07 Wave Optics

Note: The Ⓡ *marked questions are the part of reduced/non-evaluative portion for academic year 2020-21 only.*

Multiple Choice Questions (1 Mark Each)

Ⓡ 1. When light travels from an optically rarer medium to an optically denser medium, the speed decreases because of change in:
(A) **Wavelength** (B) Frequency
(C) Amplitude (D) Phase

2. Light of wavelength 5000 A.U. falls on a plane reflecting surface. The frequency of reflected light is…
(A) **6×10^{14} Hz** (B) 5×10^{14} Hz
(C) 2×10^{14} Hz (D) 1.666×10^{14} Hz

Hint: $\nu = \frac{c}{\lambda} = \frac{3\times10^8}{5000\times10^{-10}} = 6 \times 10^{14}$ Hz

3. Light follows wave nature because…
(A) light rays travel in a straight line.
(B) light exhibits the phenomenon of reflection and refraction.
(C) **light exhibits the phenomenon of interference.**
(D) light causes the phenomenon of photoelectric effect.

4. Young's double slit experiment is carried out using green, red and blue light, one colour at a time. The fringe widths recorded are W_G, W_R, and W_B respectively then…
(A) $W_G > W_B > W_R$ (B) $W_B > W_G > W_R$
(C) $W_R > W_B > W_G$ (D) **$W_R > W_G > W_B$**

Hint: Fringe width, $W \propto \lambda$ and $\lambda_R > \lambda_G > \lambda_B$

$\therefore$ $W_R > W_G > W_B$

5. The path difference between two waves meeting at a point is $(11/4)\lambda$. The phase difference between the two waves is…

(A) $11\pi/4$ **(B) $11\pi/2$**

(C) 11π (D) 22π

Hint: Phase difference, $\Delta\phi = \frac{2\pi}{\lambda}\Delta l$

$\therefore \quad \Delta\phi = \frac{2\pi}{\lambda} \times \frac{11}{4}\lambda = \frac{11\pi}{2}$

6. Which of the following cannot produce two coherent sources?

(A) Lloyd's mirror (B) Fresnel biprism

(C) Young's double slit **(D) Prism**

7. The bending of beam of light around corners of obstacle is called…

(A) reflection **(B) diffraction**

(C) refraction (D) interference

8. In a single slit diffraction pattern, first minima obtained with red light of wavelength 6600 A.U. coincides with first maxima of some other wavelength λ then is…

(A) 5500 A.U. (B) 5000 A.U.

(C) 4800 A.U. **(D) 4400 A.U.**

Hint: For first minima in diffraction pattern,

$a \sin\theta = 1 \times \lambda_{Red}$

For first maxima in diffraction pattern,

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

As both coincide, $\lambda_{Red} = \frac{3}{2}\lambda$

$\therefore \quad \lambda = \lambda_{Red} \times \frac{2}{3}$

$= 6600 \times \frac{2}{3}$

$= 4400$ A.U.

Very Short Answer (VSA) (1 Mark Each)

1. What is the shape of the wave front on Earth for Sunlight?

Ans: The shape of the wavefront on Earth for Sunlight is plane.

2. In Young's double slit experiment, if there is no initial phase difference between the light from the two slits, a point on the screen corresponds to the 5^{th} minimum. What is the path difference?

Ans: Path difference $\Delta l = (2n - 1)\dfrac{\lambda}{2} = (2 \times 5 - 1)\dfrac{\lambda}{2} = \dfrac{9\lambda}{2}$

3. Two coherent sources whose intensity ratio is 25:1 produce interference fringes. Calculate the ratio of amplitudes of light waves coming from them.

Ans: $\dfrac{I_1}{I_2} = \dfrac{25}{1} = \dfrac{a_1^{\,2}}{a_2^{\,2}} \Rightarrow \dfrac{a_1}{a_2} = \dfrac{5}{1}$

4. Why two light sources must be of equal intensity to obtain a well-defined interference pattern?

Ans: This is because, only if the intensities of two light sources are equal, the intensity of dark fringes (destructive interference) is zero and the contrast between bright and dark fringes will be maximum, thereby giving rise to well-defined interference pattern.

5. What is the relation between phase difference and optical path in terms of speed of light in vacuum?

Ans: Phase difference, $\Delta\phi' = \dfrac{\omega}{c} \times n\Delta x$

where, ω is angular frequency, c is speed of light in vacuum and $n\Delta x$ is optical path for a wave travelling in medium of refractive index n.

6. What should be the slit width to obtain pronounced diffraction with a single slit illuminated by light of wavelength λ?

Ans: To obtain pronounced diffraction with a single slit, the slit width should be of the order of wavelength λ.

7. What must be ratio of the slit width to the wavelength for a single slit, to have the first diffraction minimum at 45°?

Ans: For 1st minimum, $\sin\theta_1 = \dfrac{\lambda}{a}$. For $\theta_1 = 45°$, $\dfrac{\lambda}{a} = \sin 45° = \dfrac{1}{\sqrt{2}}$

$\therefore$ Ratio of slit width to wavelength, $a : \lambda = \sqrt{2} : 1$

Short Answer I (SA1) (2 Marks Each)

1. What are Secondary sources? State Huygens' principle.

Ans: Secondary sources are those sources which do not produce light of their own but receive light from some other source and either reflect or scatter it around.

Examples: the moon, the planets, objects.

Statement of Huygens' principle: *Each point on a wavefront acts as a secondary source of light emitting secondary light waves called wavelets in all directions which travel with the speed of light in the medium. The new wavefront can be obtained by taking the envelope of these secondary wavelets travelling in the forward direction and is thus, the envelope of the secondary wavelets in forward direction. The wavelets travelling in the backward direction are ineffective.*

2. A plane wavefront of light of wavelength 5500 A.U. is incident on two slits in a screen perpendicular to the direction of light rays. If the total separation of 10 bright fringes on a screen 2 m away is 2 cm. Find the distance between the slits.

Solution:

Given: $\lambda = 5500$ A.U. $= 5500 \times 10^{-10}$ m, D = 2 m

Distance between 10 fringes = 2 cm = 0.02 m.

Fringe width W = 0.02/10 = 0.002 m = 2×10^{-3} m

To find: Distance between slits (d)

Formula: $W = \dfrac{\lambda D}{d}$

Calculation: From formula,

$$2 \times 10^{-3} = \frac{5500 \times 10^{-10} \times 2}{d}$$

$$\therefore \quad d = \frac{5.5 \times 10^{-7} \times 2}{2 \times 10^{-3}} = \mathbf{5.5 \times 10^{-4}\ m}$$

Ans: The distance between two slits is **5.5×10^{-4} m.**

3. **State any four conditions for obtaining well – defined and steady interference pattern.**

Ans: Conditions for obtaining well – defined and steady interference pattern:

i. The two sources of light must be coherent.

ii. The two sources of light must be monochromatic.

iii. The two interfering waves must have the same amplitude.

iv. The separation between the two slits (d) must be small in comparison to the distance between the plane containing the slits and the observing screen (D).

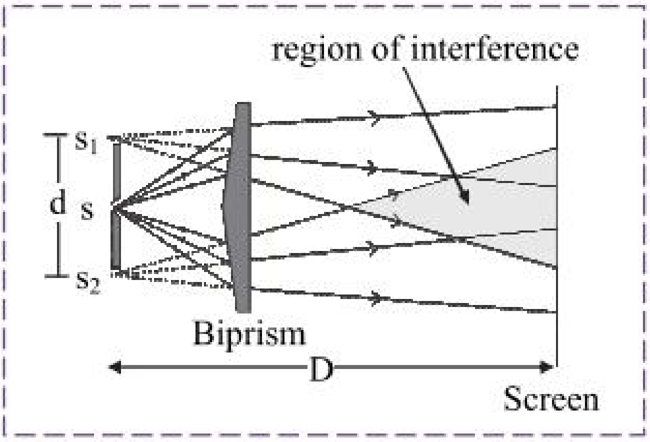
v. The two slits should be narrow.

vi. The two waves should be in the same state of polarization.

[Any four points]

4. **Draw a neat labelled ray diagram of Fresnel biprism experiment showing the region of interference.**

Ans: Fresnel biprism experiment:



5. **What is Optical path length? How is it different from actual path length?**

Ans:

i. When a wave travels a distance Δx through a medium having refractive index of n, its phase changes by the same amount as it would if the wave had travelled a distance $n\Delta x$ in vacuum.

ii. Thus, a path length of Δx in a medium of refractive index n is equivalent to a path length of $n\Delta x$ in vacuum.

iii. $n\Delta x$ is called the optical path travelled by a wave.

iv. This means, optical path through a medium is the effective path travelled by light in vacuum to generate the same phase difference.

v. Optical path in a medium can also be defined as the corresponding path in vacuum that the light travels in the same time as it takes in the given medium.

i.e., time = $\frac{d_{medium}}{v_{medium}} = \frac{d_{vacuum}}{v_{vacuum}}$

$\therefore$ $d_{vacuum} = \frac{v_{vacuum}}{v_{medium}} \times d_{medium} = n \times d_{medium}$

But d_{vacuum} = Optical path

$\therefore$ Optical path = $n \times d_{medium}$

vi. Thus, a distance d travelled in a medium of refractive index n introduces a path difference = $nd - d = d(n - 1)$ over a ray travelling equal distance through vacuum.

6. What is difference between Fresnel and Fraunhofer diffraction?

Ans:

No.	Fresnel diffraction	Fraunhofer diffraction
i.	Source of light and screen are kept at finite distance.	Source of light and screen are at infinite distance.
ii.	Spherical or cylindrical wavefronts are considered.	Only plane wavefronts are considered.
iii.	It is observed in straight edge, narrow slit etc.	It is observed in single slit, double slit etc.
iv.	Lenses are not used.	Convex lenses are used.

7. Compare Young's double slit interference pattern and single slit diffraction pattern.

Ans:

	Young's double slit interference pattern:	Single slit diffraction pattern
i.	**Dimension of slit:** For a common laboratory set up, the slits in the Young's double slit experiment are much thinner than their separation. They are usually obtained by using a biprism or a Lloyd's mirror. The separation between the slits is a few mm only.	**Dimension of slit:** The single slit used to obtain the diffraction pattern is usually of width less than 1 mm.
ii.	**Size of pattern obtained:** With best possible set up, observer can usually see about 30 to 40 equally spaced bright and dark fringes of nearly same brightness.	**Size of pattern obtained:** Taken on either side, observer can see around 20 to 30 fringes with central fringe being the brightest.

iii.	**Fringe width W:** $W = \frac{\lambda D}{d}$	**Fringe width W:** $W = \frac{\lambda D}{a}$ Except for the central bright fringe
iv.	**For n^{th} bright fringe**	
a.	Phase difference, ϕ between extreme rays: $n(2\pi)$	Phase difference, ϕ between extreme rays: $\left(n + \frac{1}{2}\right)(2\pi)$ OR $(2n + 1)\pi$
b.	Angular position, θ: $n\left(\frac{\lambda}{d}\right)$	Angular position, θ: $\left(n + \frac{1}{2}\right)\left(\frac{\lambda}{a}\right)$ OR $\frac{(2n+1)\lambda}{2a}$
c.	Path difference, Δl between extreme rays: $n\lambda$	Path difference, Δl between extreme rays: $n\lambda$
d.	Distance from the central bright spot, y: $n\left(\frac{\lambda D}{d}\right) = nW$	Distance from the central bright spot, y: $\left(n+\frac{1}{2}\right)\left(\frac{\lambda D}{a}\right) = \left(n+\frac{1}{2}\right)W$
v.	**For n^{th} dark fringe**	
a.	Phase difference, ϕ between extreme rays: $\left(n - \frac{1}{2}\right)(2\pi)$ OR $(2n - 1)\pi$	Phase difference, ϕ between extreme rays: $n(2\pi)$
b.	Angular position, θ: $\left(n - \frac{1}{2}\right)\left(\frac{\lambda}{d}\right)$ OR $(2n-1)\frac{\lambda}{2d}$	Angular position, θ: $n\left(\frac{\lambda}{a}\right)$
c.	Path difference, Δl between extreme rays: $\left(n - \frac{1}{2}\right)\lambda$ OR $(2n - 1)\frac{\lambda}{2}$	Path difference, Δl between extreme rays: $n\lambda$
d.	Distance from the central bright spot, y': $\left(n-\frac{1}{2}\right)\left(\frac{\lambda D}{d}\right) = \left(n-\frac{1}{2}\right)W$	Distance from the central bright spot, y': $n\left(\frac{\lambda D}{a}\right) = nW$

8. White light consists of wavelengths from 400 nm to 700 nm. What will be the wavelength range seen, when white light is passed through glass of refractive index 1.55?

Solution:

Given: $n = 1.55$

Smallest wavelength = 400 nm,

Largest wavelength = 700 nm

To find: Range of wavelength of light when passed through glass

Formula: $\lambda_{med} = \dfrac{\lambda_{vac}}{n}$

Calculation: For smallest wavelength (in glass),

From formula

$$\lambda_{med} = \frac{400}{1.55}$$

$= 2.5806 \times 10^2$ nm

= 258.06 nm

For largest wavelength

From formula,

$$\lambda_{med} = \frac{700}{1.55}$$

$= 4.5161 \times 10^2$ nm

= 451.61 nm

Ans: The wavelength range when white- light is passed through glass is **258.06 nm to 451.61 nm.**

9. The optical path of a ray of light of a given wavelength travelling a distance of 3 cm in flint glass having refractive index 1.6 is same as that on travelling a distance x cm through a medium having refractive index 1.25. Determine the value of x.

Solution:

Given: $d_1 = 3$ cm, $n_1 = 1.6$, $n_2 = 1.25$

To find: Optical path in medium 2 (d_2)

Formula: $n_1 d_1 = n_2 d_2$

Calculation: From formula,

$1.6 \times 3 = 1.25 \times d_2$

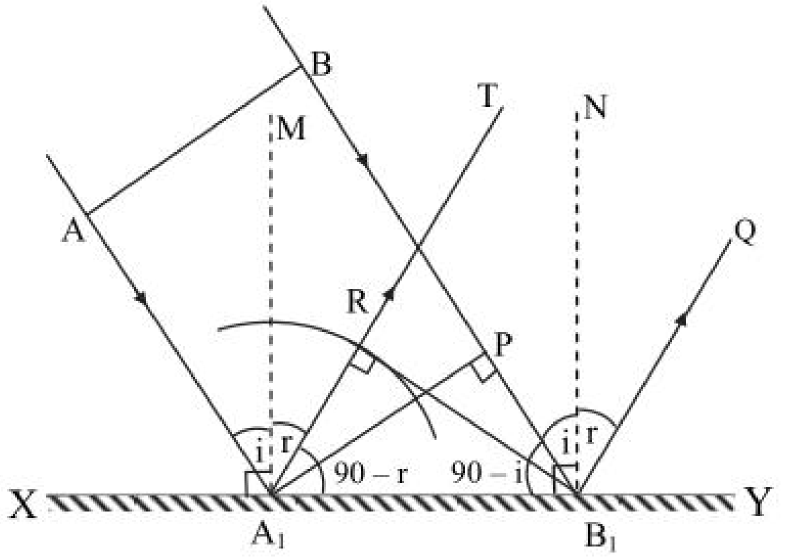
$\therefore \quad d_2 = \dfrac{1.6 \times 3}{1.25}$ **= 3.84 cm**

Ans: The value of x is **3.84 cm.**

Short Answer II (SA1) (3 Marks Each)

1. Explain reflection of light at a plane surface with the help of a neat ray diagram.

Ans:



Reflection of light

XY : Plane reflecting surface
AB : Plane wavefront
RB_1 : Reflecting wavefront
A_1M, B_1N : Normal to the plane
$\angle AA_1M = \angle BB_1N = \angle i$ = Angle of incidence
$\angle TA_1M = \angle QB_1N = \angle r$ = Angle of reflection

Explanation:

i. A plane wavefront AB is advancing obliquely towards plane reflecting surface XY. AA_1 and BB_1 are incident rays.

ii. When 'A' reaches XY at A_1, then ray at 'B' reaches point 'P' and it has to cover distance PB_1 to reach the reflecting surface XY.

iii. Let 't' be the time required to cover distance PB_1. During this time interval, secondary wavelets are emitted from A_1 and will spread over a hemisphere of radius A_1R, in the same medium.

Distance covered by secondary wavelets to reach from A_1 to R in time t is same as the distance covered by primary waves to reach from P to B_1.

Thus $A_1R = PB_1 = ct$.

iv. All other rays between AA_1 and BB_1 will reach XY after A_1 and before B_1. Hence, they will also emit secondary wavelets of decreasing radii.

v. The surface touching all such hemispheres is RB_1 which is reflected wavefront, bounded by reflected rays A_1R and B_1Q.

vi. Draw $A_1M \perp XY$ and $B_1N \perp XY$.

Thus, angle of incidence is $\angle AA_1M = \angle BB_1N = i$ and angle of reflection is $\angle MA_1R = \angle NB_1Q = r$.

$\therefore$ $\angle RA_1B_1 = 90 - r$ and $\angle PB_1A_1 = 90 - i$

vii. In ΔA_1RB_1 and ΔA_1PB_1

$\angle A_1RB_1 \cong \angle A_1PB_1$

$A_1R = PB_1$ (Reflected waves travel equal distance in same medium in equal time).

$A_1B_1 = A_1B_1$ ….(common side)

$\therefore$ $\Delta A_1RB_1 \cong \Delta A_1PB_1$

$\therefore$ $\angle RA_1B_1 = \angle PB_1A_1$

$\therefore$ $90 - r = 90 - i$

$\therefore$ $i = r$

viii. Also, from the figure, it is clear that incident ray, reflected ray and normal lie in the same plane.

ix. Assuming rays AA_1 and BB_1 to be coming from extremities of the object, A_1B_1 is the size of object. Distance between corresponding reflected rays A_1T and B_1Q will be same as A_1B_1 as they are corresponding parts of congruent triangles.

This implies size of object in reflected image is same as actual size of object.

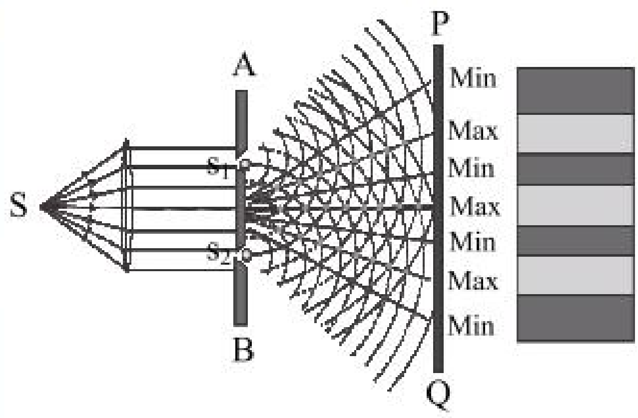
x. Also, taking A and B to be right and left sides of the object respectively, after reflection right side at A is seen at T and left side at B is seen at Q. This explains lateral inversion.

2. Describe Young's double slit experiment with a neat diagram showing points of maximum and minimum intensity.

Ans:

i. In Young's double slit interference experiment, a plane wavefront is made to fall on an opaque screen AB having two similar narrow slits S_1 and S_2.

ii. The figure below shows a cross section of the experimental set up and the slits have their lengths perpendicular to the plane of the paper.



Young's double slit experiment

iii. The slits are about 2 - 4 mm apart from each other.

iv. An observing screen PQ is placed behind of AB.

v. Assuming that the slits S_1 and S_2 are equidistant from the S, the wavefronts starting from S and reaching the S_1 and S_2 at every instant of time are in phase.

vi. When the rays fall on S_1 and S_2, the two slits act as secondary sources of light emitting cylindrical wavelets (with axis along the slit length) to the right of AB.

vii. The two secondary sources emit waves in phase with each other.

viii. The crests/troughs of the secondary wavelets superpose as shown in the figure and interfere constructively high intensity giving rise to bright band.

ix. When the crest of one wave coincides with the trough of the other causing zero intensity, dark images of the slits are produced on the screen PQ.

x. The dark and bright regions are called fringes and the whole pattern is called interference pattern.

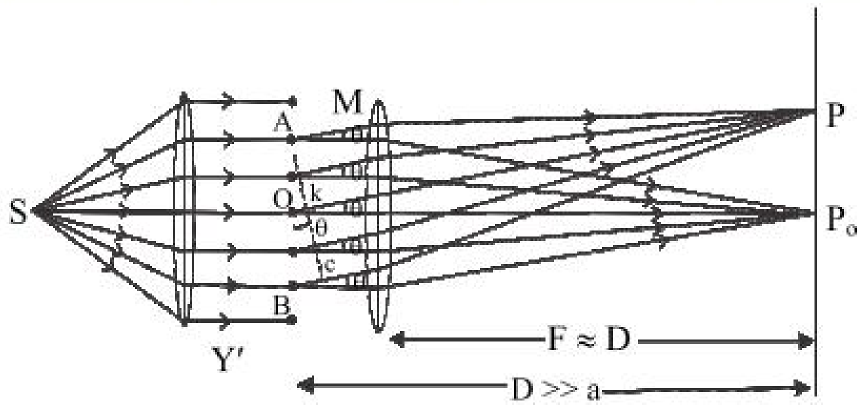
3. Explain experimental setup for Fraunhofer diffraction with neat diagram.

Ans:

i. Set up for Fraunhofer diffraction has a monochromatic source of light S at the focus of a converging lens. Ignoring aberrations, the emerging beam will consist of plane parallel rays resulting in plane wavefronts.

ii. These are incident on the diffracting element such as a slit, a circular aperture, a double slit, a grating, etc.

iii. In the case of a circular aperture, S is a point source and the lenses are bi-convex. For linear elements like slits, grating, etc., the source is linear and the lenses are cylindrical in shape so that the focussed image is also linear.



Set up for Fraunhofer diffraction

iv. Emerging beam is incident on another converging lens that focuses the beam on a screen.

4. The distance between two bright fringes in a biprism experiment using light of wavelength 6000 A.U. 0.32 mm. By how much will the distance change, if light of wavelength 4800 A.U. is used?

Solution:

Given: Distance between consecutive bright fringes,

$y_A = 0.32 \text{ mm} = 0.32 \times 10^{-3} \text{ m}$

$\lambda_A = 6000 \text{ A.U.} = 6 \times 10^{-7} \text{ m}$, $\lambda_B = 4800 \text{ A.U.} = 4.8 \times 10^{-7} \text{ m}$

Let y_B be distance between consecutive bright fringes when wavelength λ_B is used

To find: Change in distance between the fringes $|y_A - y_B|$

Formula: $y_A\lambda_B = y_B\lambda_A$

Calculation: From formula,

$$\therefore \quad y_B = \frac{y_A\lambda_B}{\lambda_A} = \frac{0.32\times10^{-3}\times4.8\times10^{-7}}{6\times10^{-7}}$$

$$= 0.256 \times 10^{-3}$$

$$\therefore \quad \text{Change} = |y_A - y_B|$$

$$= |0.320 \times 10^{-3} - 0.256 \times 10^{-3}|$$

$$= 0.064 \times 10^{-3} \text{ m}$$

$$= \mathbf{0.064 \text{ mm}}$$

Ans: The change in distance between the fringes is **0.064 mm.**

5. A parallel beam of green light of wavelength 546 nm passes through a slit of width 0.4 mm. The intensity pattern of the transmitted light is seen on a screen which is 40 cm away. What is the distance between the two first order minima?

Solution:

Given: $\lambda = 546 \text{ nm} = 546 \times 10^{-9}$ m, a = 0.4 mm = 0.4×10^{-3} m

D = 40 cm = 40×10^{-2} m

To find: Distance between two first order minima

Formula: Width of central maxima, $W_c = \frac{2\lambda D}{a}$

Calculation: From formula,

$$W_c = \frac{2 \times 546 \times 10^{-9} \times 40 \times 10^{-2}}{0.4 \times 10^{-3}}$$

$= 2 \times 546 \times 10^{-6}$

$= 1092 \times 10^{-6}$

$= 1.092 \times 10^{-3}$ m

≈ 1.1 mm

Distance between two first order minima

= Width of central maxima = **1.1 mm**

Ans: Distance between two first order minima is **1.1 mm.**

6. In Fraunhofer diffraction by a narrow slit, a screen is placed at a distance of 2 m from the lens to obtain the diffraction pattern. If the slit width is 0.2 mm and the first minimum is 5 mm on either side of central maximum. Find the wavelength of light.

Solution:

Given: D = 2 m, a = 0.2 mm = 2×10^{-4} m, y_{1d} = 5 mm

Width of central maxima = $2y_{1d} = 2 \times 5$ mm

= 10 mm = 10×10^{-3} m

To find: Wavelength of light (λ)

Formula: Width of central maxima, $W_c = \frac{2\lambda D}{a}$

Calculation: From formula,

$$10 \times 10^{-3} = \frac{2 \times \lambda \times 2}{2 \times 10^{-4}}$$

$$\therefore \quad \lambda = \frac{10 \times 10^{-3} \times 2 \times 10^{-4}}{2 \times 2} = 5 \times 10^{-7} \text{ m}$$

= 5000 Å

Ans: Wavelength of the light used is **5000 Å.**

Long Answer (LA) (4 Marks Each)

1. **Describe geometry of the Young's double slit experiment with the help of ray diagram. What is fringe width? Obtain an expression of it. Write the conditions for constructive as well as destructive interference.**

Ans:

i. Let S_1 and S_2 be the two coherent monochromatic sources which are separated by short distance d. They emit light waves of wavelength λ.

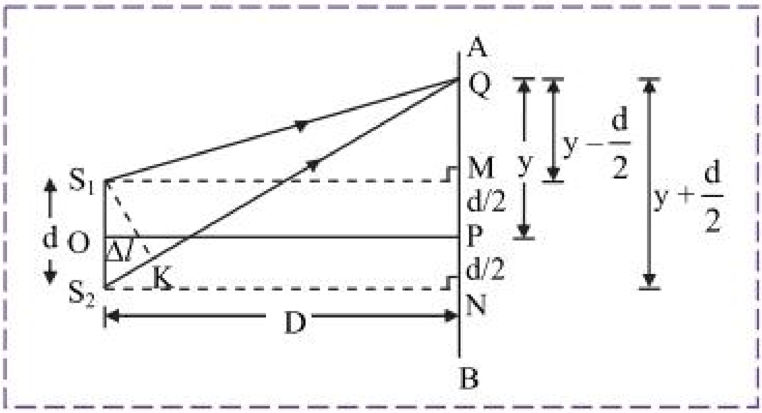
ii. Let D = horizontal distance between screen and source.

iii. Draw S_1M and $S_2N \perp AB$

OP = perpendicular bisector of slit.

Since $S_1P = S_2P$, the path difference between waves reaching P from S_1 and S_2 is zero, therefore there is a bright point at P.

iv. Consider a point Q on the screen which is at a distance y from the central point P on the screen. Light waves from S_1 and S_2 reach at Q simultaneously by covering path S_1Q and S_2Q, where they superimpose.



Derivation:

In ΔS_1MQ, $(S_1Q)^2 = (S_1M)^2 + (MQ)^2$

$$(S_1Q)^2 = D^2 + \left[y - \frac{d}{2}\right]^2 \quad \text{....(1)}$$

In ΔS_2NQ, $(S_2Q)^2 = (S_2N)^2 + (NQ)^2$

$$\therefore \quad (S_2Q)^2 = D^2 + \left[y + \frac{d}{2}\right]^2 \quad \text{....(2)}$$

Subtract equation (1) from (2),

$$(S_2Q)^2 - (S_1Q)^2 = \left[D^2 + \left(y + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(y - \frac{d}{2}\right)^2\right]$$

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

$$= \left(y + \frac{d}{2}\right)^2 - \left(y - \frac{d}{2}\right)^2$$

$$= \left(y^2 + \frac{d^2}{4} + yd\right) - \left(y^2 + \frac{d^2}{4} - yd\right)$$

$$= y^2 + \frac{d^2}{4} + yd - y^2 - \frac{d^2}{4} + yd(S_2Q)^2 - (S_1Q)^2$$

$$= 2yd$$

$\therefore$ $(S_2Q + S_1Q)(S_2Q - S_1Q) = 2yd$

$\therefore$ $$S_2Q - S_1Q = \frac{2yd}{S_2Q + S_1Q} \qquad \text{….(3)}$$

If $y << D$ and $d << D$ then, $S_1Q \approx S_2Q \approx D$

$S_2Q + S_1Q = 2D$

$\therefore$ Equation (3) becomes,

$$S_2Q - S_1Q = \frac{2yd}{2D}$$

$\therefore$ $$S_2Q - S_1Q = \frac{yd}{D}$$

$\therefore$ $$\Delta l = \frac{yd}{D} \qquad \text{….(4)}$$

Equation (4) gives the path difference of two interfering light waves.

Point Q will be bright if,

$$\Delta l = n\lambda = 2n\frac{\lambda}{2}$$

where n = 0, 1, 2,….

$\therefore$ $$\frac{y_n d}{D} = n\lambda = 2n\frac{\lambda}{2} \qquad \text{….[From equation (4)]}$$

$\therefore$ $$y_n = n\frac{\lambda D}{d} \qquad \text{….(5)}$$

Equation (5) represents distance of n^{th} bright fringe from central bright fringe.

Point Q will be dark point if,

$$\Delta l = (2n - 1)\frac{\lambda}{2}$$

where n = 1, 2, 3,……

$$\therefore \quad \frac{y'_n d}{D} = (2n - 1)\frac{\lambda}{2}$$

$$\therefore \quad y'_n = (2n - 1)\frac{\lambda D}{2d} = \left(n - \frac{1}{2}\right)\frac{\lambda D}{d} \qquad ....(6)$$

Equation (6) represents distance of n^{th} dark fringe from central maximum.

Fringe width:

The distance between any two successive dark or any two successive bright fringes is equal. This is called the **fringe width** and is given by,

Fringe width = $W = \Delta y = y_{n+1} - y_n = y'_{n+1} - y'_n$

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

Thus, both dark and bright fringes are equidistant and have equal widths.

Conditions for constructive and destructive interference:

The phase difference between the two waves reaching P, from S_1 and S_2 is given by,

$$\Delta\phi = y\frac{d}{D}\left(\frac{2\pi}{\lambda}\right) \qquad ....\left(\because \Delta l = \frac{yd}{D}\right)$$

The condition for constructive interference in terms of phase difference is given by,

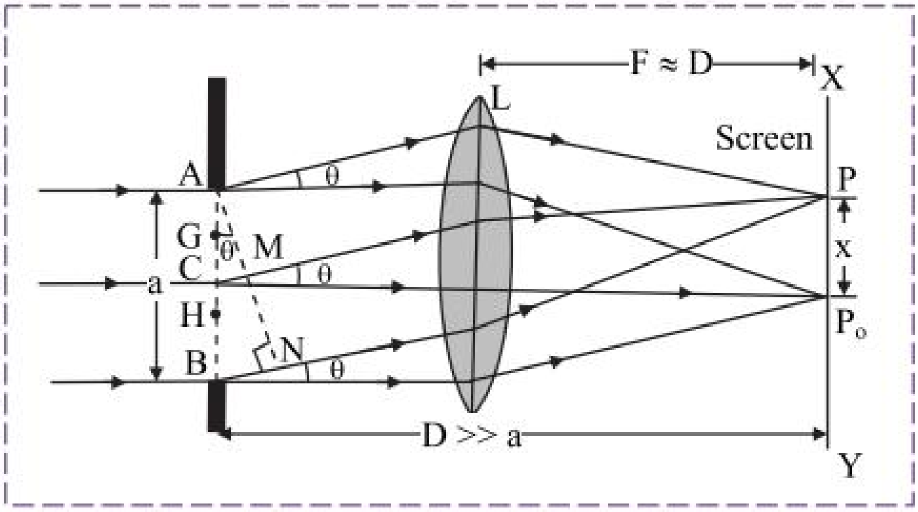
$\Delta\phi = n2\pi$, where, $n = 0, \pm 1 \pm 2$

$\therefore$ The condition for destructive interference in terms of phase difference is given by

$$\Delta\phi = \left(n - \frac{1}{2}\right)2\pi, \text{ where, } n = \pm 1, \pm 2$$

2. **Explain Fraunhofer diffraction at a single slit with neat ray diagram. Obtain expression for width of the central bright fringe.**

Ans: Fraunhofer diffraction due to single slit:



i. Consider a narrow slit AB of width 'a', kept perpendicular to the plane of the paper. The slit can be imagined to be divided into extremely thin slits or slit elements. It is illuminated by a parallel beam of monochromatic light of wavelength λ i.e., a plane wavefront is incident on AB.

ii. The diffracted light is focused by a converging lens L, on a screen XY.

iii. The screen is kept in the focal plane of the lens and is perpendicular to the plane of the paper.

iv. Let D be the distance between the slit and the screen.

v. According to Huygens' principle, each and every point of the slit acts as a source of secondary wavelets, spreading in all directions.

Position of central maxima:

i. Let C be the centre of the slit AB. The secondary wavelets travelling parallel to CP_o come to a focus at P_o. The secondary wavelets from points equidistant from C in the upper and lower halves of the slit travel equal paths before reaching P_o.

ii. The optical path difference between all these wavelets is zero and hence they interfere in the same phase forming a bright image at P_o.

iii. The intensity of light is maximum at the point P_o. It is called the central or the principal maxima of the diffraction pattern.

iv. For the line CP_o, angle $\theta = 0°$.

Position of secondary minima:

i. Consider a point P on the screen at which waves travelling in a direction making an angle θ with CP are brought to focus at P by the lens. This point P will be of maximum or minimum intensity because the waves reaching at P will cover unequal distance.

ii. Draw AN perpendicular to the direction of diffracted rays from point A. BN is the path difference between secondary waves coming from A and B.

iii. From ΔABN, $\sin\theta = \frac{BN}{AB}$

$\therefore$ $BN = AB \sin\theta = a \sin\theta$

Since θ is very small

$\therefore$ $\sin\theta \approx \theta$

$\therefore$ $BN = a\theta$

In figure, suppose $BN = \lambda$ and $\theta = \theta_1$ then $\sin\theta_1 = \frac{\lambda}{a}$

iv. Such a point on the screen will be the position of first secondary minimum. It is because, if the slit is assumed to be divided into two equal halves AC and BC, then the waves from corresponding points of two halves of the slit will have a path difference of $\lambda/2$.

It gives rise to destructive interference at P which has minimum intensity.

v. If point P on the screen is such that $BN = 2\lambda$ and angle $\theta = \theta_2$, then, $\sin\theta_2 = \frac{2\lambda}{a}$. Such a point on the screen will be the position of the second secondary minimum.

In general, for n^{th} minimum, $\sin\theta_n = \frac{n\lambda}{a}$

where, $n = \pm1, \pm2, \pm3, \ldots$

vi. If y_{n_d} is the distance of n^{th} minimum from P_o, on the screen, then

$\left(\tan\theta_{n_d}\right) = \frac{y_{n_d}}{D}$.

vii. If θ_{n_d} is very small,

$\tan\theta_{n_d} \approx \sin\theta_{n_d} = \frac{n\lambda}{a}$

$\therefore$ $\frac{y_{n_d}}{D} = \frac{n\lambda}{a}$

$\therefore$ $y_{n_d} = \frac{n\lambda D}{a} = nW$ ....(1)

where, W is fringe width

Equation (1) gives distance of n^{th} secondary minima from central maxima.

viii. The central bright fringe is spread between the first dark fringes on either side. Hence, width of the central bright fringe is the distance between the centres of first dark fringe on either side.

∴ Width of the central bright fringe,

$$W_c = 2y_{1d} = 2W = 2\left(\frac{\lambda D}{a}\right)$$

This is the required expression for width of the central bright fringe.

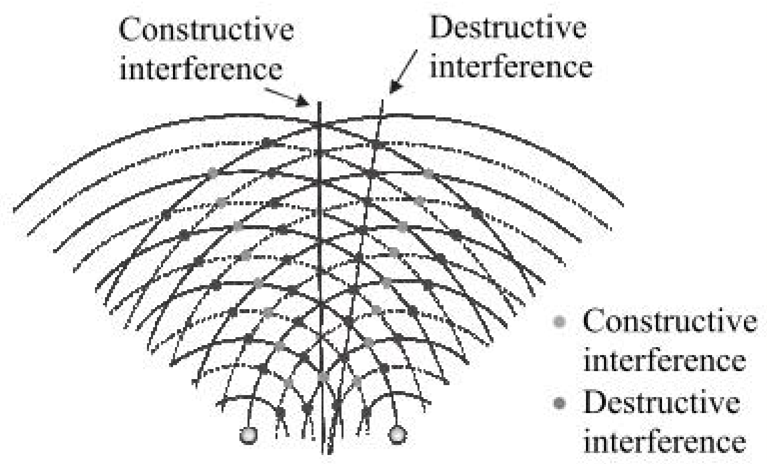
3. What is interference? Explain constructive and destructive interference with the help of diagram. What are coherent sources of light?

Ans: ***Interference of light*** *is defined as the modification in the intensity of light (larger at some places and smaller at some places) produced by the superposition of two or more light waves.*

Constructive and destructive interference:

i. Points where the crest of one wave coincides with the crest of another wave and where the trough of one wave coincides with the trough of another wave are points with the maximum displacement. At these points, displacement is twice that for each wave. These are points of constructive interference.

ii. Points where the crest of one wave is coincident with the trough of another are points with the zero displacement. These are points of destructive interference.



Interference for waves

Two sources which emit light waves of the same frequency having a constant phase difference, independent of time, are called ***coherent sources*** *of light.*