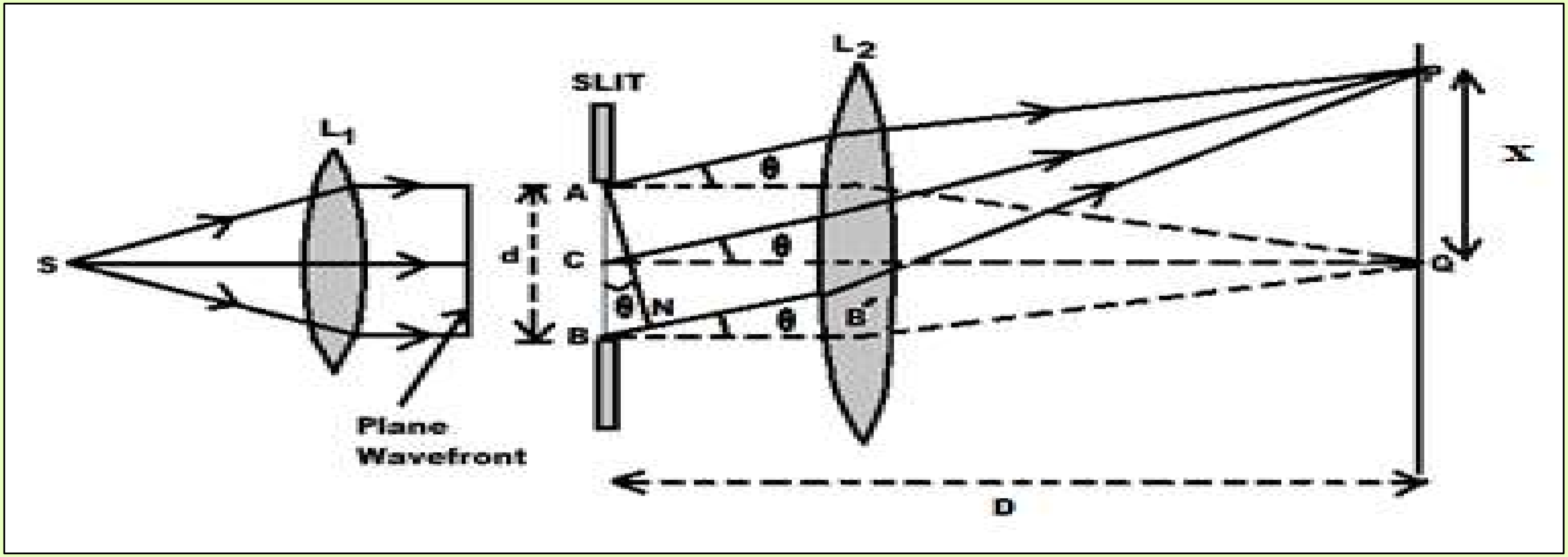


Fig:23 Fraunhofer diffraction through single slit

- **Experimental arrangement is shown in figure 23**
- **The wavefront from source S is incident on the slit AB of width'd'.**
- **According to Huygens' Principle, each point of wavefront passing through the slit AB acts as a source of secondary wavelets.**
- **A real image of diffraction pattern is formed on the screen with the help of converginglensL_{2}.**
- **Thus, diffraction pattern on screen consists of a central bright band and alternate dark and bright bands of decreasing intensity on both sides.**
- **Let C be the center of the slit AB. The secondary waves, from points equidistant from center C of the slit lying on portion CA and CB of wave front travel the same distance in reaching Q and hence the path difference between them is zero.**
- **These waves reinforce each other and give rise to the central maximum at point Q.**

Derivation of width of slit and position of minima and secondary maxima.



- Draw AN perpendicular on BB'.The path difference between the secondary wavelets originating from A and B is BN.
- From Δ BAN, $\frac{BN}{AB} = \sin\theta$ or BN = AB sinθ

∴Path difference, BN = d sin θ ≈ dθ (as θ is small)

- For Minima: If the path difference is equal to one wavelength,

  i.e., BN= d sin θ = λ, position P will be of minimum intensity.

- For first minima, for θ = θ_1, d sin θ_1 = λ or sin $\theta_1 = \frac{\lambda}{d}$

or $\theta_1 = \frac{\lambda}{d}$ (for very small value of θ)

❖ **In general, for minima of order 'm', d sinθ_m= m λ**

or sinθ_m=$\frac{m\lambda}{d}$

❖ **Since θ_m is very small, so sin θ_m = θ_m**

∴ θ_m= $\frac{m\lambda}{d}$ (here θ we use is in radians)

where m=1,2,3, ….is an integer.

For secondary maxima:

❖ **If path difference, BN = d sin θ is an odd multiple of $\frac{\lambda}{2}$,**

i.e., d sinθ_m=$\frac{(2m+1)\lambda}{2}$

❖ **Since θ_m is very small,sin θ_m = θ_m,**

$$\therefore \ \theta_m = \frac{(2m+1)\lambda}{2d}$$

where m=1 ,2, 3, …. is an integer.

Width of central maximum: 2x

- **Let 'f' be the focal length of lens L_2 .**
- **The distance of first minima on either side of the central maxima be $'x'$ as shown in fig. 23.**

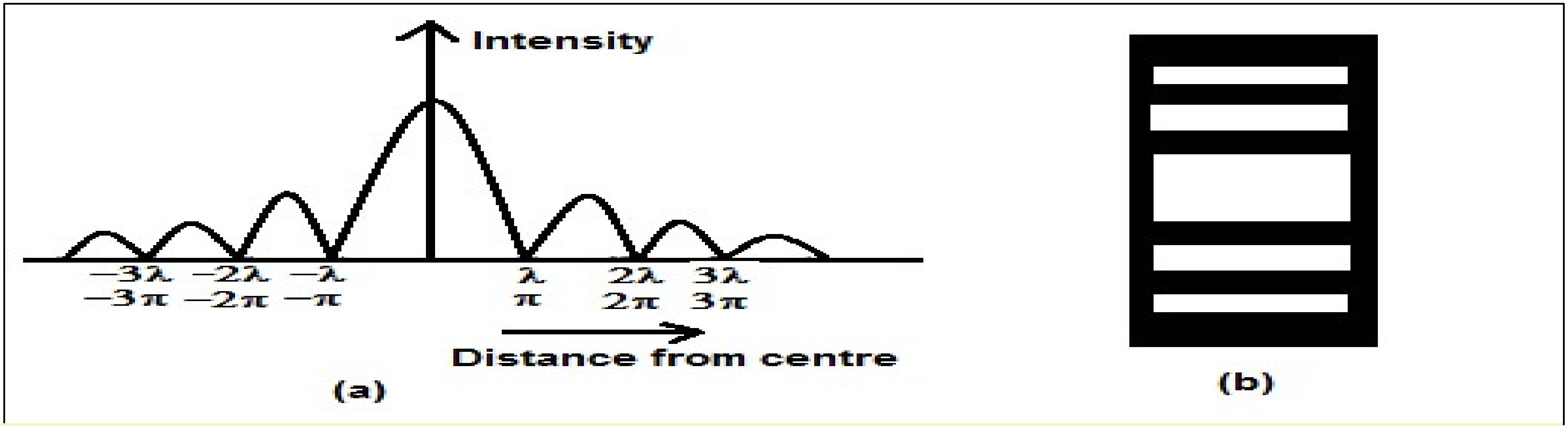
Then, $\tan\theta = \frac{x}{f}$

- **Since the lens L_2 is very close to the slit, so f = D,** $\tan\theta = \frac{x}{D}$ **---------- (1)**
- **For θ is very small,** $\tan\theta \approx \sin\theta$, $\therefore\ \tan\theta = \sin\theta = \frac{x}{D}$ **---------- (2)**
- **Also, for first minima,** $d\sin\theta = \lambda$ **or** $\sin\theta = \frac{\lambda}{d}$ **---------- (3)**
- **From eqns. (2) and (3), we have** $\frac{x}{D} = \frac{\lambda}{d}$

$$\text{or } x = \frac{\lambda}{d}D \qquad \text{---------- (4)}$$

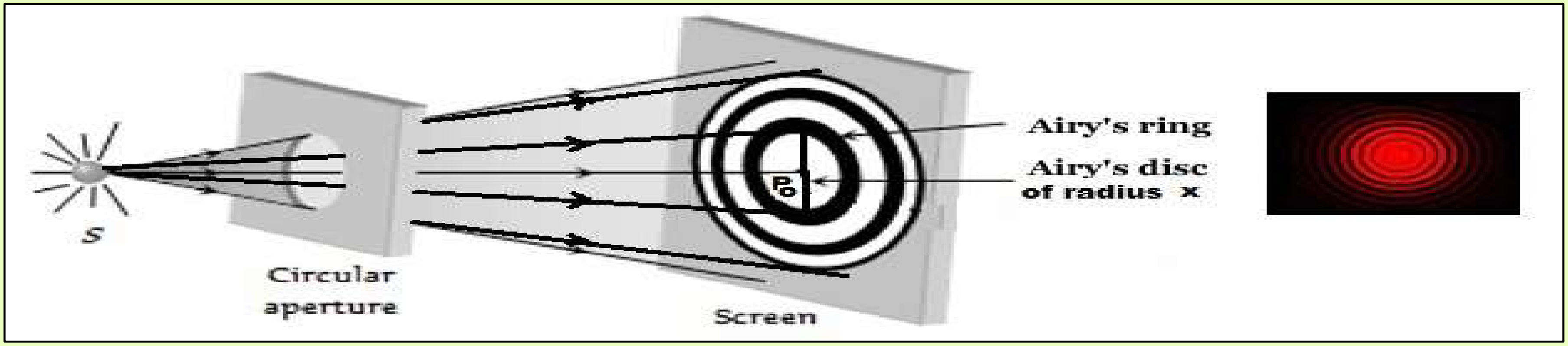
This is the distance of first minima on either side from the centre of the central maximum.

- **Width of central maximum,** $2x = \frac{2\lambda}{d}D$ **----------(5)**



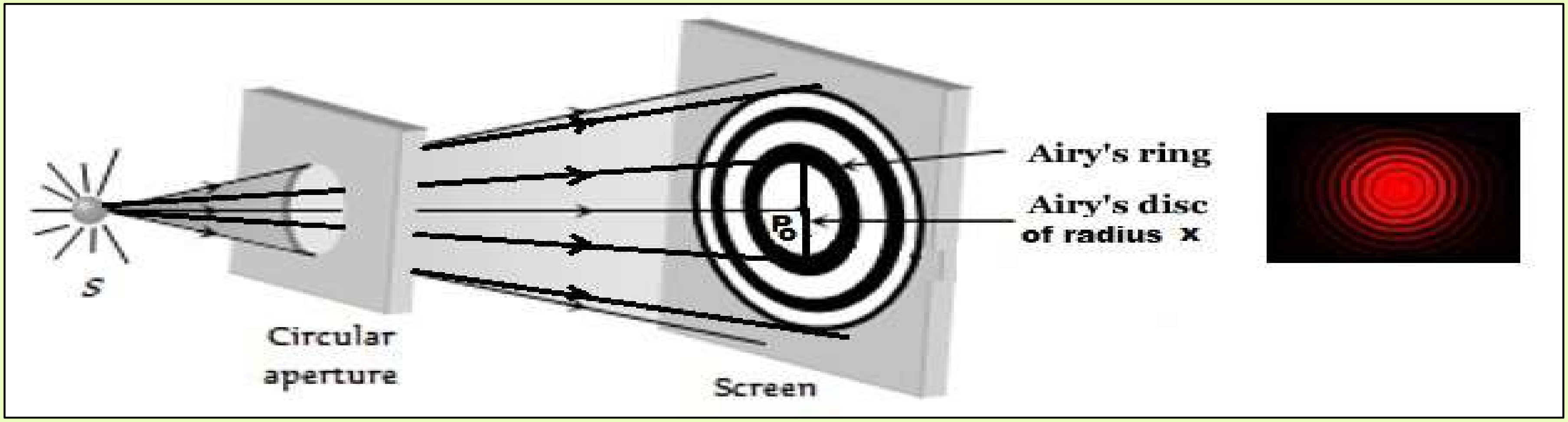
- The width of the central maximum is proportional to 'λ' , the wavelength of light.
- For longer wavelength, the width of the central maxima is more than with light of shorter wavelength.
- With a narrow slit (smaller 'd' value), the width of the central maximum is more.
- The diffraction pattern consists of alternate bright and dark bands with monochromatic light.
- With white light, the central maximum is white and the rest of the diffraction bands are coloured.
- We can see that the maxima and minima are very close to the central maximum.
- But with a narrow slit 'd' is small and hence θ is large.(because $d \sin \theta = \lambda$)
- Hence there is distinct diffraction maxima and minima on both the sides of central maximum.

FRAUNHOFER DIFFRACTION THROUGH CIRCULAR APERTURE



- When a parallel beam of light is passed through circular aperture of an opaque board, then the light is diffracted by the aperture.
- If received on a screen at a large distance, the pattern is a bright disc called Airy disc surrounded by alternate dark and bright concentric rings called Airy rings of decreasing intensity.
- The wavefront is obstructed by the opaque board and only the points of the wavefront that are exposed by the aperture send the secondary wavelets.
- The bright and dark rings are formed by the superposition of these wavelets.
- The diffracted secondary wavelets are converged on the screen by keeping a convex lens between the aperture and the screen. The screen is at the focal plane of the convex lens.

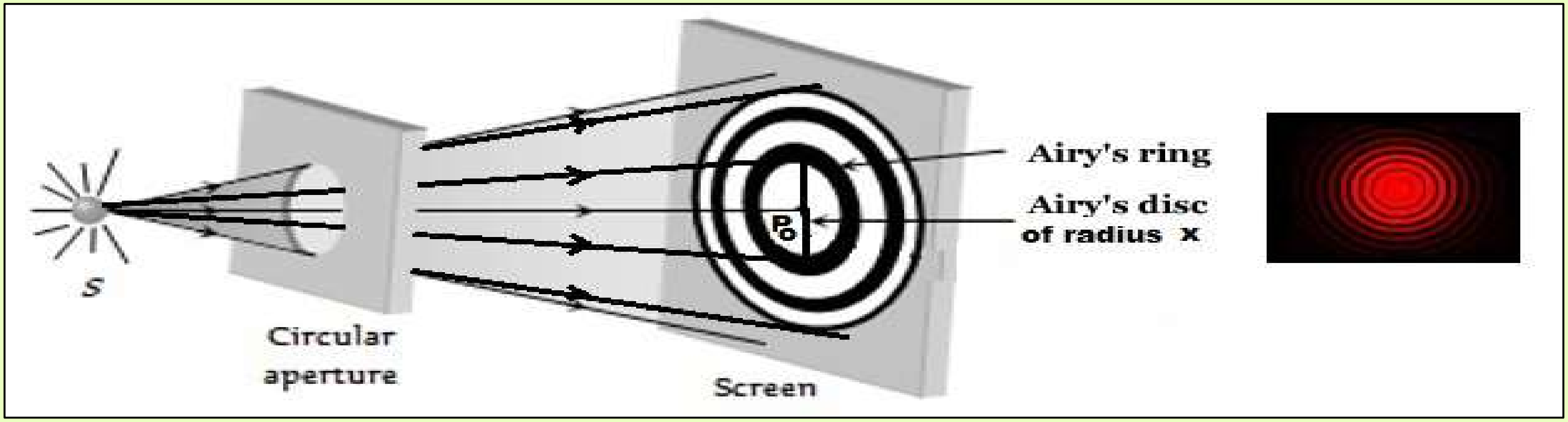
FRAUNHOFER DIFFRACTION THROUGH CIRCULAR APERTURE



- The secondary wavelets travel same distance to reach P_o and there is no path difference between these rays. Hence a bright spot is formed at P_o which is known *Airy's disc*. P_o corresponds to the central maximum.

- The secondary waves which travel at a certain angle θ with respect to central axis form a cone and hence, they form a diffracted ring on the screen.
- The radius of Airy's disc is given by $x = 1.22 \frac{\lambda f}{d}$
- Therefore, the radius of Airy's disc is inversely proportional to the diameter of the aperture. Therefore, by decreasing the diameter of aperture, the size of Airy's disc increases.
- Since the lenses used as objective and eyepieces in telescopes and microscopes are circular in shape and constitute a circular aperture. Hence Fraunhofer diffraction using circular Aperture is of the most practical interest.

RADIUS OF AIRY'S DISC



- **The secondary wavelets travel same distance to reach P_o and there is no path difference between these rays. Hence a bright spot is formed at P_o which is known *Airy's disc*. P_o corresponds to the central maximum.**

- **The secondary waves which travel at a certain angle θ with respect to central axis form a cone and hence, they form a diffracted ring on the screen.**
- **The radius of Airy's disc is given by $x = 1.22\frac{\lambda f}{d}$**
- **Therefore, the radius of Airy's disc is inversely proportional to the diameter of the aperture. Therefore, by decreasing the diameter of aperture, the size of Airy's disc increases.**
- **Since the lenses used as objective and eyepieces in telescopes and microscopes are circular in shape and constitute a circular aperture. Hence Fraunhofer diffraction using circular Aperture is of the most practical interest.**

DIFFRACTION GRATING

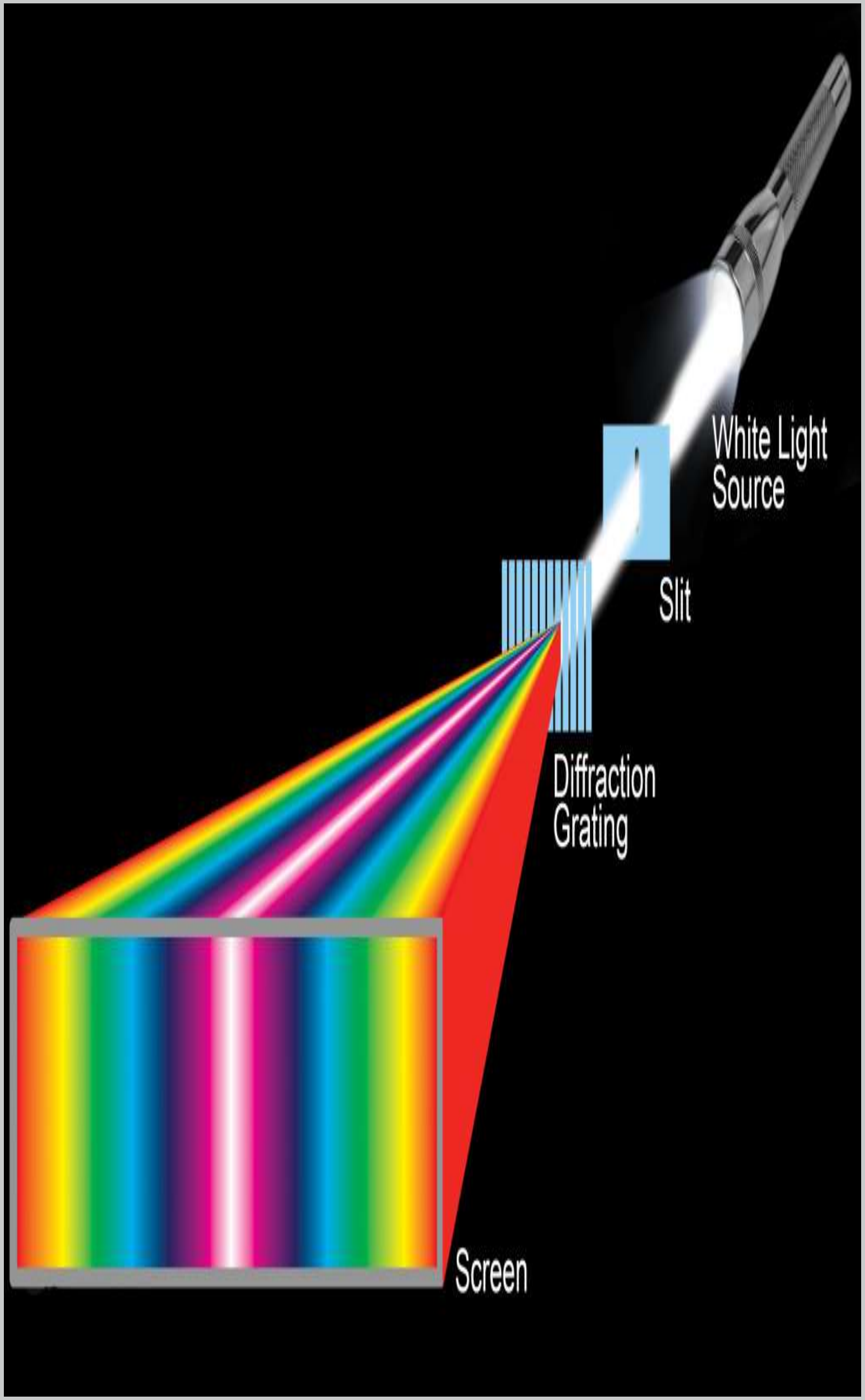
- Diffraction Gratings are optical components used to separate light into its component wavelengths.
- Diffraction Grating consists of a series of closely packed grooves(deep line cut in a surface) that have been engraved or etched into the Grating's surface.
- Plane transmission Grating is a plane sheet of transparent material on which opaque rulings are made with a fine diamond pointer.
- Thus, it consists of a large number of equally spaced parallel transparent spaces called slits.
- Grating element and grating equation:

If light is incident normally on a transmission grating of wavelength λ, then the direction of principal maxima is given by

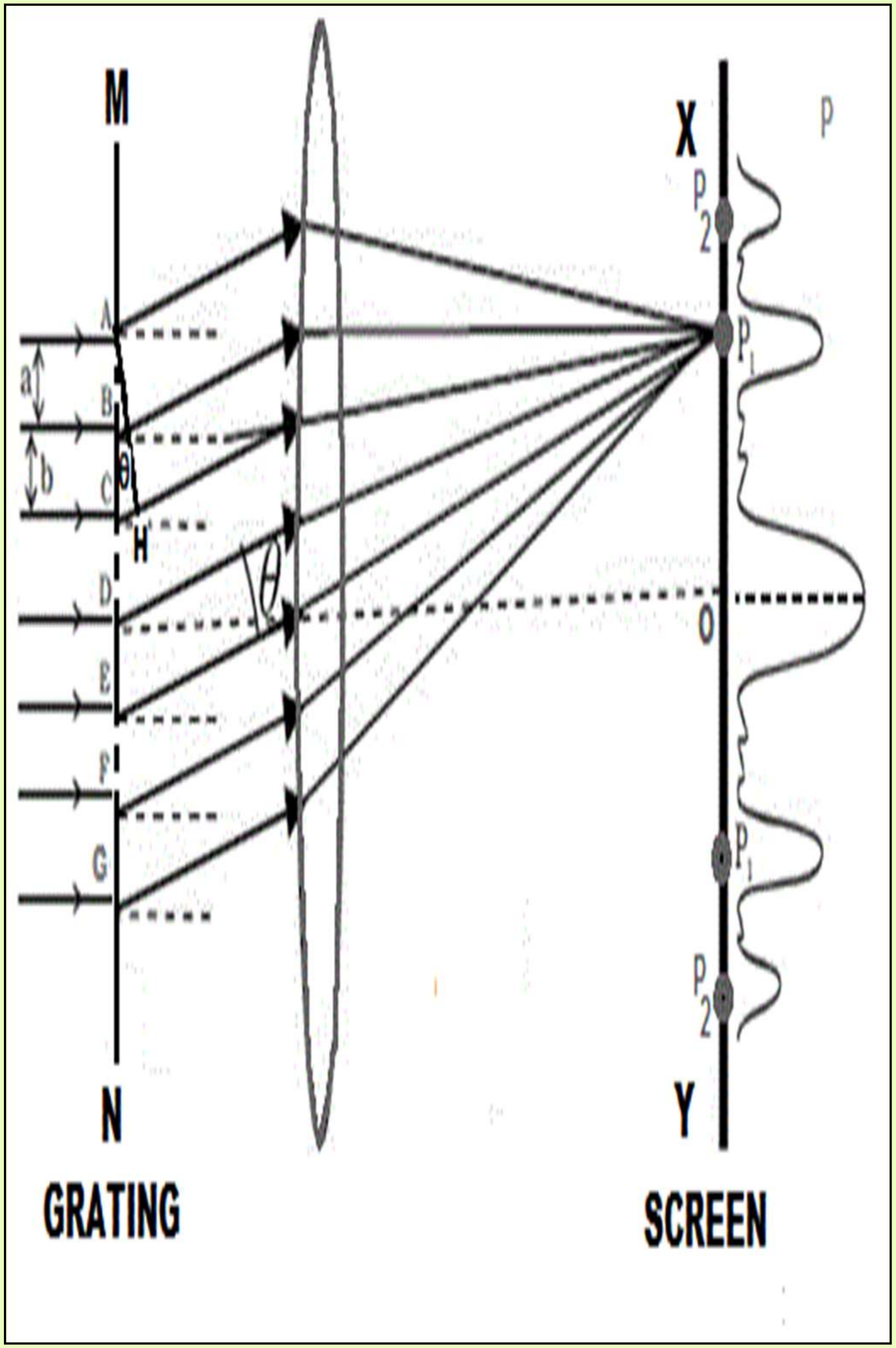
$$d \sin \theta = n\lambda$$

where'd' is the distance between two consecutive slits and n =1, 2, 3----, is the order of principal maxima.

- This Equation is called Grating equation and gives the position of principal maxima.
- The rulings on the grating act as obstacles having a definite width 'b' and the transparent space between the rulings act as slit of width 'a'.
- The combined width of a ruling and a slit is called grating element d = a + b.



DIFFRACTION THROUGH PLANE TRANSMISSION GRATING



- Let MN is the plane transmission grating having AB, CD, EF as successive slits of equal width 'a' and BC, DE represent rulings of width 'b'.
- The path difference between the wavelets from one pair of corresponding points A and C is CH = (a + b) sin θ.
- The point P_1 will be bright, when

  (a + b) sin θ = n λ where n = 0, 1, 2 3 --------

- Therefore $\sin\theta = \frac{n\lambda}{a+b}$

  or $\sin\theta = Nn\lambda$ where $N = \frac{1}{a+b}$, gives number of lines per unit width of the grating.

  Also from above equation $\therefore n = \frac{(a+b)\sin\theta}{\lambda}$

- Since the maximum angle of diffraction is 90^o, hence the maximum possible order available in grating is given by

$$\therefore n_{max.} = \frac{(a+b)}{\lambda} \text{ for } \sin\theta = 1$$

RESOLVING POWER OF GRATING

- ***Resolving power of the grating is defined as** the ability of a grating to form separate diffraction maxima of two wavelengths which are very close to each other.*
- **For two nearly equal wavelengths λ_1 and λ_2, between which a diffraction grating can just barely be distinguished, the resolving power 'R' of the grating is defined as**
- $$R = \frac{\lambda}{\lambda_2 - \lambda_1} = \frac{\lambda}{d\lambda}$$

where $\lambda = \frac{\lambda_1 + \lambda_2}{2}$ is the mean value of the two wavelengths λ_1 and λ_2 and the smallest difference $d\lambda = \lambda_2 - \lambda_1$

- **Also Resolving power of grating is found as**

$$R.P. = \frac{\lambda}{d\lambda} = nN$$

Where the order of spectrum is 'n' and total number of lines on the grating surface 'N'.

Numericals

Formulae:

(I)Wedge shaped film:

- **1.** Fringe width $\beta = \frac{\lambda}{2\mu\theta}$
- **2.** Wedge angle $\theta = \frac{\lambda}{2\mu\beta}$
- **26.Q.1 Fringes of equal thickness are observed in a glass wedge of R.I. 1.52. The fringe spacing is 0.1mm, wavelength of light being 5893Å. Calculate the wedge angle. (3) W-14**
- Ans. **Given:** $\mu = 1.52$
- $\beta = 0.1$ mm $= 10^{-4}$ m
- $\lambda = 5893\ A^0 = 5893 \times 10^{-10}$ m. θ=?
- **Solution:** Fringe width $\beta = \frac{\lambda}{2\mu}$
- Wedge angle θ is given by- $\theta = \frac{\lambda}{2\mu\beta} = \frac{5893X10^{-10}}{2X1.52X1\ ^{-4}}$ $=1.94\text{x}10^{-3}$rad $=0.11°$.

Numericals

- **(II) Newton's Rings:**
- **1.** For dark rings $D_n^2 = 4n\,\lambda\,R$
- **2.** Radius of curvature of plano-convex lens $R = \frac{D_n^2}{4n\lambda}$
- **3.** Wavelength of incident light $\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR}$

Q. 3 In Newton's ring experiment, the diameter of 5th ring is 0.336cm and the diameter of 15th ring is 0.590cm. Find the radius of curvature of plano-convex lens if the wavelength of light used is 5890Å. (3) W-15

Ans. **Given:** $\lambda = 5890\text{Å} = 5890 \times 10^{-10}$ m ,

D_{15}=0.590 cm=0.59 x10^{-2}m,

D_5=0.336 cm= 0.336x10^{-2}m, p=15-5=10, R=?

- **Solution:** $\lambda = \frac{D_{n+p}^2 - D_n^2}{4pR} \therefore R =$

$\frac{D_{n+p}^2 - D_n^2}{4p\lambda} = \frac{[(0.59X10^{-2})^2 - (0.336X\quad^{-2})^2]m^2}{4X10X5890X10^{-10}m}$ =0.9983m=99.83cm

-

Numericals

27.Q. 4 In Newton's Rings experiment, diameter of 10th dark ring due to wavelength 6000Å in air is 0.5cm, find the radius of curvature of lens. (3) W-16

Ans. **Given:** Diameter of 10th dark ring=$D_{10} = 0.5cm = 0.5X10^{-2}$m

λ=6000Å=6000X10^{-10}m, n=10, R=?

Solution: For dark ring, D_n^2= 4n λ R

$$R = \frac{D_n^2}{4n\lambda} = \frac{D_{10}^2}{4X10X\lambda} = \frac{(0.5X10^{-2})^2 m^2}{4X10X6000X10^{-10}m} = 1.04\text{m}$$

30-Q. 5 In a Newton's ring experiment, the diameter of the 15th ring was found to be 0.59cm and that if 5th ring was 0.336cm. If the radius of the plano convex lens is 100cm. Calculate the wavelength of light used. (3) S-17

Ans. Given: R = 100cm=100x10^{-2} m,

D_{15}=0.590 cm=0.59 x10^{-2} m,

D_5=0.336 cm= 0.336x10^{-2} m, p= 15-5=10, λ =?

Solution: $\lambda = \frac{D_{n+p}^2 - D_n^2}{4p} \therefore \lambda = \frac{D_{n+p}^2 - D_n^2}{4pR} = \frac{[(0.59X10^{-2})^2 - (0.336X1\ \ ^{-2})^2]m^2}{4X10X100X1\ \ ^{-2}m} = 5.8801X10^{-7}m$

=5880.1x10^{-10}m=5880.1 Å

Numericals

(III) Anti –reflection coating:

1. Minimum thickness of anti –reflection coating $\boldsymbol{t_{min.}} = \frac{\lambda}{\boldsymbol{4\mu_f}}$

28--Q.8 Find the thickness of water film with refractive index of 1.33 formed on a glass window pane to act as non-reflecting film. Given λ=5500 Å. (2) S-13

Ans. Given: λ=5500Å , μ_f= 1.33, $t_{min.}$ =?

Solution: $\boldsymbol{t_{min.}} = \frac{\lambda}{\boldsymbol{4\mu_f}} = \frac{5500Å}{4X1.33}$= 1033 Å=1033 x$10^{-10}$m.

29-Q.9 A glass of microscope lens is coated with magnesium fluoride (μ=1.38) film to increase the transmission of normally incident light of wavelength 6800Å. What is minimum film thickness needed for optimum result? (2) S-15

Ans.Given: λ=6800 Å , μ_f= 1.38, $t_{min.}$ =?

Solution: $\boldsymbol{t_{min.}} = \frac{\lambda}{\boldsymbol{4\mu_f}} = \frac{6800Å}{4X1.38}$= 1231.88 Å=1231.8x$10^{-10}$m.

Q. 10 A glass microscope lens (μ=1.5) is coated with magnesium fluoride (μ=1.30) film to increase the transmission of normally incident light (λ=5800Å). What minimum film thickness would be deposited on the lens? (3) W-14

Ans. Given: λ=5800 Å, μ_f= 1.3, $t_{min.}$ =?

- **Solution:** $\boldsymbol{t_{min.}} = \frac{\lambda}{\boldsymbol{4\mu_f}} = \frac{5800Å}{4X1.3}$= 1051 Å=1051 x$10^{-10}$m.