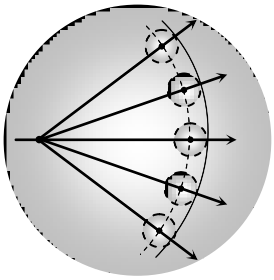




# Wave Optics

## Light Propagation

Light is a form of energy which generally gives the sensation of sight.

(1) **Different theories**

(2) **Optical phenomena explained (√) or not explained (×) by the different theories of light**

(3) **Wave front**

(i) Suggested by Huygens

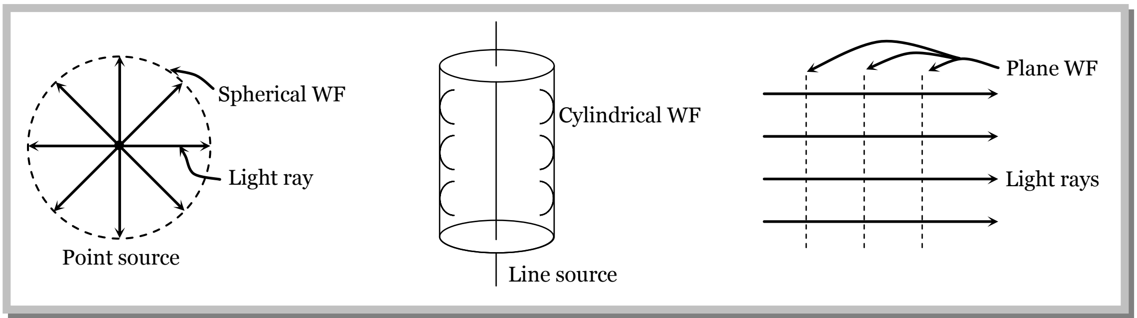
(ii) The locus of all particles in a medium, vibrating in the same phase is called Wave Front (WF)

(iii) The direction of propagation of light (ray of light) is perpendicular to the WF.

| **Newtons corpuscular theory** | **Huygen's wave theory** | **Maxwell's EM wave theory** | **Einstein's quantum theory** | **de-Broglie's dual theory of light** |
|---|---|---|---|---|
| (i) Based on Rectilinear propagation of light | (i) Light travels in a hypothetical medium ether (high elasticity very low density) as waves | (i) Light travels in the form of EM waves with speed in free space $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ | (i) Light is produced, absorbed and propagated as packets of energy called photons | (i) Light propagates both as particles as well as waves |
| (ii) Light propagates in the form of tiny particles called Corpuscles. Colour of light is due to different size of corpuscles | (ii) He proposed that light waves are of longitudinal nature. Later on it was found that they are transverse | (ii) EM waves consists of electric and magnetic field oscillation and they do not require material medium to travel | (ii) Energy associated with each photon $E = h\nu = \frac{hc}{\lambda}$<br>$h$ = planks constant $= 6.6 \times 10^{-34}\ J$ - sec<br>$\nu$ = frequency<br>$\lambda$ = wavelength | (ii) Wave nature of light dominates when light interacts with light. The particle nature of light dominates when the light interacts with matter (micro-scopic particles ) |

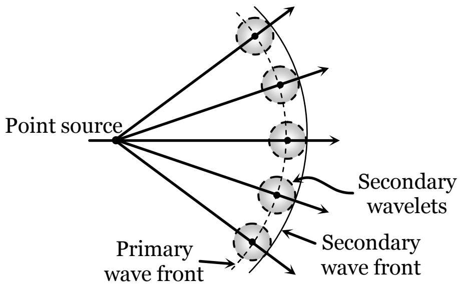
| **S. No.** | **Phenomena** | **Theory** | | | | |
|---|---|---|---|---|---|---|
| | | **Corpuscular** | **Wave** | **E.M. wave** | **Quantum** | **Dual** |
| (i) | Rectilinear Propagation | √ | √ | √ | √ | √ |
| (ii) | Reflection | √ | √ | √ | √ | √ |
| (iii) | Refraction | √ | √ | √ | √ | √ |
| (iv) | Dispersion | × | √ | √ | × | √ |
| (v) | Interference | × | √ | √ | × | √ |
| (vi) | Diffraction | × | √ | √ | × | √ |
| (vii) | Polarisation | × | √ | √ | × | √ |
| (viii) | Double refraction | × | √ | √ | × | √ |
| (ix) | Doppler's effect | × | √ | √ | × | √ |
| (x) | Photoelectric effect | × | × | × | √ | √ |

(iv) **Types of wave front**




(v) Every point on the given wave front acts as a source of new disturbance called secondary wavelets. Which travel in all directions with the velocity of light in the medium.

A surface touching these secondary wavelets tangentially in the forward direction at any instant gives the new wave front at that instant. This is called secondary wave front




Note : ❑ Wave front always travels in the forward direction of the medium.

❑ Light rays is always normal to the wave front.

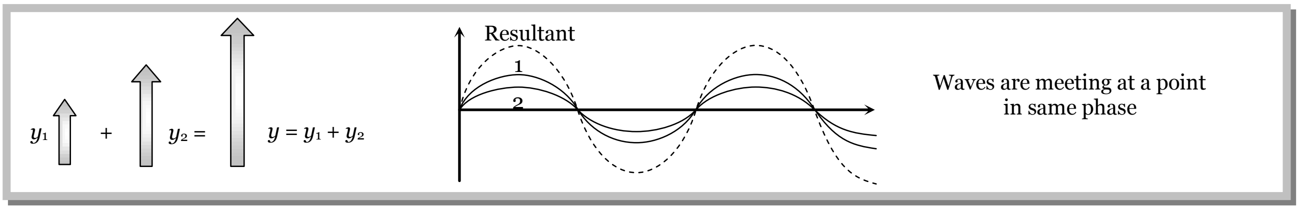
❑ The phase difference between various particles on the wave front is zero.

## Principle of Super Position

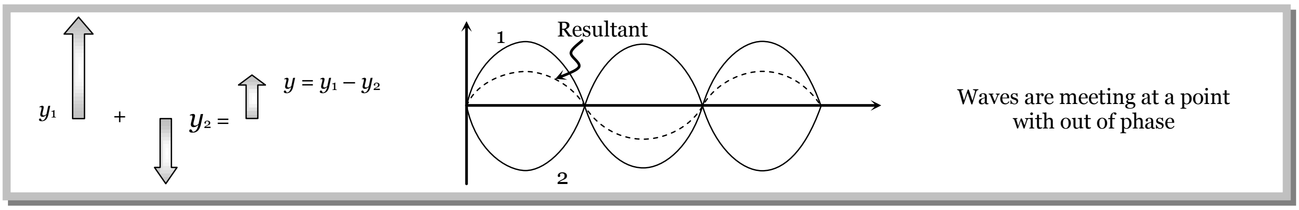
When two or more than two waves superimpose over each other at a common particle of the medium then the resultant displacement ($y$) of the particle is equal to the vector sum of the displacements ($y_1$ and $y_2$) produced by individual waves. *i.e.* $\vec{y} = \vec{y}_1 + \vec{y}_2$

(1) **Graphical view :**

(i)




(ii)

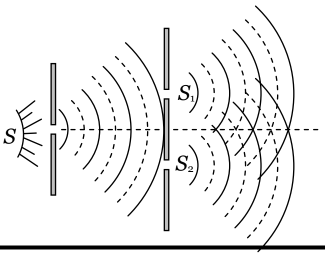
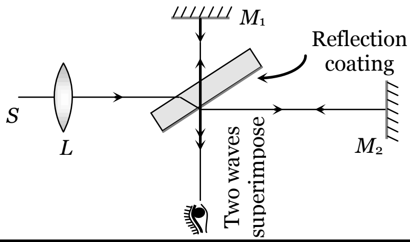



(2) **Phase / Phase difference / Path difference / Time difference**

(i) Phase : The argument of sine or cosine in the expression for displacement of a wave is defined as the phase. For displacement $y = a \sin \omega t$ ; term $\omega t$ = phase or instantaneous phase

(ii) Phase difference ($\phi$) : The difference between the phases of two waves at a point is called phase difference *i.e.* if $y_1 = a_1 \sin \omega t$ and $y_2 = a_2 \sin(\omega t + \phi)$ so phase difference = $\phi$

(iii) Path difference ($\Delta$) : The difference in path length's of two waves meeting at a point is called path difference between the waves at that point. Also $\Delta = \frac{\lambda}{2\pi} \times \phi$

| Division of wave front | Division of amplitude |
|---|---|
| The light source is narrow | Light sources is extended. Light wave partly reflected (50%) and partly transmitted (50%) |
| The wave front emitted by a narrow source is divided in two parts by reflection of refraction. | The amplitude of wave emitted by an extend source of light is divided in two parts by partial reflection and partial refraction. |
| The coherent sources obtained are imaginary *e.g.* Fresnel's biprism, Llyod's mirror Youngs' double slit *etc.* | The coherent sources obtained are real *e.g.* Newtons rings, Michelson's interferrometer colours in thin films |
|   |   |

(iv) Time difference (*T.D.*) : Time difference between the waves meeting at a point is $\boldsymbol{T.D.} = \frac{\boldsymbol{T}}{\boldsymbol{2\pi}} \times \boldsymbol{\phi}$

(3) **Resultant amplitude and intensity**

If suppose we have two waves $y_1 = a_1 \sin \omega t$ and $y_2 = a_2 \sin(\omega t + \phi)$; where $a_1, a_2$ = Individual amplitudes, $\phi$ = Phase difference between the waves at an instant when they are meeting a point. $I_1$, $I_2$ = Intensities of individual waves

**Resultant amplitude :** After superimposition of the given waves resultant amplitude (or the amplitude of resultant wave) is given by $\boldsymbol{A = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi}}$

For the interfering waves $y_1 = a_1 \sin\omega t$ and $y_2 = a_2 \cos\omega t$, Phase difference between them is 90°. So resultant amplitude $A = \sqrt{a_1^2 + a_2^2}$

**Resultant intensity** : As we know intensity $\propto$ (Amplitude)$^2$ $\Rightarrow I_1 = ka_1^2, I_2 = ka_2^2$ and $I = kA^2$ ($k$ is a proportionality constant). Hence from the formula of resultant amplitude, we get the following formula of resultant intensity $\boldsymbol{I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi}$

Note : ❑ The term $2\sqrt{I_1 I_2}\cos\phi$ is called interference term. For incoherent interference this term is zero so resultant intensity $I = I_1 + I_2$

(4) **Coherent sources**

The sources of light which emits continuous light waves of the same wavelength, same frequency and in same phase or having a constant phase difference are called coherent sources.

Two coherent sources are produced from a single source of light by adopting any one of the following two methods

Note : ❑ Laser light is highly coherent and monochromatic.

❑ Two sources of light, whose frequencies are not same and phase difference between the waves emitted by them does not remain constant *w.r.t.* time are called non-coherent.

❑ The light emitted by two independent sources (candles, bulbs *etc.*) is non-coherent and interference phenomenon cannot be produced by such two sources.

❑ The average time interval in which a photon or a wave packet is emitted from an atom is defined as the **time of coherence**. It is $\tau_c = \frac{L}{c} = \frac{\text{Distance of coherence}}{\text{Velocity of light}}$, it's value is of the order of $10^{-10}$ *sec*.

## Interference of Light

When two waves of exactly same frequency (coming from two coherent sources) travels in a medium, in the same direction simultaneously then due to their superposition, at some points intensity of light is maximum while at some other points intensity is minimum. This phenomenon is called Interference of light.

(1) **Types :** It is of following two types

| Constructive interference | Destructive interference |
|---|---|
| (i) When the waves meets a point with same phase, constructive interference is obtained at that point (*i.e.* maximum light) | (i) When the wave meets a point with opposite phase, destructive interference is obtained at that point (*i.e.* minimum light) |
| (ii) Phase difference between the waves at the point of observation $\phi = 0^o$ or $2n\pi$ | (ii) $\phi = 180^o$ or $(2n-1)\pi$; $n = 1, 2, ...$ or $(2n+1)\pi$; $n = 0,1,2.....$ |
| (iii) Path difference between the waves at the point of observation $\Delta = n\lambda$ (*i.e.* even multiple of $\lambda/2$) | (iii) $\Delta = (2n-1)\frac{\lambda}{2}$ (*i.e.* odd multiple of $\lambda/2$) |
| (iv) Resultant amplitude at the point of observation will be maximum $a_1 = a_2 \Rightarrow A_{\min} = 0$ If $a_1 = a_2 = a_0 \Rightarrow A_{\max} = 2a_0$ | (iv) Resultant amplitude at the point of observation will be minimum $A_{\min} = a_1 - a_2$ If $a_1 = a_2 \Rightarrow A_{\min} = 0$ |
| (v) Resultant intensity at the point of observation will be maximum $I_{\max} = I_1 + I_2 + 2\sqrt{I_1 I_2}$ $I_{\max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$ If $I_1 = I_2 = I_0 \Rightarrow I_{\max} = 2I_0$ | (v) Resultant intensity at the point of observation will be minimum $I_{\min} = I_1 + I_2 - 2\sqrt{I_1 I_2}$ $I_{\min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$ If $I_1 = I_2 = I_0 \Rightarrow I_{\min} = 0$ |

(2) **Resultant intensity due to two identical waves :**

For two coherent sources the resultant intensity is given by $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

For identical source $I_1 = I_2 = I_0 \Rightarrow I = I_0 + I_0 + 2\sqrt{I_0 I_0}\cos\phi = 4I_0\cos^2\frac{\phi}{2}$ $[1 + \cos\theta = 2\cos^2\frac{\theta}{2}]$

Note : ❑ In interference redistribution of energy takes place in the form of maxima and minima.

❑ Average intensity : $I_{av} = \frac{I_{\max} + I_{\min}}{2} = I_1 + I_2 = a_1^2 + a_2^2$

❑ Ratio of maximum and minimum intensities :

$$\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}}\right)^2 = \left(\frac{\sqrt{I_1/I_2}+1}{\sqrt{I_1/I_2}-1}\right)^2 = \left(\frac{a_1+a_2}{a_1-a_2}\right)^2 = \left(\frac{a_1/a_2+1}{a_1/a_2-1}\right)^2$$ also

$$\sqrt{\frac{I_1}{I_2}} = \frac{a_1}{a_2} = \left(\frac{\sqrt{\frac{I_{max}}{I_{min}}}+1}{\sqrt{\frac{I_{max}}{I_{min}}}-1}\right)$$

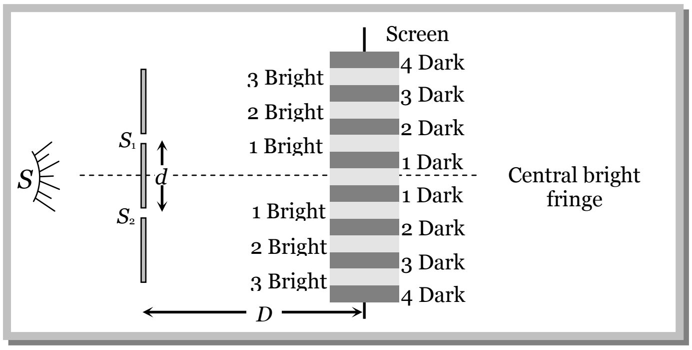
- If two waves having equal intensity ($I_1 = I_2 = I_0$) meets at two locations $P$ and $Q$ with path difference $\Delta_1$ and $\Delta_2$ respectively then the ratio of resultant intensity at point $P$ and $Q$ will be

$$\frac{I_P}{I_Q} = \frac{\cos^2\frac{\phi_1}{2}}{\cos^2\frac{\phi_2}{2}} = \frac{\cos^2\left(\frac{\pi\Delta_1}{\lambda}\right)}{\cos^2\left(\frac{\pi\Delta_2}{\lambda}\right)}$$

## Young's Double Slit Experiment (YDSE)

Monochromatic light (single wavelength) falls on two narrow slits $S_1$ and $S_2$ which are very close together acts as two coherent sources, when waves coming from two coherent sources $(S_1, S_2)$ superimposes on each other, an interference pattern is obtained on the screen. In YDSE alternate bright and dark bands obtained on the screen. These bands are called Fringes.

$d$ = Distance between slits
$D$ = Distance between slits and screen
$\lambda$ = Wavelength of monochromatic light emitted from source




(1) Central fringe is always bright, because at central position $\phi = 0^o$ or $\Delta = 0$

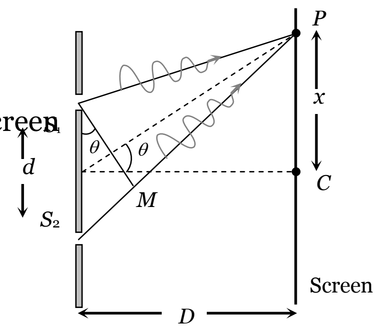
(2) The fringe pattern obtained due to a slit is more bright than that due to a point.

(3) If the slit widths are unequal, the minima will not be complete dark. For very large width uniform illumination occurs.

(4) If one slit is illuminated with red light and the other slit is illuminated with blue light, no interference pattern is observed on the screen.

(5) If the two coherent sources consist of object and it's reflected image, the central fringe is dark instead of bright one.

(6) **Path difference**



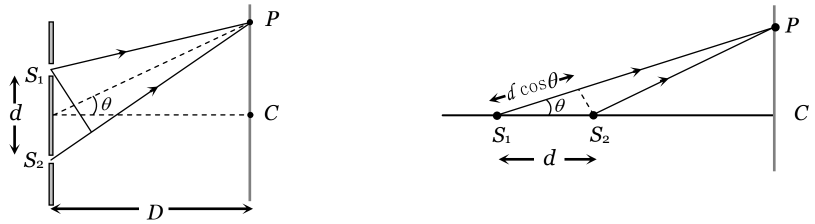

Path difference between the interfering waves meeting at a point $P$ on the screen is given by $\Delta = \frac{xd}{D} = d\sin\theta$

where $x$ is the position of point $P$ from central maxima.

For maxima at $P$: $\Delta = n\lambda$; where $n = 0, \pm 1, \pm 2, .......$

and For minima at $P$: $\Delta = \frac{(2n-1)\lambda}{2}$; where $n = \pm 1, \pm 2, \ldots\ldots$

Note : ❑ If the slits are vertical, the path difference ($\Delta$) is $d\sin\theta$, so as $\theta$ increases, $\Delta$ also increases. But if slits are horizontal path difference is $d\cos\theta$, so as $\theta$ increases, $\Delta$ decreases.




(7) **More about fringe**

(i) All fringes are of equal width. Width of each fringe is $\boldsymbol{\beta = \frac{\lambda D}{d}}$ and angular fringe width $\boldsymbol{\theta = \frac{\lambda}{d} = \frac{\beta}{D}}$

(ii) If the whole YDSE set up is taken in another medium then $\lambda$ changes so $\beta$ changes

*e.g.* in water $\lambda_w = \frac{\lambda_a}{\mu_w} \Rightarrow \beta_w = \frac{\beta_a}{\mu_w} = \frac{3}{4}\beta_a$

(iii) Fringe width $\beta \propto \frac{1}{d}$ *i.e.* with increase in separation between the sources, $\beta$ decreases.

(iv) Position of $n^{th}$ bright fringe from central maxima $\boldsymbol{x_n = \frac{n\lambda D}{d} = n\beta}$; $n = 0, 1, 2 \ldots.$

(v) Position of $n^{th}$ dark fringe from central maxima $\boldsymbol{x_n = \frac{(2n-1)\lambda D}{2d} = \frac{(2n-1)\beta}{2}}$; $n = 1, 2, 3 \ldots.$

(vi) In YDSE, if $n_1$ fringes are visible in a field of view with light of wavelength $\lambda_1$, while $n_2$ with light of wavelength $\lambda_2$ in the same field, then $\boldsymbol{n_1\lambda_1 = n_2\lambda_2}$.

(vii) Separation ($\Delta x$) between fringes

| Between $n^{th}$ bright and $m^{th}$ bright fringes $(n > m)$ | Between $n^{th}$ bright and $m^{th}$ dark fringe |
|---|---|
| $\Delta x = (n-m)\beta$ | (a) If $n > m$ then $\Delta x = \left(n - m + \frac{1}{2}\right)\beta$<br>(b) If $n < m$ then $\Delta x = \left(m - n - \frac{1}{2}\right)\beta$ |

(8) **Identification of central bright fringe**

To identify central bright fringe, monochromatic light is replaced by white light. Due to overlapping central maxima will be white with red edges. On the other side of it we shall get a few coloured band and then uniform illumination.

(9) **Condition for observing sustained interference**

(i) The initial phase difference between the interfering waves must remain constant : Otherwise the interference will not be sustained.

(ii) The frequency and wavelengths of two waves should be equal : If not the phase difference will not remain constant and so the interference will not be sustained.

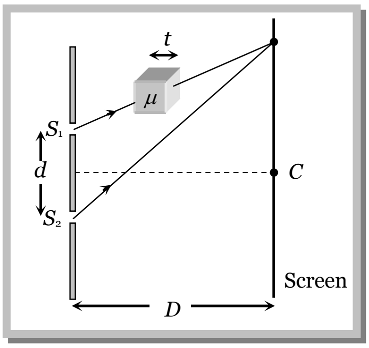
(iii) The light must be monochromatic : This eliminates overlapping of patterns as each wavelength corresponds to one interference pattern.

(iv) The amplitudes of the waves must be equal : This improves contrast with $I_{max} = 4I_0$ and $I_{min} = 0$.

(v) The sources must be close to each other : Otherwise due to small fringe width $\left(\beta \propto \frac{1}{d}\right)$ the eye can not resolve fringes resulting in uniform illumination.

(10) **Shifting of fringe pattern in YDSE**

If a transparent thin film of mica or glass is put in the path of one of the waves, then the whole fringe pattern gets shifted.




If film is put in the path of upper wave, fringe pattern shifts upward and if film is placed in the path of lower wave, pattern shift downward.

$$\text{Fringe shift} = \frac{D}{d}(\mu-1)t = \frac{\beta}{\lambda}(\mu-1)t$$

⇒ Additional path difference $= (\mu-1)t$

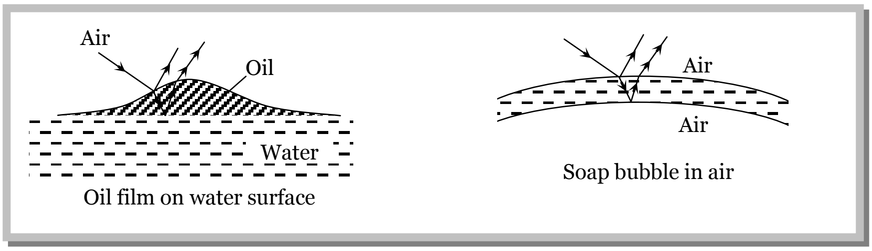
⇒ If shift is equivalent to $n$ fringes then $n = \frac{(\mu-1)t}{\lambda}$ or $t = \frac{n\lambda}{(\mu-1)}$

⇒ Shift is independent of the order of fringe (*i.e.* shift of zero order maxima = shift of $n^{th}$ order maxima.

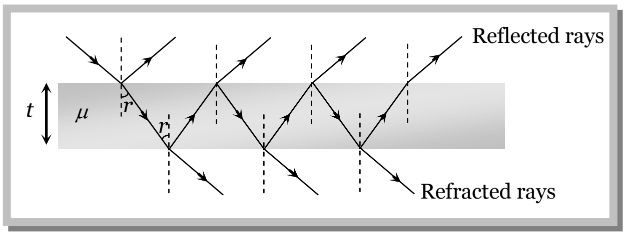
⇒ Shift is independent of wavelength.

## Illustrations of Interference

Interference effects are commonly observed in thin films when their thickness is comparable to wavelength of incident light (If it is too thin as compared to wavelength of light it appears dark and if it is too thick, this will result in uniform illumination of film). Thin layer of oil on water surface and soap bubbles shows various colours in white light due to interference of waves reflected from the two surfaces of the film.




(1) **Thin films :** In thin films interference takes place between the waves reflected from it's two surfaces and waves refracted through it.




| Interference in reflected light | Interference in refracted light |
|---|---|
| Condition of constructive interference (maximum intensity) | Condition of constructive interference (maximum intensity) |
| $\Delta = 2\mu\, t\cos r = (2n \pm 1)\frac{\lambda}{2}$ | $\Delta = 2\mu t\cos r = (2n)\frac{\lambda}{2}$ |
| For normal incidence $r = 0$ | For normal incidence |
| so $2\mu t = (2n \pm 1)\frac{\lambda}{2}$ | $2\mu t = n\lambda$ |

| | |
|---|---|
| Condition of destructive interference (minimum intensity)<br>$\Delta = 2\mu t \cos r = (2n)\frac{\lambda}{2}$<br>For normal incidence $2\mu t = n\lambda$ | Condition of destructive interference (minimum intensity)<br>$\Delta = 2\mu t \cos r = (2n \pm 1)\frac{\lambda}{2}$<br>For normal incidence $2\mu t = (2n \pm 1)\frac{\lambda}{2}$ |

## Doppler's Effect in Light

The phenomenon of apparent change in frequency (or wavelength) of the light due to relative motion between the source of light and the observer is called Doppler's effect.

If $\nu =$ actual frequency, $\nu' =$ Apparent frequency, $v$ = speed of source *w.r.t* stationary observer, $c$ = speed of light

| **Source of light moves towards the stationary observer ($v << c$)** | **Source of light moves away from the stationary observer ($v << c$)** |
|---|---|
| (i) Apparent frequency $\nu' = \nu\left(1 + \frac{v}{c}\right)$ and<br>Apparent wavelength $\lambda' = \lambda\left(1 - \frac{v}{c}\right)$ | (i) Apparent frequency $\nu' = \nu\left(1 - \frac{v}{c}\right)$ and<br>Apparent wavelength $\lambda' = \lambda\left(1 + \frac{v}{c}\right)$ |
| (ii) Doppler's shift : Apparent wavelength < actual wavelength,<br>So spectrum of the radiation from the source of light shifts towards the red end of spectrum. This is called Red shift<br>Doppler's shift $\Delta\lambda = \lambda.\frac{v}{c}$ | (ii) Doppler's shift : Apparent wavelength > actual wavelength,<br>So spectrum of the radiation from the source of light shifts towards the violet end of spectrum. This is called Violet shift<br>Doppler's shift $\Delta\lambda = \lambda.\frac{v}{c}$ |

Note : ❑ Doppler's shift $(\Delta\lambda)$ and time period of rotation ($T$) of a star relates as $\Delta\lambda = \frac{\lambda}{c} \times \frac{2\pi r}{T}$ ; $r$ = radius of star.

**Applications of Doppler effect**

(i) Determination of speed of moving bodies (aeroplane, submarine etc) in RADAR and SONAR.

(ii) Determination of the velocities of stars and galaxies by spectral shift.

(iii) Determination of rotational motion of sun.

(iv) Explanation of width of spectral lines.

(v) Tracking of satellites. (vi) In medical sciences in echo cardiogram, sonography *etc*.

### *Concepts*

- ☞ *The angular thickness of fringe width is defined as* $\delta = \frac{\beta}{D} = \frac{\lambda}{d}$, *which is independent of the screen distance D.*
- ☞ *Central maxima means the maxima formed with zero optical path difference. It may be formed anywhere on the screen.*
- ☞ *All the wavelengths produce their central maxima at the same position.*
- ☞ *The wave with smaller wavelength from its maxima before the wave with longer wavelength.*
- ☞ *The first maxima of violet colour is closest and that for the red colour is farthest.*

☞ *Fringes with blue light are thicker than those for red light.*

☞ *In an interference pattern, whatever energy disappears at the minimum, appears at the maximum.*

☞ *In YDSE, the nth maxima always comes before the nth minima.*

☞ *In YDSE, the ratio* $\frac{I_{max}}{I_{min}}$ *is maximum when both the sources have same intensity.*

☞ *For two interfering waves if initial phase difference between them is* $\phi_0$ *and phase difference due to path difference between them is* $\phi'$. *Then total phase difference will be* $\phi = \phi_0 + \phi' = \phi_0 + \frac{2\pi}{\lambda}\Delta$.

☞ *Sometimes maximm number of maximas or minimas are asked in the question which can be obtained on the screen. For this we use the fact that value of sin θ (or cos θ) can't be greater than 1. For example in the first case when the slits are vertical*

$$\sin\theta = \frac{n\lambda}{d} \qquad \textit{(for maximum intensity)}$$

$$\because \quad \sin\theta \not> 1 \qquad \therefore \quad \frac{n\lambda}{d} \not> 1 \quad or \quad n \not> \frac{d}{\lambda}$$

*Suppose in some question d/λ comes out say 4.6, then total number of maximuas on the screen will be 9. Corresponding to* $n = 0, \pm 1, \pm 2, \pm 3$ *and* $\pm 4$.

☞ ***Shape of wave front***

*If rays are parallel, wave front is plane. If rays are converging wave front is spherical of decreasing radius. If rays are diverging wave front is spherical of increasing radius.*

## Example

***Example*: 1** If two light waves having same frequency have intensity ratio 4 : 1 and they interfere, the ratio of maximum to minimum intensity in the pattern will be

(a) 9 : 1 (b) 3 : 1 (c) 25 : 9 (d) 16 : 25

*Solution*: (a) By using $\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{\frac{I_1}{I_2}}+1}{\sqrt{\frac{I_1}{I_2}}-1}\right)^2 = \left(\frac{\sqrt{\frac{4}{1}}+1}{\sqrt{\frac{4}{1}}-1}\right)^2 = \frac{9}{1}$.

***Example*: 2** In Young's double slit experiment using sodium light ($\lambda$ = 5898Å), 92 fringes are seen. If given colour ($\lambda$ = 5461Å) is used, how many fringes will be seen

(a) 62 (b) 67 (c) 85 (d) 99

*Solution*: (d) By using $n_1\lambda_1 = n_2\lambda_2 \Rightarrow 92 \times 5898 = n_2 \times 5461 \Rightarrow n_2 = 99$

***Example*: 3** 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 $\frac{\pi}{2}$ at point $A$ and $\pi$ at point $B$. Then the difference between the resultant intensities at $A$ and $B$ is

(a) $2I$ (b) $4I$ (c) $5I$ (d) $7I$

*Solution*: (b) By using $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

At point $A$ : Resultant intensity $I_A = I + 4I + 2\sqrt{I \times 4I}\cos\frac{\pi}{2} = 5I$

At point $B$ : Resultant intensity $I_B = I + 4I + 2\sqrt{I \times 4I}\cos\pi = I$. Hence the difference $= I_A - I_B = 4I$

***Example*: 4** If two waves represented by $y_1 = 4\sin\omega t$ and $y_2 = 3\sin\left(\omega t + \frac{\pi}{3}\right)$ interfere at a point, the amplitude of the resulting wave will be about **[MP PMT 2000]**

(a) 7 (b) 6 (c) 5 (d) 3.

*Solution*: (b) By using $A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$ $\Rightarrow$ $A = \sqrt{(4)^2 + (3)^2 + 2\times4\times3\cos\frac{\pi}{3}} = \sqrt{37} \approx 6$.

***Example*: 5** Two waves being produced by two sources $S_1$ and $S_2$. Both sources have zero phase difference and have wavelength $\lambda$. The destructive interference of both the waves will occur of point $P$ if $(S_1P - S_2P)$ has the value

**[MP PET 1987]**

(a) $5\lambda$ (b) $\frac{3}{4}\lambda$ (c) $2\lambda$ (d) $\frac{11}{2}\lambda$

*Solution*: (d) For destructive interference, path difference the waves meeting at $P$ (*i.e.* $S_1P - S_2P$) must be odd multiple of $\lambda/2$. Hence option (d) is correct.

***Example*: 6** Two interfering wave (having intensities are $9I$ and $4I$) path difference between them is 11 $\lambda$. The resultant intensity at this point will be

(a) $I$ (b) $9I$ (c) $4I$ (d) $25I$

*Solution*: (d) Path difference $\Delta = \frac{\lambda}{2\pi}\times\phi$ $\Rightarrow$ $\frac{2\pi}{\lambda}\times 11\lambda = 22\pi$ *i.e.* constructive interference obtained at the same point

So, resultant intensity $I_R = (\sqrt{I_1} + \sqrt{I_2})^2 = (\sqrt{9I} + \sqrt{4I})^2 = 25I$.

***Example*: 7** In interference if $\frac{I_{max}}{I_{min}} = \frac{144}{81}$ then what will be the ratio of amplitudes of the interfering wave

(a) $\frac{144}{81}$ (b) $\frac{7}{1}$ (c) $\frac{1}{7}$ (d) $\frac{12}{9}$

*Solution*: (b) By using $\frac{a_1}{a_2} = \left(\frac{\sqrt{\frac{I_{max}}{I_{min}}}+1}{\sqrt{\frac{I_{max}}{I_{min}}}-1}\right) = \left(\frac{\sqrt{\frac{144}{81}}+1}{\sqrt{\frac{144}{81}}-1}\right) = \left(\frac{\frac{12}{9}+1}{\frac{12}{5}-1}\right) = \frac{7}{1}$

***Example*: 8** Two interfering waves having intensities $x$ and $y$ meets a point with time difference $3T/2$. What will be the resultant intensity at that point

(a) $(\sqrt{x} + \sqrt{y})$ (b) $(\sqrt{x} + \sqrt{y} + \sqrt{xy})$ (c) $x + y + 2\sqrt{xy}$ (d) $\frac{x+y}{2xy}$

*Solution*: (c) Time difference T.D. $= \frac{T}{2\pi}\times\phi \Rightarrow \frac{3T}{2} = \frac{T}{2\pi}\times\phi \Rightarrow \phi = 3\pi$; This is the condition of constructive interference.

So resultant intensity $I_R = (\sqrt{I_1} + \sqrt{I_2})^2 = (\sqrt{x} + \sqrt{y})^2 = x + y + 2\sqrt{xy}$.

***Example*: 9** In Young's double-slit experiment, an interference pattern is obtained on a screen by a light of wavelength 6000 $\AA$, coming from the coherent sources $S_1$ and $S_2$. At certain point $P$ on the screen third dark fringe is formed. Then the path difference $S_1P - S_2P$ in microns is **[EAMCET 2003]**

(a) 0.75 (b) 1.5 (c) 3.0 (d) 4.5

*Solution*: (b) For dark fringe path difference $\Delta = (2n-1)\frac{\lambda}{2}$; here $n = 3$ and $\lambda = 6000\times10^{-10}\ m$

So $\Delta = (2\times 3-1)\times \frac{6\times 10^{-7}}{2} = 15\times 10^{-7}\,m = 1.5\,microns.$

***Example*: 10** In a Young's double slit experiment, the slit separation is 1 *mm* and the screen is 1 *m* from the slit. For a monochromatic light of wavelength 500 *nm*, the distance of 3rd minima from the central maxima is

(a) 0.50 *mm* (b) 1.25 *mm* (c) 1.50 *mm* (d) 1.75 *mm*

*Solution*: (b) Distance of $n^{th}$ minima from central maxima is given as $x = \frac{(2n-1)\lambda D}{2d}$

So here $x = \frac{(2\times 3-1)\times 500\times 10^{-9}\times 1}{2\times 10^{-3}} = 1.25\,mm$

***Example*: 11** The two slits at a distance of 1 *mm* are illuminated by the light of wavelength $6.5\times 10^{-7}\,m$. The interference fringes are observed on a screen placed at a distance of 1 *m*. The distance between third dark fringe and fifth bright fringe will be

**[NCERT 1982; MP PET 1995; BVP 2003]**

(a) 0.65 *mm* (b) 1.63 *mm* (c) 3.25 *mm* (d) 4.88 *mm*

*Solution*: (b) Distance between $n^{th}$ bright and $m^{th}$ dark fringe ($n > m$) is given as $x = \left(n-m+\frac{1}{2}\right)\beta = \left(n-m+\frac{1}{2}\right)\frac{\lambda D}{d}$

$\Rightarrow x = \left(5-3+\frac{1}{2}\right)\times \frac{6.5\times 10^{-7}\times 1}{1\times 10^{-3}} = 1.63\,mm$.

***Example*: 12** The slits in a Young's double slit experiment have equal widths and the source is placed symmetrically relative to the slits. The intensity at the central fringes is $I_0$. If one of the slits is closed, the intensity at this point will be**[MP PMT 1999**

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

*Solution*: (b) By using $I_R = 4I\cos^2\frac{\phi}{2}$ {where $I$ = Intensity of each wave}

At central position $\phi = 0^o$, hence initially $I_0 = 4I$.

If one slit is closed, no interference takes place so intensity at the same location will be $I$ only *i.e.* intensity become s $\frac{1}{4}th$ or $\frac{I_0}{4}$.

***Example*: 13** In double slit experiment, the angular width of the fringes is 0.20° for the sodium light ($\lambda$ = 5890 $\mathring{A}$). In order to increase the angular width of the fringes by 10%, the necessary change in the wavelength is

(a) Increase of 589 $\mathring{A}$ (b) Decrease of 589 $\mathring{A}$ (c) Increase of 6479 $\mathring{A}$ (d) Zero

*Solution*: (a) By using $\theta = \frac{\lambda}{d} \Rightarrow \frac{\theta_1}{\theta_2} = \frac{\lambda_1}{\lambda_2} \Rightarrow \frac{0.20^o}{(0.20^o + 10\%\text{ of }0.20)} = \frac{5890}{\lambda_2} \Rightarrow \frac{0.20}{0.22} = \frac{5890}{\lambda_2} \Rightarrow \lambda_2 = 6479$

So increase in wavelength = 6479 – 5890 = 589 Å.

***Example*: 14** In Young's experiment, light of wavelength 4000 $\mathring{A}$ is used, and fringes are formed at 2 *metre* distance and has a fringe width of 0.6 *mm*. If whole of the experiment is performed in a liquid of refractive index 1.5, then width of fringe will be

**[MP PMT 1994, 97]**

(a) 0.2 *mm* (b) 0.3 *mm* (c) 0.4 *mm* (d) 1.2 *mm*

*Solution*: (c) $\beta_{medium} = \frac{\beta_{air}}{\mu} \Rightarrow \beta_{medium} = \frac{0.6}{1.5} = 0.4\,mm$.

***Example*: 15** Two identical sources emitted waves which produces intensity of *k* unit at a point on screen where path difference is $\lambda$. What will be intensity at a point on screen at which path difference is $\lambda/4$ **[RPET 1996]**

(a) $\frac{k}{4}$ (b) $\frac{k}{2}$ (c) $k$ (d) Zero

*Solution*: (b) By using phase difference $\phi = \frac{2\pi}{\lambda}(\Delta)$

For path difference $\lambda$, phase difference $\phi_1 = 2\pi$ and for path difference $\lambda/4$, phase difference $\phi_2 = \pi/2$.

Also by using $I = 4I_0 \cos^2 \frac{\phi}{2} \Rightarrow \frac{I_1}{I_2} = \frac{\cos^2(\phi_1/2)}{\cos^2(\phi_2/2)} \Rightarrow \frac{k}{I_2} = \frac{\cos^2(2\pi/2)}{\cos^2\left(\frac{\pi/2}{2}\right)} = \frac{1}{1/2} \Rightarrow I_2 = \frac{k}{2}$.

**Example: 16** A thin mica sheet of thickness $2 \times 10^{-6}\, m$ and refractive index ($\mu$ = 1.5) is introduced in the path of the first wave. The wavelength of the wave used is $5000 Å$. The central bright maximum will shift **[CPMT 1999]**

(a) 2 fringes upward (b) 2 fringes downward (c) 10 fringes upward (d) None of these

*Solution*: (a) By using shift $\Delta x = \frac{p}{\lambda}(\mu - 1)t \Rightarrow \Delta x = \frac{\beta}{5000 \times 10^{-10}}(1.5 - 1) \times 2 \times 10^{-6} = 2\beta$

Since the sheet is placed in the path of the first wave, so shift will be 2 fringes upward.

**Example: 17** In a *YDSE* fringes are observed by using light of wavelength 4800 Å, if a glass plate ($\mu$ = 1.5) is introduced in the path of one of the wave and another plates is introduced in the path of the ($\mu$ = 1.8) other wave. The central fringe takes the position of fifth bright fringe. The thickness of plate will be

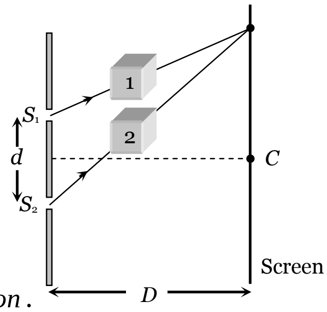
(a) 8 *micron* (b) 80 *micron* (c) 0.8 *micron* (d) None of these

*Solution*: (a) Shift due to the first plate $x_1 = \frac{\beta}{\lambda}(\mu_1 - 1)t$ (Upward)

and shift due to the second $x_2 = \frac{\beta}{\lambda}(\mu_2 - 1)t$ (Downward)

Hence net shift = $x_2 - x_1 = \frac{\beta}{\lambda}(\mu_2 - \mu_1)t$

$\Rightarrow 5p = \frac{\beta}{\lambda}(1.8 - 1.5)t \Rightarrow t = \frac{5\lambda}{0.3} = \frac{5 \times 4800 \times 10^{-10}}{0.3} = 8 \times 10^{-6} m = 8\, micron$.




**Example: 18** In young double slit experiment $\frac{d}{D} = 10^{-4}$ ($d$ = distance between slits, $D$ = distance of screen from the slits). At a point $P$ on the screen resulting intensity is equal to the intensity due to individual slit $I_0$. Then the distance of point $P$ from the central maxima is ($\lambda$ = 6000 Å)

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

*Solution*: (a) By using shift $I = 4I_0\cos^2(\phi/2) \Rightarrow I_0 = 4I_0\cos^2(\phi/2) \Rightarrow \cos(\phi/2) = \frac{1}{2}$ or $\frac{\phi}{2} = \frac{\pi}{3} \Rightarrow \phi = \frac{2\pi}{3}$

Also path difference $\Delta = \frac{xd}{D} = \frac{\lambda}{2\pi} \times \phi \Rightarrow x \times \left(\frac{d}{D}\right) = \frac{6000 \times 10^{-10}}{2\pi} \times \frac{2\pi}{3} \Rightarrow x = 2 \times 10^{-3} m = 2mm.$

**Example: 19** Two identical radiators have a separation of $d = \lambda/4$, where $\lambda$ is the wavelength of the waves emitted by either source. The initial phase difference between the sources is $\pi/4$. Then the intensity on the screen at a distance point situated at an angle $\theta = 30^o$ from the radiators is (here $I_0$ is the intensity at that point due to one radiator)

(a) $I_0$ (b) $2I_0$ (c) $3I_0$ (d) $4I_0$

*Solution*: (a) Initial phase difference $\phi_0 = \frac{\pi}{4}$; Phase difference due to path difference $\phi' = \frac{2\pi}{\lambda}(\Delta)$

where $\Delta = d\sin\theta \Rightarrow \phi' = \frac{2\pi}{\lambda}(d\sin\theta) = \frac{2\pi}{\lambda} \times \frac{\lambda}{4}(\sin 30^o) = \frac{\pi}{4}$

Hence total phase difference $\phi = \phi_0 + \phi' = \frac{\phi}{4}$. By using $I = 4I_0 \cos^2(\phi/2) = 4I_0 \cos^2\left(\frac{\pi/2}{2}\right) = 2I_0$.

***Example*: 20** In *YDSE* a source of wavelength 6000 Å is used. The screen is placed 1 *m* from the slits. Fringes formed on the screen, are observed by a student sitting close to the slits. The student's eye can distinguish two neighbouring fringes. If they subtend an angle more than 1 minute of arc. What will be the maximum distance between the slits so that the fringes are clearly visible

(a) 2.06 *mm* (b) 2.06 *cm* (c) 2.06 × 10⁻³ *mm* (d) None of these

*Solution*: (a) According to given problem angular fringe width $\theta = \frac{\lambda}{d} \geq \frac{\pi}{180 \times 60}$ $\left[\text{As } 1' = \frac{\pi}{180 \times 60} rad\right]$

*i.e.* $d < \frac{6 \times 10^{-7} \times 180 \times 60}{\pi}$ *i.e.* $d < 2.06 \times 10^{-3} m \Rightarrow d_{max} = 2.06\, mm$

***Example*: 21** the maximum intensity in case of interference of *n* identical waves, each of intensity $I_0$, if the interference is (i) coherent and (ii) incoherent respectively are

(a) $n^2 I_0, nI_0$ (b) $nI_0, n^2 I_0$ (c) $nI_0, I_0$ (d) $n^2 I_0, (n-1)I_0$

*Solution*: (a) In case of interference of two wave $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\phi$

(i) In case of coherent interference $\phi$ does not vary with time and so I will be maximum when $\cos\phi = \max = 1$

*i.e.* $(I_{max})_{co} = I_1 + I_2 + 2\sqrt{I_1 I_2} = (\sqrt{I_1} + \sqrt{I_2})^2$

So for *n* identical waves each of intensity $I_0$ $(I_{max})_{co} = (\sqrt{I_0} + \sqrt{I_0} + ......)^2 = (n\sqrt{I_0})^2 = n^2 I_0$

(ii)In case of incoherent interference at a given point, $\phi$ varies randomly with time, so $(\cos\phi)_{av} = 0$ and hence $(I_R)_{Inco} = I_1 + I_2$

So in case of *n* identical waves $(I_R)_{Inco} = I_0 + I_0 + ....... = nI_0$

***Example*: 22** 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. The ratio of the maximum to the minimum intensity in interference pattern will be

(a) $\frac{1}{a}$ (b) $\frac{9}{1}$ (c) $\frac{2}{1}$ (d) $\frac{1}{2}$

*Solution*: (b) $A_{max} = 2A + A = 3A$ and $A_{min} = 2A - A = A$. Also $\frac{I_{max}}{I_{min}} = \left(\frac{A_{max}}{A_{min}}\right)^2 = \left(\frac{3A}{A}\right)^2 = \frac{9}{1}$

***Example*: 23** A star is moving towards the earth with a speed of $4.5 \times 10^6 m/s$. If the true wavelength of a certain line in the spectrum received from the star is 5890 Å, its apparent wavelength will be about $[c = 3 \times 10^8 m/s]$

**[MP PMT 1999]**

(a) 5890 Å (b) 5978 Å (c) 5802 Å (d) 5896 Å

*Solution*: (c) By using $\lambda' = \lambda\left(1 - \frac{v}{c}\right) \Rightarrow \lambda' = 5890\left(1 - \frac{4.5 \times 10^6}{3 \times 10^8}\right) = 5802\,Å$.

***Example*: 24** Light coming from a star is observed to have a wavelength of 3737 Å, while its real wavelength is 3700 Å. The speed of the star relative to the earth is [Speed of light $= 3 \times 10^8 m/s$] **[MP PET 1997]**

(a) $3 \times 10^5 m/s$ (b) $3 \times 10^6 m/s$ (c) $3.7 \times 10^7 m/s$ (d) $3.7 \times 10^6 m/s$

*Solution*: (b) By using $\Delta\lambda = \lambda\frac{v}{c} \Rightarrow$ (3737-3700)= $3700 \times \frac{v}{3 \times 10^8} \Rightarrow v = 3 \times 10^6\, m/s$.

***Example*: 25** Light from the constellation Virgo is observed to increase in wavelength by 0.4%. With respect to Earth the constellation is **[MP PMT 1994, 97; MP PET 2003]**

(a) Moving away with velocity $1.2\times10^6 m/s$ (b) Coming closer with velocity $1.2\times10^6 m/s$

(c) Moving away with velocity $4\times10^6 m/s$ (d) Coming closer with velocity $4\times10^6 m/s$

*Solution*: (a) By using $\frac{\Delta\lambda}{\lambda}=\frac{v}{c}$; where $\frac{\Delta\lambda}{\lambda}=\frac{0.4}{100}$ and $c = 3\times10^8\ m/s \Rightarrow \frac{0.4}{100}=\frac{v}{3\times10^8} \Rightarrow v = 1.2\times10^6\ m/s$

Since wavelength is increasing *i.e.* it is moving away.

**Tricky example: 1**

In *YDSE*, distance between the slits is $2\times10^{-3}\ m$, slits are illuminated by a light of wavelength 2000Å –9000 Å. In the field of view at a distance of $10^{-3}\ m$ from the central position which wavelength will be observe. Given distance between slits and screen is 2.5 *m*

(a) 40000 Å (b) 4500 Å (c) 5000 Å (d) 5500 Å

*Solution* : (b) $x=\frac{n\lambda D}{d} \Rightarrow \lambda=\frac{xd}{nD}=\frac{10^{-3}\times2\times10^{-3}}{n\times2.5} \Rightarrow \frac{8\times10^{-7}}{n}m=\frac{8000}{n}Å$

For $n$ = 1, 2, 3……. $\lambda$ = 8000 Å, 4000 Å, $\frac{8000}{3}Å$………

Hence only option (a) is correct.

**Tricky example: 2**

*I* is the intensity due to a source of light at any point *P* on the screen. If light reaches the point *P* via two different paths (a) direct (b) after reflection from a plane mirror then path difference between two paths is $3\lambda/2$, the intensity at *P* is

(a) *I* (b) Zero (c) 2*I* (d) 4*I*

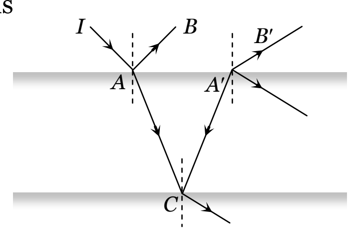
*Solution* : (d) Reflection of light from plane mirror gives additional path difference of $\lambda/2$ between two waves

$\therefore$ Total path difference $=\frac{3\lambda}{2}+\frac{\lambda}{2}=2\lambda$

Which satisfies the condition of maxima. Resultant intensity $=(\sqrt{I}+\sqrt{I})^2=4I.$

**Tricky example: 3**

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 25% of incident energy is reflected. The rays *AB* and *A′B′* undergo interference. The ratio $I_{max}/I_{min}$ is




(a) 4 : 1

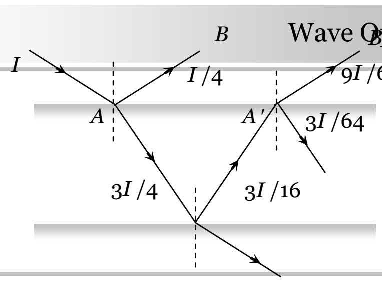
(b) 8 : 1

(c) 7 : 1

(d) 49 : 1

*Solution* : (d) From figure $I_1=\frac{I}{4}$ and $I_2=\frac{9I}{64} \Rightarrow \frac{I_2}{I_1}=\frac{9}{16}$

By using $\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{\frac{I_2}{I_1}}+1}{\sqrt{\frac{I_2}{I_1}}-1}\right) = \left(\frac{\sqrt{\frac{9}{16}}+1}{\sqrt{\frac{9}{16}}-1}\right) = \frac{49}{1}$




## Fresnel's Biprism

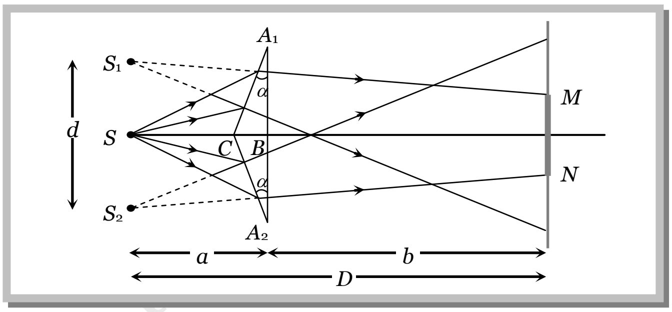
(1) It is an optical device of producing interference of light Fresnel's biprism is made by joining base to base two thin prism ($A_1BC$ and $A_2BC$ as shown in the figure) of very small angle or by grinding a thick glass plate.

(2) Acute angle of prism is about 1/2° and obtuse angle of prism is about 179°.

(3) When a monochromatic light source is kept in front of biprism two coherent virtual source $S_1$ and $S_2$ are produced.

(4) Interference fringes are found on the screen (in the *MN* region) placed behind the biprism interference fringes are formed in the limited region which can be observed with the help eye piece.

(5) Fringe width is measured by a micrometer attached to the eye piece. Fringes are of equal width and its value is $\beta = \frac{\lambda D}{d} \Rightarrow \lambda = \frac{\beta d}{D}$

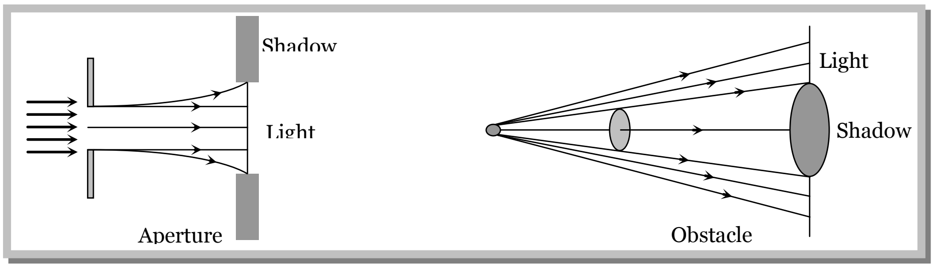



Let the separation between $S_1$ and $S_2$ be $d$ and the distance of slits and the screen from the biprism be $a$ and $b$ respectively *i.e.* $D = (a + b)$. If angle of prism is $\alpha$ and refractive index is $\mu$ then $d = 2a(\mu - 1)\alpha$

$$\therefore \qquad \lambda = \frac{\beta[2a(\mu-1)\alpha]}{(a+b)} \Rightarrow \beta = \frac{(a+b)\lambda}{2a(\mu-1)\alpha}$$

## Diffraction of Light

It is the phenomenon of bending of light around the corners of an obstacle/aperture of the size of the wavelength of light.



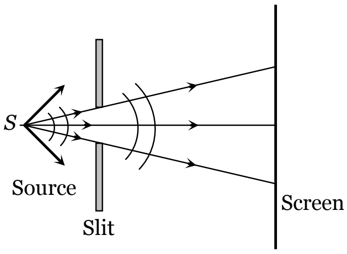
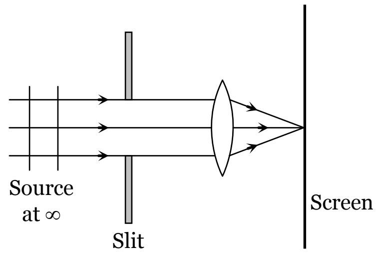

Note : ❑ Diffraction is the characteristic of all types of waves.

❑ Greater the wavelength of wave, higher will be it's degree of diffraction.

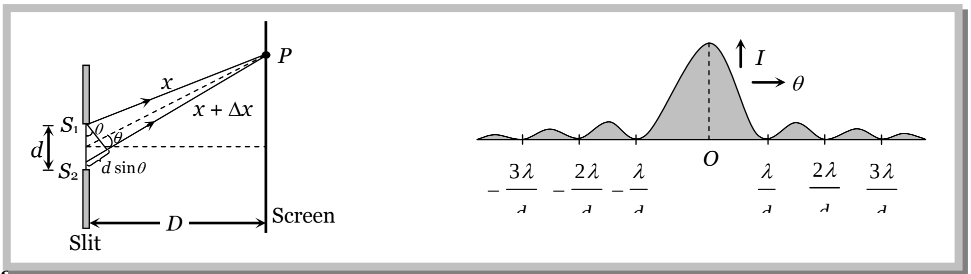
❑ Experimental study of diffraction was extended by Newton as well as Young. Most systematic study carried out by Huygens on the basis of wave theory.

- The minimum distance at which the observer should be from the obstacle to observe the diffraction of light of wavelength $\lambda$ around the obstacle of size $d$ is given by $x = \frac{d^2}{4\lambda}$.

(1) **Types of diffraction :** The diffraction phenomenon is divided into two types

| Fresnel diffraction | Fraunhofer diffraction |
|---|---|
| (i) If either source or screen or both are at finite distance from the diffracting device (obstacle or aperture), the diffraction is called Fresnel type.<br>(ii) Common examples : Diffraction at a straight edge, narrow wire or small opaque disc etc.<br> | (i) In this case both source and screen are effectively at infinite distance from the diffracting device.<br>(ii) Common examples : Diffraction at single slit, double slit and diffraction grating.<br> |

(2) **Diffraction of light at a single slit :** In case of diffraction at a single slit, we get a central bright band with alternate bright (maxima) and dark (minima) bands of decreasing intensity as shown




(i) Width of central maxima $\beta_0 = \frac{2D\lambda}{d}$, and angular width $= \frac{2\lambda}{d}$

(ii) Minima occurs at a point on either side of the central maxima, such that the path difference between the waves from the two ends of the aperture is given by $\Delta = n\lambda$ ; where $n = 1, 2, 3 ....$

*i.e.* $d\sin\theta = n\lambda \Rightarrow \sin\theta = \frac{n\lambda}{d}$

(iii) The secondary maxima occurs, where the path difference between the waves from the two ends of the aperture is given by $\Delta = (2n+1)\frac{\lambda}{2}$ ; where $n = 1, 2, 3 ....$

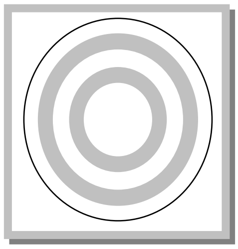
*i.e.* $d\sin\theta = (2n+1)\frac{\lambda}{2} \Rightarrow \sin\theta = \frac{(2n+1)\lambda}{2d}$

(3) **Comparison between interference and diffraction**

| Interference | Diffraction |
|---|---|
| Results due to the superposition of waves from two coherent sources. | Results due to the superposition of wavelets from different parts of same wave front. (single coherent source) |

| | |
|---|---|
| All fringes are of same width $\beta = \frac{\lambda D}{d}$ | All secondary fringes are of same width but the central maximum is of double the width $\beta_0 = 2\beta = 2\frac{\lambda D}{d}$ |
| All fringes are of same intensity | Intensity decreases as the order of maximum increases. |
| Intensity of all minimum may be zero | Intensity of minima is not zero. |
| Positions of $n$th maxima and minima $x_{n(\text{Bright})} = \frac{n\lambda D}{d}$, $x_{n(\text{Dark})} = (2n-1)\frac{\lambda D}{d}$ | Positions of $n$th secondary maxima and minima $x_{n(\text{Bright})} = (2n+1)\frac{\lambda D}{d}$, $x_{n(\text{Dark})} = \frac{n\lambda D}{d}$ |
| Path difference for $n$th maxima $\Delta = n\lambda$ | for $n$th secondary maxima $\Delta = (2n+1)\frac{\lambda}{2}$ |
| Path difference for $n$th minima $\Delta = (2n-1)\lambda$ | Path difference for $n$th minima $\Delta = n\lambda$ |

(4) **Diffraction and optical instruments :** The objective lens of optical instrument like telescope or microscope etc. acts like a circular aperture. Due to diffraction of light at a circular aperture, a converging lens cannot form a point image of an object rather it produces a brighter disc known as Airy disc surrounded by alternate dark and bright concentric rings.

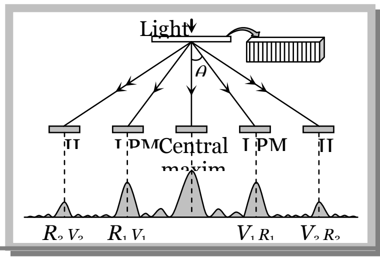


The angular half width of Airy disc $= \theta = \frac{1.22\lambda}{D}$ (where $D$ = aperture of lens)

The lateral width of the image $= f\theta$ (where $f$ = focal length of the lens)

Note : ❑ Diffraction of light limits the ability of optical instruments to form clear images of objects when they are close to each other.

(5) **Diffraction grating :** Consists of large number of equally spaced parallel slits. If light is incident normally on a transmission grating, the diffraction of principle maxima ($PM$) is given by $d\sin\theta = n\lambda$ ; where $d$ = distance between two consecutive slits and is called grating element.

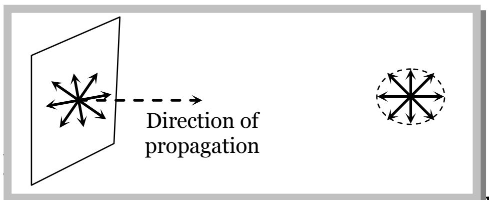


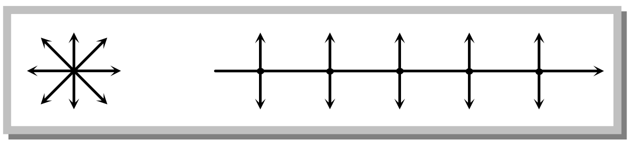

## Polarisation of Light

Light propagates as transverse EM waves. The magnitude of electric field is much larger as compared to magnitude of magnetic field. We generally prefer to describe light as electric field oscillations.

(1) **Unpolarised light**

The light having electric field oscillations in all directions in the plane perpendicular to the direction of propagation is called Unpolarised light. The oscillation may be resolved into horizontal and vertical component.




(2)

The light having oscillations only in one plane is called Polarised or plane polarised light.

(i) The plane in which oscillation occurs in the polarised light is called plane of oscillation.

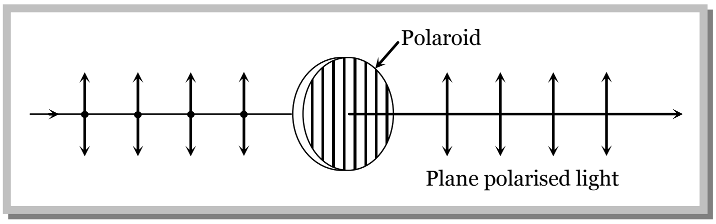
(ii) The plane perpendicular to the plane of oscillation is called plane of polarisation.

(iii) Light can be polarised by transmitting through certain crystals such as tourmaline or polaroids.

(3) **Polaroids**

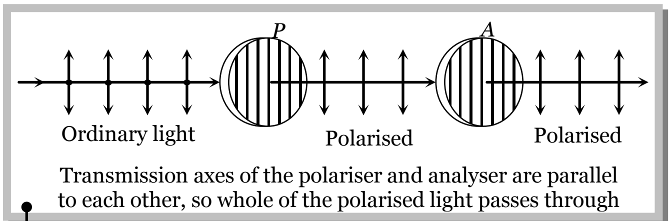
It is a device used to produce the plane polarised light. It is based on the principle of selective absorption and is more effective than the tourmaline crystal. or

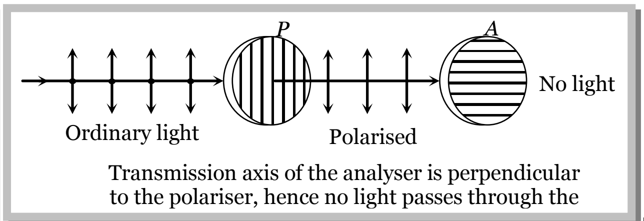
It is a thin film of ultramicroscopic crystals of quinine idosulphate with their optic axis parallel to each other.




(i) Polaroids allow the light oscillations parallel to the transmission axis pass through them.

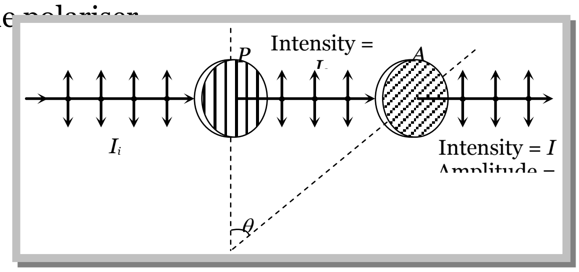
(ii) The crystal or polaroid on which unpolarised light is incident is called polariser. Crystal or polaroid on which polarised light is incident is called analyser.




Note : ❑ When unpolarised light is incident on the polariser, the intensity of the transmitted polarised light is half the intensity of unpolarised light.

(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.




(i) $I = I_0 \cos^2\theta$ and $A^2 = A_0^2 \cos^2\theta \Rightarrow A = A_0 \cos\theta$

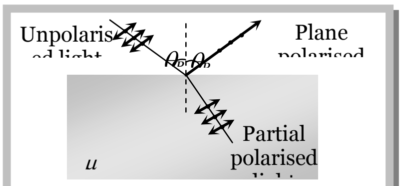
If $\theta = 0^o$, $I = I_0$, $A = A_0$, If $\theta = 45^o$, $I = \frac{I_0}{2}$, $A = \frac{A_0}{\sqrt{2}}$, If $\theta = 90^o$, $I = 0$, $A = 0$

(ii) If $I_i =$ Intensity of unpolarised light.

So $I_0 = \frac{I_i}{2}$ *i.e.* if an unpolarised light is converted into plane polarised light (say by passing it through a plaroid or a Nicol-prism), its intensity becomes half. and $I = \frac{I_i}{2}\cos^2\theta$

Note : ❑ Percentage of polarisation $= \frac{(I_{max} - I_{min})}{(I_{max} + I_{min})} \times 100$

(5) **Brewster's law :** Brewster discovered that when a beam of unpolarised light is reflected from a transparent medium (refractive index $=\mu$), the reflected light is completely plane polarised at a certain angle of incidence (called the angle of polarisation $\theta_p$).



Also $\mu = \tan\theta_p$ Brewster's law

(i) For $i < \theta_P$ or $i > \theta_P$

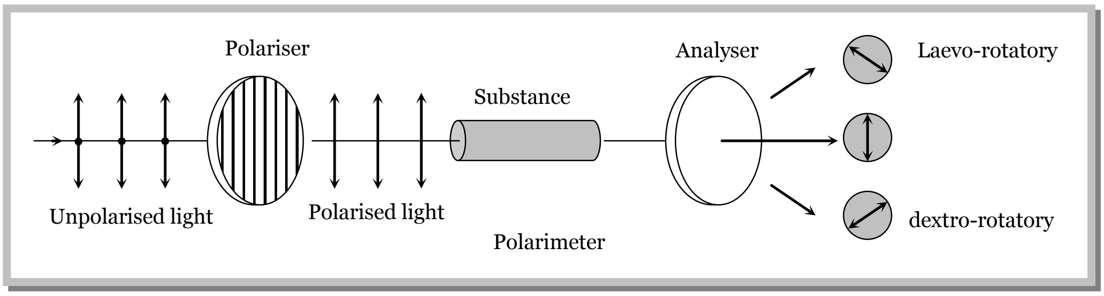
Both reflected and refracted rays becomes partially polarised

(ii) For glass $\theta_P \approx 57^o$, for water $\theta_P \approx 53^o$

(6) **Optical activity and specific rotation**

When plane polarised light passes through certain substances, the plane of polarisation of the light is rotated about the direction of propagation of light through a certain angle. This phenomenon is called optical activity or optical rotation and the substances optically active.

If the optically active substance rotates the plane of polarisation clockwise (looking against the direction of light), it is said to be *dextro-rotatory* or *right-handed*. However, if the substance rotates the plane of polarisation anti-clockwise, it is called *laevo-rotatory* or *left-handed*.




The optical activity of a substance is related to the asymmetry of the molecule or crystal as a whole, *e.g.*, a solution of cane-sugar is dextro-rotatory due to asymmetrical molecular structure while crystals of quartz are dextro or laevo-rotatory due to structural asymmetry which vanishes when quartz is fused.

Optical activity of a substance is measured with help of polarimeter in terms of 'specific rotation' which is defined as the rotation produced by a solution of length 10 *cm* (1 *dm*) and of unit concentration (*i.e.* 1 *g*/cc) for a given wavelength of light at a given temperature. *i.e.* $[\alpha]_{t^oC}^{\lambda} = \frac{\theta}{L \times C}$ where $\theta$ is the rotation in length $L$ at concentration $C$.

(7) **Applications and uses of polarisation**

(i) By determining the polarising angle and using Brewster's law, *i.e.* $\mu = \tan\theta_P$, refractive index of dark transparent substance can be determined.

(ii) It is used to reduce glare.

(iii) In calculators and watches, numbers and letters are formed by liquid crystals through polarisation of light called liquid crystal display **(LCD)**.

(iv) In CD player polarised laser beam acts as needle for producing sound from compact disc which is an encoded digital format.

(v) It has also been used in recording and reproducing three-dimensional pictures.

(vi) Polarisation of scattered sunlight is used for navigation in solar-compass in polar regions.

(vii) Polarised light is used in optical stress analysis known as 'photoelasticity'.

(viii) Polarisation is also used to study asymmetries in molecules and crystals through the phenomenon of 'optical activity'.

# Assignment

## *Nature of light and interference of light*

**1.** The dual nature of light is exhibited by **[KCET 1999; AIIMS 2001; BHU 2001; Bihar CEE 2004]**

(a) Diffraction and photoelectric effect (b) Diffraction and reflection

(c) Refraction and interference (d) Photoelectric effect

**2.** Huygen wave theory allows us to know **[AFMC 2004]**

(a) The wavelength of the wave (b) The velocity of the wave

(c) The amplitude of the wave (d) The propagation of wave fronts

**3.** When a beam of light is used to determine the position of an object, the maximum accuracy is achieved if the light is **[AIIMS 2003]**

(a) Polarised (b) Of longer wavelength (c) Of shorter wavelength (d) Of high intensity

**4.** Which of the following phenomenon does not show the wave nature of light **[RPET 2003; MP PMT 2003]**

(a) Diffraction (b) Interference (c) Refraction (d) Photoelectric effect

**5.** As a result of interference of two coherent sources of light, energy is **[MP PMT 2002; KCET 2003]**

(a) Increased

(b) Redistributed and the distribution does not vary with time

(c) Decreased

(d) Redistributed and the distribution changes with time

**6.** To demonstrate the phenomenon of interference, we require two sources which emit radiation **[AIEEE 2003]**

(a) Of the same frequency and having a definite phase relationship

(b) Of nearly the same frequency

(c) Of the same frequency

(d) Of different wavelengths

**7.** Consider the following statements

**Assertion** (*A*): Thin films such as soap bubble or a thin layer of oil on water show beautiful colours, when illuminated by white light.

**Reason (*R*)** : It happens due to the interference of light reflected from the upper surface of the thin film.

Of these statements **[AIIMS 2002]**

(a) Both *A* and *R* are true but *R* is a correct explanation of *A* (b) Both *A* and *R* are true but *R* is not a correct explanation of *A*

(c) *A* is true but *R* is false (d) A is false but R is true

(e) Both *A* and *R* are false

**8.** When light passes from one medium into another medium, then the physical property which does not change is

**[CPMT 1990; MNR 1995; AMU 1995; UPSEAT 1999, 2000; MP PET 2002; RPET 1996, 2003; AFMC 1993, 98, 2003]**

(a) Velocity (b) Wavelength (c) Frequency (d) Refractive index

**9.** The frequency of light ray having the wavelength 3000$\AA$ is **[DPMT 2002]**

(a) $9 \times 10^{13}$ *cycles/sec* (b) $10^{15}$ *cycles/sec* (c) 90 *cycles/sec* (d) 3000 *cycles/sec*

**10.** Two coherent sources of different intensities send waves which interfere. The ratio of maximum intensity to the minimum intensity is 25. The intensities of the sources are in the ratio **[RPMT 1989; UPSEAT 2002]**

(a) 25 : 1 (b) 5 : 1 (c) 9 : 4 (d) 25 : 16

**11.** What is the path difference of destructive interference **[AIIMS 2002]**

(a) $n\lambda$ (b) $n(\lambda + 1)$ (c) $\frac{(n+1)\lambda}{2}$ (d) $\frac{(2n+1)\lambda}{2}$

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

**[IIT-JEE 1988; AIIMS 1997; MP PMT 1997; MP PET 1999; KCET (Engg./Med.) 2000; MP PET 2002]**

(a) $5I$ and $I$ (b) $5I$ and $3I$ (c) $9I$ and $I$ (d) $9I$ and $3I$

**13.** Laser beams are used to measure long distance because **[DCE 2001]**
(a) They are monochromatic (b) They are highly polarised
(c) They are coherent (d) They have high degree of parallelism

**14.** Wave nature of light is verified by **[RPET 2001]**
(a) Interference (b) Photoelectric effect (c) Reflection (d) Refraction

**15.** If the wavelength of light in vacuum be $\lambda$, the wavelength in a medium of refractive index $n$ will be **[UPSEAT 2001; MP PET 2001]**
(a) $n\lambda$ (b) $\frac{\lambda}{n}$ (c) $\frac{\lambda}{n^2}$ (d) $n^2\lambda$

**16.** Newton postulated his corpuscular theory on the basis of **[UPSEAT 2001; KCET 2001]**
(a) Newton's rings (b) Colours of thin films
(c) Rectilinear propagation of light (d) Dispersion of white light

**17.** Two coherent sources of intensities. $I_1$ and $I_2$ produce an interference pattern. The maximum intensity in the interference pattern will be **[UPSEAT 2001; MP PET 2001]**
(a) $I_1 + I_2$ (b) $I_1^2 + I_2^2$ (c) $(I_1 + I_2)^2$ (d) $(\sqrt{I_1} + \sqrt{I_2})^2$

**18.** Which one among the following shows particle nature of light **[CBSE PM/PD 2001]**
(a) Photo electric effect (b) Interference (c) Refraction (d) Polarization

**19.** For constructive interference to take place between two monochromatic light waves of wavelength $\lambda$, the path difference should be
**[MNR 1992; UPSEAT 2001]**
(a) $(2n-1)\frac{\lambda}{4}$ (b) $(2n-1)\frac{\lambda}{2}$ (c) $n\lambda$ (d) $(2n+1)\frac{\lambda}{2}$

**20.** In a wave, the path difference corresponding to a phase difference of $\phi$ is **[MP PET 2000]**
(a) $\frac{\pi}{2\lambda}\phi$ (b) $\frac{\pi}{\lambda}\phi$ (c) $\frac{\lambda}{\pi}\phi$ $\frac{\lambda}{\pi}$

**21.** A beam of monochromatic blue light of wavelength $4200Å$ in air travels in water, its wavelength in water will be **[UPSEAT 2000]**
(a) $2800Å$ (b) $5600Å$ (c) $3150Å$ (d) $4000Å$

**22.** Wave front originating from a point source is **[RPET 2000]**
(a) Cylindrical (b) Spherical (c) Plane (d) Cubical

**23.** Waves that can not be polarised are **[KCET 2000]**
(a) Transverse waves (b) Longitudinal waves (c) Light waves (d) Electromagnetic waves

**24.** According to Huygen's wave theory, point on any wave front may be regarded as **[J & K CET 2000]**
(a) A photon (b) An electron (c) A new source of wave (d) Neutron

**25.** The light produced by a laser is all the following except **[JIPMER 2000]**
(a) Incoherent (b) Monochromatic
(c) In the form of a narrow beam (d) Electromagnetic

**26.** The phenomena of interference is shown by **[MNR 1994; MP PMT 1997; AIIMS 1999, 2000; JIPMER 2000; UPSEAT 1994, 2000]**
(a) Longitudinal mechanical waves only (b) Transverse mechanical waves only
(c) Electromagnetic waves only (d) All the above types of waves

**27.** If the ratio of amplitude of two waves is 4 : 3, then the ratio of maximum and minimum intensity is
**[MP PMT 1996; AFMC 1997; RPET 2000]**
(a) 16 : 18 (b) 18 : 16 (c) 49 : 1 (d) 94 : 1

**28.** If the distance between a point source and screen is doubled, then intensity of light on the screen will become
**[RPET 1997; RPMT 1999]**
(a) Four times (b) Double (c) Half (d) One-fourth

**29.** Soap bubble appears coloured due to the phenomenon of
**[CPMT 1972, 83, 86; AFMC 1995, 97; RPET 1997; CBSE PMT 1997; AFMC 1997]**
(a) Interference (b) Diffraction (c) Dispersion (d) Reflection

**30.** Two waves are known to be coherent if they have **[RPMT 1994, 95, 97; MP PMT 1996; MNR 1995]**
(a) Same amplitude (b) Same wavelength
(c) Same amplitude and wavelength (d) Constant phase difference and same wavelength

**31.** An oil flowing on water seems coloured due to interference. For observing this effect, the approximate thickness of the oil film should be **[DPMT 1987; JIPMER 1997]**

(a) 100 Å (b) 10000 Å (c) 1 *mm* (d) 1 *cm*

**32.** If $L$ is the coherence length and $c$ the velocity of light, the coherent time is **[MP PMT 1996]**

(a) $cL$ (b) $\frac{L}{c}$ (c) $\frac{c}{L}$ (d) $\frac{1}{Lc}$

**33.** By a monochromatic wave, we mean **[AFMC 1995]**

(a) A single ray (b) A single ray of a single colour

(c) Wave having a single wavelength (d) Many rays of a single colour

**34.** Two coherent sources of light produce destructive interference when phase difference between them is **[MP PMT 1994; CPMT 1995]**

(a) $2\pi$ (b) $\pi$ (c) $\pi/2$ (d) 0

**35.** Which one of the following statements is correct **[KCET 1994]**

(a) In vacuum, the speed of light depends upon frequency

(b) In vacuum, the speed of light does not depend upon frequency

(c) In vacuum, the speed of light is independent of frequency and wavelength

(d) In vacuum, the speed of light depends upon wavelength

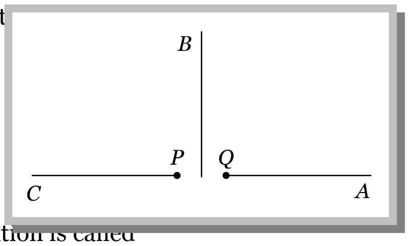
**36.** Figure here shows $P$ and $Q$ as two equally intense coherent sources emitting radiations of wavelength 20 *m*. The separation $PQ$ is 5.0 *m* and phase of $P$ is ahead of the phase of $Q$ by 90°. $A$, $B$ and $C$ are three distant points of observation equidistant from the mid-point of $PQ$. The intensity of radiations at $A$, $B$, $C$ will bear t **[NSEP 1994]**

(a) 0 : 1 : 4

(b) 4 : 1 : 0

(c) 0 : 1 : 2

(d) 2 : 1 : 0




**37.** In Huygen's wave theory, the locus of all points in the same state of vibration is called **[CBSE PMT 1993]**

(a) A half period zone (b) Vibrator (c) A wavefront (d) A ray

**38.** The idea of the quantum nature of light has emerged in an attempt to explain **[CPMT 1990]**

(a) Interference (b) Diffraction

(c) Radiation spectrum of a black body (d) Polarisation

**39.** The necessary condition for an interference by two source of light is that the **[RPMT 1988; CPMT 1989]**

(a) Two monochromatic sources should be of same amplitude but with a constant phase

(b) Two sources should be of same amplitude

(c) Two point sources should have phase difference varying with time

(d) Two sources should be of same wavelength

**40.** If the intensity of the waves observed by two coherent sources is $I$. Then the intensity of resultant waves in constructive interference will be **[RPET 1988]**

(a) $2I$ (b) $4I$ (c) $I$ (d) None of these

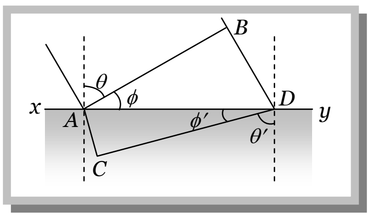
**41.** In figure, a wavefront $AB$ moving in air is incident on a plane glass surface $xy$. Its position $CD$ after refraction through a glass slab is shown also along with normals drawn at $A$ and $D$. the refractive index of glass with respect to air will be equal to **[CPMT 19**

(a) $\frac{\sin\theta}{\sin\theta'}$

(b) $\frac{\sin\theta}{\sin\phi'}$

(c) $(BD/AC)$

(d) $(AB/CD)$




**42.** Four independent waves are expressed as

(i) $y_1 = a_1 \sin\omega t$ (ii) $y_2 = a_2 \sin 2\omega t$ (iii) $y_3 = a_3 \cos\omega t$ (iv) $y_4 = a_4 \sin(\omega t + \pi/3)$

The interference is possible between **[CPMT 1986]**

(a) (i) and (ii) (b) (i) and (iv) (c) (iii) and (iv) (d) Not possible at all

**43.** Colour of light is known by its **[MP PMT 1984]**

(a) Velocity (b) Amplitude (c) Frequency (d) Polarisation

**44.** Laser light is considered to be coherent because it consists of **[CPMT 1972]**

(a) Many wavelengths (b) Uncoordinated wavelengths
(c) Coordinated waves of exactly the same wavelength (d) Divergent beams

**45.** A laser beam may be used to measure very large distances because **[CPMT 1972]**
(a) It is unidirectional (b) It is coherent (c) It is monochromatic (d) It is not absorbed

**46.** Interference patterns are not observed in thick films, because
(a) Most of the incident light intensity is observed within the film
(b) A thick film has a high coefficient of reflection
(c) The maxima of interference patterns are far from the minima
(d) There is too much overlapping of colours washing out the interference pattern

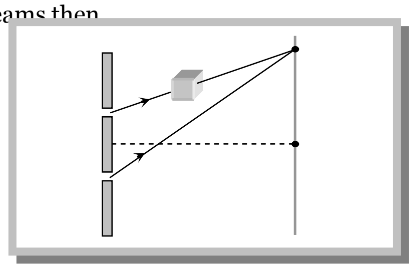
**47.** Phenomenon of interference is not observed by two sodium lamps of same power. It is because both waves have
(a) Not constant phase difference (b) Zero phase difference
(c) Different intensity (d) Different frequencies

## *Young's double slit experiment*

### *Basic Level*

**48.** In a Young's double slit experiment, the separation between the two slits is 0.9 *mm* and the fringes are observed one *metre* away. If it produces the second dark fringe at a distance of 1 *mm* from the central fringe, the wavelength of monochromatic source of light used is **[KCET 2004]**
(a) 500 *nm* (b) 600 *nm* (c) 450 *nm* (d) 400 *nm*

**49.** A monochromatic beams of light is used for the formation of fringes on the screen by illuminating the two slits in the Young's double slit mica is interposed in the path of one of the interfering beams then **[AIIMS 2004]**



(a) The fringe width increases
(b) The fringe width decreases
(c) The fringe width remains the same but the pattern shifts
(d) The fringe pattern disappears

**50.** In a Young's double-slit experiment the fringe width is 0.2 *mm*. If the wavelength of light used is increased by 10% and the separation between the slits is also increased by 10%, the fringe width will be **[MP PMT 2004]**
(a) 0.20 *mm* (b) 0.401 *mm* (c) 0.242 *mm* (d) 0.165 *mm*

**51.** In Young's experiment, the distance between the slits is reduced to half and the distance between the slit and screen is doubled, then the fringe width **[IIT 1981; MP PMT 1994; RPMT 1997; KCET (Engg./Med.) 2000; UPSEAT 2000; AMU (Engg.) 2000; C**
(a) Will not change (b) Will become half (c) Will be doubled (d) Will become four times

**52.** In an interference experiment, third bright fringe is obtained at a point on the screen with a light of 700 *nm*. What should be the wavelength of the light source in order obtain 5th bright fringe at the same point **[KCET 2003]**
(a) 500 *nm* (b) 630 *nm* (c) 750 *nm* (d) 420 *nm*

**53.** In Young's double-slit experiment the fringe width is $\beta$. If entire arrangement is placed in a liquid of refractive index $n$, the fringe width becomes **[KCET 2003]**
(a) $\frac{\beta}{n+1}$ (b) $n\beta$ (c) $\beta / n$ (d) $\beta / n - 1$

**54.** If the separation between slits in Young's double slit experiment is reduced to $\frac{1}{3}rd$, the fringe width becomes $n$ times. The value of $n$ is **[MP PET 2003]**
(a) 3 (b) $\frac{1}{3}$ (c) 9 (d) $\frac{1}{9}$

**55.** When a thin transparent plate of thickness $t$ and refractive index $\mu$ is placed in the path of one of the two interfering waves of light, then the path difference changes by **[MP PMT 2002]**
(a) $(\mu+1)t$ (b) $(\mu-1)t$ (c) $\frac{(\mu+1)}{t}$ (d) $\frac{(\mu-1)}{t}$

**56.** In a Young's double slit experiment, the source illuminating the slits is changed from blue to violet. The width of the fringes **[Kerala CET (Med.) 2002]**

(a) Increases (b) Decreases (c) Becomes unequal (d) Remains constant

**57.** In Young's double slit experiment, the intensity of light coming from the first slit is double the intensity from the second slit. The ratio of the maximum intensity to the minimum intensity on the interference fringe pattern observed is **[KCET (Med.) 2002]**

(a) 34 (b) 40 (c) 25 (d) 38

**58.** In Young's double slit experiment the wavelength of light was changed from 7000$\mathring{A}$ to 3500$\mathring{A}$. While doubling the separation between the slits which of the following is not true for this experiment **[Orissa JEE 2002]**

(a) The width of the fringes changes

(b) The colour of bright fringes changes

(c) The separation between successive bright fringes changes

(d) The separation between successive dark fringes remains unchanged

**59.** In Young's double slit experiment, the central bright fringe can be identified **[KCET (Engg.) 2002]**

(a) By using white light instead of monochromatic light (b) As it is narrower than other bright fringes

(c) As it is wider than other bright fringes (d) As it has a greater intensity than the other bright fringes

**60.** Interference was observed in interference chamber when air was present, now the chamber is evacuated and if the same light is used, a careful observer will see **[CBSE PMT 1993; DPMT 2000; BHU 2002]**

(a) No interference

(b) Interference with bright bands

(c) Interference with dark bands

(d) Interference in which width of the fringe will be slightly increased

**61.** A slit of width *a* is illuminated by white light. For red light $(\lambda = 6500\ \mathring{A})$. The first minima is obtained at $\theta = 30^o$. Then the value of *a* will be **[MP PMT 1987; CPMT 2002]**

(a) 3250 $\mathring{A}$ (b) $6.5 \times 10^{-4}\ mm$ (c) 1.24 *microns* (d) $2.6 \times 10^{-4}\ cm$

**62.** In the Young's double slit experiment with sodium light. The slits are 0.589 *m* apart. The angular separation of the third maximum from the central maximum will be (given $\lambda$ = 589 *mm*) **[Pb. PMT 2002]**

(a) $\sin^{-1}(0.33 \times 10^{8})$ (b) $\sin^{-1}(0.33 \times 10^{-6})$ (c) $\sin^{-1}(3 \times 10^{-8})$ (d) $\sin^{-1}(3 \times 10^{-6})$

**63.** In the Young's double slit experiment for which colour the fringe width is least **[MP PMT 1994; UPSEAT 2001; MP PET 2001]**

(a) Red (b) Green (c) Blue (d) Yellow

**64.** In a Young's double slit experiment, the separation of the two slits is doubled. To keep the same spacing of fringes, the distance *D* of the screen from the slits should be made **[AMU (Engg.) 2001]**

(a) $\frac{D}{2}$ (b) $\frac{D}{\sqrt{2}}$ (c) 2*D* (d) 4*D*

**65.** Consider the following statements

**Assertion** (*A*): In Young's experiment, the fringe width for dark fringes is different from that for bright fringes.

**Reason (*R*)** : In Young's double slit experiment performed with a source of white light, only black and bright fringes are observed

Of these statements **[AIIMS 2001]**

(a) Both *A* and *R* are true and *R* is a correct explanation of *A* (b) Both *A* and *R* are true but *R* is not a correct explanation of *A*

(c) Both *A* and *R* are false (d) *A* is false but *R* is true

(e) *A* is true but *R* is false

**66.** 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 600 *nm* is used. If the wavelength of light is changed to 400 *nm*, number of fringes observed in the same segment of the screen is given by **[IIT-JEE (Screening) 2001]**

(a) 12 (b) 18 (c) 24 (d) 30

**67.** In Young's double slit experiment, a mica slit of thickness *t* and refractive index $\mu$ is introduced in the ray from the first source $S_1$. By how much distance the fringes pattern will be displaced **[RPMT 1996, 97; JIPMER 2000]**

(a) $\frac{d}{D}(\mu - 1)t$ (b) $\frac{D}{d}(\mu - 1)t$ (c) $\frac{d}{(\mu - 1)D}$ (d) $\frac{D}{d}(\mu - 1)$

**68.** Young's double slit experiment is performed with light of wavelength 550 *nm*. The separation between the slits is 1.10 *mm* and screen is placed at distance of 1 *m*. What is the distance between the consecutive bright or dark fringes **[Pb. PMT 2000]**

(a) 1.5 *mm* (b) 1.0 *m* (c) 0.5 *mm* (d) None of these

**69.** In interference obtained by two coherent sources, the fringe width ($\beta$) has the following relation with wavelength ($\lambda$) **[CPMT 1997; MP PMT 2000]**

(a) $\beta \propto \lambda^2$ (b) $\beta \propto \lambda$ (c) $\beta \propto 1/\lambda$ (d) $\beta \propto \lambda^{-2}$

**70.** 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 **[IIT-JEE (Screening) 2000]**

(a) The intensities of both the maxima and the minima increase
(b) The intensity of maxima increases and the minima has zero intensity
(c) The intensity of maxima decreases and that of the minima increases
(d) The intensity of maxima decreases and the minima has zero intensity

**71.** In Young's double slit experiment with a source of light of wavelength 6320$\AA$, the first maxima will occur when **[Roorkee 1999]**

(a) Path difference is 9480 $\AA$ (b) Phase difference is $2\pi$ radian
(c) Path difference is 6320 $\AA$ (d) Phase difference is $\pi$ radian

**72.** If a transparent medium of refractive index $\mu$ = 1.5 and thickness $t = 2.5 \times 10^{-5}\, m$ is inserted in front of one of the slits of Young's double slit experiment, how much will be the shift in the interference pattern? The distance between the slits is 0.5 *mm* and that between slits and screen is 100 *cm* **[AIIMS 1999]**

(a) 5 *cm* (b) 2.5 *cm* (c) 0.25 *cm* (d) 0.1 *cm*

**73.** If a torch is used in place of monochromatic light in Young's experiment what will happens **[MH CET (Med.) 1999; KCET (Med.) 1999]**

(a) Fringe will appear for a moment then it will disappear (b) Fringes will occur as from monochromatic light
(c) Only bright fringes will appear (d) No fringes will appear

**74.** When a thin metal plate is placed in the path of one of the interfering beams of light **[KCET (Engg./Med.) 1999]**

(a) Fringe width increases (b) Fringes disappear (c) Fringes become brighter (d) Fringes become blurred

**75.** What happens by the use of white light in Young's double slit experiment **[Similar to (AIIMS 2001; Kerala 2000); IIT-JEE 1987; RPMT 1993; MP PMT 1996; RPET 1998; UPSEAT 1999]**

(a) Bright fringes are obtained
(b) Only bright and dark fringes are obtained
(c) Central fringe is bright and two or three coloured and dark fringes are observed
(d) None of these

**76.** Young's experiment is performed in air and then performed in water, the fringe width **[CPMT 1990; MP PMT 1994; RPMT 1997]**

(a) Will remain same (b) Will decrease (c) Will increase (d) Will be infinite

**77.** In Young's experiment, one slit is covered with a blue filter and the other (slit) with a yellow filter. Then the interference pattern **[MP PET 1997]**

(a) Will be blue (b) Will be yellow (c) Will be green (d) Will not be formed

**78.** Two sources give interference pattern which is observed on a screen. $D$ distance apart from the sources. The fringe width is $2w$. If the distance $D$ is now doubled, the fringe width will **[MP PET 1997]**

(a) Become $w/2$ (b) Remain the same (c) Become $w$ (d) Become $4w$

**79.** In Young's double slit experiment, angular width of fringes is 0.20° for sodium light of wavelength 5890 $\AA$. If complete system is dipped in water, then angular width of fringes becomes **[RPET 1997]**

(a) 0.11° (b) 0.15° (c) 0.22° (d) 0.30°

**80.** In two separate set-ups of the Young's double slit experiment, fringes of equal width are observed when lights of wavelengths in the ratio 1 : 2 are used. If the ratio of the slit separation in the two cases is 2 : 1, the ratio of the distances between the plane of the slits and the screen in the two set-ups is **[Kurukshetra CEE 1996]**

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

**81.** In a Young's double slit experiment, the central point on the screen is **[MP PMT 1996]**

(a) Bright (b) Dark (c) First bright and then dark (d) First dark and then bright

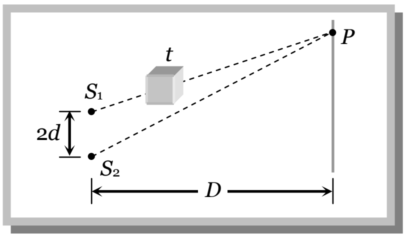
**82.** In Young's double slit experiment, the distance between sources is 1 *mm* and distance between the screen and source is 1*m*. If the fringe width on the screen is 0.06 *cm*, then $\lambda$ = **[CPMT 1996]**

(a) 6000 $\AA$ (b) 4000 $\AA$ (c) 1200 $\AA$ (d) 2400 $\AA$

**83.** In a Young's double slit experiment, the distance between two coherent sources is 0.1 *mm* and the distance between the slits and the screen is 20 *cm*. If the wavelength of light is 5460 $\AA$ then the distance between two consecutive maxima is **[RPMT 1995]**

(a) 0.5 *mm* (b) 1.1 *mm* (c) 1.5 *mm* (d) 2.2 *mm*

**84.** If a thin mica sheet of thickness $t$ and refractive index $\mu = (5/3)$ is placed in the path of one of the interfering beams as shown in figure, then the displacement of the fringe system is **[CPMT 1995]**




(a) $\frac{Dt}{3d}$

(b) $\frac{Dt}{5d}$

(c) $\frac{Dt}{4d}$

(d) $\frac{2Dt}{5d}$

**85.** In a double slit experiment, the first minimum on either side of the central maximum occurs where the path difference between the two paths is **[CPMT 1995]**

(a) $\frac{\lambda}{4}$ (b) $\frac{\lambda}{2}$ (c) $\lambda$ (d) $2\lambda$

**86.** In Young's double slit experiment, the phase difference between the light waves reaching third bright fringe from the central fringe will be ($\lambda$ = 6000 Å) **[MP PMT 1994]**

(a) Zero (b) $2\pi$ (c) $4\pi$ (d) $6\pi$

**87.** Sodium light $(\lambda = 6 \times 10^{-7} m)$ is used to produce interference pattern. The observed fringe width is 0.12 *mm*. The angle between the two interfering wave trains is **[CPMT 1993]**

(a) $5 \times 10^{-1}$ *rad* (b) $5 \times 10^{-3}$ *rad* (c) $1 \times 10^{-2}$ *rad* (d) $1 \times 10^{-3}$ *rad*

**88.** The contrast in the fringes in any interference pattern depends on **[Roorkee 1992]**

(a) Fringe width (b) Intensity ratio of the sources

(c) Distance between the slits (d) Wavelength

**89.** In Young's double slit experiment, carried out with light of wavelength $\lambda$ = 5000 Å, the distance between the slits is 0.2 *mm* and the screen is at 200 *cm* from the slits. The central maximum is at $x$ = 0. The third maximum (taking the central maximum as zeroth maximum) will be at $x$ equal to **[CBSE PMT 1992]**

(a) 1.67 *cm* (b) 1.5 *cm* (c) 0.5 *cm* (d) 5.0 *cm*

**90.** In a Young's experiment, two coherent sources are placed 0.90 *mm* apart and the fringes are observed one *metre* away. If it produces the second dark fringe at a distance of 1 *mm* from the central fringe, the wavelength of monochromatic light used would be

**[CBSE PMT 1992]**

(a) $60 \times 10^{-4}$ *cm* (b) $10 \times 10^{-4}$ *cm* (c) $10 \times 10^{-5}$ *cm* (d) $60 \times 10^{-5}$ *cm*

**91.** In Fresnel's biprism, coherent sources are obtained by **[RPET 1991]**

(a) Division of wavefront (b) Division of amplitude (c) Division of wavelength (d) None of these

**92.** In Young's experiment, the ratio of maximum and minimum intensities in the fringe system is 9 : 1. The ratio of amplitudes of coherent sources is **[NCERT 1990]**

(a) 9 : 1 (b) 3 : 1 (c) 2 : 1 (d) 1 : 1

**93.** In a certain double slit experimental arrangement interference fringes of width 1.0 *mm* each are observed when light of wavelength 5000 Å is used. Keeping the set up unaltered, if the source is replaced by another source of wavelength 6000 Å, the fringe width will be **[CPMT 1988]**

(a) 0.5 *mm* (b) 1.0 *mm* (c) 1.2 *mm* (d) 1.5 *mm*

**94.** In Young's double slit experiment, if the slit widths are in the ratio 1 : 9, then the ratio of the intensity at minima to that at maxima will be **[MP PET 1987]**

(a) 1 (b) 1/9 (c) 1/4 (d) 1/3

**95.** The Young's experiment is performed with the lights of blue ($\lambda$ = 4360 Å) and green colour ($\lambda$ = 5460 Å). If the distance of the 4th fringe from the centre is $x$, then **[CPMT 1987]**

(a) $x(\text{Blue}) = x(\text{Green})$ (b) $x(\text{Blue}) > x(\text{Green})$ (c) $x(\text{Blue}) < x(\text{Green})$ (d) $\frac{x(\text{Blue})}{x(\text{Green})} = \frac{5460}{4360}$

**96.** In Young's experiment, keeping the distance of the slit from screen constant if the slit width is reduced to half, then **[CPMT 1986]**

(a) The fringe width will be doubled (b) The fringe width will reduce to half

(c) The fringe width will not change (d) The fringe width will become $\sqrt{2}$ times

**97.** In Young's experiment, if the distance between screen and the slit aperture is increased the fringe width will **[RPET 1986]**

(a) Decrease (b) Increases but intensity will decrease

(c) Increase but intensity remains unchanged (d) Remains unchanged but intensity decreases

**98.** In Fresnel's biprism experiment, the two coherent sources are **[RPET 1985]**

(a) Real (b) Imaginary

(c) One is real and the other is imaginary (d) None of these

**99.** In Fresnel's experiment, the width of the fringe depends upon the distance **[RPET 1985]**

(a) Between the prism and the slit aperture

(b) Of the prism from the screen

(c) Of screen from the imaginary light sources

(d) Of the screen from the prism and the distance from the imaginary sources

**100.** In the Young's double slit experiment, the ratio of intensities of bright and dark fringes is 9. This means that **[IIT-JEE 1982]**

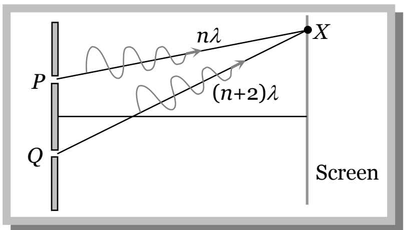
(a) The intensities of individual sources are 5 and 4 units respectively

(b) The intensities of individual sources are 4 and 1 units respectively

(c) The ratio of their amplitudes is 3

(d) The ratio of their amplitudes is 2

**101.** The figure below shows a double slit experiment. $P$ and $Q$ are the slits. The path lengths $PX$ and $QX$ are $n\lambda$ and $(n + 2)\lambda$ respectively where $n$ is a whole number and $\lambda$ is the wavelength. Taking the central bright fringe as zero, what is formed at $X$




(a) First bright

(b) First dark

(c) Second bright

(d) Second dark

**102.** A plate of thickness $t$ made of a material of refractive index $\mu$ is placed in front of one of the slits in a double slit experiment. What should be the minimum thickness $t$ which will make the intensity at the centre of the fringe pattern zero

(a) $(\mu-1)\dfrac{\lambda}{2}$ (b) $(\mu-1)\lambda$ (c) $\dfrac{\lambda}{2(\mu-1)}$ (d) $\dfrac{\lambda}{(\mu-1)}$

**103.** The thickness of a plate (refractive index $\mu$ for light of wavelength $\lambda$) which will introduce a path difference of $\dfrac{3\lambda}{4}$ is

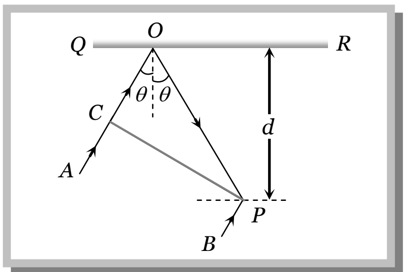
(a) $\dfrac{3\lambda}{4(\mu-1)}$ (b) $\dfrac{3\lambda}{2(\mu-1)}$ (c) $\dfrac{\lambda}{2(\mu-1)}$ (d) $\dfrac{3\lambda}{4\mu}$

## *Advance Level*

**104.** In the Young's double slit experiment, if the phase difference between the two waves interfering at a point is $\phi$, the intensity at that point can be expressed by the expression (where $A + B$ depends upon the amplitude of the two waves) **[MP PMT/PET 1998; MP PMT 2003]**

(a) $I=\sqrt{A^2+B^2\cos^2\phi}$ (b) $I=\dfrac{A}{B}\cos\phi$ (c) $I=A+B\cos\phi/2$ (d) $I=A+B\cos\phi$

**105.** In the adjacent diagram $CP$ represents wavefronts and $AO$ and $BP$ the corresponding two rays. Find the condition on $\theta$ for constructive interference at $P$ between the ray $BP$ and reflected ray $OP$ **[IIT-JEE (Screening) 2003]**




(a) $\cos\theta=3\lambda/2d$

(b) $\cos\theta=\lambda/4d$

(c) $\sec\theta-\cos\theta=\lambda/d$

(d) $\sec\theta - \cos\theta = 4\lambda/d$

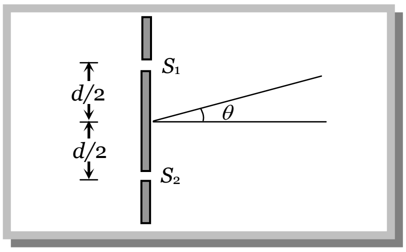
**106.** When one of the slits of Young's experiment is covered with a transparent sheet of thickness 4.8 *mm*, the central fringe shifts to a position originally occupied by the 30th bright fringe. What should be the thickness of the sheet if the central fringe has to shift to the position occupied by 20th bright fringe **[KCET (Engg.) 2002]**

(a) 3.8 *mm* (b) 1.6 *mm* (c) 7.6 *mm* (d) 3.2 *mm*

**107.** 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 remains unchanged. The minimum thickness of the glass-plate is **[IIT-JEE (Screening) 2002)]**

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

**108.** 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 distance *d* = 150 *m*. The intensity $I(\theta)$ is measured as a function of $\theta$, where $\theta$ is defined as shown. If $I_0$ is maximum intensity, then $I(\theta)$ for $0 \le \theta \le 90°$ is given by **[IIT-JEE 1995]**




(a) $I(\theta) = I_0$ for $\theta = 90°$

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

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

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

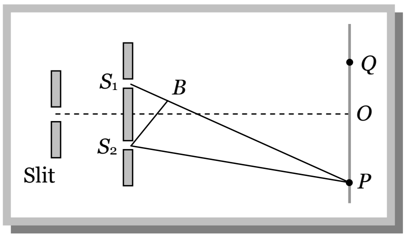
**109.** In Young's double slit experiment, white light is used. The separation between the slits is *b*. the screen is at a distance $d(d \gg b)$ from the slits. Some wavelengths are missing exactly in front of one slit. These wavelengths are **[IIT-JEE 1984; AIIMS 1995]**

(a) $\lambda = \frac{b^2}{d}$ (b) $\lambda = \frac{2b^2}{d}$ (c) $\lambda = \frac{b^2}{3d}$ (d) $\lambda = \frac{2b^2}{3d}$

**110.** In a two slit experiment with monochromatic light fringes are obtained on a screen placed at some distance from the sits. If the screen is moved by $5 \times 10^{-2} m$ towards the slits, the change in fringe width is $3 \times 10^{-5} m$. If separation between the slits is $10^{-3} m$, the wavelength of light used is **[Roorkee 1992]**

(a) 6000 Å (b) 5000 Å (c) 3000 Å (d) 4500 Å

**111.** In the figure is shown Young's double slit experiment. *Q* is the position of the first bright fringe on the right side of *O*. *P* is the 11th fringe on the other side, as measured from *Q*. If the wavelength of the light used is $6000 \times 10^{-10} m$, then $S_1B$ will be equal to **[CPMT 1986, 92]**




(a) $6 \times 10^{-6} m$

(b) $6.6 \times 10^{-6} m$

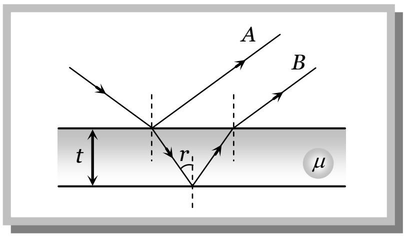
(c) $3.138 \times 10^{-7} m$

(d) $3.144 \times 10^{-7} m$

**112.** 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 set up the two slits are of equal amplitude *A* and wavelength $\lambda$ but are incoherent. The ratio of the intensity of light at the mid-point of the screen in the first case to that in the second case is **[IIT-JJE 1986]**

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

**113.** When light of wavelength $\lambda$ falls on a thin film of thickness *t* and refractive index *n*, the essential condition for the production of constructive interference fringes by the rays *A* and *B* are (*m* = 1, 2, 3, ……)




(a) $2nt\cos r = \left(m - \frac{1}{2}\right)\lambda$

(b) $2nt\cos r = m\lambda$

(c) $nt\cos r = m\lambda$

(d) $nt\cos r = (m-1)\lambda$

**114.** Four light waves are represented by

(i) $y = a_1 \sin\omega t$ (ii) $y = a_2 \sin(\omega t + \phi)$ (iii) $y = a_1 \sin 2\omega t$ (iv) $y = a_2 \sin 2(\omega t + \phi)$

Interference fringes may be observed due to superposition of

(a) (i) and (ii) (b) (i) and (iii) (c) (ii) and (iv) (d) (iii) and (iv)

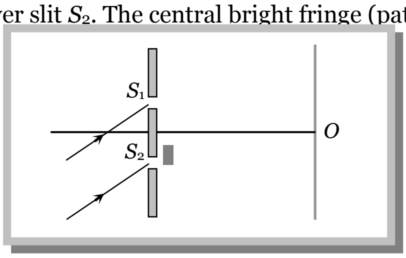
**115.** In Young's double slit experiment the $y$-coordinates of central maxima and 10th maxima are 2 $cm$ and 5 $cm$ respectively. When the YDSE apparatus is immersed in a liquid of refractive index 1.5 the corresponding $y$-coordinates will be

(a) 2 $cm$, 7.5 $cm$ (b) 3 $cm$, 6 $cm$ (c) 2 $cm$, 4$cm$ (d) 4/3 $cm$, 10/3 $cm$

**116.** The maximum intensity in Young's double slit experiment is $I_0$. Distance between the slits is $d = 5\lambda$, where $\lambda$ is the wavelength of monochromatic light used in the experiment. What will be the intensity of light in front of one of the slits on a screen at a distance $D = 10\,d$

(a) $\frac{I_0}{2}$ (b) $\frac{3}{4}I_0$ (c) $I_0$ (d) $\frac{I_0}{4}$

**117.** A monochromatic beam of light falls on YDSE apparatus at some angle (say $\theta$) as shown in figure. A thin sheet of glass is inserted in front of the lower slit $S_2$. The central bright fringe (path difference = 0) will be obtained




(a) At $O$

(b) Above $O$

(c) Below $O$

(d) Anywhere depending on angle $\theta$, thickness of plate $t$ and refractive index of glass $\mu$

**118.** In Young's double slit experiment how many maximas can be obtained on a screen (including the central maximum) on both sides of the central fringe if $\lambda = 2000\ Å$ and $d = 7000\ Å$

(a) 12 (b) 7 (c) 18 (d) 4

**119.** Young's double slit experiment is made in a liquid. The 10th bright fringe in liquid lies where 6th dark fringe lies in vacuum. The refractive index of the liquid is approximately

(a) 1.8 (b) 1.54 (c) 1.67 (d) 1.2

**120.** Light of wavelength $\lambda_0$ in air enters a medium of refractive index $n$. If two points $A$ and $B$ in this medium lie along the path of this light at a distance $x$, then phase difference $\phi_0$ between these two points is

(a) $\phi_0 = \frac{1}{n}\left(\frac{2\pi}{\lambda_0}\right)x$ (b) $\phi_0 = n\left(\frac{2\pi}{\lambda_0}\right)x$ (c) $\phi_0 = (n-1)\left(\frac{2\pi}{\lambda_0}\right)x$ (d) $\phi_0 = \frac{1}{(n-1)}\left(\frac{2\pi}{\lambda_0}\right)x$

**121.** In a Young's double slit experiment, the slits are 2 $mm$ apart and are illuminated with a mixture of two wavelength $\lambda_0 = 750\,nm$ and $\lambda = 900\,nm$. The minimum distance from the common central bright fringe on a screen 2$m$ from the slits where a bright fringe from one interference pattern coincides with a bright fringe from the other is

(a) 1.5 $mm$ (b) 3 $mm$ (c) 4.5 $mm$ (d) 6 $mm$

**122.** 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 remains unchanged. The minimum thickness of the glass plate is

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

**123.** Two wavelengths of light $\lambda_1$ and $\lambda_2$ are sent through a Young's double slit apparatus simultaneously. If the third order $\lambda_1$ bright fringe coincides with the fourth order $\lambda_2$ bright fringe then

(a) $\frac{\lambda_1}{\lambda_2} = \frac{4}{3}$ (b) $\frac{\lambda_1}{\lambda_2} = \frac{3}{4}$ (c) $\frac{\lambda_1}{\lambda_2} = \frac{5}{4}$ (d) $\frac{\lambda_1}{\lambda_2} = \frac{4}{5}$

**124.** A flake of glass (refractive index 1.5) is placed over one of the openings of a double slit apparatus. The interference pattern displaces itself through seven successive maxima towards the side where the flake is placed. if wavelength of the diffracted light is $\lambda = 600\,nm$, then the thickness of the flake is

(a) 2100 $nm$ (b) 4200 $nm$ (c) 8400 $nm$ (d) None of these

**125.** 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

(a) The intensitites of both the maxima and the minima increase

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

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

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

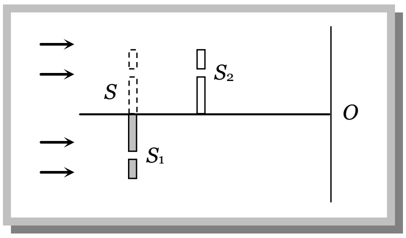
**126.** In Young's experiment the wavelength of red light is 7800 Å and that of blue light is 5200 Å. The value of $n$ for which the $(n+1)th$ blue bright band coincides with the $n^{th}$ red band is

(a) 4 (b) 3 (c) 2 (d) 1

**127.** In a double slit experiment if 5th dark fringe is formed opposite to one of the slits, the wavelength of light is

(a) $\frac{d^2}{6D}$ (b) $\frac{d^2}{5D}$ (c) $\frac{d^2}{15D}$ (d) $\frac{d^2}{9D}$

**128.** In a Young's double slit experiment one of the slits is advanced towards the screen by a distance $d/2$ and $d = n\lambda$ where $n$ is an odd integer and $d$ is the initial distance between the slits. If $I_0$ is the intensity of each wave from the slits, the intensity at $O$ is



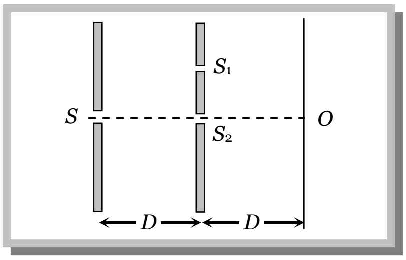

(a) $I_0$

(b) $\frac{I_0}{4}$

(c) 0

(d) $2I_0$

**129.** Two ideal slits $S_1$ and $S_2$ are at a distance $d$ apart, and illuminated by light of wavelength $\lambda$ passing through an ideal source slit $S$ placed on the line through $S_2$ as shown. The distance between the planes of slits and the source slit is $D$. A screen is held at a distance $D$ from the plane of the slits. The minimum value of $d$ for which there is darkness at $O$ is




(a) $\sqrt{\frac{3\lambda D}{2}}$

(b) $\sqrt{\lambda D}$

(c) $\sqrt{\frac{\lambda D}{2}}$

(d) $\sqrt{3\lambda D}$

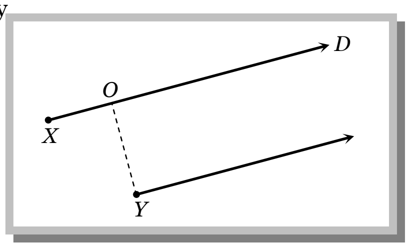
**130.** In a double slit experiment interference is obtained from electron waves produced in an electron gun supplied with voltage $V$. if $\lambda$ is the wavelength of the beam, $D$ is the distance of screen, $d$ is the spacing between coherent source, $h$ is Planck's constant, $e$ is charge on electron and $m$ is mass of electron then fringe width is given as

(a) $\frac{hD}{\sqrt{2meV}\,d}$ (b) $\frac{2hD}{\sqrt{meV}\,d}$ (c) $\frac{hd}{\sqrt{2meV}\,D}$ (d) $\frac{2hd}{\sqrt{meV}\,D}$

**131.** In a double slit arrangement fringes are produced using light of wavelength 4800 Å. One slit is covered by a thin plate of glass of refractive index 1.4 and the other with another glass plate of same thickness but of refractive index 1.7. By doing so the central bright shifts to original fifth bright fringe from centre. Thickness of glass plate is

(a) 8 $\mu m$ (b) 6 $\mu m$ (c) 4 $\mu m$ (d) 10 $\mu m$

**132.** Two point sources $X$ and $Y$ emit waves of same frequency and speed but $Y$ lags in phase behind $X$ by $2\pi l$ radian. If there is a maximum in direction $D$ the distance $XO$ using $n$ as an integer is given by



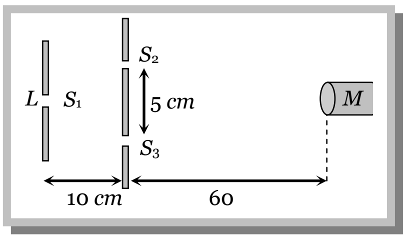

(a) $\frac{\lambda}{2}(n-l)$

(b) $\lambda(n+l)$

(c) $\frac{\lambda}{2}(n+l)$

(d) $\lambda(n-l)$

**133.** A student is asked to measure the wavelength of monochromatic light. He sets up the apparatus sketched below. $S_1, S_2, S_3$ are narrow parallel slits, $L$ is a sodium lamp and $M$ is a micrometer eye-piece. The student fails to observe interference fringes. You would advise him to



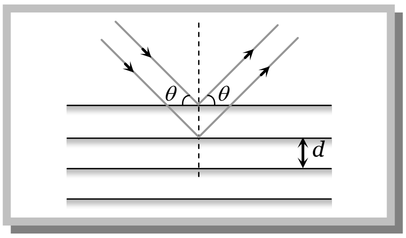

(a) Increase the width of $S_1$

(b) Decrease the distance between $S_2$ and $S_3$

(c) Replace $L$ with a white light source

(d) Replace $M$ with a telescope

**134.** A beam with wavelength $\lambda$ falls on a stack of partially reflecting planes with separation $d$. The angle $\theta$ that the beam should make with the planes so that the beams reflected from successive planes may interfere constructively is (where $n$ =1, 2, ……)



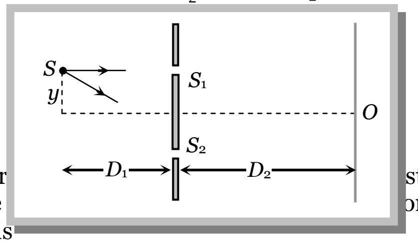

(a) $\sin^{-1}\left(\frac{n\lambda}{d}\right)$

(b) $\tan^{-1}\left(\frac{n\lambda}{d}\right)$

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

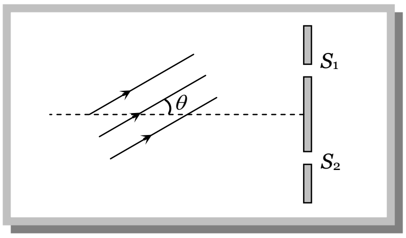
(d) $\cos^{-1}\left(\frac{n\lambda}{2d}\right)$

**135.** In a double slit experiment the source slit $S$ is at a distance $D_1$ and the screen at a distance $D_2$ from the plane of ideal slit cuts $S_1$ and $S_2$ as shown. If the source slit is shifted to by parallel to $S_1S_2$, the central bright fringe will be shifted by




(a) $y$ (b) $-y$ (c) $\frac{D_2}{D_1}y$ (d) $-\frac{D_2}{D_1}y$

**136.** A parallel beam of monochromatic light is used in a Young's double slit exper stance $d$ and the screen is placed parallel to the plane of the slits. The angle which the ormal to the plane of the slits to produce darkness at the position of central brightness is




(a) $\cos^{-1}\frac{\lambda}{d}$

(b) $\cos^{-1}\frac{2\lambda}{d}$

(c) $\sin^{-1}\frac{\lambda}{d}$

(d) $\sin^{-1}\frac{\lambda}{2d}$

**137.** In a Young's double slit experiment, let $\beta$ be the fringe width, and let $I_0$ be the intensity at the central bright fringe. At a distance $x$ from the central bright fringe, the intensity will be

(a) $I_0 \cos\left(\frac{x}{\beta}\right)$ (b) $I_0 \cos^2\left(\frac{x}{\beta}\right)$ (c) $I_0 \cos^2\left(\frac{\pi x}{\beta}\right)$ (d) $\left(\frac{I_0}{4}\right)\cos^2\left(\frac{\pi x}{\beta}\right)$

**138.** In Young's double slit experiment the distance $d$ between the slits $S_1$ and $S_2$ is 1 *mm*. What should be the width of each slit be so as to obtain 10 maxima of the two slit interference pattern with in the central maximum of the single slit diffraction pattern

(a) 0.1 *mm* (b) 0.2 *mm* (c) 0.3 *mm* (d) 0.4 *mm*

## *Diffraction of light*

**139.** When light is incident on a diffraction grating the zero order principal maximum will be **[KCET 2004]**

(a) One of the component colours (b) Absent
(c) Spectrum of the colours (d) White

**140.** A beam of light of wavelength 600 *nm* from a distant source falls on a single slit 1 *mm* wide and the resulting diffraction pattern is observed on a screen 2 *m* away. The distance between the first dark fringes on either side of the central bright fringe is

**[IIT-JEE 1994; KCET 2004]**

(a) 1.2 *mm* (b) 1.2 *cm* (c) 2.4 *cm* (d) 2.4 *mm*

**141.** Consider the following statements

**Assertion** (*A*): When a tiny circular obstacle is placed in the path of light from some distance, a bright spot is seen at the centre of the shadow of the obstacle.

**Reason (*R*)** : Destructive interference occurs at the centre of the shadow.

Of these statements **[AIIMS 2002]**

(a) Both *A* and *R* are true and *R* is a correct explanation of *A* (b) Both *A* and *R* are true but *R* is not a correct explanation of *A*
(c) *A* is true but *R* is false (d) A is false but R is true
(e) Both *A* and *R* are false

**142.** The light of wavelength 6328 $\AA$ is incident on a slit of width 0.2 *mm* perpendicularly situated at a distance of 9 *m* and the central maxima between two minima, the angular is approximately **[MP PMT 1987; Pb. PMT 2002]**

(a) 0.36° (b) 0.18° (c) 0.72° (d) 0.08°

**143.** A diffraction pattern is obtained using a beam of red light. What happens if the red light is replaced by blue light **[KCET (Eng./Med.) 2000; BHU 2001]**

(a) No change (b) diffraction bands become narrower and crowded together

(c) Bands become broader and farther apart (d) Bands disappear

**144.** Angular width ($\beta$) of central maximum of a diffraction pattern on a single slit does not depend upon **[DCE 2000, 2001]**

(a) Distance between slit and source (b) Wavelength of light used

(c) Width of the slit (d) Frequency of light used

**145.** In order to see diffraction the thickness of the film is **[J&K CEE 2001]**

(a) 100 Å (b) 10,000 Å (c) 1 *mm* (d) 1 *cm*

**146.** What will be the angle of diffracting for the first minimum due to Fraunhoffer diffraction with sources of light of wave length 550 *nm* and slit of width 0.55 *mm* **[Pb. PMT 2001]**

(a) 0.001 *rad* (b) 0.01 *rad* (c) 1 *rad* (d) 0.1 *rad*

**147.** The bending of beam of light around corners of obstacles is called **[NCERT 1990; AFMC 1995; RPET 1997; CPMT 1999; JIPMER 2000]**

(a) Reflection (b) Diffraction (c) Refraction (d) Interference

**148.** Diffraction effects are easier to notice in the case of sound waves than in the case of light waves because **[RPET 1978; KCET 2000]**

(a) Sound waves are longitudinal (b) Sound is perceived by the ear

(c) Sound waves are mechanical waves (d) Sound waves are of longer wavelength

**149.** Direction of the first secondary maximum in the Fraunhofer diffraction pattern at a single slit is given by (*a* is the width of the slit) **[KCET 1999]**

(a) $a\sin\theta = \frac{\lambda}{2}$ (b) $a\cos\theta = \frac{3\lambda}{2}$ (c) $a\sin\theta = \lambda$ (d) $a\sin\theta = \frac{3\lambda}{2}$

**150.** A slit of size 0.15 *cm* is placed at 2.1 *m* from a screen. On illuminated it by a light of wavelength $5\times10^{-5}\,cm$. The width of diffraction pattern will be **[RPET 1999]**

(a) 70 *mm* (b) 0.14 *mm* (c) 1.4 *cm* (d) 0.14 *cm*

**151.** Yellow light is used in a single slit diffraction experiment with a slit of 0.6 *mm*. If yellow light is replaced by *x*-rays, than the observed pattern will reveal **[IIT-JEE 1999]**

(a) That the central maxima is narrower (b) More number of fringes

(c) Less number of fringes (d) No diffraction pattern

**152.** 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 incident beam. At the first maximum of the diffraction pattern the phase difference between the rays coming from the edges of the slit is **[IIT–JEE 1995, 98]**

(a) 0 (b) $\frac{\pi}{2}$ (c) $\pi$ (d) $2\pi$

**153.** Diffraction and interference of light suggest **[CPMT 1995; RPMT 1998]**

(a) Nature of light is electro-magnetic (b) Wave nature

(c) Nature is quantum (d) Nature of light is transverse

**154.** A light wave is incident normally over a slit of width $24\times10^{-5}\,cm$. The angular position of second dark fringe from the central maxima is 30°. What is the wavelength of light **[RPET 1995]**

(a) 6000 Å (b) 5000 Å (c) 3000 Å (d) 1500 Å

**155.** A beam of light of wavelength 600 *nm* from a distant source falls on a single slit 1.00 *nm* wide and the resulting diffraction pattern is observed on a screen 2 *m* away. The distance between the first dark fringes on either side of the central bright fringe is **[IIT-JEE 1994]**

(a) 1.2 *cm* (b) 1.2 *mm* (c) 2.4 *cm* (d) 2.4 *mm*

**156.** A parallel beam of monochromatic light of wavelength 5000 Å is incident normally on a single narrow slit of width 0.001 *mm*. The light is focused by a convex lens on a screen placed on the focal plane. The first minimum will be formed for the angle of diffraction equal to **[CBSE PMT 1993]**

(a) 0° (b) 15° (c) 30° (d) 60°

**157.** Light appears to travel in straight lines since **[RPMT 1997; AIIMS 1998; CPMT 1987, 89, 90, 2001; KCET (Engg.) 2002; BHU 2002]**

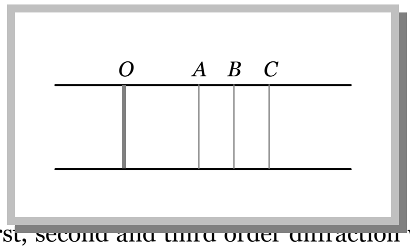
(a) It is not absorbed by the atmosphere (b) It is reflected by the atmosphere

(c) It's wavelength is very small (d) It's velocity is very large

**158.** The condition for observing Fraunhofer diffraction from a single slit is that the light wavefront incident on the slit should be **[MP PMT 1987]**

(a) Spherical (b) Cylindrical (c) Plane (d) Elliptical

**159.** The position of the direct image obtained at *O*, when a monochromatic beam of light is passed through a plane transmission grating at normal incidence is shown in fig.




The diffracted images *A, B* and *C* correspond to the first, second and third order diffraction when the source is replaced by an another source of shorter wavelength **[CPMT 1986]**

(a) All the four shift in the direction *C* to *O*
(b) All the four will shift in the direction *O* to *C*
(c) The images *C, B* and *A* will shift toward *O*
(d) The images *C, B* and *A* will shift away from *O*

**160.** To observe diffraction the size of an obstacle **[CPMT 1982]**

(a) Should be of the same order as wavelength
(b) Should be much larger than the wavelength
(c) Have no relation to wavelength
(d) Should be exactly $\frac{\lambda}{2}$

**161.** The first diffraction minima due to a single slit diffraction is at $\theta = 30^o$ for a light of wavelength 5000 Å. The width of the slit is **[CPMT 1985]**

(a) $5\times10^{-5}\,cm$ (b) $1.0\times10^{-4}\,cm$ (c) $2.5\times10^{-5}\,cm$ (d) $1.25\times10^{-5}\,cm$

**162.** Radio waves diffract pronoucedly around buildings while light waves which are also electromagnetic waves do not because **[PPE 1978]**

(a) Wavelength of the radio waves is not comparable with the size of the obstacle
(b) Wavelength of radio waves is of the order of 200-500 *m* hence they bend more than the light waves whose wavelength is very small
(c) Light waves are transverse whereas radio waves are longitudinal
(d) None of the above

**163.** One cannot obtain diffraction from a wide slit illuminated by a monochromatic light because **[PPE 1978]**

(a) The half period elements contained in a wide slit are very large so the resultant effect is general illumination
(b) The half period elements contained in a wide slit are small so the resultant effect is general illumination
(c) Diffraction patterns are superimposed by interference pattern and hence the result is general illumination
(d) None of these

**164.** In the far field diffraction pattern of a single slit under polychromatic illumination, the first minimum with the wavelength $\lambda_1$ is found to be coincident with the third maximum at $\lambda_2$. So

(a) $3\lambda_1 = 0.3\lambda_2$ (b) $3\lambda_1 = \lambda_2$ (c) $\lambda_1 = 3.5\lambda_2$ (d) $0.3\lambda_1 = 3\lambda_2$

**165.** In case of Fresnel diffraction

(a) Both source and screen are at finite distance from diffracting device
(b) Source is at finite distance while screen at infinity from diffraction device
(c) Screen is at finite distance while source at infinity from diffracting device
(d) Both source and screen are effectively at infinity from diffracting device

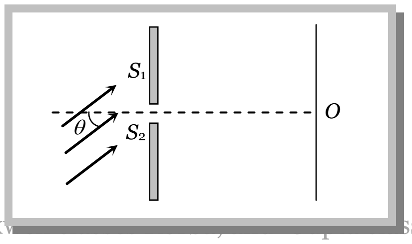
**166.** Light of wavelength $\lambda$ = 5000 $\mathring{A}$ falls normally on a narrow slit. A screen placed at a distance of 1 *m* from the slit and perpendicular to the direction of light. The first minima of the diffraction pattern is situated at 5 *mm* from the centre of central maximum. The width of the slit is

(a) 0.1 *mm* (b) 1.0 *mm* (c) 0.5 *mm* (d) 0.2 *mm*

**167.** Light falls normally on a slit of width 0.3 *mm*. A lens of focal length 40 *cm* collects the rays at its focal plane. The distance of the first dark band from the direct one is 0.8 *mm*. The wavelength of light is

(a) 4800 Å (b) 5000 Å (c) 6000 Å (d) 5896 Å

**168.** A parallel monochromatic beam of light is incident at an angle $\theta$ to the normal of a slit of width *e*. The central point *O* of the screen will be dark if




(a) $e\sin\theta = n\lambda$ where *n* = 1, 3, 5 ...
(b) $e\sin\theta = n\lambda$ where *n* = 1, 2, 3 ...
(c) $e\sin\theta = (2n-1)\lambda/2$ where *n* = 1, 2, 3 ......

(d) $e\cos\theta = n\lambda$ where $n$ = 1, 2, 3, 4 ........

## *Polarization of Light*

**169.** The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refraction index $n$) is **[AIEEE 2004]**

(a) $\sin^{-1}(n)$ (b) $\sin^{-1}\left(\frac{1}{n}\right)$ (c) $\tan^{-1}\left(\frac{1}{n}\right)$ (d) $\tan^{-1}(n)$

**170.** Through which character we can distinguish the light waves from sound waves **[CBSE PMT 1990; RPET 2002]**

(a) Interference (b) Refraction (c) Polarisation (d) Reflection

**171.** Which of following can not be polarised **[Kerala PMT 2001]**

(a) Radio waves (b) Ultraviolet rays (c) Infrared rays (d) Ultrasonic waves

**172.** A polaroid is placed at 45° to an incoming light of intensity $I_0$. Now the intensity of light passing through polaroid after polarisation would be **[CPMT 1995]**

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

**173.** Plane polarised light is passed through a polaroid. On viewing through the polaroid we find that when the polariod is given one complete rotation about the direction of the light, one of the following is observed **[MNR 1993]**

(a) The intensity of light gradually decreases to zero and remains at zero

(b) The intensity of light gradually increases to a maximum and remains at maximum

(c) There is no change in intensity

(d) The intensity of light is twice maximum and twice zero

**174.** Out of the following statements which is not correct **[CPMT 1991]**

(a) When unpolarised light passes through a Nicol's prism, the emergent light is elliptically polarised

(b) Nicol's prism works on the principle of double refraction and total internal reflection

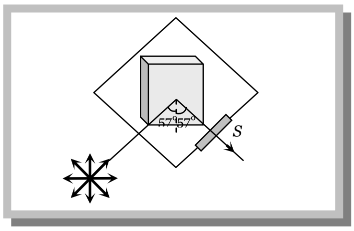
(c) Nicol's prism can be used to produce and analyse polarised light

(d) Calcite and Quartz are both doubly refracting crystals

**175.** A ray of light is incident on the surface of a glass plate at an angle of incidence equal to Brewster's angle $\phi$. If $\mu$ represents the refractive index of glass with respect to air, then the angle between reflected and refracted rays is **[CPMT 1989]**

(a) $90+\phi$ (b) $\sin^{-1}(\mu\cos\phi)$ (c) 90° (d) $90^o - \sin^{-1}(\sin\phi/\mu)$

**176.** Figure represents a glass plate placed vertically on a horizontal table with a beam of unpolarised light falling on its surface at the polarising angle of 57° with the normal. The electric vector in the reflected light on screen $S$ will vibrate with respect to the plane of incidence in a **[CPMT 1988]**



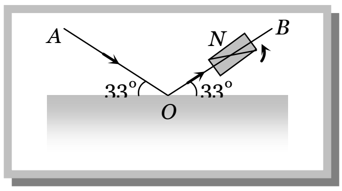

(a) Vertical plane

(b) Horizontal plane

(c) Plane making an angle of 45° with the vertical

(d) Plane making an angle of 57° with the horizontal

**177.** A beam of light $AO$ is incident on a glass slab $(\mu = 1.54)$ in a direction as shown in figure. The reflected ray $OB$ is passed through a Nicol prism on viewing through a Nicole prism, we find on rotating the prism that **[CPMT 1986]**




(a) The intensity is reduced down to zero and remains zero

(b) The intensity reduces down some what and rises again

(c) There is no change in intensity

(d) The intensity gradually reduces to zero and then again increases

**178.** Polarised glass is used in sun glasses because **[CPMT 1981]**

(a) It reduces the light intensity to half an account of polarisation (b) It is fashionable

(c) It has good colour (d) It is cheaper

**179.** In the propagation of electromagnetic waves the angle between the direction of propagation and plane of polarisation is **[CPMT 1978]**

(a) 0° (b) 45° (c) 90° (d) 180°

**180.** The transverse nature of light is shown by

**[CPMT 1972, 74, 78; RPMT 1999; MP PMT 2000; AFMC 2001; AIEEE 2002; MP PET 2004]**

(a) Interference of light (b) Refraction of light (c) Polarisation of light (d) Dispersion of light

**181.** A calcite crystal is placed over a dot on a piece of paper and rotated, on seeing through the calcite one will be see **[CPMT 1971]**

(a) One dot (b) Two stationary dots
(c) Two rotating dots (d) One dot rotating about the other

**182.** In a doubly refracting crystal, optic axis is a direction along which

(a) A plane polarised beam does not suffer deviation
(b) Any beam of light does not suffer any deviation
(c) Double refraction does not take place
(d) Ordinary and extraordinary rays undergo maximum deviation

**183.** Which is incorrect with reference to polarisation by reflection

(a) The degree of polarisation varies with the angle of incidence
(b) Percentage of the polarising light in the reflected beam is the greatest at the angle of polarisation
(c) Reflected light is plane polarised in the plane of incidence
(d) Reflected light is plane polarised in the plane perpendicular to plane of incidence

**184.** Two polarising plates have polarising directions parallel so as to transmit maximum intensity of light. Through what angle must either plate be turned if the intensities of the transmitted beam is to drop by one-third

(a) 55°18' (b) 144°22' (c) Both of these (d) None of these

**185.** The polaroid is

(a) Celluloid film (b) Big crystal
(c) Cluster of small crystals arranged in a regular way (d) Cluster of small crystals arranged in a haphazard way

**186.** Light from the cloudless sky is

(a) Fully polarised (b) Partially polarised (c) Unpolarised (d) Can not be said

## *Doppler's Effect of Light*

**187.** The observed wavelength of light coming from a distant galaxy is found to be increased by 0.5% as compared with that comparing from a terrestrial source. The galaxy is **[MP PMT 1993, 2003]**

(a) Stationary with respect to the earth
(b) Approaching the earth with velocity of light
(c) Receding from the earth with the velocity of light
(d) Receding from the earth with a velocity equal to $1.5 \times 10^6 m/s$

**188.** In hydrogen spectrum the wavelength of $H_\alpha$ line is 656 *nm* whereas in the spectrum of a distant galaxy. $H_\alpha$ line wavelength is 706*nm*. Estimated speed of the galaxy with respect to earth is **[IIT-JEE 1999; UPSEAT 2003]**

(a) $2 \times 10^8 m/s$ (b) $2 \times 10^7 m/s$ (c) $2 \times 10^6 m/s$ (d) $2 \times 10^5 m/s$

**189.** A star emits light of 5500 *Å* wavelength. Its appears blue to an observer on the earth, it means **[DPMT 2002]**

(a) Star is going away from the earth (b) Star is stationary
(c) Star is coming towards earth (d) None of the above

**190.** The 6563 Å line emitted by hydrogen atom in a star is found to be red shifted by 5 Å. The speed with which the star is receding from the earth is **[Pb. PMT 2002]**

(a) $17.29 \times 10^9 m/s$ (b) $4.29 \times 10^7 m/s$ (c) $3.39 \times 10^5 m/s$ (d) $2.29 \times 10^5 m/s$

**191.** Three observers *A*, *B* and *C* measure the speed of light coming from a source to be $v_A$, $v_B$ and $v_C$. The observer *A* moves towards the source, the observer *C* moves away from the source with the same speed. The observer *B* stays stationary. The surrounding space is vacuum very where. Then **[Kerala CET (Med.) 2002]**

(a) $v_A > v_B > v_C$ (b) $v_A < v_B < v_C$ (c) $v_A = v_B = v_C$ (d) $v_A = v_B > v_C$

**192.** A star emitting light of wavelength 5896 Å is moving away from the earth with a speed of 3600 *km/sec*. The wavelength of light observed on earth will ( $c = 3 \times 10^8 m/\sec$ is the speed of light) **[MP PET 1995, 2002]**

(a) Decrease by 5825.25 Å (b) Increase by 5966.75 Å (c) Decrease by 70.75 Å (d) Increase by 70.75 Å

**193.** The periodic time of rotation of a certain star is 22 days and its radius is $7 \times 10^8 m$. If the wavelength of light emitted by its surface be 4320 Å, the Doppler shift will be (1 day = 86400 *sec*) **[MP PET 2001]**

(a) 0.033 Å (b) 0.33 Å (c) 3.3 Å (d) 33 Å

**194.** A heavenly body is receding from earth such that the fractional change in $\lambda$ is 1, then its velocity is **[DCE 2000]**

(a) $C$ (b) $\frac{3C}{5}$ (c) $\frac{C}{5}$ (d) $\frac{2C}{5}$

**195.** A star is going away from the earth. An observer on the earth will see the wavelength of light coming from the star **[MP PMT 1999]**

(a) Decreased

(b) Increased

(c) Neither decreased nor increased

(d) Decreased or increased depending upon the velocity of the star

**196.** If the shift of wavelength of light emitted by a star is towards violet, then this shows that star is **[RPET 1996; RPMT 1999]**

(a) Stationary (b) Moving towards earth (c) Moving away from earth (d) Information is incomplete

**197.** When the wavelength of light coming from a distant star is measured it is found shifted towards red. Then the conclusion is **[JIPMER 1999]**

(a) The star is approaching the observer (b) The star recedes away from earth

(c) There is gravitational effect on the light (d) The star remains stationary

**198.** In the spectrum of light of a luminous heavenly body the wavelength of a spectral line is measured to be 4747 Å while actual wavelength of the line is 4700 Å. The relative velocity of the heavenly body with respect to earth will be (velocity of light is $3\times10^8 m/s$) **[MP PET 1997; MP PMT/PET 1998]**

(a) $3\times10^5 m/s$ moving towards the earth (b) $3\times10^5 m/s$ moving away from the earth

(c) $3\times10^6 m/s$ moving towards the earth (d) $3\times10^6 m/s$ moving away from the earth

**199.** The wavelength of light observed on the earth, from a moving star is found to decrease by 0.05%. Relative to the earth the star is **[MP PMT/PET 1998]**

(a) Moving away with a velocity of $1.5\times10^5 m/s$ (b) Coming closer with a velocity of $1.5\times10^5 m/s$

(c) Moving away with a velocity of $1.5\times10^4 m/s$ (d) Coming closer with a velocity of $1.5\times10^4 m/s$

**200.** Due to Doppler's effect, the shift in wavelength observed is 0.1 Å for a star producing wavelength 6000 Å. Velocity of recession of the star will be **[KCET 1998]**

(a) 2.5 *km/s* (b) 10 *km/s* (c) 5 *km/s* (d) 20 *km/s*

**201.** A rocket is going away from the earth at a speed of $10^6 m/s$. If the wavelength of the light wave emitted by it be 5700 Å, what will be its Doppler's shift **[MP PMT 1990, 94; RPMT 1996]**

(a) 200 Å (b) 19 Å (c) 20 Å (d) 0.2 Å

**202.** A rocket is going away from the earth at a speed 0.2 *c*, where *c* = speed of light, it emits a signal of frequency $4\times10^7 Hz$. What will be the frequency observed by an observer on the earth **[RPMT 1996]**

(a) $4\times10^6 Hz$ (b) $3.3\times10^7 Hz$ (c) $3\times10^6 Hz$ (d) $5\times10^7 Hz$

**203.** A star moves away from earth at speed 0.8 *c* while emitting light of frequency $6\times10^{14} Hz$. What frequency will be observed on the earth (in units of $10^{14} Hz$) (*c* = speed of light) **[MP PMT 1995]**

(a) 0.24 (b) 1.2 (c) 30 (d) 3.3

**204.** The sun is rotating about its own axis. The spectral lines emitted from the two ends of its equator, for an observer on the earth, will show **[MP PMT 1994]**

(a) Shift towards red end

(b) Shift towards violet end

(c) Shift towards red end by one line and towards violet end by other

(d) No shift

**205.** The time period of rotation of the sun is 25 days and its radius is $7\times10^8 m$. The Doppler shift for the light of wavelength 6000 Å emitted from the surface of the sun will be **[MP PMT 1994]**

(a) 0.04 Å (b) 0.40 Å (c) 4.00 Å (d) 40.0 Å

**206.** The apparent wavelength of the light from a star moving away from the earth is 0.01 % more than its real wavelength. Then the velocity of star is **[CPMT 1979]**

(a) 60 *km/sec* (b) 15 *km/sec* (c) 150 *km/sec* (d) 30 *km/sec*

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| **a** | **d** | **c** | **d** | **b** | **a** | **c** | **c** | **b** | **c** | **d** | **c** | **d** | **a** | **b** | **c** | **d** | **a** | **c** | **c** |
| **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** | **40** |
| **c** | **b** | **b** | **c** | **a** | **d** | **c** | **d** | **a** | **d** | **b** | **b** | **c** | **b** | **c** | **d** | **c** | **c** | **a** | **b** |
| **41** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **49** | **50** | **51** | **52** | **53** | **54** | **55** | **56** | **57** | **58** | **59** | **60** |
| **c** | **d** | **c** | **c** | **a** | **d** | **a** | **b** | **c** | **a** | **d** | **d** | **c** | **a** | **b** | **b** | **a** | **d** | **a** | **d** |
| **61** | **62** | **63** | **64** | **65** | **66** | **67** | **68** | **69** | **70** | **71** | **72** | **73** | **74** | **75** | **76** | **77** | **78** | **79** | **80** |
| **c** | **d** | **c** | **c** | **c** | **b** | **b** | **c** | **b** | **a** | **b, c** | **b** | **d** | **b** | **c** | **b** | **d** | **d** | **b** | **a** |
| **81** | **82** | **83** | **84** | **85** | **86** | **87** | **88** | **89** | **90** | **91** | **92** | **93** | **94** | **95** | **96** | **97** | **98** | **99** | **100** |
| **a** | **a** | **b** | **a** | **b** | **d** | **b** | **b** | **b** | **d** | **a** | **c** | **c** | **c** | **c** | **a** | **b** | **b** | **d** | **b,d** |
| **101** | **102** | **103** | **104** | **105** | **106** | **107** | **108** | **109** | **110** | **111** | **112** | **113** | **114** | **115** | **116** | **117** | **118** | **119** | **120** |
| **c** | **c** | **a** | **d** | **b** | **d** | **a** | **a,b** | **a,c** | **a** | **a** | **b** | **a** | **a,d** | **c** | **a** | **d** | **b** | **a** | **b** |
| **121** | **122** | **123** | **124** | **125** | **126** | **127** | **128** | **129** | **130** | **131** | **132** | **133** | **134** | **135** | **136** | **137** | **138** | **139** | **140** |
| **c** | **a** | **a** | **c** | **a** | **c** | **d** | **c** | **c** | **a** | **a** | **b** | **b** | **c** | **d** | **d** | **c** | **b** | **d** | **d** |
| **141** | **142** | **143** | **144** | **145** | **146** | **147** | **148** | **149** | **150** | **151** | **152** | **153** | **154** | **155** | **156** | **157** | **158** | **159** | **160** |
| **c** | **a** | **b** | **a** | **b** | **a** | **b** | **d** | **d** | **b** | **a** | **c** | **b** | **a** | **d** | **c** | **c** | **c** | **c** | **a** |
| **161** | **162** | **163** | **164** | **165** | **166** | **167** | **168** | **169** | **170** | **171** | **172** | **173** | **174** | **175** | **176** | **177** | **178** | **179** | **180** |
| **b** | **b** | **a** | **c** | **a** | **a** | **c** | **b** | **d** | **c** | **d** | **b** | **d** | **a** | **c** | **a** | **d** | **a** | **a** | **c** |
| **181** | **182** | **183** | **184** | **185** | **186** | **187** | **188** | **189** | **190** | **191** | **192** | **193** | **194** | **195** | **196** | **197** | **198** | **199** | **200** |
| **d** | **c** | **c** | **c** | **c** | **d** | **d** | **b** | **c** | **d** | **c** | **d** | **a** | **a** | **b** | **b** | **b** | **d** | **b** | **c** |
| **201** | **202** | **203** | **204** | **205** | **206** | | | | | | | | | | | | | | |
| **b** | **b** | **b** | **c** | **a** | **d** | | | | | | | | | | | | | | |