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# 17. WAVE OPTICS

## 1. INTRODUCTION

There have always been controversies over the nature of light. Some theories believe light to be a wave whereas some believe it to be a particle. Newton, the greatest among the great, believed that light is a collection of particles. He believed that these particles travel from a source of light in straight lines when it is not under the influence of external forces. This was one of the strongest evidence of the particle nature of light.

A Dutch physicist named Huygens (1629 – 1695), suggested that light may have a wave nature. The apparent rectilinear propagation of light explained by Newton may be just due to the fact that the wavelength of light may be much smaller than the dimensions of these obstacles. This proposal remained a dump for almost a century. Newton's theory was then challenged by the Young's double slit experiment in 1801. A series of experiments on diffraction of light conducted by French scientist Fresnel were some of the activities that put an end to the particle nature of light and established the wave nature of light.

The twist came around when the wave nature of light failed to explain the photoelectric effect in which light again behaved as particles. This again brought up the question whether light had a wave or a particle nature and an acceptance was eventually reached that light is of dual nature – particle and wave. In this material, we will focus on the study of the wave nature of light.

**Key point** – Light waves need no material medium to travel. They can propagate in vacuum.

### 1.1 Nature of Light Waves

Light waves are transverse, i.e. disturbance of the medium is perpendicular to the direction of propagation of the wave. Hence they can be polarized. If a plane light wave is travelling in the x-direction, the electric field may be along the y or z direction or any other direction in y-z plane. The equation of such a monochromatic light wave can be written as $E = E_0 \sin\omega\left(t - x/v\right)$

The speed of light is generally denoted by c. When light travels in a transparent material, the speed is decreased by a factor μ, which is called as the refractive index of the material.

$$\mu = \frac{\text{speed of light in vaccum}}{\text{speed of light in the material}}$$

The frequency of visible light varies from about $3800 \times 10^{11}$ Hz to about $7800 \times 10^{11}$ Hz.

| Colour | Wave-length |
|---|---|
| Red | 620-780 nm |
| Orange | 590-620 nm |
| Yellow | 570-590nm |

| Colour | Wave-length |
|---|---|
| Green | 500-570 nm |
| Blue | 450-500 nm |
| Violet | 380-450 nm |

Light of a single wavelength is called monochromatic light.

**Illustration 1:** The refractive index of glass is 1.5. Find the speed of light in glass. **(JEE MAIN)**

**Sol:** $\mu = \dfrac{\text{speed of light in vaccum}}{\text{speed of light in the material}}$

Thus, speed of light in glass $= \dfrac{\text{speed of light in vaccum}}{\mu} = \dfrac{3.0\times 10^{8}\,\text{ms}^{-1}}{1.5} = 2.0\times 10^{8}\,\text{ms}^{-1}$

## 2. HUYGENS'S WAVE THEORY

It has following two basic postulates:

**(a)** Consider all the points on a primary wave-front to be the sources of light, which emit disturbance known as secondary disturbance.

**(b)** Tangent envelop to all secondary wavelets gives the position of the new wave-front.

Huygens' Principle may be stated in its most general form as follows:

Various points of an arbitrary surface, when reached by a wave front, become secondary sources of light emitting secondary wavelets. The disturbance beyond the surface result from the superposition of these secondary wavelets.

### Huygens' Construction

Huygens, the Dutch physicist and astronomer of the seventeenth century, gave a beautiful geometrical description of wave propagation. We can guess that, he must have seen water waves many times in the canals of his native place Holland. A stick placed in water, oscillated up and down, becomes a source of waves. Since the surface of water is two dimensional, the resulting wave fronts would be circles instead of spheres. At each point on such a circle, the water level moves up and down. Huygens' idea is that we can think of every such oscillating point on a wave front as a new source of waves. According to Huygens' principle, what we observe is the result of adding up the waves from all these different sources. These are called secondary waves or wavelets. Huygens' Principle is illustrated in (Figure) as the simple case of a plane wave.

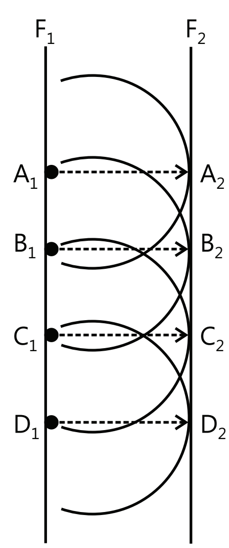


**Figure 17.1**

**(a)** At time t=0, we have a wave front $F_1$,$F_1$ separates those parts of the medium that are undisturbed from those where the wave has already reached.

**(b)** Each point on $F_1$ acts like a new source and sends out a spherical wave. After a time 't', each of these will have radius vt. These spheres are the secondary wavelets.

**(c)** After a time t, the disturbance would now have reached all points within the region covered by all these secondary waves. The boundary of this region is the new wavefront $F_2$. Notice that $F_2$ is a surface tangent to all the spheres. It is called the forward envelop of these secondary wavelets.

**(d)** The secondary wavelets from the point $A_1$ on $F_1$ touches $F_2$ at $A_2$. According to Huygens, $A_1A_2$ is a ray. It is perpendicular to the wavefronts $F_1$ and $F_2$ and has length vt. This implies that rays are perpendicular to wavefronts. Further, the time taken for light to travel between two wavefronts is the same along any ray. In our examples, the speed 'v' of the wave has been taken to be the same at all points in the medium. In this case, we can say that the distance between two wavefronts is the same measured along any ray.

**(e)** This geometrical construction can be repeated starting with $F_2$ to get the next wavefront $F_3$ a time t later, and so on. This is known as Huygens' construction.

Huygens' construction can be understood physically for waves in a material medium, like the surface of water. Each oscillating particle can set its neighbors into oscillation, and therefore acts as a secondary source. But what if there is no medium, such as for light travelling in vacuum? The mathematical theory, which cannot be given here, shows that the same geometrical construction work in this case as well.

## 3. INTERFERENCE

When two waves of the same frequency move along the same direction in a medium, they superimpose and give rise to a phenomena called interference. Points of constructive interference have maximum intensity while points of destructive interference have minimum intensity.

### 3.1 Coherent and Incoherent Sources

Two light sources of light waves are coherent if the initial phase difference between the waves emitted by the sources remains constant with time. If it changes randomly with time, the sources are said to be incoherent. Two waves produce an interference pattern only if they originate from coherent sources.

### 3.2 Intensity and Superposition of Waves

If two waves $y_1 = A_1\sin(\omega t)$ & $y_2 = A_2\sin(\omega t+\theta)$ are superimposed, resultant wave is given by $y = R\sin(\omega t+\theta)$

Where $R^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\phi$ or $I = I_1 + I_2 + 2\left(\sqrt{I_1}\sqrt{I_2}\right)\cos\phi \; \left(\because I \propto A^2\right)$ and $\tan\theta = \dfrac{A_2\sin\phi}{A_1 + A_2\cos\phi}$

For maxima, $\cos\phi = 1, \phi = 2n\pi \quad n = 0,1,2$

For minima, $\cos\phi = -1, \phi = (2n-1)\pi \quad n = 1,2,...$

If $I_1 = I_2 = I_0$; $I_1 = 4I_0\cos^2\dfrac{\phi}{2}$; $\dfrac{I_{max}}{I_{min}} = \dfrac{(A_1 + A_2)^2}{(A_1 - A_2)^2} = \dfrac{\left(\sqrt{I_1} + \sqrt{I_2}\right)^2}{\left(\sqrt{I_1} - \sqrt{I_2}\right)^2}$

**Note:** Consider two coherent sources $S_1$ and $S_2$. Suppose two waves emanating from these two sources superimpose at point P. The phase difference between them at P is $\phi$ (which is constant). If the amplitude due to two individual sources at P is $A_1$ and $A_2$, then resultant amplitude at P will be, $A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi}$

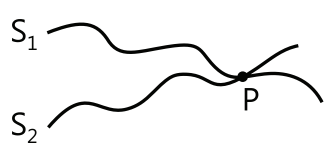


**Figure 17.2**

Similarly the resultant intensity at P is given by, $I = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi$. Here, $I_1$ and $I_2$ are the intensities due to independent sources. If the sources are incoherent then resultant intensity at P is given by, $I = I_1 + I_2$

**Illustration 2:** Light from two sources, each of same frequency and in same direction, but with intensity in the ration 4:1 interfere. Find ratio of maximum to minimum intensity. **(JEE MAIN)**

**Sol:** Interference, amplitudes added and subtracted not the intensity, $A = A_1 + A_2$.

$$\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}}\right)^2 \left(\frac{\sqrt{\frac{I_1}{I_2}}+1}{\sqrt{\frac{I_1}{I_2}}-1}\right)^2 = \left(\frac{2+1}{2-1}\right)^2 = 9:1$$

## 3.3 Conditions for Interference

**(a)** Sources should be coherent i.e. the phase difference between them should be constant. For this, frequency of sources should be the same.

**(b)** The amplitudes of both the waves should be nearly equal so as to obtain bright and dark fingers of maximum contrast.

**(c)** The two sources should be very close to each other.

**(d)** The two sources of slits should be very narrow otherwise a broad source will be equivalent to a number of narrow sources emitting their own overlapping wavelets.

If the two sources are obtained from a single parent source by splitting the light into two narrow sources, they form coherent sources which produce sustained interference pattern due to a constant phase difference between the waves.

**Illustration 3:** In a Young's experiment, the interference pattern is found to have an intensity ratio between the bright and dark fringes as 9:1, find out: **(JEE MAIN)**

**(i)** The ratio of intensities

**(ii)** Amplitude of two interfering waves.

**Sol:** In Interference, $A^2 \propto I$, $A = A_1 \pm A_2$.

$$\frac{I_{max}}{I_{min}} = \frac{9}{1}; \quad \frac{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2}{\left(\sqrt{I_1}-\sqrt{I_2}\right)^2} = \frac{9}{1}; \quad \frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}} = \frac{3}{1}; \quad \sqrt{I_1}+\sqrt{I_2} = 3\sqrt{I_1}-3\sqrt{I_2}$$

$$-2\sqrt{I_1} = -4\sqrt{I_2}; \quad \sqrt{\frac{I_1}{I_2}} = \frac{2}{1}; \quad \frac{I_1}{I_2} = \frac{4}{1}; \left(I \propto a^2\right), \frac{a_1}{a_2} = \sqrt{\frac{I_1}{I_2}}; \quad \frac{a_1}{a_2} = \sqrt{\frac{4}{1}} = \frac{2}{1}$$

**Illustration 4:** Two coherent monochromatic light beams of intensity I & 4I are superimposed. What is the max & min possible intensities in the resulting wave? **(JEE MAIN)**

**Sol:** In Interference, $A^2 \propto I$, $A = A_1 \pm A_2$.

$$I_{max} = \left(\sqrt{I_1}+\sqrt{I_2}\right)^2 = \left(\sqrt{I}+\sqrt{4I}\right)^2 = \left(3\sqrt{I_2}\right)^2 = 9I$$

$$I_{min} = \left(\sqrt{I_1}-\sqrt{I_2}\right)^2 = \left(\sqrt{I}-\sqrt{4I}\right)^2 = I$$

## 3.4 Young's Double Slit Experiment

The experiment consists of a parallel beam of monochromatic light from slit S which is incident on two narrow pinhole or slits $S_1$ and $S_2$ separated by a small distance d. The wavelets emitted from these sources superimpose at the screen placed in front of these slits to produce an alternate dark and bright fringe pattern at points on the screen depending upon whether these waves reach with a phase difference $\phi$ = (2n − 1)$\pi$ producing destructive interference or $\phi = 2n\pi$ producing constructive interference respectively. If the screen is placed at a perpendicular distance D from the middle point of the slits, the point O on the screen lies at the right bisector of $S_1$ $S_2$ and is equidistant from $S_1$ and $S_2$. The intensity at O is maximum. Consider a point P located at a distance $x_n$ from O on the screen as shown in the figure. The path difference of waves reaching at point P from $S_2$ and $S_1$ is given by Path difference $= S_2P - S_1P = \frac{x_n d}{D}$

$S_1P = XP$

$S_2P = S_2X + XP$

$\Rightarrow S_2P - S_1P = S_2X = d\sin\theta$

$\Rightarrow$ path difference $= d\sin\theta$

As $\theta$ is small $\sin\theta \approx \tan\theta = \frac{x_n}{D} \{\because D >> d\}$

$\therefore S_2P - S_1P = \frac{x_n d}{D}$

The point P will be bright or of a maximum intensity when the path difference is an integral multiple of wavelength $\lambda$ or $\phi = 2n\pi = n\lambda$ ; $\therefore$ $S_2P - S_1P = \frac{x_n d}{D} = n\lambda$

The bright fringes are thus observed at distance

$x_1 = \frac{\lambda D}{d}, x_2 = \frac{2\lambda D}{d}, x_3 = \frac{3\lambda D}{d}, ......, x_n = \frac{n\lambda D}{d}$

The distance between consecutive bright fringes,

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

The point P will be dark or of minimum intensity when the path difference is an odd multiple of half wavelength or $\phi - (2n-1)\pi$ ;

$\therefore \quad S_2P - S_1P = \frac{x_n d}{D} = n\lambda$

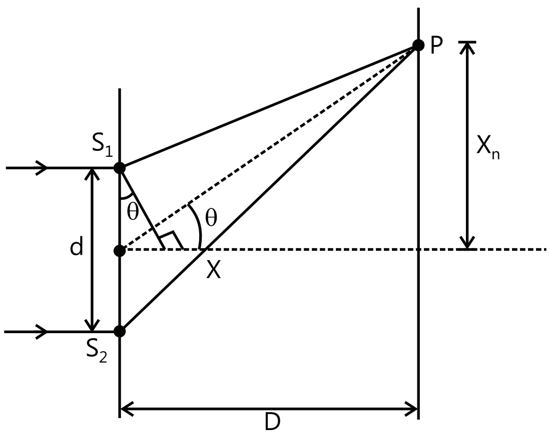



**Figure 17.3**

The bright fringes are thus observed at distances

$x_1 = \frac{\lambda D}{d}, x_2 = \frac{2\lambda D}{d}, x_3 = \frac{3\lambda D}{d}, ......, x_n = \frac{n\lambda D}{d}$

The distance between consecutive bright fringes, $\beta = \frac{n\lambda D}{d} - (n-1)\frac{\lambda D}{d} = \frac{\lambda D}{d}$

The point P will be dark or of minimum intensity when the path difference is an odd multiple of half wavelength or

$\phi = (2n-1)\pi$; $\therefore$ $\quad S_2P - S_1P = \frac{x_n d}{D} = (2n-1)\frac{\lambda}{2}$

Where n is an integer $\therefore x_n = (2n-1)\frac{\lambda D}{2d}$.

The dark fringes will be observed at distance $x_1' = \frac{\lambda D}{2d}, x_2' = \frac{3\lambda D}{2d}, x_3' = \frac{5\lambda D}{2d}, ......., x_n' = \frac{(2n-1)\lambda D}{2d}$

**Fringe width:** The spacing between any two consecutive bright or two dark fringes is equal and is called the fringe width.

The distance between two consecutive dark fringes $= \beta = \frac{(2n-1)\lambda D}{2d} - \frac{(2n-3)\lambda D}{2d} = \frac{\lambda D}{d}$

$\therefore$Fringe width $= \beta = \frac{\lambda D}{d}$

If a thin transparent plate of thickness t and refractive index $\mu$ is introduced in the path $S_1P$ of one of the interfering waves, the entire fringes pattern is shifted through a constant distance. The path $S_1P$ in air is increased to an air path equal to $S_1P + (\mu - 1)t$

$\therefore$ The path difference $\delta = S_2P - [S_1P + (\mu-1)t] = S_2P - S_1P - (\mu-1)t = \frac{x_n d}{D} - (\mu-1)t$

For nth maxima at a distance $x'_n = \frac{x_n.d}{D} - (\mu-1)t = n\lambda$; $\quad x_n = \frac{D}{d}[n\lambda + (\mu-1)t]$

Thus, when a thin transparent plate of thickness t and refractive index $\mu$ is introduced in one of the paths of the waves, the path difference changes by $\frac{xd}{D}$.

$\therefore \frac{xd}{D} = (\mu-1)t$; $x = \frac{D}{d}(\mu-1)t$

$\therefore$The central maxima shifts by a distance equal to $\frac{D(\mu-1)t}{d}$.

## PLANCESS CONCEPTS

In Young's double slit experiment, it is important to note that energy is just redistributed over the surface of screen. It is still conserved! More energy is taken by points near bright fringes whereas dark fringes have almost no energy.

**B Rajiv Reddy (JEE 2012, AIR 11)**

**Illustration 5:** $S_1$ and $S_2$ are two coherent sources of frequently 'f' each. $(\theta_1 = \theta_2 = 0°)$ $V_{sound} = 330 m/s$ . Find f

**(i)** So that there is constructive interference at 'P'

**(ii)** So that there is destructive interference at 'P' **(JEE MAIN)**

**Sol:** Path difference for constructive and destructive interference must be $\lambda$ and $\frac{\lambda}{2}$ respectively.

For constructive interference,

$K\Delta x = 2n\pi$ ; $\frac{2\pi}{\lambda} \times 2 = 2n\pi$; $\lambda = \frac{2}{n}$; $V = \lambda f \Rightarrow V = \frac{2}{n} f$; $f = \frac{330}{2} \times n$ For destructive interference,

$K\Delta x = (2n+1)\pi$; $\frac{2\pi}{\lambda}.2 = (2n+1)\pi$; $\frac{1}{\lambda} = \frac{(2n+1)}{4}$; $f = \frac{V}{\lambda} = \frac{330 \times (2n+1)}{4}$

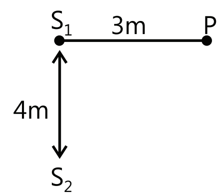



**Figure 17.4**

**Illustration 6:** In a Young's double slit experiment, the separation between the slits is 0.10 mm, the wavelength of light used is 600 nm and the interference pattern is observed on a screen 1.0 m away. Find the separation between the successive bright fringes. **(JEE MAIN)**

**Sol:** Path difference needs to be $\lambda$.

The separation between the successive bright fringes is, $\omega = \frac{D\lambda}{d} = \frac{1.0\text{m} \times 600 \times 10^{-9}\text{m}}{0.10 \times 10^{-3}\text{m}} = 6.0 \times 10^{-3}\text{m} = 6.0\text{mm}$

**Assumptions:** 2. Since d<<D, we can assume that intensities at P due to independent sources $S_1$ and $S_2$ are almost equal. or $I_1 = I_2 = I_0$ (say)

**Illustration 7:** When a plastic thin film of refractive index 1.45 is placed in the path of one of the interfering waves, then the central fringe is displaced through width of five fringes. Find the thickness of the film, if the wavelength of light is 5890 A. **(JEE MAIN)**

**Sol:** Path difference due to introducing of thin film.

$$X_0 = \frac{\beta}{\lambda}(\mu - 1)t \Rightarrow 5p = \frac{\beta(0.45)t}{5890 \times 10^{-10}} \qquad \therefore \qquad t = \frac{5 \times 589010^{-10}}{0.45} = 6.544 \times 10^{-4}\,\text{cm}$$

**Illustration 8:** Laser light of wavelength 630 nm, incident on a pair of slits produces an interference pattern in which bright fringes are separated by 8.1 mm. A second light produces an interference pattern in which the bright fringes are separated by 7.2 mm. Find the wavelength of the second light. **(JEE ADVANCED)**

**Sol:** The separation between the successive bright fringes, $\beta \propto \lambda$.

$\lambda_1 = 630\text{nm} = 630 \times 10^{-9}\text{m}$; $\beta_1 = 8.1\text{mm} = 8.1 \times 10^{-3}\text{m}$; $\beta_2 = 7.2\text{mm} = 7.2 \times 10^{-3}\text{m}$

$$\frac{\lambda_2}{\lambda_1} = \frac{\beta_2}{\beta_1}; \qquad \lambda_2 = \frac{\beta_2}{\beta_1}\lambda_1; \qquad \lambda_2 = \frac{7.2 \times 10^{-3}}{8.1 \times 10^{-3}} \times 630 \times 10^{-9} = \frac{8}{9} \times 630 \times 10^{-9} = 560 \times 10^{-9} = 560\text{nm}$$

**Illustration 9:** In a Young's double slit experiment, the two slits are illuminated by light of wavelength 5890 Angstrom and the distance between the fringes obtained on the screen is $0.2°$. If the whole apparatus is immersed in water, the angular fringe width will be: (the refractive index of water is $4/3$). **(JEE ADVANCED)**

**Sol:** Angular fringe width, $\omega \propto \lambda$.

$$\omega_a = \lambda/d; \qquad \therefore \quad \omega_a \propto \lambda \Rightarrow \frac{(\omega_a)_{water}}{\omega_a} = \frac{\lambda_{water}}{\lambda} \qquad \Rightarrow \frac{(\omega_a)_{water}}{\omega_a} = \frac{\lambda}{\mu_{water}\lambda} \qquad \Rightarrow (\omega_a)_{water} = 0.15°$$

**Illustration 10:** In a YDSE, D=1m, d=1mm and $\lambda = 1/2\text{mm}$ **(JEE ADVANCED)**

**(i)** Find the distance between the first and the central maxima of the screen.

**(ii)** Find the no. of maxima and minima obtained on the screen.

**Sol:** Here, $\sin\theta << 1$, not applicable. Hence $\Delta P = d\tan\theta = \frac{dy}{D}$ is used.

(i) D>>d Hence $\Delta P = d\sin\theta$; $\frac{d}{\lambda} = 2$,

Clearly, $n << \frac{d}{\lambda} = 2$ is not possible for any value of n.

Hence $\Delta p = \frac{dy}{D}$ cannot be used.

For 1st maxima, $\Delta p = d\sin\theta = \lambda \Rightarrow \sin\theta = \frac{\lambda}{d} = \frac{1}{2}; \Rightarrow \theta = 30°$

Hence, $y = D\tan\theta = \frac{1}{\sqrt{3}}$ meter

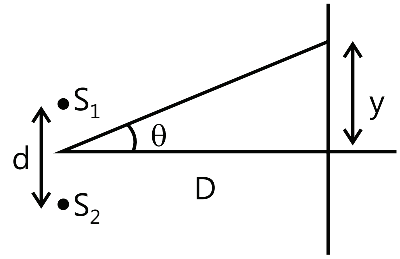



**Figure 17.5**

(ii) Maximum path difference

$\Delta P_{max} = d = 1mm$

$\Rightarrow$ Highest order maxima, $n_{max} = \left[\frac{d}{\lambda}\right] = 2$

And highest order minima $n_{min} = \left[\frac{d}{\lambda} + \frac{1}{2}\right] = 2$

Total no. of maxima $= 2n_{max} + 1^* = 5\ ^*(\text{central maxima})$

Total no. of minima $= = 2n_{min} = 4$

**Illustration 11:** Monochromatic light of wavelength 5000 A° is used in a Y.D.S.E., with slit-width, d=1mm, distance between screen and slits, D is 1m. If the intensities at the two slits are, $I_1 = 4I_0, I_2 = I_0$, find **(JEE ADVANCED)**

**(i)** Fringe width $\beta$

**(ii)** Distance of 5th minima from the central maxima on the screen.

**(iii)** Intensity at $y = \frac{1}{3}$mm

**(iv)** Distance of the 1000th maxima from the central maxima on the screen.

**(v)** Distance of the 5000th maxima from the central maxima on the screen.

**Sol:** Refer to the formulas:-

(i) $\beta = \frac{\lambda D}{d} = \frac{5000 \times 10^{-10} \times 1}{1 \times 10^{-3}} = 0.5mm$

(ii) $y = (2n-1)\frac{\lambda D}{2d}, n = 5 \Rightarrow y = 2.25mm$

(iii) At $y = \frac{1}{3}mm, y << D$ Hence $\Delta p = \frac{d.y}{D}$

$\Delta\phi = \frac{2\pi}{\lambda}\Delta p = 2\pi\frac{dy}{\lambda D} = \frac{4\pi}{3}$

Now resultant intensity

$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\Delta\phi;\ 4I_0 + I_0 + 2\sqrt{4I_0^2}\cos\Delta\phi = 5I_0 + 4I_0\cos\frac{4\pi}{3} = 3I_0$

(iv) $\frac{d}{\lambda} = \frac{10^{-3}}{0.5 \times 10^{-6}} = 2000$

n=1000 is not <<2000

Hence now $\Delta p$ =d sin $\theta$ must be used

Hence, d sin $\theta = n\lambda = 1000\lambda$ $\Rightarrow \sin\theta = 1000\frac{\lambda}{d} = \frac{1}{2}$ $\Rightarrow \theta = 30°$

$Y = D\tan\theta = \frac{1}{\sqrt{3}}$ meter

(v) Highest order maxima $n_{max} = \left[\frac{d}{\lambda}\right] = 2000$

Hence, n=5000 is not possible

**Intensity variation on screen:** If $I_0$ is the intensity of light beam coming from each slit, the resultant intensity at a point where they have a phase difference of $\phi$ is

$$I = 4I_0\cos^2\frac{\phi}{2}, \text{where}\ \phi = \frac{2\pi(d\sin\theta)}{\lambda}$$

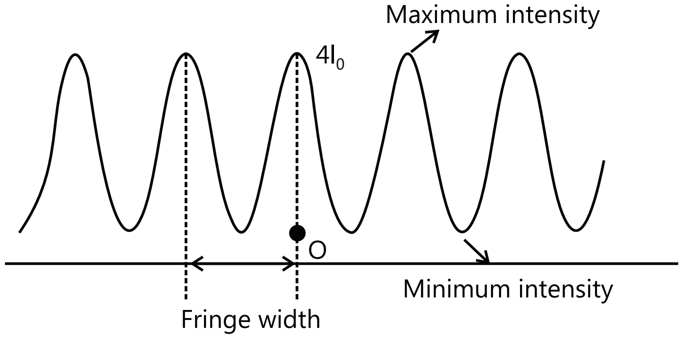



**Figure 17.6**

**For interference in reflected rays**

When $\mu_2 > \mu_1, \mu_3;$ condition for

(i) Maxima: $2t\mu_2\cos r = \left(n - \frac{1}{2}\right)\lambda,\ n = 1, 2, ....$

(ii) Minima: $2t\mu_2\cos r = n\lambda,\ n = 1, 2, ....$

When $\mu_2$ is in between $\mu_1$ & $\mu_2$, condition for

(i) Maxima: $2t\mu_2\cos r = n\lambda,\ n = 1, 2, ....$

(ii) Minima: $2t\mu_2\cos r = \left(n - \frac{1}{2}\right)\lambda,\ n = 1, 2, ....$

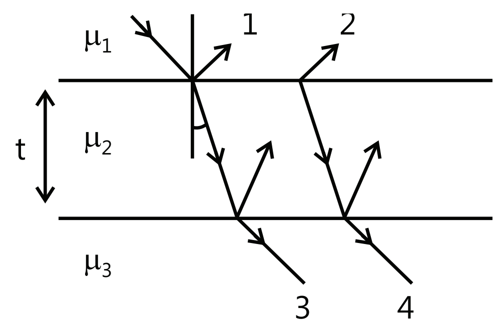



**Figure 17.7**

For interference in transmitted rays, 3 and 4 conditions are interchanged for maxima and minima in both cases of $\mu_2$.

**Illustration 12:** When a plastic thin film of refractive index 1.45 is placed in the path of one of the interfering waves then the central fringe is displaced through width of five fringes. Find the thickness of the film, if the wavelength of light is 5890 Å. **(JEE MAIN)**

**Sol:** Path difference due to introducing of thin film.

$$\therefore X_0 = \frac{\beta}{\lambda}(\mu - 1)t \Rightarrow 5p = \frac{\beta(0.45)t}{5890\times10^{-10}};\quad \therefore\quad t = \frac{5\times5890/10^{-10}}{0.45} = 6.544\times10^{-4}\,\text{cm}$$

**Useful tips:** If two slits have unequal sizes (they correspond to intensity). The intensity of the resultant is

$$I = \left(\sqrt{I_1}\right)^2 + \left(\sqrt{I_2}\right)^2 + \left(2\sqrt{I_1I_2}\right)\cos\phi$$

$$I = I_1 + I_2 + \left(2\sqrt{I_1I_2}\right)\cos\phi = k\left(S_1 + S_2 + 2\sqrt{S_1S_2}\cos\phi\right)$$

Where $S_1$ & $S_2$ is the size of slits

Coherence length, $I_{coh} = \frac{\lambda^2}{\Delta\lambda}$; Coherence radius $\rho_{coh} = \frac{\lambda^2}{\phi}$ $\quad\beta = \frac{\phi}{2}$

## 3.5 Optical Path

Actual distance travelled by light in a medium is called geometrical path $(\Delta x)$. Consider a light wave given by the equation $E = E_0 \sin(\omega t - kx + \phi)$

If the light travels by $\Delta x$, its phase changes by $k\Delta x = \frac{\omega}{v}\Delta x$, where $\omega$, the frequency of light does not depend on the medium, but v, the speed of light depends on the medium as $v = \frac{c}{\mu}$.

Consequently, change in phase $\Delta\phi = k\,\Delta x = \frac{w}{c}(\mu\Delta x)$

It is clear that a wave travelling a distance $\Delta x$ in a medium of refractive index $\mu$ suffers the same phase change as when it travels a distance $\mu\Delta x$ in vacuum i.e. a path length of $\Delta x$ in medium of refractive index $\mu$ is equivalent to a path length of $\mu\Delta x$ in vacuum.

The quantity $\mu\Delta x$ is called the optical path length of light, $\Delta x_{opt}$. And in terms of optical path length, phase difference would be given by. $\Delta\phi = \frac{\omega}{c}\Delta x_{opt} = \frac{2\pi}{\lambda_0}\Delta x_{opt}$

where $\lambda_0$ =wavelength of light in vacuum.

However in terms of the geometrical path length $\Delta x$,

$$\Delta\phi = \frac{\omega}{c}(\mu\Delta x) = \frac{2\pi}{\lambda}\Delta x$$

Where $\lambda$ = wavelength of light in the medium $\left(\lambda = \frac{\lambda_0}{\mu}\right)$.

**PLANCESS CONCEPTS**

Optical path must always be linked to phase of wave, so that it's more convincing and useful. Only learning manually will make it confusing and annoying.

If a material of thickness t interrupts the path of light and distance measured from position of an end of material, then the phase of wave which is found at a distance x(<t) through the material will be same to phase at distance (mu), if there was no material.

Fringe width (w) is the distance between two successive maximas or minimas. It is given by, $w = \frac{\lambda D}{d}$; or $w \propto \lambda$ .Two conclusions can be drawn from this relation:-

(i) If a YDSE apparatus is immersed in a liquid of refractive index $\mu$, then wavelength of light and hence, fringe width decreases $\mu$ times.

(ii) If white light is used in place of a monochromatic light then coloured fringes are obtained on the screen with red fringes of larger size than that of violet, because $\lambda_{red} > \lambda_{violet}$.

**Vaibhav Gupta (JEE 2009, AIR 54)**

**Illustration 13:** The wavelength of light coming from a sodium source is 589 nm. What will be its wavelength in water? Refractive index of water =1.33. **(JEE MAIN)**

**Sol:** The wavelength in water is $\lambda = \lambda_0/\mu$, where $\lambda_0$ is the wavelength in vacuum and $\mu$ is the refractive index of water. Thu $\lambda = \frac{589}{1.33} = 443\text{nm}$

## 3.6 Interference from Thin Films

Interference effects are commonly observed in thin films, such as thin layers of oil on water or the thin surface of a soap bubble. The various colors observed when white light is incident on such films result from the interference of waves reflected from the two surfaces of the film. Consider a film of uniform thickness t and index of refraction $\mu$ as shown in the figure. Let us assume that the rays travelling in air are nearly normal to the two surfaces of the film. To determine whether the reflected rays interfere constructively or destructively, we first note the following facts.

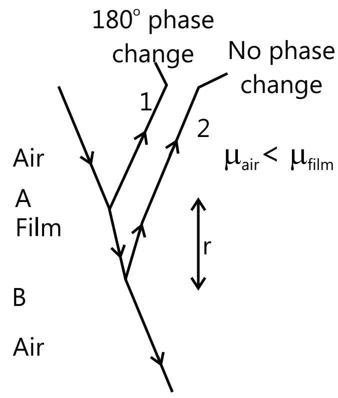



**Figure 17.8**

**(i)** The wavelength of light in a medium whose refractive index is $\mu$ is, $\lambda_\mu = \frac{\lambda}{\mu}$ Where $\lambda$ is the wavelength of light in vacuum (on air)

**(ii)** If a wave is reflected from a denser medium, it undergoes a phase change of $180°$. Let us apply these rules to the film shown in figure. The path difference between the two rays. 1 and 2 is 2t while the phase difference between them is $180°$. Hence, condition of constructive interference will be, $2t = (2n-1)\frac{\lambda\mu}{2}$ or, $2\mu t = \left(n - \frac{1}{2}\right)\lambda$ as $\lambda_\mu = \frac{\lambda}{\mu}$

Similarly, condition of destructive interference will be $2\mu t = n\lambda$ ; n=0, 1, 2, ...

**Illustration 14:** Find the minimum thickness of a film which will strongly reflect the light of wavelength 589 nm. The refractive index of the material of the film is 1.25. **(JEE MAIN)**

**Sol:** Path difference due to introducing of thin film.

For strong reflection, the least optical path difference introduced by the film should be $\lambda/2$. The optical path difference between the waves reflected from the two surface of the film is $2\mu d$.

Thus, for strong reflection, $2\mu d = \lambda/2$ or, $d = \frac{\lambda}{4\mu} = \frac{589\text{nm}}{4 \times 1.25} = 118\text{nm}$.

## 3.7 YDSE with Glass Slab

### Path difference produced by a slab

Consider two light rays 1 and 2 moving in air parallel to each other. If a slab of refractive index $\mu$ and thickness t is inserted between the path of one of the rays then a path difference $\Delta x = (\mu - 1)t$ is produced among them. This can be shown as under,

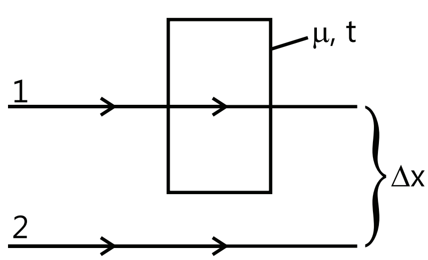



**Figure 17.9**

Speed of light in air = c

Speed of light in medium $= \frac{c}{\mu}$ Time taken by ray 1 to cross the slab, $t_1 = \frac{t}{c/\mu} = \frac{\mu t}{c}$ and time taken by ray 2 cross the same thickness t in air will be, $t_2 = \frac{t}{c}$ as $t_1 > t_2$

Difference in time $\Delta t = t_1 - t_2 = (\mu - 1)\frac{t}{c}$

**Optical path length:** Now we can show that a thickness t in a medium of refractive index $\mu$ is equivalent to a length $\mu t$ in vacuum (or air). This is called optical path length. Thus,

Optical path length= $\mu t$

**Shifting of fringes:** Suppose a glass slab of thickness t and refractive index $\mu$ is inserted onto the path of the ray emanating from source $S_1$. Then, the whole fringe pattern shifts upwards by a distance $\frac{(\mu-1)tD}{d}$. This can be shown as under Geometric path difference between $S_2P$ and $S_1P$ is, $\Delta x_1 = S_2P - S_1P = \frac{yd}{D}$ Path difference produced by the glass slab $\Delta x_2 = (\mu-1)t$

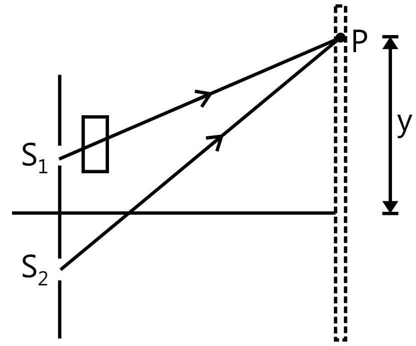



**Figure 17.10**

**Note:** Due to the glass slab, path of ray 1 gets increased by $\Delta x_2$. Therefore, net path difference between the two rays is,

$$\Delta x = \Delta x_1 - \Delta x_2 \text{ or, } \quad \Delta x = \frac{yd}{D} - (\mu-1)t$$

For $n^{th}$ maxima on upper side, or, $\frac{yd}{D} - (\mu-1)t = n\lambda$ ;

$$\therefore \quad y = \frac{n\lambda D}{d} + \frac{(\mu-1)tD}{d}$$

Earlier, it was $\frac{n\lambda D}{d}$; Shift $= \frac{(\mu-1)tD}{d}$

Following three points are important with regard to Eq. above

**(a)** Shift is independent of n, (the order of the fringe), i.e.,

Shift of zero order maximum = shift of $7^{th}$ order maximum

Shift of $5^{th}$ order maximum = shift of $9^{th}$ order minimum and so on.

**(b)** Shift in independent of $\lambda$, i.e., if white light is used then,

Shift of red colour fringes = shift of violet colour fringes.

**(c)** Number of fringes shifted = $\frac{\text{shift}}{\text{fringes width}} = \frac{(\mu-1)tD/d}{\lambda D/d} = \frac{(\mu-1)t}{\lambda}$

These numbers are inversely proportional to $\lambda$. This is because the shift is the same for all colours but the fringe width of the colour having smaller value of $\lambda$ is small, so more number of fringes of this colour will shift.

**Illustration 15:** In a YDSE with d=1mm and D=1m, slabs of $(t = 1\mu m, \mu = 3)$ and $(t = 0.5\mu m, \mu = 2)$ are introduced in front of the upper slit and the lower slit respectively. Find the shift in the fringes pattern. **(JEE MAIN)**

**Sol:** Path difference due to introducing of thin film.

Optical path for light coming from upper slit $S_1$ is $S_1P + 1\mu m(2-1) = S_2P + 0.5\mu m$

Similarly optical path for light coming from $S_2$ is $S_2P + 0.5\mu m(2-1) = S_2P + 0.5\mu m$

Path difference $\Delta p = (S_2P + 0.5\mu m) - (S_1P + 2\mu m) = (S_2P - S_1P) - 1.5\mu m = \frac{yd}{D} - 1.5\mu m$

For central bright $\Delta p = 0 \Rightarrow y = \frac{1.5\mu m}{1mm} \times 1m = 1.5mm.$

The whole pattern is shifted by 1.5mm upwards.

**Illustration 16:** Bichromatic light is used in YDSE having wavelength $\lambda_1$ = 400 mm and $\lambda_2$ = 700 mm. Find minimum order of $\lambda_1$ which overlaps with $\lambda_2$. **(JEE ADVANCED)**

**Sol:** Fringe width depends on wavelength.

Let $n_1$ bright find of $\lambda_1$ overlaps with $\lambda_2$. Then, $\frac{n_1\lambda_1 D}{d} = \frac{n_2\lambda_2 D}{d}$ Or, $\frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{700}{400} = \frac{7}{4}$. The ratio $\frac{n_1}{n_2} = \frac{7}{4}$ implies that 7th bright fringes of $\lambda_1$ will overlap with 4th bright fringes of $\lambda_2$. Similarly 14th of $\lambda_1$ will overlap with 8th of $\lambda_2$ and so on.

So the minimum order of $\lambda_1$ which overlaps with $\lambda_2$ is 7.

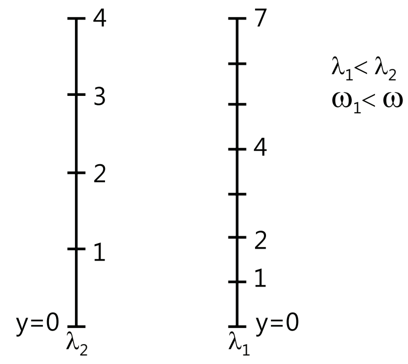



**Figure 17.11**

**Illustration 17:** In YDSE, find the thickness of a glass slab $(\mu = 1.5)$ which should be placed before the upper slit $S_1$ so that the central maximum now lies at a point where 5th bright fringe was lying earlier (before inserting the slab). Wavelength of light used is 5000 Å. **(JEE MAIN)**

**Sol:** Path difference due to introducing of thin film.

According to the question, Shift = 5 (fringe width)

$$\therefore \frac{(\mu-1)tD}{d} = \frac{5\lambda D}{d} \therefore y = \frac{5\lambda}{\mu-1} = \frac{25000}{1.5-1} = 50{,}000\ \text{Å}$$

**Tip:** If the light reaching P is direct (not reflected) from two sources then P will be a bright fringe if the path difference $= n\lambda$

If the light reaching P after reflection forms a bright fringe (at P) then path difference $= (2n+1)\frac{\lambda}{2}$ $\rightarrow$ because the reflection causes an additional path difference of $\frac{\lambda}{2}$ (or phase difference = $\pi$ rad.) If the interference occurs due to reflected light, central fringe (or ring in Newton's rings) will be dark. If the interference occurs due to transmitted light, central fringe (or ring in Newton's rings) will be bright.

## 3.8 YDSE with Oblique Incidence

In YDSE, ray is incident on the slit at an inclination of $\theta_0$ to the axis of symmetry of the experimental set-up for points above the central point on the screen, (say for $P_1$)

$$\Delta p = d\sin\theta_0 + (S_2P_1 - S_1P_1)$$

$$\Rightarrow \Delta p = d\sin\theta_0 + d\sin\theta_1 \quad (\text{if } d << D)$$

and for points below O on the screen, (say for $P_2$)

$$\Delta p = |(d\sin\theta_0 + S_2P_2) - S_1P_2| = |d\sin\theta_0 - (S_1P_2 - S_2P_2)|$$

$$\Rightarrow \Delta p = |d\sin\theta_0 - d\sin\theta_2| \quad (\text{if } d << D)$$

We obtain central maxima at a point where, $\Delta p = 0$.

$$(d\sin\theta_0 - d\sin\theta_2) = 0 \quad \text{or, } \theta_2 = \theta_0.$$

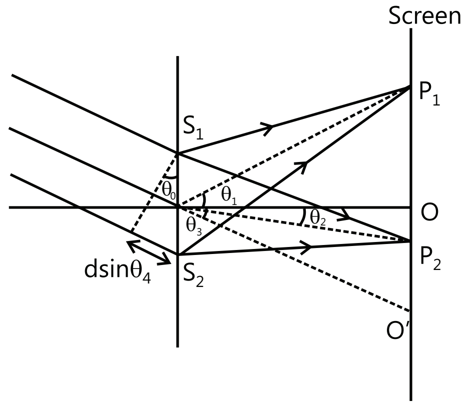



**Figure 17.12**

This corresponds to the point O’ in the diagram. Hence, we finally have the path difference as

$$\Delta p = \begin{cases} d\left(\sin\theta_0 + \sin\theta\right) & - \quad \text{for points above O} \\ d\left(\sin\theta_0 - \sin\theta\right) & - \quad \text{for points between O \& O'} \\ d\left(\sin\theta - \sin\theta_o\right) & - \quad \text{for points below O'} \end{cases}$$

**Illustration 18:** In a YDSE with D=1m, d=1mm, light of wavelength 500 nm is incident at an angle of $0.57°$ w.r.t. the axis of symmetry of the experimental set up. If the centre of symmetry of screen is O as shown, find:

**(i)** The position of central maxima.

**(ii)** Intensity at point O in terms of intensity of central maxima $I_0$.

**(iii)** Number of maxima lying between O and the central maxima. **(JEE MAIN)**

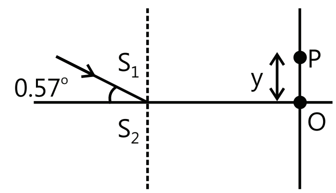


**Figure 17.13**

**Sol:** Path difference at central maxima =0.

**(i)** $\theta = \theta 0 = 0.57° \Rightarrow D\tan\theta = -D\theta = -1 \text{ meter} \times \left(\frac{0.57}{57}\text{rad}\right) \Rightarrow y = -1\text{cm}$

**(ii)** For point 0, $\theta = 0$

Hence, $\Delta p = d\sin\theta_0 \simeq d\theta_0 = 1\text{mm} \times \left(10^{-2}\text{rad}\right) = 10{,}000\text{nm} = 20 \times \left(500\text{nm}\right)$

Hence point O correspond to 20th maxima $\Rightarrow$ intensity at O=$I_0$

**(iii)** 19 maxima lie between central maxima and O, excluding maxima at O and central maxima.

## 4. DIFFRACTION

The phenomenon of bending of light around the corners of an obstacle or an aperture into the region of the geometrical shadow of the obstacle is called diffraction of light. The diffraction of light is more pronounced when the dimension of the obstacle/aperture is comparable to the wavelength of the wave.

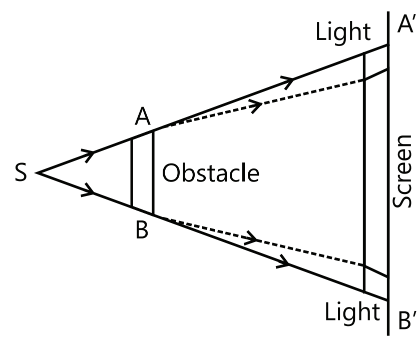


**Figure 17.14**

### 4.1 Diffraction of Light Due to Single Slit

Diverging light from monochromatic source S is made parallel after refraction through convex lens $L_1$. The refracted light from $L_1$ is propagated in the form of plane wave front WW’. The plane wave front WW’ is incident on the slit AB of width ‘d’. According to Huygens’ Principle, each point of slit AB acts as a source of secondary disturbance of wavelets.

**Path difference:** To find the path difference between the secondary wavelets originating from corresponding points A and B of the plane wave front, draw AN perpendicular on BB’. The path difference between these wavelets originating from A and B is BN.

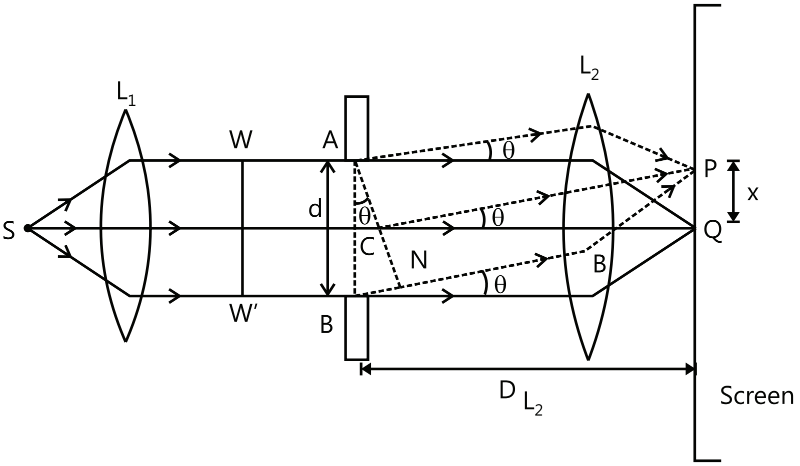



**Figure 17.15**

From $\Delta BAN, \frac{BN}{AB} = \sin\theta$ Or, $BN = AB\sin\theta$ ∴Path difference, BN=d $\sin\theta \simeq d\theta$ $(\because \theta \text{ is small})$

**(a)** **For Minima:** If the path difference is equal to one wavelength i.e., BN= $d\sin\theta = \lambda$, position P will be of minimum intensity. Hence, for first minima, $d\sin\theta_1 = \lambda$

Or $\sin\theta_1 = \lambda/d$ ...(i)

Or $\theta_1 = \lambda/d$ $(\because \theta_1 \text{ is very small})$ ...(ii)

Similarly, if BN= $2\lambda$,

Thus, for second minima, $d\sin\theta_2 = 2\lambda$ Or $\sin\theta_2 = 2\lambda/d$; $\because \sin\theta_2 = \theta_2$ Or $\theta_2 = 2\lambda/d$

In general, for minima, $d\sin\theta_m = m\lambda$ Or $\sin\theta_m = m\lambda/d$

Since $\theta_m$ is small, so sin $\theta_m = \theta_m$ ∴ $\theta_m = \frac{m\lambda}{d}$ (here $\theta$ we use is in radians)

Where, $\theta_m$ is the angle giving direction of the $m^{th}$ order minima and m=1,2,3,.... Is an integer.

**Note:** Condition for minima → Path difference between two waves should be $m\lambda$, where m is an integer.

**(b)** **For secondary maxima:** If path difference, BN= d sin $\theta$ is an odd multiple of $\lambda/2$,

i.e. $d\sin\theta_m = \left(\frac{2m+1}{2}\right)\lambda$ or $\sin\theta_m = \left(\frac{2m+1}{2}\right)\frac{\lambda}{d}$

Since $\theta_m$ is small, so $\sin\theta_m = \theta_m$; ∴ $\theta_m = \left(\frac{2m+1}{2}\right)\frac{\lambda}{d}$ ...(iv)

M=1 ,2, 3, .... Is an integer

Let f be the focal length of lens $L_2$ and the distance of first minima on either side of the central maxima be x. Then, $\tan\theta = \frac{x}{f}$

Since the lens $L_2$ is very close to the slit, so f=D

$\therefore \tan\theta = \frac{x}{d}$ Since $\theta$ is very small, so $\tan\theta \approx \sin\theta$ $\therefore \sin\theta = \frac{x}{d}$ ...(i)

Also, for first minima, $d\sin\theta = \lambda$ or $\sin\theta = \frac{y}{d}$ ...(ii)

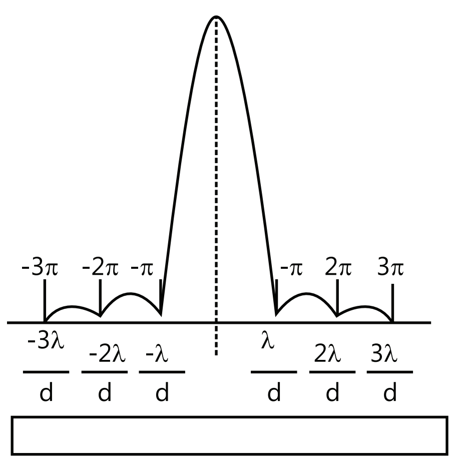



**Figure 17.16**

From eqns. (i) and (ii), we have $\frac{x}{D}=\frac{\lambda}{d}$ or $x=\frac{\lambda D}{d}$ ...(iii)

This is the distance of first minima on either side from the centre of the central maximum. Width of central maximum is given by: $\therefore 2x=\frac{2\lambda D}{d}$

Diffraction pattern due to a single slit consists of a central maximum flanked by alternate minima and secondary maxima is shown in figure.

**Note:** That $\sin\theta=0$ corresponds to central maxima while $\sin\theta=\pi$, corresponds to first minima.

**Diffraction grating:** It consists of a large number of equally spaced parallel slits. If light is incident normally on a transmission grating, the direction of principal maxima is given by $d\sin\theta=n\lambda$

Here d is the distance between two consecutive slits and is called the grating element.

N=1, 2, 3,.... is the order of principal maximas.

**Resolving power of the diffraction grating:** The diffraction grating is most useful for measuring wavelengths accurately. Like the prism, the diffraction grating can be used to disperse a spectrum into its wavelength components. Of the two devices, the grating is the more precise if one wants to distinguish two closely spaced wavelengths. For two nearly equal wavelengths $\lambda_1$ and $\lambda_2$, between which a diffraction grating can just barely distinguish, the resolving power R of the grating is defined as

$R=\frac{\lambda}{\lambda_2-\lambda_1}=\frac{\lambda}{\Delta\lambda}$ where, $\lambda=(\lambda_1+\lambda_2)/2$ and $\Delta\lambda=\lambda_2-\lambda_1$.

**Illustration 19:** A parallel beam of monochromatic light of wavelength 450 nm passes through a long slit of width 0.2 mm. Find the angular divergence in which most of the light is diffracted. **(JEE MAIN)**

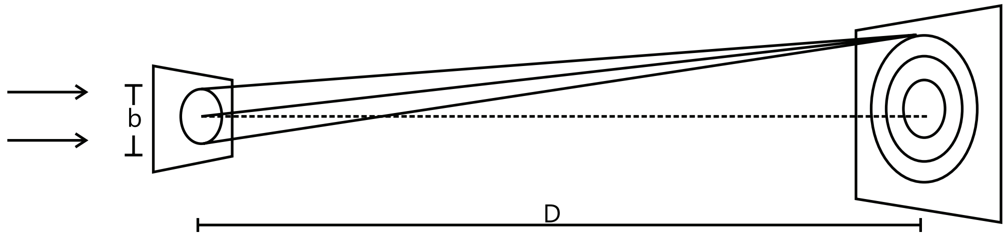
**Sol:** Most of the light is diffracted between the two first order minima. These minima occur at angles given by $b\sin\theta=\pm\lambda$

Or, $\sin\theta=\pm\lambda/b=\pm\frac{450\times10^{-9}m}{0.2\times10^{-3}m}=\pm2.25\times10^{-3}$ Or, $\theta=\pm2.25\times10^{-3}$rad

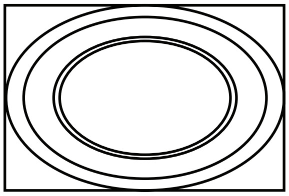
The angular divergence $=4.5\times10^{-3}$rad.

## 4.2 Diffraction by a Circular Aperture

Mathematical analysis shows that the first dark ring is formed by the light diffracted from the hole at an angle $\theta$ with the axis, where $\sin\theta=1.22\frac{\lambda}{b}$ Here, $\lambda$ is the wavelength of the light used and b is the diameter of the hole. If the screen is at a distance D(D>>b) from the hole, the radius of the first dark ring is $R=1.22\frac{\lambda D}{b}$




(a)



(b)

**Figure 17.17**

If the light transmitted by the hole is converged by a converging lens at the screen placed at the focal plane of this lens, the radius of the first dark ring is $R = 1.22\frac{\lambda f}{b}$

As most of the light coming from the hole is concentrated within the first dark ring, this radius is also called the radius of the diffraction disc.

**Illustration 20:** A beam of light of wavelength 590nm is focused by a converging lens of diameter 10.0 cm at a distance of 20 cm from it. Find the diameter of the disc image formed. **(JEE MAIN)**

**Sol:** The angular radius of the central bright disc in a diffraction pattern from circular aperture is given by $\sin\theta = \frac{1.22\lambda}{b} = \frac{1.22 \times 590 \times 10^{-9} m}{10.0 \times 10^{-2} m} = 0.7 \times 10^{-5}$ rad.

The radius of the bright disc is $0.7 \times 10^{-5} \times 20cm = 1.4 \times 10^{-4}$ cm

The diameter of the disc image $= 2.8 \times 10^{-4}$ cm

## 4.3 Diffraction of X-Rays by Crystals

The arrangement of atoms in a crystal of NaCl is shown in the above figure. Each unit cell is a cube of length of edge a. If an incident x-ray beam makes an angle $\theta$ with one of the planes, the beam can be reflected from both the planes. However, the beam reflected from the lower plane travels farther than the beam reflected from the upper plane.

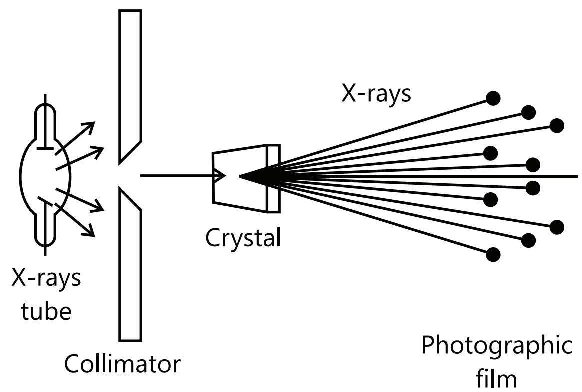



**Figure 17.18**

The effective path difference is $2d\ \sin\theta$. The two beams reinforce each other (constructive interference) when this path difference is equal to some integer multiple of $\lambda$. The same is true for reflection from the entire family of parallel planes. Hence, the condition for constructive interference (maxima in the reflected beam) is $2d\sin\theta = m\lambda$ where, m=1, 2, 3,...is an integer.

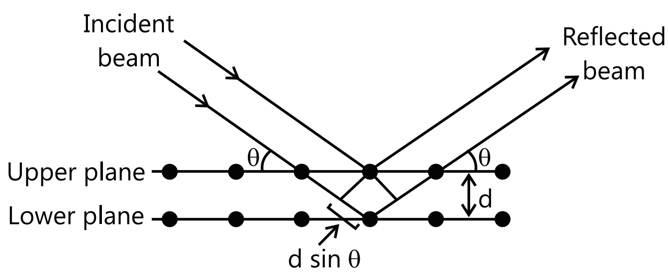



**Figure 17.19**

This condition is known as Bragg's Law, after W.L. Bragg (1890-1971), who first derived the relationship. If the wavelength and diffraction angle are measured, the above equation can be used to calculate the spacing between atomic planes.

**Note:** Each fringe in Young's Double Split Experiment has equal intensity while in diffraction, the intensity falls as the fringe order increases.

**Important Points:**

**(a) Types of diffraction:** The diffraction phenomenon is divided into two types viz. Fresnel diffraction and Fraunhofer diffraction. In the first type, either the source or the screen or both are at a finite distance from the diffracting device (obstacle of aperture). In the second type, both the source and screen are effectively at an infinite distance from the diffracting device. Fraunhofer diffraction is a particular limiting case of Fresnel diffraction.

**(b) Difference between interference and diffraction:** Both interference and diffraction are the results of superposition of waves, so they are often present simultaneously, as in Young's double slit experiment. However interference is the result of superposition of waves from two different wave fronts while diffraction results due to superposition of wavelets from different points of the same wave front.

**PLANCESS CONCEPTS**

X-ray diffraction is used in crystals to find inter-atomic distance owing to the fact that wavelengths of x-rays are of order of inter-atomic distance, the required condition for diffraction.

**Nivvedan (JEE 2009, AIR 113)**

## 5. RESOLVING POWER OF OPTICAL INSTRUMENTS

When the two images cannot be distinguished, they are said to be un-resolved. If the images are well distinguished. They are said to be well resolved. On the other hand, if the images are just distinguished, they are said to be just resolved.

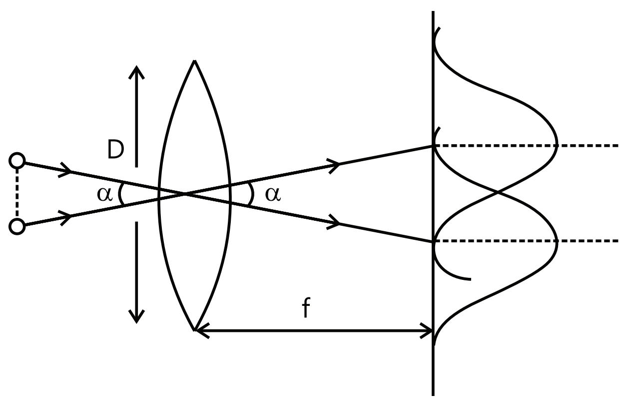



**Figure 17.20**

**Rayleigh Criterion:** According to Rayleigh, two objects or points are just resolved if the position of the central maximum of the image of one object coincides with the first minimum of the image of the other object as shown in figure (a).

## 5.1 Limit of Resolution

The minimum distance of separation between two points so that they can be seen as separate (or just resolved) by the optical instrument is known as its limit of resolution. Diffraction of light limits the ability of optical instruments.

## PLANCESS CONCEPTS

**Resolving Power:** The ability of an optical instrument to form distinctly separate images of the two closely placed points or objects is called its resolving power. Resolving power is also defined as reciprocal of the limit of resolution,

$$R.P. = \frac{1}{\text{Limit of resolution}}$$

Smaller the limit of resolution of an optical instrument, larger is its resolving power and vice-versa.

**Resolving Power of Eyes:** Since eye lens is a converging lens, the limit of resolution of the human eye is that of the objective lens of a telescope i.e. limit of resolution of the eye, $\alpha = \frac{1.22\gamma}{D}$

Where, D= diameter of the pupil of the eye.

$$\text{Resolving power of the eye} = \frac{1}{\alpha} = \frac{D}{1.22\lambda}$$

**Resolving power of an astronomical telescope:** Resolving power of a telescope,

$$R.P. = \frac{1}{\text{Limit of resolution}} \text{ or } R.P. = \frac{D}{1.22\lambda}$$

**Chinmay S Purandare (JEE 2012, AIR 698)**

**Illustration 21:** A star is seen through a telescope having objective lens diameter as 203.2cm. If the wavelength of light coming from a star is 6600 Å, find (i) the limit of resolution of the telescope and (ii) the resolving power of the telescope. **(JEE MAIN)**

**Sol:** Resolving power of the eye$=\frac{1}{\alpha}=\frac{D}{1.22\lambda}$ Here, D=203.2cm and $\lambda = 6600\,\text{Å} = 6600 \times 10^{-8}\,\text{cm} = 6.6 \times 10^{-5}\,\text{cm}$

(i) Limit of resolution of telescope, $\alpha = \frac{1.22\lambda}{D} = \frac{1.22 \times 6.6 \times 10^{-5}}{203.2} = 3.96 \times 10^{-7}\,\text{rad}$

(ii) Resolving power of telescope, $\frac{1}{\alpha} = \frac{D}{1.22\lambda} = \frac{1}{3.96 \times 10^{-7}} = 2.53 \times 10^{6}$

**Resolving power of a microscope:** Resolving power of a microscope$=\frac{1}{d_{min}}$ i.e.

$$R.P._{microscope} = \frac{2n\sin\beta}{1.22\lambda}$$

## 6. SCATTERING OF LIGHT

Scattering of light is a phenomenon in which a part of a parallel beam of light appears in directions other than the incident radiation when passed through a gas.

**Process:** Absorption of light by gas molecules followed by its re-radiation in different directions.

The strength of scattering depends on the following:

**(a)** Loss of energy in the light beam as it passes through the gas

**(b)** Wavelength of light

**(c)** Size of the particles that cause scattering

**Key point:** If these particles are smaller than the wavelength, the scattering is proportional to $1/\lambda^4$ . This is known as Rayleigh's law of scattering. Thus, red is scattered the least and violet is scattered the most. This is why, red signals are used to indicate dangers. Such a signal transmit to large distance without an appreciable loss due to scattering.

**Practical example of scattering:** The blue color of the sky is caused by the scattering of sunlight by the molecules in the atmosphere. This scattering, called Rayleigh scattering, is more effective at short wavelengths (the blue end of the visible spectrum). Therefore, the light scattered down to the earth at a large angle with respect to the direction of the sun's light, is predominantly in the blue end of the spectrum.

## 7. POLARIZATION OF LIGHT

The process of splitting of light into two directions is known as polarization.

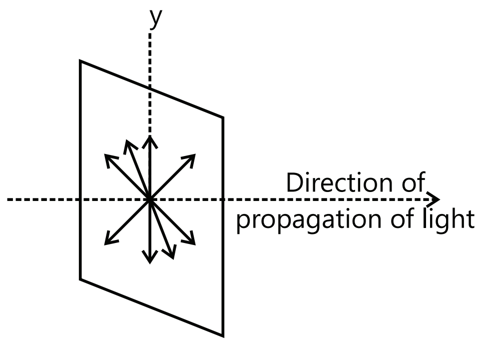
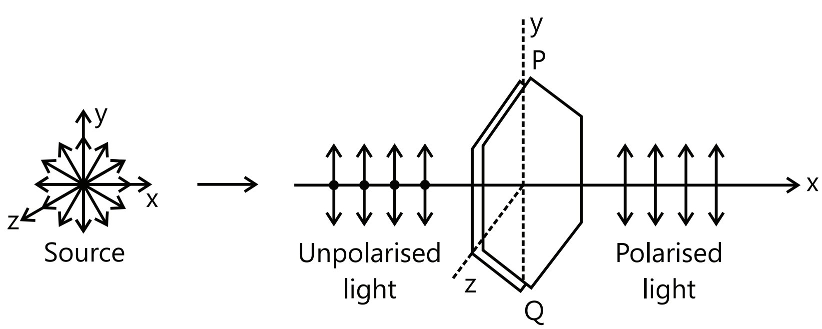



**Figure 17.21**

**Phenomenon of polarization:** The phenomenon of restricting the vibrations of a light vector of the electric field vector in a particular direction in a plane perpendicular to the direction of propagation of light is called polarization of light. Tourmaline crystal is used to polarize the light and hence it is called polarizer.




Pictorial representation of polarised light shown figure (A) and (B)

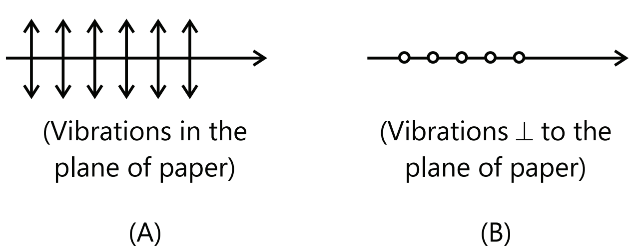



**Figure 17.22**

## 7.1 Unpolarized Light

**(a)** An ordinary beam of light consists of a large number of waves emitted by the atoms or molecules of the light source. Each atom produces a wave with its own orientation of electric vector E. However, because all directions are equally probable, the resulting electromagnetic wave is a superposition of waves produced by individual atomic sources. This wave is called as an unpolarized light wave.

**(b)** All the vibrations of an unpolarized light at a given instant can be resolved into two mutually perpendicular directions and hence an unpolarized light is equivalent to superposition of two mutually perpendicular identical plane polarized lights.

## 7.2 Plane Polarized Light

**(a)** If somehow we confine the vibrations of electric field vector in one direction perpendicular to the direction of wave motion of propagation of wave, the light is said to be plane polarized and the plane containing the direction of vibration and wave motion is called the plane of polarization.

**(b)** If an unpolarised light is converted into plane polarized light, its intensity reduces to half.

**(c)** Polarization is a proof of the wave nature of light.

**Partially polarized light:** If in case of unpolarised light, electric field vector in some plane is either more or less than in its perpendicular plane, the light is said to be partially polarized.

## 7.3 Polaroids

A polaroid is a device used to produce plane polarized light. The direction perpendicular to the direction of the alignment of the molecules of the Polaroid is known as pass-axis or the polarizing direction of the Polaroid.

**Note:** A Polaroid used to examine the polarized light is known as analyzer.

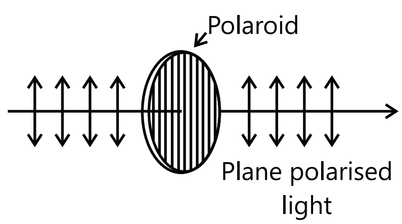



**Figure 17.23**

## 7.4 Malus' Law

This law states that the intensity of the polarised light transmitted through the analyser varies as the square of the cosine of the angle between the plane of transmission of the analyser and the plane of the polariser. Resolve E into two components: We know, intensity $\propto (\text{Amplitude})^2$

$\therefore$ Intensity of the transmitted light through the analyser is given by $I \alpha (E\cos\theta)^2$ or $I = kE^2\cos^2\theta$;

But $kE^2 = I_0$ (intensity of the incident polarised light)

$I = I_0\cos^2\theta$ Or $I \propto \cos^2\theta$ which is Malus Law.

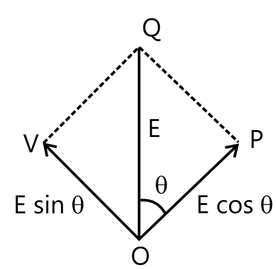



**Figure 17.24**

**PLANCESS CONCEPTS**

Plane polarized light is used for chemical purposes in measuring optical rotations of various chemical compounds. It can also be used for stating the difference in enantiomeric compounds.

**Nitin Chandrol (JEE 2012, AIR 134)**

## 7.5 BREWSTER'S LAW

According to this law, the refractive index of the refractive medium (n) is numerically equal to the tangent of the angle of polarization $(I_B)$. i.e. $n = \tan I_B$

**Illustration 22:** What is the polarizing angle of a medium of refractive index 1.732? **(JEE MAIN)**

**Sol:** As per Brewster's law, $n = \tan i_B$ or $i_B = \tan^{-1} n = \tan^{-1} 1.732 = 60°$

# PROBLEM-SOLVING TACTICS

**1.** Most of the questions in JEE are related to Young's Double slit experiment with minor variations. For any such problem, drawing a rough figure and writing down the given parameters is a good idea before solving the question.

**2.** Wave optics has a lot of derivations. It is advisable to remember the end results for faster problem solving.

**3.** Use the concept of optical path carefully and check for phase relations.

**4.** Only direct formulae related questions are asked from sections of diffraction, polarizations and scattering so these formulae must be learnt.

# FORMULAE SHEET

| S. No. | Term | Description |
|---|---|---|
| 1 | Wave front | It is the locus of points in the medium which at any instant are vibrating in the same phase. |
| 2 | Huygens' Principle | 1. Each point on the given primary wave front acts as a source of secondary wavelets spreading out disturbance in all direction.<br>2. The tangential plane to these secondary wavelets constitutes the new wave front. |
| 3 | Interference | It is the phenomenon of non-uniform distribution of energy in the medium due to superposition of two light waves. |
| 4 | Condition of maximum intensity | $\phi = 2n\pi$ or $x = n\lambda$ , where n=0,1,2,3,.... |
| 6 | Condition of minimum intensity | $\phi = (2n+1)\pi$ or $x = (2n+1)y/2$ where n=0,1,2,3... |
| 7 | Ratio of maximum and minimum intensity | $\frac{I_{max}}{I_{min}} = \frac{(a_1+a_2)^2}{(a_1-a_2)^2}$ |
| 8 | Distance of nth bright fringe from centre of the screen | $y_n = \frac{nD\lambda}{d}$ ,<br>where d is the separation distance between two coherent sources of light, D is the distance between screen and slit, $\lambda$ is the wavelength used. |

| S. No. | Term | Description |
|---|---|---|
| 9 | Angular position of nth bright fringe | $\theta_n = \frac{y_n}{D} = \frac{n\lambda}{d}$ |
| 10 | Distance of nth dark fringes from centre of the screen | $y'_n = \frac{(2n+1)D\lambda}{2d}$ |
| 11 | Angular position of nth dark fringe | $\theta'_n = \frac{y'_n}{D} = \frac{(2n+1)\lambda}{2d}$ |
| 12 | Fringe width | $\beta = \frac{D\lambda}{d}$ |

**Diffraction and polarization of light**

| S. No. | Term | Description |
|---|---|---|
| 1 | Diffraction | It is the phenomenon of bending of light waves round the sharp corners and spreading into the regions of the geometrical shadow of the object. |
| 2 | Single slit diffraction | Condition for dark fringes is $\sin\theta = \frac{n\lambda}{a}$ where $n = \pm1, \pm2, \pm3, \pm4.....$, a is the width of the slit and $\theta$ is the angle of diffraction. Condition for bright fringes is $\sin\theta = \frac{(2n+1)\lambda}{2a}$ |
| 3 | Width of central maximum is | $\theta_0 = \frac{2\lambda D}{a}$, where D is the distance between the slit and the screen. |
| 4 | Diffraction grating | The arrangement of large number of narrow rectangular slits of equal width placed side by side parallel to each other. The condition for maxima in the interference pattern at the angle $\theta$ is $d\sin\theta = n\lambda$ where n=0, 1, 2, 3, 4..... |
| 6 | Resolving power of the grating | For nearly two equal wavelengths $\lambda_1$ and $\lambda_2$ between which a diffraction grating can just barely distinguish, resolving power is $R = \frac{\lambda}{\lambda_1 - \lambda_2} = \frac{\lambda}{\Delta\lambda}$ where $\lambda = (\lambda_1 + \lambda_2)/2$ |
| 7 | Diffraction of X-Rays by crystals | The condition for constructive interference is $2d\sin\theta = n\lambda$ |
| 8 | Polarisation | It is the phenomenon due to which vibrations of light are restricted in a particular plane. |
| 9 | Brewster's law | $\mu = \tan p$ where $\mu$ is refractive index of medium and p is the angle of polarisation. |
| 10 | Law of Malus | $I = I_0 \cos^2\theta$ where I is the intensity of emergent light from analyser, $I_0$ is the intensity of incident plane polarised light and $\theta$ is the angle between planes of transmission of the analyser and the polarizer. |

# Solved Examples

## JEE Main/Boards

**Example 1:** In a YDSE, if the source consists of two wavelengths $\lambda_1$ =4000Å and $\lambda_2$ =4000 Å, find the distance from the centre where the fringes disappear, if $d = 1cm; D = 1m$.

**Sol:** The fringes disappear when the maxima of $\lambda_1$ fall over the minima of $\lambda_2$. That is $\frac{p}{\lambda_1} - \frac{p}{\lambda_2} = \frac{1}{2}$ where p is the optical path difference at the point or $p = \frac{\lambda_1\lambda_2}{2(\lambda_1 - \lambda_2)}$

Here, $\lambda_1 = 4000Å, \lambda_2 = 4002Å$

$\therefore p = 0.04cm$

In YDSE

$$p = \frac{dy}{D} \;\therefore\; y = \frac{D}{d}p = \frac{(1000)}{10}(0.4) = 40mm$$

**Example 2:** Light from a source consists of two wavelengths $\lambda_1 = 6500Å$ and $\lambda_2 = 5200Å$. If D = 2m and d=6.5 mm, find the minimum value of $y(\neq 0)$ where the maxima of both the wavelengths coincides.

**Sol:** The point where maxima coincides, consider $n_1^{th}$ maxima of $\lambda_1$ coincide with $n_2^{th}$ maxima of $\lambda_2$

Then $y_{n1} = y_{n2}$

$$\text{Or } \frac{n_1\lambda_1 D}{d} = \frac{n_2\lambda_2 D}{d} \text{ or } \frac{n_1}{n_2} = \frac{\lambda_1}{\lambda_2} = \frac{5200}{6500} = \frac{4}{5}$$

Thus, fourth maxima of $\lambda_1$ coincides with fifth maxima of $\lambda_2$ The minima value of $y(\neq 0)$ is

$$\text{given by } y = \frac{4\lambda_1 D}{d} = \frac{4(0.65\times10^{-6})(2)}{6.5\times10^{-3}} = 0.8mm$$

**Example 3:** In Young's experiment for interference of light, two narrow slits 0.2 cm apart are illuminated by yellow light $(\lambda = 5896Å)$. What would be the fringe width on a screen placed 1m from the plane of slits. What will be the fringes width if the whole system is immersed in water $(\mu = 4/3)$?

**Sol:** Wavelength changes inside water, hence

$d = 2\times10^{-3}m, \lambda = 5896\times10^{-10}m$ and $D = 1m$,

$$\beta = \frac{D}{d}(\lambda) = \frac{1\times5896\times10^{-10}}{2\times10^{-3}} = 2.948\times10^{-4}m = 0.3mm$$

Now if the system is immersed in water

$$\frac{(\beta)_w}{\beta} = \frac{\lambda_w}{\lambda} = \frac{v}{c} \qquad [\text{as } v = f\lambda \text{ and } f = \text{const.}]$$

$$\text{Or } (\beta)_w = (\beta/\mu) \qquad \left[\text{as } \mu = \frac{c}{v}\right]$$

$$\therefore (\beta)_w = (0.3)\times(3/4) = 0.225mm$$

**Example 4:** A beam of light consisting of two wavelengths 6500 Å and 5200 Å is used to obtain interference fringes in a Young's double slit experiment.

(a) Find the distance of the third bright fringe on the screen from central maxima for 6500 Å wavelength.

(b) What is the least distance from the central maxima where the bright fringes due to both the wavelengths coincide? The distance between slits is 2 mm and distance between slits and screen is 120 cm.

**Sol:** Calculate the fringe width of both light individually.

$d = 2\times10^{-3}m, D = 120cm = 1.2m, \lambda_1 = 6500Å$
$= 6.5\times10^{-7}, \lambda_2 = 5200\text{ Å} = 5.2\times10^{-7}m$

$$\text{(a) } n_1 = 3, \quad x_1 = \frac{n_1\lambda_1 D}{d} = \frac{3\times6.5\times10^{-7}\times1.2}{2\times10^{-3}}$$
$$= 1.17\times10^{-3}m = 1.17mm$$

(b) $x = n_1\beta_1 = n_2\beta_2$ where $n_1$ and $n_2$ are number of bright fringes which coincide for respective wavelengths

$\lambda_1$ and $\lambda_2$. $\frac{n_1\lambda_1 D}{d} = \frac{n_2\lambda_2 D}{d}$ or $n_1\lambda_1 = n_2\lambda_2$.

$$\text{or } \frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{5200Å}{6500Å} = \frac{4}{5}$$

min. value of $n_1 = 4$ and $n_2 = 5$

Distance of a point at fringes coincide

$$\frac{n_1\lambda_1 D}{d} = \frac{4\times6500\times10^{-10}\times1.2}{2\times10^{-3}} = 1.56mm$$

**Example 5:** What is the effect on the interference fringes in a YDSE due to each of the following operations.

(a) The screen is moved away from the plane of the slits

(b) The (monochromatic) source is replaced by another (monochromatic) source of shorter wavelength

(c) The separation between the two slits is increased

(d) The monochromatic source is replaced by source of white light

(e) The whole experimental setup is placed in a medium of refractive index $\mu$

**Sol:** Recall the formulas for YDSE and analysis the changes,

(a) Angular separation $\left(=\frac{\lambda}{d}\right)$ of the fringes remains constant. But the linear separation or fringes width increases in proportion to the distance (D) from the screen.

(b) As $\lambda$ decreases, fringe width $(\omega \propto \lambda)$ decreases

(c) As d increases, fringe width $\left(\omega \propto \frac{1}{d}\right)$ decreases

(d) If a white light is used in the double slit experiment, the different colours will be split up on the viewing screen according to their wavelengths. The violet end of the spectrum (with the shortest wavelengths) is closer to the central fringes, with the other colours being further away in order.

(e) Since in a medium, the wavelength of light is $\lambda' = \frac{\lambda}{\mu}$, therefore the fringe width is given by $\omega = \frac{\lambda' D}{d} = \frac{\lambda D}{\mu d}$

**Example 6:** A double slit apparatus is immersed in a liquid of refractive index 1.33. It has a slit separation of 1.0mm and the distance between the plane of slits and screen is 1.33m. The slits are illuminated by a parallel beam of light whose wavelength is 6300 Å. One of the slits is covered by a thin glass sheet of refractive index 1.53.

(a) Find the fringe width

(b) Find the smallest thickness of the sheet required to bring the adjacent minima at the position of earlier central maxima.

**Sol:** Change in the wavelength occur due to liquid, hence parameter depending on wavelength will change,

(a) If the double slit apparatus is immersed in a liquid medium of refractive index ${}^{a}\mu_m$ then fringe width

$$\beta' = \frac{\lambda D}{{}^{a}\mu_m d}$$

$\lambda = 1.33, d = 10^{-3}\,m$ ; $\lambda = 6300Å, D = 1.33m$

${}^{a}\mu_m = 1.33, d = 10^{-3}\,m$

$$\beta' = \frac{1.33 \times 6300 \times 10^{-10}}{1.33 \times 10^{-3}} = 0.63mm$$

(b) If t is the required minimum thickness of sheet of refractive index ${}^{m}\mu_g$ with respect to the medium, the shift in path of the fringes $= \frac{D}{d} = \left({}^{m}\mu_g - 1\right)t$

The shift required to bring adjacent minima on the axis

$$= \frac{\text{half width}}{2} = \frac{\beta'}{2} = \frac{D\lambda}{2\,{}^{a}\mu_m d}$$

Equating, $\frac{\beta'}{2} = \frac{D\lambda}{2\,{}^{a}\mu_m d} = \frac{D}{d}\left({}^{m}\mu_g - 1\right)t$

$$t = \frac{\lambda}{2\left({}^{m}\mu_g - 1\right){}^{a}\mu_m} = \frac{\lambda}{2\left[\frac{{}^{a}\mu_g}{{}^{a}\mu_m} - 1\right]{}^{a}\mu_m}$$

$$t = \frac{\lambda}{2\left({}^{a}\mu_g - {}^{a}\mu_m\right)} = \frac{6300 \times 10^{-10}}{2(1.53 - 1.33)} = 1.575\mu m$$

**Example 7:** A beam of light consisting of two wavelengths 6500 Å and 5200 Å is used to obtain interference fringes in a Young's double slit experiment. (a) Find the distance of the third bright fringe on the screen from the central maxima for the wavelength 6500 Å. (b) What is the least distance from the central maxima where the bright fringes due to both the wavelength coincide? The distance between the slits is 2 mm and the distance between the plane of the slits and screen is 120cm.

**Sol:** According to the theory of interference, position y of a point on the screen is given by $y = \frac{D}{d}(\Delta x)$ and as for 3rd maximum $\Delta x = 3\lambda$

$$y = \frac{D}{d}(3\lambda) = \frac{120}{0.2}\left(3 \times 6500 \times 10^{-8}\right)cm = 0.117cm$$

also as $\beta = (D\lambda/d), y = 3\beta$ i.e. $\beta = (y/3) = 0.039cm.$

(b) If n is the least number of fringes of $\lambda_1 (= 6500Å)$, which are coincident with $(n+1)$ of smaller wavelength $\lambda_2$ (=5200 Å), $y' = n\beta = (n+1)\beta'$, i.e., $\frac{n+1}{n} = \frac{\beta}{\beta'} = \frac{\lambda_1}{\lambda_2}$

or $n = \frac{\lambda_2}{\lambda_1 - \lambda_2} \frac{5200}{6500 - 5200} = \frac{5200}{1300} = 4$

So $y' = 4\beta = 4 \times 0.039 = 0.156\text{cm}$.

**Example 8:** In a YDSE, $\lambda = 60\text{nm}; D = 2\text{m}; \lambda = 6\text{mm}$. Find the position of a point lying between third maxima and third minima where the intensity is three-fourth of the maximum intensity of the screen.

**Sol:** Formula for intensity in terms of phase difference,

Using equation $I = 4I_0 \cos^2 \frac{\phi}{2}$

here $I = \frac{3}{4}(4I_0) = 3I_0$ $\qquad \therefore \cos\frac{\phi}{2} = \frac{\sqrt{3}}{2}$

Thus, $\frac{\phi}{2} = n\pi \pm \frac{\pi}{6}$ $\qquad$ or $\phi = 2n\pi \pm \frac{\pi}{3}$

Since $\phi = \frac{2\pi}{\lambda} p = \frac{2\pi}{\lambda}\left(\frac{d.y_n}{D}\right)$

$\therefore \frac{2\pi}{\lambda}\frac{dy_n}{D} = 2n\pi \pm \frac{\pi}{3}$ or $y_n = \left(n \pm \frac{1}{6}\right)\frac{\lambda D}{d}$

For the point lying between third minima and third maxima,

N=3 and $y_3 = \left(3 - \frac{1}{6}\right)\frac{\lambda D}{d}$ or $y_3 = \frac{17}{6}\frac{\lambda D}{d}$

Putting $\lambda = 0.6 \times 10^{-6}\text{m}; D = 2\text{m}; d = 6\text{mm}$

$$y_3 = \frac{17}{6}\frac{\left(0.6 \times 10^{-6}\text{m}\right)(2)}{6 \times 10^{-3}} = 5.67\text{mm}$$

**Example 9:** The width of one of the two slits in a Young's double slit experiment is double of the other slit. Assuming that the amplitude of the light coming from a slit is proportional to the slit-width, find the ratio of the maximum to the minimum intensity in the interference pattern.

**Sol:** Suppose the amplitude of the light wave coming from the narrower slit is A and that coming from the wider slit is 2A. The maximum intensity occurs at a place where constructive amplitude is the sum of the individual amplitudes. Thus, $A_{max} = 2A + A = 3A$

The minimum intensity occurs at a place where destructive interference takes place. The resultant amplitude is then the difference of the individual amplitudes. Thus, $A_{min} = 2A - A = A$

As the intensity is proportional to the square of the amplitude, $\frac{I_{max}}{I_{min}} = \frac{\left(A_{max}\right)^2}{\left(A_{min}\right)^2} = \frac{(3A)^2}{A^2} = 9$

**Example 10:** In a single slit diffraction experiment first minima for $\lambda_1$ – 660 nm coincides with first maxima for wavelength $\lambda_2$. Calculate $\lambda_2$.

**Sol:** Position of minima on diffraction pattern is given by $d\sin\theta - n\lambda$

For first minima of $\lambda_1$, we have $d\sin\theta_1 = (1)\lambda_1$

or $\sin\theta_1 = \frac{\lambda_1}{d}$ ...(i)

The first maxima approximately lies between first and second maxima. For wavelength $\lambda_2$, its position will be,

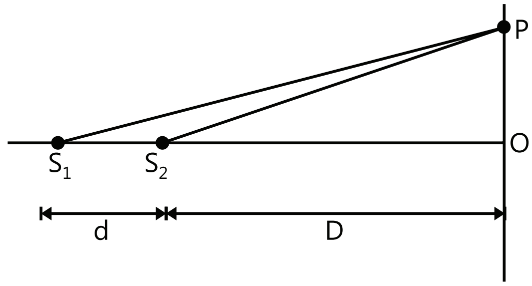
$d\sin\theta_2 = \frac{3}{2}\lambda_2 \quad \therefore \sin\theta_2 = \frac{3\lambda_2}{2d}$ ...(ii)

The two will coincide if $\theta_1 = \theta_2$ or $\sin\theta_1 = \sin\theta_2$

$\frac{\lambda_1}{d} = \frac{3\lambda_2}{2d}$ or $\lambda_2 = \frac{2}{3}\lambda_1 = \frac{2}{3} \times 660\text{nm} = 440\text{nm}$

## JEE Advanced/Boards

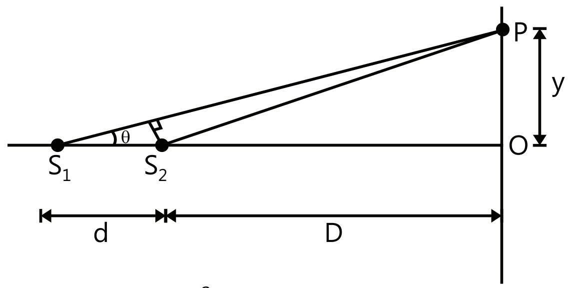
**Example 1:** Two monochromatic coherent sources of wavelength 5000 Å are placed along the line normal to the screen as shown in the figure.




(a) Determine the condition for maxima at point P.

(b) Find the order of the central bright fringe if d=0.5.mm, D=1m.

**Sol:** Consider the given geometry and get the optical path difference at P is $p = S_1P - S_2P = d\cos\theta$




Since $\cos\theta = 1 - \frac{\theta^2}{2}$ when $\theta$ is small, Therefore,

$$p = d\left(1 - \frac{\theta^2}{2}\right) = d\left[1 - \frac{y^2}{2D^2}\right] \text{Where } D + d \approx D$$

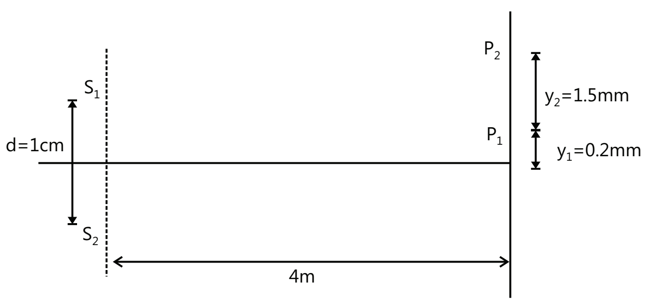
For nth maxima, $p = n\lambda \quad \therefore y = D\sqrt{2\left(1 - \frac{n\lambda}{d}\right)}$

(b) At the central maxima, $\theta = 0$

$$\therefore p = d = n\lambda \quad \text{or } n = \frac{d}{\lambda} = \frac{0.5}{0.5\times10^{-3}} = 1000$$

**Example 2:** In a YDSE conducted with white light (4000 Å-7000 Å), consider two points $P_1$ and $P_2$ on the screen at $y_1$ =0.2mm and $y_2$ =1.6mm, respectively. Determine the wavelength which forms maxima at these points.

**Sol:** Start from the formulas maxima where, the optical path difference at $P_1$ is




$p_1 = \frac{dy_1}{D} = \left(\frac{10}{4000}\right)(0.2) = 5\times10^{-4}\text{mm} = 5000\text{Å}$ In the visible range 4000-7000 Å,

$n_1 = \frac{5000}{4000} = 1.25$ and $n_2 = \frac{5000}{7000} = 0.714$ The only integer between 0.714 and 1.25 is 1.

$\therefore$ The wavelength which forms maxima at P is $\lambda$ =5000Å

$$p_2 = \frac{dy_2}{D} = \left(\frac{10}{4000}\right)(1.6) = 4\times10^{-3}\text{mm} = 40000\text{Å}$$

Here $n_1 = \frac{40000}{4000} = 10$ and $n_2 = \frac{40000}{7000} = 5.71$

The integers between 5.71 and 10 are 6,7,8,9 and 10.

$\therefore$ The wavelength which forms maxima at $P_2$ are

$\lambda_1 = 4000\text{Å}$ for $n = 10$

$\lambda_2 = 4444\text{Å}$ for $n = 9$

$\lambda_3 = 5000\text{Å}$ for $n = 8$

$\lambda_4 = 5714\text{Å}$ for $n = 7$

$\lambda_5 = 6666\text{Å}$ for $n = 6$

**Example 3:** A monochromatic beam of $\lambda = 5000\text{Å}$ is incident on two narrow slits separated by a distance of $7.5\times10^{-4}$ m to produce interference pattern on a screen placed at a distance of 1.5 m from the slits in Young's double slit experiment. A thin uniform glass plate of $\mu = 1.5$ and $2.5\times10^{-6}$ m thickness is placed normal to the beam between one of the slits and the screen.

(a) Find the internal shift of the central maxima.

(b) If the intensity at the central maxima is $I_0$, find the intensity at this point after the glass plate is introduced.

(c) If the glass plate is removed and the slits are also illuminated by an additional light of 4000 Å, find the least distance from the central maxima wavelengths will coincides.

**Sol:** Consider the theory of path difference on introducing the plate as,

(a) D=1.5m, $d = 7.5\times10^{-4}\text{m}, \mu = 1.5, t = 2.5\times10^{-6}\text{m}$

Lateral shift of central maxima

$$\frac{D}{d}(\mu-1)t = \frac{1.5\times0.5\times2.5\times10^{-6}}{7.5\times10^{-4}} = 2.5\times10^{-3}\text{m}$$
$$= 2.5\text{mm}$$

(b) Path difference caused by sheet at

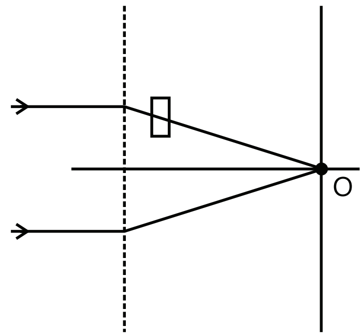
$$O = x = (\mu-1)t = (1.5-1)\times2.5\times10^{-6}$$
$$= 1.25\times10^{-6}\text{m}$$

Corresponding phase difference

$$= \phi = \frac{2\pi x}{\lambda} = \frac{2\pi\times1.25\times10^{-6}}{5000\times10^{-10}} = 5\pi$$

$A^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\phi,$

Let $a_1 = a_2 = a$




$\therefore A^2 = a^2 + a^2 + 2a^2\cos(5\pi) = 2a^2 - 2a^2 = 0$

$A^2 = 0$, there will be minima at O.

(c) Let $n_1^{th}$ maxima of $\lambda_1$ =5000 Å will coincide With $n_2^{th}$ maxima of $\lambda_2$ =4000 Å

$$\frac{n_1\lambda_1 D}{d} = \frac{n_2\lambda_2 D}{d}$$

$$\frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{4000Å}{5000Å} = \frac{4}{5}$$

For least distance where bright fringes coincide, $n_1 = 4, n_2 = 5$

$$\therefore x = \frac{4\times 5000\times 10^{-10}\times 1.5}{7.5\times 10^{-4}} = 4\times 10^{-3}m$$

**Example 4:** In an interference arrangement similar to Young's double slit experiment, slits $S_1$ and $S_2$ are illuminated with coherent microwave sources each of frequency 1 MHz. The sources are synchronized to have zero phase difference. The slits are separated by a distance d=150m. The intensity $I_0$ is measured as a function of $\theta$ with respect to the axial line passing through the middle point of the slits. If $I_0$ is maximum intensity, calculate $I(\theta)$ for

(a) $\theta = 0$

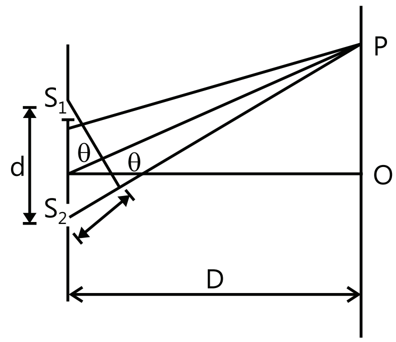
(b) $\theta = 30°$ and

(c) $\theta = 90°$

**Sol:** Addition of Amplitudes of different wavelength.

Wavelength of microwaves $\lambda$ is given by

$$\lambda = \frac{c}{f} = \frac{3\times 10^8}{10^6} = 300m.$$




Path difference, $\Delta x$, for a point P is given by,

$\Delta x = d\sin\theta$ (for small $\theta$, $\tan\theta=\sin\theta$)

Phase difference

$$= \phi = \frac{2\pi}{\lambda}(\Delta x) = \frac{2\pi}{\lambda}(d\sin\theta) = \frac{2\pi}{300}\times(150\sin\theta) = \pi\sin\theta$$

Resultant intensity due to both slits

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

As, $I_1 = I_2$

$$I = 2I_1\left[1+\cos(\pi\sin\theta)\right] = 4I_1\times\cos^2\left(\frac{\pi\sin\theta}{2}\right)$$

For I to be maximum, $\cos^2\left(\frac{\pi\sin\theta}{2}\right) = 1$

$$\therefore I_{max} = 4I_1 = I_0 \quad \text{or } I = I_0\cos^2\left(\frac{\pi\sin\theta}{2}\right)$$

(a) For $\theta = 0, I = I_0\cos^2(0) = I_0$

(b) For $\theta = 30°, I = I_0\cos^2\left(\frac{\pi}{4}\right) = \frac{I_0}{2}$

(c) For $\theta = 90°, I = I_0\cos^2\left(\frac{\pi}{2}\right) = 0.$

**Example 5:** In a modified Young's double slit experiment, a monochromatic uniform and parallel beam of light of wavelength 6000 Å and intensity $\frac{10}{\pi}W/m^2$ is incident normally on two circular apertures A and B of radii 0.001m and 0.002 m respectively. A perfectly transparent film of thickness 2000 Å and refractive index 1.5 for wavelength 6000 Å is placed in front of the aperture A. Calculate the power in watts received at the focal spot F of the lens. The lens is symmetrically placed with respect to the aperture. Assume that 10% of the power received by each aperture goes in the original direction and is brought to the focal spot.

**Sol:** First get the intensities and then apply Power= IxArea

If E is the energy incident in time t for surface area a, then intensity $I = \frac{E}{at}$

Power $= \frac{E}{t}$ or Power = Ia

Power received at $A = P_A = \frac{10}{\pi} \times \pi \times (0.001)^2 = 10^{-5}$ W

Power received at $B = P_B = \frac{10}{\pi} \times \pi \times (0.002)^2 = 4 \times 10^{-5}$ W

As only 10% of the power goes in the original direction,

$$P'_A = \frac{10}{100} \times 10^{-5} = 10^{-6} W$$

$$P'_B = \frac{10}{100} \times 4 \times 10^{-5} = 4 \times 10^{-6} W$$

Path difference due to film of thickness t and refractive index $\mu = \Delta x = (\mu - 1)t$

Phase difference produced $= \phi = \frac{2\pi}{\lambda}(\mu - 1)t$

$$\phi = \frac{2\pi}{6000 \times 10^{-10}}(1.5 - 1) \times 2000 \times 10^{-10} = \frac{\pi}{3}$$

If $I_1$ is intensity of A and $I_2$ is intensity of B, the resultant intensity I due to interference is given by,

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

The resultant power, P, at area a of focal spot is given by,

$$P = Ia = I_A a + I_B b + 2\sqrt{I_A I_B} \times a \times \cos\phi$$

$$P = P'_A + P'_B + 2\sqrt{P'_A P'_B}.\cos\phi$$

$$= (10^{-6}) + (4 \times 10^{-6}) + 2 \times \sqrt{1 \times 4 \times 10 - 12} \times \cos\frac{\pi}{3}$$

$$= 10^{-6}\left[1 + 4\left(4 \times \frac{1}{2}\right)\right] = 7 \times 10^{-6} \text{Watt.}$$

**Example 6:** In a modified Young's double slit experiment, a monochromatic uniform and parallel beam of light of wavelength 6000 Å and intensity (10/π)W/m$^2$ is incident normally on two circular apertures A and B of radii 0.001 m and 0.002 m respectively. A perfectly transparent film of thickness 2000 Å and refractive index 1.5 for wavelength 6000 Å is placed in front of aperture A. Calculate the power (in watts) received at the focal spot F of the lens. The lens is symmetrically placed with respect to the aperture. Assume that 10% of the power received by each aperture goes in the original direction and is brought to the focal spot.

**Sol:** As intensity and power are defined as

$I = \frac{E}{St}$, $\quad P = \frac{E}{t}$ $\quad$ and P=IS

So power received at A and B is respectively,

$$P_A = \frac{10}{\pi} \times \pi(0.001)^2 = 10^{-5} W \text{ and}$$

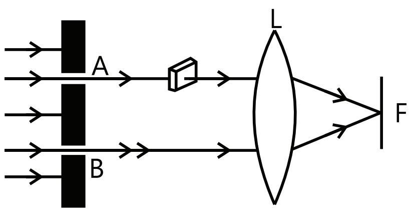
$$P_B = \frac{10}{\pi} \times \pi(0.002)^2 = 4 \times 10^{-5} W$$

and as only 10% of the incident power passes,

$$P'_A = \frac{10}{100} \times 10^{-5} = 10^{-6} W \text{ and}$$

$$P'_a = \frac{10}{100} \times 4 \times 10^{-5} = 4 \times 10^{-6} W$$

Now due to 10% of the introduction of film the path difference produced




$$\Delta x = (\mu - 1)t = (1.5 - 1) \times 2000 = 1000 \text{Å}$$

So, $\phi = \frac{2\pi}{\lambda}(\Delta x) = \frac{2\pi}{6000} \times 1000 = \frac{\pi}{3}$

But as in interference,

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

and S is the area of focal sport,

$$P = IS = I_A S + I_B S + 2S\left(\sqrt{I_A I_B}\right)\cos\phi$$

i.e., $P = P'_A + P'_B + 2\sqrt{P'_A P'_B}\cos(\pi/3)$

or, $P = 10^{-6}\left[1 + 4 + 2\left(\sqrt{1 \times 4}\right) \times (1/2)\right] = 7 \times 10^{-6}$ watt.

**Example 7:** In an interference arrangement similar to Young's double-slit experiment, slits $S_1$ and $S_2$ are illuminated with coherent microwave sources each of frequency 1 MHz. The sources are synchronized to have zero phase difference. The slits are separated by distance d=150.0m. The intensity $I_{(0)}$ is measured as a function of $\theta$, where $\theta$ is defined as shown in figure. If $I_0$ is maximum intensity, calculate $I_{(0)}$ for (a) $\theta = 0°$ (b) $\theta = 30°$ and (c) $\theta = 90°$

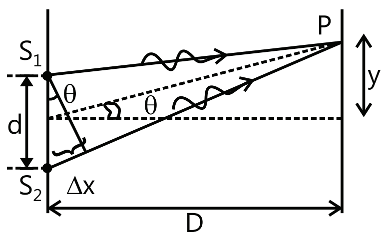
**Sol:** For microwaves, as $c = f\lambda$,

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10^6} = 300\text{m}$$

And as $\Delta x = d\sin\theta$

$$\phi = \frac{2\pi}{\lambda}(d\sin\theta) = \frac{2\pi}{300}(150\sin\theta) = \pi\sin\theta$$

So, $I = I_1 + I_2 + 2\left(\sqrt{I_1 I_2}\right)\cos\phi$




With $I_1 = I_2$ and $\phi = \pi\sin\theta$ reduced to

$$I_R = 2I_1\left[1+\cos(\pi\sin\theta)\right] = 4I_1\cos^2(\pi\sin\theta/2)$$

and as $I_R$ will be max. when $\cos^2\left[\left(\pi(\sin\theta)/2\right)\right] = \max = 1$

So that, $(I_R)_{max} = 4I_1 = I_0$ (given)

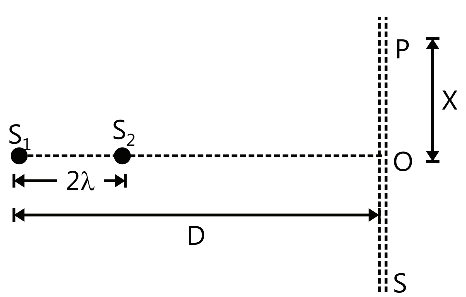
And hence, $I = I_0\cos^2\left[(\pi\sin\theta)/2\right]$ ...(i)

So (a) If $\theta = 0$ $\quad I = I_0\cos^2(0) = I_0$

(b) If $\theta = 30°$ $\quad I = I_0\cos^2(\pi/4) = (I_0/2)$

(c) If $\theta = 90°$ s $\quad I = I_0\cos^2(\pi/2) = 0$

**Example 8:** Two coherent narrow slits emitting lights of wavelength $\lambda$ in the same phase are placed parallel to each other at a small separation of $2\lambda$. The light is collected on a screen S which is placed at a distance ($D >> \lambda$) from the slit $S_1$ as shown in figure. Find the finite distance x such that the intensity at P is equal to intensity at O.



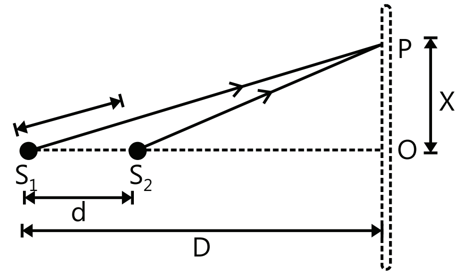

**Sol:** Path difference at O, $S_1O - S_2O = 2\lambda$ i.e., maximum intensity is obtained at O. Next maxima will be obtained at point P where,

$S_1P - S_2P = \lambda$ Or $\quad d\cos\theta = \lambda$

Or $\quad (2\lambda)\cos\theta = \lambda$

Or $\quad \cos\theta = \dfrac{1}{2}$

$\therefore \theta = 60°$



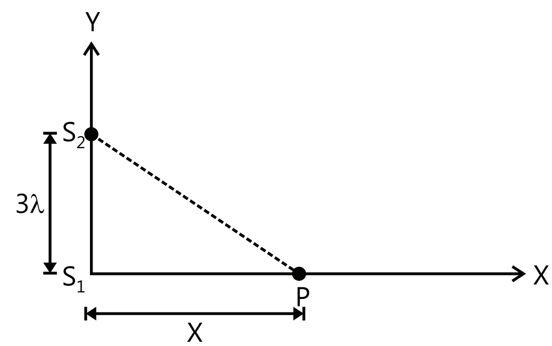

Now in $\Delta S_1PO$, $\quad \dfrac{PO}{S_1O} = \tan\theta$ or

$\dfrac{x}{d} = \tan 60° = \sqrt{3}$; $\quad \therefore \quad x = \sqrt{3}D$

**Note:** At point O, the path difference is $2\lambda$, i.e., we obtain second order maxima. At point P, where path difference is $\lambda$ (i.e., $x = \sqrt{3}D$), we get first order maxima. The next, i.e., zero order maxima will be obtained where path difference, i.e., $d\cos\theta = 0$ or $\theta = 90°$, $x = \infty$. So, our answer i.e., finite distance of x should be $x = \sqrt{3}D$, corresponding to first order maxima.

**Example 9:** An interference is observed due to two coherent sources $S_1$ placed at origin and $S_2$ placed at $(0, 3\lambda, 0)$. Here $\lambda$ is the wavelength of the sources. A detector D is moved along the positive x-axis. Find x-coordinates on the x-axis (excluding x=0 and $x = \infty$) where maximum intensity is observed.

**Sol:** At x = 0, path difference is $3\lambda$. Hence, third order maxima will be obtained. At $x = \infty$, path difference is zero. Hence, zero order maxima is obtained in between first and second order maximas.



**First order maxima:** $S_2P - S_1P = \lambda$ Or $\sqrt{x^2 + 9\lambda^2} - x = \lambda$

Or $\sqrt{x^2 + 9\lambda^2} = x + \lambda$

Squaring both sides, we get

$x^2 + 9\lambda^2 = x^2 + \lambda^2 + 2x\lambda$

Solving this, we get $x = 4\lambda$

Second order maxima: $S_2P - S_1P = 2\lambda$

Or $\sqrt{x^2 + 9\lambda^2} - x = 2\lambda$

Or $\sqrt{x^2 + 9\lambda^2} = (x + 2\lambda)$

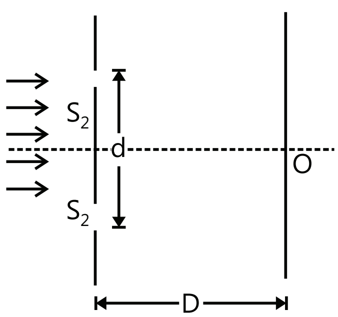
Squaring both sides, we get $x^2 + 9\lambda^2 = x^2 + 4\lambda^2 + 4x\lambda$

Solving, we get $x = \frac{5}{4}\lambda = 1.25\lambda$

Hence, the desired x coordinates are,

$x = 1.25\lambda$ and $x = 4\lambda$

**Example 10:** A young double slit apparatus is immersed in a liquid of refractive index $\mu_1$. The slit plane touches the liquid surface. A parallel beam of monochromatic light of wavelength $\lambda$ (in air) is incident normally on the slits.




(a) Find the fringe width.

(b) If one of the slits (say, $S_2$) is covered by a transparent slab of refractive index $\mu_2$ and thickness t as shown, find the new position of the central maxima.

(c) Now the other slit $S_1$ is also covered by a slab of same thickness and refractive index $\mu_3$ as shown in the figure due to which the central maxima recovers its position. Find the value of $\mu_3$.

(d) Find the ratio of intensities at O in the three conditions (a), (b) and (c).

**Sol:** wavelength changes inside the liquid,

(a) Fringe width $w = \frac{\lambda_1 D}{d} = \frac{\lambda D}{\mu_1 d}$

(b) Position of central maximum is shifted upwards by a distance $\frac{(\mu_2 - 1)tD}{d}$

(c) $\frac{(\mu_2 - 1)tD}{d} = \frac{\left(\frac{\mu_3}{\mu_1} - 1\right)tD}{d}$

$\therefore \frac{\mu_3}{\mu_1} = \mu_2$ or $\mu_3 = \mu_1\mu_2$

(d) $I = I_{max}\cos^2\left(\frac{\phi}{2}\right)$

Where $\phi = \left(\frac{2\pi}{\lambda}\right)\Delta x$ or $\frac{\phi}{2} = \left(\frac{\pi}{\lambda}\right)\Delta x$ $\quad I \propto \cos^2\left(\frac{\phi}{2}\right)$

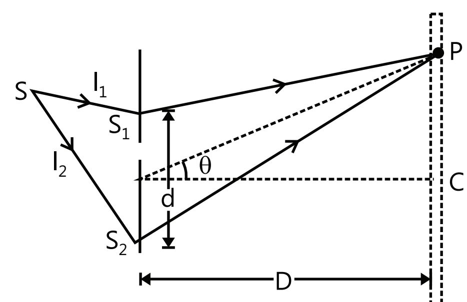
In the first and third case, $\Delta x = 0$ while in second case, $\Delta x = (\mu_2 - 1)t$. Therefore, the desired ratio is

$I_1 : I_2 : I_3 = I : \cos^2\left\{\frac{\pi(\mu_2 - 1)t}{\lambda}\right\} : 1$

**Example 11:** In a Young's experiment, the light source is at distance $I_1 = 20\mu m$ and $I_2 = 40\mu m$ from the slits. A light of wavelength $\lambda = 500$ nm is incident on slits separated at a distance $10\mu m$. A screen is placed at a distance D=2m away from the slits as shown in figure. Find

(a) The values of $\theta$ relative to the central line where maxima appear on the screen?

(b) How many maxima will appear on the screen?




(c) What should be the minimum thickness of a slab of refractive index 1.5 be placed on the path of one of the rays so that minima occurs at C?

**Sol:** For the maxima, total path difference is to be consider here, as some path difference already exist in the two beams before coming to the slits.

(a) The optical path difference between the beams arriving at P, $\Delta x = (l_2 - l_1) + d\sin\theta$ The condition for maximum intensity is,

$\Delta x = n\lambda \quad n = 0 \pm 1, \pm 2, ...$

Thus, $\sin\theta = \frac{1}{d}\left[\Delta x - \left(l_2 - l_1\right)\right] = \frac{1}{d}\left[n\lambda - \left(l_2 - l_1\right)\right]$

$= \frac{1}{10\times10^{-6}}\left[n\times500\times10^{-9} - 20\times10^{-6}\right]$

$= 2\left[\frac{n}{40} - 1\right]$; Hence, $\theta = \sin^{-1}\left[2\left(\frac{n}{40} - 1\right)\right]$

(b) $\left|\sin\theta\right| \le 1$

$\therefore -1 \le 2\left[\frac{n}{40} - 1\right] \le 1$ Or $-20 \le \left(n - 40\right) \le 20$

Or $20 \le n \le 60$

Hence, number of maxima =60-20=40

(c) At C, phase difference,

$$\phi = \left(\frac{2\pi}{\lambda}\right)\left(l_2 - l_1\right) = \left(\frac{2\pi}{500\times10^{-9}}\right)\left(20\times10^{-6}\right) = 80\pi$$

Hence, maximum intensity will appear at C. For minimum intensity at C, $\left(\mu - 1\right)t = \frac{\lambda}{2}$

Or $t = \frac{\lambda}{2\left(\mu - 1\right)} = \frac{500\times10^{-9}}{2\times0.5} = 500mm$

# JEE Main/Boards

## Exercise 1

**Q.1** State the essential condition for diffraction of light to occur. The light of wavelength 600mn is incident normally on a slit of width 3mm. Calculate the linear width of central maximum on a screen kept 3m away from the slit.

**Q.2** (a) State the postulates of Huygens's wave theory. (b) Draw the type of wave front that correspond to a beam of light (i) coming from a very far-off source and (ii) diverging from a point source.

**Q.3** In a single slit diffraction pattern, how does the angular width of central maximum change, when (i) slit width is decreased (ii) distance between the slit and screen in increased and (iii) light of smaller visible wavelength is used? Justify your answer in each case.

**Q.4** Derive Snell's law of refraction using Huygens's wave theory.

**Q.5** Explain with reason, how the resolving power of a compound microscope will change when (i) frequency of the incident light on the objective lens in increased, (ii) focal length of the objective lens is increased, and (iii) aperture of the objective lens is increased.

**Q.6** What is a wavefront? What is the geometrical shape of a wave front of light emerging out of a convex lens, when point source is placed at its focus? Using Huygens's principles show that, for a parallel beam incident on a reflecting surface, the angle of reflection is equal to the angle of incidence.

**Q.7** Two slits in Young's double slit experiment are illuminated by two different lamps emitting light of the same wavelength. Will you observe the interference pattern? Justify your answer.

Find the ratio of intensities at two points on a screen in Young's double slit experiment, when waves from the two slits have path difference of (i) 0 (ii) $\lambda/4$

**Q.8** Two narrow slits are illumination by a single monochromatic source. Name the pattern obtained on the screen. One of the slits is now completely covered. What is the name of the pattern now obtained on the screen? Draw intensity pattern obtained in the two cases. Also write two difference between the patterns obtained in the above two cases.

**Q.9** Using Huygens's Principle, draw a diagram to show propagation of a wave-front originating from a monochromatic point source. Describe diffraction of light due to a single slit. Explain formation of a pattern of fringes obtained on the screen and plot showing variation of intensity with angle $\theta$ in single slit diffraction.

**Q.10** What are coherent sources of light? State two conditions for two light sources to be coherent. Derive a mathematical expression for the width of interference fringes obtained in Young's double slit.

**Q.11** Define resolving power of a compound microscope. How does the resolving power of a compound microscope change when

(i) refractive index of the medium between the object and objective lens increases?

(ii) wavelength of the radiation used in increased?

**Q.12** State one feature by which the phenomenon of interference can be distinguished from that of diffraction. A parallel beam of light of wavelength 600nm is incident normally on a slit of width 'a'. If the distance between the slits and the screen is 0.8 m and the distance of $2^{nd}$ order minimum from the centre of the screen is 15 mm. Calculate the width of the slit.

**Q.13** How would the angular separation of interference fringes in Young's double slit experiment change when the distance between the slits and screen is doubled?

**Q.14** Define the term 'linearly polarized light'. When does the intensity of transmitted light become maximum, when a polaroid sheet is rotated between two crossed polaroids?

**Q.15** In Young's double slit experiment, monochromatic light of wave length 630nm illuminates the pair of slits and produce an interference pattern in which two consecutive bright fringes are separated by 8.1mm. Another source of monochromatic light produces the interference pattern in which the two consecutive bright fringes are separated by 7.2 mm. Find the wavelength of light from the second source. What is the effect on the interference fringes if the monochromatic source is replaces by a source of white light?

**Q.16** (a) In a single slit diffraction experiment, a slit of width 'd' is illuminated by red light of wavelength 650nm. For what value of 'd' will

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

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

(b) Why does the intensity of the secondary maximum becomes less as compared to the central maximum?

**Q.17** When light travels from a rarer to a denser medium, the speed decreases. Does this decrease in speed imply a decrease in the energy carried by the light wave? Justify your answer.

**Q.18** In Young's double slit experiment, the two slits 0.12 mm apart are illuminated by monochromatic light of wavelength 420 nm. The screen is 1.0 m away from the slits.

(a) Find the distance of the second (i) bright fringes, (ii) dark fringes from the central maximum.

(b) How will the fringes pattern change if the screen is moved away from the slits?

**Q.19** How does an unpolarised light get polarized when passes through a polaroid?

Two polaroids are set in crossed position. A third Polaroid is placed between the two making an angle $\theta$ with the pass axis of the first Polaroid. Write the expression for the intensity of light transmitted from the second Polaroid. In what orientations will the transmitted intensity be (i) minimum and (ii) maximum?

**Q.20** 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.21** For the same value of angle of incidence, the angle of refraction in three media A, B and C are $15°$, $25°$ and $35°$ respectively. In which medium would the velocity of light be minimum?

**Q.22** (a) In Young's double slit experiment, derive the condition for (i) constructive interference and (ii) destructive interference at a point in the screen.

(b) A beam of light consisting of two wavelengths, 800nm and 600nm is used to obtain in the interference fringes in a Young's double slit experiment on a screen placed 1.4 m away. If the two slits are separated by 0.28 mm, calculate the least distance from the central bright maximum where the bright fringes of the two wavelengths coincide.

**Q.23** (a) How does an unpolarized light incident on light on polaroid get polarized?

Describe briefly, with the help of a necessary diagram, the polarization of light by reflecting from a transparent medium.

(b) Two polaroids 'A' and 'B' are kept in crossed position. How should a third polaroid 'C' be placed between them so that the intensity of polarized light transmitted by polaroid B reduce to 1/8th of the intensity of unpolarized light incident on A?

**Q.24** Two sources of intensity $I_1$ and $I_2$ undergo interference in Young's double slit experiment. Show that $\frac{I_{max}}{I_{min}} = \left(\frac{a_1 + a_2}{a_1 - a_2}\right)^2$

Where $a_1$ and $a_2$ are the amplitudes of disturbance for two sources $S_1$ and $S_2$.

**Q.25** Two coherent waves of equal amplitude produce interference pattern in Young's double slit experiment. What is the ratio of intensity at a point where phase different is $\pi/2$ to intensity at centre.

# Exercise 2

### Single Correct Choice Type

**Q.1** Two coherent monochromatic light beams of intensities I and 4I are superposed. The maximum and minimum possible intensities in the resulting beam are:

(A) 5I and I (B) 5I and 3I

(C) 9I and I (D) 9I and 3I

**Q.2** When light is refracted into a denser medium,

(A) Its wavelength and frequency both increase

(B) Its wavelength increase but frequency remains unchanged

(C) Its wavelength decreases but frequency remain unchanged

(D) It wavelength and frequency both decrease.

**Q.3** In YDSE how many maxima can be obtained on the screen if wavelength of light used is 200nm and d=700nm:

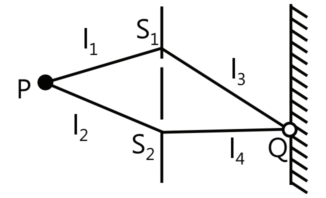
(A) 12 (B) 7

(C) 18 (D) None of these

**Q.4** In Young's double slit experiment, the wavelength of red light is 7800Å and that of blue is 5200 Å. The value of n for which $n^{th}$ bright band due to red light coincides with $(n+1)^{th}$ bright band due to blue light is:

(A) 1 (B) 2 (C) 3 (D) 4

**Q.5** Two identical narrow slits $S_1$ and $S_2$ are illuminated by light of wavelength $\lambda$ from a point source P. If, as shown in the diagram above, the light is then allowed to fall on a screen, and if n is a positive integer, the condition for destructive interference at Q is




(A) $(l_1 - l_2) = (2n+1)\lambda/2$

(B) $(l_3 - l_4) = (2n+1)\lambda/2$

(C) $(l_1 + l_2) - (l_3 + l_4) = n\lambda$

(D) $(l_1 + l_3) - (l_2 + l_4) = (2n+1)\lambda/2$

**Q.6** In a young's double slit experiment, a small detector measures an intensity of illumination of I units at the centre of the fringe pattern. If one of the two (identical) slits is now covered, the measured intensity will be

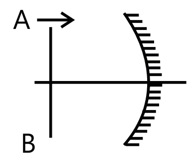
(A) 2I (B) I (C) I/4 (D) I/2

**Q.7** In a Young's double slit experiment D equals the distance of screen and d is the separation between the slit. The distance of the nearest point to the central maximum where the intensity is same as that due to a single slit, is equal to

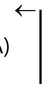
(A) $\frac{D\lambda}{d}$ (B) $\frac{D\lambda}{2d}$

(C) $\frac{D\lambda}{3d}$ (D) $\frac{2D\lambda}{d}$

**Q.8** A plane wavefront AB is incident on a concave mirror as shown.

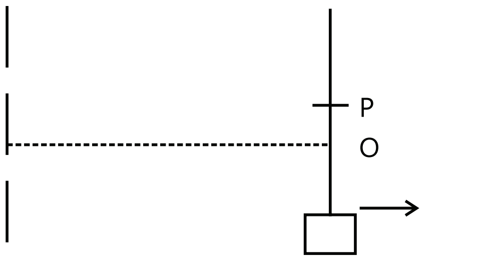



Then, the wavefront just after reflection is

(A)  (B)  (C) 

(D) None of the above

**Q.9** In a Young's double slit experiment, first maxima is observed at a fixed point P on the screen. Now the screen is continuously moved away from the plane of slits. The ratio of intensity at point P to the intensity at point O (center of the screen)



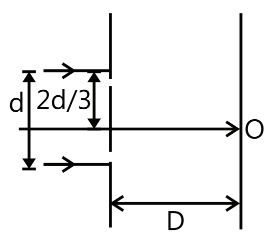

(A) Remains constant

(B) Keeps on decreasing

(C) First decrease and then increases

(D) First decreases and then becomes constant

**Q.10** In the figure shown if a parallel beam of white light is incident on the plane of the slits then the distance of the white spot on the screen from O is [Assumed d<<D $\lambda$<<d]




(A) 0 (B) d/2

(C) d/3 (D) d/6

**Q.11** In Young's double slit arrangement, water is filled in the space between screen and slits. Then:

(A) Fringe pattern shifts upwards but fringes width remain unchanged.

(B) Fringe width decreases and central bright fringe shift upwards.

(C) Fringe width increases and central bright fringe does not shift.

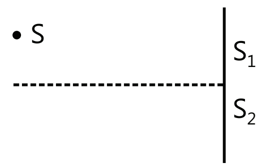
(D) Fringe width decreases and central bright fringe does not shift.

**Q.12** Light of wavelength $\lambda$ in air enters a medium of refractive index $\mu$. Two points in this medium, lying along the path of this light, are at a distance x apart. The phase difference between these points is:

(A) $\frac{2\pi\mu x}{\lambda}$ (B) $\frac{2\pi x}{\mu\lambda}$

(C) $\frac{2\pi(\mu-1)x}{\lambda}$ (D) $\frac{2\pi x}{(\mu-1)\lambda}$

**Q.13** In YDSE, the source placed symmetrically with respect to the slit is now moved parallel to the plane of the slits so that it is closer to the upper slit, as shown. Then,




(A) The fringe width will remain and fringe pattern will shift down

(B) The fringe width will remain same but fringe pattern will shift up

(C) The fringe width will decrease and fringe pattern will shift down

(D) The fringe width will remain same but fringe pattern will shift down

**Q.14** In a YDSE with two identical slits, when the upper slit is covered with a thin, perfectly transparent sheet of mica, the intensity at the centre of screen recs to 75% of the initial value. Second minima is observed to the above this point and third maxima below it. Which of the following can not be a possible value of phase difference caused by the mica sheet.

(A) $\frac{\pi}{3}$ (B) $\frac{13\pi}{3}$

(C) $\frac{17\pi}{3}$ (D) $\frac{11\pi}{3}$

**Q.15** Two monochromatic and coherent point sources of light are placed at a certain distance from each other in the horizontal plane. The locus of all those points in the horizontal plane which have constructive interference will be:

(A) A hyperbola

(B) Family of hyperbolas

(C) Family of straight lines

(D) Family of parabolas

**Q.16** A circular planar wire loop is dipped in a soap solution and after taking it out, held with its plane vertical in air. Assuming thickness of film at the top to be very small, as sunlight falls on the soap film, & observer receive reflected light

(A) The top portion appears dark while the first colour to be observed as one moves down is red

(B) The top portion appears violet while the first colour to be observed as one moves down is indigo

(C) The top portion appears dark while the first colour to be observed as one moves down is violet

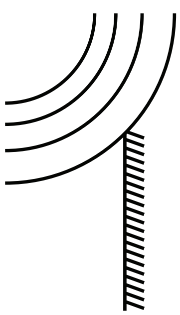
(D) The top portion appears dark while the first colour to be observed as one moves down is depends on the refractive index of the soap solution.

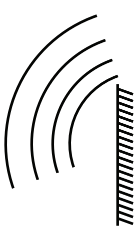
**Q.17** A thin film of thickness t and index of refraction 1.33 coats a glass with index of refraction 1.50. What is the least thickness t that will strongly reflect light with wavelength 600nm incident normally?

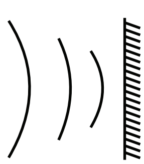
(A) 225nm (B) 300nm

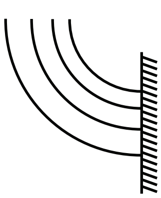
(C) 400nm (D) 450nm

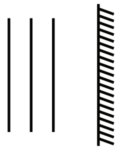
**Q.18** Spherical wave fronts shown in figure, strike a plane mirror. Reflected wavefronts will be as shown in



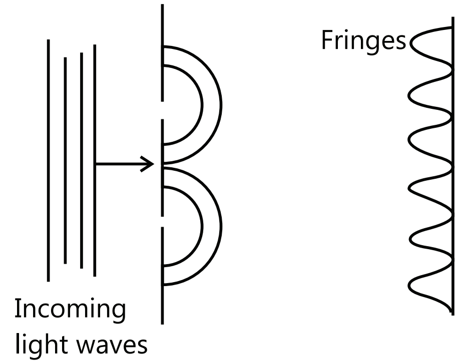
(A) 

(B) 

(C) 

(D) 

**Q.19** In a Young's double slit experiment, green light is incident on the two slits. The interference pattern is observed on a screen. Which of the following changes would cause the observed fringes to be more closely spaced?




(A) Reducing the separation between the slits

(B) Using blue light instead of green light

(C) Used red light instead of green light

(D) Moving the light source further away from the slits.

**Q.20** In the previous question, films of thickness $t_A$ and $t_B$ and refractive indices $\mu_A$ and $\mu_B$, are placed in front of A and B respectively. If $\mu_A t_A = \mu_B t_B$, the central maximum will:

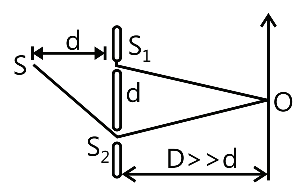
(A) Not shift

(B) Shift towards A

(C) Shift towards B

(D) Option (B), if $t_B > t_A$; option (C) if $t_B < t_A$

**Q.21** To make the central fringe at the centre O, a mica sheet of refractive index 1.5 is introduced. Choose the correct statement(s).




(A) The thickness of sheet is $2\left(\sqrt{2}-1\right)d$ in front of $S_1$.

(B) The thickness of sheet is $\left(\sqrt{2}-1\right)d$ in front of $S_2$.

(C) The thickness of sheet is $2\sqrt{2}$ in front of $S_1$

(D) The thickness of sheet is $\left(2\sqrt{2}-1\right)d$ in front of $S_1$.

## Previous Years' Questions

**Q.1** In Young's double slit experiment, the separation between the slits is halved and the distance between the slits and the screen is doubled. The fringe width is ***(1981)***

(A) Unchanged (B) Halved

(C) Doubled (D) Quadrupled

**Q.2** Two coherent monochromatic light beams of intensities I and 4I are superimposed. The maximum and minimum possible intensities in the resulting beam are ***(1988)***

(A) 5I and I (B) 5I and 3I

(C) 9I and I (D) 9I and 3I

**Q.3** In a double slit experiment instead of taking slits of equal widths, one slit is made twice as wide as the other, then in the interference pattern. ***(2000)***

(A) The intensities of both the maxima and the minima increase

(B) The intensity of the maxima increases and the minima has zero

(C) The intensity of the maxima decreases and that minima increases.

(D) The intensity of the maxima decreases and the minima has zero.

**Q.4** Two beams of light having intensities I and 4I interfere to produce a fringe pattern on a screen. The phase difference between the beams is $\pi/2$ at point A and $\pi$ at point B. Then the difference between resultant intensities at A and B is ***(2001)***

(A) 2I (B) 4I

(C) 5I (D) 7I

**Q.5** In a YDSE bi-chromatic light of wavelengths 400nm and 560nm is used. The distance between the slits is 0.1mm and the distance between the plane of the slits and the screen is 1 m. The minimum distance between two successive regions of complete darkness is ***(2004)***

(A) 4mm (B) 5.6mm

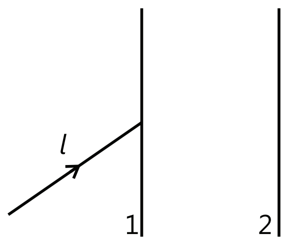
(C) 14mm (D) 28mm

**Q.6** In Young's double slit experiment intensity at a point is (1/4) of the maximum intensity. Angular position of this point is ***(2005)***

(A) $\sin^{-1}\left(\frac{\lambda}{d}\right)$ (B) $\sin^{-1}\left(\frac{\lambda}{2d}\right)$

(C) $\sin^{-1}\left(\frac{\lambda}{3d}\right)$ (D) $\sin^{-1}\left(\frac{\lambda}{4d}\right)$

**Q.7** A narrow monochromatic beam of light intensity I is incident on a glass plate as shown in 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 transmits the remaining. Find the ratio of the minimum and maximum intensities in the interference pattern formed by the two beams obtained after one reflection at each plate. ***(1990)***




**Q.8** Angular width of central maximum in the Fraunhofer diffraction pattern of a slit is measured. The slit is illuminated by light of wavelength 6000 Å . When the slit is illuminated by light of another wavelength, the angular width decreases by 30%. Calculate the wavelength of this light. The same decrease in the angular width of central maximum is obtained when the original apparatus is immersed in a liquid. Find refractive index of the liquid. ***(1996)***

**Q.9** A double slit apparatus is immersed in a liquid of refractive index 1.33. it has slit separation of 1mm and distance between the plane of slits and screen is 1.33m. The slits are illuminated by a parallel beam of light whose wavelength in air is 6300 Å . ***(1996)***

(a) Calculate the fringes width.

(b) One of the slits of the apparatus is covered by a thin glass sheet of refractive index 1.53. Find the smallest thickness of the sheet to bring the adjacent minimum as the axis.

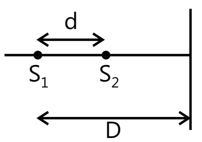
**Q.10** In a Young's double slit experiment, two wavelengths of 500nm and 700nm were used. What is the minimum distance from the central maximum where their maximas coincide again? Take $D/d = 10^3$. Symbols have their usual meanings. ***(2004)***

**Q.11** 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) $I_0/2$ (B) $I_0/4$

(C) $I_0/8$ (D) $I_0$

**Q.12** 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) Straight lines (B) Semi-circles

(C) Concentric circles (D) Points

**Q.13** 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 $I_A/I_B$ equals: ***(2014)***

(A) 1 (B) 1/3

(C) 3 (D) 3/2

**Q.14** The box of 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 $\lambda$ 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 $(\text{say } b_{min})$ when: ***(2016)***

(A) $a=\sqrt{\lambda L}$ and $b_{min}=\left(\frac{2\lambda^2}{L}\right)$

(B) $a=\sqrt{\lambda L}$ and $b_{min}=\sqrt{4\lambda L}$

(C) $a=\frac{\lambda^2}{L}$ and $b_{min}=\sqrt{4\lambda L}$

(D) $a=\frac{\lambda^2}{L}$ and $b_{min}=\left(\frac{2\lambda^2}{L}\right)$

## JEE Advanced/Boards

## Exercise 1

**Q.1** Two coherent waves are described by the expressions.

$$E_1=E_0\sin\left(\frac{2\pi x_1}{\lambda}-2\pi ft+\frac{\pi}{6}\right)$$

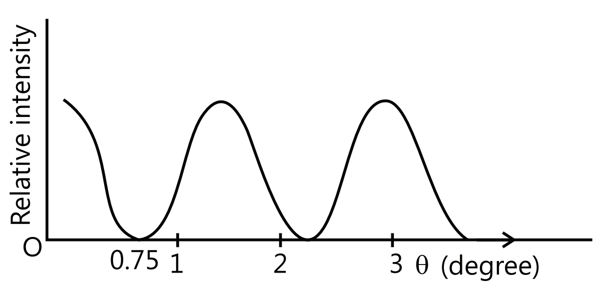
$$E_1=E_0\sin\left(\frac{2\pi x_2}{\lambda}-2\pi ft+\frac{\pi}{8}\right)$$

Determine the relationship between $x_1$ and $x_2$ that produces constructive interference when the two waves are superposed.

**Q.2** In a Young's double slit experiment for interference of light, the slits are 0.2 cm apart and are illuminated by yellow light $(\lambda=600\text{nm})$. What would be the fringe width on a screen placed 1m from the plane of slits if the whole system is immersed in water of index 4/3?

**Q.3** In young's double slit experiment the slits are 0.5 mm apart and the interference is observed on a screen at a distance of 100cm from the slit. It is found that the 9th bright fringe is at a distance of 7.5mm from the second dark fringe from the centre of the fringe pattern on same side. Find the wavelength of the light used.

**Q.4** Light of wavelength 520nm passing through a double slit, produce interference pattern of relative intensity versus deflection angle $\theta$ as shown in the figure. Find the separation d between the slits.



**Q.5** In a YDSE apparatus, d=1mm, $\lambda = 600\text{nm}$ and D=1m. The slits individually produce same intensity on the screen. Find the minimum distance between two points on the screen having 75% intensity of the maximum intensity.

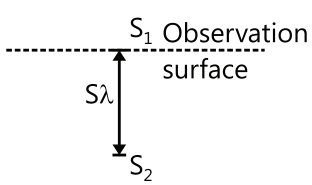
**Q.6** The distance between two slits is a YDSE apparatus is 3mm. The distance of the screen from the slits is 1 m. Microwaves of wavelength 1mm are incident on the plane of the slits normally. Find the distance of the first maxima on the screen from the central maxima. Also find the total number of maxima on the screen.

**Q.7** One slit of a double slit experiment is covered by a thin glass plate of refractive index 1.4 and the other by a thin glass plate of refractive index 1.7. The point on the screen, where central bright fringe was formed before the introduction of the glass sheets, is now occupied by the $5^{th}$ bright fringe. Assuming that both the glass plates have same thickness and wavelength of light used is 4800Å, find their thickness.

**Q.8** A monochromatic light of $\lambda = 5000\text{Å}$ is incident on two slits separated by a distance of $5 \times 10^{-4}$ m. The interference pattern is seen on a screen placed at a distance of 1m from the slits. A thin glass plate of thickness $1.5 \times 10^{-6}$ m & refractive index $\mu = 1.5$ is placed between one of the slits & the screen. Find the intensity at the centre of the screen, if the intensity there is $I_0$ in the absence of the plate. Also find the internal shift of the central maximum.

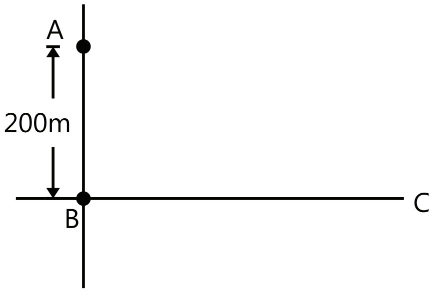
**Q.9** One radio transmitter A operating at 60.0 MHz is 10.0 m from another similar transmitter B that is 180° out of the phase with transmitter. A. How far must an observe move from transmitter A toward transmitter B along the line connecting A and B to reach the nearest point where the two beams are in phase?

**Q.10** Two microwaves coherent point sources emitting waves of wavelength $\lambda$ are placed at $5\lambda$ distance apart. The interference is being observed on a flat non-reflecting surface along a line passing through one source, in a direction perpendicular to the line joining the two sources (refer figure).

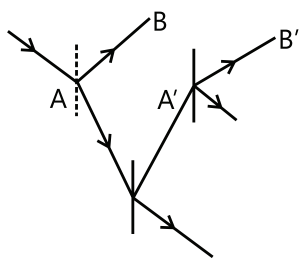



Considering $\lambda$ as 4mm, calculate the position of maxima and draw shape of interference pattern. Take initial phase difference between the two sources to be zero.

**Q.11** Two radio antennas radiating wave in phase are located at points A and B , 200m apart (Figure). The radio waves have a frequency of 5.80MHz. A radio receiver is moved out from point B along a line perpendicular to the line connecting A and B (line BC shown in figure). At what distance from B will there be destructive interference?




**Q.12** A ray of light of intensity I is incident on a parallel glass-slab at a point A as shown in figure. It undergoes partial reflection and refraction. At each reflection 20% of incident energy is reflected. The rays AB and A′ B′ undergo interference. Find the ratio $I_{max}/I_{min}$ .




[Neglect the absorption of light]

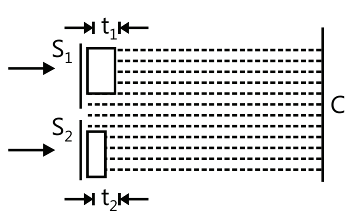
**Q.13** If the slits of the double slit were moved symmetrically apart with relative velocity v, calculate the number of fringes passing per unit time at a distance x from the centre of the fringes system formed on a screen y distance away from the double slits if wavelength of light is $\lambda$. Assume y>>d & d>>$\lambda$.

**Q.14** A thin glass plate of thickness t and refractive index $\mu$ is inserted between screen & one of the slits in a Young's experiment. If the intensity at the centre of the screen is I, what was the intensity at the same point prior to the introduction of the sheet?

**Q.15** In Young's experiment, the source is red light of wavelength $7 \times 10^{-7}$ m. When a thin glass plate of refractive index 1.5 at this wavelength is put in the path of one of the interfering beams, the central bright fringe shifts by $10^{-3}$ m to the position previously occupied by the $5^{th}$ bright fringe. Find the thickness of the plate. When the source is now changed to green light of wavelength $5\times10^{-7}$ m, the central fringe shift to a position initially occupied by the $6^{th}$ bright fringe due to red light without the plate. Find the refractive index of glass for the green light. Also estimate the change in fringe width due to the change in wavelength.

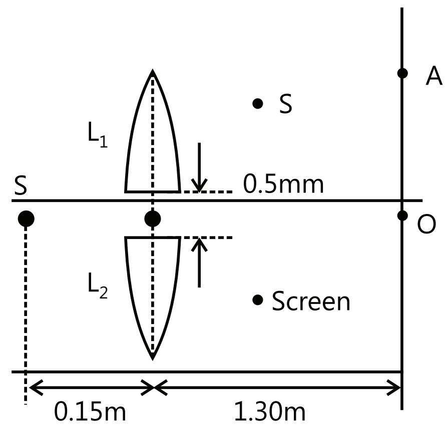
**Q.16** In a Young's experiment, the upper slit is covered by a thin glass plate of refractive index 1.4 while the lower slit is covered by another glass plate having the same thickness as the first one but having refractive index 1.7. Interference pattern is observed using light of wavelength 5400 Å . It is found that the point P on the screen where the central maximum (n=0) fell before the glass plates were inserted now has ¾ the original intensity. It is further observed that what used to be the $5^{th}$ maximum earlier, lies below (Absorption of light by glass plate may be neglected).

**Q.17** A screen is at a distance D=80cm from a diaphragm having two narrow slits $S_1$ is and $S_2$ which are d=2 mm apart. Slit $S_1$ is covered by a transparent sheet of thickness $t_1$ =2.5 μm and $S_2$ by another sheet of thickness $t_2$ =1.25 μm as shown in figure. Both sheets are made of same material having refractive index $\mu$ =1.40. Water is filled in space between diaphragm and screen. A monochromatic light beam of wavelength $\lambda$ =5000 Å is incident normally on the diaphragm. Assuming intensity of beam to be uniform and slits of equal width, calculate ratio of intensity at C to maximum intensity of interference pattern obtained on the screen, where C is foot of perpendicular bisector of $S_1 S_2$. (Refractive index of water, $\mu_w$ =4/3)




**Q.18** In the figure shown S is a monochromatic point source emitting light of wavelength=500nm. A thin lens of circular shape and focal length 0.10 m is cut into identical halves $L_1$ and $L_2$ by a plane passing through a diameter. The two halves are placed symmetrically about the central axis SO with a gap of 0.5 mm. The distance along the axis from the S to $L_1$ and $L_2$ is 0.15m, while that from $L_1$ and $L_2$ to O is 1.30m. The screen at O is normal SO.

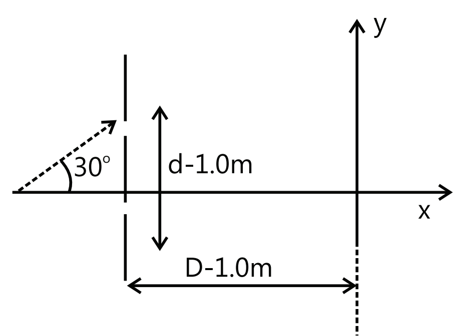
(i) If the third intensity maximum occurs at the point A on the screen, find the distance OA.




(ii) If the gap between $L_1$ & $L_2$ is reduced from its original value of 0.5 mm, will the distance OA increase, decrease or remain the same?

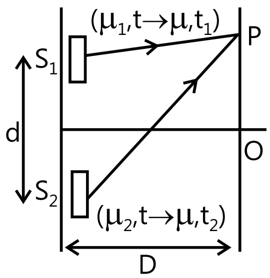
**Q.19** A coherent parallel beam of microwave of wavelength $\lambda = 0.5$ mm falls on a Young's double slit apparatus. The separation between the slits is 1.0 mm. The intensity of microwaves in measured on screen placed parallel to the plane of the slits at a distance of 1.0m from it, as shown in the figure.

(a) If the incident beam falls normally on the double slit apparatus, find the y-coordinates of all the interference minima on the screen.




(b) if the incident beam makes an angle of 30° with the x-axis (as in the dotted arrow shown in the figure), find the y-coordinates of the first minima on either side of the central maximum.

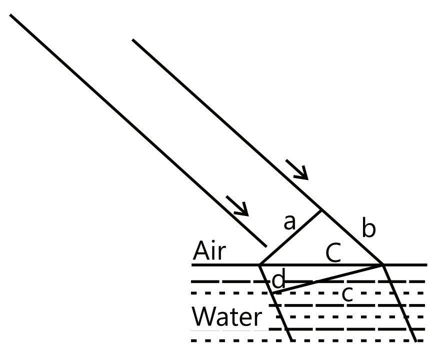
**Q.20** In a YDSE with visible monochromatic light two thin transparent sheets are used in front of the slits $S_1$ and $S_2$ with $\mu_1$ =1.6 and $\mu_2$ =1.4 respectively. If both sheets have thickness t, the central maximum is observed at a distance of 5mm from centre O. Now the sheets are replaced by two sheets of same material refractive index $\frac{\mu_1 + \mu_2}{2}$ but having thickness $t_1$ & $t_2$ such that $t = \frac{t_1 + t_2}{2}$. Now central maximum is observed at distance of 8mm from centre O on the same side as before. Find the thickness $t_1$ (in $\mu m$) [Given: d=1mm. D=1m].




## Exercise 2

### Single Correct Choice Type

**Q.1** Figure shows plane waves refracted from air to water using Huygens's principle a, b, c, d, e are lengths on the diagram. The refractive index of water w.r.t. air is the ratio:




(A) a/e (B) b/e (C) b/d (D) d/b

**Q.2** In a YDSE, the central bright fringe can be identified:

(A) As it has greater intensity than the other bright fringes.

(B) As it is wider than the other bright fringes.

(C) As it is narrower than the other bright fringes.

(D) By using white light instead of single wavelength light.

**Q.3** In Young's double slit experiment, the two slits act as coherent sources of equal amplitude A and wavelength $\lambda$. In another experiment with the same setup the two slits are sources of equal amplitude A and wavelength $\lambda$ but are incoherent. The ratio of the average intensity of light at the midpoint of the screen in the first case to that in the second case is

(A) 1:1 (B) 2:1

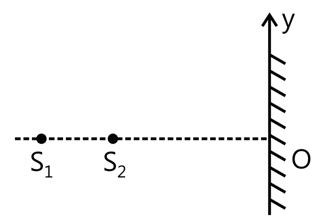
(C) 4:1 (D) None of these

**Q.4** Two point monochromatic and coherent sources of light wavelength $\lambda$ are placed on the dotted line in front of a large screen. The source emit waves in phase with each other. The distance between $S_1$ and $S_2$ is 'd' while their distance from the screen is much larger. Then,

(1) If $d = 7\lambda/2$, O will be a minima

(2) If $d = 4.3\lambda$, there will be a total of 8 minima on y axis.

(3) If $d = 7\lambda$, O will be a maxima.



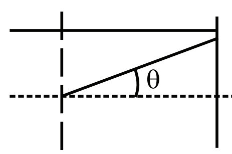

(4) If $d = \lambda$, there will be only one maxima on the screen.

Which is the set of correct statement

(A) 1, 2, & 3 (B) 2, 3 & 4

(C) 1, 2, 3 & 4 (D) 1, 3 & 4

**Q.5** Two slits are separated by 0.3 mm. A beam of 500nm light strikes the slits producing an interference pattern. The number of maxima observed in the angular range- $0° < \theta < 30°$.

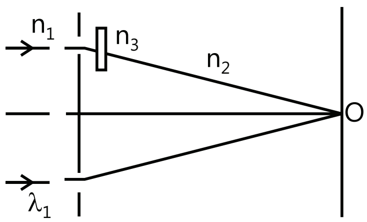



(A) 300 (B) 150 (C) 599 (D) 601

**Q.6** In the above question of the light incident is monochromatic and point O is a maxima, then the wavelength of the light incident cannot be

(A) $\frac{d^2}{3D}$ (B) $\frac{d^2}{6D}$ (C) $\frac{d^2}{12D}$ (D) $\frac{d^2}{18D}$

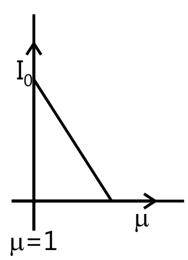
**Q.7** In the figure shown in YDSE, a parallel beam of light is incident on the slit from a medium of refractive index $n_1$. The wavelength of light in this medium is $\lambda_1$. A transparent slab of thickness 't' and refractive index $n_3$ is put infront of one slit. The medium between the screen and the plane of the slits is $n_2$. The phase difference between the light waves reaching point 'O' (symmetrical, relative to the slits) is:

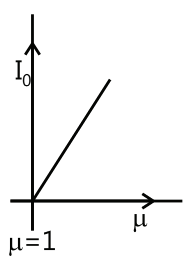


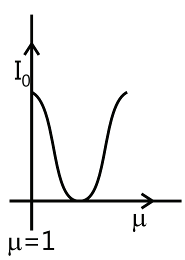

(A) $\frac{2\pi}{n_1\lambda_1}(n_3 - n_2)t$ (B) $\frac{2\pi}{\lambda_1}(n_3 - n_2)t$

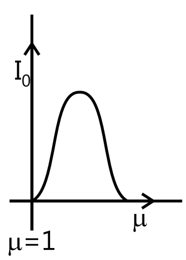
(C) $\frac{2\pi n_1}{n_2\lambda_1}\left(\frac{n_3}{n_2} - 1\right)t$ (D) $\frac{2\pi n_1}{\lambda_1}(n_3 - n_1)t$

**Q.8** In A YDSE experiment if a slab whose refractive index can be varied is placed in front of one of the slits then the variation of resultant intensity at mid-point of screen with '$\mu$' will be best represented by $(\mu \geq 1)$. [Assumes slits of equal width and there is no absorption by slab]

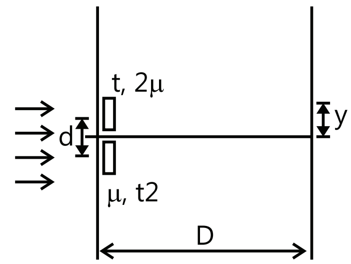
(A)



(B)



(C)



(D)



**Q.9** In the YDSE shown the two slits are covered with thin sheets having thickness t & 2t and refractive index $2\mu$ and $\mu$. Find the position (y) of central maxima




(A) Zero (B) $\frac{tD}{d}$

(C) $-\frac{tD}{d}$ (D) None

**Multiple Correct Choice Type**

**Q.10** In a YDSE apparatus, if we use white light then:

(A) The fringe next to the central will be red

(B) The central fringe will be white

(C) The fringe next to the central will be violet

(D) There will not be a completely dark fringe.

**Q.11** If one of the slits of a standard YDSE apparatus is covered by a thin parallel sided glass slab so that it transmit only one half of the light intensity of the other, then:

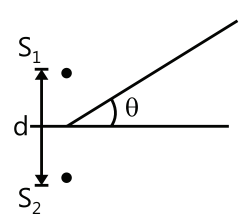
(A) The fringe pattern will get shifted towards the covered slit

(B) The fringe pattern will get shifted away from the covered slit

(C) The bright fringes will be less bright and the dark ones will be more bright

(D) The fringe width will remain unchanged.

**Q.12** In an interference arrangement similar to Young's double-slit experiment, the slits $S_1$ & $S_2$ are illuminated with coherent microwave sources, each of frequency $10^6$ Hz. The sources are synchronized to have zero phase difference. The slits are separated by a distance d=150.0m. The intensity $I(\theta)$ is measured as a function of $\theta$ at a large distance from $S_1$ & $S_2$, where $\theta$ is defined as shown if $I_0$ is the maximum intensity then



$I(\theta)$ for $0 \le \theta \le 90°$ is given by:

(A) $I(\theta) = \frac{I_0}{2}$ for $\theta=30°$

(B) $I(\theta) = \frac{I_0}{4}$ for $\theta=90°$

(C) $I(\theta) = I_0$ for $\theta=0°$

(D) $I(\theta)$ is constant for all values of $\theta$

**Q.13** To observe a sustained interference pattern formed by two light waves, it is not necessary that they must have:

(A) The same frequency

(B) Same amplitude

(C) A constant phase difference

(D) The same intensity

**Q.14** If the source of light used in a Young's Double Slit Experiment is changed from red to blue, then

(A) The fringes will become brighter

(B) Consecutive fringes will come closer

(C) The number of maxima formed on the screen increases

(D) The central bright fringe will become a dark fringe.

**Q.15** In a Young's double-slit experiment, let A and B be the two slits. A thin film of thickness t and refractive index $\mu$ is placed in front of A. Let $\beta$ =fringe width. The central maximum will shift:

(A) towards A (B) towards B

(C) by $t(\mu-1)\frac{\beta}{\lambda}$ (D) by $\mu t\frac{\beta}{\lambda}$

**Q.16** In a standard YDSE apparatus a thin film $(\mu = 1.5, t - 2.1\mu m)$ is placed in front of upper slit. How far above or below the centre point of the screen are two nearest maxima located? Take D=1m, d=1 mm, $\lambda = 4500Å$ .(Symbols have usual meaning)

(A) 1.5mm (B) 0.6mm

(C) 0.15mm (D) 0.3mm

**Assertion Reasoning Type**

(A) Statement-I is true, statement-II is true and statement-II is correct explanation for statement-I

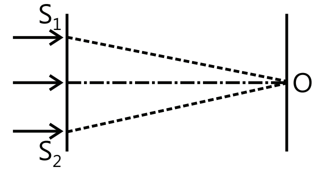
(B) Statement-I is true, statement-II is true and statement-II is NOT the correct explanation for statement-I

(C) Statement-I is true, statement-II is false

(D) Statement-I is false, statement-II is true

**Q.17 Statement-I:** In YDSE, as shown in figure, central bright fringe is formed at O. If a liquid is filled between plane of slits and screen, the central bright fringe is shifted in upward direction.

**Statement-II:** If path difference at O increases y-coordinate of central bright fringe will change.




**Q.18 Statement-I:** In glass, red light travels faster than blue light.

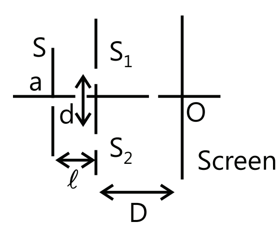
**Statement-II:** Red light has a wavelength longer than blue.

**Q.19 Statement-I:** In standard YDSE set up with visible light, the position on screen where phase difference is zero appears bright

**Statement-II:** In YDSE set up magnitude of electromagnetic field at central bright fringe is not varying with time.

**Comprehension Type**

The figure shows a schematic diagram showing the arrangement of Young's Double Slit Experiment:




**Q.20** Choose the correct statement(s) related to the wavelength of light used

(A) Larger the wavelength of light larger the fringe width

(B) The position of central maxima depends on the wavelength of light used

(C) If white light is used in YDSE, then the violet forms its first maxima closest to the central maxima

(D) The central maxima of all the wavelength coincide

**Q.21** If the distance D is varied, then choose the correct statement(s)

(A) The angular fringe width does not change

(B) The fringe width change in direct proportion

(C) The change in fringe width is same for all wavelengths

(D) The position of central maxima remains unhanged

**Q.22** If the distance d is varied, then identify the correct statement

(A) The angular width does not change

(B) The fringe width changes in inverse proportion

(C) The positions of all maxima change

(D) The positions of all minima change

## Previous Years' Questions

**Q.1** A narrow slit of width 1mm is illuminated by monochromatic light of wavelength 600nm. The distance between the first minima on either side of a screen at a distance of 2 m is. ***(1994)***

(A) 1.2 cm (B) 1.2 mm

(C) 2.4 cm (D) 2.4 mm

**Q.2** A parallel monochromatic beam of light is incident normally on a narrow slit. A diffraction pattern is formed on a screen placed perpendicular to the direction of the incident beam. At the first minimum of the diffraction pattern, the phase difference between the rays coming from the two edges of the slit is ***(1998)***

(A) Zero (B) $\pi/2$

(C) $\pi$ (D) $2\pi$

**Q.3** In a Young's double slit experiment, 12 fringes are observed to be formed in a certain segment of the screen when light of wavelength 600nm is used. If the wavelength of light is changed to 400nm, number of fringes observed in the same segment of the screen is given by ***(2001)***

(A) 12 (B) 18

(C) 24 (D) 30

**Q.4** In the ideal double-slit experiment, when a glass-plate (refractive index 1.5) of thickness t is introduced in the path of one of the interfering beams (wavelength $\lambda$), the intensity at the position where the central maximum occurred previously remain unchanged. The minimum thickness of the glass-plate is ***(2002)***

(A) $2\lambda$ (B) $\frac{2\lambda}{3}$

(C) $\frac{\lambda}{3}$ (D) $\lambda$

**Q.5** The phases of the light wave at c, d, e and f are $\phi_c, \phi_d, \phi_e$ and $\phi_f$ respectively. It is given that $\phi_c \neq \phi_f$ ***(2007)***

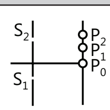
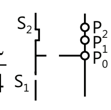
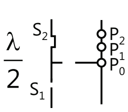
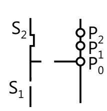
(A) $\phi_c$ cannot be equal to $\phi_d$

(B) $\phi_d$ cannot be equal to $\phi_e$

(C) $(\phi_d - \phi_f)$ is equal to $(\phi_c - \phi_e)$

(D) $(\phi_d - \phi_c)$ is not equal to $(\phi_f - \phi_e)$

**Q.6** Shows four situations of standard Young's doubles slit arrangement with the screen placed away from the slits $S_1$ and $S_2$. In each of these cases $S_1P_0 = S_2P_0, S_1P_1 - S_2P_1 = \frac{\lambda}{4}$ and $S_1P_2 - S_2P_2 = \frac{\lambda}{3}$, where $\lambda$ is the wavelength of the light used. In the cases B, C and D, a transparent sheet of refractive index $\mu$ and thickness t is pasted on slit $S_2$. The thickness of the sheets are different in different cases. The phase difference between the light waves reaching a point P on the screen from the two slits is donated by $\delta(P)$ and the intensity by I (P). Match each situation given in Column I with the statement(s) in Column II valid that situation. ***(2009)***

| **Column I** | **Column II** |
|---|---|
| (A)   | (p) $\delta(P_0) = 0$ |
| (B) $(\mu - 1)t = \frac{\lambda}{4}$   | (q) $\delta(P_1) = 0$ |
| (C) $(\mu - 1)t = \frac{\lambda}{2}$   | (r) $I(P_1) = 0$ |
| (D) $(\mu - 1)t = \frac{3\lambda}{4}$   | (s) $I(P_0) > I(P_1)$ |
| | (t) $I(P_2) > I(P_1)$ |

**Q.7** In the Young's double slit experiment, the interference pattern is found to have an intensity ratio between the bright and dark fringes as 9. This implies that ***(1982)***

(A) The intensities at the screen due to the two slits are 5 units and 4 units respectively.

(B) The intensities at the screen due to the two slits are 4 units and 1 unit respectively

(C) The amplitude ratio is 3

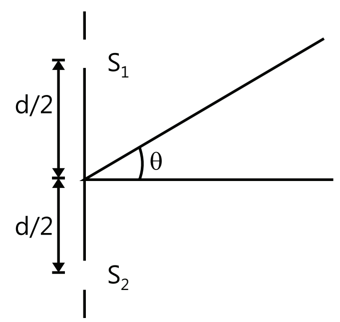
(D) The amplitude ratio is 2

**Q.8** White light is used to illuminate the two slits in a Young's double slit experiment. The separation between the slits is b and the screen is at a distance d (>>b) from the slits. At a point on the screen directly in front of one of the slits, certain wavelengths are missing. Some of these missing wavelengths are

(A) $\lambda = b^2/d$ (B) $\lambda = 2b^2/d$

(C) $\lambda = b^2/3d$ (D) $\lambda = 2b^2/3d$

**Q.9** In an interference arrangement similar to Young's double-slit experiment, the slits $S_1$ and $S_2$ are illuminated with coherent microwave sources, each of frequency $10^6$ Hz. The sources are synchronized to have zero phase difference. The slits are separated by a distance d=150.0m. The intensity I ($\theta$) is measured as a function of $\theta$ where $\theta$ is defined as shown. If $I_0$ is the maximum intensity then I




($\theta$) for $0 \le \theta \le 90°$ is given by ***(1995)***

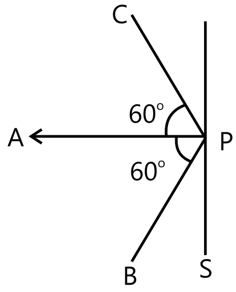
(A) $I(\theta) = I_0/2$ for $\theta = 30°$

(B) $I(\theta) = I_0/4$ for $\theta = 90°$

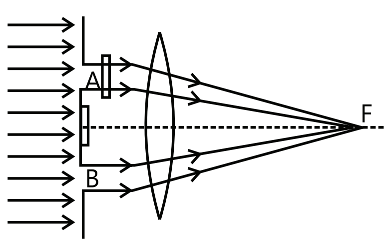
(C) $I(\theta) = I_0$ for $\theta = 0°$

(D) $I(\theta)$ = is constant for all values of $\theta$

**Q.10** Screen S is illuminated by two point sources A and B. Another source C sends a parallel beam of light towards point P on the screen (see figure). Line AP is normal to the screen and the lines AP, BP and CP are in one plane. The radiant powers of sources A and B are 90 W and 180 W respectively. The beam from C is of intensity $20\,W/m^2$. Calculate intensity at P on the screen.




**Q.11** In a modified Young's double slit experiment, a monochromatic uniform and parallel beam of light of wavelength 6000 Å and intensity $(10/\pi)\ Wm^2$ is incident normally on two apertures A and B of radii 0.001 m and 0.002 m respectively. A perfectly transparent film of thickness 2000 Å and refractive index 1.5 for the wavelength of 6000 Å is placed in front of aperture A (see figure). Calculate the power (in W) received at the focal spot F of the lens. The lens is symmetrically placed with respect to the apertures. Assume that 10% of the power received by each aperture goes in the original direction and is brought to the focal spot. ***(1989)***




**Q.12** In Young's experiment, the source is red light of wavelength $7 \times 10^{-7}$ m. When a thin glass plate of refractive index 1.5 at this wavelength is put in the path of one of the interfering beams, the central bright fringe shift by $10^{-3}$ m to the position previously occupied by the 5th bright fringe. Find the thickness of the plate. When the sources is now changed to green light of wavelength $5 \times 10^{-7}$ m, the central fringe shifts to a position initially occupied by the 6th bright fringe due to red light. Find the refractive index of glass for green light. Also estimate the change in fringe width due to change in wavelength. ***(1997)***

**Q.13** In a Young's experiment, the upper slit is covered by a thin glass plate of refractive index 1.4 while the lower slit is covered by another glass plate, having the same thickness as the first one but having refractive index 1.7. Interference pattern is observed using light of wavelength 5400 Å. It is found that the point P on the screen, where the central maximum (n=0) fall before the glass plates were inserted, now has $\frac{3}{4}$ the original intensity. It is further observed that what used to be the fifth maximum earlier lies below the point P while the sixth minima lies above P. Calculate the thickness of glass plate. (Absorption of light by glass plate may be neglected). ***(1997)***

**Q.14** In the Young's double slit experiment using a monochromatic light of wavelength $\lambda$, the path difference (in terms of an integer n) corresponding to any point having half the peak intensity is ***(2013)***

(A) $(2n+1)\frac{\lambda}{2}$ (B) $(2n+1)\frac{\lambda}{4}$

(C) $(2n+1)\frac{\lambda}{8}$ (D) $(2n+1)\frac{\lambda}{16}$

**Q.15** A light source, which emits two wavelengths $\lambda_1 = 400$ mm and $\lambda_2 = 600$ nm, is used in a Young's double slit experiment. If recorded fringe widths for $\lambda_1$ and $\lambda_2$ are $\beta_1$ and $\beta_2$ and the number of fringes for them within a distance y on one side of the central maximum are $m_1$ and $m_2$, respectively, then ***(2014)***

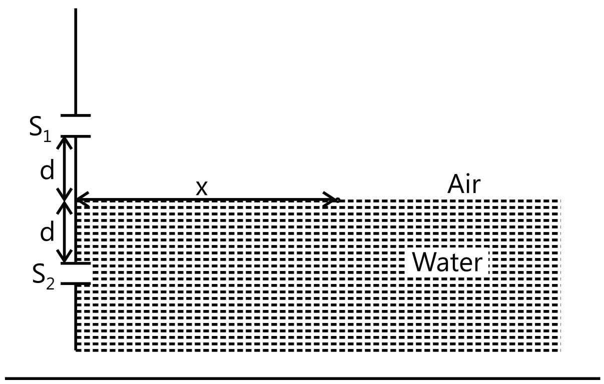
(A) $\beta_2 > \beta_1$

(B) $m_1 > m_2$

(C) From the central maximum, 3rd maximum of $\lambda_2$ overlaps with 5th minimum of $\lambda_1$

(D) The angular separation of fringes for $\lambda_1$ is greater than $\lambda_2$

**Q.16** A Young's double slit interference arrangement with slits $S_1$ and $S_2$ is immersed in water (refractive index = 4/3) as shown in the figure. The positions of maxima on the surface of water are given by $x^2 = p^2m^2\lambda^2 - d^2$, where $\lambda$ is the wavelength of light in air (refractive index = 1), 2d is the separation between the slits and m is an integer. The value of p is ***(2015)***




# PlancEssential Questions

## JEE Main/Boards

### Exercise 1

Q. 12 Q.15 Q.16
Q.18 Q.22 Q.23

### Exercise 2

Q.4 Q.5 Q.8
Q.15 Q.16

### Previous Years' Questions

Q.5 Q.7 Q.8
Q.9

## JEE Advanced/Boards

### Exercise 1

Q.2 Q.3 Q.8
Q.12 Q.15

### Exercise 2

Q.4 Q.7

### Previous Years' Questions

Q.3 Q.9

# Answer Key

## JEE Main /Boards

### Exercise 1

**Q.1** $1.2\times10^{-3}$

**Q.3** (i) Angular width increases (ii) no change (iii) angular width increases

**Q.5** (i) Resolving power increases (ii) remains unchanged (iii) resolving power increases

**Q.7** No, Ratio=2:1

**Q.9** Intensity becomes $\frac{I_0}{4}$

**Q.12** $6.4\times10^{-4}$ mm

**Q.13** Fringe width becomes twice

**Q.15** 560nm, when the monochromatic source is replaced by a source of white light; the fringe width would change.

**Q.16** (a) (i) 1300nm; (ii) 1950nm

(b) Intensity of secondary maximum is lesser as compared to central maxima

**Q.17** No, Energy carried by a wave depends on the amplitude of the wave, not on the speed of wave propagation.

**Q.18** (a) (i) 0.007m, (ii) 0.00525m (b) If screen is moved away from the slits fringe pattern will shrink.

**Q.25** $\frac{1}{2}$

### Exercise 2

**Single Correct Question**

| | | | | | |
|---|---|---|---|---|---|
| **Q.1** C | **Q.2** C | **Q.3** B | **Q.4** B | **Q.5** D | **Q.6** C |
| **Q.7** C | **Q.8** C | **Q.9** C | **Q.10** D | **Q.11** D | **Q.12** A |
| **Q.13** D | **Q.14** A | **Q.15** B | **Q.16** C | **Q.17** A | **Q.18** C |
| **Q.19** B | **Q.20** D | **Q.21** A | | | |

### Previous Years' Questions

| | | | | | |
|---|---|---|---|---|---|
| **Q.1** D | **Q.2** C | **Q.3** A | **Q.4** B | **Q.5** D | **Q.6** C |
| **Q.7** $1/49$ | **Q.8** (a) 4200 Angstrom, (b) 1.4 | | **Q.9** (a) 0.63mm, (b) 1.579 $\mu$m | | **Q.10** 3.5mm |
| **Q.11** B | **Q.12** C | **Q.13** B | **Q.14** B | | |

## JEE Advanced/Boards

### Exercise 1

**Q.1** $\left(n-\frac{1}{48}\right)\lambda = x_1 - x_2$

**Q.2** 0.225mm

**Q.3** 5000 Å

**Q.4** $1.99\times10^{-2}$ mm

**Q.5** 0.2 mm

**Q.6** 35.35 cm app., 5

**Q.7** 8 $\mu$m

**Q.8** 0, 1.5mm

**Q.9** 1.25m

**Q.10** 48, 21, $\frac{32}{3},\frac{9}{2}$,0 m.m

**Q.11** 760m, 21.8m, 89.4m, 19.6m

**Q.12** 81:1

**Q.13** $\frac{x}{\lambda y}v$

**Q.14** $I_0 = I\sec^2\left[\frac{\pi(\mu-1)t}{\lambda}\right]$

**Q.15** 7 $\mu m$, 1.6, $\frac{400}{7}$ $\mu m$ (decrease)

**Q.16** 9.3 $\mu m$

**Q.17** 3/4

**Q.18** (i) 1 mm (ii) increase

**Q.19** (a) $\frac{1}{\sqrt{15}}, \frac{3}{4}$ ; (b) No shift

**Q.20** 33

## Exercise 2

### Single Correct Choice Type

**Q.1** C **Q.2** D **Q.3** B **Q.4** C **Q.5** C **Q.6** A
**Q.7** A **Q.8** C **Q.9** B

### Multiple Correct Choice Type

**Q.10** B, C, D **Q.11** A, C, D **Q.12** A, C **Q.13** B, D **Q.14** B, C **Q.15** A, C
**Q.16** C, D

### Assertion Reasoning Type

**Q.17** D **Q.18** A **Q.19** C

### Comprehension Type

**Q.20** A, C, D **Q.21** A, B, D **Q.22** B, D

## Previous Years' Questions

**Q.1** D **Q.2** D **Q.3** B **Q.4** A **Q.5** C

**Q.6** A $\rightarrow$ p, s; B $\rightarrow$ q; C $\rightarrow$ t; D $\rightarrow$ s **Q.7** B, D **Q.8** A, C **Q.9** A, C

**Q.10** 13.97 $W/m^2$ **Q.11** $7\times10^{-6}$ W **Q.12** (a) $7\times10^{-6}$ m ; (b) 1.6; (c) $-5.71\times10^{-5}$ m

**Q.13** 9.3 $\mu m$ **Q.14** B **Q.15** A, B, C **Q.16** 3

# Solutions

## JEE Main/Boards

### Exercise 1

**Sol 1:** Size of obstacle must be comparable to wavelength of light width = $\frac{2\lambda D}{d}$

$= \frac{2\times6\times10^{-9}\times3\times10^{2}}{3\times10^{-3}} = 1.2 \times 10^{-3}$ m.

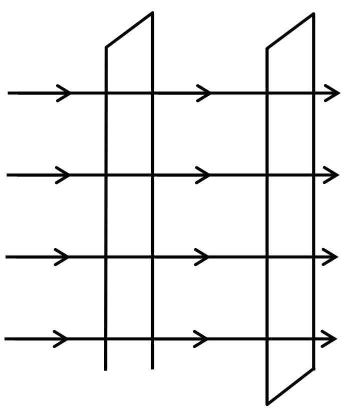
**Sol 2:** (a) Wave front is the locus of all particles of the medium which vibrate in same phase and where disturbances reach at the same point of time.

Consider all the point on a primary wave front to be sources of light, which emit disturbances known as secondary disturbances.

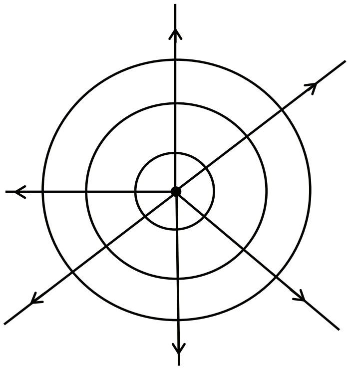
Tangent envelope to all secondary wavelets gives the position of new wave front.

(b)

(i)



(ii)



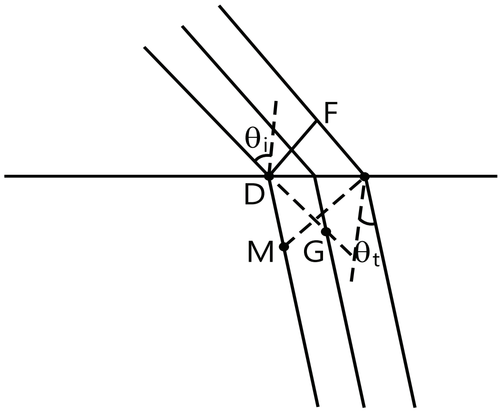
**Sol 3:** $\theta \propto \frac{\lambda}{d}$

(i) If d decrease, $\theta$ increases

(ii) Doesn't depend on D

(iii) If $\lambda$ decreases, $\theta$ decreases

**Sol 4:** According to Huygens theory each point on the leading surface of a wave disturbance may be regarded as a secondary source of spherical wave, which themselves progress with the speed of light in the medium & whose envelope at later times constitutes the new wave front.




$DM = V_t t = V_t\left(\frac{DG}{V_i}\right)$

$DM = \left(\frac{n_i}{n_t}\right)DG$

$\Rightarrow \frac{n_i}{n_t} = \frac{\sin\theta_t}{\sin\theta_i}$

**Sol 5:** R. P. = $\frac{D}{1.22\lambda}$

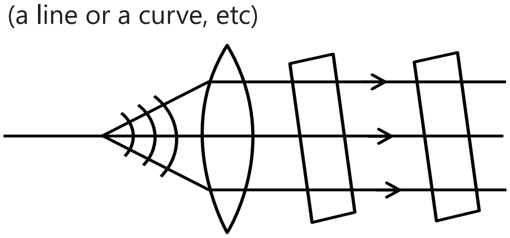
(i) If f increases, $\lambda$ decreases

R. P. increases

(ii) R. P. doesn't depend on f.

(iii) If D increases, R. P increases

**Sol 6:** Wave front is the locus of points having the same phase (a line or a curve, etc)



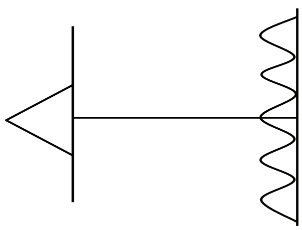
**Sol 7:** If the wavelength of both the sources is same, then interference may not be possible as even phase difference must be constant

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

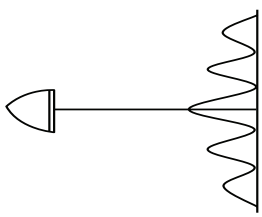
(i) $\theta = 0;\ I_1 = 4I_0;$

(ii) $\theta = 90°\ \frac{I_1}{I_2} = 2\ ;\ I_2 = 2I_0$

**Sol 8:** With 2 slits → interference pattern



With 1 slit → diffraction pattern

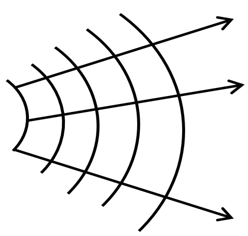


In first case, the maximum intensity is constant as we go from centre.

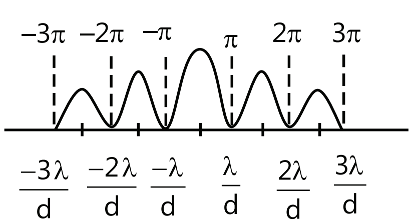
In second case, the intensities at maximum decrease as we go from centre.

In first case, the fringe length is fixed. In second case, the fringe angle is fixed.

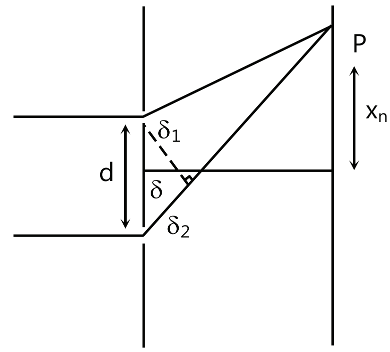
**Sol 9:**



In diffraction pattern




**Sol 10:** Two sources are said to be coherent if their frequencies are equal and they have a constant phase difference. Two independent sources of light cannot be coherent




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

$\left[\because \frac{\delta}{d} = \frac{x_n}{D}\right]$

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

we will observe maximum intensity

If $\frac{x_n d}{\lambda} = (2n+1)\frac{\lambda}{2}$

we will observe minimum intensity.

**Sol 11:** Resolving power of an instrument is its capacity to resolve 2 points which are close together

(i) It doesn't depend on μ of the medium

(ii) It's inversely proportional to λ of light.

**Sol 12:** Difference between interference and diffraction: Interference is due to superposition of two distinct waves coming from two coherent sources. Diffraction is produced as a result of superposition of the secondary wavelets coming from different parts of the same wavefront.

Numerical: Here, $\lambda = 600\,\text{nm} = 600 \times 10^{-19} = 6 \times 10^{-7}\,\text{m}$

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

$n = 2, a = ?$

$\because\ a\frac{x}{D} = n\lambda$

$a = \frac{n\lambda D}{x} = \frac{2 \times 6 \times 10^{-7} \times 0.8}{15 \times 10^{-3}} = 6.4 \times 10^{-5}\,\text{m}$

**Sol 13:** Angular separation of interference fringes in YDSE depends only on λ, d but not on D.

**Sol 14:** Linearly polarised light is light in which all the electric field of all the photons are confined to 1 direction perpendicular to direction of wave.

$I = I_0\cos^2\theta$

$I \propto \cos^2\theta$

$\theta = 180°$

**Sol 15:** $\beta = \frac{\lambda D}{d}$

$\Rightarrow \beta\ \alpha\ \lambda;\quad \frac{\beta_1}{\beta_2} = \frac{\lambda_1}{\lambda_2}$

If white light is used, there will no complete darkness as all colours will not be out of phase at a single point centre will be brightest as all colours will be in phase at that point.

**Sol 16:** First maxima $\rightarrow \theta = \frac{3\lambda}{2d}$

First minima $\rightarrow \theta = \frac{\lambda}{d}$

**Sol 17:** $E = h\nu = \frac{hc}{\lambda}$. c value decrease & $\lambda$ also decreases maintaining the frequency constant. So E is constant.

**Sol 18:** $\beta = \frac{\lambda D}{d}$

(a) (i) $2^{nd}$ bright : $y = 2\beta$

(ii) $1^{st}$ dark : $y = \frac{\beta}{2}$

(b) If D increases

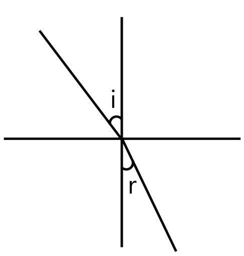
$\beta$ decreases, so fringe width increases.

**Sol 19:** The centre reflects the components perpendicular to the direction

$I = I_0\cos^2\theta$

**Sol 20:** In single slit diffraction angular fringe width depends only of $\lambda$, d but not on D.

**Sol 21:**




$\mu = \frac{\sin i}{\sin r}$

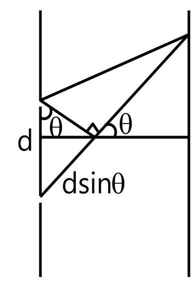
$C = \frac{C_0}{\mu}$ as $C \propto \frac{1}{\mu}$

$\Rightarrow C \propto \sin r.$

Minimum for r = 15°.

**Sol 22:** (a) $d\sin\theta = n\lambda$ (for constructive)

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




(b) $\beta_1 = \frac{\lambda_1 D}{d}$

$= \frac{8\times10^{-7}\times1.4}{2.8\times10^{-4}} = 4\times10^{-3}$ m = 4 mm

$\beta_2 = \frac{\lambda_2 D}{d} = \frac{6\times10^{-7}\times1.4}{2.8\times10^{-4}} = 3$ mm.

$3\beta_1 = 4\beta_2$

$3^{rd}$ bright of $1^{st}$ light = $4^{th}$ bright of $2^{nd}$ light

**Sol 23:** (a) The transparent medium allows components of E only in 1 direction & reflects all its perpendicular components.

(b) As A & B are crossed, $I_0 = \rightarrow \frac{I_0}{2}$

& $\frac{I_0}{2}\cos^2\theta = \frac{I_0}{8}$

**Sol 24:** $I_{min} = I_1 + I_2 + 2\sqrt{I_1 I_2}.\cos\phi$ & $I = a^2$

$I_{max} = a_1^2 + a_2^2 + 2a_1a_2(1) = (a_1 + a_2)^2$

$I_{min} = a_1^2 + a_2^2 + 2a_1a_2(-1) = (a_1 - a_2)^2$

**Sol 25:** $I_0 = 4I_1$

$I'_0 = I_1 + I_1 + 2I_1\cos90° = 2I_1 = \frac{I_0}{2}$

# Exercise 2

### Single Correct Choice Type

**Sol 1: (C)** $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

$I_{max} \to \cos\phi = 1$

$I = 9I$

$I_{min} \to \cos\phi = -1$

$I_{min} = I$

**Sol 2: (C)** $\gamma = \dfrac{c}{\lambda}$

In denser medium, c decreases but frequency remains the same.

$\therefore$ $\lambda$ also decreases

**Sol 3: (B)** Maximum path difference = 100 nm = 3.5 $\lambda$

So, we can get pd of $-3\lambda, -2\lambda, \ldots, 3\lambda$.

i.e. 7 maxima.

**Sol 4: (B)** $\dfrac{n\lambda_1 D}{d} = \dfrac{(n+1)\lambda_2 D}{d}$

n(2200) = (n + 1)(5200)

$\Rightarrow 3n = 2(n + 1)$

$\Rightarrow n = 2$

**Sol 5: (D)** $(l_1 + l_3) - (l_2 + l_4) = \dfrac{(2n+1)\lambda}{2}$

$\downarrow$ path by $S_1$ ; $\downarrow$ path by $S_2$

**Sol 6: (C)** Let intensity due to single slit by $I_1$. By two slits we get I.

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

and $\phi = 0°$ at centre.

$\Rightarrow I = 4I_1$

$\Rightarrow I_1 = \dfrac{I}{4}$

**Sol 7: (C)** Let I be intensity due to single slit.

$I = I + I + 2\sqrt{I.I}\cos\phi$

$\Rightarrow \cos\phi = \dfrac{-I}{2I} = \dfrac{-1}{2}$

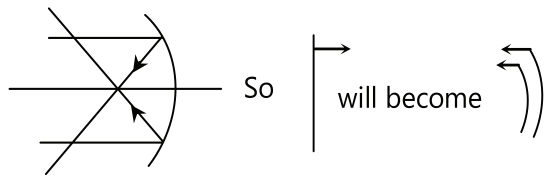
$\Rightarrow \phi = 120°$

Phase difference = $\dfrac{2\pi}{3}$

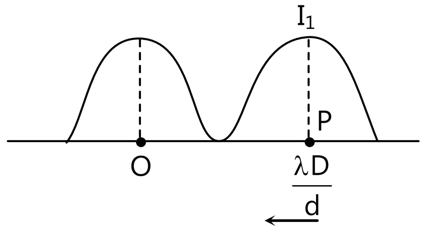
for $2\pi \to \dfrac{\lambda D}{d}$

for $\dfrac{2\pi}{3} \to \dfrac{\lambda D}{3d}$

**Sol 8: (C)**




**Sol 9: (C)**

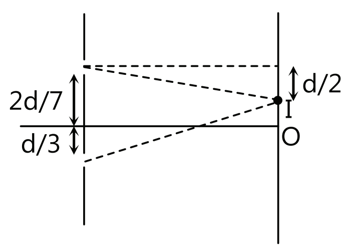



as D increases

$I_1$ moves away from O.

$\therefore$ I first decreases, then increases.

**Sol 10: (D)**




$OI = \dfrac{2d}{3} - \dfrac{d}{2} = \dfrac{d}{6}$

$\dfrac{d}{6} = \dfrac{n\lambda D}{d}$

$\Rightarrow \lambda = \dfrac{d^2}{6nD}$

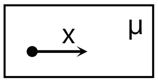
So $\dfrac{d^2}{3D}$ is not possible.

**Sol 11: (D)** $\beta = \dfrac{2\lambda D}{d}$

as c decreases, $\lambda$ also decreases

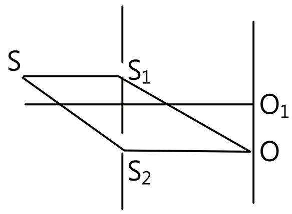
so $\beta$ decreases but there won't be any shift.

**Sol 12: (A)** d = μx




phase difference = $\dfrac{\mu x}{\dfrac{\lambda}{2\pi}} = \dfrac{2\pi\mu x}{\lambda}$

**Sol 13: (D)**




Fringe width will not change it depends only on λ, d, D.

To get Pd = 0, $S_1O > S_2O$.

So O will be below $O_1$ pattern will shift downwards.

**Sol 14: (A)** $I_{max} = 4I_0$

75% of $I_{max} = 3I_0$

$3I_0 = I_0 + I_0 + 2I_0.\cos\phi$

$\cos\phi = \dfrac{1}{2}$

$\Rightarrow \phi = 2n\pi \pm 60^\circ$

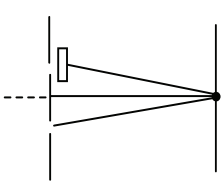
It's between

3π 6π

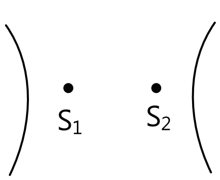
↓ ↓

2nd minima 3rd maxima

only $\dfrac{\pi}{3}$ is not possible in the options



**Sol 15: (B)**

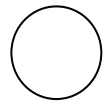



$S_1P - S_2P = n\lambda$

Family of hyperbolas with n as variable.

**Sol 16: (C)** First coloured to be received is violet. As frequency of violet is high, $\lambda_{red}$ is high and

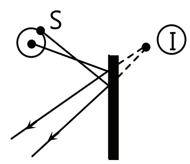
$\mu_{red} > \mu_{violet}$



**Sol 17: (A)** $\dfrac{\lambda}{2} = 1.33\ t$

$\Rightarrow t = \dfrac{300}{1.33} = 225$ nm

**Sol 18: (C)** Image will coincide with S but on opposite side.




**Sol 19: (B)** They will get closer, if we use light of lower λ.

i.e. using blue light.

If 'd' decreases, β increases

β doesn't depend on distance between source and slits.

**Sol 20: (D)** $P_1 = \mu_A t_A + t_B$

$P_2 = t_A + \mu_B t_B$

$Pd = t_A.t_B$

If $t_A > t_B \rightarrow$ towards B

[same as in previous question]

If $t_B < t_A \rightarrow$ towards A

**Sol 21: (A)** If we put mica sheet in front of $S_1$.

$(\sqrt{2} - 1)d = (\mu - 1)t$

$\Rightarrow t = 2(\sqrt{2} - 1)d$

In front of $S_2$

$(\sqrt{2} - 1)d + (\mu - 1)t = n\lambda$.

## Previous Years' Questions

**Sol 1: (D)** $\omega = \dfrac{\lambda D}{d}$

d is halved and D is doubled

$\therefore$ Fringe width $\omega$ will become four times.

**Sol 2: (C)** $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2 = (\sqrt{4I} + \sqrt{I})^2 = 9I$

$I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2 = (\sqrt{4I} - \sqrt{I})^2 = I$

**Sol 3: (A)** In interference we know that

$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$ and $I_{min} = (\sqrt{I_1} \sim \sqrt{I_2})^2$

Under normal conditions (when the widths of both the slits are equal)

$I_1 \approx I_2 = I$ (say)

$\therefore I_{max} = 4I$ and $I_{min} = 0$

When the width of one of the slits is increased. Intensity due to that slit would increase, while that of the other will remain same. So, let :

$I_1 = I$ and $I_2 = \eta I$ $(\eta > 1)$

Then, $I_{max} = I(1 + \sqrt{\eta})^2 > 4I$

And $I_{min} = I(\sqrt{\eta} - 1)^2 > 0$

$\therefore$ Intensity of both maxima and minima is increased.

**Sol 4: (B)** $I(\phi) = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$ ...(i)

Here, $I_1 = I$ and $I_2 = 4I$

At point A, $\phi = \dfrac{\pi}{2}$ $\therefore I_A = I + 4I = 5I$

At point B, $\phi = \pi$ $\therefore$ IB = I + 4I – 4I = I

$\therefore I_A - I_B = 4I$

Note: Equation (i) for resultant intensity can be applied only when the sources are coherent. In the question it is given that the rays interfere. Interference takes place only when the sources are coherent. That is why we applied equation number (i). When the sources are incoherent, the resultant intensity is given by $I = I_2 + I_2$

**Sol 5: (D)** Let *n*th minima of 400 nm coincides with *m*th minima of 560 nm, then

$$(2n-1)\left(\frac{400}{2}\right) = (2m-1)\left(\frac{560}{2}\right)$$

or $\dfrac{2n-1}{2m-1} = \dfrac{7}{5} = \dfrac{14}{10} = \ldots$

i.e., 4 th minima of 400 nm coincides with 3rd minima of 560 nm.

Location of this minima is,

$$Y_1 = \frac{(2\times4-1)(1000)(400\times10^{-6})}{2\times0.1} = 14 \text{ mm}$$

Next 11th minima of 400 nm will coincide with 8th minima of 560 nm.

Location of this minima is,

$$Y_1 = \frac{(2\times11-1)(1000)(400\times10^{-6})}{2\times0.1} = 42 \text{ mm}$$

$\therefore$ Required distance = $Y_2 - Y_1$ = 28 mm

**Sol 6: (C)** $I = I_{max}\cos^2\left(\dfrac{\phi}{2}\right)$

$\therefore \dfrac{I_{max}}{4} = I_{max}\cos^2\dfrac{\phi}{2}$

$\cos\dfrac{\phi}{2} = \dfrac{1}{2}$

or $\dfrac{\phi}{2} = \dfrac{\pi}{3}$

$\therefore \phi = \dfrac{2\pi}{3} = \left(\dfrac{2\pi}{\lambda}\right)\Delta x$ ... (i)

where $\Delta x = d\sin\theta$

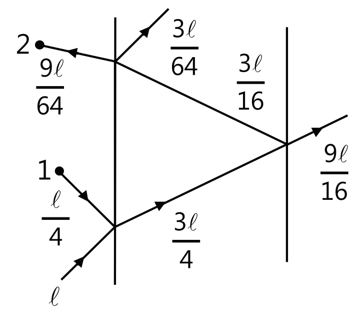
Substituting in Eq. (i), we get

$\sin\theta = \dfrac{\lambda}{3d}$

or $\theta = \sin^{-1}\left(\dfrac{\lambda}{3d}\right)$

**Sol 7:** Each plate reflects 25% and transmits 75%.

Incident beam has an intensity I. This beam undergoes multiple reflections and refractions. The corresponding intensity after each reflection and refraction (transmission) are shown in figure.



Interference pattern is to take place between rays 1 and 2.

$I_1 = I/4$ and $I_2 = 9I/64$

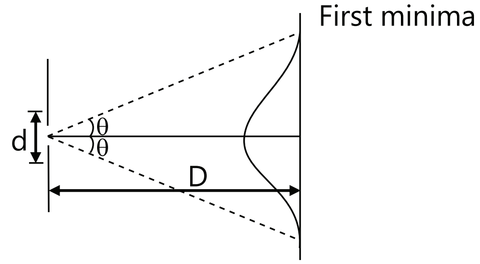
$$\therefore \frac{I_{min}}{I_{max}} = \left(\frac{\sqrt{I_1}-\sqrt{I_2}}{\sqrt{I_1}+\sqrt{I_2}}\right)^2 = \frac{1}{49}$$

**Sol 8:** Given $\lambda$ = 6000 Å

Let b be the width of slit and D the distance between screen and slit.

First minima is obtained at b sin $\theta = \lambda$

or $b\theta = \lambda$ as $\sin\theta = \theta$




or$\theta = \frac{\lambda}{b}$ Angular width of first maxima = $2\theta$

$= \frac{2\lambda}{b} \propto I$

Angular width will decrease by 30% when $\lambda$ is also decreased by 30%.

Therefore, new wavelength

$$\lambda' = \left\{(6000) - \left(\frac{30}{100}\right)6000\right\} \text{ Å}$$

$\lambda'$ = 4200 Å

(b) When the apparatus is immersed in a liquid of refractive index $\mu$, the wavelength is decreased $\mu$ times. Therefore,

$$4200 \text{ Å} = \frac{6000\text{Å}}{\mu}$$

$\therefore \mu = \frac{6000}{4200}$ or $\mu = 1.429 \approx 1.43$

**Sol 9:** Given, $\mu$ = 1.33, d = 1 mm, D = 1.33 m,

$\lambda$ = 6300 Å

(a) Wavelength of light in the given liquid:

$$\lambda' = \frac{\lambda}{\mu} = \frac{6300}{1.33} \text{ Å} = 4737 \text{ Å} = 4737 \times 10^{-10} \text{ m}$$

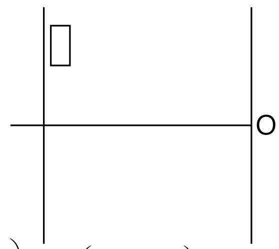
$\therefore$ Fringe width, $\omega = \frac{\lambda' D}{d}$

$$\omega = \frac{(4737\times10^{-10}\text{m})(1.33\text{m})}{(1\times10^{-3}\text{m})} = 6.3\times10^{-4} \text{ m}$$

$\omega$ = 0.63 mm

(b) Let t be the thickness of the glass slab

Path difference due to glass slab at centre O.




$$\Delta x = \left(\frac{\mu_{glass}}{\mu_{liquid}} - 1\right) t = \left(\frac{1.53}{1.33} - 1\right) t$$

or $\Delta x$ = 0.15t

Now, for the intensity to be minimum at O, this path difference should be equal to $\frac{\lambda'}{2}$

$\therefore \Delta x = \frac{\lambda'}{2}$

or 0.15 t = $\frac{4737}{2}$ Å

$\therefore$ t = 15790 Å

or t = 1.579 $\mu$m

**Sol 10:** Let $n_1$ bright fringe corresponding to wavelength $\lambda_1$ = 500 nm coincides with $n_2$ bright fringe corresponding to wavelength $\lambda_2$ = 700 nm.

$$\therefore \quad n_1\frac{\lambda_1 D}{d} = n_2\frac{\lambda_2 D}{d}$$

$$\text{or} \quad \frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{7}{5}$$

This implies that 7$^{th}$ maxima of $\lambda_1$ coincides with 5$^{th}$ maxima of $\lambda_2$. Similarly 14$^{th}$ maxima of $\lambda_1$ will coincide with 10$^{th}$ maxima of $\lambda_2$ and so an.

$\therefore$Minimum distance = $\frac{n_1\lambda_1 D}{d} = 7\times5\times10^{-7}\times10^3$

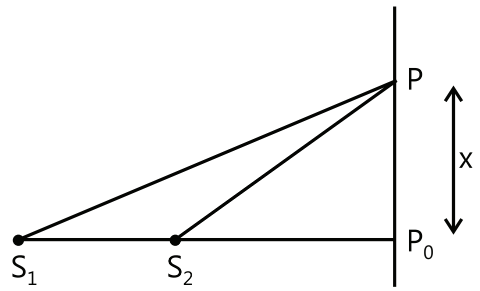
= 3.5 × 10$^{-3}$ m = 3.5 mm

**Sol 11: (B)** Intensity of light transmitted by $A = \frac{I_0}{2}$

According to Malus law, the intensity of light transmitted by B

$$= \frac{I_0}{2}\cos^2\theta = \frac{I_0}{2}\cos^2(45°) = \frac{I_0}{4}$$

**Sol 12: (C)** Consider a point P on the screen. The path difference between the waves from $S_1$ and $S_2$ on reaching P is $(S_2P - S_1P)$. This path difference is constant for every point on a circle of radius x with $P_0$ as the centre. Hence the figures will be concentric circles with common centre at $P_0$.




Note that $S_1$ and $S_2$ are point sources and (not slit sources as in Young's experiment).

**Sol 13: (B)**

$I_A \cos^2 30 = I_B \cos^2 60$

$\frac{I_A}{I_B} = \frac{1}{3}$

**Sol 14: (B)** We know that

Geometrical spread = a

and diffraction spread = $\frac{\lambda L}{a}$

So spot size(b) = $a + \frac{\lambda L}{a}$

For minimum spot size $a = \frac{\lambda L}{a} \Rightarrow a = \sqrt{\lambda L}$

and $b_{min} = \sqrt{\lambda L} + \sqrt{\lambda L} = \sqrt{4\lambda L}$

# JEE Advanced/Boards

## Exercise 1

**Sol 1:** For constructing interference

$\phi = 2x\pi$

$$\frac{2\pi(x_1 - x_2)}{\lambda} = \frac{\pi}{8} - \frac{\pi}{6} + 2n\pi$$

$$\Rightarrow (x_1 - x_2) = \left(n - \frac{1}{48}\right)\lambda.$$

**Sol 2:** $\beta = \frac{\lambda D}{d}$; $\lambda = \frac{\lambda_0}{\mu}$

$\therefore \beta = \frac{6\times10^{-7}}{4} \times 3 \times \frac{1}{2\times10^{-3}} = 2.25 \times 10^{-4}$ m.

**Sol 3:** $9^{th}$ Bright fringe = $\frac{9\lambda D}{d}$

$2^{nd}$ dark fringe = $\frac{1.5\lambda D}{d}$

$7.5 \times 10^{-3} = \frac{\lambda\times1}{5\times10^{-4}}(9 - 1.5)$

$\Rightarrow \lambda = 5 \times 10^{-7}$ m = 5000 Å.

**Sol 4:** Pd = d sin θ

$d \sin\theta = \frac{\lambda}{2}$

$d \times 0.75 \frac{\pi}{180°} = 2.6 \times 10^{-7}$

$\Rightarrow d = 2 \times 10^{-2}$ mm.

**Sol 5:** $I_{max} = 4I_0$

75% of $I_{max} = 3I_0$

$3I_0 = I_0 + I_0 + 2\sqrt{I_0 I_0}\cos\phi$

$\Rightarrow \cos\phi = \frac{1}{2}$

$\phi = 60°, -60°, 120°$

$360 \rightarrow \frac{\lambda D}{d}$

$120° \rightarrow \frac{\lambda D}{3d} = 0.2$ mm.

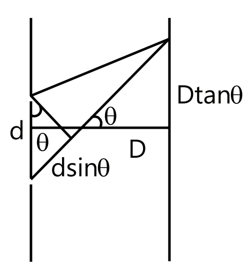
**Sol 6:** Possible pd for maxima $\rightarrow -2\lambda_1, \ldots 2\lambda$

i. e. 5

$d \sin\theta = \lambda$ for $1^{st}$ maxima

$\Rightarrow 3 \sin\theta = 1$

$\sin\theta = \frac{1}{3}$



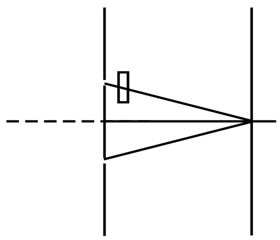

$\Rightarrow \tan\theta = \frac{1}{\sqrt{8}}$

y = tan θ = 0.353 m.

**Sol 7:** $(\mu_1 - \mu_2)\ t = Pd = 5\lambda$

$$t = \frac{5\times(48\times10^{-8})}{0.3} = 8\,\mu m$$

**Sol 8:** $I_0 = 4I_1$



$Pd = (y - 1)\ t$

$= 0.5 \times 1.5 \times 10^{-6}$

$= 7.5 \times 10^{-7}$ m

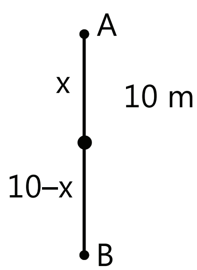
$\lambda = 5 \times 10^{-7}$ m

$Pd = 1.5\ \lambda$

$\therefore I_0 = 0$

Shift $= 1.5\ \frac{\lambda D}{d} = 1.5$ mm

**Sol 9:** $\lambda = \frac{c}{\nu} = \frac{3\times10^8}{6\times10^7} = 5m$




$\Delta p$ must be $\frac{\lambda}{2}$

$10 - x - x = \frac{\lambda}{2}\ (2n + 1)$

$10 - 2x = 2.5$ or $7.5$

to get minimum x

$10 - 2x = 7.5$

$$x = \frac{10-7.5}{2} = 1.25m$$

**Sol 10:** $\sqrt{25\lambda^2 + d^2} - d = n\lambda$

Possible values of

n = 5, 4, .... . 1

for each value of d, we will get a circle with $S_1$ as center.

**Sol 11:** $|\ AB - BC\ | = (2n+1)\frac{\lambda}{2}$

AB = 200 m

$\lambda = \frac{c}{\nu} = \frac{3\times10^8}{5.8\times10^6}$

**Sol 12:** $I_{A'B'} = \frac{4}{5}\times\frac{4}{5}I = \frac{16}{25}I$

$$\frac{I_{max}}{I_{min}} = \frac{1+\frac{16}{25}+2\sqrt{\frac{16}{25}}}{1+\frac{16}{2\sqrt{5}}-2\sqrt{\frac{16}{25}}} = 81:1$$

**Sol 13:** $n = \frac{x}{\beta}$

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

$\frac{dn}{dt} = \frac{x}{\lambda D}\frac{d(d)}{dt} = \frac{xv}{\lambda y}$

**Sol 14:** Let intensity of individual slit be $I_1$

$I_0 = 4I_1$

with glass plate

$\phi = 2\pi \times \frac{(\mu-1)t}{\lambda}$

$I = 2I_1 + 2I_1 \cos\phi$

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

$\Rightarrow I_0 = \frac{2I}{2\cos^2\frac{\phi}{2}}$

**Sol 15:** $\phi_1 = \frac{(\mu-1)t}{\lambda r}\times 2\pi$ ; $10^{-3} = 5\beta_1 = \frac{5\lambda_r D}{d}$

and $\phi = 10\pi$

$\phi_2 = \frac{(\mu-1)t}{\lambda_g}\times 2\pi$

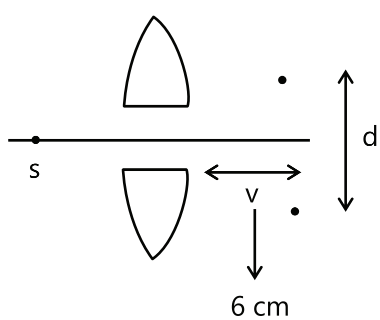
$\Delta y_c = 6\beta_1$

**Sol 16:** $Pd = (\mu_1 - \mu_2)\ t$

$I_1 = \frac{3}{4}\ I_{max}$

$\Rightarrow \phi = 60°$ or $- 60° \pm 2\ n\pi$

$\phi$ must lie between $10\pi$, $11\pi$.



**Sol 17:** $\phi = \dfrac{(\mu_2-\mu_1)(t_2-t_1)}{\lambda_0}\times 2\pi$

$I_c = 2I_0 + 2I_0 \cos\phi$

$I_{max} = 4I_0$.

**Sol 18:** S will have 2 images which will act as sources and is similar to YDSE

$\dfrac{1}{v}-\dfrac{1}{u}=\dfrac{1}{f}$

f = 10 cm

u = – 15 cm

$\dfrac{1}{v}=\dfrac{1}{10}-\dfrac{1}{15} = \dfrac{1}{30}$

$d = 0.5 \times \dfrac{v}{u} = 1\text{mm}$

**Sol 19:** Minima possible when

(a) $Pd = (2n+1)\dfrac{\lambda}{2}$

i. e. – 0.75, – 0.25, 0.25, 0.75

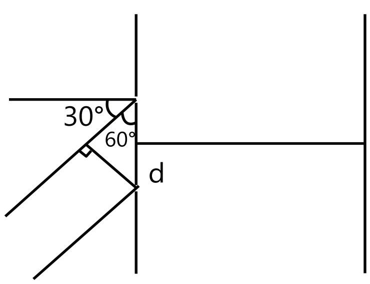
$d \sin\theta = pd$

$y = D\tan\theta$

$\sin\theta = \dfrac{0.25}{1}, \dfrac{0.75}{1} \Rightarrow \dfrac{1}{4}, \dfrac{3}{4}$

$\Rightarrow \tan\theta = \dfrac{1}{\sqrt{15}}, \dfrac{3}{4}$

(b) We need to find the initial Pd




$Pd = d\sin 30° = \dfrac{d}{2} = 0.5\text{ mm} = \lambda$

So, there will be no shift.

**Sol 20:** Let $\beta = \dfrac{\lambda D}{d}$

$\dfrac{5}{\beta}=\dfrac{Pd}{\lambda}$ $Pd = (\mu_1 - \mu_2)t$

$\dfrac{8}{\beta}=\dfrac{(\mu-1)(t_2-t_1)}{\lambda}$

# Exercise 2

### Single Correct Choice Type

**Sol 1: (C)** $\dfrac{b}{V_{air}} = \dfrac{d}{V_{water}}$

$\Rightarrow \dfrac{b}{d} = \dfrac{V_{air}}{V_{water}} = \dfrac{\mu_{water}}{\mu_{air}}$

**Sol 2: (D)** For monochromatic light, $I_{max}$ and fringe width is constant.

so, we use white light to determine central maximum.

**Sol 3: (B)** Case-I $\rightarrow I_1 = I_0+I_0+2\sqrt{I_0I_0}\cos(0°) = 4I_0$

Case-II $\rightarrow I_2 = I_0+I_0+2\sqrt{I_0I_0}\cos(90°) = 2I_0$

$\dfrac{I_1}{I_2} = 2$

**Sol 4: (C)** At O, $Pd = S_1S_2 = d$

if $d = \dfrac{(2n+1)\lambda}{2} \rightarrow 0 \rightarrow$ minima

$d = n\lambda \rightarrow 0 \rightarrow$ maxima

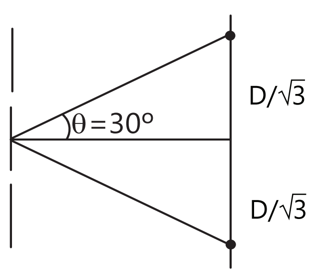
if $d = 4.3\ \lambda$,

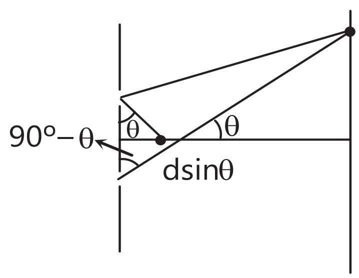
Possible minima

$\rightarrow -3.5\lambda, -2.5\lambda, \ldots.\ 3.5\lambda$.

i.e. 8 points.

**Sol 5: (C)**



$Pd = d \sin\theta$

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

$= \frac{3}{10} \times 5 \times 10^{-7} \times 10^{3}$ m $= 300\ \lambda$

So, possible maxima

$-299\lambda, -298\lambda, \ldots\ldots 299\lambda$

i.e. 599 maxima

**Sol 6: (A)** In the YDSE experiment, $\Delta x = \frac{yd}{D}$,

for the maxima, $\Delta x = n\lambda \Rightarrow \frac{yd}{D} = n\lambda$

$\Rightarrow y = \frac{n\lambda D}{d}$. In the question, $y = \frac{d}{6}$.

Then, $\frac{d}{6} = \frac{n\lambda D}{d} \Rightarrow \lambda = \frac{d^2}{6nD}$ where, n = 1, 2 , 3 , 4....

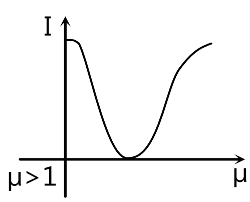
**Sol 7: (A)** $Pd = n_3 t - n_2 t$

$\phi = \frac{(n_3 t - n_2 t)}{\lambda_0} \times 2n = \frac{2\pi}{n_1 \lambda_1}(n_3 - n_2)t$

**Sol 8: (C)** $Pd = (\mu - 1)\ t$

$\phi = \frac{(\mu - 1)t}{\lambda} \times 2\pi$

$I = I_0 + I_0 + 2I_0\cos\phi$




**Sol 9: (B)** $Pd = 2\mu t + t - \mu(2t)$

$Pd = t$

$\frac{y}{Pd} = \frac{D}{d} \Rightarrow y = \frac{Dt}{d}$

**Multiple Correct Choice Type**

**Sol 10: (B, C, D)** Central fringe will white as phase difference = 0 for all colours.

We can't get completely dark fringe as all colours will not have phase difference = 0 at a single point.

**Sol 11: (A, C, D)** $I_{max} = I_1 + kI_1 + 2\sqrt{k}\, I_1\cos\phi$; $(\cos\phi \to 1)$

$= I_1(1 + k + 2\sqrt{k})$ and $k < 1$

$I_{min} = I_1(1 + k - 2\sqrt{k})$

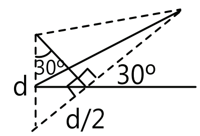
so $I_{max} < I_0$ and $I_{min} > 0$

$\beta$ doesn't change.

Fringes will shift towards covered slit.

**Sol 12: (A, C)** $\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{10^6} = 300$ m

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




$I_1 = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(0°)$

$I_0 = 4I_1$

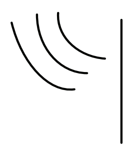
If $\theta = 90°$ ; $\phi = \frac{\lambda}{2}$; $I = 0$

If $\theta = 30°$; $\Delta Pd = \frac{d}{2} = \frac{\lambda}{4}$; $\phi = 90°$

$I = 2I_1 = \frac{I_0}{2}$

**Sol 13: (B, D)** They must have same frequency and constant $\phi$.

They need not have same $A_1 I$.



**Sol 14: (B, C)** $\lambda_{red} > \lambda_{blue}$

$\therefore \beta_{red} > \beta_{blue}$

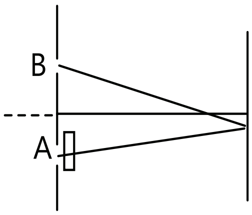
Fringe length decreases.

So, no. of maxima increases.

**Sol 15: (A, C)** Central maxima will shift towards A as $(\mu - 1)t$ is added before A.

$\Delta x = (\mu - 1)t$

$\Delta y = \frac{(\mu - 1)t}{\lambda} \times \beta$.




**Sol 16: (C, D)** $\beta = \frac{2\lambda D}{d} = \frac{2\times 4.5\times 10^{-7}}{10^{-3}} = 9 \times 10^{-4}$ m

$\frac{\lambda D}{d} = 4.5 \times 10^{-4}$ m.

Pd = $(\mu - 1)t = 0.5 \times 2.1 \times 10^{-6}$

$\phi = \frac{Pd}{\lambda}$

$= \frac{10.5\times 10^{-7}}{4.5\times 10^{-7}} = 2 + \frac{1}{3}$

So $\frac{\lambda d}{3D}, \frac{2\lambda d}{3D}$

**Assertion Reasoning Type**

**Sol 17: (D)** Statement-I is false as path difference will be zero.

$P_{S_1} = \mu S_1 O$

$P_{S_2} = \mu S_2 O$

Pd = 0

**Sol 18: (A)** $\nu = \frac{c}{\lambda}$; $\lambda_{red} > \lambda_{blue}$

And $\mu_{red} > \mu_{blue}$

So, light speed of red > light speed of blue.

**Sol 19: (C)** Electromagnetic field at a point depends also on time.

It's magnitude depends with time

So statement-II is false.

**Comprehension Type**

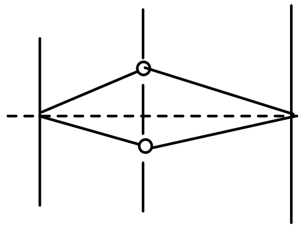
**Sol 20: (A, C, D)** $\beta = \frac{2\lambda d}{D}$

So $\beta \propto \lambda$

Central maxima is always at O in this case.

$\lambda_{violet} < \lambda_{red}$, $\lambda_{violet}$ is minimum in visible region.

So, violet maxima is closest.



**Sol 21: (A, B, D)** $\beta \propto \frac{1}{D}$

Angular fringe width doesn't depend on D.

Central fringe doesn't change from O.

**Sol 22: (B, D)** $\beta_x$ angular fringe width depends on 'd'

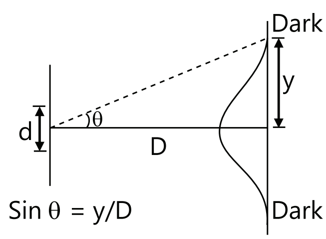
Position of central maxima doesn't change.

Rest all maxima, minima positions change.

## Previous Years' Questions

**Sol 1: (D)** For first dark fring on either side d sin $\theta = \lambda$ or $\frac{dy}{D} = \lambda \therefore y = \frac{yD}{d}$

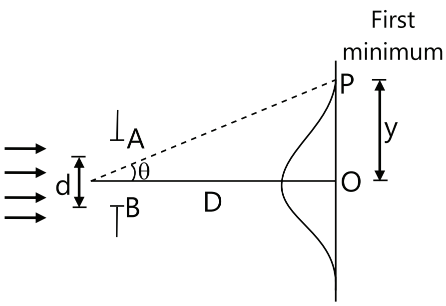
Therefore distance between two dark fringes on either side = $2y = \frac{2yD}{d}$




Substituting that values, we have

Distance = $\frac{2(600\times 10^{-6}\text{mm})(2\times 10^{3}\text{mm})}{(1.0\text{mm})}$ = 2.4 mm

**Sol 2: (D)** At First minima, $b \sin \theta = \lambda$




or $b\theta = \lambda$ or $b\left(\frac{y}{D}\right) = l$

or $y = \frac{\lambda D}{b}$ or $\frac{\lambda b}{D} = \lambda$ ...(i)

Now, at P (First minima) path difference between the rays reaching from two edges (A and B) will be

$\Delta x = \frac{\lambda b}{D}$ (Compare with $\Delta x = \frac{\lambda b}{D}$ in YDSE)

or $\Delta x = \lambda$[From eq. (i)]

Corresponding phase difference ($\phi$) will be

$\phi = \left(\frac{2\pi}{\lambda}\right).\Delta x$, $\phi = \frac{2\pi}{\lambda}.\lambda = 2\pi$

**Sol 3: (B)** Fringe width, $\omega = \frac{\lambda D}{d} \propto l$

When the wavelength is decreased from 600 nm to 400 nm, fringe width will also decrease by a factor of $\frac{4}{6}$ or $\frac{2}{3}$ or the number of fringes in the same segment will increase by a factor of 3/2.

Therefore, number of fringes observed in the same segment $= 12 \times \frac{3}{2} = 18$

**Note**: since $\omega \propto \lambda$, if YDSE apparatus is immersed in a liquid of refractive index $\mu$, the wavelength $\lambda$, and thus the fringe width will decrease $\mu$ times.

**Sol 4: (A)** Path dirrerence due to slab should be integeral multiple of $\lambda$ or $\Delta x = n\lambda$

or $(\mu - 1)t = n\lambda$ n = 1, 2, 3

or $t = \frac{n\lambda}{\mu - 1}$

For minimum value of t, n = 1

$\therefore t = \frac{\lambda}{\mu - 1} = \frac{\lambda}{1.5 - 1} = 2\lambda$

**Sol 5: (C)** All points on a wavefront are at the same phase.

$\therefore \phi_d = \phi_c$ and $\phi_f = \phi_e$

$\therefore \phi_d - \phi_f = \phi_c - \phi_e$

**Sol 6:** (A) $\rightarrow$ (p, s) $\rightarrow$ Intensity at $P_0$ is maximum. It will continuously decrease from $P_0$ towards $P_2$.

(B) $\rightarrow$ (q) $\rightarrow$ Path difference due to slap will be compensated by geometrical path difference. Hence $\delta(P_1) = 0$

(C) $\rightarrow$ (t) $\rightarrow$ $\delta(P_1) = \frac{\lambda}{2}$, $\delta(P_1) = \frac{\lambda}{2} - \frac{\lambda}{4} = \frac{\lambda}{4}$ and $\delta(P_2) = \frac{\lambda}{2} - \frac{\lambda}{3} = \frac{\lambda}{6}$. When path difference increases from 0 to $\frac{\lambda}{2}$, intensity will decrease from maximum to zero.

Hence in this case, $I(P_2) > I(P_1) > I(P_0)$

(D) $\rightarrow$ (r) $\rightarrow$ Intensity is zero at $P_1$

**Sol 7: (B, D)** $\frac{I_{max}}{I_{min}} = \frac{\left(\sqrt{I_1} + \sqrt{I_2}\right)^2}{\left(\sqrt{I_1} - \sqrt{I_2}\right)^2} = \left(\frac{\sqrt{I_1 / I_2} + 1}{\sqrt{I_1 / I_2} - 1}\right)^2 =$ 9 (Given)

Solving this, we have $\frac{I_1}{I_2} = 4$

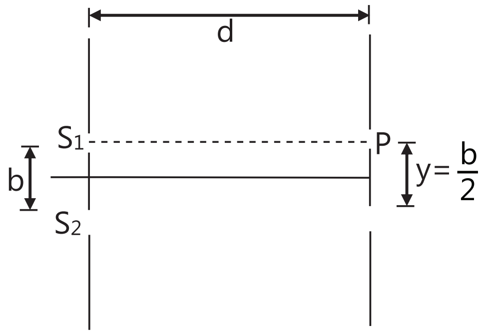
But $I \propto A^2 \therefore \frac{A_1}{A_2} = 2$

**Sol 8: (A, C)** At P (directly infrom of $S_1$) $y = \frac{b}{2}$

$\therefore$ Path difference,

$\Delta X = S_2P - S_1P = \frac{y.(b)}{d}$

$= \frac{\left(\frac{b}{2}\right)(b)}{d} = \frac{b^2}{2d}$




Those wavelengths will be missing for which

$$\Delta X = \frac{\lambda_1}{2}, \frac{3\lambda_2}{2}, \frac{5\lambda_3}{2} ...$$

$$\therefore \lambda_1 = 2\Delta x = \frac{b^2}{d}\ \lambda_2 = \frac{2\Delta x}{3} = \frac{b^2}{3d}$$

$$\lambda_3 = \frac{2\Delta x}{5} = \frac{b^2}{5d}$$

**Sol 9: (A, C)** The intensity of light is $I(\theta) = I_0 \cos^2\left(\frac{\delta}{2}\right)$

where $\delta = \frac{2\pi}{\lambda}(\Delta\pi) = \left(\frac{2\pi}{\lambda}\right)(d \sin \theta)$

(a) for $\theta$ = 30°

$$\lambda = \frac{c}{v} = \frac{3\times10^8}{10^6} = 300 \text{ m and } d = 150 \text{ m}$$

$$\delta = \left(\frac{2\pi}{300}\right)(150)\left(\frac{1}{2}\right) = \frac{\pi}{2}$$

$$\therefore \frac{\delta}{2} = \frac{\pi}{4}$$

$$\therefore I(\theta) = I_0 \cos^2\left(\frac{\pi}{4}\right) = \frac{I_0}{2} \text{ [option (a)]}$$

(b) For $\theta$ = 90°

$$\delta = \left(\frac{2\pi}{300}\right)(150)(1) = p$$

$$\text{or } \frac{\delta}{2} = \frac{\pi}{2} \text{ and } I(\theta) = 0$$

(c) For $\theta = 0°$, $\delta = 0$ or $\frac{\delta}{2} = 0$

$\therefore I(\theta) = I_0$ [option (c)]

**Sol 10:** Resultant intensity at P

$$I_p = I_A + I_B + I_C$$

$$= \frac{P_A}{4\pi(PA)^2} + \frac{P_B}{4\pi(PB)^2}\cos 60° + I_C \cos 60°$$

$$= \frac{90}{4\pi(3)^2} + \frac{180}{4\pi(1.5)^2}\cos60° + 20\cos 60°$$

$$= 0.79 + 3.18 + 10$$

$$= 13.97 \text{ W/m}^2$$

**Sol 11:** Power received by aperture A,

$$P_A = I(\pi r_A^2) = \frac{10}{\pi}(\pi)(0.001)^2 = 10^{-5} \text{ W}$$

Power received by aperture B,

$$P_B = I(\pi r_B^2) = \frac{10}{\pi}(\pi)(0.002)^2 = 4\times10^{-5} \text{ W}$$

Only 10% of $P_A$ and $P_B$ goes to the original direction

Hence, 10% of $P_A = 10^{-6} = P_1$ (say)

and 10% of $P_B = 4 \times 10^{-6} = P_2$ (say)

Path difference created by slab

$\Delta x = (\mu - 1)t = (1.5 - 1)(2000) = 1000$Å

Corresponding phase difference,

$$\phi = \frac{2\pi}{\lambda}.\Delta x = \frac{2\pi}{6000} \times 1000 = \frac{\pi}{3}$$

Now, resultant power at the focal point

$$P = P_1 + P_2 + 2\sqrt{P_1P_2}\cos\phi$$

$$= 10^{-6}+4\times10^{-6}+2\sqrt{(10^{-6})(4\times10^{-6})}\cos\frac{\pi}{3}$$

$$= 7 \times 10^{-6} \text{ W}$$

**Sol 12:** (a) Path difference due to the glass slab,

$\Delta x = (\mu - 1)t = (1.5 - 1)t = 0.5t$

Due to this slab, 5 red fringes have been shifted upwards.

Therefore, $\Delta x = 5\lambda_{red}$ or $0.5t = (5)(7 \times 10^{-7}\text{m})$

$\therefore t$ = thickness of glass slab $= 7\times10^{-6}$m

(b) Let $\mu'$ be the refractive index for green light then

$\Delta x' = (\mu' - 1)$

Now the shifting is of 6 fringes of red light. Therefore,

$\Delta x' = 6\lambda_{red}$

$\therefore (\mu' - 1)t = 6\lambda_{red}$

$$\therefore (\mu' - 1) = \frac{(6)(7\times10^{-7})}{7\times10^{-6}} = 0.6$$

$\therefore \mu' = 1.6$

(c) In part (a), shifting of 5 bright fringes was equal to $10^{-3}$ m. Which implies that

$5\omega_{red} = 10^{-3}$ m

(Here $\omega$ = Fringe width)

$\therefore \omega_{red} = \frac{10^{-3}}{5} m = 0.2 \times 10^{-3}$ m

Now since $\omega = \frac{\lambda D}{d}$ or $\omega \propto l$

$\therefore \frac{\omega_{green}}{\omega_{red}} = \frac{\lambda_{green}}{\lambda_{red}}$

$\therefore \omega_{green} = \omega_{red}\frac{\lambda_{green}}{\lambda_{red}} = (0.2\times10^{-3})\left(\frac{5\times10^{-7}}{7\times10^{-7}}\right)$

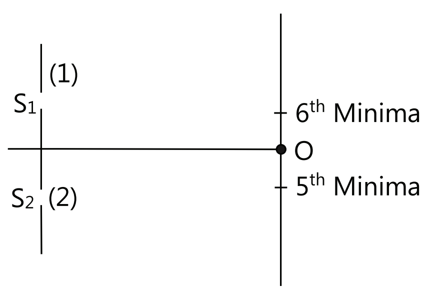
$\omega_{green} = 0.143 \times 10^{-3}$ m

$\therefore \Delta\omega = \omega_{green} - \omega_{red} = (0.143 - 0.2) \times 10^{-3}$m

$\Delta\omega = -5.71 \times 10^{-5}$ m

**Sol 13:** $\mu_1 = 1.4$ and $\mu_2 = 1.7$ and let t be the thickness of each glass plates.

Path difference at O, due to insertion of glass plates will be




$\Delta x = (\mu_2 - \mu_1)t = (1.7 - 1.4)t = 0.3t$ ...(i)

Now, since 5th maxima (earlier) lies below O and 6th minima lies above O.

This path difference should lie between $5\lambda$ and $5\lambda + \frac{\lambda}{2}$

So, let $\Delta x = 5\lambda + \Delta$ ...(ii)

Where $\Delta < \frac{\lambda}{2}$

Due to the path difference $\Delta x$, the phase difference at O will

$\phi = \frac{2\pi}{\lambda}\Delta x = \frac{2\pi}{\lambda}(5\lambda + \Delta)$

$= (10\pi + \frac{2\pi}{\lambda}.\Delta)$ ...(iii)

Intensity at O is given $\frac{3}{4}I_{max}$ and since

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

$\therefore \frac{3}{4}I_{max} = I_{max}\cos^2\left(\frac{\phi}{2}\right)$

or $\frac{3}{4} = \cos^2\left(\frac{\phi}{2}\right)$ ...(iv)

From Equation (iii) and (iv), we find that

$\Delta = \frac{\lambda}{6}$

i.e., $\Delta x = 5\lambda + + \frac{\lambda}{6} = \frac{31}{6}\lambda = 0.3t$

$\therefore t = \frac{31\lambda}{6(0.3)} = \frac{(31)(5400\times10^{-10})}{1.8}$

or $t = 9.3 \times 10^{-6}$ m = 9.3 μm

**Sol 14: (B)** $\frac{I_{max}}{2} = I_m\cos^2\left(\frac{\phi}{2}\right)$

$\Rightarrow \cos\left(\frac{\phi}{2}\right) = \frac{1}{\sqrt{2}}$

$\Rightarrow \frac{\phi}{2} = \frac{\pi}{4}$

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

$\Rightarrow \Delta x = \frac{\lambda}{2\pi}\phi = \frac{\lambda}{2\pi}\times\frac{\pi}{2}(2n+1) = \frac{\lambda}{4}(2n+1)$

**Sol 15: (A, B, C)** $\beta = \frac{D\lambda}{d}$

$\because \lambda_2 > \lambda_1 \Rightarrow \beta_2 > \beta_1$

Also $m_1\beta_1 = m_2\beta_2 \Rightarrow m_1 > m_2$

Also $3\left(\frac{D}{d}\right)(600\text{ nm}) = (2\times5-1)\left(\frac{D}{2d}\right)400$ nm

Angular width $\theta = \frac{\lambda}{d}$

**Sol 16:** For maxima,

$\frac{4}{3}\sqrt{d^2+x^2} - \sqrt{d^2+x^2} = m\lambda$, m is an integer

So, $x^2 = 9m^2\lambda^2 - d^2$

$\therefore p = 3$

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