10 Wave Optics

10.2 Huygens Principle

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10.5 Interference of Light Waves and Young's Experiment

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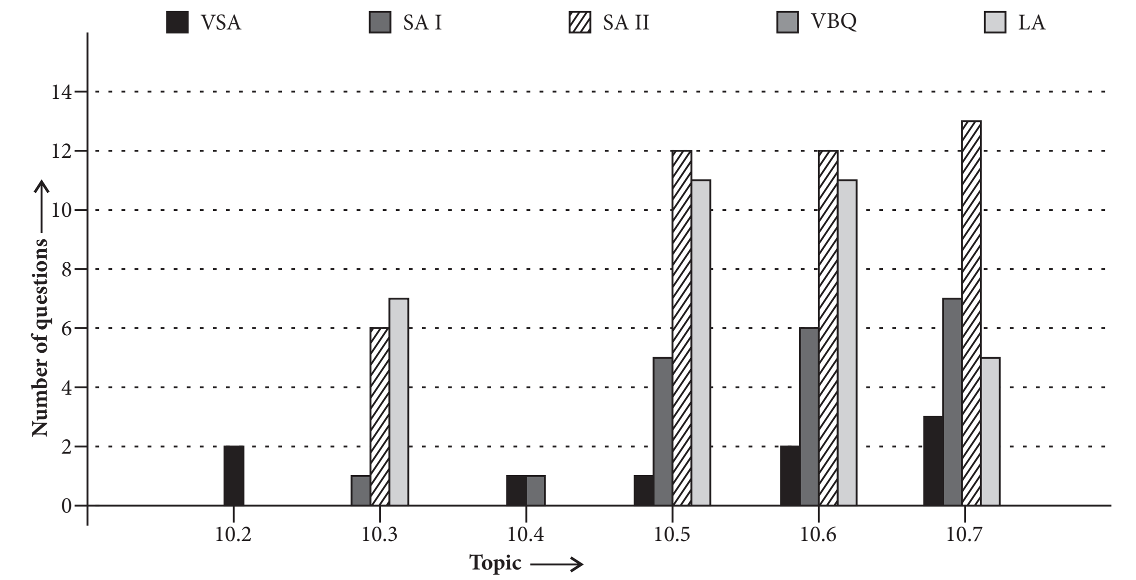
Topicwise Analysis of Last 10 Years' CBSE Board Questions



- Maximum weightage is of *Diffraction*.
- Maximum VSA, SA and SA II type questions were asked from *Polarisation*.
- No VBQ type questions were asked till now.

QUICK RECAP

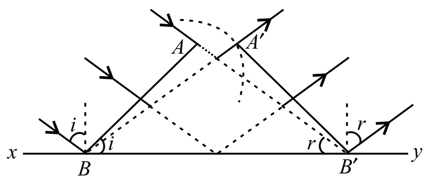
- **Wavefront :** The locus of all particles of the medium vibrating in the same phase at a given instant is known as wavefront.
  Depending on the shape of sources of light, wavefront can be of three types
  - **Spherical wavefront :** When the source of light is a point source, the wavefront is spherical.
  - **Cylindrical wavefront :** When the source of light is linear, the wavefront is cylindrical.
  - **Plane wavefront :** When the point source or

linear source of light is at very large distance, a small portion of spherical or cylindrical wavefront appears to be plane. Such a wavefront is known as plane wavefront.

- **Huygens principle :** According to Huygens principle,
  - Every point on given wavefront (primary wavefront) acts as a fresh source of new disturbance, called secondary wavelets.
  - The secondary wavelets spread out in all the directions with the speed of light in the medium.
  - A surface touching these secondary wavelets tangentially in the forward direction at any instant gives the new (secondary) wavefront at that instant.

Laws of reflection by Huygens' principle

- Let us consider a plane wavefront AB incident on the plane reflecting surface xy. The tangent $B'A'$ represent reflected wavefront after time t.



For every point on wavefront AB, a corresponding point lies on the reflected wavefront $A'B'$.
So, comparing two triangle $\Delta BAB'$ and $\Delta B'A'B$
We find that

$AB' = A'B = ct$, BB' = common

$\angle A = \angle A' = 90°$

Thus two triangles are congruent, hence

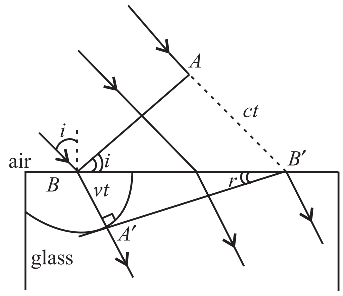
$\angle i = \angle r$

This proves first law of reflection.

- Also incident rays, reflected rays and normal to them all lie in the same plane. This gives second law of reflection.

Laws of refraction by Huygens principle

- Let us consider a plane wavefront AB incident on the plane refracting surface xy. The tangent $B'A'$ represent refracted wavefront after time 't'. For every point on primary wavefront AB, a corresponding point lies on the refracted wavefront $A'B'$.



From $\Delta ABB'$ and $\Delta A'B'B$, Snell's law can be proved.

$$\frac{\sin i}{\sin r} = \frac{ct / BB'}{vt / BB'} = \frac{c}{v} = {}^{a}\mu_{g}$$

So, first law of refraction can be proved.

- Also, the incident ray, refracted rays and normal to the rays, all lie in the same plane. This gives the second law of refraction.
  - Effect on frequency, wavelength and speed during refraction. When a wave passes from one medium to another then change in speed v take place, wavelength λ also changes, whereas its frequency υ remains the same.
- **Coherent and incoherent sources :** The sources of light, which emit continuous light waves of the same wavelength, same frequency and in same phase or having a constant phase difference are known as coherent sources. Two sources of light which do not emit light waves with a constant phase difference are called incoherent sources.

Interference of light : It is the phenomenon of redistribution of energy on account of superposition of light waves from two coherent sources. Interference pattern produce points of maximum and minimum intensity. Points where resultant intensity is maximum, interference is said to be constructive and at the points of destructive interference, resultant intensity is minimum.

- **Intensity distribution :** If a, b are the amplitudes of interfering waves due to two coherent sources and ϕ is constant phase difference between the two waves at any point P, then the resultant amplitude at P will be

$$R = \sqrt{a^2 + b^2 + 2ab\cos\phi}$$

Resultant intensity

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

- When $\cos\phi = 1$; $I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$
- When $\cos\phi = -1$, $I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$

$$\frac{I_{max}}{I_{min}} = \frac{\left(\sqrt{I_1} + \sqrt{I_2}\right)^2}{\left(\sqrt{I_1} - \sqrt{I_2}\right)^2}$$

- **Conditions for sustained interference of light :** The two sources should continously emit waves of the same wavelength or frequency.
  - The amplitudes of waves from two sources should preferably be equal.
  - The waves emitted by the two sources should either be in phase or should have a constant phase difference.
  - The two sources must lie very close to each other.
  - The two sources should be very narrow.

Young's double slit experiment : Young's double slit experiment was the first to demonstrate the phenomenon of interference of light. Using two slits illuminated by monochromatic light source, he obtained bright and dark bands of equal width placed alternately. These were called interference fringes.

- For constructive interference (*i.e.* formation of bright fringes)

  For n^{th} bright fringe,

  Path difference $= x_n \dfrac{d}{D} = n\lambda$

  where $n = 0$ for central bright fringe
  $n = 1$ for first bright fringe,
  $n = 2$ for second bright fringe and so on
  d = distance between two slits
  D = distance of slits from the screen
  x_n = distance of n^{th} bright fringe from the centre.

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

- For destructive interference (*i.e.* formation of dark fringes).

  For n^{th} dark fringe,

  path difference $= x_n \dfrac{d}{D} = (2n-1)\dfrac{\lambda}{2}$

  where
  $n = 1$ for first dark fringe,
  $n = 2$ for 2nd dark fringe and so on.
  x_n = distance of n^{th} dark fringe from the centre

  $\therefore\ x_n = (2n-1)\dfrac{\lambda D}{2d}$

- **Fringe width :** The distance between any two consecutive bright or dark fringes is known as fringe width.

  Fringe width, $\beta = \dfrac{\lambda D}{d}$

- **Angular fringe width :** $\theta = \dfrac{\beta}{D} = \dfrac{\lambda}{d}$

  If W_1, W_2 are widths of two slits, I_1, I_2 are intensities of light coming from two slits; *a, b* are the amplitudes of light from these slits, then

$$\frac{W_1}{W_2} = \frac{I_1}{I_2} = \frac{a^2}{b^2}$$

$$\frac{I_{max}}{I_{min}} = \frac{(a+b)^2}{(a-b)^2}$$

  - When entire apparatus of Young's double slit experiment is immersed in a medium of refractive index μ, then fringe width becomes

$$\beta' = \frac{\lambda' D}{d} = \frac{\lambda D}{\mu d} = \frac{\beta}{\mu}$$

  - When a thin transparent plate of thickness t and refractive index μ is placed in the path of one of the interfering waves, fringe width remains unaffected but the entire pattern shifts by

$$\Delta x = (\mu - 1)\, t\, \frac{D}{d} = (\mu - 1)\, t\, \frac{\beta}{\lambda}$$

  This shifting is towards the side in which transparent plate is introduced.

- **Colour of thin films :** A soap film or a thin film of oil spread over water surface, when seen in white light appears coloured. This effect can be explained in terms of phenomenon of interference.

Diffraction of light : It is the phenomenon of bending of light around corners of an obstacle or aperture in the path of light.

- **Diffraction due to a single slit :** The diffraction pattern produced by a single slit of width a consists of a central maximum bright band with alternating bright and dark bands of decreasing intensity on both sides of the central maximum.
  - Condition for n^{th} secondary maximum is
    Path difference $= a\sin\theta_n = (2n+1)\frac{\lambda}{2}$
    where n = 1, 2, 3,.......
  - Condition for n^{th} secondary minimum is
    Path difference = $a\sin\theta_n = n\lambda$
    where n = 1, 2, 3,.......
  - Width of secondary maxima or minima
    $\beta = \frac{\lambda D}{a}$
    where a = width of slit
    D = distance of screen from the slit
  - Width of central maximum $= \frac{2\lambda D}{a}$
  - Angular fringe width of central maximum $= \frac{2\lambda}{a}$
  - Angular fringe width of secondary maxima or minima $= \frac{\lambda}{a}$
- **Fresnel distance :** It is the minimum distance a beam of light has to travel before its deviation from straight line path becomes significant.
  Fresnel distance, $Z_F = \frac{a^2}{\lambda}$
- **Resolving power :** It is the ability of an optical instrument to produce distinctly separate images of two close objects i.e. it is the ability of the instrument to resolve or to see as separate, the images of two close objects.
- **Limit of resolution :** The minimum distance between two objects which can just be seen as separate by the optical instrument is known as the limit of resolution of the instrument. Smaller the limit of resolution of the optical instrument, greater is its resolving power and vice-versa.
- **Rayleigh's criterion of limiting resolution :** According to Rayleigh, two nearby images are said to be resolved if the position of the central maximum of one coincides with the first secondary minimum of the other and vice versa.
- **Resolving power of a microscope :** It is defined as the reciprocal of the minimum distance d between two point objects, which can just be seen through the microscope as separate.
  Resolving power $= \frac{1}{d} = \frac{2\mu\sin\theta}{\lambda}$
  where μ is refractive index of the medium between object and objective lens, θ is half the angle of cone of light from the point object, d represents limit of resolution of microscope and $\mu\sin\theta$ is known as the numerical aperture.
- **Resolving power of a telescope :** It is defined as reciprocal of the smallest angular separation ($d\theta$) between two distant objects, whose images are just seen in the telescope as separate.
  Resolving power $= \frac{1}{d\theta} = \frac{D}{1.22\,\lambda}$
  where D is diameter or aperture of the objective lens of the telescope, $d\theta$ represents limit of resolution of telescope.
- **Polarisation of light :** The phenomenon of restricting the vibrations of light (electric vector) in a particular direction, perpendicular to direction of wave motion is known as polarisation of light.
- **Angle of polarisation :** The angle of incidence for which an ordinary light is completely polarised in the plane of incidence when it gets reflected from a transparent medium.
- **Laws of Malus :** According to law of Malus, when a beam of completely plane polarised light is incident on an analyser, the resultant intensity of light (I) transmitted from the analyser varies directly as the square of the cosine of the angle (θ) between plane of transmission of analyser and polariser
  i.e. $I \propto \cos^2\theta$
- **Brewster's law :** According to Brewster's law, when unpolarised light is incident at polarising angle (i_p) on an interface separating a rarer medium from a denser medium of refractive index μ, such that $\mu = \tan i_p$
  then light is reflected in the rarer medium is completely polarised. The reflected and refracted rays are perpendicular to each other.

Previous Years' CBSE Board Questions

10.2 Huygens Principle

VSA (1 mark)

1. State Huygens' principle of diffraction of light. (*AI 2011C*)

2. What type of wavefront will emerge from a (i) point source, and (ii) distant light source? *(Delhi 2009)*

10.3 Refraction and Reflection of Plane Waves using Huygens Principle

SA I (2 marks)

3. How is a wavefront defined? Using Huygen's construction draw a figure showing the propagation of a plane wave refracting at a plane surface separating two media. Hence verify Snell' law of refraction. *(Delhi 2008)*

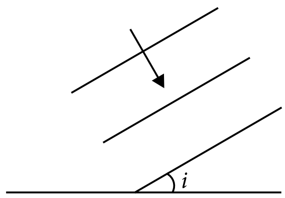
SA II (3 marks)

4. Define the term wavefront. State Huygen's principle. Consider a plane wavefront incident on a thin convex lens. Draw a proper diagram to show how the incident wavefront traverses through the lens and after refraction focusses on the focal point of the lens, giving the shape of the emergent wavefront. *(AI 2016)*

5. Explain the following, giving reasons:
   (i) When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency as the incident frequency.
   (ii) When light travels from a rarer to a denser medium, the speed decreases. Does this decrease in speed imply a reduction in the energy carried by the wave ?
   (iii) In the wave picture of light, intensity of light is determined by the square of the amplitude of the wave. What determines the intensity in the photon picture of light? *(AI 2016)*

6. Use Huygen's principle to show how a plane wavefront propagates from a denser to rarer medium. Hence verify Snell's law of refraction. *(AI 2015)*

7. A plane wavefront propagating in a medium of refractive index 'μ_1' is incident on a plane surface making the angle of incidence i as shown in the figure. It enters into a medium of refraction of refractive index 'μ_2' ($\mu_2 > \mu_1$). Use Huygens' construction of secondary wavelets to trace the propagation of the refracted wavefront. Hence verify Snell's law of refraction. *(Foreign 2015)*



8. Use Huygen's principle to verify the laws of refraction. *(Delhi 2011)*

9. Using Huygens' principle draw a diagram showing how a plane wave gets refracted when it is incident on the surface separating a rarer medium from a denser medium. Hence verify Snell's law of refraction. *(AI 2011C)*

LA (5 marks)

10. (a) Define a wavefront. How is it different from a ray?
    (b) Depict the shape of a wavefront in each of the following cases.
    (i) Light diverging from point source.
    (ii) Light emerging out of a convex lens when a point source is placed at its focus.
    (iii) Using Huygen's construction of secondary wavelets, draw a diagram showing the passage of a plane wavefront from a denser into a rarer medium. *(AI 2015C)*

11. (a) State Huygen's principle. Using this principle draw a diagram to show how a plane wavefront incident at the interface of the two media gets refracted when it propagates from a rarer to a denser medium. Hence verify Snell's law of refraction.

(b) When monochromatic light travels from a rarer to a denser medium, explain the following, giving reasons:
(i) Is the frequency of reflected and refracted light same as the frequency of incident light?
(ii) Does the decrease in speed imply a reduction in the energy carried by light wave? *(Delhi 2013)*

12. (a) Use Huygen's geometrical construction to show how a plane wave-front at $t = 0$ propagates and produces a wave-front at a later time.
(b) Verify, using Huygen's principle, Snell's law of refraction of a plane wave propagating from a denser to a rarer medium.
(c) When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency. Explain why. *(Delhi 2013C)*

13. Define a wavefront. Use Huygens' geometrical construction to show the propagation of a plane wavefront from a rarer medium to a denser medium undergoing refraction. Hence derive Snell's law of refraction. *(Foreign 2012)*

14. (a) Use Huygens' geometrical construction to show the behaviour of a plane wavefront
(i) passing through a biconvex lens.
(ii) reflecting by a concave mirror.
(b) When monochromatic light is incident on a surface separating two media, why does the refracted light have the same frequency as that of the incident light? *(Foreign 2012)*

15. (i) A plane wavefront approaches a plane surface separating two media. If medium 'one' is optically denser and medium 'two' is optically rarer, using Huygens' principle, explain and show how a refracted wavefront is constructed.
(ii) Hence verify Snell's law.
(iii) When a light wave travels from rarer to denser medium, the speed decreases. Does it imply reduction in its energy? Explain. *(Foreign 2011)*

16. Using Huygen's construction, draw a figure showing the propagation of a plane wave reflecting at the interface of the two media. Show that the angle of incidence is equal to the angle of reflection. *(Delhi 2010)*

10.4 Coherent and Incoherent addition of waves

VSA (1 mark)

17. Define the term 'coherent sources' which are required to produce interference pattern in Young's double slit experiment. *(Delhi 2014C)*

SA I (2 marks)

18. (a) Write the conditions under which light sources can be said to be coherent.
(b) Why is it necessary to have coherent sources in order to produce an interference pattern? *(AI 2013C)*

10.5 Interference of Light Waves and Young's Experiment

VSA (1 mark)

19. How does the fringe width of interference fringes change, when the whole apparatus of Young's experiment is kept in a liquid of refractive index 1.3? *(Delhi 2008)*

SA I (2 marks)

20. For a single slit of width 'a', the first minimum of the interference pattern of a monochromatic light of wavelength λ occurs at an angle of $\frac{\lambda}{a}$. At the same angle of $\frac{\lambda}{a}$, we get a maximum for two narrow slits separated by a distance 'a'. Explain. *(Delhi 2014)*

21. State two conditions required for obtaining coherent sources.
In Young's arrangement to produce interference pattern, show that dark and bright fringes appearing on the screen are equally spaced. *(Delhi 2012C)*

22. Laser light of wavelength 640 nm incident on a pair of slits produces an interference pattern in which the bright fringes are separated by 7.2 mm. Calculate the wavelength of another source of light which produces interference fringes separated by 8.1 mm using same arrangement. Also find the minimum value of the order (n) of bright fringe of shorter wavelength which coincides with that of the longer wavelength. *(AI 2012 C)*

23. Two slits are made one millimetre apart and the screen is placed one metre away. What is the fringe separation when blue-green light of wavelength 500 nm is used? *(Delhi 2011C)*

24. Laser light of wavelength 630 nm incident on a pair of slits produces an interference pattern in which the bright fringes are separated by 7.2 mm. Calculate the wavelength of another source of laser light which produces interference fringes separated by 8.1 mm using same pair of slits. *(AI 2011C)*

SA II (3 marks)

25. Answer the following questions :
(a) In a double slit experiment using light of wavelength 600 nm, the angular width of the fringe formed on a distant screen is 0.1°. Find the spacing between the two slits.
(b) Light of wavelength 500 Å propagating in air gets partly reflected from the surface of water. How will the wavelengths and frequencies of the reflected and refracted light be affected? *(Delhi 2015)*

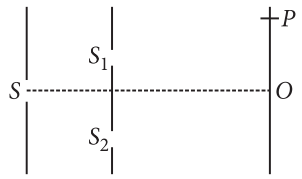
26. Why cannot two independent monochromatic sources produce sustained interference pattern? Deduce, with the help of Young's arrangement to produce interference pattern, an expression for the fringe width. *(Foreign 2015)*

27. (a) The ratio of the widths of two slits in Young's double slit experiment is 4 : 1.
Evaluate the ratio of intensities at maxima and minima in the interference pattern.
(b) Does the appearance of bright and dark fringes in the interference pattern violate, in any way, conservation of energy? Explain. *(AI 2015C)*

28. (a) Two monochromatic waves emanating from two coherent sources have the displacements represented by
$y_1 = a \cos \omega t$ and $y_2 = a \cos (\omega t + \phi)$
where ϕ is the phase difference between the two displacements. Show that the resultant intensity at a point due to their superposition is given by $I = 4\, I_0 \cos^2 \phi/2$, where $I_0 = a^2$.
(b) Hence obtain the conditions for constructive and destructive interference. *(AI 2014C)*

29 In what way is diffraction from each slit related to the interference pattern in a double slit experiment? *(1/3, Delhi 2013)*

30. In a modified set-up of Young's double slit experiment, it is given that $SS_2 - SS_1 = \lambda/4$, *i.e.* the source 'S' is not equidistant from the slits S_1 and S_2.

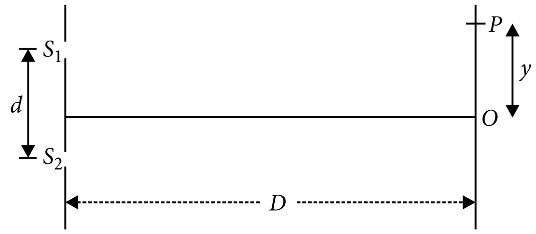


(a) Obtain the conditions for constructive and destructive interference at any point P on the screen in terms of the path difference $\delta = S_2P - S_1P$.
(b) Does the observed central bright fringe lie above or below 'O'? Give reason to support your answer. *(AI 2013C)*

31. (a) Why are coherent sources necessary to produce a sustained interference pattern?
(b) In Young's double slit experiment using monochromatic light of wavelength λ, the intensity of light at a point on the screen where path difference is λ, is K units. Find out the intensity of light at a point where path difference is $\lambda/3$. *(Delhi 2012)*

32. Describe Young's double slit experiment to produce interference pattern due to a monochromatic source of light. Deduce the expression for the fringe width. *(Delhi 2011)*

33. The intensity at the central maxima (O) in Young's double slit experiment is I_0. If the distance OP equals one-third of the fringe width of the pattern, show that the intensity at point P would be $\frac{I_0}{4}$. *(Foreign 2011)*



34. In Young's double slit experiment, the two slits 0.15 mm apart are illuminated by monochromatic light of wavelength 450 nm. The screen is 1.0 m away from the slits.
(a) Find the distance of the second (i) bright fringe, (ii) dark fringe from the central maximum.
(b) How will the fringe pattern change if the screen is moved away from the slits? *(AI 2010)*

35. A beam of light consisting of two wavelengths, 650 nm and 520 nm, is used to obtain interference fringes in a Young's double slit experiment. What is the least distance from the central maximum where the bright fringes due to the both the wavelengths coincide? The distance between the slits is 2 mm and the distance between the plane of the slits and screen is 120 cm. *(Foreign 2010)*

36. A beam of light, consisting of two wavelengths, 600 nm and 450 nm is used to obtained interference fringes in a Young's double slit experiment. Find the least distance, from the central maximum, where the bright fringes, due to both the wavelengths, coincide. The distance between the two slits is 4.0 mm and the screen is at a distance 1.0 m from the slits. *(Delhi 2010C)*

LA (5 marks)

37. In Young's double slit experiment, deduce the condition for (a) constructive, and (b) destructive interference at a point on the screen. Draw a graph showing variation of intensity in the interference pattern against position 'x' on the screen. *(4/5, Delhi 2016)*

38. (a) Consider two coherent sources S_1 and S_2 producing monochromatic waves to produce interference pattern. Let the displacement of the wave produced by S_1 be given by
$Y_1 = a\cos\omega t$
and the displacement by S_2 be
$Y_2 = a\cos(\omega t + \phi)$
Find out the expression for the amplitude of the resultant displacement at a point and show that the intensity at that point will be
$I = 4a^2\cos^2\phi/2$.
Hence establish the conditions for constructive and destructive interference.
(b) What is the effect on the interference fringes in Young's double slit experiment when (i) the width of the source slit is increased ; (ii) the monochromatic source is replaced by a source of white light? *(AI 2015)*

39. (a) (i) Two independent monochromatic sources of light cannot produce a sustained interference pattern. Give reason.
(ii) Light waves each of amplitude "a" and frequency "ω", emanating from two coherent light sources superpose at a point. If the displacements due to these waves is given by $y_1 = a\cos\omega t$ and $y_2 = a\cos(\omega t + \phi)$ where ϕ is the phase difference between the two, obtain the expression for the resultant intensity at the point.
(b) In Young's double slit experiment, using monochromatic light of wavelength λ, the intensity of light at a point on the screen where path difference is λ, is K units. Find out the intensity of light at a point where path difference is $\lambda/3$. *(Delhi 2014)*

40. (a) In Young's double slit experiment, describe briefly how bright and dark fringes are obtained on the screen kept in front of a double slit. Hence obtain the expression for the fringe width.
(b) The ratio of the intensities at minima to the maxima in the Young's double slit experiment is 9 : 25. Find the ratio of the widths of the two slits. *(AI 2014)*

41. (a) In Young's double slit experiment, derive the condition for (i) constructive interference and (ii) destructive interference at a point on the screen.
(b) A beam of light consisting of two wavelengths, 800 nm and 600 nm is used to obtain the interference fringes in a Young's double slit experiment on a screen placed 1.4 m away. If the two slits are separated by 0.28 mm, calculate the least distance from the central bright maximum where the bright fringes of the two wavelengths coincide. *(AI 2012)*

42. (a) What is the effect on the interference fringes in a Young's double slit experiment when
(i) the separation between the two slits is decreased?

(ii) the width of the source slit is increased?

(iii) the monochromatic source is replaced by a source of white light?

Justify your answer in each case.

(b) The intensity at the central maxima in Young's double slit experimental set-up is I_0. Show that the intensity at a point where the path difference is $\lambda/3$ is $I_0/4$. *(Foreign 2012)*

43. State the importance of coherent sources in the phenomenon of interference.

In Young's double slit experiment to produce interference pattern, obtain the conditions for constructive and destructive interference. Hence deduce the expression for the fringe width.

How does the fringe width get affected, if the entire experimental apparatus of Young's is immersed in water? *(AI 2011)*

44. In Young's double slit experiment, the two slits are kept 2 mm apart and the screen is positioned 140 cm away from the plane of the slits. The slits are illuminated with light of wavelength 600 nm. Find the distance of the third bright fringes, from the central maximum, in the interference pattern obtained on the screen. If the wavelength of the incident light were changed to 480 nm, find out the shift in the position of third bright fringe from the central maximum. *(3/5, AI 2010C)*

45. (a) What are coherent sources of light? Two slits in Young's double slit experiment are illuminated by two different sodium lamps emitting light of the same wavelength. Why is no interference pattern observed?

(b) Obtain the condition for getting dark and bright fringes in Young's experiment. Hence write the expression for the fringe width.

(c) If s is the size of the source and d is the distance from the plane of the two slits, what should be the criterion for the interference fringes to be seen? *(AI 2008)*

46. What are coherent sources? Why are coherent sources required to produce interference of light? Give an example of interference of light in everyday life.

In Young's double slit experiment, the two slits are 0.03 cm apart and the screen is placed at a distance of 1.5 m away from the slits. The distance between the central bright fringe and fourth bright fringe is 1 cm. Calculate the wavelength of light used. *(Delhi 2007)*

47. What are coherent sources of light? Why are coherent sources required to obtain sustained interference pattern? *(2/5, AI 2007)*

10.6 Diffraction

VSA (1 mark)

48. How does the angular separation between fringes in single-slit diffraction experiment change when the distance of separation between the slit and screen is doubled? *(AI 2012)*

49. For a given single slit, the diffraction pattern is obtained on a fixed screen, first by using red light and then with blue light. In which case, will the central maxima, in the observed diffraction pattern, have a larger angular width? *(Delhi 2010C)*

SA I (2 marks)

50. A parallel beam of light of 500 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1 m away. It is observed that the first minimum is at a distance of 2.5 mm from the centre of the screen. Calculate the width of the slit. *(AI 2013)*

51. Yellow light (λ = 6000 Å) illuminates a single slit of width 1×10^{-4} m. Calculate (i) the distance between the two dark lines on either side of the central maximum, when the diffraction pattern is viewed on a screen kept 1.5 m away from the slit; (ii) the angular spread of the first diffraction minimum. *(AI 2012C)*

52. Two convex lenses of same focal length but of aperture A_1 and A_2 ($A_2 < A_1$), are used as the objective lenses in two astronomical telescope having identical eyepieces. What is the ratio of their resolving power? Which telescope will you prefer and why? Give reason. *(Delhi 2011)*

53. Yellow light (λ = 6000 Å) illuminates a single slit of width 1×10^{-4} m. Calculate the distance between two dark lines on either side of the central maximum, when the diffraction pattern is viewed on a screen kept 1.5 m away from the slit. *(AI 2011C)*

54. State one feature by which the phenomenon of interference can be distinguish from that of diffraction.
A parallel beam of light of wavelength 600 nm is incident normally on a slit of width 'a'. If the distance between the slits and the screen is 0.8 m and the distance of 2^{nd} order maximum from the centre of the screen is 1.5 mm, calculate the width of the slit. *(AI 2008)*

55. Define resolving power of a compound microscope. How does the resolving power of a compound microscope change when
(i) refractive index of the medium between the object and objective lens increases?
(ii) wavelength of the radiation used is increased? *(AI 2007)*

SA II (3 marks)

56. A parallel beam of monochromatic light falls normally on a narrow slit of width 'a' to produce a diffraction pattern on the screen placed parallel to the plane of the slit.
Use Huygens' principle to explain that
(i) the central bright maxima is twice as wide as the other maxima.
(ii) the intensity falls as we move to successive maxima away from the centre of on either side. *(Delhi 2014C)*

57. Two wavelengths of sodium light 590 nm and 596 nm are used, in turn to study the diffraction taking place at a single slit of aperture 2×10^{-4} m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of the first maxima of the diffraction pattern obtained in the two cases. *(2/3, Delhi 2013)*

58. Use Huygen's principle to explain the formation of diffraction pattern due to a single slit illuminated by a monochromatic source of light.
When the width of the slit is made double the original width, how would this affect the size and intensity of the central diffraction band? *(Delhi 2012)*

59. In a single slit diffraction experiment, the width of the slit is reduced to half its original width. How would this affect the size and intensity of the central maximum? *(2/3, Delhi 2012C)*

60. Define the resolving power of a microscope. Write two factors by which resolving power can be increased. *(2/3, AI 2012C)*

61. What would be the effect on the resolving power of the telescope if its objective lens is immersed in a transparent medium of higher refractive index? *(1/3, AI 2012C)*

62. (a) In a single slit diffraction pattern, how does the angular width of the central maximum vary, when
(i) aperture of slit is increased?
(ii) distance between the slit and the screen is decreased?
(b) How is the diffraction pattern different from the interference pattern obtained in Young's double slit experiment? *(Delhi 2011C)*

63. Define the resolving power of a microscope. How is this affected when
(i) the wavelength of illuminating radiations is decreased, and
(ii) the diameter of the objective lens is decreased?
Justify your answer. *(Foreign 2010)*

64. A parallel beam of monochromatic light of wavelength 500 nm falls normally on a narrow slit and the resulting diffraction pattern is obtained on a screen 1 m away. It is observed that the first minimum is at a distance of 2.5 mm from the centre of the screen. Find
(a) the width of the slit.
(b) the distance of the second maximum from the centre of the screen.
(c) the width of the central maximum. *(Foreign 2010)*

65. In a single slit diffraction experiment, when a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the shadow of the obstacle. Explain why?
State two points of difference between the interference pattern obtained in Young's double slit experiment and the diffraction pattern due to a single slit. *(Delhi 2009)*

66. (a) In a single slit diffraction experiment, a slit of width 'd' is illuminated by red light of wavelength 650 nm. For what value of 'd' will

(i) the first minimum fall at an angle of diffraction of 30°, and

(ii) the first maximum fall at an angle of diffraction of 30°?

(b) Why does the intensity of the secondary maximum become less as compared to the central maximum? *(AI 2009)*

67. Define the term 'resolving power' of an astronomical telescope. How does it get affected on

(i) increasing the aperture of the objective lens?

(ii) increasing the wavelength of the light used?

Justify your answer in each case. *(Delhi 2007)*

LA (5 marks)

68. Compare the interference pattern observed in Young's double slit experiment with single slit diffraction pattern, pointing out three distinguishing features. *(1/5, Delhi 2016)*

69. (i) State the essential conditions for diffraction of light.

(ii) Explain diffraction of light due to a narrow single slit and the formation of pattern of fringes on the screen.

(iii) Find the relation for width of central maximum in terms of wavelength 'λ' width of slit 'a' and separation between slit and screen 'D'.

(iv) If the width of the slit is made double the original width, how does it affect the size and intensity of the central band? *(Foreign 2016)*

70. (a) Using Huygens' construction of secondary wavelets explain how a diffraction pattern is obtained on a screen due to a narrow slit on which a monochromatic beam of light is incident normally.

(b) Show that the angular width of the first diffraction fringe is half that of the central fringe.

(c) Explain why the maxima at $\theta = \left(n + \frac{1}{2}\right)\frac{\lambda}{a}$ become weaker and weaker with increasing n. *(Delhi 2015)*

71. (a) Describe briefly how a diffraction pattern is obtained on a screen due to a single narrow slit illuminated by a monochromatic source of light. Hence obtain the conditions for the angular width of secondary maxima and secondary minima.

(b) Two wavelengths of sodium light of 590 nm and 596 nm are used in turn to study the diffraction taking place at a single slit of aperture 2×10^{-6} m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of first maxima of the diffraction pattern obtained in the two cases. *(AI 2014)*

72. (a) Write three characteristic features to distinguish between the interference fringes in Young's double slit experiment and the diffraction pattern obtained due to a narrow single slit.

(b) A parallel beam of light of wavelength 500 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1 m away. It is observed that the first minimum is a distance of 2.5 mm away from the centre. Find the width of the slit. *(Foreign 2014)*

73. (a) A monochromatic source of light of wavelength λ illuminates a narrow slit of width d to produce a diffraction pattern on the screen. Obtain the conditions when secondary wavelets originating from the slit interfere to produce maxima and minima on the screen.

(b) How would the diffraction pattern be affected when

(i) the width of the slit is decreased?

(ii) the monochromatic source of light is replaced by white light? *(Foreign 2013)*

74. (a) Obtain the conditions for the bright and dark fringes in diffraction pattern due to a single narrow slit illuminated by a monochromatic source.

Explain clearly why the secondary maxima go on becoming weaker with increasing n.

(b) When the width of the slit is made double, how would this affect the size and intensity of the central diffraction band ? Justify. *(Foreign 2012)*

75. In a single narrow slit (illuminated by a monochromatic source) diffraction experiment, deduce the conditions for the central maximum and secondary maxima and minima observed in the diffraction pattern. Also explain why the secondary maxima go on becoming weaker in intensity as the order increases.
(b) Answer the following questions:
(i) How does the width of the slit affect the size of the central diffraction band?
(ii) When a tiny circular obstacle is placed in the path of light from a distant source, why is a bright spot seen at the centre of the shadow of the obstacle? *(AI 2010C)*

76. State the condition under which the phenomenon of diffraction of light takes place. Derive an expression for the width of the central maximum due to diffraction of light at a single slit.
A slit of width '*a*' is illuminated by a monochromatic light of wavelength 700 nm at normal incidence. Calculate the value of '*a*' for position of
(i) first minimum at an angle of diffraction of 30°
(ii) first maximum at an angle of diffraction of 30° . *(Delhi 2007)*

77. State the essential condition for diffraction of light to take place.
Use Huygens' principle to explain diffraction of light due to a narrow single slit and the formation of a pattern of fringes obtained on the screen. Sketch the pattern of fringes formed due to diffraction at a single slit showing variation of intensity with angle θ. *(AI 2007)*

78. State three characteristics features which distinguish the interference pattern due to two coherency illuminated sources as compared to that observed in a diffraction pattern due to a single slit. *(3/5, AI 2007)*

10.7 Polarisation

VSA (1 mark)

79. Which of the following waves can be polarized (i) Heat waves (ii) Sound waves? Give reason to support your answer. *(Delhi 2013)*

80. In what way is plane polarised light different from an unpolarised light? *(AI 2012C)*

81. If the angle between the pass axis of polariser and the analyser is 45°, write the ratio of the intensities of original light and the transmitted light after passing through the analyser. *(Delhi 2009)*

SA I (2 marks)

82. State Brewster's law.
The value of Brewster angle for a transparent medium is different for light of different colours. Give reason. *(Delhi 2016)*

83. Distinguish between polarized and unpolarized light. Does the intensity of polarized light emitted by a polaroid depend on its orientation? Explain briefly.
The vibration in beam of polarized light make an angle of 60° with the axis of the polaroid sheet. What percentage of light is transmitted through the sheet? *(Foreign 2016)*

84. Find an expression for intensity of transmitted light when a polaroid sheet is rotated between two crossed polaroids. In which position of the polaroid sheet will the transmitted intensity be maximum? *(Delhi 2015)*

85. Distinguish between unpolarised and a linearly polarised light. Describe, with the help of a diagram, how unpolarised light gets linearly polarised by scattering. *(Delhi 2015C)*

86. Explain briefly, giving a suitable diagram, how an unpolarised light incident on the interface separating two transparent media gets polarised on reflection. Deduce the necessary condition for it. *(Delhi 2012C)*

87. What does a polaroid consist of? Using a simple polaroid, show that light waves are transverse in nature. *(AI 2012C)*

88. (a) What is unpolarised light?
(b) An unpolarised beam of light, of intensity I_0, is incident on a combination of two polaroids. Find the net intensity, of the light, transmitted by the combination, when the 'pass-axis', of the two polaroids are inclined to each other at an angle of 60°. *(AI 2010C)*

SA II (3 marks)

89. (i) State law of Malus.
(ii) Draw a graph showing the variation of intensity (I) of polarised light transmitted by an analyser with angle (θ) between polariser and analyser.
(iii) What is the value of refractive index of a medium of polarising angle 60° ? *(Delhi 2016)*

90. State clearly how an unpolarised light gets linearly polarised when passed through a polaroid.
(i) Unpolarised light of intensity I_0 is incident on a polaroid P_1 which is kept near another polaroid P_2 whose pass axis is parallel to that of P_1. How will the intensities of light, I_1 and I_2, transmitted by the polaroids P_1 and P_2 respectively, change on rotating P_1 without disturbing P_2?
(ii) Write the relation between the intensities I_1 and I_2. *(AI 2015)*

91. (a) Good quality sun-glasses made of polaroids are preferred over ordinary coloured glasses. Justifying your answer.
(b) Two polaroids P_1 and P_2 are placed in crossed postions. A third polaroid P_3 is kept between P_1 and P_2 such that pass axis of P_3 is parallel to that of P_1. How would the intensity of light (I_2) transmitted through P_2 vary as P_3 is rotated? Draw a plot of intensity 'I_2" versus the angle 'θ' between pass axes of P_1 and P_3. *(AI 2015C)*

92. (a) Using the phenomenon of polarisation, show how transverse nature of light can be demonstrated.
(b) Two polaroids P_1 and P_2 are placed with their pass axes perpendicular to each other. Unpolarised light of intensity I_0 is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its pass axis makes an angle of 30° with that of P_1. Determine the intensity of light transmitted through P_1, P_2 and P_3. *(AI 2014)*

93. (a) What is linearly polarized light? Describe briefly using a diagram how sunlight is polarised.
(b) Unpolarised light is incident on a polaroid. How would the intensity of transmitted light change when the polaroid is rotated? *(AI 2013)*

94. When unpolarised light is incident on the boundary separating the two transparent media, explaning, with the help of a suitable diagram, the conditions under which the reflected light gets polarised. Hence define Brewster's angle and write its relationship in terms of the relative refractive index of the two media. *(Foreign 2013)*

95. (a) Describe briefly, with the help of suitable diagram, how the transverse nature of light can be demonstrated by the phenomenon of polarization.
(b) When unpolarized light passes from air to transparent medium, under what condition does the reflected light get polarized? *(Delhi 2011)*

96. The velocity of a certain monochromatic light, in a given transparent medium is 2.25×10^8 m/s. What is the (a) critical angle of incidence, (b) polarising angle for this medium? *(AI 2011)*

97. (i) Light passes through two polaroids P_1 and P_2 with axis of P_2 making an angle θ with the pass axis of P_1. For what value of θ is the intensity of emergent light zero?
(ii) A third polaroid is placed between P_1 and P_2 with its pass axis making an angle β with the pass axis of P_1. Find a value of β for which the intensity of light emerging from P_2 is $\frac{I_0}{8}$, where I_0 is the intensity of light on the polaroid P_1. *(Foreign 2011)*

98. (a) Explain, with the help of diagram, how plane polarised light is obtained by scattering.
(b) Between two polaroids placed in crossed position a third polaroid is introduced. The axis of the third polaroid makes an angle of 30° with the axis of the first polaroid. Find intensity of transmitted light from the system assuming I_0 to be the intensity of polarised light obtained from the first polaroid. *(AI 2011C)*

99. How does an unpolarised light get polarised when passed through a polaroid?
Two polaroids are set in crossed positions. A third polaroid is placed between the two making an angle θ with the pass axis of the first polaroid. Write the expression for the intensity of light

transmitted from the second polaroid. In what orientations will the transmitted intensity be (i) minimum and (ii) maximum? *(AI 2010)*

100. A beam of unpolarised light is incident on the boundary between two transparent media.
If the reflected light is completely plane polarised, how is its direction related to the direction of the corresponding refracted light?
Define Brewster's angle. Obtain the relation between this angle and the refractive index for the given pair of media. *(Delhi 2010C)*

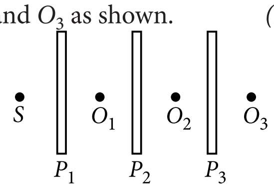
101. Distinguish between unpolarised and plane polarised light. An unpolarised light is incident on the boundary between two transparent media. State the condition when the reflected wave is totally plane polarised. Find out the expression for the angle of incidence in this case. *(AI 2008)*

LA (5 marks)

102. (a) How does one demonstrate, using a suitable diagram, that unpolarised light when passed through a polaroid gets polarised?
(b) A beam of unpolarised light is incident on a glass-air interface. Show, using a suitable ray diagram, that light reflected from the interface is totally polarised, when $\mu = \tan i_B$ where μ is the refractive index of glass with respect to air and i_B is the Brewster's angle. *(Delhi 2014)*

103. (a) Distinguish between linearly polarised and unpolarised light.
(b) Show that the light waves are transverse in nature.
(c) Why does light from a clear blue portion of the sky show a rise and fall of intensity when viewed through a polaroid which is rotated? Explain by drawing the necessary diagram. *(Delhi 2014C)*

104. (a) Describe briefly how an unpolarised light get linearly polarized when it passes through a polaroid.
(b) Three identical polaroid sheets P_1, P_2 and P_3 are oriented so that the pass axis of P_2 and P_3 are inclined at angle of 60° and 90° respectively with respect to the pass axis of P_1. A monochromatic source S of unpolarised light of intensity I_0 is kept in front of the polaroid sheet P_1 as shown in the figure. Determine the intensities of light as observed by the observers O_1, O_2 and O_3 as shown. *(Delhi 2013C)*



105. (a) How does an unpolarized light incident on a polaroid get polarized?
Describe briefly, with the help of a necessary diagram, the polarization of light by reflection from a transparent medium.
(b) Two polaroids 'A' and 'B' are kept in crossed position. How should a third polaroid 'C' be placed between them so that the intensity of polarized light transmitted by polaroid B reduces to $1/8^{\text{th}}$ of the intensity of unpolarized light incident on A? *(AI 2012)*

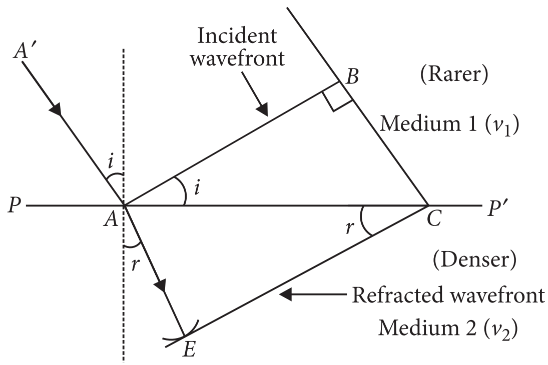
106. (a) What is plane polarised light? Two polaroids are placed at 90° to each other and the transmitted intensity is zero. What happens when one more polaroid is placed between these two, bisecting the angle between them? How will the intensity of transmitted light vary on further rotating the third polaroid?
(b) If a light beam shows no intensity variation when transmitted through a polaroid which is rotated, does it mean that the light is unpolarised? Explain briefly. *(Delhi 2008)*

Detailed Solutions

1. According to Huygens' principle, each point on a wavefront is a source of secondary waves, which add up to give a wavefront at any later time.

2. (i) Spherical wavefront emerges from a point source.
(ii) Plane wavefront emerges from a distant light source.

3. (i) Wavefront : The continuous locus of all the particles of a medium, which are vibrating in the same phase is called a wavefront.
(ii) Snell's law of refraction : Let PP' represents the surface separating medium 1 and medium 2 as shown in figure.



Let v_1 and v_2 represents the speed of light in medium 1 and medium 2 respectively. We assume a plane wavefront AB propagating in the direction $A'A$ incident on the interface at an angle i. Let t be the time taken by the wavefront to travel the distance BC.

$\therefore$ $BC = v_1 t$ [$\because$ distance = speed × time]

In order to determine the shape of the refracted wavefront, we draw a sphere of radius $v_2 t$ from the point A in the second medium (the speed of the wave in second medium is v_2).
Let CE represents a tangent plane drawn from the point C. Then
$AE = v_2 t$
$\therefore$ CE would represent the refracted wavefront.
In ΔABC and ΔAEC, we have

$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC} \quad \text{and} \quad \sin r = \frac{AE}{AC} = \frac{v_2 t}{AC}$$

Where i and r are the angles of incident and refraction respectively.

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{v_1 t}{AC} \cdot \frac{AC}{v_2 t}$$

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

If c represents the speed of light in vacuum, then

$$\mu_1 = \frac{c}{v_1} \text{ and } \mu_2 = \frac{c}{v_2}$$

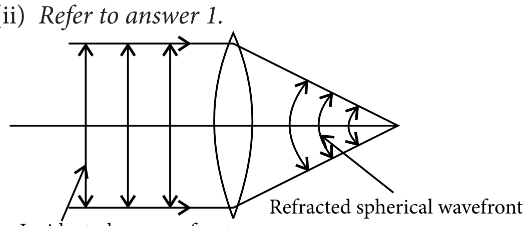
$$\Rightarrow \quad v_1 = \frac{c}{\mu_1} \text{ and } v_2 = \frac{c}{\mu_2}$$

Where μ_1 and μ_2 are the refractive indices of medium 1 and medium 2.

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{c/\mu_1}{c/\mu_2} \Rightarrow \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \Rightarrow \mu_1 \sin i = \mu_2 \sin r$$

This is the Snell's law of refraction.

4. (i) *Refer to answers 3(i).*
(ii) *Refer to answer 1.*

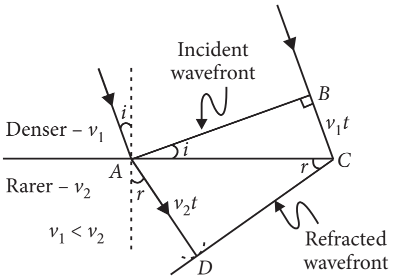


5. (i) Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of the incident light. Hence frequency remains unchanged.
(ii) (Energy carried by a wave depends on the frequency of the wave, not on the speed of wave propagation.
(iii) For a given frequency, intensity of light in the photon picture is determined by

$$I = \frac{\text{Energy of photons}}{\text{area} \times \text{time}} = \frac{n \times h\upsilon}{A \times t}$$

Where n is the number of photons incident normally on crossing area A in time t.

6. Given figure shows the refraction of a plane wavefront at a rarer medium *i.e.*, $v_2 > v_1$



The incident and refracted wavfronts are shown in figure.
Let the angles of incidence and refraction be i and r respectively.
From right ΔABC, we have,

$$\sin \angle BAC = \sin i = \frac{BC}{AC}$$

From right ΔADC, we have,

$$\sin \angle DCA = \sin r = \frac{AD}{AC}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t} \text{ or } \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2$$

(a constant)

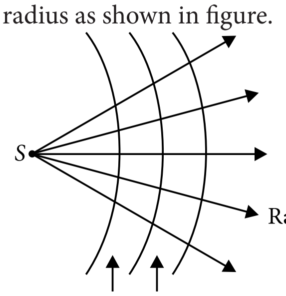
This verifies Snell's law of refraction. The constant ${}^1\mu_2$ is called the refractive index of the second medium with respect to first medium.

7. *Refer to answer 3(ii).*

8. *Refer to answer 6.*

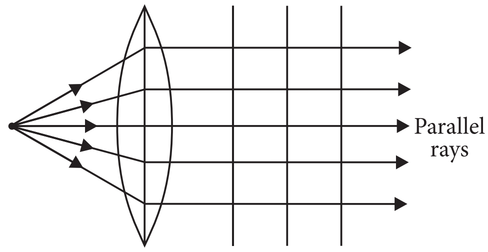
9. *Refer to answer 6.*

10. (a) A wavefront is defined as the locus of all the particles vibrating in same phase at any instant. A line perpendicular to the wavefront in the direction of propagation of light wave is called a ray.
(b) (i) The wavefront will be spherical of increasing radius as shown in figure.



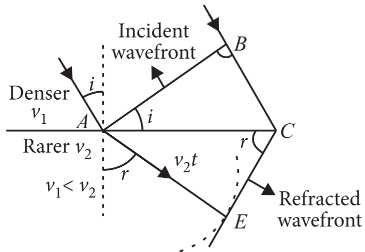
Spherical wavefront

(ii) When source is at the focus, the rays coming out of the convex lens are parallel, so wavefront is plane as shown in figure.



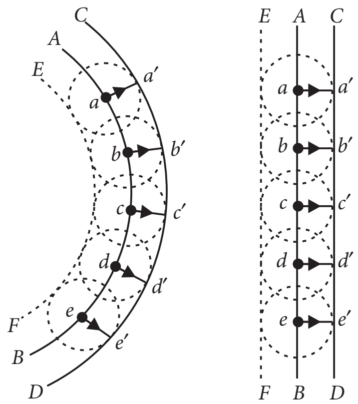
Plane wavefront

(iii)



11. (a) (i) *Refer to answer 1*
(ii) *Refer to answer 7*
(b) (i) *Refer to answer 5(i).*
(ii) Since the frequency remains same, hence there is no reduction in energy.

12. (a) Consider a spherical or plane wavefront moving towards right. Let AB be its position at any instant of time. The region on its left has received the wave while region on the right is undisturbed.



(a) (b)

Huygens's geometrical construction for the propagation of (a) spherical, (b) plane wavefront.

According to Huygens' principle, each point on AB becomes a source of secondary disturbance, which takes with the same speed c. To find the new wavefront after time t, we draw spheres of radii ct, from each point on AB.
The forward envelope or the tangential surface CD of the secondary wavelets gives the new wavefront after time t.

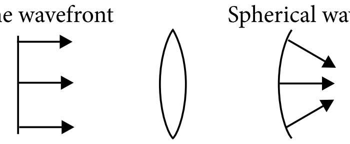
The lines aa', bb', cc', etc., are perpendicular to both AB and CD. Along these lines, the energy flows from AB to CD. So these lines represent the rays. Rays are always normal to wavefronts.

(b) *Refer to answer 6.*

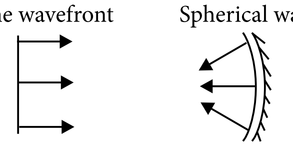
(c) *Refer to answer 5(i).*

13. *Refer to answer 3.*

14. (a) (i) The action of convex lens : A plane wavefront becomes spherical convergent wavefront after refraction.

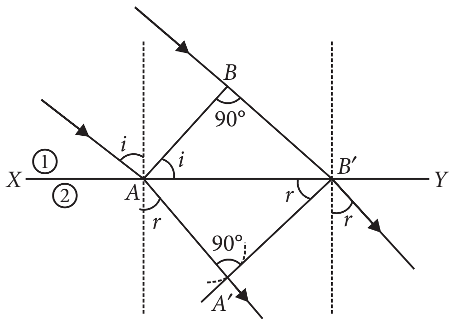


(ii) Action of concave mirror : A plane wavefront becomes spherical convergent after reflection.



(b) *Refer to answer 5(i).*

15. (i) When a wave starting from one homogeneous medium enters the another homogeneous medium, it is deviated from its path. This phenomenon is called refraction. In transversing from first medium to another medium, the frequency of wave remains unchanged but its speed and the wavelength both are changed. Let XY be a surface separating the two media '1' and '2'. Let v_1 and v_2 be the speeds of waves in these media.



Suppose a plane wavefront AB in first medium is incident obliquely on the boundary surface XY and its end A touches the surface at A at time $t = 0$ while the other end B reaches the surface at point B' after time-interval t. Clearly $BB' = v_1t$. As the wavefront AB advances, it strikes the points between A and B' of boundary surface. According to Huygen's principle, secondary spherical wavelets originate from these points, which travel with speed v_1 in the first medium and speed v_2 in the second medium.

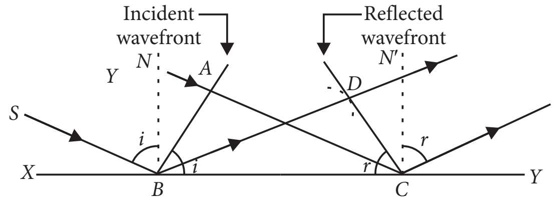
First of all secondary wavelet starts from A, which traverses a distance AA' $(=v_2t)$ in second medium in time t. In the same time-interval t, the point of wavefront transverses a distance BB' $(=v_1t)$ in first medium and reaches B', from where the secondary wavelet now starts. Clearly $BB' = v_1t$ and $AA' = v_2t$.

Assuming A as centre, we draw a spherical arc of radius AA' $(=v_2t)$ and draw tangent $B'A'$ on this arc from B'. As the incident wavefront AB advances, the secondary wavelets start from points between A and B', one after the other and will touch $A'B'$ simultaneously. According to Huygen's principle, $A'B'$ is the new position of wavefront AB in the second medium. Hence $A'B'$ will be the refracted wavefront.

(ii) *Refer to answer 6*

(iii) No, because energy of wave depends on its frequency and not on its speed.

16. Consider a plane wavfront AB incident on the plane reflecting surface being perpendicular to the plane of paper.



Wavefronts and corresponding rays for reflection from a plane surface.

First the wavefront touches the reflecting surface at B and then at the successive points towards C. In accordance with Huygens' principle, from each point on BC secondary wavelets start growing with the speed c. During the time the disturbance from A reaches the point C, the secondary wavelets from from B must have spread over a hemisphere of radius $DB = AC = ct$, where t is the time taken by the disturbance to travel from A to C. The tangent plane CD drawn from the point C over this hemisphere of radius ct will be the new reflected wavefront.

Let angles of incidence and reflection be i and r respectively. In ΔABC and ΔDCB, we have

$\angle BAC = \angle CDB$ [Each is 90°]
$BC = BC$ [Common]
$AC = BD$ [Each is equal to ct]
$\therefore \quad \Delta ABC \cong \Delta DCB$
Hence $\angle ABC = \angle DCB$
or $\quad i = r$
i.e., the angle of incidence is equal to the angle of reflection. This prove the first law of reflection.

17. Two sources are said to be coherent, if they emit light waves of same frequency or wavelength and of a stable phase difference.

18. (a) The essential condition, which must satisfied sources to be coherent are :
(i) the two light waves should be of same wavelength.
(ii) the two light waves should either be in phase or should have a constant phase difference.
(b) Because coherent sources emit light waves of same frequency or wavelength and of a stable phase difference.

19. Fringe width of interference fringes decreases to $\beta' = \frac{\beta}{\mu} = \frac{\beta}{1.3}$

20. For a single slit of width "a" the first minima of the interference pattern of a monochromatic light of wavelength λ occurs at an angle of (λ/a) because the light from centre of the slit differs by a half of a wavelength.
Whereas a double slit experiment at the same angle of (λ/a) and slits separation "a" produces maxima because one wavelength difference in path length from these two slits is produced.

21. (a) *Refer to answer 18(a).*
(b) For bright fringes (maxima),
Path difference, $\frac{xd}{D} = n\lambda$
$\therefore \quad x = n\lambda\frac{D}{d}$, where $n = 0, 1, 2, 3, ...$
For dark fringes (minima),
path difference, $\frac{xd}{D} = (2n-1)\frac{\lambda}{2}$
$\therefore \quad x = (2n-1)\frac{\lambda}{2}\frac{D}{d}$, where $n = 1, 2, 3, ...$
The separation between the centre of two consecutive bright fringes is the width of a dark fringe.
$\therefore$ Fringe width, $\beta = x_n - x_{n-1}$

$$\beta = n\frac{\lambda D}{d} - (n-1)\frac{\lambda D}{d}$$
$$\therefore \quad \boxed{\beta = \frac{\lambda D}{d}}$$

22. Fringe width $\beta = \frac{D\lambda}{d}; \beta \propto \lambda$
$\therefore \quad \frac{\beta_1}{\beta_2} = \frac{\lambda_1}{\lambda_2}$ or $\lambda_2 = \frac{\beta_2}{\beta_1}\lambda_1 = \frac{8.1}{7.2} \times 640$ nm
$\lambda_2 = 720$ nm
$\because \quad x = n_1\beta_1 = n_2\beta_2$
or $\frac{n_1 D\lambda_1}{d} = \frac{n_2\lambda_2 D}{d}$ or $n_1\lambda_1 = n_2\lambda_2$
$\because$ Bright fringes coincides at least distance x, if $n_1 = n_2 + 1$
$\Rightarrow \quad n_1 \times 640 = (n_1 - 1) \times 720$
$\frac{n_1 - 1}{n_1} = \frac{640}{720}$ or $n_1 = 9$

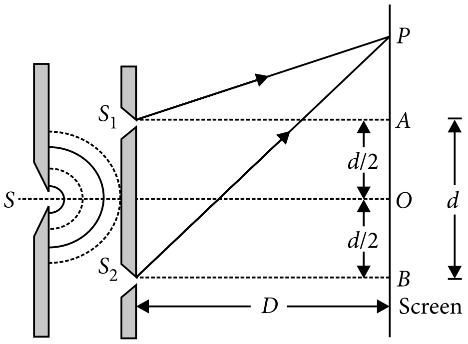
23. Here, $d = 1$ mm $= 1 \times 10^{-3}$ m
$D = 1$ m, $\lambda = 500$ nm $= 5 \times 10^{-7}$ m
Fringe spacing,
$$\beta = \frac{\lambda D}{d} = \frac{5 \times 10^{-7} \times 1}{1 \times 10^{-3}}$$
$= 5 \times 10^{-4}$ m $= 0.5$ mm

24. Fringe width, $\beta = \frac{D\lambda}{d}$
When D and d are kept fixed, $\frac{\beta}{\beta_1} = \frac{\lambda}{\lambda_1}$
or $\quad \lambda_1 = \frac{\lambda\beta_1}{\beta} = \frac{630 \times 8.1}{7.2} = \frac{5103}{7.2} = 708.75$ nm

25. Angular width, $\theta = \frac{\lambda}{d}$ or $d = \frac{\lambda}{\theta}$
Here, $\lambda = 600$ nm $= 6 \times 10^{-7}$ m
$\theta = 0.1° = \frac{0.1 \times \pi}{180}$ rad $= \frac{\pi}{1800}$ rad, $d = ?$
$\therefore \quad d = \frac{6 \times 10^{-7} \times 1800}{\pi} = 3.44 \times 10^{-4}$ m
(b) Frequency of a light depends on its source only. So, the frequencies of reflected and refracted light will be same as that of incident light.
Reflected light is in the same medium (air) so its wavelength remains same as 500 Å.
Wavelength of refracted light, $\lambda_r = \frac{\lambda}{\mu_w}$
μ_w = refractive index of water.
So, wavelength of refracted wave will be decreased.

26. (i) Two independent monochromatic sources cannot produce sustained interference pattern because the phase difference between the light waves from two independent sources keeps on changing continuously.

(ii)



Consider a point P on the screen at distance x from the centre O. The nature of the interference at the point P depends on path difference,

$p = S_2P - S_1P$

From right-angled ΔS_2BP and ΔS_1AP,

$(S_2P)^2 - (S_1P)^2 = [S_2B^2 + PB^2] - [S_1A^2 + PA^2]$

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

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

or $\quad S_2P - S_1P = \dfrac{2xd}{S_2P + S_1P}$

In practice, the point P lies very close to O, therefore $S_1P \simeq S_2P \simeq D$. Hence

$$p = S_2P - S_1P = \frac{2xd}{2D}$$

or $\quad p = \dfrac{xd}{D}$

Positions of bright fringes : For constructive interference,

$$p = \frac{xd}{D} = n\lambda$$

or $\quad x = \dfrac{nD\lambda}{d}$ where $n = 0, 1, 2, 3, ...$

Positions of dark fringes : For destructive interference,

$$p = \frac{xd}{D} = (2n-1)\frac{\lambda}{2}$$

or $\quad x = (2n-1)\dfrac{D\lambda}{2d}$ where $n = 1, 2, 3$

Width of a dark fringe = Separation between two consecutive bright fringes

$$= x_n - x_{n-1} = \frac{nD\lambda}{d} - \frac{(n-1)D\lambda}{d} = \frac{D\lambda}{d}$$

Width of bright fringe = Separation between two consecutive dark fringes

$$= x'_n - x'_{n-1} = (2n-1)\frac{D\lambda}{2d} - [2(n-1)-1]\frac{D\lambda}{2d} = \frac{D\lambda}{d}$$

Clearly, both the bright and dark fringes are of equal width.

Hence the expression for the fringe width in Young's double slit experiment can be written as

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

27. (a) The intensity of light due to slit is directly proportional to width of slit.

$$\therefore \quad \frac{I_1}{I_2} = \frac{w_1}{w_2} = \frac{4}{1}$$

$$\Rightarrow \quad \frac{a_1^2}{a_2^2} = \frac{4}{1} \text{ or } \frac{a_1}{a_2} = \frac{2}{1} \text{ or } a_1 = 2a_2$$

$$\frac{I_{max}}{I_{min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{(2a_2 + a_2)^2}{(2a_2 - a_2)^2} = \frac{9a_2^2}{a_2^2} = 9:1$$

(b) No, the appearance of bright and dark fringes in the interference pattern does not violate the law of conservation of energy.

When interference takes place, the light energy which disappears at the regions of destructive interference appears at regions of constructive interference so that the average intensity of light remains the same. Hence, the law of conservation of energy is obeyed in the phenomenon of interference of light.

28. (a) $y_1 = a \cos \omega t$, $y_2 = a \cos (\omega t + \phi)$

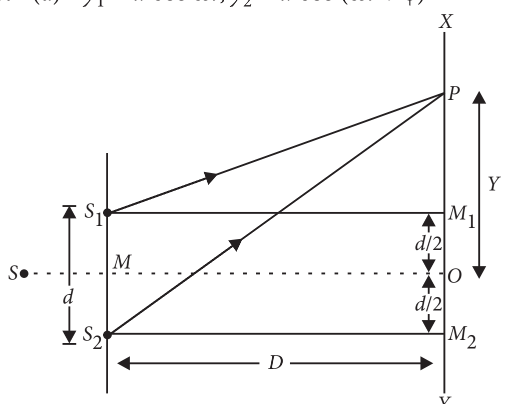


Fig. : Theory of interference bands

where ϕ is phase difference between them. Resultant displacement at point P will be,

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

$= a [\cos \omega t + \cos (\omega t + \phi)]$

$$= a\left[2\cos\frac{(\omega t + \omega t + \phi)}{2}\cos\frac{(\omega t - \omega t - \phi)}{2}\right]$$

$$y = 2a\cos\left(\omega t + \frac{\phi}{2}\right)\cos\left(\frac{\phi}{2}\right) \quad \text{...(i)}$$

Let $y = 2a\cos\left(\frac{\phi}{2}\right) = A$, the equation (i) becomes

$$y = A\cos\left(\omega t + \frac{\phi}{2}\right)$$

where A is amplitude of resultant wave,

Now, $A = 2a\cos\left(\frac{\phi}{2}\right)$

On squaring, $A^2 = 4a^2\cos^2\left(\frac{\phi}{2}\right)$

Hence, resultant intensity,

$$I = 4I_0\cos^2\left(\frac{\phi}{2}\right)$$

(b) Condition for constructive interference,

$\cos \Delta\phi = +1$

$$2\pi\frac{\Delta x}{\lambda} = 0, 2\pi, 4\pi...$$

or $\Delta x = n\lambda$; $n = 0, 1, 2, 3, ...$

Condition for destructive interference, $\cos \Delta\phi = -1$

$$2\pi\frac{\Delta x}{\lambda} = \pi, 3\pi, 5\pi...$$

or $\Delta x = (2n - 1)\lambda/2$

where $n = 1, 2, 3...$

29. If the width of each slit is comparable to the wavelength of light used, the interference pattern thus obtained in the double-slit experiment is modified by diffraction from each of the two slits.

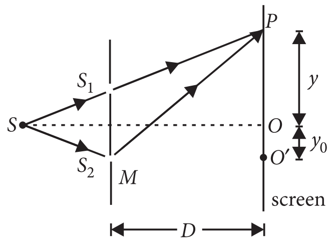
30. (a) Given : $SS_2 - SS_1 = \frac{\lambda}{4}$

Now path difference between the two waves from slit S_1 and S_2 on reaching point P on screen is

$\Delta x = (SS_2 + S_2P) - (SS_1 + S_1P)$

or $\Delta x = (SS_2 - SS_1) + (S_2P - S_1P)$

or $\Delta x = \frac{\lambda}{4} + \frac{yd}{D}$



(i) For constructive interference at point P, path difference, $\Delta x = n\lambda$

or $\frac{\lambda}{4} + \frac{yd}{D} = n\lambda$

or $\frac{yd}{D} = \left(n - \frac{1}{4}\right)\lambda$ ...(i)

where $n = 0, 1, 2, 3,...,$

(ii) For destructive interference at point P, path difference

$$\Delta x = (2n-1)\frac{\lambda}{2} \text{ or } \frac{\lambda}{4} + \frac{yd}{D} = (2n-1)\frac{\lambda}{2}$$

or $\frac{yd}{D} = \left(2n - 1 - \frac{1}{2}\right)\frac{\lambda}{2} = (4n-3)\frac{\lambda}{4}$ ...(ii)

where $n = 1, 2, 3, 4,...$

For central bright fringe, putting $n = 0$ in equation (i), we get

$$\frac{yd}{D} = -\frac{\lambda}{4} \text{ or } y = \frac{-\lambda D}{4d}$$

(b) The *-ve* sign indicates that central bright fringe will be observed at a point O' below the centre O of screen.

31. (a) Coherent sources are necessary to produce a sustained interference pattern otherwise the phase difference changes very rapidly with time and hence no interference will be observed.

(b) Intensity at a point, $I = 4I_0\cos^2\left(\frac{\phi}{2}\right)$

$$\text{Phase difference} = \frac{2\pi}{\lambda} \times \text{ Path difference}$$

At path difference λ,

Phase difference, $\phi = \frac{2\pi}{\lambda} \times \lambda = 2\pi$

$\therefore$ Intensity, $K = 4I_0\cos^2\left(\frac{2\pi}{2}\right)$

[$\because$ Given $I = K$, at path difference λ]

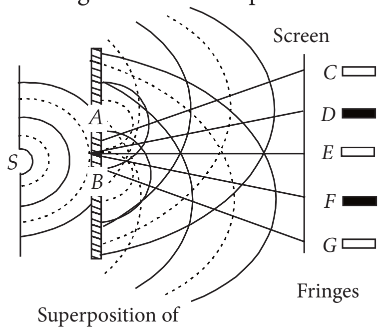
$K = 4I_0$ ...(i)

If path difference is $\frac{\lambda}{3}$, then phase difference will be

$$\phi' = \frac{2\pi}{\lambda} \times \frac{\lambda}{3} = \frac{2\pi}{3}$$

$\therefore$ Intensity, $I' = 4I_0 \cos^2\left(\frac{2\pi}{6}\right) = \frac{K}{4}$ (Using (i))

32. (i) Young's double slit experiment :



S is a narrow slit (of width about 1 mm) illuminated by a monochromatic source of light, *S*. At a suitable distance (about 10 cm) from *S*, there are two fine slits *A* and *B* about 0.5 mm apart placed symmetrically parallel to *S*. When a screen is placed at a large distance (about 2 m) from the slits *A* and *B*, alternate bright and dark fringes running parallel to the lengths of slits appear on the screen. These are the interference fringes. The fringes disappear when one of the slits *A* or *B* is covered.

(ii) *Refer to answer 26(ii)*

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

$$y = \frac{\beta}{3} = \frac{\lambda D}{3d}$$

Path difference $(\Delta p) = \frac{yd}{D} \Rightarrow \Delta p = \frac{\lambda D}{3d} \cdot \frac{d}{D} = \frac{\lambda}{3}$

$$\Delta\phi = \frac{2\pi}{\lambda} \cdot \Delta p = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{3} = \frac{2\pi}{3}$$

Intensity at point $P = I_0 \cos^2 \Delta\phi$

$$= I_0\left[\cos\frac{2\pi}{3}\right]^2 = I_0\left(\frac{1}{2}\right)^2 = \frac{I_0}{4}$$

34. Given that distance between the two slits, $d = 0.15$ mm

Wavelength of monochromatic light, $\lambda = 450$ nm

Distance between the screen and slits, $D = 1$ m

(a) (i) Distance of n^{th} bright fringe from central maximum $= \frac{n\lambda D}{d}$

$$= 2 \times \frac{450 \times 10^{-9} \times 1}{0.15 \times 10^{-3}} \quad [\because n = 2]$$

$= 6 \times 10^{-3}$ m = 6 mm

(ii) Distance of n^{th} dark fringe from central maximum

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

$$= (2 \times 2 - 1) \times \frac{450 \times 10^{-9} \times 1}{2 \times 0.15 \times 10^{-3}} \quad [\because n = 2]$$

$$= \frac{3}{2} \times 3 \times 10^{-3} = 4.5 \text{ mm}$$

(b) Since, width of bright or dark fringes is given by $\beta = \frac{\lambda D}{d}$,

Thus when screen is moved away, *D* increases and hence fringe width increases.

35. For least distance of coincidence of fringes, there must be a difference of 1 in order of λ_1 and λ_2.

As $\lambda_1 > \lambda_2$, $n_1 < n_2$

If $n_1 = n$, $n_2 = n + 1$

$\therefore$ $(y_n)_{\lambda_1} = (y_{n+1})_{\lambda_2} \Rightarrow \frac{nD\lambda_1}{d} = \frac{(n+1)D\lambda_2}{d}$

$\Rightarrow$ $n\lambda_1 = (n+1)\lambda_2$

$\Rightarrow$ $n = \frac{\lambda_2}{\lambda_1 - \lambda_2} = \frac{520 \text{ nm}}{(650 - 520) \text{ nm}}$ or $n = \frac{520}{130} = 4$

$= 2.6 \times 10^{-3}$ m = 2.6 mm

Here $D = 120$ cm = 1.20 m

and $d = 2$ mm = 2×10^{-3} m

$\therefore$ Least distance,

$$y_{\min} = \frac{nD\lambda_1}{d} = \frac{4 \times 1.2 \times 650 \times 10^{-9}}{2 \times 10^{-3}} \text{ m}$$

$= 1.56 \times 10^{-3}$ m = 1.56 mm

36. Here $d = 4.0$ mm = 4×10^{-3} m, $D = 1.0$ m

For wavelength λ_A = 600 nm = 600×10^{-9} m = 6×10^{-7} m

For wavelength λ_B = 450 nm = 450×10^{-9} m = 4.5×10^{-7} m

As $\lambda_A = \lambda_B$, $n_A = n_B$

If $n_A = n$ then $n_B = n + 1$

$\therefore$ $(y_n)\lambda_A = (y_{n+1})\lambda_B$

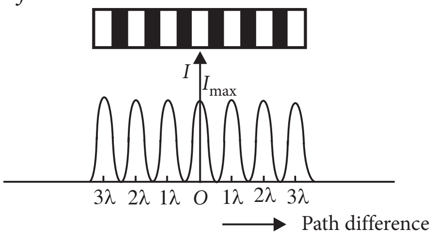
$\Rightarrow$ $n\lambda_A = (n+1)\lambda_B$

or, $n = \frac{\lambda_B}{\lambda_A - \lambda_B} = \frac{450}{150} = 3$

$\therefore$ Least distance from central maxima,

$$\lambda_{min} = \frac{3\times1\times600\times10^{-9}}{4\times10^{-3}} = 0.45\times10^{-3}\text{ m} = 0.45\text{ mm}$$

37. *Refer to answer 28.*



38. (a) *Refer to answer 28.*

(b) $\beta = \dfrac{\lambda D}{d}$

(i) On increasing the width of slit *d*, the fringe width decreases.
(ii) On replacing monochromatic light with white light, the fringes of all colours will be overlapping in interference pattern.

39. (a) (i) Two independent monochromatic sources cannot produce sustained interference pattern because the phase difference between the light waves from two independent sources keeps on changing continuously.
(ii) *Refer to answer 28.*
(b) *Refer to answer 31(b).*

40. (a) *(i) Refer to answer 32(i).*
(ii) Refer to answer 26(ii).
(b) We have

$$\frac{I_{max}}{I_{min}} = \frac{(a_1+a_2)^2}{(a_1-a_2)^2} = \frac{25}{9}$$

$$\therefore \quad \frac{a_1}{a_2} = \frac{4}{1}$$

$$\therefore \quad \frac{w_1}{w_2} = \frac{I_1}{I_2} = \frac{(a_1)^2}{(a_2)^2} = \frac{16}{1}$$

41. (a) *Refer to answer 28*
(b) The two bright fringes will coincide at least distance *x* from the central maximum if,

$$x = n\lambda_1\frac{D}{d} = (n+1)\,\lambda_2\frac{D}{d}$$

or $n\lambda_1 = (n+1)\lambda_2$
or $n\times 800 = (n+1)\times 600$
or $4n = 3n + 3$ or $n = 3$

$$\therefore \quad x = \frac{3D\lambda_1}{d} = \frac{3\times1.4\times800\times10^{-9}}{0.28\times10^{-3}}$$

$= 12\times10^{-3}\text{m} = 12$ mm

42. (a) (i) Fringe width $(\beta) = \dfrac{\lambda D}{d}$
If *d* decreases then β increases.
(ii) For interference fringe, the condition is $\dfrac{s}{D} < \dfrac{\lambda}{d}$
where s = size of source, D = distance of source from slits.
If the source slit width increases, fringe pattern gets less sharp or faint.
When the source slit is made wide which does not fullfil the above condition and interference pattern not visible.
(iii) The central fringes are white. On the either side of the central white fringe the coloured bands (few coloured maxima and minima) will appear. This is because fringes of different colours overlap.
(b) *Refer to answer 33.*

43. (a) Coherent sources are necessary to produce sustained interference pattern. Otherwise the phase difference between the two interfering waves will change rapidly and the interference pattern will be lost.
(b) *Refer to answer 28.*
(c) As $\lambda' = \dfrac{\lambda}{\mu}$, so on immersing the apparatus in water, wavelength λ of light decreases and hence fringe width β also decreases.

44. Here $d = 2\text{ mm} = 2\times10^{-3}$ m
$D = 140\text{ cm} = 1.40$ m
$\lambda = 600\text{ nm} = 600\times10^{-9} = 6\times10^{-7}$ m
Position of bright fringes is given by

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

$\therefore$ Distance of the third bright fringe is

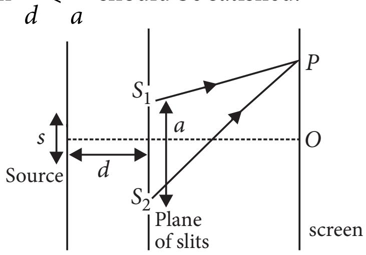
$$x_3 = n\lambda\frac{D}{d} = 3\times6\times10^{-7}\times\frac{1.40}{2\times10^{-3}}$$

$= 12.6\times10^{-4} = 1.26\times10^{-3}$ m $= 1.26$ mm
For $\lambda = 480\text{ nm} = 480\times10^{-9}\text{ m} = 4.8\times10^{-7}$ m
$\therefore$ Distance of the third bright fringe is

$$x_3 = 3\lambda\frac{D}{d} = 3\times4.8\times10^{-7}\times\frac{1.40}{2\times10^{-3}}$$

$= 10.08 \times 10^{-4} = 1.008 \times 10^{-3}$ m
$= 1.01 \times 10^{-3}$ m = 1.01 mm
$\therefore$ Shift in the position of the third bright fringe
= 1.26 – 1.01 = 0.25 mm

45. (a) The sources of light, which emit continuous light waves of the same wavelength, same frequency and in same phase are called coherent sources of light.
Interference pattern is not obtained when slits are illuminated through different source of light. This is because phase difference between the light waves emitted from two different sodium lamps (source) will change continuously.
(b) *Refer to answer 26(ii).*
(c) For interference fringes to be seen distinctly the condition $\frac{s}{d} < \frac{\lambda}{a}$ should be satisfied.



46. (i) *Refer to answer 45(a).*
In everyday life we see colours by a thin film of oil spreading out on water surface. This is the result of interference of light.
(ii) Given : d = 0.03 cm, D = 1.5 m
y_4 = 1 cm
Formula : $y_n = \frac{n\lambda D}{d}$ $(\because n = 4)$

$$\lambda = \frac{y_n d}{nD} = \frac{10^{-2} \times 3 \times 10^{-4}}{4 \times 1.5} = 5 \times 10^{-7} \text{ m}$$

$\lambda = 5 \times 10^{-7}$ m

47. *Refer to answer 45(a)*

48. In a single slit diffraction separation between fringes $\theta \propto \frac{n\lambda}{a}$
So, there is no effects on angular separation 2θ by changing of the distance of separation 'D' between slit and the screen.

49. Angular width of central maxima is given by
$$2\theta = \frac{2\lambda}{a}$$
Since $\lambda_r > \lambda_b$. Therefore, width of central maxima of red light is greater than the width of central maxima of blue light.

50. Position of first minimum in diffraction pattern
$$y = \frac{D\lambda}{a}$$
So, slit width $a = \frac{D\lambda}{y} = \frac{1 \times 500 \times 10^{-9}}{2.5 \times 10^{-3}} = 2 \times 10^{-4}$ m

51. (i) Here $a = 1 \times 10^{-4}$ m, D = 1.5 m
λ = 6000 Å $= 6000 \times 10^{-10}$ m
The distance between the two dark bands on each side of central band is equal to width of the central bright band, *i.e.,* $\frac{2D\lambda}{a}$

$$= \frac{2 \times 1.5 \times 6000 \times 10^{-10}}{1 \times 10^{-4}} = 18 \text{ mm}$$

(ii) Angular spread $= \frac{\lambda}{a} = \frac{6000 \times 10^{-10}}{1 \times 10^{-4}}$
$= 6 \times 10^{-3}$ m = 6 mm

52. Resolving power $= \frac{A}{1.22\,\lambda}$
where A is the aperture of the objective lens of the telescope.
$$\therefore \frac{(R.P)_1}{(R.P)_2} = \frac{A_1}{A_2}$$
The telescope with objective of aperture A_1 should be prefered due to following reasons
(i) It gives a better resolution.
(ii) It have a high light gathering power.

53. *Refer to answer 51(i).*

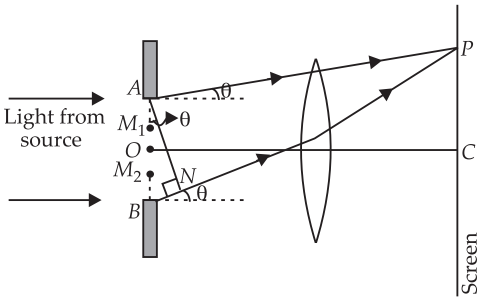
54. Difference between interference and diffraction: Interference is due to superposition of two distinct waves coming from two coherent sources and diffraction is produced as a result of superposition of the secondary wavelets coming from different parts of the same wavefront.
Numerical : Here $\lambda = 600$ nm $= 600 \times 10^{-9} = 6 \times 10^{-7}$ m
D =0.8 m, x = 15 mm $= 15 \times 10^{-3}$ m, $n = 2$, a = ?
For second order maxima, $\theta = \frac{5\lambda}{2a}$
The distance of second order maxima from centre of screen,
$$x = \theta . D = \frac{5D\lambda}{2a} \Rightarrow a = \frac{5D\lambda}{2x}$$
$$= \frac{5 \times 0.8 \times 6 \times 10^{-7}}{2 \times 15 \times 10^{-3}} = 8 \times 10^{-5} \text{ m} = 0.08 \text{ mm}$$

55. Resolving power of a microscope is the reciprocal of the minimum separation of two points seen as a distinct through microscpoe. Resolving power $= \frac{1}{d_{min}} = \frac{2\mu \sin\beta}{\lambda}$.

(i) As resolving power $\propto \mu$, on increasing the refractive index of the medium between the object and objective lens, resolving power also increases.

(ii) As resolving power $\propto \frac{1}{\lambda}$, on increasing the wavelength of the radiation, resolving power will decreases.

56. (i)

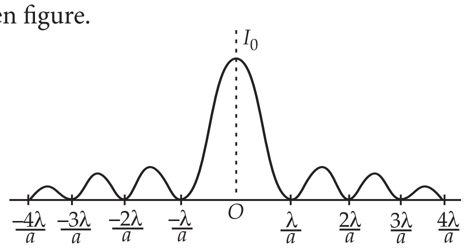


Consider a parallel beam of monochromatic light is incident normally on a single slit AB of width a as shown in the figure. According to Huygens principle every point of slit acts as a source of secondary wavelets spreading in all directions. The mid point of the slit is O. A straight line through O perpendicular to the slit plane meets the screen at C. At the central point C on the screen, the angle θ is zero. All path differences are zero and hence all the parts of the slit contribute in phase. This gives maximum intensity at C.
Consider a point P on the screen.
The observation point is now taken at P.
Secondary minima : Now we divide the slit into two equal haves AO and OB, each of width $\frac{a}{2}$. For every point, M_1 in AO, there is a corresponding point M_2 in OB, such that $M_1M_2 = \frac{a}{2}$. The path difference between waves arriving at P and starting from M_1 and M_2 will be $\frac{a}{2}\sin\theta = \frac{\lambda}{2}$.
$a\sin\theta = \lambda$

In general, for secondary minima
$a\sin\theta = n\lambda$ where $n = \pm1, \pm2, \pm3$......

Secondary maxima : Similarly it can be shown that for secondary maxima
$a\sin\theta = (2n+1)\frac{\lambda}{2}$ where $n = \pm1, \pm2$........

The intensity pattern on the screen is shown in the given figure.



Width of central maximum $= \frac{2D\lambda}{a}$,

(ii) The reason is that the intensity of the central maximum is due to the constructive interference of wavelets from all parts of the slit, the first secondary maximum is due to the contribution of wavelets from one third part of the slit (wavelets from remaining two parts interfere destructively), the second secondary maximum is due to the contribution of wavelets from the one fifth part only (the remaining four parts interfere destructively) and so on. Hence the intensity of secondary maximum decreases with the increase in the order n of the maximum.

57. Given that: Wavelength of the light beam,
$\lambda_1 = 590$ nm $= 5.9 \times 10^{-7}$ m
Wavelength of another light beam,
$\lambda_2 = 596$ nm $= 5.96 \times 10^{-7}$ m
Distance of the slits from the screen $= D = 1.5$ m
Slits width $= a = 2 \times 10^{-4}$ m
For the first secondary maxima,

$$\sin\theta = \frac{3\lambda_1}{2a} = \frac{x_1}{D}$$

$$x_1 = \frac{3\lambda_1 D}{2a} \text{ and } x_2 = \frac{3\lambda_2 D}{2a}$$

$\therefore$ Separation between the positions of first secondary maxima of two sodium lines,

$$x_2 - x_1 = \frac{3D}{2a}(\lambda_2 - \lambda_1)$$

$$= \frac{3\times1.5}{2\times2\times10^{-4}}(5.96\times10^{-7} - 5.9\times10^{-7})$$

$= 6.75 \times 10^{-5}$ m

58. *Refer to answer 56(i).*
When width of slit (a) is doubled, central maximum width is halved. Its area becomes $(1/4)^{th}$. Hence intensity of central diffraction band becomes 4 times.

59. The width of central maximum is given by

$$\beta_0 = \frac{2D\lambda}{a}$$

(a) If width of slit is reduced to half then the size of central maxima will become double.

(b) If width of slit is reduced to half its original width then the intensity of central maximum will be one-fourth.

60. (i) Resolving power of a microscope is defined as the reciprocal of the least separation between two closed object, so that they appear just separated, when seen though microscope.

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

(ii) It can be increased with decrease in value of wavelength and with increase in the value of refractive index.

61. Resolving power of an optical telescope will increase as the wavelength decreases due to light passing though higher refractive index.

62. (a) The angular width of central maximum is given by

$$2\theta_0 = \frac{2\lambda}{a}, \quad \text{...(i)}$$

where the letters have their usual meanings.

(i) Effect of slit width : From the equations (i), it follows that $\beta_0 \propto \frac{1}{a}$. Therefore, as the slit width is increased, the width of the central maximum will decrease.

(ii) Effect of distance between slit and screen (D) : From the equation (i), it follows that $2\theta_0$ is independent of D. So the angular width will remain same whatever the value of D.

(b) Difference between interference and diffraction

Experiment to observe diffraction pattern

Interference	**Diffraction**
1. Interference is caused by superposition two waves starting from two coherent sources.	1. Diffraction is caused by superposition of a number of waves starting from the slit.
2. All bright and dark fringes are of equal width.	2. Width of central bright fringe is double of all other maxima.
3. All bright fringes are of same intensity.	3. Intensity of bright fringes decreases sharply as we move away from central bright fringe.
4. Dark Fringes are perfectly dark.	4. Dark fringes are not perfectly dark.

63. *Refer to answer 60(i).*

(i) When wavelength λ decreases, resolving power increases.

(ii) When diameter of objective lens decreases, θ decreases; so resolving power decreases.

64. (a) Given $\lambda = 500$ nm $= 5 \times 10^{-7}$ m, $D = 1$ m

If a is width of slit, then for first minimum

$$\sin\theta_1 = \frac{\lambda}{a}$$

For small θ_1, $\sin\theta_1 = \frac{y_1}{D}$

$$\therefore \quad \frac{y_1}{D} = \frac{\lambda}{a}$$

$y_1 = 2.5$ mm $= 2.5 \times 10^{-3}$ m

$$\therefore \quad a = \frac{\lambda D}{y_1} = \frac{5\times10^{-7}\times1}{2.5\times10^{-3}} = 2\times10^{-4}\,\text{m} = 0.2\text{ mm}$$

(b) Position of n^{th} maximum, $y_n = \left(n + \frac{1}{2}\right)\frac{D\lambda}{a}$

For second maximum $n = 2$

$$\therefore \quad (y_2)_{\max} = \left(2 + \frac{1}{2}\right)\frac{1\times5\times10^{-7}}{2.5\times10^{-3}}$$

$$= 5\times10^{-4}\,\text{m} = 0.5\text{ mm}$$

(c) Width of central maximum, $\left(= \frac{2D\lambda}{a}\right)$

= Separation between first minima on either side of centre of screen

= 2.5 + 2.5 = 5 mm

65. (i) The bright spot is produced due to constructive interference of waves diffracted from the edge of the circular obstacle.

(ii) *Refer to answer 62(b).*

66. (a) (i) For first minimum of diffraction pattern

$d \sin\theta = n\lambda$

or $d \sin\theta = \lambda$ $[n = 1]$

or $d \sin 30° = 650 \times 10^{-9}$ m

or $d \times \frac{1}{2} = 650 \times 10^{-9}$ m

or $d = 1300 \times 10^{-9}$ m $= 1.3 \times 10^{-6}$ m

(ii) For first maximum of diffraction pattern

$$d\sin\theta = (2n+1)\frac{\lambda}{2}$$

or $d\sin 30° = (2\times1+1)\times\dfrac{650\times10^{-9}}{2}$ $[n=1]$

or $d\times\dfrac{1}{2} = 3\times325\times10^{-9}\,\text{m}$

or $d = 1950\times10^{-9}\,\text{m} = 1.95\times10^{-6}\,\text{m}$

(b) Because wavelets from the lesser and lesser part of slit will produce constructive interference in the secondary maxima.

67. Resolving power of an astronomical telescope is the reciprocal of smallest angular separation between two distant objects whose images can be just resolved by it.

$$\text{Resolving power} = \frac{1}{\alpha_{min}} = \frac{D}{1.22\lambda}$$

(i) As resolving power $\propto D$, on increasing the aperture of the objective lens, resolving power also increases.

(ii) As resolving power $\propto \dfrac{1}{\lambda}$, so on increasing the wavelength of the light used, resolving power decreases.

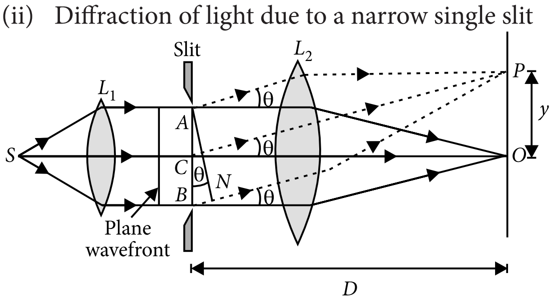
68. *Refer to answer 62(b).*

69. (i) Essential conditions for diffraction of light.

(a) Source of light should be monochromatic.

(b) Wavelength of the light used should be comparable to the size of the obstacle.

(ii) Diffraction of light due to a narrow single slit



Consider a set of parallel rays from a lens L_1 falling on a slit, form a plane wavefront. According to Huygens principle, each point on the unblocked point of plane wavefront AB sends out secondary wavelets in all directions. The secondary waves from points equidistant from the centre C of the slit lying in the portion CA and CB of the wavefront travel the same distance in reaching at O and hence the path difference between them is zero. These secondary waves reinforce each other, resulting maximum intensity at point O.

Position of secondary minima : The secondary waves travelling in the direction making an angle θ with CO, will reach a point P on the screen. The intensity at P will depend on the path difference between the secondary waves emitted from the corresponding points of the wavefront. The wavelets from points A and B will have a path difference equal to BN. If this path difference is λ, then P will be a point of minimum intensity. This is because the whole wavefront can be considered to be divided into two equal halves CA and CB. If the path difference between secondary waves from A and B is λ, then the path difference between secondary waves from A and C will be $\lambda/2$ and also the path difference between secondary waves from B and C will again be $\lambda/2$. Also for every point in the upper half AC, there is a corresponding point in the lower half CB for which the path difference between secondary waves reaching P is $\lambda/2$. Thus, at P destructive interference will take place.

From the right-angled ΔANB given in figure

$BN = AB\sin\theta$

$BN = a\sin\theta$

Suppose $BN = \lambda$ and $\theta = \theta_1$

$\therefore\ \lambda = a\sin\theta_1$

$$\sin\theta_1 = \frac{\lambda}{a}$$

Such a point on the screen will be the position of the first secondary minimum.

If $BN = 2\lambda$ and $\theta = \theta_2$, then,

$2\lambda = a\sin\theta_2$

$$\sin\theta_2 = \frac{2\lambda}{a}$$

Such a point on the screen will be the position of the second secondary minimum.

In general, for n^{th} minimum at point P.

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

For small $\theta_n, \theta_n = \dfrac{n\lambda}{a}$ ...(i)

Position of secondary maxima :

If any other P' is such that path difference at point is given by

$$a\sin\theta = \frac{3\lambda}{2}$$

Then P_1 will be position of first secondary maximum. Here, we can consider the wavefront to be divided into three equal parts, so that the path difference between secondary waves from corresponding points in the 1st two parts will be $\lambda/2$. This will give rise to destructive interference. However, the secondary waves from the third part remain unused and therefore, they will reinforce each other and produce first secondary maximum.

Similarly if the path difference at that points given by

$$a\sin\theta_5 = \frac{5\lambda}{2}$$

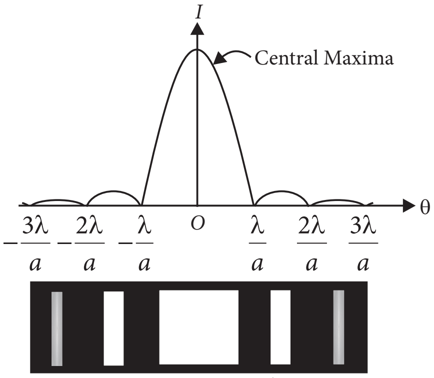
We get second secondary maximum of lower intensity.

In general, for n^{th} secondary maximum, we have

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

For small $\theta_n, \theta_n = (2n+1)\frac{\lambda}{2a}$

The diffraction pattern on the screen is shown below along with intensity distribution of fringes



(iii) If y_n is the distance of the n^{th} minimum from the centre of the screen, then from right-angled ΔCOP

$$\tan\theta_n = \frac{OP}{CO}$$

$$\tan\theta_n = \frac{y_n}{D} \quad \text{...(ii)}$$

In case θ_n is small, $\sin\theta_n \approx \tan\theta_n$

$\therefore$ From equations (i) and (ii), we get

$$\frac{y_n}{D} = \frac{n\lambda}{a}$$

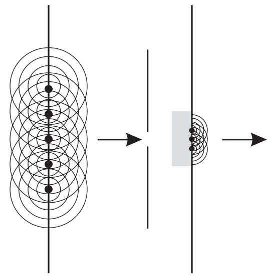
$$y_n = \frac{nD\lambda}{a}$$

Width of the central maximum,

$$2y_1 = \frac{2D\lambda}{a}$$

(iv) The size of central band reduces by half according to the relation $\frac{\lambda}{a}$. Intensity of the central band will be four times as intensity is proportional to square of slit width.

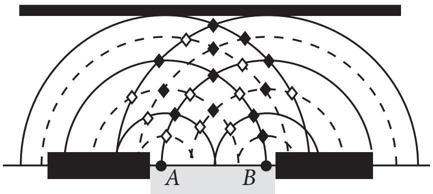
70. (a) Waves diffract when they encounter obstacles. A wavefront impinging on a barrier with a slit in it, only the points on the wavefront that move into the slit can continue emitting forward moving waves but because a lot of the wavefront has been blocked by the barrier, the points on the edges of the hole emit waves that bend round the edges.



Before the wavefront strikes the barrier the wavefront generates another forward moving wavefront. Once the barrier blocks most of the wavefront the forward moving wavefront bends around the slit because the secondary waves they would need to interfere with to create a straight wavefront have been blocked by the barrier.

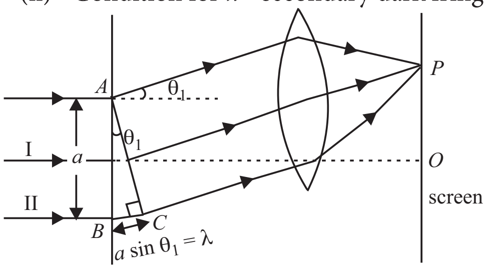
According to Huygen's principle, each point on the wavefront moving through the slit acts like a point source. We can think about some of the effect of this if we analyse what happens when two point sources are close together and emit wavefronts with the same wavelength and frequency. These two point sources represent the point sources on the two edges of the slit and we can call the source A and source B as shown in the figure.

Each point source emits wavefronts from the edge of the slit. In the diagram we show a series of wavefronts emitted from each point source. The continuous lines show peaks in the waves emitted by the point sources and the dotted lines represent troughs. We label the places where constructive interference (peak meets a peak or trough meets a trough) takes place with a solid diamond and places where destructive interference (trough meets a peak) takes place with a hollow diamond. When the wavefronts hit a barrier there will be places on the barrier where constructive interference takes place and places where destructive interference happens.



The measurable effect of the constructive or destructive interference at a barrier depends on what type of waves we are dealing with.

(b) (ii) Condition for n^{th} secondary dark fringe :



Light rays which on passing through the slit of width 'a' get diffracted by an angle θ_1, such that the path difference between extreme rays on emerging from slit is $a \sin\theta_1 = \lambda$

Then the waves from first half and second half of slit have a path difference of $\lambda/2$, so they interfere destructively at point P on screen, forming first secondary dark fringe.

Thus condition for first secondary dark fringe or first secondary minimum is

$$\sin\theta_1 = \frac{\lambda}{a}$$

Similarly, condition for n^{th} secondary dark fringe or n^{th} secondary minimum is

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

where $n = 1, 2, 3, 4$,...........

Angular width of first diffraction fringe, $\theta_1 = \frac{\lambda}{a}$

Angular width of central maxima,

$$\theta_1 + \theta_1 = 2\theta_1 = 2\frac{\lambda}{a}$$

$\therefore$ $\theta = \theta_{1/2}$.

(c) On increasing the value of n, the part of slit contributing to the maxima decreases. Hence, the maxima become weaker.

71. *Refer to answer 69 (ii)*

(a) Width of the secondary maximum,

$$\beta = y_n - y_{n-1} = \frac{nD\lambda}{a} - \frac{(n-1)D\lambda}{a}$$

$$\beta = \frac{D\lambda}{a} \quad \text{...(i)}$$

$\therefore$ β is independent of n, all the secondary maxima are of the same width β.

If $BN = \frac{3\lambda}{2}$ and $\theta = \theta_1'$, from above equation, we have

$$\sin\theta_1' = \frac{3\lambda}{2a}$$

Such a point on the screen will be the position of the first secondary maximum.

Corresponding to path difference,

$BN = \frac{5\lambda}{2}$ and $\theta = \theta_2'$, the second secondary maximum is produced. In general, for the n^{th} maximum at point P,

$$\sin\theta_n' = \frac{(2n+1)\lambda}{2a} \quad \text{...(ii)}$$

If y'_n is the distance of n^{th} maximum from the centre of the screen, then the angular position of the n^{th} maximum is given by

$$\tan\theta_n' = \frac{y_n'}{D} \quad \text{...(iii)}$$

In case θ'_n is small,

$$\sin\theta_n' \approx \tan\theta_n'$$

$$\therefore \quad y_n' = \frac{(2n+1)D\lambda}{2a}$$

Width of the secondary minimum,

$$\beta' = \frac{D\lambda}{a} \quad \text{...(iv)}$$

Since β' is independent of n, all the secondary minima are of the same width β'.

(b) Here, $\lambda_1 = 590$ nm $= 590 \times 10^{-9}$ m, $\lambda_2 = 596$ nm $= 596 \times 10^{-9}$ m, $d = 2 \times 10^{-6}$ m, $D = 1.5$ m

Distance of first secondary maximum from the centre of the screen is

$$x = \frac{3}{2}\frac{\lambda D}{d}$$

For the two wavelengths,

$$x_1 = \frac{3}{2}\frac{D\lambda_1}{d} \text{ and } x_2 = \frac{3}{2}\frac{D\lambda_2}{d}$$

Spacing between the first two maximum of sodium lines,

$$x_2 - x_1 = \frac{3D}{2d}(\lambda_2 - \lambda_1)$$

$$= \frac{3\times1.5}{2\times2\times10^{-6}}(596\times10^{-9} - 590\times10^{-9})$$

$$= \frac{3\times1.5\times6\times10^{-3}}{4} = 6.75\times10^{-3}\text{ m} = 6.75 \text{ mm}$$

72. (a) *Refer to answer 62(b).*
(b) *Refer to answer 64(a).*

73. (a) *Refer to answer 69(ii).*
(b) (i) Effect of the width of the slit
For given monochromatic waves, if slit width is decreased, the fringe pattern becomes broader.

$$d.\frac{y_n}{D} = \left(n+\frac{1}{2}\right)\lambda \qquad \left[\theta = \frac{y_n}{D}\right]$$

$$\Rightarrow \quad d\cdot y_n = \text{constant} \Rightarrow y_n \propto \frac{1}{d}$$

(ii) If monochromatic source of light is replaced by white light, instead of white fringes we have few coloured fringes on either side of central white fringe, and then uniform illumination on the screen.
$y_n \propto \lambda$ (λ for VIBGYOR)

74. *Refer to answer 69(ii).*

75. (a) *Refer to answer 74(a)*

(b) (i) The width of central maximum, $\beta = \frac{2D\lambda}{d}$

(ii) The central bright spot is produced due to the constructive interference of waves diffracted from the edge of the circular obstacle.

76. (a) Diffraction takes place when dimensions of aperture or obstacle must be order of the wavelength of light.
(b) Width of central maximum
Refer to answers 69(ii) and (iii).
Given : $\lambda = 700 \times 10^{-9}$m
(i) Value of 'a' for position of first minimum at an angle of diffraction of 30°
$a \sin 30° = 700 \times 10^{-9}$

$$a = \frac{7\times10^{-7}}{1/2} = 14\times10^{-7} \text{ m}$$

(ii) Value of 'a' for position of first maximum at an angle of diffraction of 30°

$$a\sin\theta = \frac{(2n+1)\lambda}{2}, \; a\sin30° = \frac{3\lambda}{2}$$

$$a = \frac{3\lambda}{2\sin30°} = \frac{3\times7\times10^{-7}}{2\times(1/2)} = 21\times10^{-7} \text{ m}$$

77. (i) *Refer to answers 69(i) and (ii).*

78. *Refer to answer 62(b).*

79. As only the transverse wave can be polarized, that is why the heat waves which are transverse wave and have vibrations perpendicular to the direction of propagation can be polarized whereas the sound waves cannot be polarized being longitudinal in nature and having vibrations in the direction of propagation.

80. Polarised light : If the vibrations of a wave are present in one direction in a plane perpendicular to the direction of propagation, the waves is said to polarised.
Unpolarised light : A transverse wave in which vibrations are present in all direction in a plane perpendicular to direction of propagation, is said to be unpolarised.

81. Let I_0 be the intensity of original light

$$\theta = 45° \;\therefore\; \cos\theta = \cos45° = \frac{1}{\sqrt{2}}$$

$$\therefore \quad I = \frac{I_0}{2}\cos^2\theta \quad \therefore \quad I = \frac{I_0}{2}\left(\frac{1}{\sqrt{2}}\right)^2$$

$$\frac{I}{I_0} = \frac{1}{4} \Rightarrow I : I_0 = 1:4$$

82. Brewster's law : The tangent of the polarizing angle of incidence of a transparent medium is equal to its refractive index, *i.e.*, $\mu = \tan(i_p)$
Brewster angle, $i_p = \tan^{-1}(\mu)$

Refractive index of a transparent medium depends on the wavelength of light which falls on the medium. So a transparent medium has different values of refractive index for light of different colours. Hence the value of Brewster angle for a transparent medium is different for light of different colours.

83. Unpolarized light waves are those light waves whose planes of vibrations are randomly oriented about the direction of propagation of the wave.
Polarized light waves are those light waves in which planes of vibrations can occur in one particular plane only.
Yes, the intensity of polarized light emitted by a polaroid depends on its orientation. When polarized light is incident on a polaroid, the resultant intensity of light transmitted varies directly as the square of the

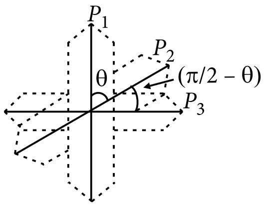
cosine of the angle between polarization direction of light and axis of the polaroid.
The intensity of light transmitted can be given using Malus law as

$$I = I_o \cos^2\theta = I_0 \cos^2 60° = \frac{I_0}{4}$$

Percentage of light is transmitted though the polaroid

sheet is $= \dfrac{I_0 - \dfrac{I_0}{4}}{I_0} \times 100 = 75\%$

84. Let I_0 be the intensity of polarised light after passing through the first polariser P_1. Then the intensity of light after passing through second polariser P_2 will be

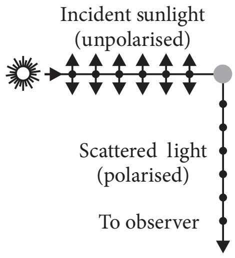


$I = I_0 \cos^2\theta$,
Let P_2 be the polaroid sheet rotated between P_1 and P_3. As the angle between polariser P_1 and P_3 is $\pi/2$ and angle between P_1 and P_2 is θ. So the angle between P_2 and P_3 is $(\pi/2 - \theta)$.
Outcoming intensity after P_3 is
$I' = I\cos^2(\pi/2 - \theta)$

$$I' = I_0 \cos^2\theta \sin^2\theta = \frac{I_0}{4}\sin^2 2\theta$$

Maximum outcoming intensity is received, when $\theta = \pi/4$

85. (a) *Refer to answer 80*
(b) The acceleration of the charges, in the scattering molecules, due to the electric field of the incident radiation, can be in two mutually perpendicular directions.



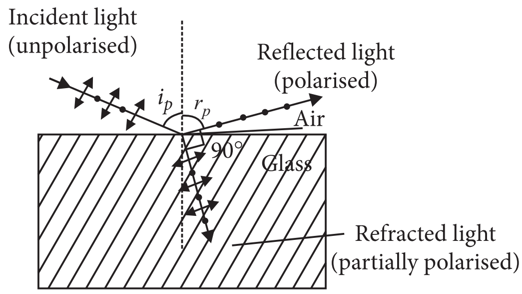
The observer, however, received the scattered light, corresponding to only one of these two sets of the accelerated charges.
This causes scattered light to get polarised.

86. When ordinary light is incident on the surface of a transparent medium, the reflected light is partially plane polarised. The extent of polarisation depends on the angle of incidence. For a particular angle of incidence, the reflected light is found to be completely polarised with its vibrations perpendicular to the plane of incidence.

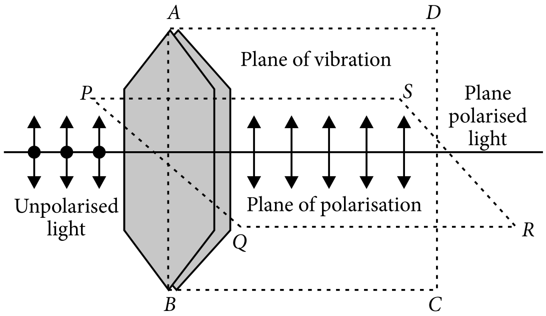
The angle of incidence at which a beam of unpolarised light falling on a transparent surface is reflected as a beam of completely plane polarised light is called polarising or Brewster angle. It is denoted by i_p.
Suppose i_p is the polarising angle of incidence and r_p, the corresponding angle of refraction. Then
$i_p + r_p = 90°$
$r_p = 90° - i_p$
From Snell's law, refractive index of the transparent medium is

$$\mu = \frac{\sin i_p}{\sin r_p} = \frac{\sin i_p}{\sin(90° - i_p)} = \frac{\sin i_p}{\cos i_p} \text{ or } \mu = \tan i_p$$

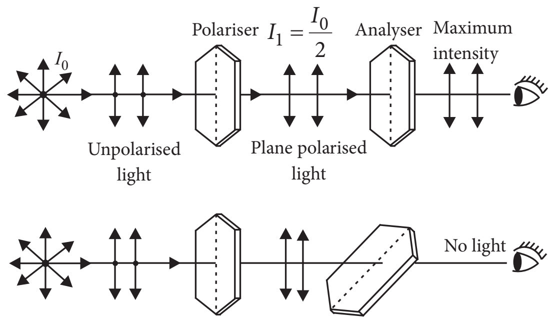
This relation is known as Brewster Law. The law states that the tangent of the polarising angle of incidence of transparents medium is equal to its refractive index.
At a particular angle of incidence, called Brewster angle, the reflected light is completely polarised as shown below :



87. A polaroid consists a material Tourmaline, which polarises light.
If an unpolarised light wave is incident on such a polaroid then the light wave get linearly polarised with the electric vector oscillating along a direction perpendicular to the aligned molecules.
Consider a beam of unpolarised light propagating along x-axis. The vibrations are confined in yz-plane as shown in given figure :



Light waves are transverse in nature. The electric field associated with a propagating light wave is always at right angles to the direction of propagation of the wave. If a light wave is incident on the polaroid, the electric vectors along the direction of the aligned molecules get absorbed.



Demonstration of polarisation of light

This experiment proves that light exhibits polarisation and hence light is transverse in nature. If the light was longitudinal in nature rotation of analyser would not have affected the outcoming intensity.

88. (a) A light which has vibrations in all directions in a plane perpendicular to the direction of propagation is said to be unpolarised light.

(b) Here $\theta = 60°$

The net intensity of transmitted polarised light is given by

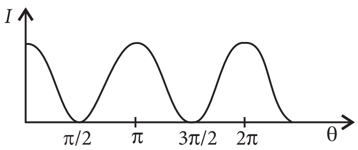
$$I = \frac{I_0}{2}\cos^2 60°$$

[$\frac{I_0}{2}$ = intensity of polarised light on passing though polariser]

$$I = \frac{I_0}{2}\left(\frac{1}{2}\right)^2 = \frac{1}{8}I_0$$

89. (i) Law of Malus states that when a beam of completely plane polarised light (I_0) is passed through analyser after polariser, the intensity I of outcoming transmitted light is proportional to square of the cosine of the angle 'θ' between the transmission axis of polariser and analyser. $I = I_0 \cos^2\theta$

(ii)



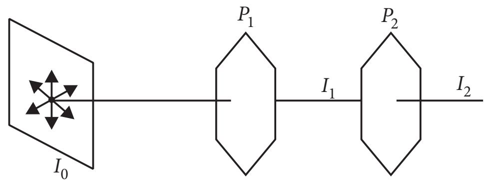
(iii) According to Brewster law, $\mu = \tan i_p$

$= \tan 60° = \sqrt{3} = 1.732$

90. When unpolarised light is made to pass through a tourmaline crystal, only those electric field vectors, parallel to its crystallographic axis emerge out of it. Thus the emerging light is plane polarised. Such a crystal is called polariser.

If the emergent plane polarised light is passed through another crystal called analyser with its plane of transmission normal to that of polariser then no light emerges from it has maximum intensity.

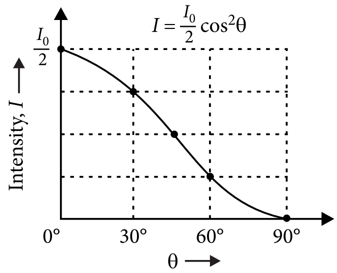
(i)



When P_1 and P_2 are parallel,

$$I_1 = \frac{I_0}{2}\ ;\ I_2 = I_1 = \frac{I_0}{2}$$

(ii) When P_1 is rotated by θ, without disturbing P_2. θ is angle between P_1 and P_2.



The intensity of light transmitted by P_2 varies as function of $\cos^2\theta$ as per relation :

$I_2 = I_1 \cos^2\theta$

$$I = \frac{I_0}{2}\cos^2\theta$$

I Versus θ graph for P_2 is shown in figure.

91. Sun glasses filled with polaroid sheets protect our eyes from glare. Polaroids reduce head light glare of motor car being driven at night. Polaroids are used in three dimensional pictures, *i.e.,* in holography.

(b) Let two polaroids P_1 and P_2 are placed in crossed positions. Let P_3 be the polaroid sheet placed between P_1 and P_2 making an angle θ with pass axis of P_1

If I_1 = intensity of polarised light after passing through P_1 then intensity of light after passing through P_3 will be

$I = I_1 \cos^2\theta$ ...(i)

Now angle between P_2 and P_3

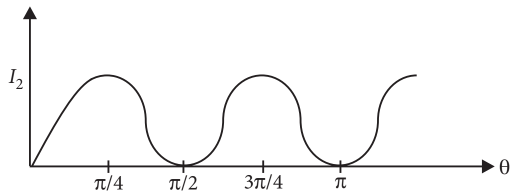
$= \left(\frac{\pi}{2} - \theta\right)$ [$\because$ P_1 and P_2 are in crossed position]

$\therefore$ Outcoming intensity after P_2 is,

$I_2 = I \cos^2 (90° - \theta)$

or $I_2 = I_1 \cos^2\theta \sin^2\theta$

$= I_1\left(\frac{1}{2}\sin 2\theta\right)^2$



92. *Refer to answer 90.*

(b) Intensity of light transmitted through $P_1 = I_0/2$

Intensity of light transmitted through

$P_3 = (I_0/2) \times \cos^2 30° = 3I_0/8$

Intensity of light transmitted through

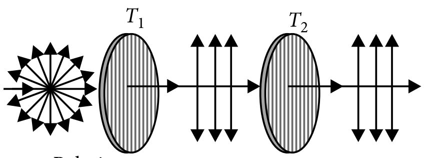
$$P_2 = \frac{3}{8} I_0 \cos^2 60° = \frac{3}{32} I_0$$

93. (a) *Refer to answer 85(b).*

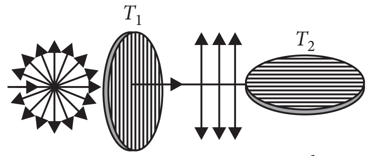
(b) When unpolarsied light is incident on a polaroid, then transmitted light will be polarised with half the intensity of unpolarised light. When polaroid is rotated, then the intensity of transmitted light remains same/unchanged/constant.

94. *Refer to answer 86.*

95. (a)



Polarizer (a) Analyser



Polarizer (b) Analyser

If two thin plates of tourmaline crystals T_1 and T_2 are rotated with the same angular velocity in the same direction as shown in the figure above, no change in intensity of transmitted light is observed.

The phenomenon can be explained only when we assume that light waves are transverse. Now the unpolarized light falling on T_1 has transverse vibrations of electric vector lying in all possible directions. The crystal T_1 allows only those vibrations to pass through it, which are parallel to its axis. When the crystal T_2 is, introduced with its axis kept parallel to the axis of T_1, the vibrations of electric vector transmitted by T_1 are also transmitted through T_2. However, when axis of T_2 is perpendicular to axis of T_1, vibrations of electric vector transmitted from T_1 are normal to the axis of T_2. Therefore, T_2 does not allow them to pass and hence eye receives no light.

Light coming out of the crystal T_1 is said to be polarized i.e. it has vibrations of electric vector which are restricted only in one direction (i.e. parallel to the optic axis of crystal T_1).

Since the intensity of polarized light on passing through a tourmaline crystal changes, with the relative orientation of its crystallographic axes with that of polariser, therefore, light must consist of transverse waves.

(b) The reflected ray is totally plane polarised, when reflected rays and refracted rays are perpendicular to each other.

96. Here $v = 2.25 \times 10^8$ m/s

Speed of light in vacuum, $c = 3 \times 10^8$ m/s

$$\mu = \frac{c}{v} = \frac{3\times 10^8}{2.25\times 10^8} = 1.33$$

(a) If C is the critical angle, then $\mu = \frac{1}{\sin C}$

$$1.33 = \frac{1}{\sin C}$$

$$\sin C = \frac{1}{1.33} = 0.75$$

$C = \sin^{-1} (0.75)$

(b) If i_β is the polarising angle
then, $\tan i_\beta = \mu$ or, $\tan i_\beta = 1.33$
$i_\beta = \tan^{-1}(1.33) \Rightarrow i_\beta = 53.06°$

97. (i) At $\theta = 90°$, the intensity of emergent light is zero.

(ii) Intensity of polarised light coming out from polariser $P_1 = \frac{I_0}{2}$

Intensity of light coming out from $P_3 = \left(\frac{I_0}{2}\right)\cos^2\beta$

Intensity of light coming out from

$$P_2 = \frac{I_0}{2}\cos^2\beta\cos^2(90-\beta)$$

$$= \frac{I_0}{2}\cdot\cos^2\beta\cdot\sin^2\beta$$

$$= \frac{I_0}{2}\left[\frac{(2\cos\beta\cdot\sin\beta)^2}{4}\right]$$

$$I = \frac{I_0}{8}(\sin 2\beta)^2$$

But it is given that intensity transmitted from P_2 is

$$I = \frac{I_0}{8}$$

So, $\frac{I_0}{8} = \frac{I_0}{8}(\sin 2\beta)^2$ or, $(\sin 2\beta)^2 = 1$

$$\sin 2\beta = \sin\frac{\pi}{2} \Rightarrow \beta = \frac{\pi}{4}$$

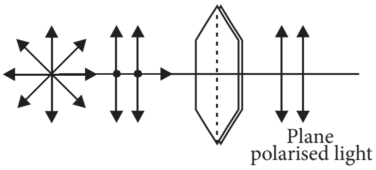
98. (a) *Refer to answer 85(b).*

(b) Intensity of the transmitted light from the system is

$$I = I_0\left[\frac{1}{2}\sin 2\theta\right]^2 = \frac{I_0}{4}(\sin 2\times 30°)^2$$

$$= \frac{I_0}{4}\times\frac{\sqrt{3}}{2}\times\frac{\sqrt{3}}{2} = \frac{I_0}{4}\times\frac{3}{4} = \frac{3I_0}{16}$$

99. When unpolarised light is made to pass through a polaroid, only those electric field vectors, parallel to its crystallographic axis emerge out of it. Thus the emerging light is plane polarised. Such a crystal is called polariser.



Demonstration of polarisation of light.

Let two polaroids P_1 and P_3 are placed in crossed positions.

Let P_2 be the polaroid sheet placed between P_1 and P_3 making an angle θ with pass axis of P_1.

If I_1 = intensity of polarised light after passing through P_1, then intensity of light after passing through P_2 will be

$$I_2 = I_1\cos^2\theta \quad \text{...(i)}$$

Now angle between P_2 and $P_3 = \left(\frac{\pi}{2}-\theta\right)$

[$\because$ P_1 and P_3 are in crossed position]

$\therefore$ Outcoming intensity after P_3 is

$$I_3 = I_2\cos^2\left(\frac{\pi}{2}-\theta\right)$$

$$I_3 = I_1\cos^2\theta\cdot\cos^2\left(\frac{\pi}{2}-\theta\right) \quad \text{[Using (i)]}$$

$$= I_1\cos^2\theta\,\sin^2\theta = I_1\left(\frac{1}{2}\sin 2\theta\right)^2$$

If I_0 = intensity of unpolarised light, then

$$I_1 = \frac{I_0}{2} \Rightarrow \therefore \quad I_3 = \frac{I_0}{2}\left(\frac{1}{2}\sin 2\theta\right)^2$$

(i) Maximum outcoming intensity is received when

$$\sin 2\theta = \frac{\pi}{2} \text{ or } \theta = \frac{\pi}{4}$$

$$\Rightarrow (I_3)_{max} = \frac{I_0}{2}\left(\frac{1}{2}\right)^2 = \frac{I_0}{8}$$

(ii) Minimum intensity, when $\sin 2\theta = 0$

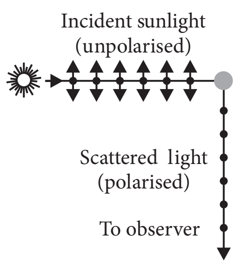
or, $\theta = \frac{\pi}{2} \Rightarrow (I_3)_{min} = 0$

100. *Refer to answer 86.*

101. *Refer to answers 80 and 86.*

102. (a) *Refer to answer 95(a).*
(b) *Refer to answer 86.*

103. (a) *Refer to answer 80*
(b) *Refer to answer 95(a).*
(c) When light from the sun travels through the earth's atmosphere, the different wavelengths get scattered from their path through different amounts obeying Rayleigh's law of scattering. Since the wave



length of the blue colour is approximately half the wavelength of red colour, the scattering of blue light is about 2^4 times. *i.e.* 16 times more than that of red light. Due to this blue colour predominates and the sky appears blue. Due to scattering blue light gets polarised. When this polarised light is passed though a Polaroid which is rotating. Intensity of transmitted light will rise and fall.

104. (a) *Refer to answer 95(a).*

(b) Intensity observed by observer $O_1 = \dfrac{I_0}{2}$

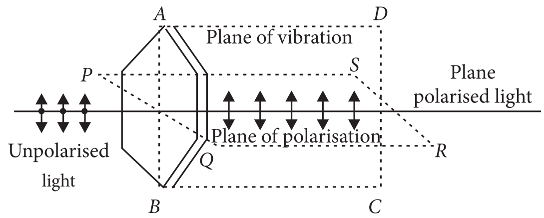
Intensity observed by observer

$$O_2 = \frac{I_0 \cos^2 60°}{2} = \frac{I_0}{2} \times \frac{1}{4} = \frac{I_0}{8}$$

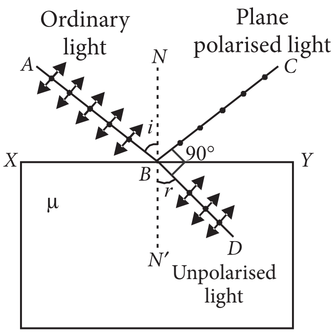
Intensity observed by observer O_3

$$= \frac{I_0}{8}\cos^2(90° - 60°) = \frac{I_0}{8}\sin^2 30° = \frac{I_0}{8} \times \left(\frac{1}{2}\right)^2 = \frac{I_0}{32}$$

105. (a) When unpolarised light falls on a polaroid, it lets only those of its electric vectors that are oscillating along a direction perpendicular to its aligned molecules to pass through it. The incident light thus gets linearly polarised.



Whenever unpolarised light is incident on a transparent surface, the reflected light gets partially or completely polarized. The reflected light gets completely polarized when the reflected and refracted light are perpendicular to each other.



(b) Let θ be the angle between the pass axis of A and C. Intensity of light passing through $A = \dfrac{I_0}{2}$

Intensity of light passing through $C = \left(\dfrac{I_0}{2}\right)\cos^2\theta$

Intensity of light passing through

$$B = \left(\frac{I_0}{2}\right)\cos^2\theta[\cos^2(90-\theta)]$$

$$= \left(\frac{I_0}{2}\right)\cdot(\cos\theta\cdot\sin\theta)^2 = \frac{I_0}{8} \text{ (Given)}$$

$\therefore$ $\sin 2\theta = 1$, $2\theta = 90°$ or, $\theta = 45°$

The third Polaroid is placed at $\theta = 45°$

106. (a) If the vibrations of a wave are present in just one direction in a plane perpendicular to the direction of propagation, the wave is said to be plane polarised light.

Let intensity of light incident on P_1 be I_0, then intensity of light after emerging from $P_1 = I_0/2$.

$\because$ Angle between P_1 and P_3 is 45°

Intensity of light on emerging from P_3 is

$$I_1 = \frac{I_0}{2}\cos^2 45° = \frac{I_0}{2} \times \frac{1}{2} = \frac{I_0}{4}$$

$\because$ Angle between P_3 and P_2 is also 45°

So intensity of finally emerging light from P_2 is

$$I = I_1 \cos^2 45° = \frac{I_0}{4} \times \frac{1}{2} = \frac{I_0}{8}$$

Assume polaroid (P_3) is further rotated by an angle θ.

So intensity of light on emerging from P_3 is

$$I_1 = \frac{I_0}{2}\cos^2(45° + \theta)$$

Angle between P_3 and P_2 is

$(90° - 45° - \theta°) = (45 - \theta)$

So intensity of finally emerging high from P_2.

$I = I_1 \cos^2(45° - \theta)$

$$I_1 = \frac{I_0}{2}\cos^2(45° + \theta)\cos^2(45 - \theta)$$

which is required relation between I and θ.

(b) Yes, the light incident on the rotating polaroid is unpolarised. On passing through polaroid it becomes plane polarised in the plane of transmission of polariod whatever the angle it makes with vertical. So, intensity of transmitted plane polarised light does not change on rotating the polariod.