Wave optics

Previous Years' CBSE Board Questions

10.3 Refraction and Reflection of Plane Waves using Huygens Principle

MCQ

1. According to Huygens principle, the amplitude of secondary wavelets is
   (a) equal in both the forward and the backward directions.
   (b) maximum in the forward direction and zero in the backward direction.
   (c) large in the forward direction and small in the backward direction.
   (d) small in the forward direction and large in the backward direction. *(2023)* R

2. A plane wavefront is incident on a concave mirror of radius of curvature R. The radius of the refractive wavefront will be
   (a) $2R$ (b) R (c) $\frac{R}{2}$ (d) $\frac{R}{4}$
   (2023) U

SA I (2 marks)

7. A plane wavefront is incident on a surface separating two media of refractive indices n_1 and n_2 ($> n_1$). With the help of a suitable diagram, explain its propagation from the rarer to denser medium. Hence, verify Snell's law. *(2022C)* An

8. A plane wavefront is propagating from a rarer into a denser medium. Use Huygens principle to show the refracted wavefront and verify Snell's law. *(Term II 2021-22)*

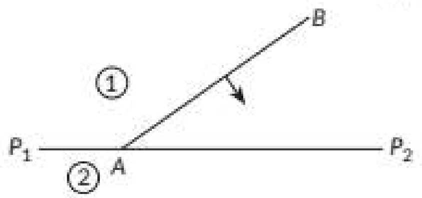
9. Define the term, "refractive index" of a medium. Verify Snell's law of refraction when a plane wavefront is propagating from a denser to a rarer medium. *(Delhi 2019)* Ap

10. Define the term wavefront. Using Huygens wave theory, verify the law of reflection. *(Delhi 2019)*

11. 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.

3. Define wavefront of a travelling wave. Using Huygens principle, obtain the law of refraction at a plane interface when light passes from a rarer to a denser medium. *(2020)*

4. Define the term 'wavefront of light'. A plane wave front *AB* propagating from denser medium (1) into a rarer medium (2) is incident on the surface P_1P_2 separating the two media as shown in figure.
Using Huygens' principle, draw the secondary wavelets and obtain the refracted wavefront in the diagram. *(2020)* An



SA II (3 marks)

5. A plane wave-front propagating in a medium of refractive index 'μ_1' is incident on a plane surface making an angle of incidence (*i*). It enters into a medium of refractive index μ_2 ($\mu_2 > \mu_1$).
Use Huygen's construction of secondary wavelets to trace the refracted wavefront. Hence, verify Snell's law of refraction. *(2023)* Ev

6. Using Huygen's construction, show how a plane wave is reflected from a surface. Hence verify the law of reflection. *(2023)*

LA (5 marks)

15. What is a wavefront? How does it propagate? Using Huygens' principle, explain reflection of a plane wavefront from a surface and verify the laws of reflection. *(2/5, 2020)*

OR

Define a wavefront. Using Huygen's principle verify the laws of reflection at a plane surface. *(2018)* Ap

16. Define wavefront. Use Huygen's principle to verify the laws of refraction. *(3/5, AI 2017)*

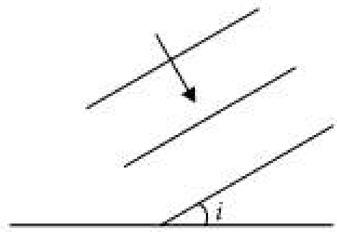
17. (a) Define a wavefront. How is it different from a ray?
(b) Depict the shape of a wavefront in each of the following cases.
(i) Light diverging from point source.
(ii) Light emerging out of a convex lens when a point source is placed at its focus.

(AI 2016)

12. 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 ? *(2/3 AI 2016)* An

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

14. 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)*



in a liquid of reference index μ, the new fringe width will be

(a) β (b) $\mu\beta$ (c) $\frac{\beta}{\mu}$ (d) $\frac{\beta}{\mu^2}$

(2023) R

VSA (1 mark)

22. Young's double slit experiment is performed by using green, red and blue monochromatic light sources, one at a time. The value of the fringe width will be maximum in case of ______ light. *(2020C)* R

23. In Young's double slit experiment, the path difference between two interfering waves at a point on the screen is $\frac{5\lambda}{2}$, λ being wavelength of the light used. The _____ dark fringe will lie at this point. *(2020)*

24. If one of the slits in Young's double slit experiment is fully closed, the new pattern has _____ central maximum in angular size. *(2020)* Ap

(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)* An

10.4 Coherent and Incoherent Addition of Waves

VSA (1 mark)

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

10.5 Interference of Light Waves and Young's Experiment

MCQ

19. In a Young's double-slit experiment, the screen is moved away from the plane of the slits. What will be its effect on the following?
    (i) Angular separation of the fringes.
    (ii) Fringe-width.
    (a) Both (i) and (ii) remain constant
    (b) (i) remains constant, but (ii) decreases
    (c) (i) remains constant, but (ii) increases
    (d) Both (i) and (ii) increase. *(2023)*

20. In an interference experiment, third bright fringe is obtained at a point on the screen with a light of 700 nm. What should be the wavelength of the light source in order to obtain the fifth bright fringe at the same point?
    (a) 420 nm (b) 750 nm
    (c) 630 nm (d) 500 nm *(2023)*

21. In a Young's double slit experiment,the fringe width is found to be β. If the entire apparatus is immersed

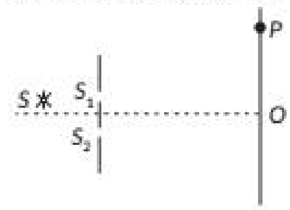
25. Write the conditions on path difference under which (i) constructive (ii) destructive interference occur in Young's double slit experiment. *(2020)* U

SA I (2 marks)

26. (a) In a Young's double slit experimental set-up, the intensity of the light waves from two coherent sources are in the ratio of 9 : 1. Find the ratio of intensity of bright and dark fringes in the interference pattern.
    (b) Monochromatic light of wavelength 600 nm is incident from air on a water surface. If the refractive index of water is $\frac{4}{3}$, then find the wavelength of the refracted light.
    (Term II 2021-22) Ap

27. In interference of light, write the expression for the intensity of resultant wave if I_0 is the intensity of light wave from each slit. Hence, obtain an expression for the intensity of resultant wave if the two sources are (i) incoherent, and (ii) coherent. *(2021C)*

28. The figure shows a modified Young's double slit experimental set-up. Here $SS_2 - SS_1 = \lambda/4$.

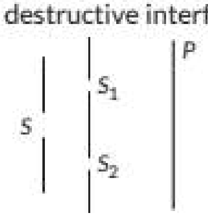


Write the condition for constructive interference. *(1/2, AI 2019)*

29. 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 λ/a. At the same angle of λ/a, we get a maximum for two narrow slits separated by a distance 'a'. Explain. *(Delhi 2014)* An

SA II (3 marks)

30. (i) In a Young's double-slit experiment $SS_2 - SS_1 = \frac{\lambda}{4}$, where S_1 and S_2 are the two slits as shown in the figure. Find the path difference $(S_2P - S_1P)$ for constructive and destructive interference at P.



(ii) What is the effect on the interference fringes in a Young's double-slit experiment, if the

36. (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)*

37. (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 $I = 4I_0\cos^2\phi/2$, where $I_0 = a^2$.

monochromatic source S is replaced by a source of white light? (2023)

31. A beam of light consisting of two wavelengths 600 nm and 500 nm is used in a Young's double slit experiment. The slit separation is 1.0 mm and the screen kept 0.60 m away from the plane of the slits. Calculate :
 (i) the distance of the second bright fringe from the central maximum for wavelength 500 nm, and
 (ii) the least distance from the central maximum where the bright fringes due to both the wavelengths coincide. (Term II 2021-22) Ap

32. Briefly explain how bright and dark fringes are formed on the screen in Young's double slit experiment. Hence derive the expression for the fringe width. (Term II 2021-22)

33. (a) If one of two identical slits producing interference in Young's experiment is covered with glass, so that the light intensity passing through it is reduced to 50%, find the ratio of the maximum and minimum intensity of the fringe in the interference pattern.
 (b) What kind of fringes do you expect to observe if white light is used instead of monochromatic light? (2018) Ap

34. 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) Ap

35. Why cannot two independent monochromatic sources produce sustained interference pattern? (1/3, Foreign 2015) U

 (b) Hence obtain the conditions for constructive and destructive interference. (AI 2014C) An

LA (5 marks)

38. 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) Ev

39. (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) An

40. (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)

41. 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. (2/5, AI 2014) An

 (ii) the screen is moved closer to the slit,
 (iii) the slit width is decreased?
 Justify your answer in each case. (Term II 2021-22) U

49. In single slit diffraction, explain why the maxima at $\theta = \left(n+\frac{1}{2}\right)\left(\frac{\lambda}{a}\right)$ becomes weaker and weaker as n increases. State two important difference between interference and diffraction pattern. (2022C)

10.6 Diffraction

VSA (1 mark)

42. In a single slit diffraction experiment, the phase difference between the waves originating from the two edges of the slit at the first minimum of the diffraction pattern is ________ rad. *(2020C)* U

SA I (2 marks)

43. How would the angular width of central maximum of diffraction pattern be affected when (i) width of the slit is decreased, and (ii) monochromatic light is replaced by polychromatic light? Justify your answer. *(2021C)* U

44. In a single slit diffraction experiment, the width of the slit is decreased. How will the (i) size (ii) intensity of the central bright band be affected. Justify your answer. *(2020)* Ap

45. Draw the intensity pattern for single slit diffraction and double slit interference. Hence, state two differences between interference and diffraction patterns. *(AI 2017)*

SA II (3 marks)

46. (i) In diffraction due to a single slit, the phase difference between light waves reaching a point on the screen is 5π. Explain whether a bright or a dark fringe will be formed at the point.
    (ii) What should the width (a) of a each slit be to obtain eight maxima of two double-slit patterns (slit separation *d*) within the central maximum of the single slit pattern?
    (iii) Draw the plot of intensity distribution in a diffraction pattern due to a single slit. *(2023)*

47. (i) State two conditions for two light sources to be coherent.
    (ii) Give two points of difference between an interference pattern due to a double slit and a diffraction pattern due to a single slit. *(2022)* R

48. In a diffraction pattern due to a single slit, how will be angular width of central maximum change, if
    (i) Orange light is used in place of green light,

50. (a) Explain the formation of the fringes due to diffraction at a single slit, when path difference of light waves from the ends of the slit on reaching a point on the screen is (i) λ, and (ii) $\frac{3\lambda}{2}$.
    (b) Show the intensity distribution in the fringes due to diffraction at a single slit. *(2021C)* U

51. How can you differentiate whether a pattern is produced by a single slit or double slits? Derive the expression for the angular position of (i) bright and (ii) dark fringes produced in a single slit diffraction. *(Term II 2021-22)*

52. A slit of width 0.6 mm is illuminated by a beam of light consisting of two wavelengths 600 nm and 480 nm. The diffraction pattern is observed on a screen 1.0 m from the slit. Find:
    (i) The distance of the second bright fringe from the central maximum pertaining to light of 600 nm.
    (ii) The least distance from the central maximum at which bright fringes due to both the wavelengths coincide. *(Term II 2021-22)*

53. In a single slit diffraction experiment, light of wavelength λ illuminates the slit of width '*a*' and the diffraction pattern is observed on a screen.
    (a) Show the intensity distribution in the pattern with the angular position θ
    (b) How are the intensity and angular width of central maxima affected when
    (i) width of slit is increased, and
    (ii) separation between slit and screen is decreased? *(2020)* Ev

54. (a) Explain how diffraction pattern is formed due to interference of secondary wavelengths of light waves from a slit.
    (b) Sodium light consists of two wavelengths, 5900 Å and 5960 Å. If a slit of width 2×10^{-4} m is illuminated by sodium light, find the separation between the first secondary maxima of the diffraction pattern of the two wavelengths on a screen placed 1.5 m away. *(2019C)* Ap

55. Describe any two characteristic features which distinguish between interference and diffraction phenomena. Derive the expression for the intensity

at a point of the interference pattern in Young's double slit experiment. (3/5, *Delhi 2019*)

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*)

LA (5 marks)

57. A parallel beam of light of wavelength 500 nm falls on a narrow slit and the resulting diffraction pattern is obtained on a screen 1 m away. If the first minimum is formed at a distance of 2.5 mm from the centre of the screen, find the (i) width of the slit, and (ii) distance of first secondary maximum from the centre of the screen. (3/5, 2020)

58. In the diffraction due to a single slit experiment, the aperture of the slit is 3 mm. If monochromatic light of wavelength 620 nm is incident normally on the slit, calculate the separation between first order minima and the 3rd order maxima on one side of the screen. The distance between the slit and the screen is 1.5 m. (2/5, *Delhi 2019*) Ap

59. (a) In a single slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band? Explain.
(b) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot in seen at the centre of the obstacle. Explain why. (3/5, 2018)

60. (a) Explain two features to distinguish between the interference pattern in Young's double slit experiment with the diffraction pattern obtained due to a single slit.
(b) A monochromatic light of wavelength 500 nm is incident normally on a single slit of width 0.2 mm to produce a diffraction pattern. Find the angular width of the central maximum

61. 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*) An

62. (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*) Ev

63. (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*)

64. (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*) Ap

65. (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.

obtained on the screen.

Estimate the number of fringes obtained in Young's double slit experiment with fringe width 0.5 mm, which can be accommodated within the region of total angular width of the central maximum due to single slit. *(Delhi 2017)* Ap

(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)* Ap

CBSE Sample Questions

10.3 Refraction and Reflection of Plane Wave Using Huygens Principle

SA II (3 marks)

1. Define wavefront. Draw the shape of refracted wavefront when the plane incident wave undergoes refraction from optically denser medium to rarer medium. Hence prove Snell's law of refraction. *(Term II 2021-22)* U

LA (5 marks)

2. (a) Define a wavefront.
   (b) Draw the diagram to show the shape of plane wavefront as they pass through (i) a thin prism and (ii) a thin convex lens. State the nature of refracted wave front.
   (c) Verify Snell's law of refraction using Huygens's principle. *(2020-21)*

10.5 Interference of Light Waves and Young's Experiment

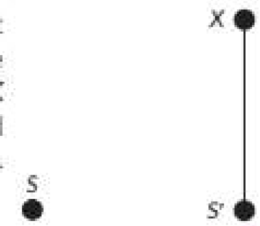
MCQ

3. In a Young's double slit experiment, the path difference at a certain point on the screen between two interfering waves is $\frac{1}{8}$th of the wavelength. The ratio of intensity at this point to that at the centre of a bright fringe is close to
   (a) 0.80 (b) 0.74
   (c) 0.94 (d) 0.85 *(2022-23)* Ap

4. Two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.
   (a) Both A and R are true and R is the correct explanation of A.
   (b) Both A and R are true and R is NOT the correct explanation of A.

SA I (2 marks)

5. Two waves from two coherent sources S and S' superimpose at X as shown in the figure. If X is a point on the second minima and $SX - S'X$ is 4.5 cm. Calculate the wavelength of the waves. *(2020-21)* Ap



10.6 Diffraction

SA I (2 marks)

6. Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through single slit. *(2020-21)* An

7. What should be the width of each slit to obtain n maxima of double slit pattern within the central maxima of single slit pattern? *(2020-21)*

SA II (3 marks)

8. A narrow slit is illuminated by a parallel beam of monochromatic light of wavelength λ equal to 6000 Å and the angular width of the central maximum in the resulting diffraction pattern is measured. When the slit is next illuminated by light of wavelength λ' the angular width decreases by 30%. Calculate the value of the wavelength λ'. *(2022-23)* Ap

9. (a) "If the slits in Young's double slit experiment are identical, then intensity at any point on the screen may vary between zero and four times to the intensity due to single slit".
   Justify the above statement through a relevant mathematical expression.
   (b) Draw the intensity distribution as function of phase angle when diffraction of light takes place through coherently illuminated single slit. *(Term II 2021-22)* An

(c) A is true but R is false.

(d) A is false and R is also false.

Assertion (A) : In an interference pattern observed in Young's double slit experiment, if the separation (d) between coherent sources as well as the distance (D) of the screen from the coherent sources both are reduced to $1/3^{rd}$, then new fringe width remains the same.

Reason (R) : Fringe width is proportional to (d/D).

(2022-23)

is made of a transparent material of refractive index $\frac{2}{\sqrt{3}}$. Trace the path of the ray as it passes through the prism. Calculate the angle of emergence and the angle of deviation.

(2022-23) Ap

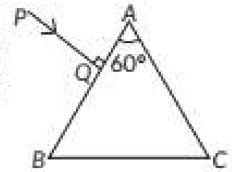
11. (a) Write two points of difference between an interference pattern and a diffraction pattern.

(b) (i) A ray of light incident on face AB of an equilateral glass prism, shows minimum

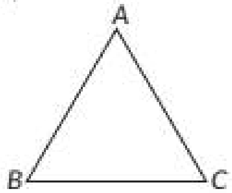
LA **(5 marks)**

10. (a) Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through a single slit. What is the width of the central maximum in comparison to that of a secondary maximum?

(b) A ray PQ is incident normally on the face AB of a triangular prism of refracting angle 60° as shown in figure. The prism



deviation of 30°. Calculate the speed of light through the prism.



(ii) Find the angle of incidence at face AB so that the emergent ray grazes along the face AC.

(2022-23)

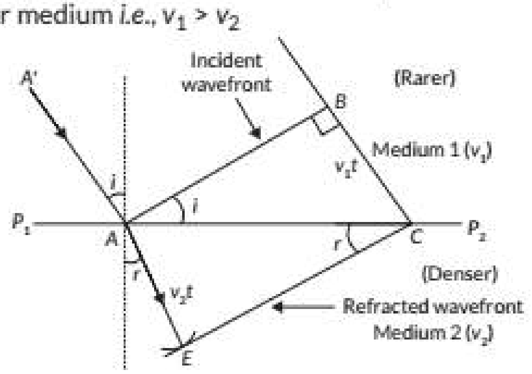
Detailed SOLUTIONS

Previous Years' CBSE Board Questions

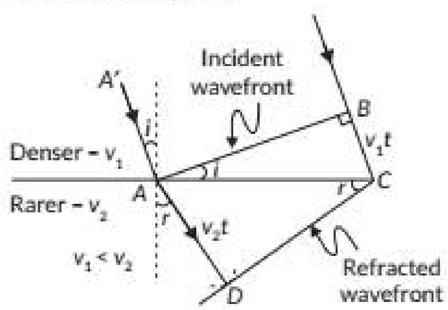
1. **(a):** According to Huygen's principle each point on the wavefront acts as a source of secondary wavelets and the amplitude of these secondary wavelets is equal in both the forward and backward directions.
The new wavefront is the tangential surface of all these secondary wavelets.

2. **(c):** If a plane wavefront is incident on a concave mirror, then the emergent wavefront will be spherical with centre of the wavefront at its focus.

3. A source of light sends the disturbance in all the directions and continuous locus of all the particles vibrating in same phase at any instant is called as wavefront.
Given figure shows the refraction of a plane wavefront at a rarer medium *i.e.*, $v_1 > v_2$



4. A source of light sends the disturbance in all the directions and continuous locus of all the particles vibrating in same phase at any instant is called as wavefront.
P_1P_2 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.

$\therefore \quad BC = v_1t \qquad$ [$\because$ distance = speed × time]

In order to determine the shape of the refracted wavefront, we draw a sphere of radius v_2t from the point A in the second medium (the speed of the wave in second medium is v_2).

Let CD represents a tangent plane drawn from the point

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,

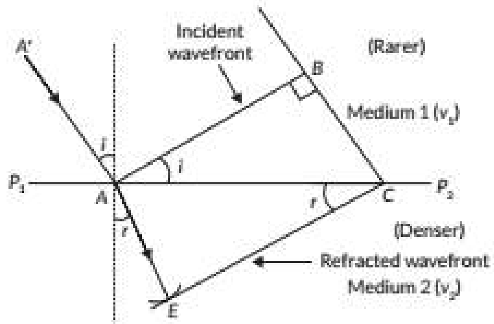
$$\sin \angle BAC = \sin i = \frac{BC}{AC}$$

From right ΔAEC, we have,

$$\sin \angle ECA = \sin r = \frac{AE}{AC}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AE} = \frac{v_1 t}{v_2 t} \text{ or } \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2 \quad \text{(a constant)}$$

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.



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.

$\therefore \quad BC = v_1 t \qquad$ [$\because$ 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

$AE = v_2 t$

$\therefore \quad CE$ 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.

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

If c represents the speed of light in vacuum, then

C. Then

$AE = v_2 t$

$\therefore \quad CD$ would represent the refracted wavefront.

Concept Applied

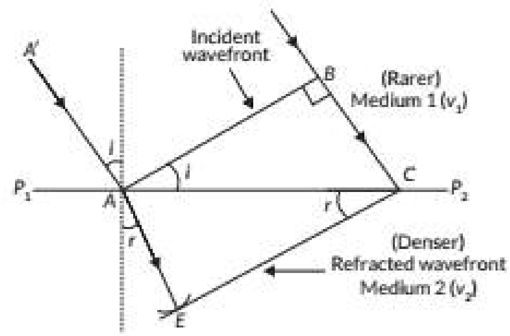
- Huygens' principle tells us that each point on a wavefront is a source of secondary waves called secondary wavelets. A surface touching these secondary wavelets tangentially in the forward direction at any instant gives the new (secondary) wavefront at that instant.

5. Snell's law of refraction : Let P_1P_2 represents the surface separating medium 1 and medium 2 as shown in figure.

This proves first law of reflection.

Also $\angle i$, $\angle r$ and normal all lie in the same plane. This gives second law of reflection.

7. Snell's law of refraction : Let P_1P_2 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.

$\therefore \quad BC = v_1 t \qquad$ [$\because$ 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

$AE = v_2 t$

$\therefore \quad CE$ would represent the refracted wavefront.

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

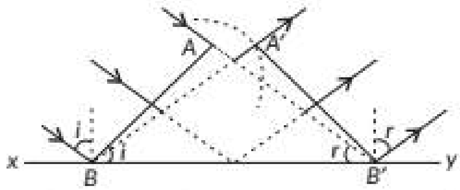
$\Rightarrow \quad v_1 = \frac{c}{\mu_1}$ and $v_2 = \frac{c}{\mu_2}$

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

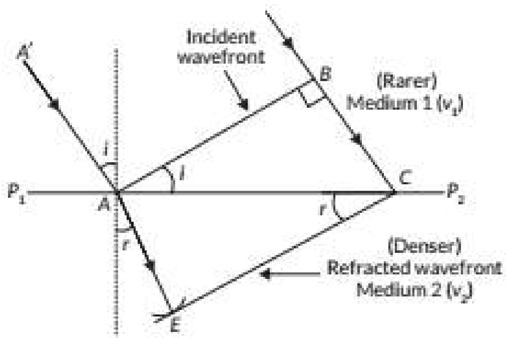
$\therefore \quad \frac{\sin i}{\sin r} = \frac{c/\mu_1}{c/\mu_2} \Rightarrow \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \Rightarrow \mu_1 \sin i = \mu_2 \sin r$

This is the Snell's law of refraction.

6. Let us consider a plane wavefront *AB* incident on the plane reflecting surface *xy*. The tangent *B'A'* represents 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 , $\angle i = \angle r$



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*.

$\therefore \quad BC = v_1 t \qquad [\because \text{distance} = \text{speed} \times \text{time}]$

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

In ΔABC and ΔAEC, we have

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

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

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

$\Rightarrow \quad v_1 = \frac{c}{\mu_1}$ 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.

8. Snell's law of refraction : Let P_1P_2 represents the surface separating medium 1 and medium 2 as 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, $\sin \angle DCA = \sin r = \frac{AD}{AC}$

$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t}$

or $\quad \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2 \qquad$ (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.

10. A source of light sends the disturbance in all the directions and continuous locus of all the particles vibrating in same phase at any instant is called as wavefront.

Laws of reflection by Huygens' principle :

Let us consider a plane wavefront *AB* incident on the plane reflecting surface *xy*. Incident rays are normal to

C. Then

$AE = v_2 t$

$\therefore$ CE would represent the refracted wavefront.

In ΔABC and ΔAEC, we have

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

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

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

If c represents the speed of light in vacuum, then

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

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

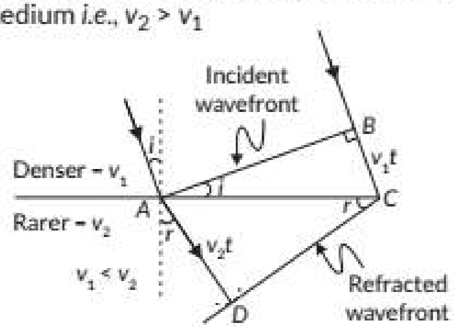
$$\therefore \quad \frac{\sin i}{\sin r} = \frac{c/\mu_1}{c/\mu_2} \Rightarrow \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \Rightarrow \mu_1 \sin i = \mu_2 \sin r$$

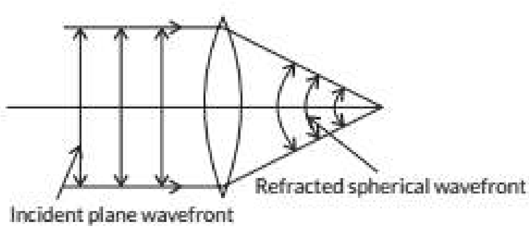
This is the Snell's law of refraction.

9. Refractive index (μ) : Refractive index of a medium is defined as the ratio of the speed of light in vacuum to the speed of light in that medium. *i.e.*,

$$\mu = \frac{c}{v} = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

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



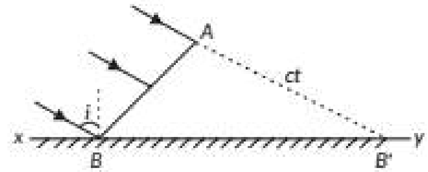


12. (i) Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of the incident light. Hence frequency remains unchanged.

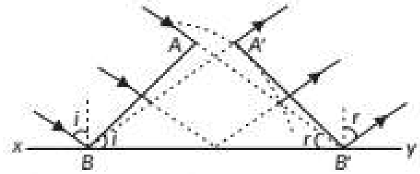
(ii) Energy carried by a wave depends on the frequency of the wave, not on the speed of wave propagation.

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

the wavefront AB.



Let in time t the secondary wavelets reaches B' covering a distance ct. Similarly from each point on primary wavefront AB. Secondary wavelets start growing with the speed c. To find reflected wavefront after time t, let us draw a sphere of radius ct taking B as center and now a tangent is drawn from B' on the sphere the tangent $B'A'$ represents reflected wavefront after time t.



For every point on wavefront AB a corresponding point lie 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.

11. Wavefront : The continuous locus of all the particles of a medium, which are vibrating in the same phase is called a wavefront.

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.

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.

$\therefore \quad BC = v_1 t \qquad$ [$\because$ 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).

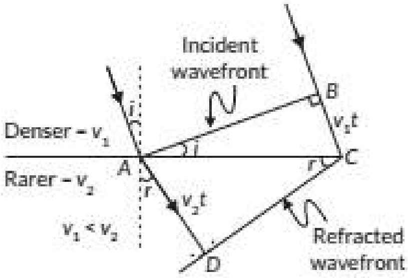
Let CE represents a tangent plane drawn from the point C. Then

$AE = v_2 t$

$\therefore$ CE would represent the refracted wavefront.

In ΔABC and ΔAEC, we have

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



Let the angles of incidence and refraction be i and r respectively.

From right ΔABC, we have,

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

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$$\sin \angle DCA = \sin r = \frac{AD}{AC} \quad \therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t}$$

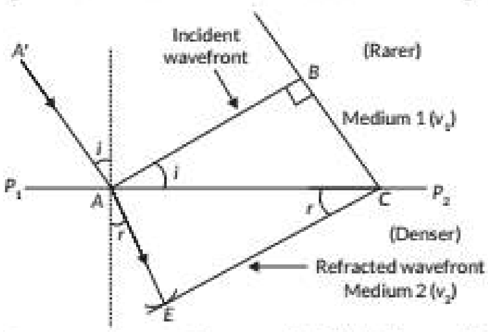
or $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2$ (a constant)

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.

Concept Applied

- According to Huygens principle, when the speed of light is independent of direction, the secondary waves are spherical.

14. Snell's law of refraction : Let P_1P_2 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

For every point on wavefront AB a corresponding point lie on the reflected wavefront $A'B'$.

So, comparing two triangle $\Delta BAB'$ and $\Delta B'A'B$

We find that

$$AB' = A'B = ct$$

$$BB' = \text{common}$$

$$\angle A = \angle A' = 90^\circ$$

Thus two triangles are congruent, hence $\angle i = \angle r$

This proves first law of reflection.

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

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

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.

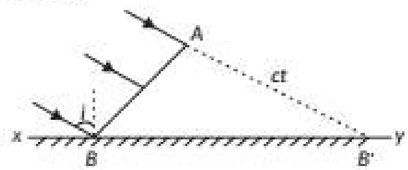
$$\therefore \quad \frac{\sin i}{\sin r} = \frac{c/\mu_1}{c/\mu_2} \Rightarrow \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \Rightarrow \mu_1 \sin i = \mu_2 \sin r$$

This is the Snell's law of refraction.

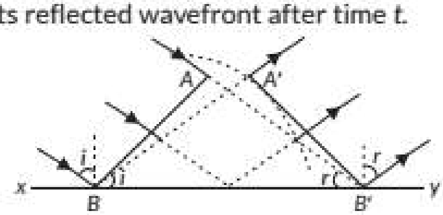
15. A source of light sends the disturbance in all the directions and continuous locus of all the particles vibrating in same phase at any instant is called as wavefront. Phase speed is the speed with which a wavefront moved outwards from the source.

Laws of reflection by Huygens' principle :

Let us consider a plane wavefront AB incident on the plane reflecting surface xy. Incident rays are normal to the wavefront AB.



Let in time t the secondary wavelets reaches B' covering a distance ct. Similarly from each point on primary wavefront AB. Secondary wavelets start growing with the speed c. To find reflected wavefront after time t, let us draw a sphere of radius ct taking B as center and now a tangent is drawn from B' on the sphere the tangent $B'A'$ represents reflected wavefront after time t.



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

This is the Snell's law of refraction.

17. (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

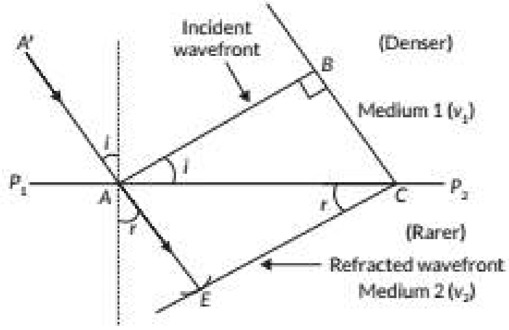
wave is called a ray.

(b) (i) The wavefront will be spherical of increasing

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

16. Wavefront : The continuous locus of all the particles of a medium, which are vibrating in the same phase is called a wavefront.

Snell's law of refraction : Let P_1P_2 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.

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

In order to determine the shape of the refracted wavefront, we draw a sphere of radius v_2t 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

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

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

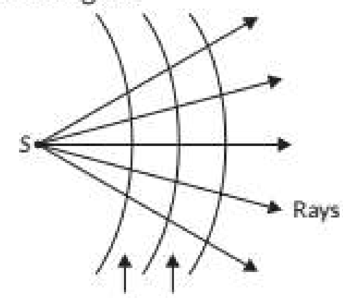
$\therefore \quad \frac{\sin i}{\sin r} = \frac{v_1 t}{AC} \cdot \frac{AC}{v_2 t}$; $\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$

If c represents the speed of light in vacuum, then

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

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

radius as shown in figure.

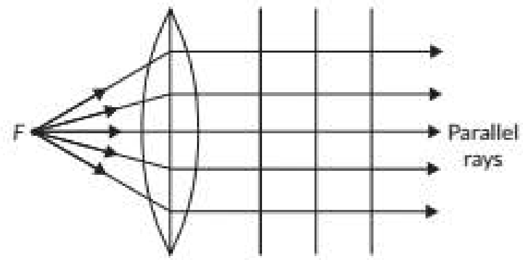


Spherical wavefront

Key Points

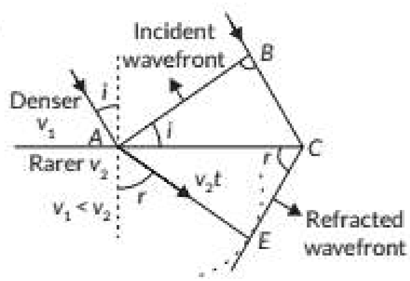
- All the rays of light are always perpendicular to wavefront.

(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)



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

19. (c): (i) Angular separation $= \frac{\lambda}{d}$ remain same

(ii) Fringe width, $\beta = \frac{D\lambda}{d}$

so, as D increases fringe width increases.

(i) remain same, but (ii) increases.

20. (a): $\lambda = 700$ nm, $\lambda' = ?$

$y_3 = y_5$

$$\frac{3\times700D}{d}=\frac{5\times\lambda' D}{d}$$

$$\lambda'=\frac{2100}{5}=420\,\text{nm}$$

21. (c): Fringe width is given as

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

Now, entire apparatus is placed in liquid of refractive index μ.

Thus, wavelength of incident wave changes to

$$\lambda'=\frac{\lambda}{\mu}$$

$\therefore$ Now fringe width, $\beta'=\frac{\lambda' D}{d}$

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

So, answer is option (c).

22. Fringe width, $\beta=\frac{\lambda D}{d}$

As, $\beta \propto \lambda$, fringe width will be maximum for red light source.

23. For destructive interference, $\Delta x=\left(n+\frac{1}{2}\right)\lambda$

$\Rightarrow \left(n+\frac{1}{2}\right)\lambda=\frac{5}{2}\lambda \Rightarrow n=2$

$\therefore$ The third dark fringe will be at this point.

24. In young's double slit experiment, if one slit is fully closed, the new pattern has larger central maximum in angular size.

25. For constructive interference,
Path difference, $\Delta x = n\lambda$ (where n = 0, 1, 2, ...)

For destructive interference, $\Delta x=\left(n+\frac{1}{2}\right)\lambda$
(where n = 0, 1, 2, ...)

26. (a) Intensities of light waves from two coherent sources are in ratio $\frac{I_1}{I_2}=\frac{9}{1}$

We know, $\frac{I_1}{I_2}=\frac{a^2}{b^2}$ $\quad \frac{a}{b}=\sqrt{\frac{I_1}{I_2}}=\sqrt{\frac{9}{1}}=\frac{3}{1}$

$$\frac{I_{max}}{I_{min}}=\frac{(a+b)^2}{(a-b)^2}=\frac{(3+1)^2}{(3-1)^2}=\left(\frac{4}{2}\right)^2=\frac{4}{1}$$

Ratio of intensity of bright and dark fringe is 4 : 1.

(b) Wavelength, $\lambda = 600$ nm

Refractive index, $\mu_w=\frac{4}{3}$

Wavelength in given medium of refracted light ($\lambda_2 = ?$)

For $I_1 = I_2 = I_0$

$$I_R=4I_0\cos^2\frac{\phi}{2}$$

(i) For incoherent sources :
According to superposition of light waves
$I_1 = I_2 = I_0 \therefore I_0 = I_1 = I_2 = 2I_0(1 + \cos(\theta_1 - \theta_2))$
For coherent sources
$I_0 = I_1 = I_2$

$I=I_1+I_2+2\sqrt{I_1I_2}\cos\phi$ or $I_0 = I_1 = I_2$

$= 2I_0 + 2I_0\cos(\theta) = 2I_0(1 + \cos(\theta))$

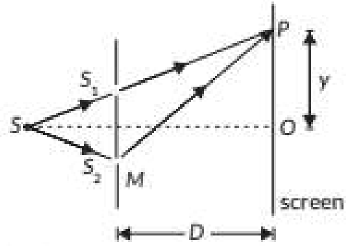
28. Given : $SS_2-SS_1=\frac{\lambda}{4}$

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 $\Delta x=\frac{\lambda}{4}+\frac{yd}{D}$, where d is the slits separation.



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,...,

29. 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.

30. (i) 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 $\Delta x=\frac{\lambda}{4}+\frac{yd}{D}$

As, $n_1\lambda_1 = n_2\lambda_2$ have

$n_1 = 1$

$\lambda_1 = 600$ nm

$n_2 = \frac{4}{3}$; $\lambda_2 = \frac{3}{4} \times 600 = 450$ nm

27. Resultant intensity is given by

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

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

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

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

where $n = 0, 1, 2, 3, \ldots$,

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

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

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

where $n = 1, 2, 3, 4, \ldots$

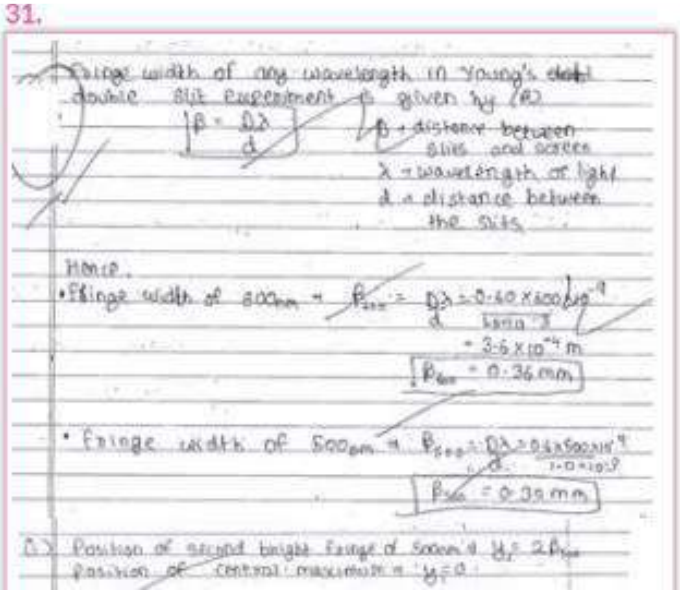
For central bright fringe, putting $n = 0$ in equation (i), we get

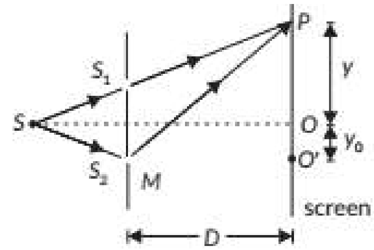
$\frac{yd}{D} = -\frac{\lambda}{4}$ or $y = \frac{-\lambda D}{4d}$

The negative sign indicates that central bright fringe will be observed at a point O' below the centre O of screen.

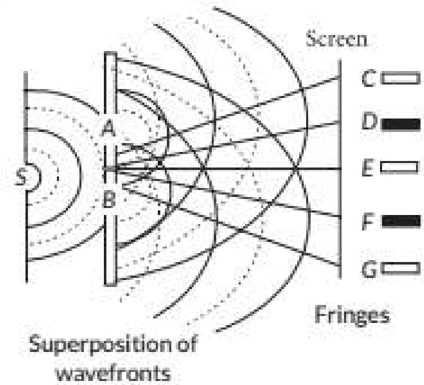
(ii) The central fringes are white. On the either side of the central white fringe the coloured bands (few coloured maxima and minima) will appear. This is because fringes of different colours overlap.

31.


Fringe width of any wavelength in Young's double slit experiment is given by
$\beta = \frac{D\lambda}{d}$
D = distance between slits and screen
λ = wavelength of light
d = distance between the slits
Hence,
• Fringe width of 800 nm = $\beta_{800} = \frac{D\lambda}{d}$ = 3.6 × 10⁻⁴ m
β_{800} = 0.36 mm
• Fringe width of 500 nm = $\beta_{500} = \frac{D\lambda}{d}$
β_{500} = 0.39 mm
Position of second bright fringe of 500 nm = $y_2 = 2\beta_{500}$
Position of central maximum = $y_0 = 0$

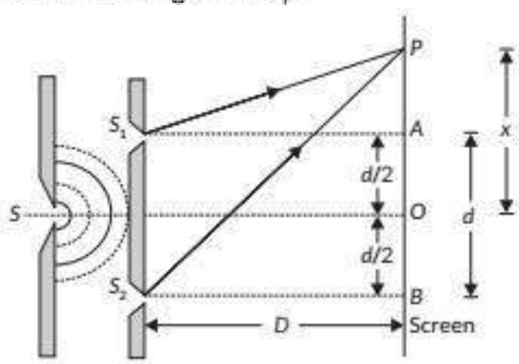


32. Young's double slit experiment :



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.

Expression for fringe width β:

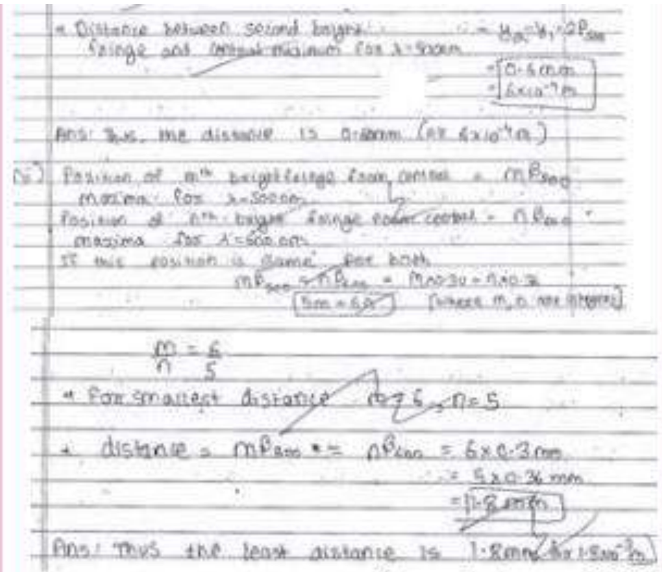


Consider a point P on the screen at distance x from the centre O. The nature of the interference at the point P depends on path difference,

$p = S_2P - S_1P$

From right-angled ΔS_2BP and ΔS_1AP,

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



[Topper's Answer, 2022]

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

Positions of dark fringes : For destructive interference,

$$p=\frac{xd}{D}=(2n-1)\frac{\lambda}{2} \quad \text{or} \quad x=(2n-1)\frac{D\lambda}{2d}$$

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

33. (a) We know, $\frac{I_{max}}{I_{min}}=\frac{(a_1+a_2)^2}{(a_1-a_2)^2}$

According to question, I_2 = 50% of I_1

$I_2 = 0.5I_1;\quad a_2^2 = 0.5\,a_1^2$ $\qquad (\because I \propto a^2)$

$a_2 = \frac{a_1}{\sqrt{2}}$

Hence,

$$\frac{I_{max}}{I_{min}}=\frac{(a_1+a_1/\sqrt{2})^2}{(a_1-a_1/\sqrt{2})^2}=\frac{(1+1/\sqrt{2})^2}{(1-1/\sqrt{2})^2}=\left(\frac{\sqrt{2}+1}{\sqrt{2}-1}\right)^2\approx 34$$

(b) 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.

Concept Applied

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

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

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

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

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

or $p=\frac{xd}{D}$

Positions of bright fringes : For constructive interference,

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

or $x=\frac{nD\lambda}{d}$

35. 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.

Commonly Made Mistake

- Here student thinks two independent monochromatic sources have constant phase. But for sustained interference two monochromatic source should produced from common source which have constant phase.

36. (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.

Answer Tips

- Constructive interference results in bright bands and destructive interference results in dark bands.

- In YDSE, if white light is used, different colours overlap at centre to produce bright fringe. Since violet colour has lowest λ, the closest fringe on either side of central white fringe is violet and farthest fringe is red as fringe width, $\beta \propto \lambda$.

34. (a) Angular width, $\theta = \frac{\lambda}{d}$ or $d = \frac{\lambda}{\theta}$

Here, $\lambda = 600\text{ nm} = 6 \times 10^{-7}\text{ m}$

$\theta = 0.1° = \frac{0.1\times\pi}{180}\text{ rad} = \frac{\pi}{1800}\text{ rad}, d = ?$

$\therefore \quad d = \frac{6\times10^{-7}\times1800}{\pi} = 3.44 \times 10^{-4}\text{ m}$

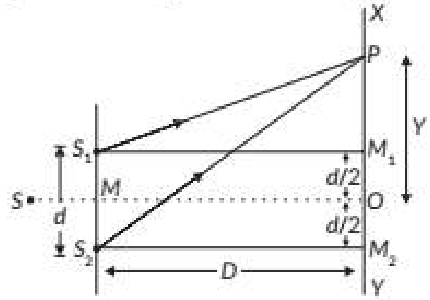
(b) Frequency of a light depends on its source only. So, the frequencies of reflected and refracted light will be same as that of incident light.
Reflected light is in the same medium (air) so its wavelength remains same as 500 Å.

Wavelength of refracted light, $\lambda_r = \frac{\lambda}{\mu_w}$

μ_w = refractive index of water.

So, wavelength of refracted wave will be decreased.

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



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

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

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

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

$y = 2a\cos\left(\omega t+\frac{\phi}{2}\right)\cos\left(\frac{\phi}{2}\right)$ ...(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 $n = 1, 2, 3...$

38. (a) Condition for constructive interference,
$\cos\Delta\phi = +1$

$y = 2a\cos\left(\omega t+\frac{\phi}{2}\right)\cos\left(\frac{\phi}{2}\right)$ ...(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, $I = 4I_0\cos^2\left(\frac{\phi}{2}\right)$

(ii) 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 $n = 1, 2, 3...$

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

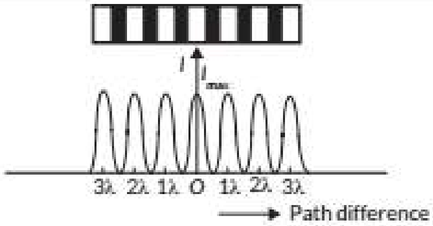
or $\Delta x = n\lambda$; $n = 0, 1, 2, 3, ...$

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

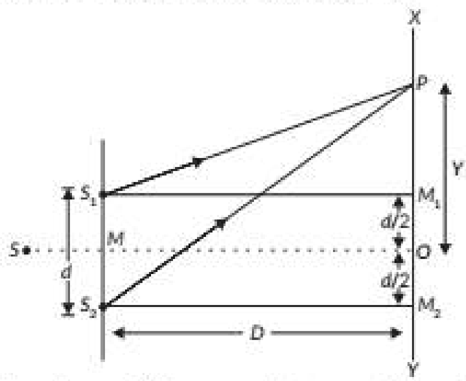
$2\pi\frac{\Delta x}{\lambda}=\pi, 3\pi, 5\pi...$

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

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



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



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

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

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

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

$y=2a\cos\left(\omega t+\frac{\phi}{2}\right)\cos\left(\frac{\phi}{2}\right)$ ...(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) Since fringe width is give by $\beta=\frac{\lambda D}{d}$

(i) On increasing the width of slit d, the fringe width decreases.

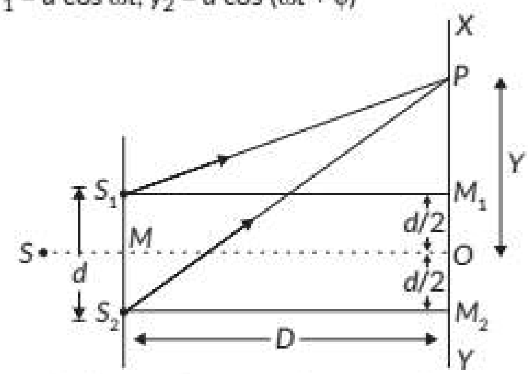
(ii) On replacing monochromatic light with white light, the fringes of all colours will be overlapping in interference pattern.

Answer Tips

- The resultant displacement of wave at any point is the sum of the displacements of the individual waves of the two sources.

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



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

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

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

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

43. (i) As we know,

Angular width of central maxima is $\theta_0=\frac{2\lambda}{a}$

where, λ is wavelength and a is width of slit $\theta_0\propto\frac{1}{a}$

So, angular width will increase as the with of slit decreases.

(ii) As, $\theta_0=\frac{2\lambda}{a}$; $\theta_0\propto\lambda$

So, angular width will increase as the wavelength increases and decreases as the wavelength decrease. When we use poly chromatic light, the diffracted image of slit will get dispersed into constitute colours of white light and central maxima will be white. There is no change in slit.

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

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

41. We have

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

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

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

Concept Applied

- Intensity of any light wave is directly proportional to the square of its amplitude.

42. At first minima a $\sin\theta = h$

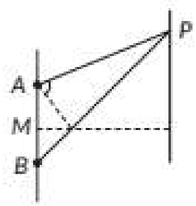
$AP - BP = h$

$AP - MP = \frac{h}{2}$

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

$= \frac{2\pi}{\lambda} \times \frac{\lambda}{2}$

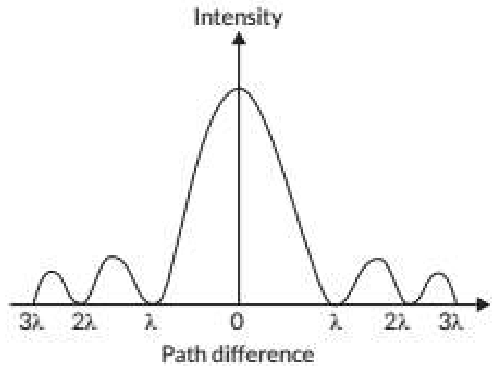
$\Delta\phi = \pi$ Radians



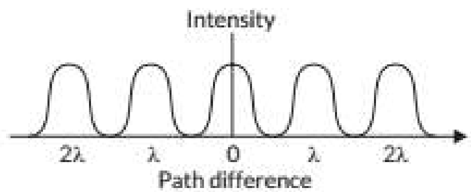
44. Width of central maximum is given by $\beta_0 = \frac{2D\lambda}{a}$

If width of slit is reduced then (i) size of central maxima will increase and (ii) intensity of central maximum will decrease.

45. (i) Single slit diffraction:



Double slit interference:



(ii) Difference between interference and diffraction

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.

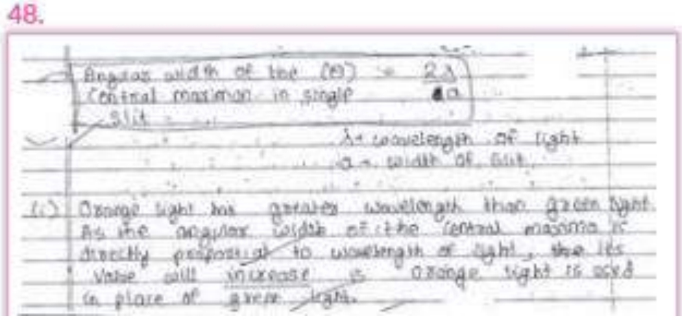
46. (i) Given $\Delta\phi = 5\pi$

As, $\Delta\phi = \frac{2\pi}{\lambda} \cdot \Delta x$

$\Rightarrow 5\pi = \frac{2\pi}{\lambda} \cdot \Delta x$

5λ

48.



$\Rightarrow \quad \Delta x = \frac{5\lambda}{2}$

So, path difference $= (2\times2+1)\frac{\lambda}{2}$

$(2n+1)\frac{\lambda}{2} \rightarrow$ It is secondary maximum *i.e.*, bright fringe.

(ii) Given, the width of each slit is 'a' linear separation between 8 fringes is given by,

$x = 8\beta = 8\frac{\lambda D}{d}$

Corresponding angular separation is,

$\theta_1 = \frac{x}{D} = \frac{8\lambda}{d}$

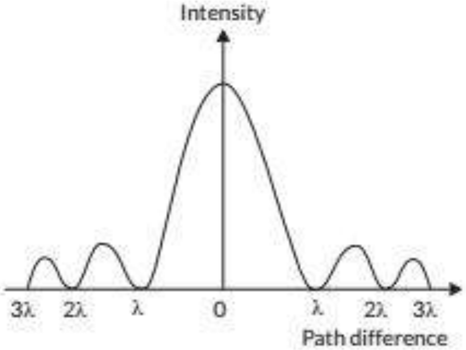
Now, the angular width of central maximum in the diffraction pattern of a single slit is given by, $\theta_2 = \frac{2\lambda}{a}$

Since, $\theta_2 = \theta_1$

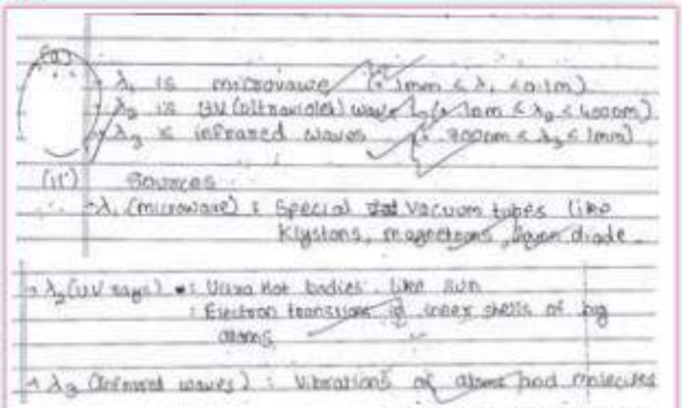
$\frac{2\lambda}{a} = \frac{8\lambda}{d} \Rightarrow a = \frac{d}{4}$

$\Rightarrow \quad a = \frac{d}{4}$

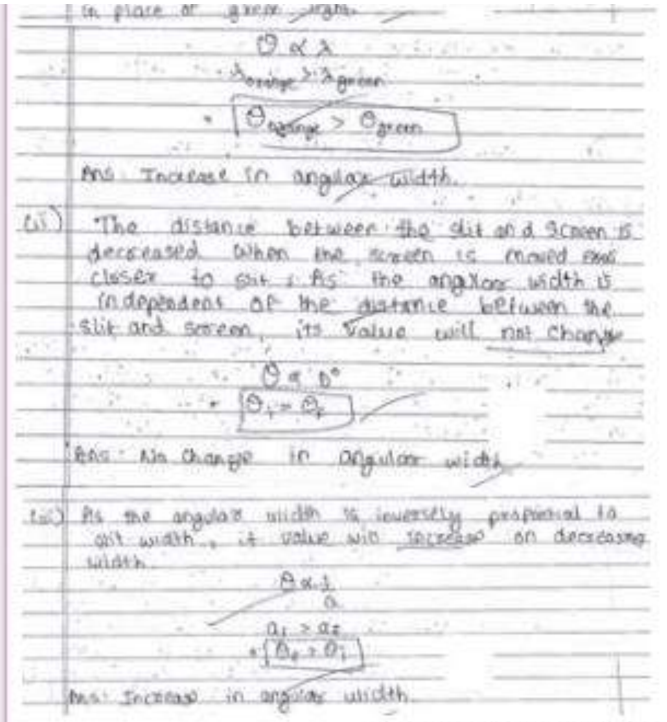
(iii) Single slit diffraction pattern, intensity distribution



47.


(i) λ1 is microwave (1mm < λ1 < 0.1m)
λ2 is UV (ultraviolet) wave (1nm < λ2 < 400nm)
λ3 is infrared waves (700nm < λ3 < 1mm)
(ii) Sources
λ1 (microwave): Special vacuum tubes like Klystrons, magnetrons, Gunn diode
λ2 (UV rays): Very hot bodies like sun; Electron transition in inner shells of big atoms
λ3 (infrared waves): Vibrations of atoms and molecules

[Topper's Answer, 2022]


in place of green light.
θ ∝ λ
λ orange > λ green
θ orange > θ green
Ans: Increase in angular width.
(ii) The distance between the slit and screen is decreased when the screen is moved more closer to slit. As the angular width is independent of the distance between the slit and screen, its value will not change.
θ ∝ D°
θ1 = θ2
Ans: No change in angular width
(iii) As the angular width is inversely proportional to slit width, its value will increase on decreasing width.
θ ∝ 1/a
a1 > a2
θ2 > θ1
Ans: Increase in angular width.

[Topper's Answer, 2022]

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

Interference	Diffraction
1. All bright fringes are of same intensity.	1. Intensity of bright fringes decreases sharply as we move away from central bright fringe.
2. Dark Fringes are perfectly dark.	2. Dark fringes are not perfectly dark.

50. Path difference for diffraction

$= (2n+1)\frac{\lambda}{2}$ (for secondary maximum)

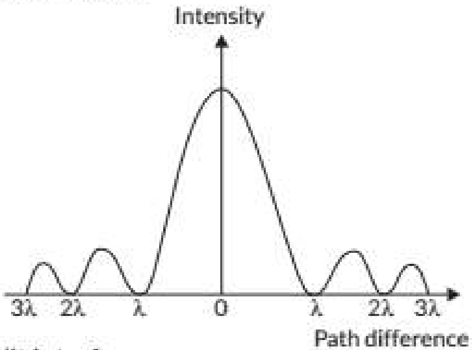
$= n\lambda$ (for secondary minimum)

(i) If path difference $= \lambda$, first secondary minimum would be formed.

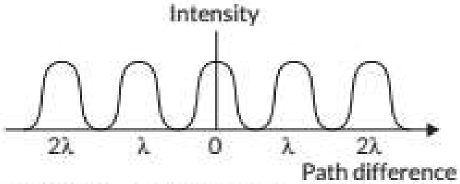
(ii) If path difference $= \frac{3\lambda}{2}$, first secondary maximum would be formed.

51. Due to single slit, the width of central bright fringe is maximum and width of successive fringes keeps on decreasing while due to double slits all the bright fringes are of equal width.

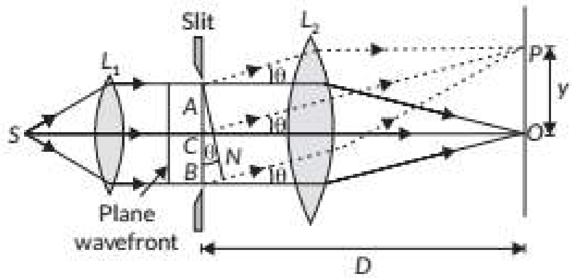
Single slit diffraction:



Double slit interference:



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 λ/2 and also the path

$BN = a \sin\theta$

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

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

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

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 $\theta_n, \theta_n = \dfrac{n\lambda}{a}$

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′* 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 1^{st} two parts will be λ/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

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

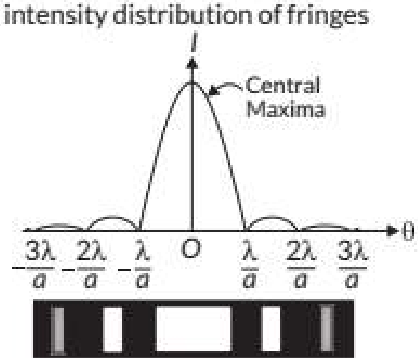
We get second secondary maximum of lower intensity.

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

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

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

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



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

$BN = AB \sin\theta$

For second bright fringe, $n = 2$

$$x = 2 \times 600 \times \frac{1.0}{0.6 \times 10^{-3}} = 2000 \times 10^3 \text{ nm}$$

$x = 2 \times 10^{-3}$ m

(ii) We can consider that n^{th} bright fringe of λ_2 and the $(n-1)^{th}$ bright fringe of wavelength λ_1 coincide with each other.

$\Rightarrow n\lambda_2 = (n-1)\lambda_1 \Rightarrow 400n = 600n - 600$

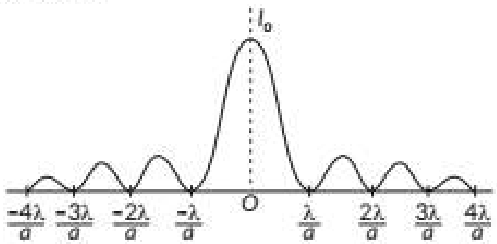
$\Rightarrow 200n = 600 \Rightarrow n = 3$

Therefore, the least distance from the central maximum can be obtained as

$$x' = n\lambda_2 \frac{D}{d} = 3 \times 480 \times \frac{1.0}{0.6 \times 10^{-3}} \text{nm}$$

$x' = 2400 \times 10^3$ nm $= 2.4 \times 10^{-3}$ m

53. (a) The intensity pattern on the screen is shown in the given figure.



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

(b) The angular width of central maximum is given by

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

where a is the slit width and λ is the wavelength of light.

(i) From equation (i), it follows that $2\theta_0 \propto \frac{1}{a}$.

Therefore, as the slit width is increased, the width of the central maximum will decrease and the intensity of central maxima will increase.

52. First wavelength of light, $\lambda_1 = 600$ nm

Second wavelength of light, $\lambda_2 = 480$ nm

Distance between the slit and the screen = 1.0 m

Distance between the slits = 0.6 mm

(i) The relation between the n^{th} bright fringe and the width of fringe is $x = n\lambda_1 \frac{D}{d}$

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

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

(b) For first maximum $y_1 = \frac{\lambda D}{a}$,

where $a = 2 \times 10^{-4}$ m; $D = 1.5$ m

For $\lambda_1 = 5900$ Å $= 5900 \times 10^{-10}$ m

$$\therefore y_1 = \frac{5900 \times 10^{-10} \times 1.5}{2 \times 10^{-4}} = 4425 \times 10^{-6} \text{ m}$$

For $\lambda_2 = 5960$ Å $= 5960 \times 10^{-10}$ m

$$y_2 = \frac{5960 \times 10^{-10} \times 1.5}{2 \times 10^{-4}} = 4470 \times 10^{-6} \text{ m}$$

Separation, $y = y_2 - y_1 = 45 \times 10^{-6}$ m

55. Difference between interference and diffraction :

Interference	Diffraction
1. Interference is caused by superposition of 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.

Let the waves from two coherent sources of light be represented as

$y_1 = a \sin\omega t$

$y_2 = b \sin(\omega t + \phi)$

where a and b are the respective amplitudes of the two waves and ϕ is the constant phase angle by which second wave leads the first wave.

According to superposition principle, the displacement (y) of the resultant wave at time (t) would be given by

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

$= a \sin\omega t + b \sin\omega t \cos\phi + b \cos\omega t \sin\phi$

$y = \sin\omega t\,(a + b\cos\phi) + \cos\omega t . b \sin\phi$

(ii) From equation (i), it follows that $2\theta_0$ is independent of D. So the angular width and intensity will remain same when the separation between slit and screen is decreased.

54. (a) The first secondary minimum. 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.

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

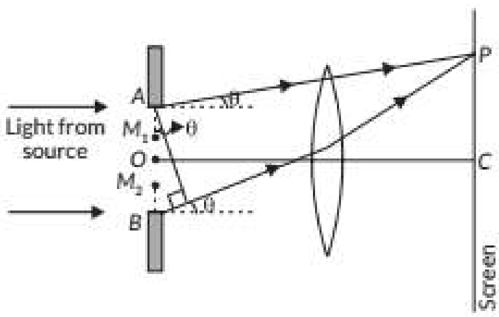
For small $\theta_n, \theta_n = \frac{n\lambda}{a}$ ...(i)

Position of secondary maxima :

Commonly Made Mistake

- For constructive interference, the intensity will be minimum. For destructive interference, the intensity is maximum and $I_R = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2 = 0$, if light waves have equal intensity.

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

Put $a + b\cos\phi = R\cos\theta$ ...(i)

$b\sin\phi = R\sin\theta$ ...(ii)

$y = \sin\omega t.R\cos\theta + \cos\omega t.R\sin\theta = R[\sin\omega t\cos\theta + \cos\omega t\sin\theta]$

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

Thus the resultant wave is a harmonic wave of amplitude R.

Squaring equation (i) and (ii) and adding, we get

$R^2(\cos^2\theta + \sin^2\theta) = (a + b\cos\phi)^2 + (b\sin\phi)^2$

$R^2 \times 1 = a^2 + b^2\cos^2\phi + 2ab\cos\phi + b^2\sin^2\phi$

$= a^2 + b^2(\cos^2\phi + \sin^2\phi) + 2ab\cos\phi$

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

As intensity is directly proportional to the square of the amplitude of the wave

$\therefore \quad I_1 = Ka^2, I_2 = Kb^2,$

and $I_R = KR^2 = K(a^2 + b^2 + 2ab\cos\phi)$

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

(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. (i) Given $\lambda = 500 \times 10^{-9}$ m, $D = 1$ m, $y_{min} = 2.5$ mm

$\therefore \quad y_{min} = \frac{n\lambda D}{d} = \frac{1 \times 500 \times 10^{-9} \times 1}{d} \Rightarrow d = 0.2 \text{ mm}$

(ii) Now the distance between first secondary maximum from centre of the screen,

$y_{max} = \frac{\left(n + \frac{1}{2}\right)\lambda D}{d} = \frac{3}{2}\frac{\lambda D}{d} = 3.75 \text{ mm}$

58. Given, $\lambda = 620$ nm, $D = 1.5$ m, $d = 3 \times 10^{-3}$ m

For 3rd maxima, $d\sin\theta = (2n + 1)\frac{\lambda}{2} = \frac{7\lambda}{2}$

For 1st minima, $d\sin\theta = n\lambda = \lambda$

$\therefore (y_{max_3} - y_{min_1}) = \left(\frac{7\lambda}{2} - \lambda\right) \times \frac{D}{d_1} = \frac{5}{2}\frac{\lambda D}{d}$

$= \frac{5}{2} \times \frac{620 \times 10^{-9} \times 1.5}{3 \times 10^{-3}} = 7.75 \times 10^{-4}$ m

59. (a) Intensity distribution of light in diffraction at a signal slit is shown in figure.

halves 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 $\frac{a}{2}\sin\theta = \frac{\lambda}{2}$.

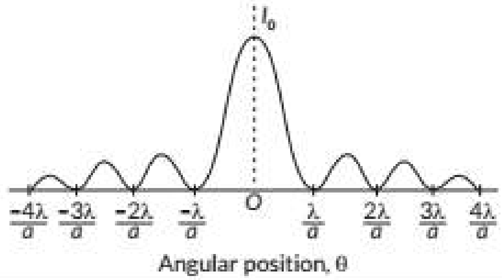
$a\sin\theta = \lambda$

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 $n = \pm1, \pm2$.......

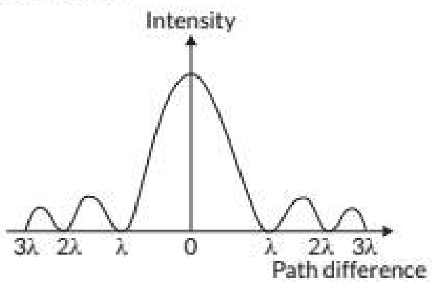
The intensity pattern on the screen is shown in the given figure.



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

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.

Single slit diffraction:



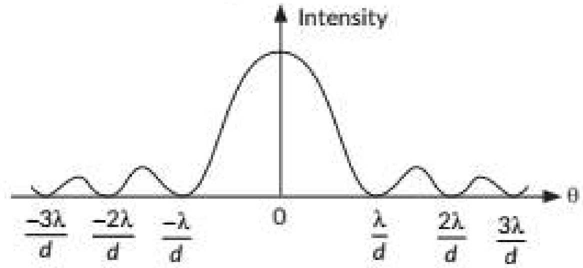
(b) $\lambda = 500$ nm $= 5 \times 10^{-7}$ m, $a = 0.2$ mm $= 2 \times 10^{-4}$ m

Angular width of central maxima,

$$\theta_0 = \frac{2\lambda}{a} = \frac{2 \times 5 \times 10^{-7}}{2 \times 10^{-4}} = 5 \times 10^{-3} \text{ rad}$$

For Young's double slit experiment, $\beta = 0.5$ mm
$= 5 \times 10^{-4}$ m

Required number of fringes, $N = \frac{\theta_0 D}{\beta}$



Width of central maximum is given by

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

When width (d) of the slit is increased, the width of central maximum decreases and the intensity increases.

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

Concept Applied

➲ Diffraction and interference occur simultaneously.

60. (a) Difference between interference and diffraction

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.

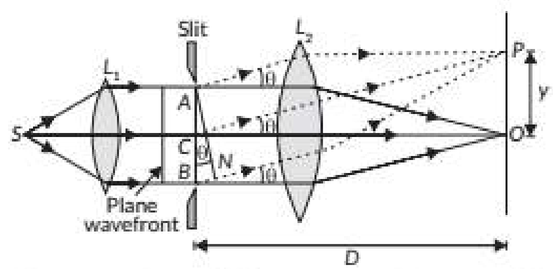
2. All bright and dark fringes are of equal width.	2. Width of central bright fringe is double of all other maxima.
3. All bright fringes are of same intensity.	3. Intensity of bright fringes decreases sharply as we move away from central bright fringe.
4. Dark Fringes are perfectly dark.	4. Dark fringes are not perfectly dark.

62. (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.

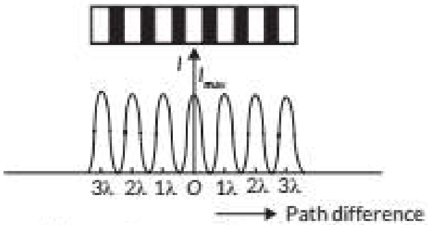
(ii) Diffraction of light due to a narrow single slit



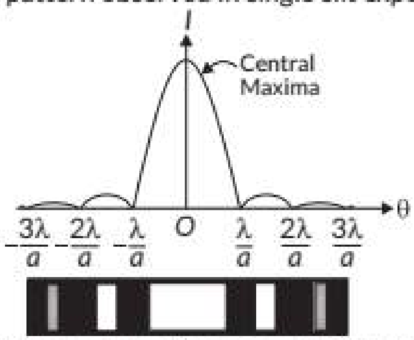
Consider a set of parallel rays from a lens L_1 falling on a slit, form a plane wavefront. According to Huygens principle, each point on the unblocked point of plane wavefront AB sends out secondary wavelets in all

Assume $D = 1$ m, $N = \dfrac{5\times10^{-3}\times1}{5\times10^{-4}} = 10$

61. Interference pattern observed in young Double slit experiment



Diffraction pattern observed in single slit experiment



Difference between interference and diffraction

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.

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

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

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

$2\lambda = a \sin\theta_2$

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

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

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

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

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

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 $\theta = \theta_1$

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

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

$\tan\theta_n = \dfrac{y_n}{D}$ ...(ii)

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

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

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

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

Width of the central maximum,

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

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

$a\sin\theta_3 = \frac{3\lambda}{2}$

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

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

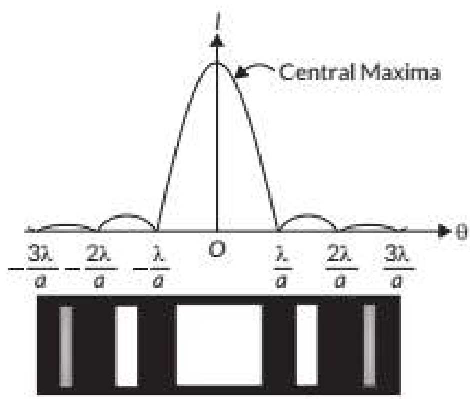
We get second secondary maximum of lower intensity.

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

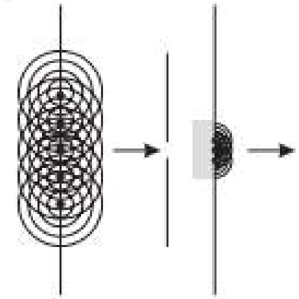


(iii) If y_n is the distance of the n^{th} minimum from the centre of the screen, then from right-angled ΔCOP

Key Points

- If I = Intensity of light
  W = Width of slit
  then, $\frac{I_1}{I_2} = \frac{W_1^2}{W_2^2}$

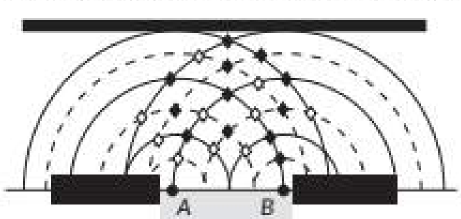
63. (a) Waves diffract when they encounter obstacles. A wavefront impinging on a barrier with a slit in it, only the points on the wavefront that move into the slit can continue emitting forward moving waves but because a lot of the wavefront has been blocked by the barrier, the points on the edges of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

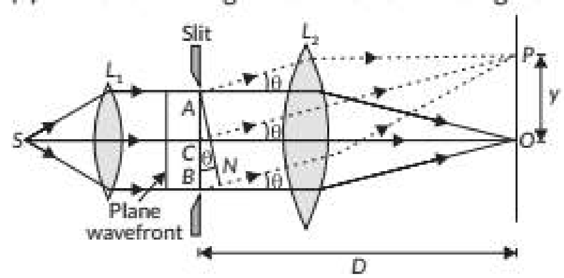
According to Huygen's principle, each point on the wavefront moving through the slit acts like a point source. We can think about some of the effect of this if we analyse what happens when two point sources are close together and emit wavefronts with the same wavelength and frequency. These two point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



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

64. (a) Diffraction of light due to a narrow single slit



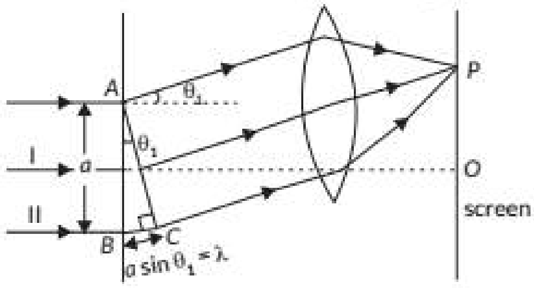
Consider a set of parallel rays from a lens L_1 falling on a slit, form a plane wavefront. According to Huygens principle, each point on the unblocked point of plane wavefront AB sends out secondary wavelets in all

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

Concept Applied

- A single narrow slit is illuminated by a monochromatic source of light. The diffraction pattern is obtained on the screen placed in front of the slits.

(b) 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,

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

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

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

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

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

Position of secondary maxima :

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

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 $\theta = \theta_1$

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

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

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.

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

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

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

$a\sin\theta_3 = \frac{3\lambda}{2}$

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

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

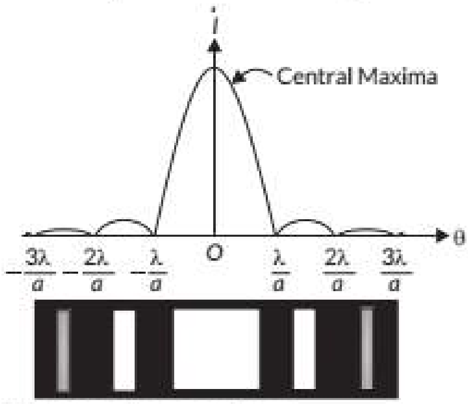
We get second secondary maximum of lower intensity.

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



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,

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

In case θ'_n is small,

$\sin\theta_n' = \tan\theta_n'$

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

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,

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

Spacing between the first two maximum of sodium lines,

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

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

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

65. (a) Difference between interference and diffraction

Interference	Diffraction
1. Interference is caused by superposition of 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.

(b) Given λ = 500 nm = 5×10^{-7} m; D = 1 m

If a is width of slit, then for first minimum,

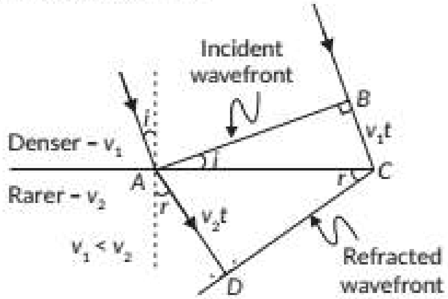
$\sin\theta_1 = \frac{\lambda}{a}$; For small θ_1, $\sin\theta_1 = \frac{y_1}{D}$

$\therefore \frac{y_1}{D} = \frac{\lambda}{a} \Rightarrow a = \frac{\lambda D}{y_1} = \frac{5\times10^{-7}\times1}{2.5\times10^{-3}} = 0.2$ mm.

CBSE Sample Questions

1. Wavefront : The continuous locus of all the particles of a medium, which are vibrating in the same phase. **(1)**

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



The incident and refracted wavefront 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,

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

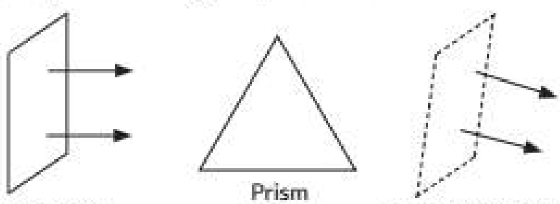
$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t}$ or $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2$ (a constant)

This is Snell's law of refraction. The constant ${}^1\mu_2$ is called the refractive index of the second medium with respect to first medium. **(2)**

2. (a) Wavefront : The continuous locus of all the particles of a medium, which are vibrating in the same phase is called a wavefront. **(1)**

(b) Ray diagram showing shapes of wavefront:

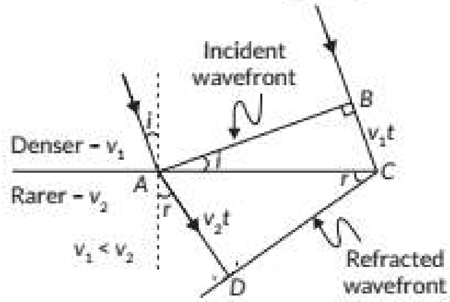
(i)



(ii)

After passing through prism the wavefront will be plane whereas for convex lens, it will be spherical. **(2)**

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



The incident and refracted wavefronts 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, $\sin \angle DCA = \sin r = \frac{AD}{AC}$

$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t}$ 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. **(2)**

3. (d): Given, path difference, $\Delta x = \frac{\lambda}{8}$

Phase difference, $\Delta\phi = \frac{2\pi}{\lambda}\cdot\Delta x \Rightarrow \Delta\phi = \frac{\pi}{4}$

At any point, intensity $I = I_{max}\cos^2\left(\frac{\Delta\phi}{2}\right)$

$I = I_{max}\cos^2\left(\frac{\pi/4}{2}\right)$

$\frac{I}{I_{max}} = \left[\cos\left(\frac{\pi}{8}\right)\right]^2 = (0.9239)^2 = 0.853$ **(1)**

4. (c): Fringe width, $\beta = \frac{\lambda D}{d}$. As, $d' = \frac{d}{3}$ and $D' = \frac{D}{3}$

$\therefore$ New fringe width, $\beta' = \frac{\lambda D'}{d'} = \frac{\lambda \times \frac{D}{3}}{\frac{d}{3}} = \frac{\lambda D}{d}$ **(1)**

5. Given, $SX - S'X$ = 4.5 cm

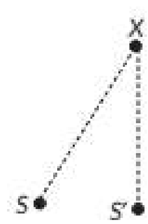
$\therefore$ Path difference at X,

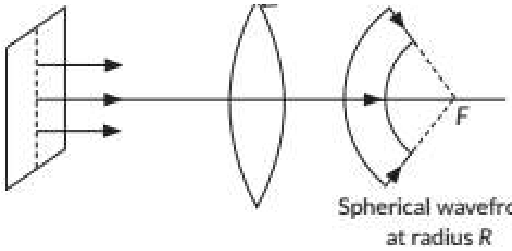
Δx = 4.5 cm

Given at X, there is second minima.

$\therefore \Delta x = \left(n + \frac{1}{2}\right)\lambda$

Where n = 0, 1, 2, 3.....

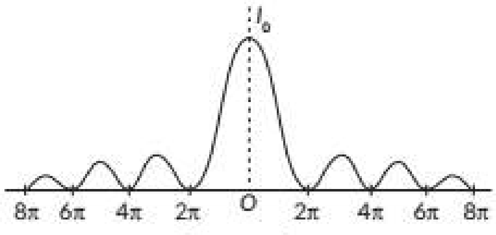




Putting $n = 1$,

$$4.5 = \left(1+\frac{1}{2}\right)\lambda \Rightarrow \lambda = \frac{4.5\times 2}{3} = 3\text{ cm} \qquad \textbf{(2)}$$

6. Intensity distribution as function of phase angle, when diffraction of light takes place through coherently illuminated single slit.



(2)

7. $\frac{n\lambda}{d} = \frac{2\lambda}{a} \Rightarrow n = \frac{2d}{a}$

where d is separation between slit and a width of slit. **(2)**

8. Angular width $2\varphi = \frac{2\lambda}{d}$.

Given, $\lambda = 6000$ Å

In case of new λ (assumed λ' here), angular width decreases by 30%

New angular width = 0.70 (2φ)

$\frac{2\lambda'}{d} = 0.70\times\left(\frac{2\lambda}{d}\right) \quad \therefore \lambda' = 4200$ Å

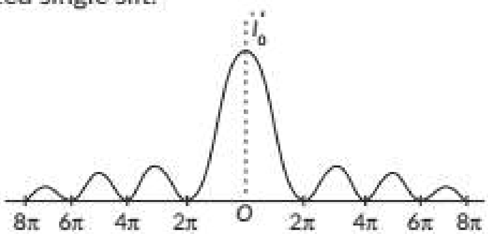
9. (a) The total intensity at a point where the phase difference is ϕ, is given by $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$. Here I_1 and I_2 are the intensities of two individual sources which are identical.

When ϕ is 0, $I = 4I_1$.

When ϕ is 180°, $I = 0$

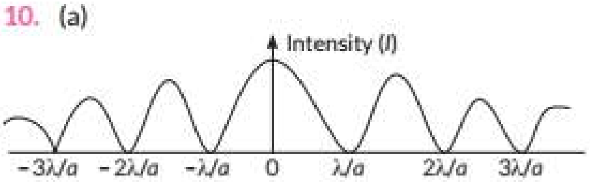
Thus intensity on the screen varies between $4I_1$ and 0. **(1)**

(b) Intensity distribution as function of phase angle, when diffraction of light takes place through coherently illuminated single slit.



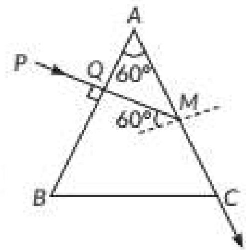
(2)

10. (a)



Width of central maximum is twice that of any secondary maximum.

(b) Given: $\angle A = 60°$, $\angle i = 0°$



At M: $\sin C = \frac{1}{\mu} = \frac{\sqrt{3}}{2} = \sin 60°$

$\therefore \quad C = 60°$

So, the ray PM after refraction from the face AC grazes along AC.

$\therefore \quad \angle e = 90°$

From, $\angle i + \angle e = \angle A + \angle\delta$ or $0° + 90° = 60° + \angle\delta$

$\therefore \quad \angle\delta = 90° - 60° = 30°$

11. (a) (i) The interference pattern has a number of equally spaced bright and dark bands. The diffraction pattern has a central bright maximum which is twice as wide as the other maxima. The intensity falls as we go to successive maxima away from the centre, on either side.

(ii) We calculate the interference pattern by superposing two waves originating from the two narrow slits. The diffraction pattern is a superposition of a continuous family of waves originating from each point on a single slit. **(2)**

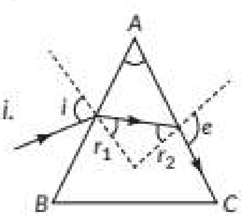
(b) (i) $\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{60+30}{2}\right)}{\sin\left(\frac{60°}{2}\right)} = \sqrt{2}$

Also, $\mu = \frac{c}{v} \Rightarrow v = \frac{3\times 10^8}{\sqrt{2}}$ m/s

(ii) At face AC, let the angle of incidence be r_2.

For grazing ray, $e = 90°$

$\Rightarrow \mu = \frac{1}{\sin r_2} \Rightarrow r_2 = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right) = 45°$



Let angle of refraction at face AB be r_1.

Now, $r_1 + r_2 = A$

$\therefore \quad r_1 = A - r_2 = 60° - 45° = 15°$

Let angle of incidence at this face be i.

$\mu = \frac{\sin i}{\sin r_1} \Rightarrow \sqrt{2} = \frac{\sin i}{\sin 15°}$

$\therefore \quad i = \sin^{-1}(\sqrt{2}\cdot\sin 15°) = 21.5°$ **(3)**