10 Wave Optics

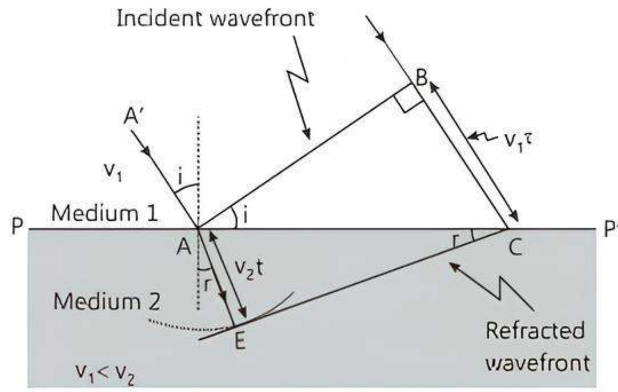
Fastrack Revision

- **Wavefront:** A wavefront is defined as a surface of constant phase. It is the locus of points having the same phase of oscillation.
- **Rays:** Rays are the lines perpendicular to the wavefront, which show the direction of propagation of energy.
- **Time Taken:** The time taken for light to travel from one wavefront to another is the same along any ray.
- **Huygens' Principle**
  - According to Huygens, each point on the given wavefront (called primary wavefront) acts as a fresh source of new disturbance, called secondary wavelet, which travels in all directions with the velocity of light in the medium.
  - A surface touching these secondary wavelets, tangentially in the forward direction at any instant gives the new wavefront at that instant. This is called secondary wavefront.
- **Some Important Points Related to Huygens' Principle**
  - Huygens' principle or Huygens wave theory successfully explains the phenomenon of interference, diffraction and polarisation.
  - As, frequency $\nu\left(=\frac{1}{T}\right)$ is a characteristic of the source, therefore it remains the same as light travels from one medium to another.
  - The law of reflection ($\angle i = \angle r$) and the Snell's law of refraction, $\left(\frac{\sin i}{\sin r} = \text{constant}\right)$ can be proved by Huygens' principle.
- **Relation between Frequency and Speed:** The speed v of a wave is given by

$$v = \frac{\lambda}{T} = \nu\lambda$$

where, λ is the wavelength of the wave and $T(= 1/\nu)$ is the period of oscillations.

- **Refraction and Reflection of Plane Wave using Huygens' Principle**
  - **Refraction of Plane Wave:** A plane wave AB is incident at an angle i on the surface PP' separating medium 1 and medium 2 as shown in figure.



The plane wave undergoes refraction and CE represents the refracted wavefront. The figure corresponds to $v_2 < v_1$ so that the refracted waves bends towards the normal.

If we consider the triangles ABC and AEC, we readily obtain

$$\sin i = \frac{BC}{AC} = \frac{v_1\tau}{AC} \qquad ...(1)$$

and

$$\sin r = \frac{AE}{AC} = \frac{v_2\tau}{AC} \qquad ...(2)$$

From eqs. (1) and (2),

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} \qquad ...(3)$$

If c represents the speed of light in vacuum, then $n_1 = \frac{c}{v_1}$

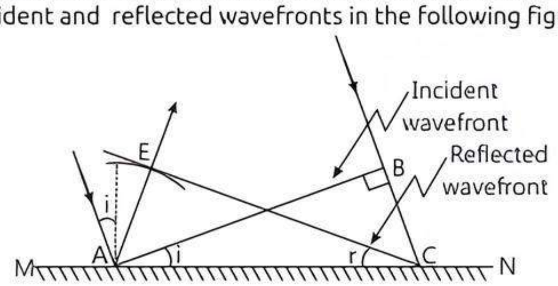
and $n_2 = \frac{c}{v_2}$.

$\therefore$ From eq. (3),

$$n_1 \sin i = n_2 \sin r$$

This equation shows Snell's law of refraction.

- **Reflection of Plane Wave:** Reflection of a plane wave AB by the reflecting surface MN. AB and CE represents incident and reflected wavefronts in the following figure:



Consider the triangles EAC and BAC, they are congruent.

i.e. $\Delta EAC \cong \Delta BAC$

$\therefore$ $\angle EAC = \angle BAC$ or $i = r$

This proves the 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.

- **Superposition Principle**

According to superposition principle, a particular point in the medium, the resultant displacement produced by a number of waves, is the vector sum of the displacements produced by each of the waves.

i.e. $y = y_1 + y_2 + y_3 + ...$

- **Interference of Light Wave**

When two light waves of exactly equal frequency having constant phase difference with respect to time travelled in same direction and superimpose (overlap) with each other, then intensity of resultant wave does not remain uniform in space.

This phenomenon of formation of maximum intensity at some points and minimum intensity at some other points by the two identical light waves travelling in same direction is called the interference of light.

Depending on phase difference in superimposing waves, interference is divided into two categories as follows:

  - **Constructive Interference:** When the two waves meet in same phase, *i.e.* the intensity of light is maximum, is called the constructive interference.
  - **Destructive Interference:** When the two waves meet in opposite phase, *i.e.* the intensity of light is minimum, is called the destructive interference.

- **Expression for Resultant Intensity in Interference of Two Waves**
  - According to the superposition principle, when two or more wave motions travelling through a medium superimpose one another, a new wave is formed in which resultant displacement is due to the individual waves at that instant.
  - The average of the total intensity will be

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

where, ϕ is the inherent phase difference between the two superimposing waves.

  - The significance is that the intensity due to two sources of light is not equal to the sum of intensities due to each of them.
  - The resultant intensity depends on the relative location of the point from the two sources, since it changes the path difference as we go from one point to another.
  - As a result, the resulting intensity will vary between maximum and minimum values, determined by the maximum and minimum values of the cosine function. These will be

$$I_{max.} = I_1 + I_2 + 2\sqrt{I_1 I_2} = (\sqrt{I_1} + \sqrt{I_2})^2$$

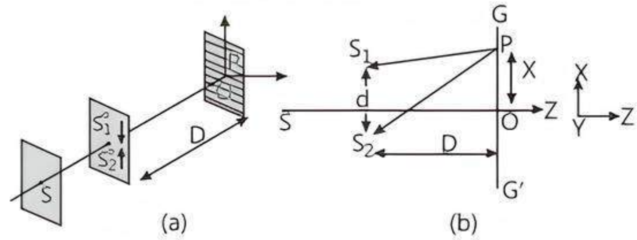
$$I_{min.} = I_1 + I_2 - 2\sqrt{I_1 I_2} = (\sqrt{I_1} - \sqrt{I_2})^2$$

- **Coherent and Incoherent Sources**

Light sources can be coherent or incoherent which are as follows:

  - **Coherent Sources:** Two sources of light which continuously emit light waves of same frequency with a zero or constant phase difference between them are called coherent sources.
  - **Incoherent Sources:** Two sources of light which do not emit light waves with a constant phase difference are called incoherent sources.

- **Young's Double Slit Experiment:** Two parallel and very close slits S_1 and S_2 (illuminated by another narrow slit) behave like two coherent sources and produce a pattern of dark and bright bands – interference fringes on a screen.



Young 's arrangement to produce interference pattern

  - For a point P on the screen, the path difference

$$S_2P - S_1P = \frac{y_1 d}{D}$$

where, d is the separation between two slits, D is the distance between the slits and the screen and y_1 is the distance of the point P from the central fringe.

  - For constructive interference (bright band), the path difference must be an integer multiple of λ, *i.e.*,

$$\frac{y_1 d}{D} = n\lambda \text{ or } y_1 = \frac{nD\lambda}{d};$$

$$n = 0, \pm 1, +2, ...$$

  - For destructive interference (dark band), the path difference is

$$\frac{y\,d}{D} = \left(n + \frac{1}{2}\right)\lambda \text{ or } y = \left(n + \frac{1}{2}\right)\frac{}{d};\ n = 0, \pm 1, \pm 2$$

  - The separation Δy_1 between adjacent bright and dark fringes is,

$$\Delta y_1 = \frac{D\lambda}{d}$$

Using this λ can be measured.

  - For Young's double slit interference experiment,

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

where, D is the distance between the slit and the screen, d is the distance between the two slits.

- **Sustained Interference of Light**
  - For sustained interference of light to occur, the following conditions must be met:
    - Coherent sources of light are needed.
    - Amplitudes and intensities must be nearly equal to produce sufficient contrast between maxima and minima.
    - Two sources must be very close to each other.
    - The sources should emit light waves continuously.
    - The sources must be monochromatic.
  - **For Constructive Interference**
    - **Phase difference:** $\Delta\phi = 2\pi n$, where n is an integer.
    - **Path difference:** $\Delta x = n\lambda$, where n is an integer.
  - **For Destructive Interference**
    - **Phase difference:** $\Delta\phi = \left(n + \frac{1}{2}\right)2\pi$, where n is an integer.
    - **Path difference:** $\Delta x = \left(n + \frac{1}{2}\right)\lambda$, where n is an integer.

- **Diffraction of Light:** The phenomenon of bending of light around the sharp corners and the spreading of light within the geometrical shadow of the opaque obstacles is called diffraction of light.
  - **Diffraction due to Single Slit**
    - Angular width of the central maxima $= \dfrac{2\lambda}{d}$.
    - Width of the central maxima $= \dfrac{2\lambda D}{d}$.

  where, D is the distance of the slit from the screen and d is the slit width.
- **Condition for the Minima on the either Side of the Central Maxima**

$$d \sin\theta = n\lambda, \qquad \text{where } n = 1,2,3,....$$

- **Relation between Phase Difference and Path Difference**

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

where, $\Delta\phi$ is the phase difference and Δx is the path difference.

Practice Exercise

Multiple Choice Questions

Q 1. Which of the following is correct for light diverging from a point source?
a. The intensity decreases in proportion for the distance squared.
b. The wavefront is parabolic.
c. The intensity at the wavefront does not depend on the distance.
d. None of the above

Q 2. The refractive index of glass is 1.5 for light waves of $\lambda = 6000$ Å in vacuum. Its wavelength in glass is:
a. 2000 Å b. 4000 Å
c. 1000 Å d. 3000 Å

Q 3. The phenomena which is not explained by Huygens' construction of wavefront:
a. reflection b. diffraction
c. refraction d. origin of spectra

Q 4. A plane wave passes through a convex lens. The geometrical shape of the wavefront that emerges is:
a. plane b. diverging spherical
c. converging spherical d. None of these

Q 5. In a Young's double slit experiment, the path difference at a certain point on the screen between two interfering waves is 1/8th of the wavelength. The ratio of intensity at this point to that at the centre of a bright fringe is close to: *(CBSE SQP 2022-23)*
a. 0.80 b. 0.74
c. 0.94 d. 0.85

Q 6. When interference of light takes place:
a. energy is created in the region of maximum intensity.
b. energy is destroyed in the region of maximum intensity.
c. conservation of energy holds good and energy is redistributed.
d. conservation of energy does not hold good.

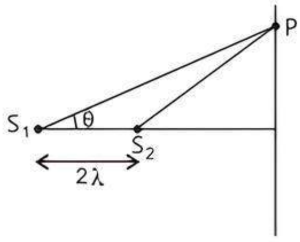
Q 7. In the case of light waves from two coherent sources S_1 and S_2, there will be constructive interference at an arbitrary point P, if the path difference $S_1P - S_2P$ is:
a. $\left(n+\dfrac{1}{2}\right)\lambda$ b. $n\lambda$
c. $\left(n-\dfrac{1}{2}\right)\lambda$ d. $\dfrac{\lambda}{2}$

Q 8. 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? *(CBSE 2023)*
(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

Q 9. In the Young's double slit experiment, the fringe pattern as seen on the screen is:
a. parabola b. hyperbola
c. ellipse d. spiral

Q 10. The light sources used in Young's double slit experiment are:
a. incoherent b. coherent
c. white light d. blue-green-red light

Q 11. In Young's double slit experiment, the slits are horizontal. The intensity at a point P as shown in figure is $\dfrac{3}{4}I_0$, where I_0 is the maximum intensity. Then the value of θ is:
(Given the distance between the two slits S_1 and S_2 is 2λ.)



a. $\cos^{-1}\left(\dfrac{1}{12}\right)$ b. $\sin^{-1}\left(\dfrac{1}{12}\right)$
c. $\tan^{-1}\left(\dfrac{1}{12}\right)$ d. $\sin^{-1}\left(\dfrac{3}{5}\right)$

Q 12. Young's experiment is performed with light of wavelength 6000 Å wherein 16 fringes occupy a certain region on the screen. If 24 fringes occupy the same region with another light of wavelength λ, then λ is:

a. 6000 Å b. 4500 Å c. 5000 Å d. 4000 Å

Q 13. In Young's double slit experiment two disturbances arriving at a point P have phase difference of $\frac{\pi}{3}$. The intensity of this point expressed as a fraction of maximum intensity I_0 is :

a. $\frac{3}{2}I_0$ b. $\frac{1}{2}I_0$ c. $\frac{4}{3}I_0$ d. $\frac{3}{4}I_0$

Q 14. In a Young's double slit experiment, the source is white light. One of the holes is covered by a red filter and another by a blue filter. In this case: *(NCERT EXEMPLAR)*

a. there shall be alternate interference patterns of red and blue
b. there shall be an interference pattern for red distinct from that for blue
c. there shall be no interference fringes
d. there shall be an interference pattern for red mixing with one for blue

Q 15. 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? *(CBSE 2023)*

a. 420 nm b. 750 nm c. 630 nm d. 500 nm

Q 16. In a single-slit diffraction experiment, the width of the slit is halved. The width of the central maximum, in the diffraction pattern, will become: *(CBSE 2023)*

a. half b. twice
c. four times d. one-fourth

Q 17. A slit of width a is illuminated by white light. The first minimum for red light ($\lambda = 6500$ Å) will fall at $\theta = 30°$ when a will be :

a. 3200 Å b. 6.5×10^{-4} mm
c. 1.3 micron d. 2.6×10^{-4} cm

Q 18. A parallel beam of light of wavelength 600 nm is incident normally on a slit of width d. If the distance between the slits and the screen is 0.8 m and the distance of 2nd order maximum from the centre of the screen is 15 mm. The width of the slit is :

a. 40 μm b. 80 μm c. 160 μm d. 200 μm

Q 19. In single slit diffraction pattern:

a. central fringe has negligible width than others
b. all fringes are of same width
c. central fringes do not exist
d. None of the above

Q 20. In a single slit diffraction experiment, the width of the slit is made double its original width. Then, the central maxima on the diffraction pattern will become :

a. narrower and fainter b. narrower and brighter
c. broader and fainter d. broader and brighter

Assertion & Reason Type Questions

Directions (Q.Nos. 21-29): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 21. Assertion (A): In Young's experiment, the fringe width for dark fringes is different from that for white fringes.
Reason (R): In Young's double slit experiment, the fringes are performed with a source of white light, then only black and bright fringes are observed.

Q 22. Assertion (A): For best contrast between maxima and minima in the interference pattern of Young's double slit experiment, the intensity of light emerging out of the two slits should be equal.
Reason (R): The intensity of interference pattern is proportional to square of amplitude.

Q 23. Assertion (A): In Young's double slit experiment, the fringes become indistinct if one of the slit is covered with cellophane paper (a thin transparent sheet made of regenerated cellulose).
Reason (R): The cellophane paper decreases the wavelength of light.

Q 24. Assertion (A): The fringe closest on either side of the central white fringe in case of interference pattern due to white light is red and the farthest appears blue.
Reason (R): The interference patterns due to different component colours of white light overlap.

Q 25. Assertion (A): The film which appears bright in reflected system will appear dark in the transmitted light and vice-versa.
Reason (R): The conditions for film to appear bright or dark in reflected light are just reverse to those in the transmitted light.

Q 26. Assertion (A): Thin films such as soap bubble or a thin layer of oil on water show beautiful colours when illuminated by white light.
Reason (R): It happens due to the interference of light reflected from the upper surface of the thin film.

Q 27. Assertion (A): When a tiny circular obstacle is placed in the path of light from some distance, a bright spot is seen at the centre of shadow of the obstacle.
Reason (R): Destructive interference occurs at the centre of the shadow.

Q 28. Assertion (A): Coloured spectrum is seen when we look through a muslin cloth.

Reason (R): It is due to the diffraction of white light on passing through fine slits.

Q 29. Assertion (A): If we look clearly at the shadow cast by an opaque object, close to the region of geometrical shadow, alternate dark and bright regions can be seen.

Reason (R): This happens due to the phenomenon of interference.

Fill in the Blanks Type Questions

Q 30. Wavefront is the locus of all points, where the particles of the medium vibrate with the same ....

Q 31. In Young's double slit experiment with monochromatic light, the central fringe will be ....

Q 32. In the phenomenon of ...., energy is conserved but it is redistributed.

Q 33. .... of light occurs when size of the obstacle of aperture is comparable to wavelength of light.

Answers

1. (a) The intensity decreases in proportion for the distance squared.

2. (b) 4000 Å

We know, $\mu = \frac{c}{v} = \frac{\lambda_v}{\lambda_g}$

$$\therefore \quad \lambda_g = \frac{\lambda_v}{\mu} = \frac{6000}{1.5} = 4000 \text{ Å}$$

3. (d) origin of spectra

4. (c) converging spherical

5. (d) 0.85

In Young's double slit experiment, the relation between path difference and phase difference is given by,

$$\Delta\delta = \frac{2\pi}{\lambda} \times \Delta x$$

where, $\Delta\delta$ = phase difference
Δx = path difference
λ = wavelength

When path difference = $\lambda/8$

Phase difference, $\Delta\delta = \frac{2\pi}{\lambda} \times \frac{\lambda}{8} = \frac{\pi}{4}$

$$\therefore \text{ Intensity, } I = I_0 \cos^2\left(\frac{\Delta\delta}{2}\right) = I_0 \cos^2\left(\frac{\pi}{8}\right)$$

$$= I_0\left(\frac{1+\cos\frac{\pi}{4}}{2}\right) \quad [\because \cos 2\theta = 2\cos^2\theta - 1]$$

$$= I_0\left(\frac{1+\frac{1}{\sqrt{2}}}{2}\right)$$

$$= 0.85\, I_0$$

6. (c) conservation of energy holds good and energy is redistributed

7. (b) $n\lambda$

Constructive interference occurs when the path difference ($S_1P - S_2P$) is an integral multiple of λ.

i.e., $S_1P - S_2P = n\lambda$

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

8. (c) (i) remains constant but (ii) increases.

9. (b) hyperbola

10. (b) coherent

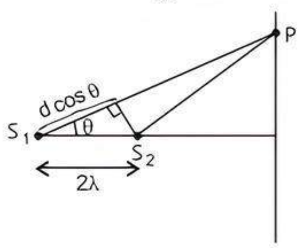
11. (a) $\cos^{-1}\left(\frac{1}{12}\right)$

Here, $\frac{I}{I_0} = \frac{3}{4}$ (given)

$$\Rightarrow \cos^2\left(\frac{\phi}{2}\right) = \frac{3}{4} \qquad \left[\because I = I_0 \cos^2\left(\frac{\phi}{2}\right)\right]$$

$$\text{or} \quad \cos\frac{\phi}{2} = \frac{\sqrt{3}}{2} \quad \text{or} \quad \phi = 60^\circ = \frac{\pi}{3}$$

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



From the figure, path difference

$d\cos\theta = 2\lambda\cos\theta$ $(\because d = 2\lambda)$

$$\therefore \quad \frac{\pi}{3} = \frac{2\pi}{\lambda} 2\lambda\cos\theta$$

$$\cos\theta = \frac{1}{12}$$

$$\theta = \cos^{-1}\left(\frac{1}{12}\right)$$

12. (d) 4000 Å

We know, $n_1\lambda_1 = n_2\lambda_2$

$$\Rightarrow \quad \lambda_2 = \frac{n_1}{n_2} \cdot \lambda_1$$

$$= \frac{16 \times 6000 \text{ Å}}{24} = 4000 \text{ Å}$$

13. (d) $\frac{3}{4} I_0$

The resultant intensity, $I = I_0 \cos^2\frac{\phi}{2}$

Here, I_0 is the maximum intensity and $\phi = \frac{\pi}{3}$.

$$\therefore \quad I = I_0\cos^2\left(\frac{\pi}{3\times 2}\right) = I_0\cos^2\frac{\pi}{6} = \frac{3}{4} I_0$$

14. (c) there shall be no interference fringes.

The light from two slits of Young's double slit experiment is of different colours/wavelengths/frequencies. Hence, there shall be no interference fringes.

15. (a) 420 nm

Given, $\lambda = 700$ nm

□ We know that, position of nth bright fringe

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

□ For 3rd bright fringe $y_3 = \frac{3\times 700\times D}{d} = \frac{2100\,D}{d}$

□ The 5th bright fringe due to light of wavelength λ' is formed at y_3.

□ $$y_5 = y_3$$

or $$\frac{5\times\lambda' D}{d} = \frac{2100D}{d}$$

$$5\lambda' = 2100$$

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

16. (b) twice

17. (c) 1.3 micron

For first minimum, $a\sin\theta = 1\lambda$

$$a = \frac{\lambda}{\sin\theta} = \frac{6.5\times 10^{-7}}{\sin 30^\circ}$$

$$= 13\times 10^{-7} = 1.3 \text{ micron}$$

18. (b) 80 μm

Distance of 2nd order maximum from the centre of the screen

$$x = \frac{5}{2}\frac{D\lambda}{d}$$

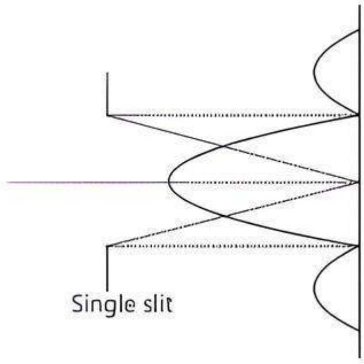
Here, $D = 0.8$ m, $x = 15$ mm $= 15\times 10^{-3}$ m

$\lambda = 600$ nm $= 600\times 10^{-9}$ m

$$\therefore \quad d = \frac{5}{2}\cdot\frac{D\lambda}{x} = \frac{5}{2}\times\frac{0.8\times 600\times 10^{-9}}{15\times 10^{-3}} = 80\,\mu\text{m}$$

19. (d) None of the above.

The following diagram shows a single slit diffraction pattern.



Intensity pattern

As, it is clear from above diagram, in single slit diffraction, the central fringe has maximum intensity and has width double than other fringes.

20. (a) When the width of the slit become double *i.e.* $d = 2d$, then the central maxima on the diffraction pattern will become narrower and fainter.

Width of central maxima,

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

As, we increase d to $2d$, β become $\beta/2$.

So, it becomes narrower and fainter.

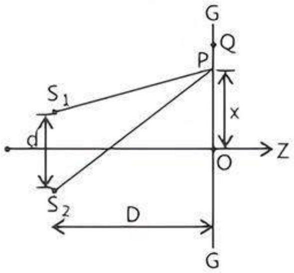
21. (d) In Young's experiments fringe width for dark and white fringes are same while in Young's double slit experiment when a white light as a source is used, the central fringe is white around which few coloured fringes are observed on either side.

22. (b) When intensity of light emerging from two slits is equal, the intensity at minima $I_{min} = (\sqrt{I_a} - \sqrt{I_b})^2 = 0$, or absolute dark.

It provides a better contrast.

23. (c) When one of slits is covered with cellophane paper, the intensity of light emerging from the slit is decreased (because this medium is translucent). Now the two interfering beam have different intensities or amplitudes. Hence intensity at minima will not be zero and fringes will become indistinct.

24. (b) The interference patterns due to different component colours of white light overlap incoherently.



The central bright fringes for different colours are at the same position. Therefore, the central fringe is white. For a point P at which $S_2P - S_1P = \frac{\lambda_b}{2}$, where $\lambda_b = 4000$ Å represents the wavelength for the blue colour, the blue component will be absent and the fringe will appear red in colour. Slightly farther away where $S_2Q - S_1Q = \lambda_b = \frac{\lambda_r}{2}$ where $\lambda_r \approx 8000$ Å is the wavelength for the red colour, the fringe will be predominantly blue. Thus, the fringe closest on either side of the central white fringe is red and the farthest will appear blue.

25. (a) For reflected system of the film, the maxima or constructive interference is $2\mu t\cos r = \frac{(2n-1)\lambda}{2}$ while the maxima for transmitted system of film is given by equation $2\mu t\cos r = n\lambda$, where t is thickness of the film and r is angle of reflection.

From these two equations, we can see that condition for maxima in reflected system and transmitted system are just opposite.

26. (c) The beautiful colours are seen on account of interference of light reflected from the upper and the lower surfaces of the thin films.

27. (c) As the waves diffracted from the edges of circular obstacle, placed in the path of light interfere constructively at the centre of the shadow resulting in the formation of a bright spot.

28. (a) It is quite clear that the coloured spectrum is seen due to diffraction of white light on passing through fine slits made by fine threads in the muslin cloth.

29. (c) This happens due to the phenomenon of diffraction. It is a general characteristics exhibited by all types of waves, sound waves, light waves, water waves or matter waves.

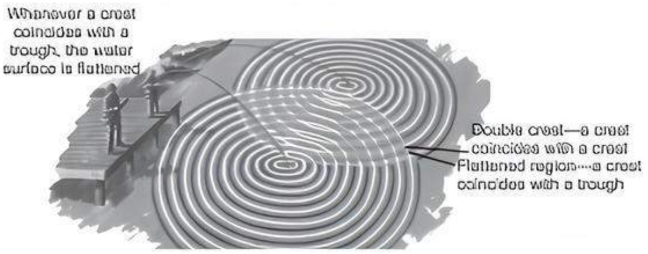
30. phase 31. bright

32. interference 33. Diffraction

Case Study Based Questions

Case Study 1

Jimmy and Johnny both were creating a series of circular waves while fishing in the water. The waves form a pattern similar to the diagram as shown. Their friend, Anita, advised Jimmy and Johnny not to play with water for a long time. She then observed beautiful patterns of ripples which became very colourful. When her friend Lata poured an oil drop on it. Lata, a 12th standard girl, had explained the cause for colourful ripple patterns to Anita earlier.



Read the given passage carefully and give the answer of the following questions:

Q 1. Name the phenomenon involved in the activity :

a. reflection b. refraction

c. interference d. polarisation

Q 2. A surface over which an optical wave has a constant phase is called :

a. wave b. wavefront

c. elasticity d. None of these

Q 3. Which of the following is correct for light diverging from a point source ?

a. The intensity decreases in proportion for the distance squared.

b. The wavefront is parabolic.

c. The intensity at the wavelength does not depend on the distance.

d. None of the above

Q 4. Huygens' concept of secondary wave :

a. allows us to find the focal length of a thick lens

b. is a geometrical method to find a wavefront

c. is used to determine the velocity of light

d. is used to explain polarisation

Answers

1. (c) interference
2. (b) wavefront

   A wavefront is the locus of points having the same phase of oscillation.
3. (a) The intensity decreases in proportion for the distance squared.
4. (b) is a geometrical method to find a wavefront

Case Study 2

Geeta was watching her favourite TV programme KBC. Suddenly the picture started shaking on the TV screen. She asked her elder brother to check the dish antenna. Her brother found nothing wrong with the antenna. A little later, Geeta again noticed the same problem on the TV screen. At the same time, she heard the sound of a low flying aircraft passing over their house. She asked her brother again. Her brother being a Physics student explained the cause of shaking the picture on the TV screen when aircraft passes over head.

Read the given passage carefully and give the answer of the following questions:

Q 1. Why does the picture started shaking when a low flying aircraft passes overhead?

a. Due to interference b. Due to reflection

c. Due to refraction d. Due to polarisation

Q 2. The main principle used in interference is ....

a. Heisenberg's Uncertainty Principle

b. Superposition Principle

c. Quantum Mechanics

d. Fermi Principle

Q 3. When two waves of same amplitude add constructively, the intensity becomes :

a. double b. half

c. four times d. one-fourth

Q 4. The shape of the fringes observed in interference is:

a. straight b. circular c. hyperbolic d. elliptical

Answers

1. (a) Due to Interference
2. (b) Superposition Principle

   Interference is based on superposition principle.
3. (c) four times.

   $I \propto A^2$
4. (c) hyperbolic

   Fringes observed in interference is hyperbolic.

Case Study 3

Rohan observed a thin film such as soap bubble or a thin layer of oil on water show beautiful colours

when illuminated by white light. He felt happy and surprised to see that. He went to his Physics teacher to understand the reason behind it. The teacher explained him that a thin film of oil spread over water shows interference of light due to interference between the light waves reflected by the lower and upper surface of the thin film. On understanding the phenomenon, Rohan then gave an example of thin film of kerosene oil which is spread over water to prevent malaria and dengue.

Read the given passage carefully and give the answer of the following questions:

Q 1. If instead of monochromatic light, white light is used for interference of light, what would be the change in the observation?

a. The pattern will not be visible.

b. The shape of the pattern will change from hyperbolic to circular.

c. Coloured fringes will be observed with a white bright fringe at the centre.

d. The bright and dark fringes will change position

Q 2. Zero order fringe can be identified using:

a. white light b. yellow light

c. achromatic light d. monochromatic light

Q 3. The interference pattern of soap bubble changes continuously.

a. True b. False

c. Neither a. nor b. d. Both a. and b.

Q 4. A thin sheet of refractive index 1.5 and thickness 1 cm is placed in the path of light. What is the path difference observed?

a. 0.003 m b. 0.004 m c. 0.005 m d. 0.006 m

Answers

1. (c) Coloured fringes will be observed with a white bright fringe at the centre.
2. (a) white light 3. (a) True
4. (c) 0.005 m

   Given, $\mu = 1.5$

   Thickness $t = 1$ cm $= 0.01$ m

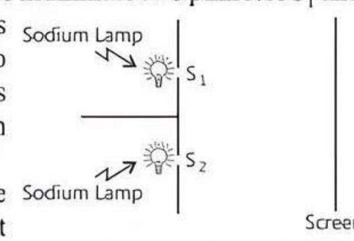
   $\therefore$ Path difference $= (\mu - 1)t = (1.5 - 1) \times 0.01$

   $= 0.5 \times 0.01 = 0.005$ m

Case Study 4

Interference is based on the superposition principle. According to this principle, at a particular point in the medium, the resultant displacement produced by a number of waves is the vector sum of the displacements produced by each of the waves.

If two sodium lamps illuminate two pinholes S_1 and S_2, the intensities will add up and no interference fringes will be observed on the screen.



Here the source undergoes abrupt phase change in times of the order of 10-10 seconds.

Read the given passage carefully and give the answer of the following questions:

Q 1. Two coherent sources of intensity 10 W/m^2 and 25 W/m^2 interfere to form fringes. Find the ratio of maximum intensity to minimum intensity.

Q 2. What is the maximum number of possible interference maxima for slit separation equal to twice the wavelength in Young's double-slit experiment?

Q 3. What is the resultant amplitude of a vibrating particle by the superposition of the two waves

$$y_1 = a \sin\left(\omega t + \frac{\pi}{3}\right) \text{ and } y_2 = a \sin \omega t?$$

Q 4. Interference is based on which principle?

Answers

1. Given $I_1 = 10$ W/m^2 and $I_2 = 25$ W/m^2

$$\therefore \frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} \Rightarrow \frac{10}{25} = \frac{a_1^2}{a_2^2} \Rightarrow \frac{a_1}{a_2} = \frac{3.16}{5}$$

or $a_1 = \dfrac{3.16}{5} a_2 = 0.6324\, a_2$

$$\therefore \frac{I_{max}}{I_{min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{[0.6324\, a_2 + a_2]^2}{[0.6324\, a_2 - a_2]^2}$$

$$= \frac{\left(\frac{0.6324 a_2}{a_2} + 1\right)^2}{\left(\frac{0.6324 a_2}{a_2} - 1\right)^2} = \left(\frac{1.6324}{-0.3676}\right)^2 = 19.724$$

2. The condition for possible interference maxima on the screen is, $d \sin\theta = n\lambda$
where d is slit separation and λ is the wavelength.
As $d = 2\lambda$ (given)

$\therefore \quad 2\lambda \sin\theta = n\lambda$

or $\quad 2 \sin\theta = n$

For number of interference maxima to be maximum,

$\sin\theta = 1$

$\therefore \quad n = 2$

The interference maxima will be formed when

$n = 0, \pm 1, \pm 2$

Hence, the maximum number of possible maxima is 5.

3. Given, $y_1 = a \sin\left(\omega t + \frac{\pi}{3}\right)$ and $y_2 = a \sin \omega t$

Resultant amplitude,

$$A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2 \cos\phi}, \text{ where } \phi = \frac{\pi}{3} \text{ and}$$

$$a_1 = a_2 = a$$

$$= \sqrt{a^2 + a^2 + 2aa \cos\frac{\pi}{3}} = \sqrt{3}\,a$$

4. Superposition principle.

Case Study 5

Diffraction of light is bending of light around the corners of an object whose size is comparable with the wavelength of light. Diffraction actually defines the limits of ray optics. This limit for optical instruments is set by the wavelength of light. An experimental arrangement is set up to observe the diffraction pattern due to a single slit.

Read the given passage carefully and give the answer of the following questions:

Q 1. How will the width of central maxima be affected if the wavelength of light is increased?

Q 2. Under what condition is the first minima obtained?

Q 3. Write two points of difference between interference and diffraction patterns.

Or

Two students are separated by a 7 m partition wall in a room 10 m high. If both light and sound waves can bend around obstacles, how is it that the students are unable to see each other even though they can converse easily? *(CBSE 2023)*

Answers

1. The width of the central maxima is directly proportional to the wavelength, therefore if the wavelength of light is increased, then width of central maxima also increases.

2. Condition for first minima due to a single slit,
$a \sin\theta = \lambda$
where, a = width of slit.

3. **Difference between Interference and Diffraction Pattern**

S. No.	Basis of Difference	Interference Pattern	Diffraction Pattern
1.	Fringe width	Fringe width is constant.	Fringe width varies.
2.	Source of fringes	Fringes are obtained with the coherent light coming from two slits.	Fringes are obtained with the monochromatic light coming from single slit.

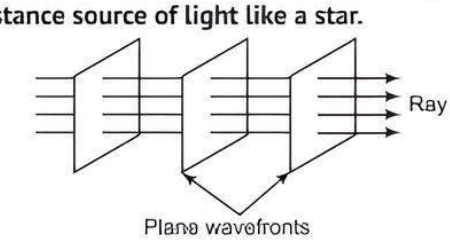
Or

Bending of waves by obstacles by a large angle is possible when the size of the obstacle is comparable to the wavelength of the waves. On the one hand, the wavelength of light waves is too small in comparison to the size of the obstacle. Thus, the diffraction angle will be very small. Hence, the students are unable to see each other. On the other hand, the size of the wall is comparable to the wavelength of the sound waves. Thus, the bending of waves takes place at a large angle. Hence, the students are able to hear each other.

Very Short Answer Type Questions

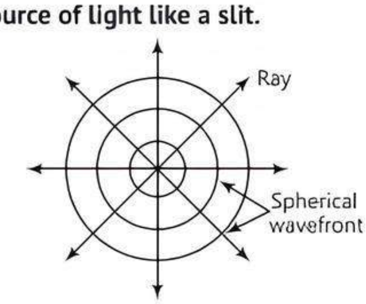
Q 1. Sketch the wavefront that will emerge from a distance source of light like a star.

Ans.



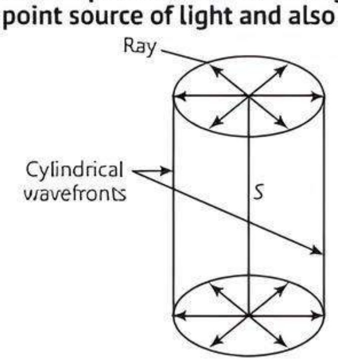
Q 2. Sketch the wavefront that will emerge from a linear source of light like a slit.

Ans.



Q 3. Sketch the shape of wavefront emerging/diverging from a point source of light and also mark the rays.

Ans.

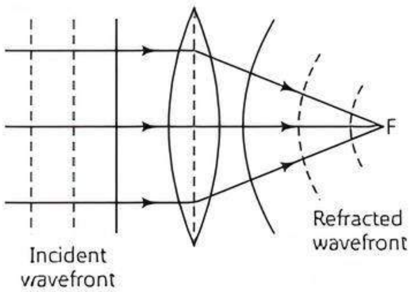


TiP

Practice plane wavefront, spherical wavefront and cylindrical wavefront.

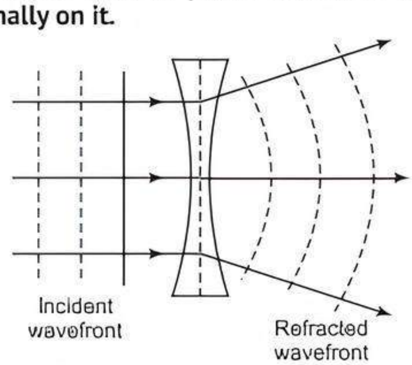
Q 4. Sketch the refracted wavefront emerging from a convex lens, if plane wavefront is incident normally on it. *(CBSE 2016, 15)*

Ans.



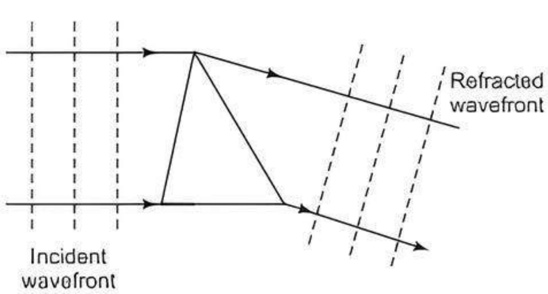
Q 5. Sketch the refracted wavefront emerging from a concave lens, if plane wavefront is incident normally on it.

Ans.



Q 6. Sketch the refracted wavefront emerging from a prism, if plane wavefront is incident normally on it.

Ans.



Q 7. What is the phase difference between two points on the same wavefront?

Ans. Phase difference between two points on the same wavefront is zero.

Q 8. Can Huygens' theory explain the photoelectric effect ?

Ans. No, Huygens' theory cannot explain the photoelectric effect.

Q 9. When a wave undergoes reflection at an interface from rarer to denser medium, what is the adhoc change in its phase ? *(CBSE 2020)*

Ans. The adhoc change in its phase is π.

Q 10. Two coherent monochromatic light beams of intensities I and $4I$ superimpose. What will be the maximum and minimum intensities?

Sol. $I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}$

$$= I + 4I + 2\sqrt{I \times 4I} = 9I$$

$I_{min} = I_1 + I_2 - 2\sqrt{I_1 I_2}$

$$= I + 4I - 2\sqrt{I \times 4I} = I$$

Q 11. The ratio of intensities of two waves is 1:25, what is the ratio of their amplitudes ?

Sol. Ratio of amplitudes $= \sqrt{\dfrac{1}{25}} = \dfrac{1}{5} = 1:5$

Q 12. What should be the order of the size of obstacle/ aperture for observing diffraction of light?

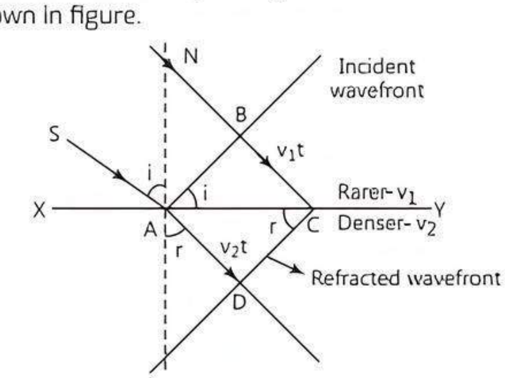
Ans. It should be of the order of the wavelength of light used.

Short Answer Type-I Questions

Q 1. Define wavefront of a travelling wave. Using Huygens' principle, obtain the law of refraction at a plane interface when light passes from denser to rarer medium. *(CBSE 2020)*

Ans. Wavefront: The locus of all those particles which are vibrating in the same phase at any instant is called wavefront. Thus, a wavefront is a surface of constant phase.

Laws of refraction on the basis of Huygens wave theory: Consider a plane wavefront AB incident on a plane surface XY, separating two media 1 and 2, as shown in figure.



Let v_1 and v_2 be the velocities of light in two media, with $v_2 < v_1$.

The wavefront first strikes at point A and then at the successive points towards C. According to Huygens' principle, from each point on AC, the secondary wavelets starts growing in the second medium with speed v_2. Let the disturbance takes time t to travel from B to C, then BC = $v_1 t$.

During the time the disturbance from B reaches the point C, the secondary wavelets from point A must have spread over a hemisphere of radius AD = $v_2 t$ in the second medium. The tangent plane CD drawn from point C over this hemisphere of radius $v_2 t$ will be the new refracted wavefront.

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

From right angle ΔABC, we have,

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

From right angle ΔADC, we have,

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

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

or
$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}_1\mu_2$$

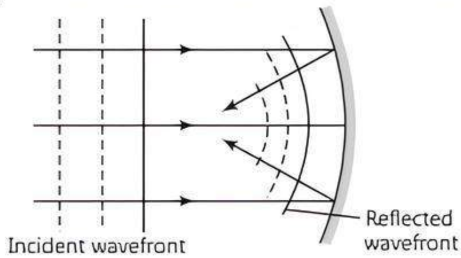
This proves Snell's law of refraction.
Further, since the incident ray SA, the normal AN and the refracted ray AD are respectively perpendicular to the incident wavefront AB, the dividing surface XY and the refracted wavefront CD, all perpendicular to the plane of the paper, therefore, they lie in the plane of the paper, *i.e.*, in the same plane. This proves another law of refraction.

COMMON ERR(!)R

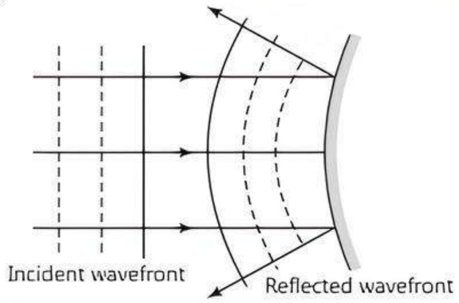
Students often misunderstand the question as reflection instead of refraction or vice-versa.

Q 2. Sketch the reflected wavefront emerging from a (i) concave mirror, (ii) convex mirror, if plane wavefront is incident normally on it. *(CBSE 2015)*

Ans. (i) **Reflected wavefront from a concave mirror:**



(ii) **Reflected wavefront from a convex mirror:**



Q 3. Define wavefront. How is it different from a ray? *(CBSE 2017, 16, 15)*

Ans. Wavefront: Continuous locus of all the particles of a medium vibrating in the same phase is called wavefront .

Difference from a ray:

(i) A ray is always normal to the wavefront at each point.

(ii) A ray gives the direction of propagation of light wave while the wavefront is the surface of constant phase.

TIP

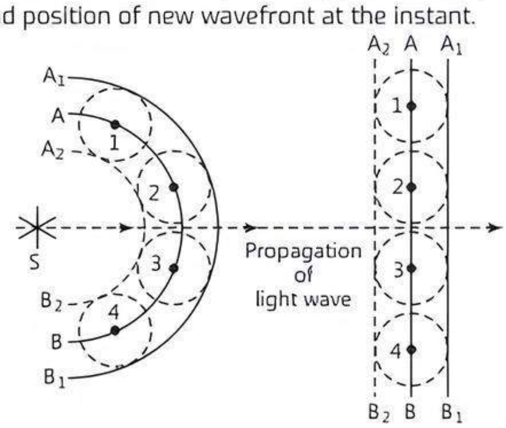
Learn definition of wavefront by heart.

Q 4. State Huygens' Principle. *(CBSE 2016, 15)*

Ans. Huygens' Principle:

(i) Each point on the wavefront acts as a fresh source of new disturbance, called secondary wavelets, which spreads out in all directions with the same velocity as that of the original wave.

(ii) The forward envelope of these secondary wavelets drawn at any instant, gives the shape and position of new wavefront at the instant.



COMMON ERR(!)R

Many students forget to write all points of Huygens' principle.

Q 5. A narrow slit is illuminated by a parallel beam of monochromatic light of wavelength λ equals to 6000 Å and the angular width of the central maxima 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'. *(CBSE SQP 2022-23)*

Sol. We know, angular width, $2\theta = 2\lambda/d$

Given, $\lambda = 6000$ Å

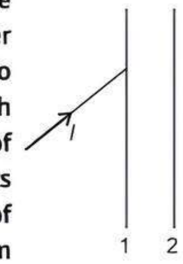
In case of new wavelength (assumed λ' here), angular width decreases by 30%.

$$= \left(\frac{100-30}{100}\right) 2\theta = 0.70\,(2\theta)$$

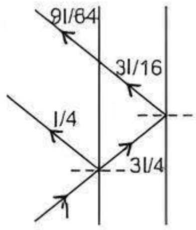
$$\frac{2\lambda'}{d} = 0.70 \times (2\lambda/d)$$

$$\therefore \qquad \lambda' = 4200 \text{ Å}$$

Q 6. A narrow monochromatic beam of light of intensity I is incident on a glass plate as shown in the figure. Another identical glass plate is kept close to the first one and parallel to it. Each glass plate reflects 25 per cent of the light incident on it and transmits the remaining. Find the ratio of the minimum and the maximum intensities in the interference pattern formed by the two beams obtained after one reflection at each plate.



Sol. As it is clear from the figure, the intensities of the two reflected beams will be $I/4$ and $9I/64$.



Now, $I_{max} = K(a_1 + a_2)^2$

$$= K\left[\frac{\sqrt{I}}{2} + \frac{3\sqrt{I}}{8}\right]^2 = \frac{49\,IK}{64}$$

and $I_{min} = K\left[\frac{\sqrt{I}}{2} - \frac{3\sqrt{I}}{8}\right]^2 = \frac{IK}{64}$.

$$\therefore \quad \frac{I_{min}}{I_{max}} = \frac{I/64}{49I/64} = 1:49$$

Q 7. In Young's double slit experiment using monochromatic light of wavelength λ, the intensity at a point on the screen where path difference is λ, is K units. What is the intensity of light at a point where path difference is $\lambda/3$? *(NCERT EXERCISE)*

Sol. If two waves of intensities I_1 and I_2 having phase difference ϕ travelling in the same direction superpose upon each other, then resultant intensity after superposition is given by,

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

If $\quad I_1 = I_2 = I_0$, then

$$I = 2I_0(1 + \cos\phi) = 4I_0\cos^2\frac{\phi}{2}$$

When path difference is λ, the phase difference is 2π.

$$\therefore \quad I = 4I_0\cos^2\pi = 4I_0 = K \qquad \text{(given)} \; ....(1)$$

When path difference, $\Delta x = \frac{\lambda}{3}$, the phase difference is given by,

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

$$I' = 4I_0\cos^2\frac{\pi}{3} \qquad (\text{since } K = 4I_0)$$

$$= K\cos^2\frac{\pi}{3} = K \times \left(\frac{1}{2}\right)^2 = \frac{K}{4}.$$

Q 8. Find the intensity at a point on a screen in Young's double slit experiment where the interfering waves of equal intensity have a path difference of (i) $\lambda/4$, and (ii) $\lambda/3$. *(CBSE 2017)*

Sol. We know that, $\quad I = I_0\cos^2\frac{\phi}{2}$

(i) If path difference $= \frac{\lambda}{4}$

$$\therefore \quad \Delta\phi = \frac{2\pi}{\lambda} \times \Delta x \quad \Rightarrow \quad \Delta\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \frac{\pi}{2}$$

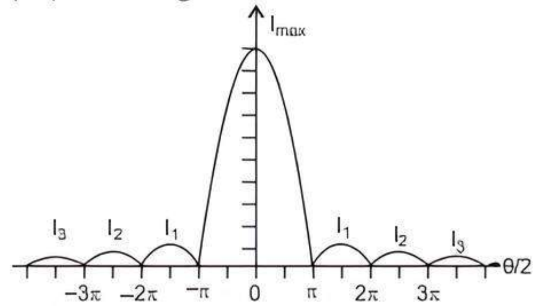
Also, $\quad I = 4I_0\cos^2\frac{\Delta\phi}{2} = 4I_0\cos^2\frac{\pi}{4} = 2I_0$

(ii) If path difference, $\Delta x = \frac{\lambda}{3} \quad \Rightarrow \Delta\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{3} = \frac{2\pi}{3}$

$$\therefore \quad I = 4I_0\cos^2\frac{\Delta\phi}{2} = 4I_0\cos^2\left(\frac{2\pi}{3 \times 2}\right) = I_0$$

Q 9. Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through single slit.

Ans. Plot of intensity distribution of diffraction with proper labelling.



Q 10. A slit of width 'a' is illuminated by red light of wavelength 6500Å. For what value of 'a' will be :

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

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

Sol. Given, $\lambda = 6500$ Å $= 6500 \times 10^{-10}$ m

(i) We know, $a\sin\theta_1 = \lambda$

$$\Rightarrow \quad a = \frac{\lambda}{\sin\theta_1} = \frac{6500 \times 10^{-10}}{\sin 30°}$$

$$= \frac{6500 \times 10^{-10}}{1/2} = 2 \times 6500 \times 10^{-10}$$

$$= 1.3 \times 10^{-6}\,\text{m}$$

(ii) We know, $a\sin\theta_1 = 3\lambda/2$

$$\Rightarrow a = \frac{3\lambda}{2\sin\theta_1} = \frac{3 \times 6500 \times 10^{-10}}{2 \times \sin 30°}$$

$$= \frac{3 \times 6500 \times 10^{-10}}{2 \times 1/2} = 3 \times 6500 \times 10^{-10}$$

$$= 1.95 \times 10^{-6}\,\text{m}$$

Q 11. The wavelengths of two sodium lights 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 position of first maxima of the diffraction pattern observed in the two cases. *(CBSE 2017)*

Sol. Given, $\lambda_1 = 590$ nm $= 590 \times 10^{-9}$ m,

$\lambda_2 = 596$ nm $= 596 \times 10^{-9}$ m,

$D = 1.5$ m, $a = 2 \times 10^{-6}$ m, $y_2 - y_1 = ?$

TiP

First maxima, $y_1 = \frac{3D\lambda}{2a}$.

$$\therefore \; y_2 - y_1 = \frac{3D}{2a}(\lambda_2 - \lambda_1)$$

$$= \frac{3 \times 1.5}{2 \times 2 \times 10^{-6}}(596 \times 10^{-9} - 590 \times 10^{-9})$$

$$= \frac{3 \times 1.5 \times 6 \times 10^{-3}}{4} = 6.75 \times 10^{-3}\,\text{m}$$

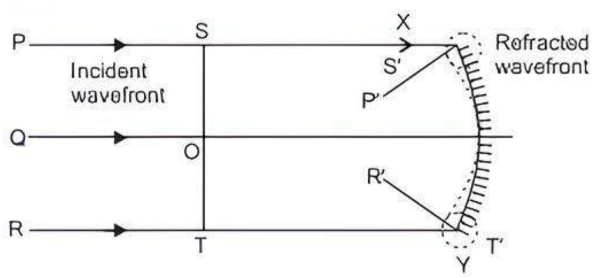
Q 12. State Huygens' principle. How did Huygens' explain the absence of the backwave? *(CBSE 2023)*

Ans. Huygens' principle states that, each point on the given wavefront, called primary wavefront acts as a fresh source of new disturbance, called secondary wavelet which travels in all directions with velocity of light in the medium.

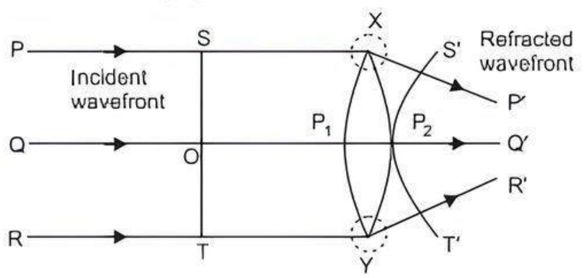
Huygens' argued that the amplitude of the secondary wavelets is maximum in the forward direction and zero in the backward direction, by making this adhoc assumption. He could explain the absence of the backwave.

Q 13. Use Huygens' principle to show reflection/refraction of a plane wave by (i) concave mirror and (ii) a convex lens?

Ans. (i) By a concave mirror.



(ii) By a converging lens

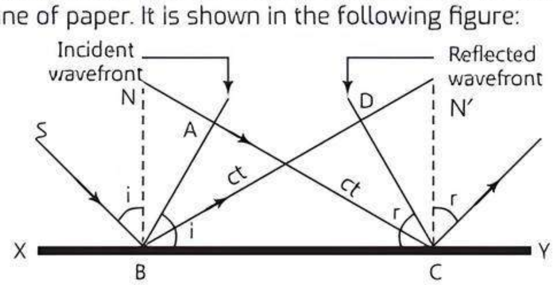


Short Answer Type-II Questions

Q 1. Define the term wavefront. Using Huygens' wave theory, verify the laws of reflection. *(CBSE 2023, 24)*

Ans. Wavefront: The locus of all those particles which are vibrating in the same phase at any instant is called wavefront. Thus, a wavefront is a surface of constant phase.

Laws of reflection on the basis of Huygens' wave theory: Consider a plane wavefront AB incident on the reflecting surface XY, both the wavefront and the reflecting surface being perpendicular to the plane of paper. It is shown in the following figure:



First the wavefront touches the reflecting surface at B and then at the successive points towards C. In accordance with Huygens' principle, from each point on BC, secondary wavelets start growing with the speed 'c'.

During this time the disturbance from A reaches the point C, the secondary wavelets from B must have spread over a hemisphere of radius BD = AC = *ct*, where '*t*' is the time taken by the disturbance to travel from A to C. The tangent plane, CD drawn from the point C over this hemisphere of radius *ct* will be the new reflected wavefront.

Let angles of incidence and reflection be *i* and *r*, respectively.

In ΔABC and ΔDCB, we have

$\angle BAC = \angle CDB$ (each is 90°)

$BC = BC$ (common side)

$CA = BD$ (equal to ct)

$\therefore \quad \Delta ABC \cong \Delta DCB$

Hence, $\angle ABC = \angle DCB$

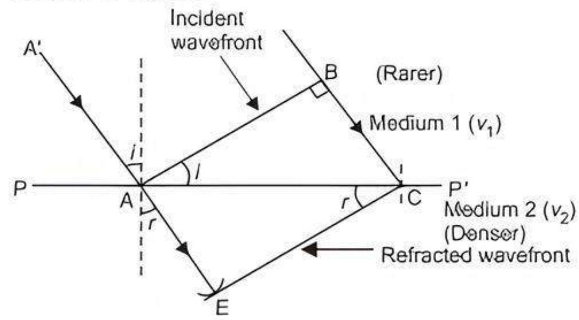
or $\angle i = \angle r$

i.e., the angle of incidence is equal to the angle of reflection. This proves the first law of reflection.

Further, since the incident ray SB, the normal BN and the reflected ray BD are perpendicular respectively to the incident wavefront AB, the reflecting surface XY and the reflected wavefront CD, all of which are perpendicular to the plane of the paper, therefore, they lie in the plane of the paper, *i.e.*, in the same plane. This proves the second law of reflection.

Q 2. A plane wavefront 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 Huygens' construction of secondary wavelets to trace the refracted wavefront. Hence, verify Snell's law of refraction. *(CBSE 2023)*

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



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

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

In order to determine the shape of the refracted wavefront, we draw a sphere, 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 $\quad AE = v_2 t$

$\therefore$ CE would represents the refracted wavefront.
In ΔABC and ΔAEC, we have

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

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

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

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

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.

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

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

$$\Rightarrow \quad \mu_1 \sin i = \mu_2 \sin r$$

This is the Snell's law of refraction.

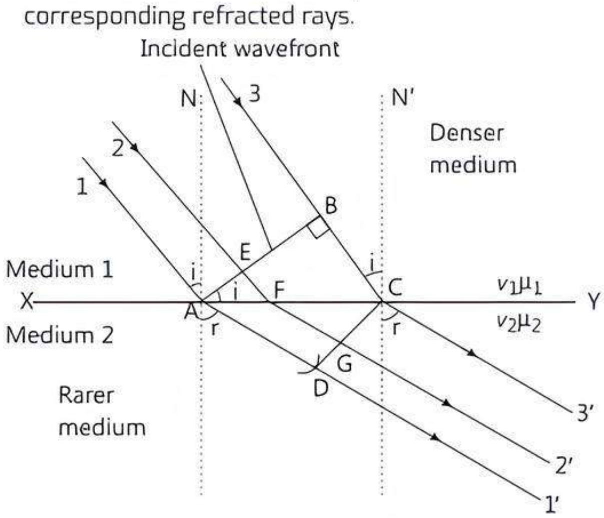
COMMON ERR(!)R

Students often make mistakes in the diagram.

Q 3. 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. *(CBSE SQP 2022 Term-2)*

Ans. **Wavefront:** It is the locus of points (wavelets) having the same phase (a surface of constant phase) of oscillations.

Laws of Refraction (Snell's Law) at a Plane Surface: Let 1, 2, 3 be the incident rays and 1′, 2′, 3′ be the corresponding refracted rays.



If v_1, v_2 are the speeds of light in the two media and t is the time taken by light to go from B to C or A to D or E to G through F, then

$$t = \frac{EF}{v_1} + \frac{FG}{v_2}$$

In ΔAFE, $\quad \sin i = \frac{EF}{AF}$

In ΔFGC, $\quad \sin r = \frac{FG}{FC}$

$$\Rightarrow \quad t = \frac{AF \sin i}{v_1} + \frac{FC \sin r}{v_2} \quad \text{...(1)}$$

$$\Rightarrow \quad t = \frac{AC \sin r}{v_2} + AF\left(\frac{\sin i}{v_1} - \frac{\sin r}{v_2}\right)$$

For rays of light from different parts on the incident wavefront, the values of AF are different. But light from different points of the incident wavefront should take the same time to reach the corresponding points on the refracted wavefront. So, t should not depend upon AF. This is possible only, if

$$\frac{\sin i}{v_1} - \frac{\sin r}{v_2} = 0$$

$$\Rightarrow \quad \frac{\sin}{\sin r} \quad \frac{}{v} \quad \text{...(2)}$$

This is the Snell's law of refraction.

Q 4. Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are wavelength, frequency and speed of (i) reflected light, (ii) refracted light? The refractive index of water is 1.33. *(NCERT EXERCISE)*

Sol. (i) The reflected light travels in air. Hence, its wavelength, frequency and speed are same as of the incident light. The wavelength is $\lambda = 589$ nm.

The frequency is

$$\nu = \frac{c}{\lambda} = \frac{3.0 \times 10^8 \text{ ms}^{-1}}{589 \times 10^{-9} \text{ m}}$$

$$= 5.09 \times 10^{14} \text{ s}^{-1} \text{ (Hz)}.$$

The speed of light in vacuum (or roughly in air) is 3.0×10^8 ms^{-1}.

(ii) The refracted light travels in water. The frequency of light, being independent of the medium, is same as in air, that is

$$\nu = 5.09 \times 10^{14} \text{ Hz}.$$

According to wave theory, the speed of light in water is

$$v = \frac{c}{n} = \frac{3.0 \times 10^8 \text{ ms}^{-1}}{1.33}$$

$$= 2.26 \times 10^8 \text{ ms}^{-1}.$$

Now, the wavelength of light in water is

$$\lambda = \frac{v}{\nu} = \frac{2.26 \times 10^8 \text{ ms}^{-1}}{5.09 \times 10^{14} \text{ s}^{-1}}$$

$$= 0.444 \times 10^{-6} \text{ m}$$

$$= 444 \times 10^{-9} \text{ m} = 444 \text{ nm}.$$

Q 5. (i) 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.

(ii) What kind of fringes do you expect to observe if white light is used instead of monochromatic light? *(CBSE 2018)*

Sol. (i) Given, $\frac{I_2}{I_1} = 50\% = \frac{1}{2} \Rightarrow I_2 = \frac{1}{2}I_1$

Now, ratio of maximum and minimum intensity is given as,

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

$$= \left(\frac{\sqrt{I_1}+\sqrt{I_1/2}}{\sqrt{I_1}-\sqrt{I_1/2}}\right)^2 = \frac{(\sqrt{I_1}+\sqrt{I_1/2})^2}{(\sqrt{I_1}-\sqrt{I_1/2})^2}$$

$$= \frac{(1+1/\sqrt{2})^2}{(1-1/\sqrt{2})^2} = \frac{(\sqrt{2}+1)^2}{(\sqrt{2}-1)^2} = \frac{3+2\sqrt{2}}{3-2\sqrt{2}}$$

$$= \left(\frac{3+2\sqrt{2}}{3-2\sqrt{2}}\right)\times\left(\frac{3+2\sqrt{2}}{3+2\sqrt{2}}\right)$$

$$= \frac{(3+2\sqrt{2})^2}{(3)^2-(2\sqrt{2})^2}$$

$$= 17+12\sqrt{2}$$

(ii) When a white light source is used, the interference patterns due to different component colours of white light overlap incoherently. The central bright fringe for different colours is at centre. So, central bright fringe is white. As $\lambda_{blue} < \lambda_{red}$, fringe closest on either side of central bright fringe is blue and farthest is red. After few fringes, no clear pattern of fringes will be visible.

Q 6. Answer the following questions:

(i) 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.

(ii) 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? *(CBSE 2015)*

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

Here, $\lambda = 600 \text{ nm} = 6\times10^{-7}$ m

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

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

(ii) 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.

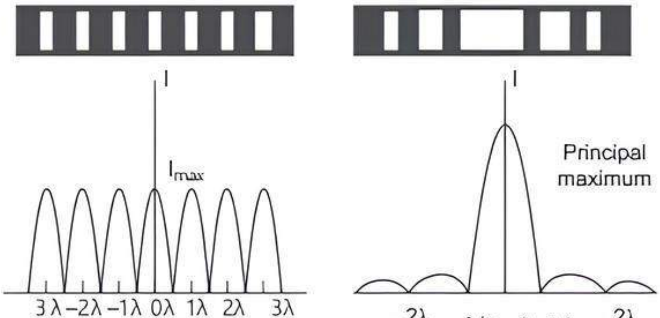
Wavelength of refracted light, $\lambda_r = \lambda/\mu_w$

where, μ_w = refractive index of water.

So, wavelength of refracted wave will be decreased.

Q 7. Draw the intensity pattern for double slit interference and single slit diffraction. Hence, state differences between interference and diffraction patterns.

Ans. Intensity Pattern:



Interference fringe pattern

Diffraction fringe pattern

Difference between Interference and Diffraction

S. No.	Basis of Difference	Interference	Diffraction
1.	Fringe width	Fringe width is constant.	Fringe width varies.
2.	Source of fringes	Fringes are obtained with the coherent light coming from two slits.	Fringes are obtained with the monochromatic light coming from single slit.
3.	Dependency	It depends upon the distance between two openings.	It depends upon the aperture of single slit opening.
4.	Visibility	Many fringes are visible.	Fewer fringes are visible.
5.	Brightness	All fringes are of same brightness.	Central fringe has maximum brightness so, it reduces gradually.
6	Slit or Obstacle	Not required	Required

TiP

The diagrams of the interference and the diffraction should be carefully observed.

Q 8. **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.**

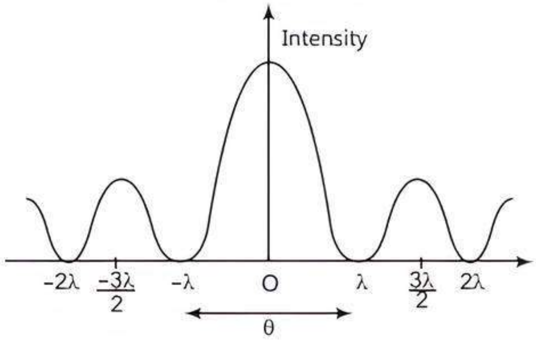
(i) Show the intensity distribution in the pattern with the angular position θ.

(ii) How are the intensity and angular width of central maxima affected when:

(a) width of slit is increased and

(b) separation between slit and screen is decreased? *(CBSE 2020)*

Ans. (i) The intensity distribution in the pattern with the angular position θ is given below:



(ii) (a) Intensity increases and angular width decreases.

(b) Intensity increases but no effect on angular width.

Q 9. **(i) "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.

(ii) Draw the intensity distribution as function of phase angle when diffraction of light takes place through coherently illuminated single slit.

Ans. (i) The total intensity at a point where the phase difference is ϕ is given by

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

where, I_1 and I_2 are the intensities of two individual sources which are equal.

$\therefore \quad I_1 = I_2$ and $\phi = 0$

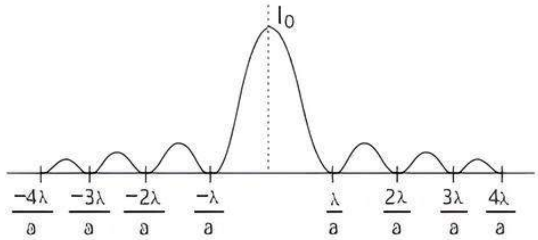
$\therefore \quad I = I_1 + I_1 + 2\sqrt{I_1 I_2}\cos 0°$

$I = 4I_1$

= four times the intensity due to single slit

Thus, intensity on the screen varies between $4I_1$ and 0.

(ii) Intensity distribution as function of phase angle, when diffraction of light takes place through coherently illuminated single slit, is as shown in figure below.



Long Answer Type Questions

Q 1. **(i) Define a wavefront. How is it different from a ray?**

(ii) Using Huygens' construction of secondary wavelets draw a diagram showing the passage of a plane wavefront from a denser to a rarer medium. Using it verify Snell's law.

(iii) In a double slit experiment using light of wavelength 600 nm and the angular width of the fringe formed on a distant screen is 0.1°. Find the spacing between the two slits.

(iv) Write two differences between interference pattern and diffraction pattern.

Ans. (i) **Wavefront:** Continuous locus of all the particles of a medium vibrating in the same phase is called wavefront .

Difference from a ray:

(a) A ray is always normal to the wavefront at each point.

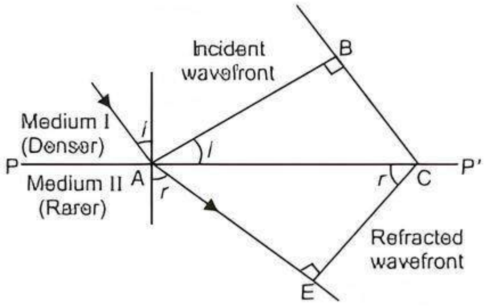
(b) A ray gives the direction of propagation of light wave while the wavefront is the surface of constant phase.

(ii) In the diagram, AB is incident plane wavefront and CE is refracted wavefront.

$\sin i = BC/AC$ and $\sin r = AE/AC$

$\sin i / \sin r = BC/AE = v_1/v_2$ = constant.

This is Snell's law.



(iii) $\theta = \lambda/a$ i.e., $a = \dfrac{\lambda}{\theta} = \dfrac{6\times10^{-7}}{0.1\times\dfrac{\pi}{180}} = 3.4\times10^{-4}$ m

(iv) Difference between Interference and Diffraction:

S. No.	Basis of Difference	Interference	Diffraction
1.	Fringe width	Fringe width is constant.	Fringe width varies.

2.	Source of fringes	Fringes are obtained with the coherent light coming from two slits.	Fringes are obtained with the monochromatic light coming from single slit.

Q 2. (i) 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.

(ii) 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 obtained on the screen.

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

Ans. (i) The features to distinguish is given as:

(a) In Young's experiment, width of all the fringes are equal but in diffraction fringes, width of central fringe is twice the other fringes.

(b) The intensity of all the fringes are equal in interference fringe but intensity of fringes go on decreasing in diffraction as we go away from the central fringe.

(ii) Given, wavelength,

$$\lambda = 500 \text{ nm} = 500 \times 10^{-9} \text{ m}$$

Width of single slit

$$d = 0.2 \text{ mm} = 0.2 \times 10^{-3} \text{ m}$$

Angular width of central fringe $= 2 \times \dfrac{\lambda}{d}$

$$= \frac{2 \times 500 \times 10^{-9}}{0.2 \times 10^{-3}} = \frac{10^{-6}}{2 \times 10^{-4}}$$

$$= \frac{1}{200} = 5 \times 10^{-3} \text{ radian}$$

Let distance between the slit and screen be 1 m.

Linear width of central fringe of single slit

$$= 5 \times 10^{-3} \times 10^{3} \text{ mm} = 5 \text{ mm}$$

Number of double slit fringe accommodated in central fringe $= \dfrac{50}{5} = 10$ fringes.

Q 3. (i) 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

$$I = 4a^2 \cos^2 \frac{\phi}{2}$$

Hence, establish the conditions for constructive and destructive interference.

(ii) What is the effect on the interference fringes in Young's double slit experiment when (a) the width of the source slit is increased; (b) the monochromatic source is replaced by a source of white light? *(CBSE 2015)*

Ans. (i) Given, $y_1 = a \cos \omega t$

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

The resultant displacement is given by

$$y = y_1 + y_2$$
$$= a \cos \omega t + a \cos (\omega t + \phi)$$
$$= a \cos \omega t + a \cos \omega t \cos \phi - a \sin \omega t \sin \phi$$
$$= a \cos \omega t (1 + \cos \phi) - a \sin \omega t \sin \phi$$

Put, $R \cos \theta = a(1 + \cos \phi)$ ...(1)

and $R \sin\theta = a \sin \phi$ ...(2)

By squaring and adding eqs. (1) and (2), we get

$$R^2 = a^2 (1 + \cos^2 \phi + 2 \cos \phi) + a^2 \sin^2 \phi$$

$$= 2a^2(1+\cos\phi) = 4a^2 \cos^2 \frac{\phi}{2}$$

$$I = R^2 = 4a^2 \cos^2 \frac{\phi}{2}$$

For constructive interference, $\cos \dfrac{\phi}{2} = \pm 1$

$$\Rightarrow \quad \frac{\phi}{2} = n\pi$$

$$\Rightarrow \quad \phi = 2n\pi$$

For destructive interference,

$$\cos \frac{\phi}{2} = 0 \quad \Rightarrow \quad \frac{\phi}{2} = (2n+1)\frac{\pi}{2}$$

$$\Rightarrow \quad \phi = (2n + 1)\pi$$

(ii) (a) For fringes to be seen, $s/S \leq \lambda/d$

Condition should be satisfied.

where, s = size of the source and S = distance of the source from the plane of two slits. As, the source slit width increase, the fringe pattern get less and less sharp.

When the source slit is so wide, then above condition is not satisfied and the interference pattern disappears.

(b) The interference pattern due to different colour components of white light overlap. The central bright fringes for different colours are at the same position. Therefore, the central fringes are white. And on the either side of the central fringe, *i.e.* central maxima, Coloured bands will appear.

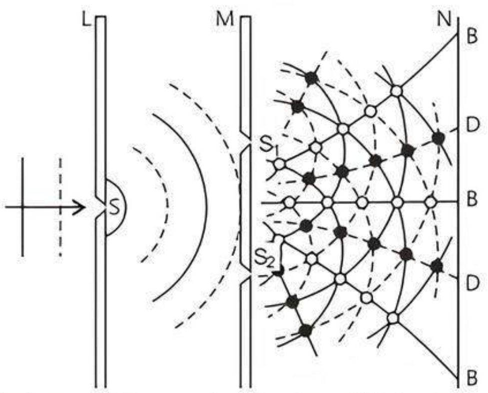
The fringe closed on either side of central white fringe is red and the farthest will be blue. After a few fringes, no clear fringes pattern is seen.

Q 4. (i) What is interference of light waves? Name the interference happen at a place where intensity of light is maximum and minimum.

(ii) In a Young's double slit experiment, the separation between slits is 2×10^{-3} m whereas

the distance of screen from the slits is 2.5 m. A light of wavelengths in the range of 2000-8000 Å is allowed to fall on the slits. Find the wavelength in the visible region that will be present on the screen at 10^{-3} m from the central maximum. Also find the wavelength that will be present at that point of screen in the infrared as well as in the ultraviolet region.**

Ans. (i) **Interference of Light Waves :** When two light waves of same frequency travel simultaneously in the same direction then, due to their superposition, the resultant intensity of light at any point in space is different from the sum of intensities of the two waves. At some points the resultant intensity is maximum while at some other points it is minimum (nearly



darkness). The re-distribution of light intensity due to the superposition of two light waves is called 'interference of light'.

The interference is said to be 'constructive' at points where the resultant intensity is maximum and 'destructive' at points where the resultant intensity is minimum or zero.

TiP

Phase difference for destructive interference is odd [i.e., $(2n + 1)\pi$] and for constructive interference is even [i.e. $2n\pi$].

(ii) The distance of bright fringes from the central maximum on the screen is given by

$$x = m\frac{D\lambda}{d}, \qquad m = 0, 1, 2 \ldots$$

where $m = 0$ corresponds to the central maximum.

$$\therefore \quad \lambda = \frac{xd}{mD}$$

For $m = 1$,
$$\lambda_1 = \frac{(10^{-3}\,\text{m}) \times (2 \times 10^{-3}\,\text{m})}{1 \times (2.5\,\text{m})}$$
$$= 8 \times 10^{-7}\ \text{m}$$
$$= 8000\ \text{Å (infrared)}$$

For $m = 2$,
$$\lambda_2 = \frac{8000\ \text{Å}}{2}$$
$$= 4000\ \text{Å (visible)}$$

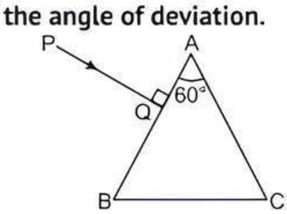
For $m = 3$,
$$\lambda_3 = \frac{8000\ \text{Å}}{3}$$
$$= 2666\ \text{Å (ultraviolet)}$$

For $m = 4$,
$$\lambda_4 = \frac{8000\ \text{Å}}{4}$$
$$= 2000\ \text{Å (ultraviolet)}$$

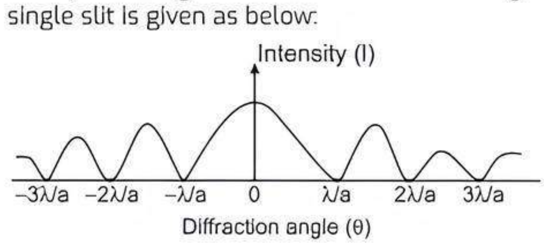
Q 5. (i) Draw the graph showing intensity distribution of fringes with phase angle due to diffraction through a single slit. What is the width of the central maximum in comparison to that of a secondary maximum?

(ii) A ray *PQ* is incident normally on the face *AB* of a triangular prism of refracting angle 60° as shown in figure. The prism 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. *(CBSE SQP 2022-23)*

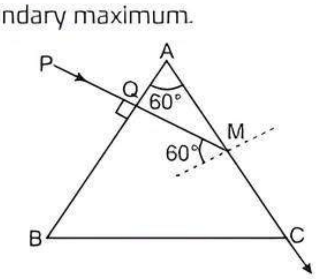


Ans. (i) The graph showing intensity distribution of fringes with phase angle due to diffraction through a single slit is given as below:



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

(ii)



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

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

$\therefore \quad C = 60°$

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

$\therefore$ Angle of emergence, $\angle e = 90°$

From $\quad \angle i + \angle e = \angle A + \angle\delta$

or, $\quad 0° + 90° = 60° + \angle\delta$

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

$\therefore$ Angle of deviation = 30°

Q 6. **(i) 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.**

(ii) 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 the 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. *(CBSE 2019)*

Ans. (i) Difference between Interference and Diffraction:

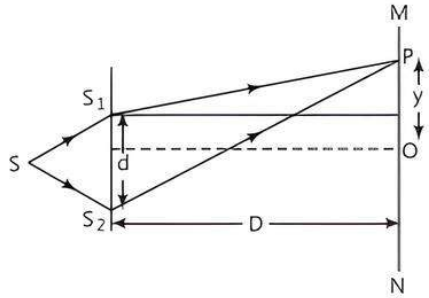
(a) Interference pattern has number of equally spaced bright and dark bands while diffraction pattern has central bright maximum which is twice as wide as the other maxima.

(b) Interference is obtained by the superposition of two waves originating from two narrow slits. The diffraction pattern is the superposition of the continuous family of waves originating from each point on a single slit.

COMMON ERROR

Some students do not know the correct difference between interference of light and diffraction of light.

Derivation: Consider two coherent sources of light S_1 and S_2. The two sources of light will produce an interference pattern on the screen MN. Consider a point P on the screen. Let ϕ be the phase difference due to the path difference $S_2P - S_1P$. Young's arrangement to produce interference pattern is shown in figure.



The electric field from the light at each of the sources S_1 and S_2 can be written as,

$$E_1 = E_0 \sin \omega t \text{ and } E_2 = E_0 \sin (\omega t + \phi)$$

where, each source of light has maximum electric field strength E_0.

At P, by principle of superposition,

$$E_P = E_1 + E_2 = E_0 \sin \omega t + E_0 \sin (\omega t + \phi)$$

$$= 2E_0 \cos \frac{\phi}{2} \sin\left(\omega t + \frac{\phi}{2}\right)$$

As intensity is the square of the amplitude,

$$I = 4E_0^2 \cos^2\left(\frac{\phi}{2}\right)$$

Note that $I_0 = E_0^2$

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

(ii) Given, size of aperture, $a = 3 \text{ mm} = 3 \times 10^{-3}$ m

Wavelength of light, $\lambda = 620 \text{ nm} = 620 \times 10^{-9}$ m

Distance from screen, $D = 1.5$ m

Size of one maxima/minima (except the central),

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

$$d = \frac{620 \times 10^{-9} \text{ m}}{3 \times 10^{-3} \text{ m}} \times 1.5 \text{ m} = 3.1 \times 10^{-4} \text{m}$$

Now, the required separation has four fringes. Hence, the distance is

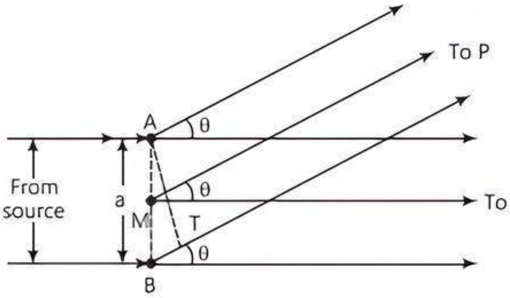
$$4d = 3.1 \times 10^{-4} \times 4 = 1.24 \times 10^{-3} \text{m}$$
$$= 1.24 \text{ mm}$$

COMMON ERROR

Students often forget to convert quantities in SI unit.

Q 7. **A monochromatic light of wavelength λ is incident normally on a narrow slit of width 'a' to produce a diffraction pattern on the screen placed at a distance D from the slit. With the help of a relevant diagram, deduce the condition for obtaining maxima and minima on the screen. Use these conditions to show that angular width of central maximum is twice the angular width of secondary maximum.** *(CBSE 2017)*

Ans. When plane wavefront coming from distant source illuminates the slit of size (= d), each other point within the slit becomes the source of secondary wavelets and these wavelets superpose on each other to generate the maxima and minima on the screen; path difference between the rays, directing to the point P on the screen can be given as :



In ΔABT

$$\sin \theta = \frac{BT}{AB} = \frac{\Delta}{a}$$

Path difference, $\Delta = a \sin \theta$

Condition of Minima: If slit AB is divided into the equal halves (or in even parts) each of size $d/2$, for every point in part AM, there is a point in part MB that contribute the secondary wavelets out of phase (*i.e.*, 180°). So, net contribution from two halves becomes zero and hence intensity falls to zero for path difference

$$\Delta = n\lambda$$

$$\therefore \qquad a \sin\theta = n\lambda$$

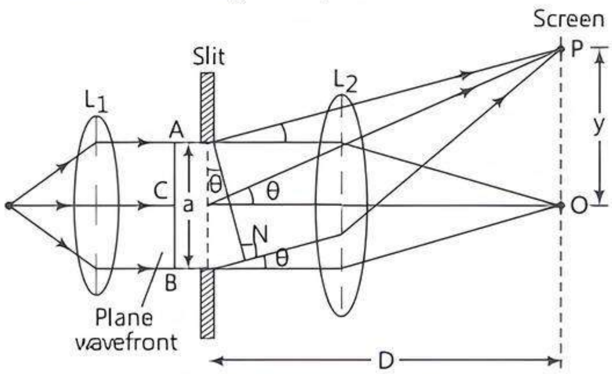
where, n is integer except $n = 0$.

Condition of Maxima: If slit AB is divided into three equal parts (or in odd parts). First two-third of the slit having a path difference $\lambda/2$ between them cancel each other, and only the remaining one-third of the slit contributes to the intensity at the point between two minima, so for path difference

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

We have, $\quad a \sin\theta = \left(n + \frac{1}{2}\right)\lambda$

where, n is integer except $n = 0$



The wavelets from points A and B will have a path difference equal to BN.

From the right-angled ΔANB, we have

$$BN = AB \sin\theta$$

or $\qquad BN = a \sin\theta$

Suppose that the point P on the screen is at such a distance from the centre of the screen that BN = λ and the angle $\theta = \theta_1$.

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

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

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

For nth minimum at point P,

$$\sin\theta_n = \frac{n\lambda}{a} \qquad ...(1)$$

If y_n is the distance of the nth minimum from the centre of the screen and D is the distance between the slit and the screen, then from right-angled ΔCOP, we have

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

or $\qquad \tan\theta_n = \frac{y_n}{D} \qquad ...(2)$

In case θ_n is small

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

Therefore, from the eqs. (1) and (2), we have

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

or $\qquad y_n = \frac{n\lambda D}{a} \qquad ...(3)$

The width of the secondary maxima,

$$\beta = y_n - y_{n-1}$$

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

Since β is independent of n, all the secondary maxima are of same width β. The central maxima extends up to the distance y_1 (the distance of first secondary minima) on both sides of the centre of the screen.

Therefore, the width of the central maxima, $\beta_0 = 2y_1$

From eq. (3) setting $n = 1$, we have

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

Therefore, $\beta_0 = \frac{2D\lambda}{a} \qquad ...(4)$

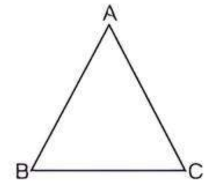
It follows that $\beta_0 = 2\beta$ *i.e.*, the central maxima is twice as wide as any other secondary maxima or minima.

TR!CK

Divide derivation into steps and then proceed.

Q 8. (i) Write two points of difference between an interference pattern and a diffraction pattern.

(ii) (a) A ray of light incident on face AB of an equilateral glass prism, shows minimum deviation of 30°. Calculate the speed of light through the prism.



(b) Find the angle of incidence at face AB so that the emergent ray grazes along the face AC. *(CBSE SQP 2022-23)*

Ans. (i) Difference between an interference pattern and a diffraction pattern are given below:

(a) The interference pattern has a number of equally spaced bright and dark bands. On the other hand, 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.

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

(ii) (a) Given minimum deviation of ray of light = 30°

We have,

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

Also $\mu = \frac{c}{v}$

$$\Rightarrow \quad v = \frac{3\times10^8}{\sqrt{2}} \text{ m/s}$$

∴ Speed of light through the prism

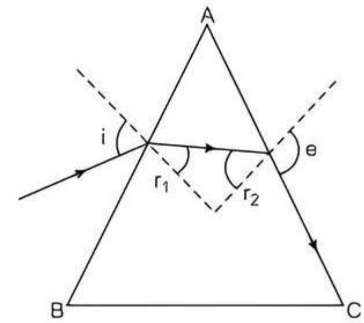
$$= 15\sqrt{2}\times10^7 \text{ m/s}$$

(b) At face AC, let the angle of incidence be r_2. For grazing ray,

$$e = 90°$$

$$\Rightarrow \quad \mu = \frac{1}{\sin r_2}$$

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



Let angle of refraction 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.

Then, $\mu = \frac{\sin i}{\sin r_1}$

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

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

So, the angle of incidence at face $AB = 21.5°$.

Chapter Test

Multiple Choice Questions

Q 1. Wavefront is the locus of all points, where the particles of the medium vibrate with the same:

a. phase b. amplitude
c. frequency d. period

Q 2. A plane wave passes through a convex lens. The geometrical shape of the wavefront that emerges is:

a. plane b. diverging spherical
c. converging spherical d. None of these

Assertion and Reason Type Questions

Directions (Q.Nos. 3-4): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 3. Assertion (A): Wavefronts obtained from light emitted by a point source in an isotropic medium are always spherical.
Reason (R): Speed of light in isotropic medium is constant.

Q 4. Assertion (A): All bright interference bands have same intensity.
Reason (R): All bands receive same light from two sources.

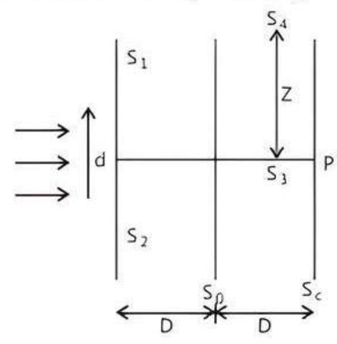
Fill in the blanks

Q 5. Interference is based on the ....

Q 6. In Young's double slit experiment with monochromatic light, the central fringe will be ....

Case Study Based Question

Q 7. Consider the situation shown in given figure. The two slits S_1 and S_2, placed symmetrically around the central line are illuminated by monochromatic light of wavelength λ. The separation between the slits is d. The light transmitted by the slits falls on a screen S_0 place at a distance D from the slits. The slit S_3 is at the central line and the slit S_4 is at a distance from S_3. Another screen S_c is placed a further distance D away from S_0.

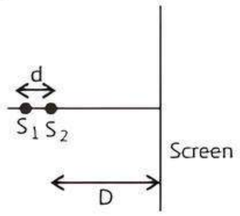


Read the given passage carefully and give the answer of the following questions:

(i) Find the path difference if $Z = \frac{\lambda D}{2d}$.

(ii) Find the ratio of maximum and minimum intensity observed on S_c if $Z = \frac{\lambda D}{d}$.

(iii) Two coherent point sources S_1 and S_2 are separated by a small distance d as shown in figure. What will be the fringes obtained on the screen?



(iv) Two monochromatic light waves of amplitude $3A$ and $2A$ interfering at a point have a phase difference of 60°. What will be intensity at the point ?

Very Short Answer Type Questions

Q 8. How does the angular separation between fringes in single slit diffraction experiment change when the distance of separation between the slit and screen is doubled?

Q 9. State Huygens' principle of diffraction of light?

Short Answer Type-I Questions

Q 10. What should be the width of each slit to obtain n maxima of double slit pattern within the central maxima of single slit pattern?

Q 11. A parallel beam of light of wavelength 5500 Å falls normally on a slit of width 22.0×10^{-5} cm. Find the angular positions of the first two minima on the two sides of the central maximum of the diffraction pattern.

Short Answer-II Type Questions

Q 12. Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are wavelength, frequency and speed of (i) reflected light, (ii) refracted light? The refractive index of water is 1.33.

Q 13. (i) 'Two independent monochromatic sources of light cannot produces a sustained interference pattern'. Give reason.

(ii) What is the effect on the interference fringes in Young's double slit experiment when (a) the width of the source slit is increased; (b) the monochromatic source is replaced by a source of white light?

Q 6. Answer the following questions:

(i) 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.

(ii) 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?

(CBSE 2015)

Long Answer Type Questions

Q 15. A monochromatic light of wavelength λ is incident normally on a narrow slit of width 'a' to produce a diffraction pattern on the screen placed at a distance D from the slit. With the help of a relevant diagram, deduce the condition for obtaining maxima and minima on the screen. Use these condition to show that angular width of central maximum is twice the angular width of secondary maximum.

Q 16. (i) What is interference of light ? Name the interference happen at a place where intensity of light is maximum and minimum.

(ii) In a Young's double-slit experiment, the separation between slits is 2×10^{-3} m whereas the distance of screen from the slits is 2.5 m. A light of wavelengths in the range of 2000-8000 Å is allowed to fall on the slits. Find the wavelength in the visible region that will be present on the screen at 10^{-3} m from the central maximum. Also find the wavelength that will be present at that point of screen in the infrared as well as in the ultraviolet region.