Wave Theory of Light

Explain Newton's Corpuscular Theory of Light.

- Every source of light emits large number of tiny particles known as corpuscles in a medium surrounding the source.
- These particles are perfectly elastic, rigid and weightless.
- Corpuscles travel in straight line with very high speeds which are different in different media.
- Different colours of light are due to different sizes of these corpuscles.
- One gets sensation of light when this corpuscle falls on retina.
- The weight of the corpuscular being very small, they are not affected by gravitational force of attraction. Hence they always travel in a straight line.
- To explain phenomenon of reflection, Newton proposed particles of light are repelled by reflecting surface while to explain refraction Newton proposed that particles of light are attracted by refracting.

Drawbacks

- Newton's theory was unable to explain the partial reflection & refraction of light at the surface of transparent medium.
- Corpuscular theory was unable to explain many phenomena in light like double refraction, interference, polarization, diffraction etc.
- Corpuscular theory predicted that speed of light in rarer medium is smaller than speed of light in denser medium. This was experimentally proved wrong by Foucault.
- If light consists of material particles, emission of light from a source should cause reduction in the mass of the source of light. But Experiments shows that there is no such reduction in the mass of the source.

Explain Huygen's wave theory of light

- Light travels in the form of longitudinal waves which travels with uniform velocity in homogeneous medium.
- Different colours are due to different wavelengths of light waves.
- We get the sensation of light when these waves enter our eyes.
- In order to explain the propagation of waves of light through vacuum. Huygen suggested the existence of a hypothetical medium called **luminiferous ether**, which is present in vacuum as well as in all material objects. Since ether couldn't be detected, it was attributed properties like,
  - It is continuous & is made up of elastic particles.
  - It has zero density.
  - It is perfectly transparent.
  - It is present everywhere.

State Advantages of Hugenes' Wave Theory Of Light:

- Phenomena like interference, laws of refraction, Reflection Simultaneous refraction and reflection, Double Refraction can be explained on the basis of this theory.
- According To Huygens, theory the velocity of light in denser medium is less than velocity of light in a rarer medium as was experimentally proved by Focault.

Give Limitations of Huygens' Wave Theory of Light

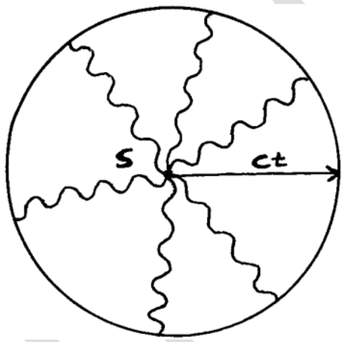
- It could not explain rectilinear propagation of light
- It could not explain phenomenon of polarisation of light and phenomenon like Compton Effect, photoelectric effect.
- Michelson and Morley experiment concluded that there is no ether drag when earth moves through it. This proves ether doesn't exist. All the other attempts / experiments to detect Luminiferous ether failed , which proves that luminiferous ether does not exist.

Maxwell's electromagnetic theory

- Maxwell postulated existence of electromagnetic waves.
- Velocity of electromagnetic waves was experimentally found to be equal to that of light waves. Hence light waves were assumed to be electromagnetic waves.
- No medium is necessary for propagation of electromagnetic waves.

What is Wave surface, Wave front, Wave Normal?

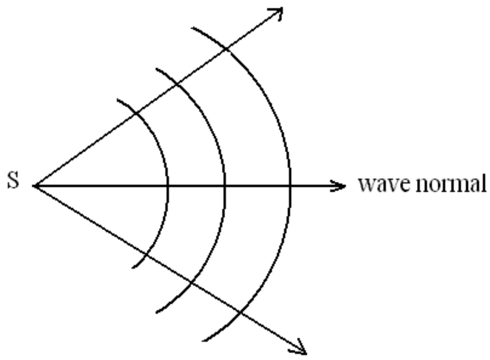
Wave surface : If point source s emits light waves with velocity c in a medium , these waves will reach distance ct in time t. If we draw a sphere with centre s and radius ct, it is called as spherical wave surface.

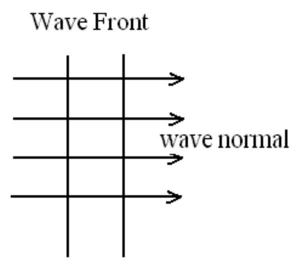


Wave front: It is defined as the locus of all the points of the medium to which waves reach simultaneously, so that all the points are in same phase.

Wave Normal:-

Perpendicular drawn to surface of wave front at any point in direction of propagation of light is called as wave normal.





State Huygens Principle. State its application and explain the construction of spherical wave front

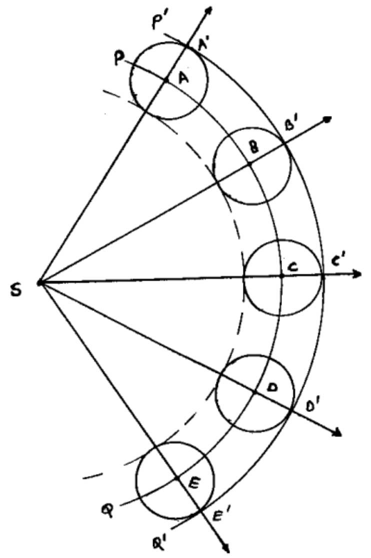
Huygens Principles

- Every point on wave front acts as a secondary source of light, sending out secondary waves in all possible directions.
- New secondary wavelets are more effective in forward direction only (direction of propagation of light).
- The tangent to all secondary wavelets at any instant, gives the resultant wave front at that instant.

Application

- If nature of wave front at any instant is known, we can determine its nature and position at any later instant by using Huygens' construction.

Construction of Spherical Wave front:

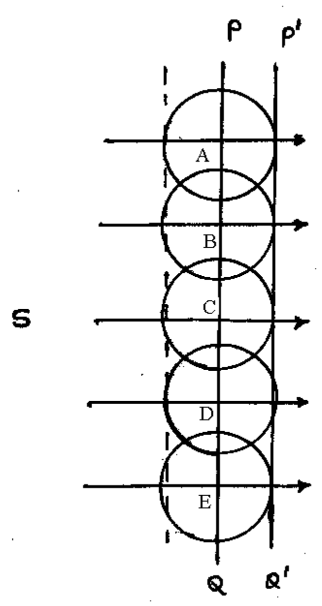


- Consider a point source S of light situated in air. The waves are emitted by the source in all possible directions. Let PQ is cross section of spherical wave front at time t=0.
- Consider points A, B, C, D on PQ. According to Huygens ' Principle every point on wave front will act as a secondary source and will be able to emit secondary waves in all directions.

- In time t, theses secondary wavelets will travel distance ct, where c is velocity of light in medium.
- To determine the wave front after time t draw spheres with A, B, C, and D as centers & Ct as radius. Each sphere will represent a secondary wave front.
- Draw the tangential surface P'Q' to these Secondary Wave fronts.
- Surface P'Q' will represent the position of (new) wave front after time t.
- Secondary waves moving in backward directions do not exist.

Explain construction of Plane wave front

- Suppose PQ represent a plane wave front perpendicular to the plane of the paper due to point source S at very large distance. PQ is considered as primary wave front. Moving from left to right in air.



- According to Huygens ' Principle every point on wave front will act as a secondary source and will be able to emit secondary waves in all directions.
- To find the position of the wavefront after time t. Take points A, B, C, and D as centers, and Ct as a radius and draw the spheres. Each sphere will represent secondary wavefront.
- Draw a plane surface P'Q' tangential to these spheres.
- P'Q' is the position of (new) plane wavefront after time t.

With neat diagram prove the laws of Reflection of Light using hygenes wave theory of light.

- Let AB be a plane wavefront bounded by the ray PA & QB incident at an angle i over the reflecting surface XY.
- Wavefront first reaches XY at point A'. At this instant B reaches B'. As soon as wave reaches A' it behaves as secondary source of light and begins to emit seconadry waves in same medium. Let the wavefront at point B' moves to point C in time t , Let c be the velocity of light in the medium. Then B'C = ct.
- In the same time interval the secondary waves starting from point A' will cover the same distance; Secondary wavefront is shown by dotted hemisphere. Radius of this wavefront is Ct and center A'.
- Tangent CD is drawn to this hemisphere. C and D has same phase because light reaches at this point simultaneously. Hence CD represents reflected wavefront.
- If normal A'N is drawn to XY , $\angle PA'N = \angle i =$ angle of incidence and $\angle DA'N = \angle r =$ angle of reflection

  $\angle DA'C = 90 - i$

  From fig $\angle NA'B' = 90 - i$

  From triangle A'B'C and triangle A'DC

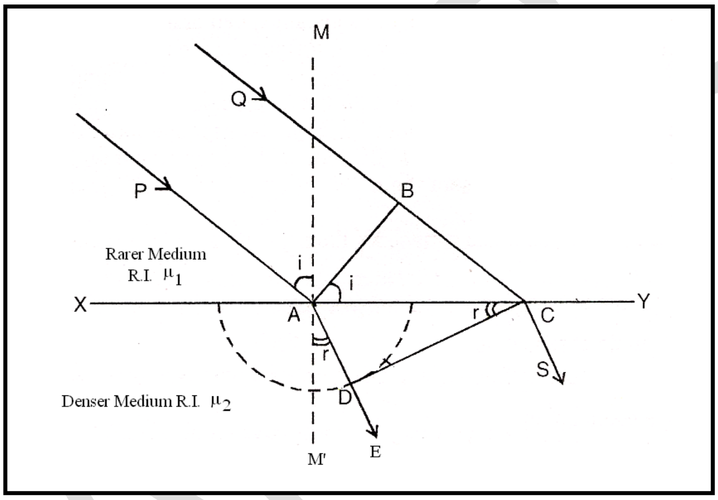
$$\angle A'DC \cong \angle A'B'C$$
$$A'D = B'C \quad (both\ ct)$$
$$A'C \cong A'C \quad (common)$$
$$\therefore \Delta A'B'C \cong \Delta A'CD$$

$$\therefore \angle B'A'C \cong \angle A'CD$$
$$\therefore i = r$$

Thus angle of incidence is equal to angle of reflection.

From figure incident ray, reflected ray and normal lie in same plane and incident ray and refracted ray lie on opposite sides of normal. Thus Reflection of plane wavefront can be explained and laws of reflection can be proved by Huygens' wave theory.

Prove the laws of refraction and snail's law using hygenes wave theory of light



- Consider XY as a plane surface separating two media. R.I. Of rarer media is μ_1 and R.I. of denser media be μ_2. Plane Wavefront AB, bounded by two rays PA and QB, is incident in rarer medium on surface XY.
- The wavefront will first come in contact with point A of surface XY. Point A becomes secondary source sending out secondary waves in denser medium.
- Let incident wavefront moves from B to C in time t. if c_1 is velocity of light in rarer medium,
$$BC = c_1 t$$
- In the same time secondary wavefront emitted by A will cover distance c_2t in denser medium, where c_2 is velocity of light in denser medium.
- The secondary wavefront is shown by dotted semicircle. Draw CD tangent to this semicircle.
$$AD = c_2 t$$
- When incident wavefront reach point C refracted wavefront will reach point D. Hence CD represents refracted wavefront

Draw Normal MM' to surface XY at A

$\angle PAM = \angle i = angle\,of\ incidence$ And

$\angle DAM' = \angle r = \text{angle of refraction}$

From geometry of figure it is clear that $\angle BAC = \angle i\ and\ \angle ACD = \angle r$

From $\Delta BAC\ and\ \Delta ACD$

$$\sin i = \frac{BC}{AC}\,and\quad \sin r = \frac{AD}{AC}$$

$$\therefore\ \frac{\sin i}{\sin r} = \frac{BC/AC}{AD/AC} = \frac{BC}{AD} = \frac{c_1 t}{c_2 t} = \frac{c_1}{c_2}\ \ldots\ldots\ldots\ldots\ldots\ldots 1$$

By definition of refractive index

$$\frac{c_1}{c_2} = \frac{\mu_2}{\mu_1}\ \ldots\ldots\ldots\ldots\ldots\ldots 2$$

From 1 and 2

$$\frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r}$$

Thus Snell's law is proved, using Huygens's principle.

- Also from figure $\angle i > \angle r$

  $\therefore \sin i > \sin r$

  $\therefore \dfrac{\sin i}{\sin r} > 1$

  $\therefore \dfrac{\mu_2}{\mu_1} > 1$

  $\therefore \dfrac{c_1}{c_2} > 1$

  $\therefore c_1 > c_2$

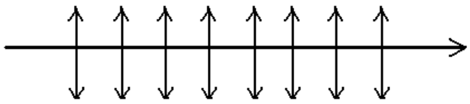
  i.e. velocity of light in rarer medium is greater than velocity of light in denser medium.
- Also from figure it is clear that incident ray, refracted ray and normal lies in same plane. And incident ray and refracted rays are on opposite sides of normal. This proves laws of refraction.

What is plane polarized light? What is polarisation?

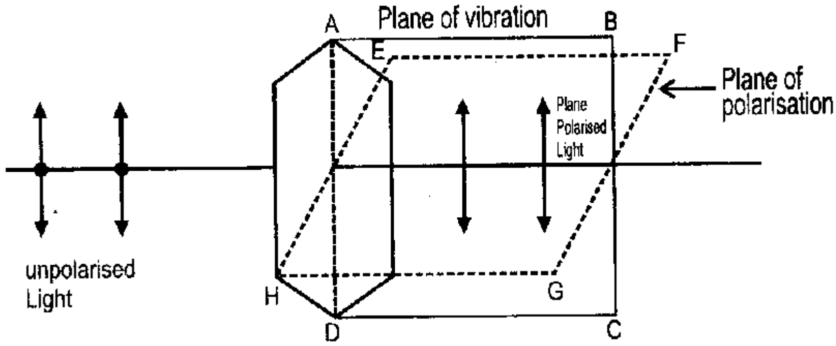
- When the vibrations of electric vectors are confined in one plane, the light is called plane polarised light.
- The phenomenon of restriction of the vibrations of electric vectors of light waves in a particular plane perpendicular to the direction of wave motion is called as **polarisation.**

a) Plane polarised light with vibrations perpendicular to plane of paper.

b) Plane polarised light with vibrations in the plane of paper.



Explain the terms Plane of polarization and plane of vibration.

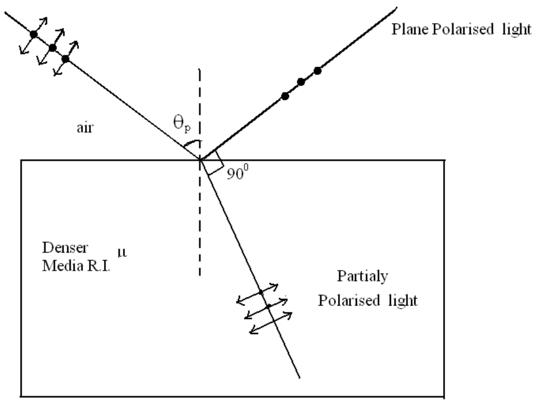


- **Plane of vibration-**The plane in which vibrations of electric vectors of polarized light takes place is called as plane of vibration.
- **Plane of polarisation-**The plane perpendicular to plane of vibration in which there are no vibrations of electric vectors of polarized light is called plane of polarisation.

Polarization by reflection-

- When ray of light is incident on transparent material part of light is reflected and rest is transmitted, Malus discovered that the reflected light is partially polarised.

State and prove Brewster's law



- Sir David Brewster discovered that when ray of light is incident on a transparent medium at polarizing angle (θ_p), the reflected light is completely plane polarized in the plane of incident and reflected and refracted rays are separated by 90^0.

Brewster's law –

- Tangent of polarizing angle is equal to refractive index of refractive medium at which reflection takes place.

Proof

Consider ordinary light incident on transparent surface at angle of incidence θ_p. Hence it will undergo partial reflection and refraction, reflected and refracted rays will be perpendicular.

Here angle of incidence = θ_p.

From geometry

Angle of refraction r = $90^0 - \theta_p$

From Snell's law

$$\mu = \frac{\sin\theta_p}{\sin r} = \frac{\sin\theta_p}{\sin(90-\theta_p)} = \frac{\sin\theta_p}{\cos\theta_p}$$

$$\mu = \tan\theta_p$$

From Brewster's law, it follows that polarizing angle depends on wavelength and is different for different colours. However in most transparent media it found that dispersion is too small to affect polarizing angle appreciably. Brewster's law is not applicable for polished metallic surfaces.

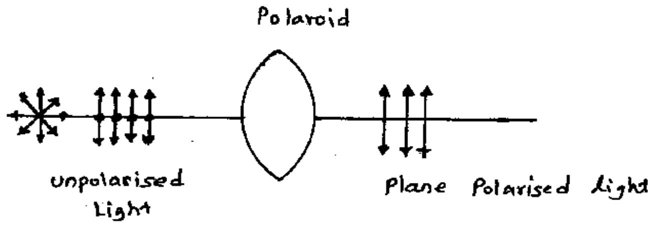
Double refraction-

- When unpolarised light incident on crystals like calcite or quartz, it is split into two refracted rays. This phenomenon of refraction in which two refracted rays are produced is called as double refraction.
- The crystal producing double refraction is called as bifringent.
- The two refracted rays are plane polarized in mutually perpendicular directions.
- One ray that obeys Snell's law is called ordinary ray.
- Ray which does not obey Snell's law is called extra-ordinary ray.
- **Optic axis**- In double refracting crystals there exist a direction, along which if light is incident; it doesn't get separated into two rays. This direction is called as optic axis.

What is Polaroid?

- It is large sheet of synthetic material packed with tiny crystals of dichroic substance oriented parallel to one another so that it transmit light in which electric field vectors are confined to vibrate in only one plane.
- The property by which some doubly refracting crystals absorb the ordinary rays (O-rays) completely and allow extraordinary rays whose direction is parallel to the optic axis pass through the crystal, is called **Dichroism**. The crystals possessing Dichroism property is called **Dichroic Crystal**. E.g. Tourmaline crystal.
- This phenomenon of selective absorption is used in construction of Polaroid.
- Herapath discovered a synthetic material, Iodosulphate of quinine, known as heraphite shows Dichroism, but these crystals are unstable and gets affected by slight strain.

- In 1934 Lamb developed polarizer called as Polaroid by arranging heraphite crystals side by side in way that the optic axis of each of them was parallel to each other so that they act as single crystal of large dimensions.

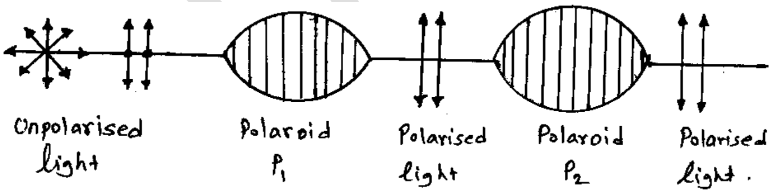


Uses of Polaroid

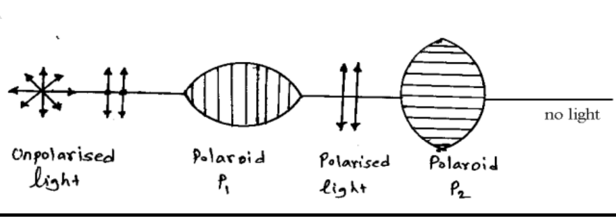
- In motor car headlights to remove headlight glare.
- In three dimensional moving pictures.
- To produce and analyse polarized light.
- Used as filter in photography.
- In window of aero plane to control amount of light.
- In polarizing sunglasses (goggles) to protect eyes from glare of sunlight.
- To improve colour contrast in old oil paintings.
- They are used in calculators, watches, monitors of laptop which have LCD screens.

Polaroid as polarizer and analyzer.

- Two Polaroid P_1 and P_2 are kept such that their axes are parallel to each other. When ordinary light is incident on $P_{1,}$ emergent light is plane polarized. This light can pass through P_2.



- If Polaroid P_2 is rotated, intensity of light emerging out of it goes on decreasing. When axis of P_2 is perpendicular to P_1 (crossed to each other), intensity will become zero. This proves transverse nature of light waves.



For JEE/NEET

- If light passes through single Polaroid its intensity becomes half. $I_{transmitted} = \frac{I}{2}$.
- If A_0 is amplitude of polarised light incident on analyser , amplitude of light transmitted by it is given by $A = A_0 \cos\theta$.

- If light of intensity I passes through two Polaroid's (polariser and analyser) such that angle between there transmission axis is ϕ then intensity of light transmitted by analyser is given by $I_{transmitted} = \frac{I}{2}\cos^2\phi = I_0 \cos^2\phi$

  Here $I_0 = \frac{I}{2} =$ light transmitted by polariser
- If angle between there transmission axis of polariser and analyser is 90^0 , no light will be transmitted.
- If angle between there transmission axis of polariser and analyser is 90^0, no light will be transmitted. $[\cos\phi = 0]$
- If transmission axis of polariser and analyser are parallel all light transmitted by polariser will be transmitted by analyser. $[\cos\phi = 1]$

Doppler Effect in light

- Apparent change in frequency of light due to relative motion between source and observer is called as Doppler Effect.
- In case of sound waves, apparent frequency depends on who is moving source or observer, hence Doppler Effect in sound is asymmetric.
- Doppler Effect in light is symmetric i.e. change in frequency depends only on relative velocity of source and observer irrespective of which of the two is moving. This is because light does not require medium for propagation, speed of light is same for any observer irrespective of whether the observer and/or source are moving.
- Apparent frequency of light obtained by theory of relativity is

$$\nu' = \nu\left(\frac{1 \pm \frac{V_r}{c}}{\sqrt{1-\left(\frac{V_r}{c}\right)^2}}\right)$$

Where V_r is radial component of velocity of source relative to observer.

If $V_r << c$,

Then $\sqrt{1-\left(\frac{V_r}{c}\right)^2} \approx 1$

$$\nu' = \nu\left(1 \pm \frac{V_r}{c}\right)$$

This formula further leads to

$$\frac{\Delta\nu}{\nu} = \frac{\Delta\lambda}{\lambda} = \frac{V_r}{c}$$

Red And blue shift

Due to Doppler Effect,

- If source and observer move towards each other, apparent frequency increases (wavelength decreases) , hence middle of visible spectrum will shift towards blue , called as blue shift
- If source and observer move away from each other, apparent frequency decreases (wavelength increases) , hence middle of visible spectrum will shift towards red , called as red shift
- The terms blue shift indicates frequency increase while red shift indicates frequency decrease.
- Terms red shirt and blue shift are used even when wavelengths under consideration doesn't belong to visible region.
- The measurement of Doppler shift helps to study the motion of stars and galaxies.

Applications of Doppler Effect in light

- ***To measure radial velocities of distant galaxies.***
- ***To determine speed of rotation of sun.***
  East and west edges of sun are photographed, each contains absorption lines due to iron vapourised in the sun and due to oxygen in earth's atmosphere, when two photographs are put together so that oxygen lines coincides, the iron lines in two photographs are displaced relative to each other because one edge of the sun is approaching earth and opposite edge recedes from earth. The measurement of this relative shift gives rotational speed of sun.
- ***To determine plasma temperature in thermonuclear fusion experiments.***
  In thermonuclear fusion experiment we come across extremely hot gases or plasma, at such high temperature molecules of glowing gas are moving away and towards observer. Hence apparent wavelength of particular spectral line changes and it becomes broad. One edge corresponds to increased wavelength due to molecules moving directly away from observer and other edge corresponds to decreased wavelength due to molecules moving directly towards observer. The breadth of the line can be measured using diffraction grating, since λ and c are known; velocity v of gas molecules can be calculated. From rms velocity of gas molecules, temperature of gas can be calculated using kinetic theory of gases. $v = \sqrt{\frac{3RT}{M}}$
  Where R is universal gas constant, T is absolute temperature and M is mass of one mole of gas.

Formulae

- $C = f\lambda$
- $\mu_m = \frac{C}{C_m}$
- ${}_1\mu_2 = \frac{C_1}{C_2} = \frac{\mu_2}{\mu_1}$
- ${}_1\mu_2 = \frac{\sin i}{\sin r}$
- ${}_1\mu_2 = \frac{C_1}{C_2} = \frac{f\lambda_1}{f\lambda_2} = \frac{\lambda_1}{\lambda_2}$

- $$\frac{\text{width of incidant wavefron}}{\text{width of refracted wavefront}} = \frac{\cos i}{\cos r}$$
- Critical angle when light travels from denser medium of RI μ to rarer medium

  $$i_c = \sin^{-1}\left(\frac{1}{\mu}\right)$$
- Critical angle when light travels from denser media of RI μ_1 to rarer media of RI μ_2 is

  $$i_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$
- **Polarisation by Reflection**

  Brewster's law: $\tan\theta_p = \mu$

  $$\theta_p + r = 90^0$$
- **Doppler effect**

  $$\nu' = \nu\left(1 \pm \frac{V_r}{c}\right)$$

  $$\frac{\Delta\nu}{\nu} = \frac{\Delta\lambda}{\lambda} = \frac{V_r}{c}$$

<u>Numerical Problem</u>

1) A light waves has a wavelength of 4 X 10^{-7} m in vacuum. Its velocity in vacuum is 3 X 10^8 m/sec. find the frequency. Find the Wavelength and frequency when it enters a medium of refractive index 1.6. (Ans : $7.5\times10^{14}\,Hz$, 2.5 X 10^7m)
2) Find the velocity of light in water if its velocity in glass of R.I.1.5 is 2 x 10^8 m/s. R.I. of water is 1.33. (Ans : 2.26 x 10^8 m/sec.)
3) Diamond has a refractive index of 2.4 for sodium light of wavelength 5893 A^o. Find the speed and the wavelength of this light in diamond. c = 3 x 10^8 m/sec. (Ans: 2455 A^0)
4) The refractive indices of glass and water are 1.5 and 4/3 respectively. If the difference in the velocity of light in glass, and water is 2.5 x 10^7 m/s, find the velocity of light in glass, water and air. (Ans. 2 x 10^5 km/s, 1.15 x 10^8m/s. 3 x 10^3 m/s)
5) A parallel beam of light is incident on a glass surface at an angle of 45°. If the refractive index of glass is 1.5, find the ratio of the width of the incident beam and that of the refracted beam. (Ans.0.8018)
6) Compare the wavelengths of light in glass and in water if the refractive indices of glass and water relative to air are 3/2 and 4/3 respectively. (Asn. 8 : 9)

7) Light waves have a wavelength 4000 A^0. Calculate the frequency and wave number. What would happen to its velocity, wavelength, wave number and frequency when it enters a liquid of refractive index 1.25 ? Velocity of light in vacuum is 3 x 10^{10}cm/s. (Ans. 0.75 x 10^{15}Hz, 2.5 x 10^6 m^l. 2.4 x 10^8 m/s, same, 3200A.U.)

8) The velocity of light in air is 3 x 10^8 *m/s*. Find the frequency and wavelength in diamond of a beam of light whose wavelength in air is 4800 A^0. Refractive index of diamond is 2.4. (Ans. 6.25 x 10^{14} Hz, 2000A.U.) (0.89) .

9) The refractive index of glass with respect to water is 9/8. If the velocity and wavelength of light in glass are 2 x $l0^8$ m/s and 4000 A^o respectively find the velocity and wavelength of light in water? (Ans. 2.25 x 10^8 m/s ; 4500 A.U.) (O.90)

10) Determine the change in the wavelength of a ray of light during the passage from air to glass if the refractive index of glass is 1.5 and the frequency of the ray is 4 x 10^{14} m/sec. (Ans. 2500 A.U) (M.92)

11) A ray of light is incident on a glass slab making an angle of 60° with the surface. Calculate the angle of refraction in glass of refractive index 1.5. (Ans.19° 28') (Oct.94)

12) The refractive index of diamond is 2.4 and that of water is 1.33. Find the velocity of light in diamond and in water. (Ans.1.25 x 10^8 m/s, 2.26 x 10^8 m/s) (M.96)

13) The velocity of light in air is 3 x 10^8 m/s. Calculate the frequency and the wave length of a beam of light in diamond. Its wave length in air is 4800 A:U. R.I. of diamond is 2.4. (Ans. 6.25 x 10^{14}Hz: 20000A.U.) (Mar.97)

14) Find the critical angle for light of wavelength in glass is 4000. A.u. where wavelength of light in air is 6000 A.u. (Ans. i_c = 41^0 48')

15) A parallel beam of monochromatic light is incident on the surface of water at angle of 45° of RI. *4/3*. Find the ratio of the width of the Refracted beam to that of the incident beam. (Ans. the ratio of the widths = 1.2)

16) A parallel beam of light is incident on a water surface at an ang1e of incidence 60^0. the RI. Of water is 4/3. Find the ratio of the width of the incident beam and that of the refracted beam. (Ans. 0.66)

17) Find the critical angle for light of wavelength in diamond is 2500 A^0. Where wavelength of light in air is 6 x $l0^{-7}$ m. (Ans. i_c = 24° 37')

18) Calculate the change in wavelength of a ray of light during the passage from air to glass. If the R.I. of glass is 1.5 and the frequency of the ray is 4 x 10^{14} Hz.

19) The refractive indices of glass and water are 3/2 and 4/3 respectively. If the difference in the velocity of light in glass and water is 2.5 x 10^7 m/s. Find the velocity of light in glass and water and air. (Ans.2 x 10^8 m/s, 2.25 x 10^8 m/s, 3 x 10^8 m/s)

20) Wave number of a beam of light in air is 2.25 x 10^6 m^{-1}. What is the wave number in water. If the R.I. of water w.r.t. air is 4/3. (Ans.3 x 10^6 m^{-1})

21) The wave numbers of a beam of light in air is 2.25 x 10^6 m^{-1}. What is the wave number in water? If the R.I. of water w.r.t. air is 4/3. (Ans. 3 x 10^6 m^{-1})

22) Refractive index of material is 1.6, find polarizing angle and corresponding angle of incidence.

23) If critical angle of medium is $\sin^{-1}\left(\frac{3}{5}\right)$ find polarizing angle. $\left(ans : i_p = 59^0 02'\right)$

24) Ray of light travelling through air falls on surface of glass slab at angle $\angle i$, it is found that angle between incident ray and refracted ray is 90^0. If the speed of light in the glass is $2\times10^8 m/s$, find the angle of incidence. $\left[c = 3\times10^8 m/s\right]$ $\left(ans : i_p = 56^0 19'\right)$.

25) Width of plane incident wavefront is found to be doubled in a denser medium. If it makes an angle of 70^0 with surface, calculate refractive index of denser medium. (1.289).

Interference and Diffraction

State Principle of Superposition

When two or more waves traveling through the medium arrive at a point simultaneously, each wave produces its own displacement independent of other. Then the resultant displacement at that point is vector sum of individual displacement produced due to each wave.

What is Interference of Light? Explain the constructive interference and destructive interference

Interference of light: Modification in the intensity of light (redistribution of light energy) produced

by the superposition of two or more light waves is called interference of light.

Due to interference of two light waves redistribution of energy takes takes place in the medium. The light energy, which disappears at the position of minima, appears at position of maxima.

Constructive Interference

When two light waves of same amplitude and same wavelength arrive at a point in phase

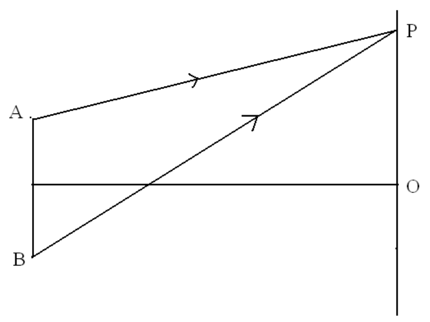
i.e. in such way that the crest of one wave incident on the crest of other or the trough of one wave on the trough of other) then the addition of displacements due to two waves take-place.

Due to this point appears to be bright. This phenomenon is called as constructive interference.

Destructive Interference: -

When two light waves of the same amplitude and same wavelength arrive at a point out of phase (i.e. in such a way that the crest of one wave incident on the trough of other & trough of one wave incident on the crest of other) then the cancellation of two-displacement take place. Due to this point appears to be dark. This phenomenon is called as destructive interference.

State conditions for constructive and destructive interference.



A and B are two coherent ,monochromatic , point sources of light. Consider the point P in the medium. The path difference between the waves reaching at P is BP-AP

Constructive interference

- Point P will be bright (constructive interference) if two waves arrive at p in phase.
  i.e. phase difference is $0, 2\pi, 4\pi....$ or path difference is $\lambda, 2\lambda, 3\lambda....n\lambda$

  i.e path difference should be whole multiple of λ or even multiple of $\frac{\lambda}{2}$.

  For constructive interference BP-AP = 2n $\left(\frac{\lambda}{2}\right)$ where n = 0,1,2…

  For n =0 we get central bright band at O and for n=1,2,3 etc 1^{st} , 2^{nd} , 3^{rd} bright band will obtained on either side of O.

Destructive interference

- Point P will be dark (destructive interference) if two waves arrive at p out of phase.
  I.e. phase difference is $\pi, 3\pi, 5\pi....$ or path difference is $\frac{\lambda}{2}, 3\frac{\lambda}{2}, 5\frac{\lambda}{2}...(2n-1)\frac{\lambda}{2}$

  i.e path difference should be odd multiple of $\frac{\lambda}{2}$.

  For destructive interference BP-AP = (2n-1) $\left(\frac{\lambda}{2}\right)$ where n = 1,2,3…

State the Conditions for steady Interference Pattern:-

- **The two sources of light should be coherent.**
  Two sources of light, emitting light waves of equal frequency and amplitude and which are always in same phase or constant phase differences are known as coherent sources.
- **The two sources of light should be monochromatic. I.e** they should emit the light waves of only one wavelength.
- Two interfering waves must be in **same state of polarization.**
- The two sources of light should emit the light waves of **equal amplitude** or intensity.
- **Two sources should be close to each other, and screen should be at large distance from two sources.**
- Two sources should be **narrow.**
- Two interfering waves must travel in **same direction.**

Explain why the two sources of light should be coherent?

- The two sources of light are coherent if they emit the light Waves with constant or zero Phase difference

- If the two sources are not coherent then the phase difference between the two light waves reaching point of medium may go on changing. Hence the point on the screen will become bright and dark so frequently that due to persistence of vision no steady interference pattern will be obtained and only uniform illumination will be observed. Therefore in order to get steady interference pattern the two sources of light should be coherent.

Young's Experiment: -

- The experimental arrangement is as shown in the fig. It consists of a hard board having a pinhole S. In front of which there is a second hard board having two more pin holes S_1 & S_2 exactly at the same distance from S and are close to each other.
- The pinholes S are illuminated with sun light. The spherical waves emerging from S will reach simultaneously at S_1 & S_2 will act as a coherent sources.

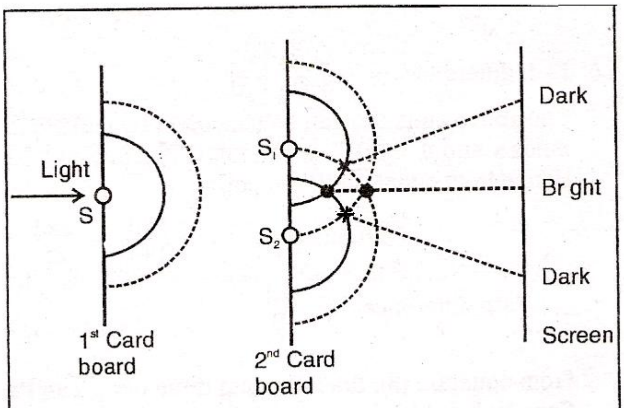


Fig. 4

- These two coherent sources will emit the spherical waves of same amplitude and of same wavelength. These spherical waves will superpose.
- In figure crest are represented by continuous circular lines and trough are represented by dotted circular lines. Points marked with cross (x) crest of one wave are superposed on trough on other and these points are dark points. At points marked with dots (•) crest of one wave are superposed on crest of other or trough of one wave are superposed on trough of other, these points are points with maximum brightness.
- Since the sunlight consist of different wavelengths (not monochromatic) interference pattern will be coloured, diffused and indistinct.
- Hence in double slit experiment Young replaced sunlight with monochromatic source of light and instead of pin holes S_1 & S_2 he used narrow slits. The number of alternate bright and dark fringes running parallel to length of the slits was observed on the screen. These fringes are of equal width and they are called interference fringes.

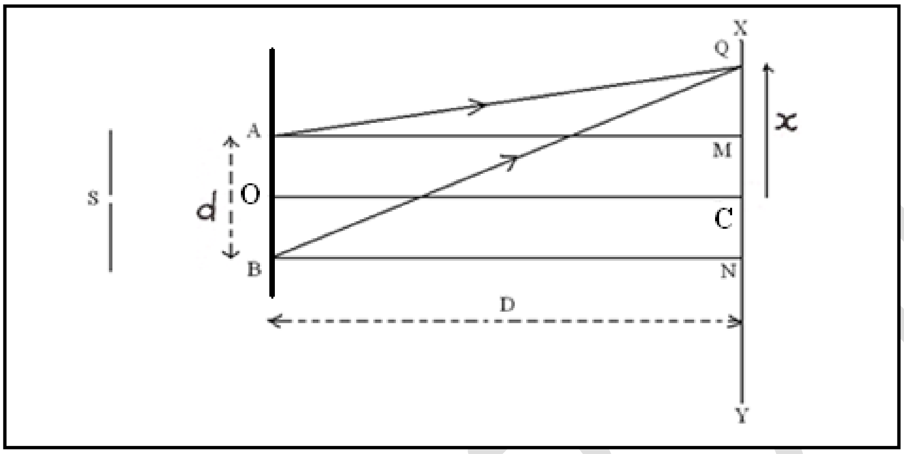
Importance Of Young's Experiment: -

- It was very first successful experiment to show interference of light.

- It proves conclusively that light propagates in the form of waves.

- Wavelength of monochromatic light can be determined using formula $\lambda = \frac{Xd}{D}$ where X is bandwidth; d is distance between two slits, D distance of screen from Sources.

Theory of interference Fringes, Obtain expression for Band width.



- Suppose S is a narrow slit illuminated by monochromatic light of wavelength λ . A and B are two parallel narrow slits separated by short distance d and equidistant from S.
- Light waves emitted by S will arrive at A and B in same phase. A and B will act as secondary source of light, and will produce interference pattern on the screen placed at distance.
- Drop the normal, A M and B N on the screen. OC is perpendicular bisector of line joining AB.
- Let Q be any point on screen at a distance of x from the center C of the interference pattern.
- The nature of this point Q depends on the path difference in between the waves from A & B reaching at Q given by (BQ – AQ)
- From fig QM= x-d and QN = x+d

  From $\triangle BNQ$

  $$BQ^2 = BN^2 + QN^2 = D^2 + \left(x + \frac{d}{2}\right)^2$$

  From $\triangle AMQ$

  $$AQ^2 = AM^2 + QM^2 = D^2 + \left(x - \frac{d}{2}\right)^2$$

  $$\therefore BQ^2 - AQ^2 = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 - \left(x - \frac{d}{2}\right)^2\right]$$

  $$= 2xd$$

  $$\therefore (BQ + AQ)(BQ - AQ) = 2xd$$

  $$\therefore BQ - AQ = \frac{2xd}{BQ + AQ}$$

  As distance between the sources is very small compared to distance of screen from source

$\therefore BQ + AQ \approx 2D$

$\therefore$ Path difference $BQ - AQ = \dfrac{2xd}{2D} = \dfrac{xd}{D}$

$\therefore$ path difference = $\dfrac{xd}{D}$

This is expression for path difference in terms of D and d.

Conditions For bright band

Point Q will be bright if path difference is whole multiple of λ (i.e. even multiple of $\dfrac{\lambda}{2}$)

i.e. $BQ - AQ = \dfrac{xd}{D} = n\lambda$

Where n is order of fringe (band) Having values 0,1,2…

Conditions For dark band

Point will be dark if path difference is odd multiple of $\dfrac{\lambda}{2}$

i.e. $BQ - AQ = \dfrac{xd}{D} = (2n-1)\dfrac{\lambda}{2}$

Where n is order of fringe having Value 1, 2, 3…

Expression For Bandwidth:

Bandwidth is defined as the distance between centers of two adjacent bright bands (or dark band).

Distance between successive bright bands:

Let n^{th} and $(n+1)^{th}$ bright bands are formed at distance x_n and x_{n+1} from the center C of interference pattern respectively.

For n^{th} bright band

$$\frac{x_n d}{D} = n\lambda$$

$$\therefore x_n = n\frac{\lambda D}{d}$$

And for the $(n+1)^{th}$ bright band,

$$\frac{x_{n+1} d}{D} = (n+1)\lambda$$

$$\therefore x_{n+1} = (n+1)\frac{\lambda D}{d}$$

Distance between n^{th} and $(n+1)^{th}$ bright bands = band Width = X = $\therefore\ x_{n+1} - x_n$

$$\therefore\ X = (n+1)\frac{\lambda D}{d} - n\frac{\lambda D}{d}$$

$$\therefore\ X = \frac{\lambda D}{d}$$

Distance between successive dark bands:

Similarly Let m[th] and (m+1)[th] dark bands are formed at distance x_m and x_{m+1} from the center C of interference pattern respectively.

According to condition of dark point,

For the m[th] dark band, $\frac{x_m d}{D} = (2m-1)\frac{\lambda}{2}$

$$x_m = (2m-1)\frac{\lambda D}{2d}$$

And for the $(m+1)^{th}$ dark band, $\frac{x_{m+1} d}{D} = \left[2(m+1)-1\right]\frac{\lambda}{2}$

$$x_{m+1} = \left[2m+1\right]\frac{\lambda D}{2d}$$

Distance between m[th] and (m+1)[th] dark bands = band Width = X

$$X = x_{m+1} - x_m$$

$$X = (2m+1)\frac{\lambda D}{2d} - (2m-1)\frac{\lambda D}{2d}$$

$$X = (2m+1-2m+1)\frac{\lambda D}{2d}$$

$$X = \frac{\lambda D}{d}$$

Thus Band width for bright or dark bands is equal.

- Bright bands occur at $x = 0, \frac{\lambda D}{d}, \frac{2\lambda D}{d}, \frac{3\lambda D}{d} \ldots$ (x = distance from central bright band)

  Dark bands occur at $x = \frac{\lambda D}{2d}, \frac{3\lambda D}{2d}, \frac{5\lambda D}{2d} \ldots$ (x = distance from central bright band)

  This proves that interference fringes are equally spaced.

Expression for resultant intensity due to interference of light waves.

Let two waves originating from the two sources A and B is denoted by

$y_1 = a_1 \sin \omega t$ And

$y_2 = a_2 \sin(\omega t + \Phi)$

Where Φ is phase difference between the waves

The resultant displacement due to superposition of these two waves is

$$y = y_1 + y_2 = R\sin(\omega t + \theta)$$

The resultant wave is also a harmonic wave of same frequency, the resultant amplitude and initial phase are given by

$$R = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi}$$

$$\theta = \tan^{-1}\left(\frac{a_2 \sin\phi}{a_1 + a_2 \cos\phi}\right)$$

The intensity of resultant wave is proportional to square of amplitude, we have

$$I_R \propto a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi$$

If I_1 *and* I_2 are intensities of two interfering waves then

$$I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

If $I_1 = I_2 = I$ then

$$I_R = 2I + 2I\cos\phi$$

$$I_R = 2I\left(1 + \cos\phi\right)$$

$$I_R = 4I\cos^2\left(\frac{\phi}{2}\right)$$

$\dfrac{I_{\max}}{I_{\min}} = \dfrac{\left(a_1 + a_2\right)^2}{\left(a_1 - a_2\right)^2} = \left(\dfrac{r+1}{r-1}\right)^2$, where $r = \dfrac{a_1}{a_2}$ is called as amplitude ratio.

JEE / NEET corner

If a thin transparent plate of thickness t and refractive index μ is introduced in path of one of the interfering waves, it is observed that the entire fringe pattern is shifted upward or downward through a distance given by $x_0 = \dfrac{D}{d}\left(\mu - 1\right)t$.

Shift is upward if plate is introduced in path of light coming from upper slit, and shift is downward if plate is introduced in path of light coming from lower slit.

If the CBB shifts to the position of previous n^th bright fringe then

$$x_0 = n\left(\frac{\lambda D}{d}\right)$$

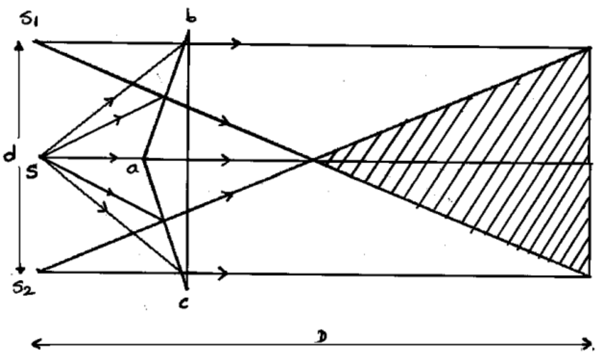
$$\therefore \frac{D}{d}\left(\mu - 1\right)t = n\left(\frac{\lambda D}{d}\right)$$

$$\therefore \left(\mu - 1\right)t = n\lambda$$

- The introduction of plate has **no effect on fringe width**. The shift occurs because the original path difference changes by $(\mu - 1)t$.

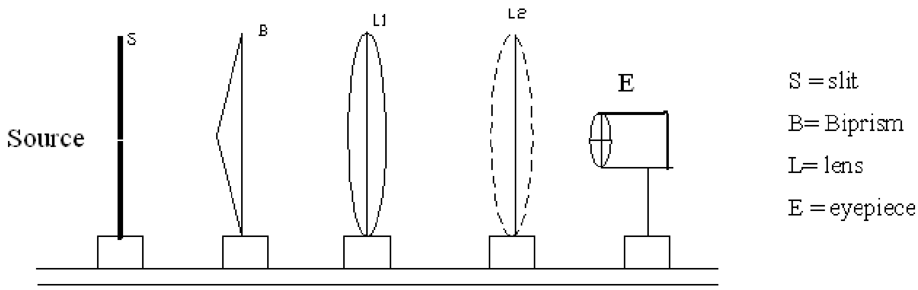
Explain Fresnel's Biprism Experiment to determine wavelength of monochromatic light.

- Biprism is a thin glass prism of obtuse angle of about 179^0



- Biprism is kept in front of the slit with its refracting edge parallel to the slit. When monochromatic light from slit S passes through the two halves of Biprism, It appears to come from virtual Sources S_1 and S_2.
- As these virtual sources are derived from the same original source they act as coherent sources. Interference fringes are observed in shaded region through micrometer eyepiece.

Experimental Arrangement



- Optical bench is about 1.5 m long with scale marked on it . Four adjustable stands carrying the slit (S) , biprism (B) , Lens (L) and micrometer eyepiece (E) are mounted on optical bench as shown in fig.
- The slit and the eyepiece can be rotated about horizontal axis.
- Initially slit , biprism , and eyepiece are kept at same height such that their centers are in same line. Slit is illuminated by monochromatic light whose wavelength is to be determined.
- Biprism is rotated slowly about horizontal axis so that refracting edge becomes parallel to slit.
- When refracting edge is exactly parallel to slit, interference pattern appears in the field of view of eyepiece.

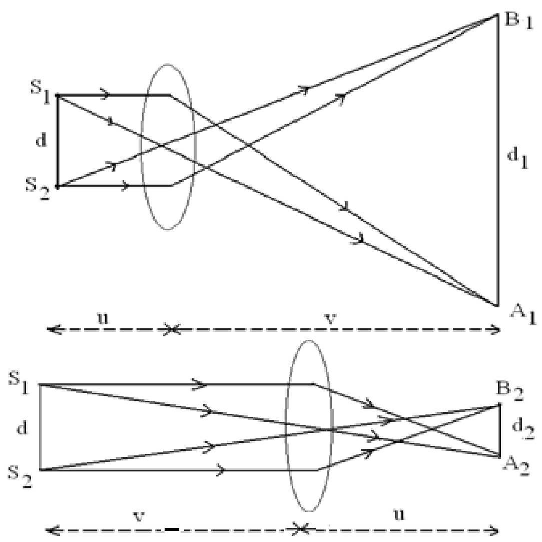
<u>Measurements</u>

- The dist. D between the slit S and the micrometer eyepiece can be recorded directly from the scale marked on optical-bench.

- Band width X is measured with help of micrometer eyepiece. Vertical cross wire in the eyepiece is adjusted at the center of bright fringe. The micrometer reading is noted. Now eyepiece is moved until crosswire is moved over known number N of the bright fringes , again micrometer reading is noted. The difference between two readings of micrometer gives distance x through which eyepiece has moved.

  Then average band width is given by $X = \frac{x}{N}$

- Distance d between coherent sources can't be measured directly because sources are virtual. Conjugate foci method is used to determine d.



- Initially convex lens of short focal length is introduced between biprism and eyepiece without disturbing slit and biprism eyepiece is moved back so that its distance from the slit becomes greater than four times focal length of lens. Lens is now moved towards the slit and placed in such a way that two magnified images A_1 and B_1 are formed of S_1 and S_2 in the focal plane of the eyepiece. The distance d_1 between A_1 and B_1 is measured by micrometer.

$$\frac{\text{size of image}}{\text{size of object}} = \frac{\text{distance of image}}{\text{distance of object}}$$

$$\therefore \frac{d_1}{d} = \frac{v}{u} \quad \text{.............................1}$$

- Lens is now moved towards the eyepiece to position L_2 , where two diminished images A_2 and B_2 of the slit are formed in the focal plane of the eyepiece. The distance d_2 between them is measured by micrometer.

  According to principle of conjugate foci, object and image distance gets interchanged

$$\frac{\text{size of image}}{\text{size of object}} = \frac{\text{distance of image}}{\text{distance of object}}$$

$$\therefore \frac{d_2}{d} = \frac{u}{v} \text{ ....2}$$

Taking product of equation 1 and 2

$$\therefore \frac{d_1 d_2}{d^2} = \frac{v}{u} \times \frac{u}{v} = 1$$

$$d^2 = d_1 d_2$$

$$\therefore \ d = \sqrt{d_1 d_2}$$

- Thus knowing D, X and d , we can calculate wavelength of monochromatic light by the equation.

$$\lambda = \frac{Xd}{D}$$

How coherent sources are obtained?

<u>In young's expt</u>:

coherent sources are obtained by keeping two narrow slits S_1 & S_2 at the same distance from the point source of light S so that the light waves will reach simultaneously at S_1 & S_2. **(Draw diagram)**

<u>In fresnel's biprism expt</u>

Biprism is kept in front of the slit with its refracting edge parallel to the slit. When monochromatic light from slit S passes through the two halves of Biprism, It appears to come from virtual Sources S_1 and S_2. As these virtual sources are derived from the same original source they act as coherent sources. **(Draw Diagram)**

What is diffraction of light?

- The bending of light near the edges of an obstacle or slit and spreading into the region of geometrical shadow is known as diffraction of light.

  Eg.

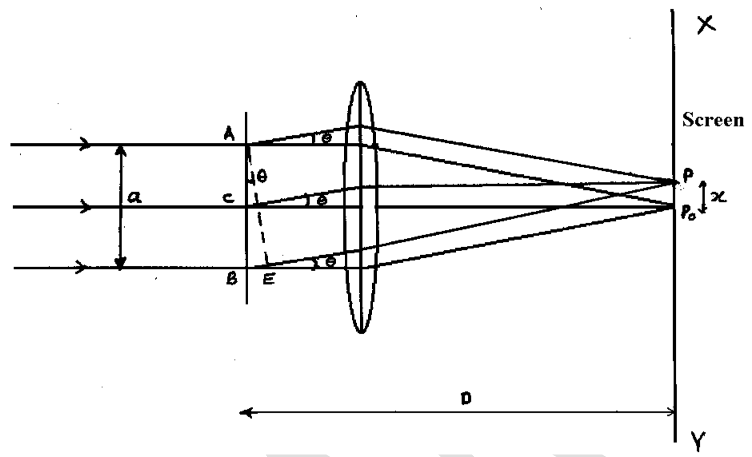
  I. When the sun is seen through a fine piece of cloth, coloured spectra is observed.
  II. The luminous boarder that surrounds the profile of a mountain just before sun rises behind it.

Types of diffraction: The diffraction phenomenon is broadly classified into two types for the convenience of mathematical treatments.

1) **<u>Fraunhofer diffraction:</u>** the source of light and the screen on which diffraction pattern is obtained are effectively at infinite distances from the diffracting system. In this case, we consider plane wavefront. The diffraction pattern is obtained by using convex lens.
2) **<u>Fresnel Diffraction:</u>** The source of light and screen are kept at finite distance from the diffracting system. In this case, we consider cylindrical or spherical wave fronts.

With neat diagram explain Fraunhofer Diffraction due to a single slit:

- Suppose a parallel beam of monochromatic light of wavelength λ is incident normally upon a narrow slit AB of width a, kept perpendicular to the plane of paper.
- Suppose the diffracted light is focused by a convex lens L on the screen XY which is kept in the focal plane of the lens.



Central maxima:

- According to Huygens' Principle each and every point on the AB act as a source of secondary waves. Let C be the centre of the slit.
- The secondary waves travelling in the direction parallel to CP_0 come to focus at P_0.
- The secondary waves from points equidistant from C and situated in the upper and lower halves CA and CB of the slit travel the same distance in reaching P_0 and hence the path difference between them is zero.
- Hence P_0 will be a point of maximum intensity. It is called central maximum and it is the brightest band in diffraction pattern.

Position of secondary minimum:

- Consider the secondary waves traveling in the direction inclined at angle θ to the direction of CP_0. All the secondary waves travelling in this direction reach the point P on the screen.
- Intensity at P depends upon the path difference BE between the secondary waves starting from A and B

  From $\Delta ABE,\ \sin\theta = \dfrac{BE}{AB}$

  $\therefore$ Path difference BE = AB $\sin\theta = a\sin\theta$

- If the path difference between the secondary waves from A and B is λ. Then the path difference between the secondary waves from these points A and C is $\dfrac{\lambda}{2}$.

- For every point in the upper half CA, there is a corresponding point in the lower half CB such that path difference between the secondary waves from these point to point p is $\frac{\lambda}{2}$. Thus, destructive interference takes place and the point P will be of minimum intensity.
- **In general** if path difference BE is λ, 2λ, 3λ …then secondary minima will be obtained.

$$a\sin\theta_n = n\lambda$$

$$\sin\theta_n = \frac{n\lambda}{a}$$

Where $n = \pm 1, \pm 2, \pm 3.......$

Here θ_n gives the direction of the nth minimum.

- **Position of secondary maximum:**

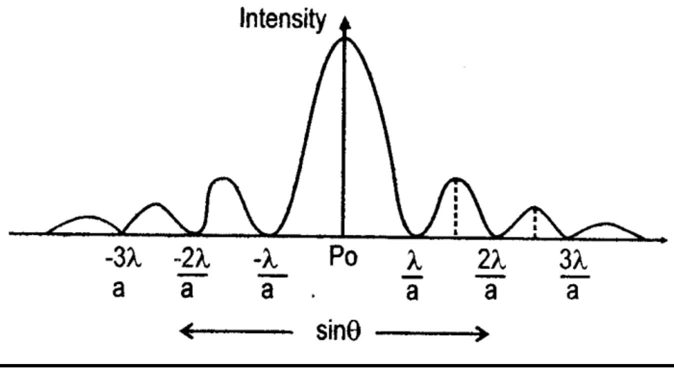
If, however, the path difference is odd multiple of $\frac{\lambda}{2}$, the direction of secondary maxima is obtained.

$$a\sin\theta_n = (2n+1)\frac{\lambda}{2}$$

$$\sin\theta_n = \frac{(2n+1)\lambda}{2a}$$

$n = \pm 1, \pm 2, \pm 3.......$

- The diffraction pattern due to a single slit consist of a central bright maximum at P_0 followed by alternate secondary minima and maxima on both sides of P_0.



Obtain expression for Width of central maximum:

- Let x be distance of 1st minima from centre P_0.
For first secondary minima

$$\sin\theta = \frac{\lambda}{a} \quad ……………1$$

- If the lens L is very near the slit or the screen is far away from the lens L, then focal length (f) of the lens is approximately equal to the distance (D) of the slit from the screen.

  From figure $\sin\theta = \theta = \dfrac{x}{f} = \dfrac{x}{D}$ $\left(\because \text{If is small, then } \sin\theta \approx \theta\right)$ ………...2

  From equation 1 and 2

  $\dfrac{x}{D} = \dfrac{\lambda}{a}$ Or $x = \dfrac{\lambda D}{a}$

  $\therefore$ The width of central maxima = 2x which is given as

  $\therefore w = \dfrac{2\lambda D}{a} = \dfrac{2\lambda f}{a}$

- Note: the angular half width of the central maximum is given by $\theta = \dfrac{\lambda}{a}$ and angular width

  $2\theta = \dfrac{2\lambda}{a}\, if\, \theta\ is\, small$

The width of central maximum is proportional to the wavelength of light. With red light, the width of the central maximum is more than the violet light. With narrow slit, the width of central maximum is more. From equation if the width of slit a is large $\sin\theta$ is small and hence θ is small. The maxima and minima are very close to central maxima at P_0. But with narrow slit a is small and θ is large. This result in a distinct diffraction maxima and minima on both the sides of P_0.

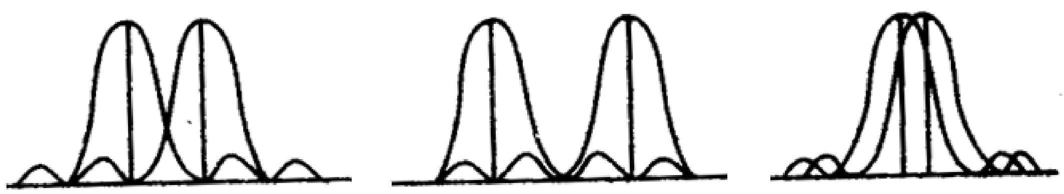
Explain the terms Limit of resolution, resolving power.

- The smallest angular or linear separation between the two points objects at which they appear to be just resolved is called **limit of resolution** of an optical instrument
- The reciprocal of the limit of resolution is called its **resolving power.**

Rayleigh's Criteria for resolution

- According to Rayleigh's criterion, the images of two point objects close to each other are regarded as just separated if the central maximum of one falls on the first minimum of the other.

  In other words, when central bright image of one falls on the first dark ring of the other, the two images are said to be just resolved

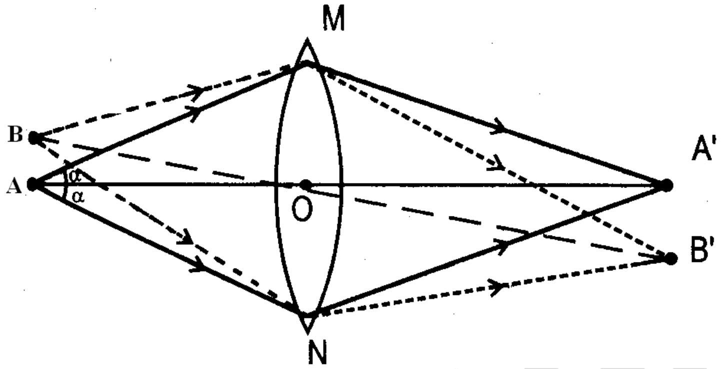


a) Images just Resolved b) Images Well resolved c) Images unresolved

- The two objects are said to be well resolved, if the separation between the central maximum of the two objects is greater than the distance between the central maximum and first minimum of any of the two objects.
- The two objects are said to be unresolved, if the separation between the central maximum of the two object is less than the distance between the central maximum and first minimum of any of the two objects.

What is resolving power of microscope? Obtain expression for Resolving power of microscope. How it can be increased?

- The minimum distance by which two point objects are separated from each other so that their images as produced by the microscope are just seen separate is called the limit of resolution and the reciprocal of limit of resolution is called the resolving power of microscope.



- Suppose that A and B are two point objects at a distance d apart and A' and B' are their respective image formed by the objective MN of a microscope.
- A' and B' are surrounded by alternate dark and bright diffraction rings. According to Rayleigh's criterion, the two images are said to be just resolved if the position of the central maximum of one falls on the first minimum of the other and vice versa.
- Let the object A subtend angle 2α at the aperture of the objective MN. Then for the condition of resolution it can be shown that the separation d between the two objects A and B should be such that

$$d = \frac{1.22\lambda}{2\sin\alpha}$$

- Equation is based on the assumption that the object A and B are self luminous. Resolving power depends upon the mode of illumination. According to Abbe, the least distance between two objects so that they are just resolve is given by

$$d = \frac{\lambda}{2\sin\alpha}$$

- If an oil impression objective is used limit of resolution of microscope is given by

$$d = \frac{\lambda}{2\mu\sin\alpha}$$

Where μ is the refractive index of an oil. The expression $\mu\sin\alpha$ is called the numerical aperture (NA) of the objective of the microscope.

- The reciprocal of limit of resolution is resolving power of a microscope.

$$\therefore R.P. of\ microscope = \frac{1}{d} = \frac{2\mu\sin\alpha}{\lambda}$$

The resolving power of microscope can be increased by

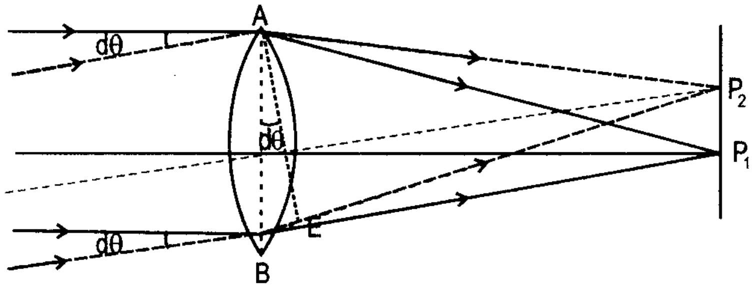
I. Increasing its numerical aperture $(\mu\sin\alpha)$

II. Decreasing the wavelength of light (λ) used to illuminate the objects. The R. P. of microscope can be increased by using ultraviolet light to illuminate the objects.

III. Using quartz lens.

Define Resolving power of telescope. Obtain expression for it.

- The resolving power of a telescope is defined as the reciprocal of the least angle subtended at the objective by the two distant point objects which can be distinguished just resolved in the focal plane of the telescope.



- Let $d\theta$ be the angular separation between two neighboring points lying on distant object and a is the diameter of the objective of telescope.
- Consider the rays of light from two neighboring point on a distant object. The image of each point is a Frounholfer diffraction pattern, contains central maxima followed by secondary minima and maxima. P_1 and P_2 are the positions of the central maxima of the two images, as shown in figure.
- According to Rayleigh's criterion, these two images P_1 and P_2 are said to be just resolved if the central maximum in diffraction pattern of first objects falls on the first minimum of the diffraction pattern of second object and vice versa.
- The path difference between AP_1 and BP_1 is zero and hence P_1 is the position of central maxima of the image of first object. The path difference between the secondary waves travelling in the direction BP_2 and AP_2 is equal to BE.

  From Δ ABE
  BE = AB $\sin\theta$
  $= a.d\theta$
- If this path difference $a.d\theta=\lambda$, the position of P_2 correspond to the first minimum of the first image. But P_2 is also the position of central maximum of the second image. Thus Rayleigh's condition for just resolution is satisfied, if

  $a.d\theta=\lambda$

  Or $d\theta = \dfrac{\lambda}{a}$

  This equation holds good for rectangular apertures. According to Airy, the equation for circular aperture is

  $d\,\theta=\dfrac{1.22\,\lambda}{a}$

Where λ Is the wavelength of light and a is aperture of telescope. Here $d\theta$ represents the limit of resolution of the telescope.

- The reciprocal of $d\theta$ gives the resolving power of the telescope.

  R. P of telescope $= \dfrac{1}{d\theta} = \dfrac{a}{1.22\lambda}$

  From equation it is clear that the telescope with large diameter of the objective has higher resolving power.

Explain why Oil immersion objective is used in microscopes.

- In a high resolving power microscope the space between the objective and the object is filled with oil. Resolving power of such microscope is given by

  $\therefore R.P. of\ microscope = \dfrac{1}{d} = \dfrac{2\mu \sin\alpha}{\lambda}$

  Where μ is R.I. of oil

  Thus Oil immersion increases resolving power of the microscope.
- Also it reduces loss of light by reflection at first lens surface.

Distinguish between interference and diffraction

Interference	Diffraction
Interference pattern is result of superposition of light coming from two different wave fronts of two coherent sources.	Diffraction pattern is result of superposition of light coming from different parts of the same wave front.
Interference fringes are of equal width	Diffraction fringes have unequal width.
In interference pattern all bright bands have same intensity	In diffraction pattern all bright bands are not of same intensity. Central maximum has highest intensity.
In Interference pattern dark band is perfectly dark	In diffraction pattern dark band is not perfectly dark

---

Formulae

1. Resultant Amplitude due to superposition of waves $R = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi}$

2. **Resultant intensity** $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

   If $I_1 + I_2 = I$ then $I_R = 4I\cos^2\left(\dfrac{\phi}{2}\right)$

3. Contrast ratio = $\dfrac{I_{\max}}{I_{\min}} = \dfrac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \left(\dfrac{r+1}{r-1}\right)^2$

4. **Condition for Constructive interference**

   Phase difference is $0, 2\pi, 4\pi....(2n)\pi$ or

   Path difference is $\lambda, 2\lambda, 3\lambda....n\lambda$

5. Condition for destructive interference

Phase difference is $\pi, 3\pi, 5\pi \ldots.(2n-1)\pi$

Path difference is $\frac{\lambda}{2}, 3\frac{\lambda}{2}, 5\frac{\lambda}{2} \ldots (2n-1)\frac{\lambda}{2}$

6. Bandwidth $X = \frac{\lambda D}{d}$

7. **Distance of n^th^ bright band from CBB** $X_n = nX = n\frac{\lambda D}{d}$

8. **Distance of n^th^ dark band from CBB** $X_n = (2n-1)\frac{x}{2} = \frac{(2n-1)}{2}\left(\frac{\lambda D}{d}\right)$

9. If a **thin transparent plate of thickness t and refractive index μ is introduced in path** of one of the interfering waves, fringe pattern is shifted through a distance

$x_0 = \frac{D}{d}(\mu - 1)t$.

10. Distance between virtual images in biprism experiment (d)

$$\frac{\text{size of image}}{\text{size of object}} = \frac{\text{distance of image}}{\text{distance of object}}$$

$$\frac{d_1}{d} = \frac{v}{u}$$

$$d = \sqrt{d_1 d_2}$$

11. Bandwidth in biprism experiment

$$X = \frac{\lambda D}{\sqrt{d_1 d_2}}$$

12. Position of secondary minima in diffraction due to single slit

$$a \sin\theta_n = n\lambda$$

13. Position of secondary maxima in diffraction due to single slit

$$a \sin\theta_n = (2n+1)\frac{\lambda}{2}$$

14. Angular width of central Maxima

$$2\theta = \frac{2\lambda}{a} \qquad if\, \theta\ is\, small$$

[Remember above is approx formula to be used only when θ *is small* , if θ is not small, find position of 1st secondary minima using $\sin\theta = \frac{\lambda}{a}$ and width of central maxima is 2θ]

Linear width of central Maxima

$$\therefore w = \frac{2\lambda D}{a} = \frac{2\lambda f}{a}$$

15. Limit of resolution and resolving power of microscope

$$d = \frac{1.22\lambda}{2\mu \sin\alpha}$$ **if object is self illuminating**

$$d = \frac{\lambda}{2\mu \sin\alpha}$$ **if object is not self illuminating**

[Normally for microscope objects are nor self illuminating]

$$\therefore R.P. of\ microscope = \frac{1}{d} = \frac{2\mu \sin\alpha}{\lambda}$$

Numerical Aperture = $\mu \sin\alpha$

16. Limit of resolution and resolving power of telescope

$$d\theta = \frac{1.22\lambda}{a}$$

$$\text{R. P of telescope} = \frac{1}{d\theta} = \frac{a}{1.22\lambda}$$

Numerical Problems

1. Two slits in Young's experiment have widths in the ratio 81:1, what is the ratio of the amplitudes of light coming from them. $(9:1)$
2. Find the ratio of intensities at two points x and y on screen in young's double slit experiment, where waves from two sources have path difference 0 and $\frac{\lambda}{4}$ respectively. $(2:1)$
3. Two coherent sources whose intensity ratio is 25:1 produce interference fringes. Calculate the ratio of intensity of maxima and minima in the fringe system. $(9:4)$
4. In young's experiment, the distance between two slits is 0.8 mm and the distance of screen from slit is 1.2 m. if the fringe width is 0.79 mm, calculate the wavelength of light.
5. The optical path difference between two identical light waves arriving at a point is 60.5 wavelengths. Is the point bright or dark? Explain.
6. A path difference between two waves arriving at points is 85.5 λ. is the point bright or dark? If path difference is 42.5 micrometer calculate wavelength
7. In a biprism experiment the dist. of 20^{th} bright band from the center of the interference pattern is 8mm. Calculate the dist. of 30^{th} bright band from centre. (12 mm)
8. In a biprism experiment the dist. between 4^{th} and 13^{th} bright fringes is measured, when a light of wavelength 6000 A.U. is used. On replacing the source by another source of wavelength without

disturbing the adjustment, it is found that the distance between 5^{th} & 15^{th} bright fringe is equal to dist measured before. What is wave length of light is used? (5400 A.U.)

9. In biprism experiment the eyepiece is kept at a distance of 1.5 m from the slit. The dist. of 2nd dark band from the central bright band is 1.2 mm. The size of magnified and diminished images of the slits is found to be 2.4 mm & 0.6mm apart respectively. Calculate the wavelength of the light used. (6400 A.U.)
10. In a biprism expt. the dist between the slit & screen is 1m and the separation between the two virtual images of the slit is 0.8 mm. If the wavelength of light used is 5000 A.U. Find the dist. of the 3rd dark band from the center of the interference pattern. (0.156 cm).
11. Two narrow slits are separated by a dist. of 0.85 mm and illuminated by a light of wavelength 6000 A.U. What is the phase difference between the two interfering waves on the screen 2.8 m away from the slits at a point of 2.5 mm from the central bright band? (7.941 rad)
12. In young's expt. interference bands are produced on the screen placed at 1.5 m form the two slits separated by a dist. of 1.5mm and illuminated by a light of wavelength 4500 A.U. Find the change in bandwidth if the screen is brought towards the slit by 50 cm. (0.015 cm)
13. In Biprism experiment the fringes are observed in focal plane of eyepiece at a distance of 1.2 m from slit. The distance between central bright band and 20^{th} bright band is 0.4cm. When convex lens is interposed between the biprism and eyepiece at a distance of 90 cm from the eyepiece, the distance between two magnified virtual images is found to be 0.9 cm. Find Wavelength of light used. (5000 AU)
14. In Young's experiment, the wavelength of monochromatic light used is 6000AU. The optical path difference between two rays from two coherent sources at point p on screen is 0.0075 mm and at point Q on the screen is 0.0015 mm. How many bright and dark bands are observed between points P and Q if they are on opposite sides of screen?
15. A certain fringe width is observed when green light of wavelength 5350 A.U. is used where the distance between the slit and the screen is 1.28 m. What should be the distance between the slit and screen if red light of wavelength 6400 A.U. is used to get the same fringe width without disturbing the distance between the coherent sources?
16. In Young's experiment the distance between two consecutive bright bands produced on a screen placed at 1.5 m from two slits is 6.5 mm. What would be the fringe width if the screen is brought towards the slit by 50 cm for the same setting?
17. In biprism experiment the distance between the slit and the eyepiece is 100 cm. When a convex lens is introduced between the biprism and the eyepiece, image of the slit obtained in the two positions of the lens are 2×10^{-3} m and 4.5×10^{-3} m part. If the wavelength of light used is 6000A,

find the distance between the fourth bright band on one side and fourth dark band on the other side of central bright band.

18. In a biprism experiment interference pattern is observed by the micrometer eyepiece, which is 1.5 m away from the slit. The distance between the two virtual sources is 0.15 mm and the wavelength of light used is 6500 A. Find the distance between the 8^{th} bright and 5^{th} dark band on the same side from the central bright band.
19. In a biprism experiment, the slit is illuminated by a light of wavelength 4800 A. The distance between the slit and biprism is 20 cm and the distance between the biprism and eyepiece is 80 cm. If the distance between two virtual sources is 0.3 cm, determine the distance between the 5^{th} bright band on one side of the central band and the 5^{th} dark on the other side.
20. In fraunhofer's diffraction due to narrow slit, screen is placed 2m away from lens. If width of slit is 0.2mm and first minima is at 5mm on either side of central maxima find wavelength of light. (5000 AU)
21. The semiverticle angle of cone of the ray's incident on the objective of microscope is 20^0. If wavelength of incident light ray is 6600 AU calculate the smallest distance between two points which can be just resolved. (10700 AU)
22. Monochromatic light of wavelength 4300 AU falls on slit of width a , for what value of a the first maximum falls at 30^0 ?
23. A converging lens telescope 3.00cm in diameter has focal length 20 cm , **a)** what angular separation two distinct point objects should have in order to satisfy Rayleigh's criteria ? Assume wavelength 5500 AU. **b)** how far apart are the centers of the diffraction pattern in the focal plane of the lens ? $\left(2.237\times10^{5} rad, 4.4740\times10^{-6} m\right)$
24. Fringes are produced by biprism on the screen are 108 cm away from the slit. A convex lens is inserted between the biprism and eyepiece. The image of slit produced for the two position of a lens is 1.6mm & 0.9mm apart. If the wavelength of light is 5893 A.U. calculate the bandwidth. (0.053cm)
25. What is the minimum angular separation between two stars if telescope is used to observe them with an objective of aperture 20cm. Wavelength of light used is 5900AU.
