CHAPTER 24

Wave Optics

1. To demonstrate the phenomenon of interference, we require two sources which emit radiation **[2003]**
   (a) of nearly the same frequency
   (b) of the same frequency
   (c) of different wavelengths
   (d) of the same frequency and having a definite phase relationship

2. The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refractive index n), is **[2004]**
   (a) $\tan^{-1}(1/n)$ (b) $\sin^{-1}(1/n)$
   (c) $\sin^{-1}(n)$ (d) $\tan^{-1}(n)$

3. The maximum number of possible interference maxima for slit-separation equal to twice the wavelength in Young's double-slit experiment is **[2004]**
   (a) three (b) five
   (c) infinite (d) zero

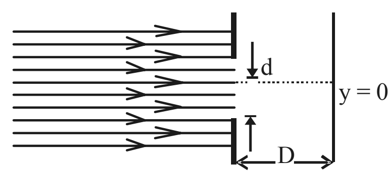
4. A Young's double slit experiment uses a monochromatic source. The shape of the interference fringes formed on a screen is **[2005]**
   (a) circle (b) hyperbola
   (c) parabola (d) straight line

5. If I_0 is the intensity of the principal maximum in the single slit diffraction pattern, then what will be its intensity when the slit width is doubled? **[2005]**
   (a) $4I_0$ (b) $2I_0$
   (c) $\frac{I_0}{2}$ (d) I_0

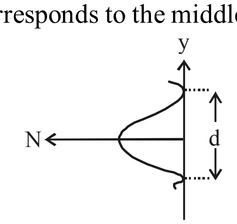
6. When an unpolarized light of intensity I_0 is incident on a polarizing sheet, the intensity of the light which does not get transmitted is **[2005]**
   (a) $\frac{1}{4}I_0$ (b) $\frac{1}{2}I_0$
   (c) I_0 (d) zero

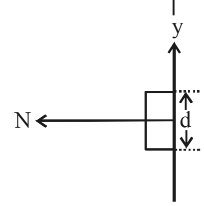
7. In a Young's double slit experiment the intensity at a point where the path difference is $\frac{\lambda}{6}$ (λ being the wavelength of light used) is I. If I_0 denotes the maximum intensity, $\frac{I}{I_0}$ is equal to **[2007]**
   (a) $\frac{3}{4}$ (b) $\frac{1}{\sqrt{2}}$
   (c) $\frac{\sqrt{3}}{2}$ (d) $\frac{1}{2}$

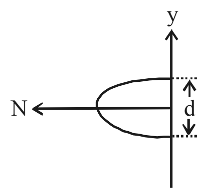
8. In an experiment, electrons are made to pass through a narrow slit of width 'd' comparable to their wavelength. They are detected on a screen at a distance 'D' from the slit (see figure).

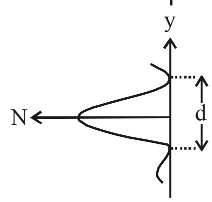


Which of the following graphs can be expected to represent the number of electrons 'N' detected as a function of the detector position 'y'(y = 0 corresponds to the middle of the slit) **[2008]**

(a) 

(b) 

(c) 

(d) 

9. A mixture of light, consisting of wavelength 590 nm and an unknown wavelength, illuminates Young's double slit and gives rise to two overlapping interference patterns on the screen. The central maximum of both lights coincide. Further, it is observed that the third bright fringe of known light coincides with the 4th bright fringe of the unknown light. From this data, the wavelength of the unknown light is: **[2009]**

(a) 885.0 nm (b) 442.5 nm
(c) 776.8 nm (d) 393.4 nm

Directions : Questions number 10-12 are based on the following paragraph.

An initially parallel cylindrical beam travels in a medium of refractive index $\mu(I) = \mu_0 + \mu_2 I$, where μ_0 and μ_2 are positive constants and I is the intensity of the light beam. The intensity of the beam is decreasing with increasing radius

10. As the beam enters the medium , it will **[2010]**

(a) diverge
(b) converge
(c) diverge near the axis and converge near the periphery
(d) travel as a cylindrical beam

11. The initial shape of the wavefront of the beam is **[2010]**

(a) convex
(b) concave
(c) convex near the axis and concave near the periphery
(d) planar

12. The speed of light in the medium is **[2010]**

(a) minimum on the axis of the beam
(b) the same everywhere in the beam
(c) directly proportional to the intensity I
(d) maximum on the axis of the beam

13. This question has a paragraph followed by two statements, Statement – 1 and Statement – 2. Of the given four alternatives after the statements, choose the one that describes the statements.

A thin air film is formed by putting the convex surface of a plane-convex lens over a plane glass plate. With monochromatic light, this film gives an interference pattern due to light reflected from the top (convex) surface and the bottom (glass plate) surface of the film.

Statement – 1 : When light reflects from the air-glass plate interface, the reflected wave suffers a phase change of π.

Statement – 2 : The centre of the interference pattern is dark. **[2011]**

(a) Statement – 1 is true, Statement – 2 is true, Statement – 2 is the correct explanation of Statement – 1.
(b) Statement – 1 is true, Statement – 2 is true, Statement – 2 is not the correct explanation of Statement – 1.
(c) Statement – 1 is false, Statement – 2 is true.
(d) Statement – 1 is true, Statement – 2 is false.

14. At two points P and Q on screen in Young's double slit experiment, waves from slits S_1 and S_2 have a path difference of 0 and $\frac{\lambda}{4}$, respectively. The ratio of intensities at P and Q will be : **[2011 RS]**

(a) 2 : 1 (b) $\sqrt{2}:1$
(c) 4 : 1 (d) 3 : 2

15. In a Young's double slit experiment, the two slits act as coherent sources of wave of equal amplitude A and wavelength λ. In another experiment with the same arrangement the two slits are made to act as incoherent sources of waves of same amplitude and wavelength. If the intensity at the middle point of the screen in the first case is I_1 and in the second case is I_2, then the ratio $\frac{I_1}{I_2}$ is **[2011 RS]**

(a) 2 (b) 1
(c) 0.5 (d) 4

16. **Statement - 1:** On viewing the clear blue portion of the sky through a Calcite Crystal, the intensity of transmitted light varies as the crystal is rotated.

Statement - 2: The light coming from the sky is polarized due to scattering of sun light by particles in the atmosphere. The scattering is largest for blue light. **[2011 RS]**

(a) Statement -1 is true, statement-2 is false.
(b) Statement-1 is true, statement-2 is true, statement-2 is the correct explanation of statement-1
(c) Statement-1 is true, statement-2 is true, statement-2 is not the correct explanation of statement-1
(d) Statement-1 is false, statement-2 is true.

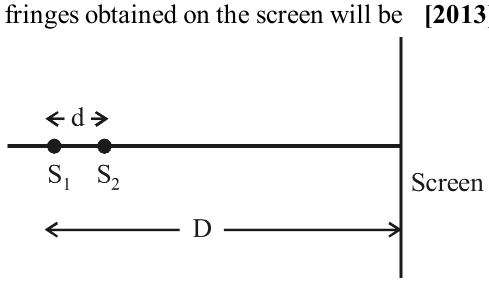
17. In Young's double slit experiment, one of the slit is wider than other, so that amplitude of the light from one slit is double of that other slit. If I_m be the maximum intensity, the resultant intensity I when they interfere at phase difference ϕ is given by : **[2012]**

(a) $\frac{I_m}{9}(4+5\cos\phi)$
(b) $\frac{I_m}{3}\left(1+2\cos^2\frac{\phi}{2}\right)$
(c) $\frac{I_m}{5}\left(1+4\cos^2\frac{\phi}{2}\right)$
(d) $\frac{I_m}{9}\left(1+8\cos^2\frac{\phi}{2}\right)$

18. A beam of unpolarised light of intensity I_0 is passed through a polaroid A and then through another polaroid B which is oriented so that its principal plane makes an angle of 45° relative to that of A. The intensity of the emergent light is **[2013]**

(a) I_0 (b) $I_0/2$
(c) $I_0/4$ (d) $I_0/8$

19. Two coherent point sources S_1 and S_2 are separated by a small distance 'd' as shown. The fringes obtained on the screen will be **[2013]**



(a) points (b) straight lines
(c) semi-circles (d) concentric circles

20. Two beams, A and B, of plane polarized light with mutually perpendicular planes of polarization are seen through a polaroid. From the position when the beam A has maximum intensity (and beam B has zero intensity), a rotation of polaroid through 30° makes the two beams appear equally bright. If the initial intensities of the two beams are I_A and I_B respectively, then $\frac{I_A}{I_B}$ equals: **[2014]**

(a) 3 (b) $\frac{3}{2}$
(c) 1 (d) $\frac{1}{3}$

21. Assuming human pupil to have a radius of 0.25 cm and a comfortable viewing distance of 25 cm, the minimum separation between two objects that human eye can resolve at 500 nm wavelength is : **[2015]**

(a) 100 μm (b) 300 μm
(c) 1 μm (d) 30 μm

22. The box of a pin hole camera, of length L, has a hole of radius a. It is assumed that when the hole is illuminated by a parallel beam of light of wavelength λ the spread of the spot (obtained on the opposite wall of the camera) is the sum of its geometrical spread and the spread due to diffraction. The spot would then have its minimum size (say b_{min}) when : **[2016]**

(a) $a=\sqrt{\lambda L}$ and $b_{min}=\sqrt{4\lambda L}$
(b) $a=\frac{\lambda^2}{L}$ and $b_{min}=\sqrt{4\lambda L}$
(c) $a=\frac{\lambda^2}{L}$ and $b_{min}=\left(\frac{2\lambda^2}{L}\right)$
(d) $a=\sqrt{\lambda l}$ and $b_{min}=\left(\frac{2\lambda^2}{L}\right)$

23. In a Young's double slit experiment, slits are separated by 0.5 mm, and the screen is placed 150 cm away. A beam of light consisting of two wavelengths, 650 nm and 520 nm, is used to obtain interference fringes on the screen. The least distance from the common central maximum to the point where the bright fringes due to both the wavelengths coincide is : **[2017]**

(a) 9.75 mm (b) 15.6 mm
(c) 1.56 mm (d) 7.8 mm

Answer Key

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(d)	(d)	(b)	(d)	(a)	(b)	(a)	(d)	(b)	(b)	(d)	(a)	(b)	(a)	(a)
16	17	18	19	20	21	22	23							
(b)	(d)	(c)	(d)	(d)	(d)	(a)	(d)							

SOLUTIONS

1. **(d)** For the phenomenon of interference we require two sources of light of same frequency and having a definite phase relationship (a phase relationship that does not change with time)

2. **(d)** The angle of incidence for total polarization is given by $\tan\theta = n \Rightarrow \theta = \tan^{-1} n$
Where n is the refractive index of the glass.

3. **(b)** For constructive interference $d\sin\theta = n\lambda$

given $d = 2\lambda \Rightarrow \sin\theta = \frac{n}{2}$

$n = 0, 1, -1, 2, -2$ hence five maxima are possible

4. **(d)** The shape of interference fringes formed on a screen in case of a monochromatic source is a straight line. Remember for double hole experiment a hyperbola is generated.

5. **(a)** $I = I_0\left(\frac{\sin\phi}{\phi}\right)^2$ and $\phi = \frac{\pi}{\lambda}(b\sin\theta)$

When the slit width is doubled, the amplitude of the wave at the centre of the screen is doubled, so the intensity at the centre is increased by a factor 4.

6. **(b)** $I = I_0\cos^2\theta$

Intensity of polarized light $= \frac{I_0}{2}$

$\Rightarrow$ Intensity of untransmitted light

$$= I_0 - \frac{I_0}{2} = \frac{I_0}{2}$$

7. **(a)** For path difference of λ, the phase difference is 2π

For path difference of $\frac{\lambda}{6}$, the phase difference is

$$\frac{2\pi \times \lambda/6}{\lambda} = \frac{\pi}{3}$$

$\therefore$ Intensity $I = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\frac{\pi}{3}$

$\therefore\ I = I_1 + I_2 + \sqrt{I_1}\sqrt{I_2}$

when $I_1 = I_2 = I'$ (say) then $I = 3I'$

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

$$= \left(\sqrt{I'} + \sqrt{I'}\right)^2 = \left(2\sqrt{I'}\right)^2 = 4I'$$

$$\therefore\ \frac{I}{I_{max}} = \frac{3}{4}$$

ALTERNATE SOLUTION

The intensity of light at any point of the screen where the phase difference due to light coming from the two slits is ϕ is given by

$I = I_0\cos^2\left(\frac{\phi}{2}\right)$ where I_0 is the maximum intensity.

NOTE This formula is applicable when $I_1 = I_2$. Here $\phi = \pi/3$

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

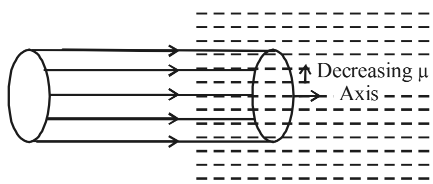
8. **(d)** The electron beam will be diffracted and the maxima is obtained at $y = 0$. Also the distance between the first minima on both side will be greater than d.

9. **(b)** Third bright fringe of known light coincides with the 4th bright fringe of the unknown light.

$$\therefore\ \frac{3(590)D}{d} = \frac{4\lambda D}{d}$$

$$\Rightarrow \lambda = \frac{3}{4} \times 590 = 442.5\,\text{nm}$$

10. **(b)** In the medium, the refractive index will decrease from the axis towards the periphery of the beam.
Therefore, the beam will move as one move from the axis to the periphery and hence the beam will converge.



11. **(d)** Initially the parallel beam is cylindrical . Therefore, the wavefront will be planar.

12. **(a)** The speed of light (c) in a medium of refractive index (μ) is given by

$\mu = \frac{c_0}{c}$, where c_0 is the speed of light in vacuum

$$\therefore c = \frac{c_0}{\mu} = \frac{c_0}{\mu_0 + \mu_2(I)}$$

As I is decreasing with increasing radius, it is maximum on the axis of the beam. Therefore, c is minimum on the axis of the beam.

13. **(b)** A phase change of π rad appears when the ray reflects at the glass-air interface. Also, the centre of the interference pattern is dark.

14. **(a)** Path difference at p

$\Delta x_1 = 0$

$\therefore$ Phase difference at P

$\Delta\phi_1 = 0°$

Intensity at p

$I_1 = I_0 + I_0 + 2I_0 \cos 0° = 4I_0$

Path difference at Q

$$\Delta x_2 = \frac{\lambda}{4}$$

$\therefore$ Phase difference at Q

$$\Delta\phi_2 = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4} = \left(\frac{\pi}{2}\right)$$

Intensity at Q.

$$I_2 = I_0 + I_0 + 2I_0 \cos\frac{\pi}{2} = 2I_0$$

Thus, $\frac{I_1}{I_2} = \frac{4I_0}{2I_0} = \frac{2}{1}$

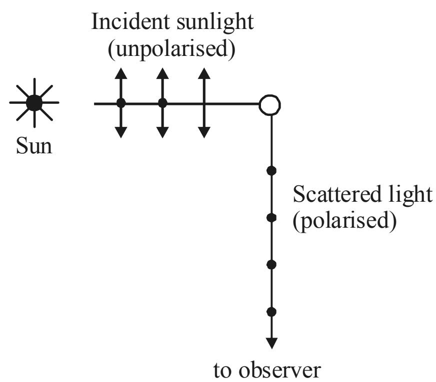
15. **(a)** For coherent sources :

$I_1 = 4I_0$

For incoherent sources

$I_2 = 2I_0 \quad \therefore \frac{I_1}{I_2} = \frac{2}{1}$

16. **(b)** When viewed through a polaroid which is rotated then the light from a clear blue portion of the sky shows a rise and fall of intensity.



17. **(d)** Let $a_1 = a, I_1 = a_1^2 = a^2$

$a_2 = 2a, I_2 = a_2^2 = 4a^2$

$I_2 = 4I_1$

$$I_r = a_1^2 + a_2^2 + 2a_1a_2 \cos\phi$$
$$= I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$
$$I_r = I_1 + 4I_1 + 2\sqrt{4I_1^2}\cos\phi$$
$$\Rightarrow I_r = 5I_1 + 4I_1\cos\phi \quad \ldots(1)$$

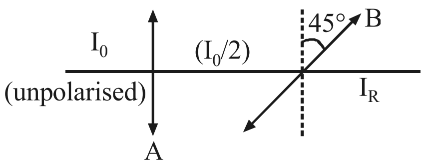
Now, $I_{max} = (a_1 + a_2)^2 = (a + 2a)^2 = 9a^2$

$$I_{max} = 9I_1 \Rightarrow I_1 = \frac{I_{max}}{9}$$

Substituting in equation (1)

$$I_r = \frac{5I_{max}}{9} + \frac{4I_{max}}{9}\cos\phi$$
$$I_r = \frac{I_{max}}{9}[5 + 4\cos\phi]$$
$$I_r = \frac{I_{max}}{9}\left[5 + 8\cos^2\frac{\phi}{2} - 4\right]$$
$$I_r = \frac{I_{max}}{9}\left[1 + 8\cos^2\frac{\phi}{2}\right]$$

18. **(c)** Relation between intensities



$$I_r = \left(\frac{I_0}{2}\right)\cos^2(45°) = \frac{I_0}{2} \times \frac{1}{2} = \frac{I_0}{4}$$

19. **(d)** It will be concentric circles.

20. **(d)** According to malus law, intensity of emerging beam is given by,

$I = I_0 \cos^2\theta$

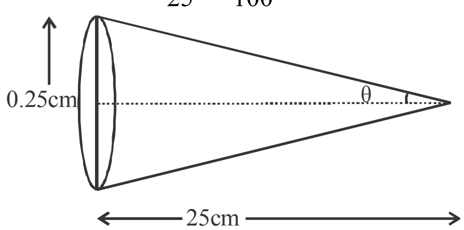
Now, $I_{A'} = I_A \cos^2 30°$

$I_{B'} = I_B \cos^2 60°$

As $I_{A'} = I_{B'}$

$$\Rightarrow \quad I_A \times \frac{3}{4} = I_B \times \frac{1}{4}\,;\quad \frac{I_A}{I_B} = \frac{1}{3}$$

21. **(d)** $\sin\theta = \dfrac{0.25}{25} = \dfrac{1}{100}$



Resolving power $= \dfrac{1.22\lambda}{2\mu\sin\theta} = 30\ \mu\text{m}.$

22. **(a)** Given geometrical spread = a

Diffraction spread $= \dfrac{\lambda}{a} \times L = \dfrac{\lambda L}{a}$

The sum $b = a + \dfrac{\lambda L}{a}$

For b to be minimum

$$\frac{db}{da} = 0 \qquad \frac{d}{da}\left(a + \frac{\lambda L}{a}\right) = 0$$

$a = \sqrt{\lambda L}$

b min $= \sqrt{\lambda L} + \sqrt{\lambda L} = 2\sqrt{\lambda L} = \sqrt{4\lambda L}$

23. **(d)** For common maxima, $n_1\lambda_1 = n_2\lambda_2$

$$\Rightarrow \quad \frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{520 \times 10^{-9}}{650 \times 10^{-9}} = \frac{4}{5}$$

For λ_1

$$y = \frac{n_1\lambda_1 D}{d}, \lambda_1 = 650\,\text{nm}$$

$$y = \frac{4 \times 650 \times 10^{-9} \times 1.5}{0.5 \times 10^{-3}} \quad \text{or,} \quad y = 7.8\ \text{mn}$$