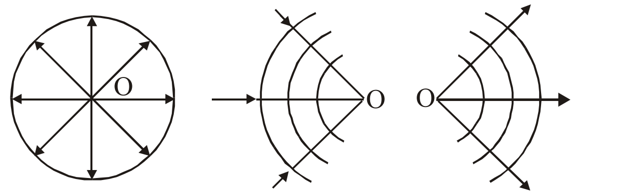
Chapter 25

Wave Optics

WAVEFRONT

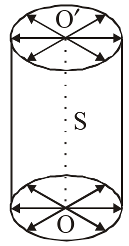
The locus of all particles of the medium vibrating in the same phase at a given instant is called a wavefront. Depending on the shape of source of light, **wavefront can be of three types.**

(i) Spherical wavefront: A spherical wavefront is produced by a point source of light. This is because the locus of all such points which are equidistant from the point source will be a sphere. Spherical wavefronts are further divided into two headings: (i) converging spherical and (ii) diverging spherical wavefront.



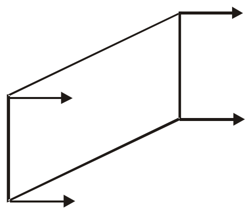
Spherical wavefront — Converging spherical wavefront — Diverging spherical wavefront

(ii) Cylindrical wavefront: When the source of light is linear in shape such as a slit, the cylindrical wavefront is produced. This is because all the points equidistant from a line source lie on the surface of a cylinder.



Cylindrical wavefront

(iii) Plane wavefront: A small part of a spherical or cylindrical wavefront due to a distant source will appear plane and hence it is called plane wave-front. The wavefront of parallel rays is a plane wavefront.



Plane wavefront

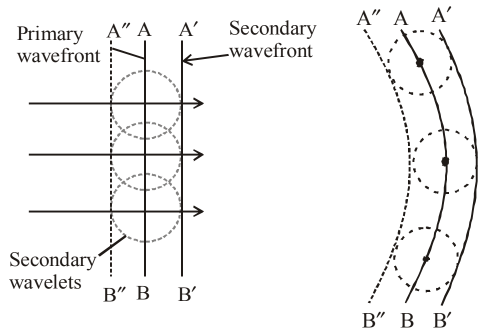
HUYGENS WAVE THEORY

(Geometrical method to find the secondary wavefront)

(i) Each point source of light is a centre of disturbance from which waves spread in all directions.

(ii) Each point on primary wavelets acts as a new source of distrubance and produces secondary wavelets which travel in space with the speed of light.

(iii) The forward envelope of the secondary wavelets at any instant gives the new wavefront.



(iv) In a homogeneous medium the wavefront is always perpendicular to the direction of wave propagation.

Note : With the help of Huygen's wave theory, law of reflection and refraction, total internal reflection and dispersion can be explained easily. This theory also explain interference, diffraction and polarization successfully.

Drawbacks of Huygens Wave Theory

(a) This theory cannot explain photo-electric effect, compton, and Raman effect.

(b) Hypothetical medium in vacuum is not true imagination.

(c) The theory predicted the presence of back wave, which proved to be failure.

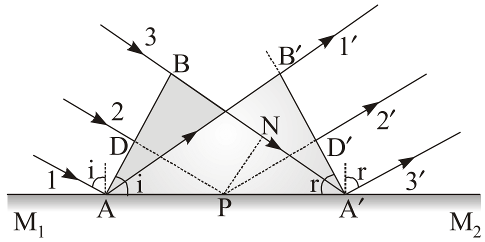
REFLECTION AND REFRACTION OF PLANE WAVES USING HUYGENS PRINCIPLE

Reflection on the Basis of Wave Theory

According to Huygens principle, every point on AB is a source of secondary wavelets. Let the secondary wavelets from B strike reflecting surface M_1M_2 at A′ in t seconds.

$\therefore \quad BA' = c \times t \qquad \ldots$(i)

where c is the velocity of light in the medium.



The secondary wavelets from A will travel the same distance c × t in the same time. Therefore, with A as centre and c × t as radius, draw an arc B′, so that

$AB' = c \times t$ … (ii)

A′B′ is the true reflected wavefront.

angle of incidence, i = $\angle BAA'$

and angle of reflection, r = $\angle B'A'A$

In Δs AA′B and AA′B′,

AA′ is common, $BA' = AB' = c \times t$, and $\angle B = \angle B' = 90°$

∴ Δs are congruent ∴ $\angle BAA' = \angle B'A'A$, *i.e.*, $\angle i = \angle r$ … (iii)

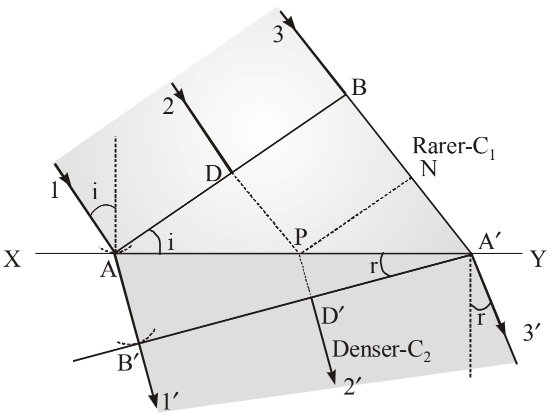
Which is the *first law of reflection*.

Further, the incident wavefront AB, the reflecting surface M_1M_2 and the reflected wavefront A′B′ are all perpendicular to the plane of the paper. Therefore, *incident ray, normal to the mirror M_1M_2 and reflected ray all lie in the plane of the paper. This is second law of reflection.*

Refraction on the Basis of Wave Theory

XY is a plane surface that separates a denser medium of refractive index μ from a rarer medium. If c_1 is velocity of light in rarer medium and c_2 is velocity of light in denser medium, then by definition.

$$\mu = \frac{c_1}{c_2} \quad \ldots (iv)$$



AB is a plane wave front incident on XY at $\angle BAA' = \angle i$. 1, 2, 3 are the corresponding incident rays normal to AB.

According to Huygens principle, every point on AB is a source of secondary wavelets. Let the secondary wavelets from B strike XY at A′ in t seconds.

∴ $BA' = c_1 \times t$ … (v)

The secondary wavelets from A travel in the denser medium with a velocity c_2 and would cover a distance ($c_2 \times t$) in t seconds.

A′B′ is the true refracted wavefront. Let r be the angle of refraction.

As angle of refraction is equal to the angle which the refracted plane wavefront A′B′ makes with the refracting surface AA′, therefore, $\angle AA'B' = r$.

Let $\angle AA'B' = r$, angle of refraction.

In ΔAA′B, $\sin i = \frac{BA'}{AA'} = \frac{c_1 \times t}{AA'}$

In Δ AA′B′, $\sin r = \frac{AB'}{AA'} = \frac{c_2 \times t}{AA'}$

∴ $\frac{\sin i}{\sin r} = \frac{c_1}{c_2} = \mu$ [using (iv)]

Hence $\mu = \frac{\sin i}{\sin r}$ … (vi)

which proves *Snell's law of refraction.*

It is clear from fig. that the incident rays, normal to the interface XY and refracted rays, all lie in the same plane (i.e., in the plane of the paper). This is the second law of refraction.

Hence laws of refraction are established on the basis of wave theory.

Keep in Memory

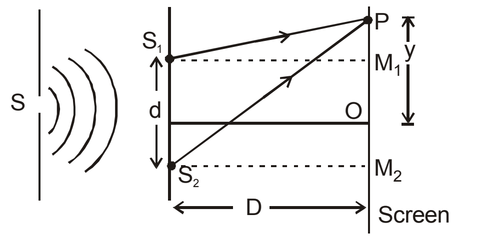
1. In 1873, Maxwell showed that light is an electromegnetic wave i.e. it propagates as transverse non-mechnical wave at speed c in free space given by
$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ ms}^{-1}$$
2. There are some phenomenon of light like photoelectric effect, Compton effect, Raman effect etc. which can be explained only on the basis of particle nature of light.
3. Light shows the dual nature i.e. particle as well as wave nature of light. But the wave nature and particle nature both cannot be possible simultaneously.
4. Interference and diffraction are the two phenomena that can be explained only on the basis of wave nature of light.

INTERFERENCE OF LIGHT WAVES AND YOUNG'S DOUBLE SLIT EXPERIMENT

The phenomenon of redistribution of light energy in a medium on account of superposition of light waves from two coherent sources is called ***interference of light waves****.*

Young performed the experiment by taking two coherent sources of light. Two source of light waves are said to be coherent if the initial phase difference between the waves emitted by the source remains constant with time.

(i) The rays of light from two coherent sources S_1 and S_2 superpose each other on the screen forming alternately maxima and minima (constructive and destructive interference).



(ii) Let the equation of waves travelling from S_1 & S_2 are

$y_1 = A_1 \text{Sin } \omega t$ ...(1)

$y_2 = A_2 \text{Sin } \omega t$ ...(2)

where A_1 & A_2 are amplitudes of waves starting from S_1 & S_2 respectively. These two waves arrive at P by traversing different distances S_2P & S_1P. Hence they are superimposed with a phase difference (at point P) given by

$$\delta(\text{phase difference}) = \frac{2\pi}{\lambda}\times\Delta(\text{path difference})$$

$$= \frac{2\pi}{\lambda}(S_2P - S_1P). \quad ....(3)$$

where S_2P (from fig) $= D^2 + \left(y + \frac{d}{2}\right)^2$

$$\approx D + \frac{1}{2}\frac{(y+d/2)^2}{2D} \quad [\because D >> (y+d)]$$

Similarly, $S_1P \approx D + \frac{(y-d/2)^2}{4D}$

so, $S_2P - S_1P = \frac{yd}{D}$ ....(4)

(A) Conditions for maximum & minimum intensity :

(i) **Conditions for maximum intensity or constructive interference :** If phase difference

$\delta = 0, 2\pi, 4\pi --- 2n\pi$

or, path difference $\Delta = S_2P - S_1P = 0, \lambda, 2\lambda --- n\lambda$

then resultant intensity at point P due two waves emanating from S_1 & S_2 is

$$I = A^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\delta \quad (\because I \propto A^2)$$

or $I = (A_1 + A_2)^2$

or $I = I_1 + I_2 + 2\sqrt{I_1I_2}$ ....(5)

It means that resultant intensity is greater than the sum of individual intensity (where A is the amplitude of resultant wave at point P).

(ii) **Conditions for minimum intensity or destructive interference :** If phase difference,

$\delta = \pi, 3\pi, 5\pi ---- (2n+1)\pi$

or, path difference

$$\Delta = S_2P - S_1P = \frac{\lambda}{2}, \frac{3\lambda}{2} --- (2n+1)\frac{\lambda}{2}$$

then resultant intensity at point P is

$$I = A^2 = A_1^2 + A_2^2 - 2A_1A_2\cos\delta$$

or $I = (A_1 - A_2)^2$

or $I = I_1 + I_2 - 2\sqrt{I_1}\sqrt{I_2}$ ...(6)

It means that resultant intensity I is less than the sum of individual intensities. Now as the position of point P on the screen changes, then the path difference at point P due to these two waves also changes & intensity alternately becomes maximum or minimum. These bright fringes (max. intensity) & dark fringes (min. intensity) make an interference pattern.

It must be clear that there is no loss of energy (at dark fringe) & no gain of energy (at bright fringe), but, only there is a redistribution of energy.

The shape of fringe obtained on the screen is approximately linear.

(B) Position of fringe:

(i) If $\Delta = S_2P - S_1P = n\lambda$, then we obtain bright fringes at point P on the screen and it corresponds to constructive interference. So from equation (4) the position of n^{th} bright fringe

$$\Delta = S_2P - S_1P = n\lambda = \frac{yd}{D}$$

or $y = \left(\frac{nD}{d}\right)\lambda$ ...(7)

(Position of n^{th} bright fringe)

(ii) If $\Delta = S_2P - S_1P = (2n+1)\frac{\lambda}{2}$, then we obtain dark fringe at point P on the screen and corresponds to destructive interference. So from equation(4), the position of, n^{th} dark fringe is

$$\Delta = S_2P - S_1P = (2n+1)\frac{\lambda}{2} = \frac{yd}{D}$$

or $y = \frac{(2n+1)D\lambda}{2d}$ ...(8)

(Position of n^{th} dark fringe)

(C) Spacing or fringe width :

Let y_n and y_{n+1} are the distance of n^{th} and $(n+1)^{th}$ bright fringe from point O then

$$y_n = \frac{Dn\lambda}{d} \quad \& \quad y_{n+1} = \frac{D(n+1)\lambda}{d}$$

So spacing β between n^{th} and $(n+1)^{th}$ bright fringe is

$$\beta = y_{n+1} - y_n = \frac{D\lambda}{d} \quad ...(9)$$

Since it is independent of n, so fringe width or spacing between any two consecutive bright fringes is same. Similarly the fringe width between any two consecutive dark fringe is

$$\beta = \frac{D\lambda}{d} \quad ...(10)$$

(D) Conditions for sustained interference:

(i) The two sources should be coherent i.e they should have a constant phase difference between them.

(ii) The two sources should give light of same frequency (or wavelength).

(iii) If the interfering waves are polarized, then they must be in same state of polarization.

(E) Conditions for good observation of fringe:

(i) The distance between two sources i.e. d should be small.

(ii) The distance of screen D from the sources should be quite large.

(iii) The two interfering wavefronts must intersect at a very small angle.

(F) Conditions for good contrast of fringe :

(i) Sources must be monochromatic i.e they emit waves of single wavelength.

(ii) The amplitude of two interfering waves should be equal or nearly equal.

(iii) Both sources must be narrow.

(iv) As Intensity I is directly proportional to the square of amplitude, hence Intensity of resultant wave at P,

$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$; if $I_1 = I_2 = I_0$., then

$I = 4I_0 \cos^2\left(\phi/2\right)$

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

If $I_1 = I_2 = I_0$, then $I_{max} = 4I_0$

$I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$, if $I_1 = I_2 = I_0$, then $I_{min} = 0$

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

(vii) Angular fringe-width $\theta_0 = \frac{\beta}{D} = \frac{\lambda}{d}$

(viii) The width of all interference fringes are same. Since fringe width β is proportional to λ, hence fringes with red light are wider than those for blue light.

(ix) If the interference experiment is performed in a medium of refractive index μ instead of air, the wavelength of light will change from λ to $\frac{\lambda}{\mu}$.

i.e. $\beta' = \frac{D}{d}\left(\frac{\lambda}{\mu}\right) = \frac{\beta}{\mu}$

(x) If a transparent sheet of refractive index μ and thickness t is introduced in one of the paths of interfering waves, then due to its presence optical path will become μt instead of t. Due to this a given fringe from present position shifts to a new position. So the lateral shift of the fringe,

$$y_0 = \frac{D}{d}(\mu - 1)t = \frac{\beta}{\lambda}(\mu - 1)t$$

(xi) In **Young's double slit experiment** (coherent sources in phase): Central fringe is a bright fringe. It is on the prerpendicular bisector of coherent sources. Central fringe position is at a place where two waves having equal phase superpose.

(xii) Young's experiment with the white light will give white central fringe flanked on either side by coloured bands.

COHERENCE

The phase relationship between two light waves can very from time to time and from point to point in space. The property of definite phase relationship is called coherence.

1. Temporal coherence : A light wave (photon) is produced when an excited atom goes to the ground state and emits light.

(i) The duration of this transition is about 10^{-9} to 10^{-10} sec. Thus the emitted wave remains sinusoidal for this much time. This time is known as coherence time (τ_c).

(ii) Definite phase relationship is maintained for a length $L = c\tau_c$ called coherence length.

For neon $\lambda = 6238$ Å, $\tau_c \approx 10^{-10}$ sec. and L = 0.03 m.

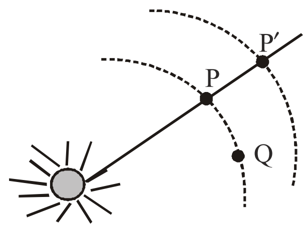
For cadmium $\lambda = 6238$ Å, $\tau_c = 10^{-9}$ and L = 0.3 m

For Laser $\tau_c = 10^{-5}$ sec and L = 3 km.

(iii) The spectral lines width $\Delta\lambda$ is related to coherence length L and coherence time τ_c.

$$\Delta\lambda \approx \frac{\lambda^2}{c\tau_c} \quad \text{or} \quad \Delta\lambda \approx \frac{\lambda^2}{L}$$

2. Spatial coherence : Two points in space are said to be spatially coherence if the waves reaching there maintains a constant phase difference. Points P and Q are at the same distance from S, they will always be having the same phase. Points P and P′ will be spatially coherent if the distance between P and P′ is much less than the coherence length i.e. $PP' << c\tau_c$



Methods of Obtaining Coherent Sources

Two coherent sources are produced from a single source of light by two methods :

(i) By division of wavefront and (ii) By division of amplitude.

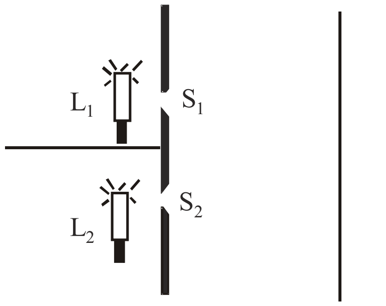
(i) Division of wavefront : The wavefront emitted by a narrow source is divided in two parts by reflection, refraction or diffraction. The coherent sources so obtained are imaginary. **Example :** Fresnel's biprism, Llyod's mirror, Young's double slit, etc.

(ii) Division of amplitude : In this arrangement light wave is partly reflected (50%) and partly transmitted (50%) to produced two light rays. The amplitude of wave emitted by an extended source of light is divided in two parts by partial reflection and partial refraction. The coherent sources obtained are real and are obtained in Newton's rings, Michelson's interferometer, etc.

Incoherence of Two Conventional Light Sources

Let two conventional light sources L_1 and L_2 (like two sodium lamps or two monochromatic bulbs) illuminate two pin holes S_1 and S_2. Then we will find that no interference pattern is seen on the screen.

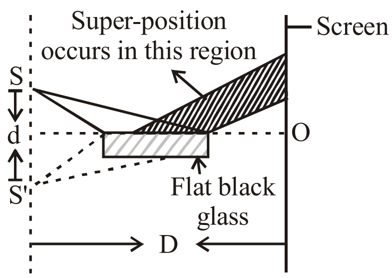
The reason is as follows : In conventional light source, light comes from a large number of independent atoms, each atom emitting light for about 10^{-9} seconds i.e., light emitted by an atom is essentially a pulse lasting for only 10^{-9} seconds.



Even if all the atoms were emitting light pulses under similar conditions, waves from different atoms would differ in their initial phases. Consequently light coming out from the holes S_1 and S_2 will have a fixed phase relationship only for 10^{-9} sec. Hence any interference pattern formed on the screen would last only for 10^{-9} sec. (a billionth of a second), and then the pattern will change. The human eye can notice intensity changes which last at least for a tenth of a second and hence we will not be able to see any interference pattern. Instead due to rapid changes in the pattern, we will only observe a uniform intensity over the screen.

Lloyd's Mirror

The two sources are slit S (parallel to mirror) and its virtual image S′.



Lloyd mirror arrangement

(i) If screen is moved so that, point O touches the edge of glass plate, the geometrical path difference for two wave trains is zero. The phase change of π radian on reflection at denser medium causes a dark fringe to be formed.

- The fring width remains unchanged on introduction of transparent film.
- If the film is placed in front of upper slit S_1, the fringe pattern will shift upwards. On the other hand if the film is placed in front of lower slit S_2, the fringe pattern shifts downwards.

(ii) This interference pattern is frequently seen in a ripple tank when one uses a wave train to demonstrate the law of reflection.

(iii) In this case, fringe width $\beta = \frac{D\lambda}{d}$

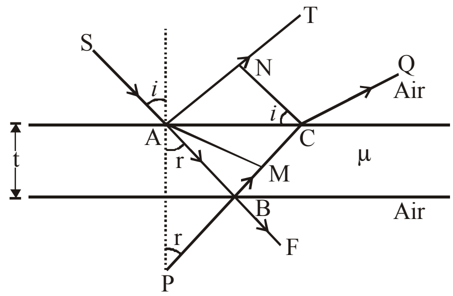
Optical path : (Equivalent path in vacuum or air) In case of medium of refractive index μ and thickness t, the optical path = μt.

Interference in Thin Films

We are familiar with the colours produced by a thin film of oil on the surface of water and also by the thin film of a soap bubble. Hooke observed such colours in thin films of mica and similar thin transparent plates. Young was able to explain the phenomenon on the basis of interference between light reflected from the top and bottom surface of a thin film. It has been observed that interference in the case of thin films takes place due to
(i) *reflected light and* (ii) *transmitted light*.

Interference due to reflected light

From the figure, the optical path difference between the reflected ray (AT) from the top surface and the reflected ray (CQ) from the bottom surface can be calculated. Let it be x, then



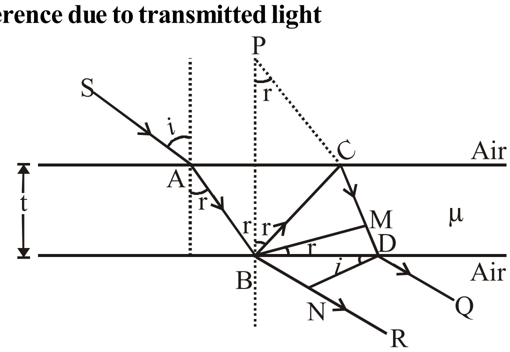
$$x = \mu(AB + BC) - AN$$

On simplification, we get

$$x = 2\mu t \cos r$$

1. If $2\mu t \cos r = (2n+1)\frac{\lambda}{2}$, where n = 0,1,2, ...then **constructive interference** takes place and the film appears bright.
2. If $2\mu t \cos r = n\lambda$, where n = 0, 1, 2, 3,............ then destructive interference takes place and the film appears dark.

Interference due to transmitted light



The optical path difference between the reflected ray (DQ) and the transmitted ray (NR) is given by

$$x = \mu(BC + CD) - BN$$

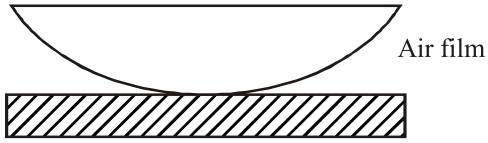
On simplification, we get

$$x = 2\mu t \cos r$$

1. If $2\mu t \cos r = n\lambda$, where n = 0, 1, 2, 3, ...then **constructive interference** takes place and the film appears bright.
2. If $2\mu t \cos r = (2n+1)\frac{\lambda}{2}$, n = 0, 1, 2, ... then **destructive interference** takes place and the film appears dark.

Newton's Rings

Newton observed the formation of interference rings when a plano-convex lens is placed on a plane glass plate. When viewed with white light, the fringes are coloured while with monochromatic light, the fringes are bright and dark. These fringes are produced due to interference between the light reflected from the lower surface of the lens and the upper surface of the glass plate. Interference can also take place due to transmitted light.

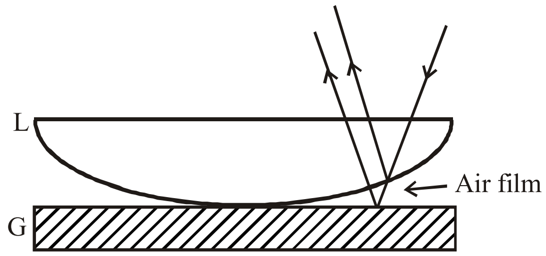


Newton's rings by reflected light :

Here, interference takes place due to reflected light. Therefore, for bright rings,

$$2\mu t\cos\theta = (2n-1)\frac{\lambda}{2} \text{ where } n = 1, 2, 3, ...$$

And for dark rings, $2\mu t\cos\theta = n\lambda,\ n = 1, 2, 3,\ ......$



Proceeding further, we get the radius of rings as follows:

For bright rings, $r = \sqrt{\frac{(2n-1)\lambda R}{2}}$

For dark rings, $r = \sqrt{n\lambda R}$, where R = radius of curvature of lens.

Note :

(i) The centre is dark and alternately dark and bright rings are produced.

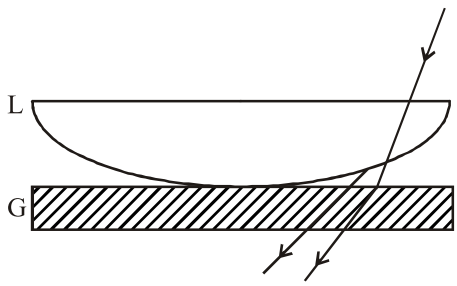
(ii) While counting the order of the dark rings 1, 2, 3, etc. the central ring is not counted. Therefore,

for 1st dark ring, n = 1 and $r_1 = \sqrt{\lambda R}$

for 2nd dark ring, n = 2 and $r_2 = \sqrt{2\lambda R}$

Newton's rings by transmitted light

Here, interference takes place due to transmitted light.



Therefore,

For bright rings, $2\mu t\cos\theta = n\lambda,\ n = 0, 1, 2, ...$

For dark rings, $2\mu t\cos\theta = (2n-1)\frac{\lambda}{2},\ n = 0, 1, 2, ...$

Proceeding further, we get Radius of bright ring,

$$r = \sqrt{\frac{(2n-1)\lambda R}{2}}$$

Note :

(i) The centre is bright and alternately bright and dark rings are obtained.

(ii) The ring pattern due to reflected light is just opposite to that of transmitted light.

Keep in Memory

1. If D_n and D_{n+m} be the diameters of n th and (n + m)th dark rings then the wavelength of light used is given by

$$\lambda = \frac{(D_{n+m})^2 - (D_n)^2}{4mR}$$

where, R is the radius of curvature of the lens.

2. If D_n = diameter of nth dark ring when air is present betwen the glass plate and the lens

D_{n+m} = diameter of (n+m)th dark ring when air is present between the glass plate and the lens

D'_n = diameter of n th dark ring when a liquid is poured between the plate and the lens

D'_{n+m} = diameter of (n+m)th dark ring when a liquid is poured between the plate and the lens

Then the refractive index of the liquid is given by

$$\mu = \frac{(D_{n+m})^2 - (D_n)^2}{(D'_{n+m})^2 - (D'_n)^2} \text{ or,}$$

$$\mu = \frac{4m\lambda R}{(D'_{n+m})^2 - (D'_n)^2}$$

Example 1.

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

Solution :

For dark fringes, $x = (2n-1)\frac{\lambda D}{2d}$

$$\therefore\ \lambda = \frac{2\,x\,d}{(2n-1)D} = \frac{2\times10^{-3}\times0.9\times10^{-3}}{(2\times2-1)\times1}$$

or, $\lambda = 0.6\times10^{-6}\text{ m} = 6\times10^{-5}\text{ cm}.$

Example 2.

Two beam of light having intensities I and 4 I interfere to produce a fringe pattern on a screen. The phase difference between the beams is π/2 at point A and π at point B. Then find the difference between the resultant intensities at A and B.

Solution :

Here, $I_1 = I;\ I_2 = 4I;\ \theta_1 = \pi/2,\ \theta_2 = \pi$

$$I_A = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\theta_1$$

$$= I + 4I + 2\sqrt{I \times 4\,I}\cos\pi/2 = 5I$$

$$I_B = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\theta_2$$

$$= I + 4I + 2\sqrt{I4I}\cos\pi = 5I - 4I = I\,;$$

$$\therefore\ I_A - I_B = 5I - I = 4I$$

Example 3.

In a biprism experiment, 5th dark fringe is obtained at a point. If a thin transparent film is placed in the path of one of waves, then 7th bright fringe is obtained at the same point. Determine the thickness of the film in terms of wavelength λ and refractive index μ.

Solution :

For 5th dark fringe, $x_1 = (2n-1)\frac{\lambda}{2}\frac{D}{d} = \frac{9\lambda D}{2d}$

For 7th bright fringe, $x_2 = n\lambda\frac{D}{d} = \frac{7\lambda D}{d}$

but $x_2 - x_1 = (\mu-1)t\frac{D}{d}\ ;\ \frac{\lambda D}{d}\left[7 - \frac{9}{2}\right] = (\mu-1)t\frac{D}{d}$

$\therefore$ Thickness, $t = \frac{2.5\lambda}{(\mu-1)}$

Example 4.

In Young's experiment, the interference pattern is found to have an intensity ratio between the bright and dark fringes as 9. What is the ratio of (a) intensities (b) amplitudes of the two interfering waves ?

Solution :

In case of interference, $I = I_1 + I_2 + 2\left(\sqrt{I_1 I_2}\right)\cos\phi$

(a) For I to be maximum and minimum $\cos\phi$ is 1 and –1 respectively, i.e.,

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

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

According to given problem,

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

i.e., $\frac{I_{max}}{I_{min}} = \frac{\sqrt{I_1} + \sqrt{I_2}}{\sqrt{I_1} - \sqrt{I_2}} = \frac{3}{1}$

By comonendo and dividendo,

$$\frac{\sqrt{I_1}}{\sqrt{I_2}} = \frac{3+1}{3-1}\ \text{i.e.,}\ \frac{I_1}{I_2} = \frac{4}{1} = 4$$

(b) Now as for a wave $I \propto A^2$,

$$\frac{I_1}{I_2} = \left[\frac{A_1}{A_2}\right]^2,\ \left[\frac{A_1}{A_2}\right]^2 = 4,\quad \text{i.e.,}\ \frac{A_1}{A_2} = 2$$

Example 5.

In a Young's double slit experiment the angular width of a fringe formed on a distant screen is 1°. The wavelength of the light used is 6280 Å. What is the distance between the two coherent sources ?

Solution :

The angular fringe width is given by $\alpha = \frac{\lambda}{d}$

where λ is wavelength and d is the distance between two coherent sources. Thus $d = \frac{\lambda}{\alpha}$

Given, $\lambda = 6280$ Å, $\alpha = 1° = \frac{\pi}{180}$ radian

Thus $d = \frac{6280 \times 10^{-10}}{3.14} \times 180 = 3.6 \times 10^{-5}\,m = 0.036$ mm

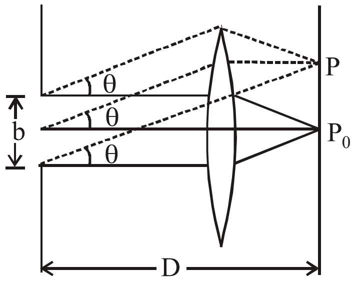
DIFFRACTION

When a wave is obstructed by an obstacle, the rays bend round the corner. This phenomenon is known as ***diffraction.***

Fraunhoffer Diffraction by Single Slit

In Fraunhoffer diffraction experiment, the source and the screen are effectively at infinite distance from the diffracting element.

In single slit diffraction, imagine aperature to be divided into two equal halves. Secondary sources in these two halves give first minima at $b\sin\theta = \lambda$



In general, *$b\sin\theta = n\lambda$ for minima and,* $b\sin\theta = (2n+1)\frac{\lambda}{2}$ *for maxima.*

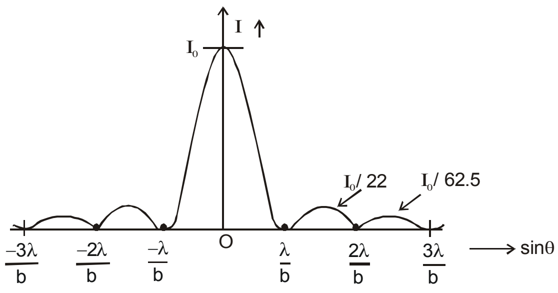
(i) The points of the maximum intensity lie nearly midway between the successive minima. The amplitude E_0' of the electric field at a general point P is

$$E_0' = E_0\frac{\sin\beta}{\beta}\ \text{where}\ \beta = \frac{\pi\, b\sin\theta}{\lambda}\ \text{and}$$

E_0 = amplitude at the point P_0 i.e. at $\theta = 0$

The intensity at a general point P is given as $I = I_0\frac{\sin^2\beta}{\beta^2}$

(ii) The graph for the variation of intensity as a function of sinθ is as follows :



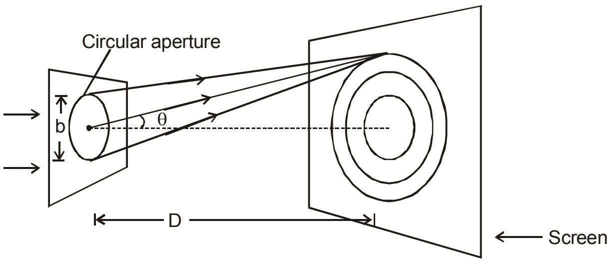
(iii) The width of the central maxima is $\left(\frac{2\lambda D}{b}\right)$ and angular width of central maxima is $\left(\frac{2\lambda}{b}\right)$.

Fraunh offer Diffraction by a Circular Aperture

(i) The 1st dark ring is formed by the light diffracted from the circular aperture at an angle θ with the axis where

$$\sin\theta \approx \frac{1.22\lambda}{b}$$ where λ = wavelength of light used,

b = diameter of circular aperture



(ii) If the screen is at a distance D (D >> b) from the circular aperture, the radius of the 1st dark ring is,

$$R \approx \frac{1.22\lambda D}{b}$$

(iii) If the light transmitted by the hole is converged by a converging lens at the screen placed at the focal plane of the lens, the radius of the 1st dark ring is $R = \frac{1.22\lambda f}{b}$

This radius is also called the **radius of diffraction disc**.

For plane transmission diffraction grating

$(a + b)\sin\theta_n = n\lambda$ for maxima, where a = width of transparent portion, b = width of opaque portion.

Difference between Interference and Diffraction of light

Interference	Diffraction
1. Interference is due to the superposition of two wavefronts originating from two coherent sources.	1. Diffraction is due to the superposition of two secondary wavelets originating from the different points of the same wavefront.
2. In Interference pattern, all the maxima i.e. bright fringes are of the same intensity.	2. In diffraction pattern, the bright fringes are of varying intensity.
3. In Interference pattern, the dark fringes are usually almost perfectly dark.	3. In diffraction pattern, the dark fringes are not perfectly dark.
4. In Interference pattern, the width of fringes (bright and dark) is equal.	4. In diffraction pattern, the widths of fringes are not equal.
5. In Interference, bands are large in number.	5. In diffraction, bands are a few in number.
6. In Interference, bands are equally spaced.	6. In diffraction, bands are unequally spaced.

Example 6.

In a single slit diffraction experiment, the angular position of the first (secondary) maximum is found to be 5.2°, when the slit width is 0.01 mm. If sin 52° = 0.0906, then find the wavelength of light used.

Solution :

For single-slit diffraction, the angular position of the first maximum is determined from the relation

$$a\sin\theta_1' = \frac{3\lambda}{2}$$

It is given that a = 0.01 mm

$= 1 \times 10^{-5}$, $\theta_1' = 5.2°$, $\sin\theta_1' = 0.0906$. Therefore,

$$\lambda = \frac{2}{3}a\sin\theta_1' = \frac{2}{3}\times 10^{-5}\times 0.0906 = 6040\ \text{Å}$$

Example 7.

In Fraunhaufer diffraction from a single slit of width 0.3 mm the diffraction pattern is formed in the focal plane of a lens of focal length 1m. If the distance of third minimum from the central maximum is 5mm, then find the wavelength of light used.

Solution :

The distance of n^{th} minimum from the central maximum is given by $X_n = \frac{n\lambda f}{a}$

where it is given that

$a = 0.3 \times 10^{-3}$ m, n = 3, f = 1m, $X_n = 5 \times 10^{-3}$ m

Therefore,

$$\lambda = \frac{aX_n}{nf} = \frac{0.3\times 10^{-3}\times 5\times 10^{-3}}{3\times 1} = 5\times 10^{-7}\ \text{m} = 500\ \text{nm}$$

POLARISATION

An ordinary source such as bulb consists of a large number of waves emitted by atoms or molecules in all directions symmetrically. Such light is called **unpolarized** light (see fig - a)

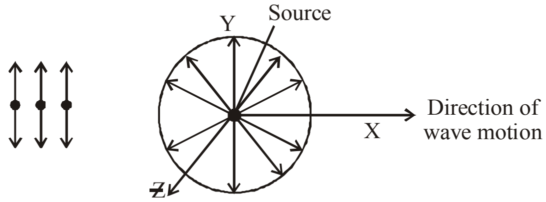


Fig (a) Unpolarised light

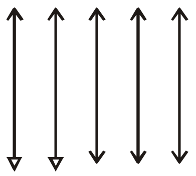


Fig (b) Polarised light

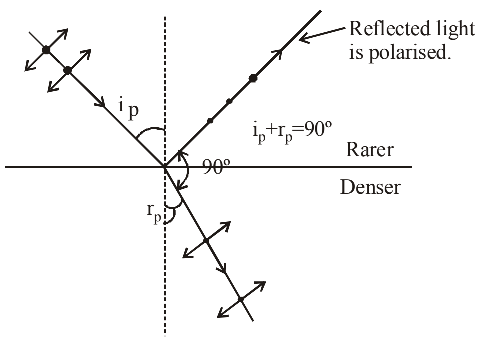
If we confine the direction of wave vibration of electric vector in one direction perpendicular to direction of wave propagation, then such type of light is called **plane polarised** or linearly polarised (with the help of polaroids or Nicol prism). *The phenomenon by which, we restrict the vibrations of wave in a particular direction (see fig-b) ⊥ to direction of wave propagation is called* ***polarization****.*

The plane of vibration is that which contains the vibrations of electric vector $\vec{E}$ and plane of polarisation is perpendicular to the plane of vibration

- Tourmaline and calcite polarizes an e.m. wave passing through it.

Polarization by Reflection (Brewster's Law)

During reflection of a wave, we obtain a particular angle called angle of polarisation, for which the reflected light is completely plane polarised.



$\mu = \tan(i_p)$

where, i_p = angle of incidence, such that the reflected and refracted waves are perpendicular to each other.

Law of Malus : If the electric vector is at angle θ with the transmission axis, light is partially transmitted. The intensity of transmitted light is

$I = I_0 \cos^2\theta$ where I_0 is the intensity when the incident electric vector is parallel to the transmission axis.

- Polarization can also be achieved by scattering of light
- (a) Plane polarized : oscillating $\vec{E}$ field is in a single plane.

  (b) Circularly polarized : tip of oscillating $\vec{E}$ field describes a circle.

  (c) Elliptically polarized : tip of oscillating $\vec{E}$ field describes an ellipse.

Example 8 :

The intensity of the polarised light becomes 1/20th of its initial intensity after passing through the analyser. What is the angle between the axis of the analyser and the initial amplitude of the light beam ?

Solution :

Here $I = \frac{1}{20} I_0 = 0.05\, I_0$

Using $I = I_0 \cos^2\theta$, we get $0.05\, I_0 = I_0 \cos^2\theta$

$\Rightarrow \cos^2\theta = 0.05$ or $\cos\theta = \sqrt{0.05} = 0.2236$

$\therefore \theta = \cos^{-1}(0.2236) = 76°9'$

Example 9 :

A beam of polarised light makes an angle of 60° with the axis of the polaroid sheet. How much is the intensity of light transmitted through the sheet ?

Solution :

Here θ = 60°,

Using $I = I_0 \cos^2\theta$, we get

$$I = I_0(\cos 60°)^2 = \frac{1}{4} I_0 \left(\because \cos 60° = \frac{1}{2}\right)$$

$\therefore$ Intensity of transmitted light $= \frac{1}{4} \times 100 = 25\%$

Thus, the intensity of the transmitted light is 25% of the intensity of incident light.

Example 10:

A ray of light strikes a glass plate at an angle of 60° with the glass surface. If the reflected and refracted rays are at right angles to each other, find the refractive index of the glass.

Solution.

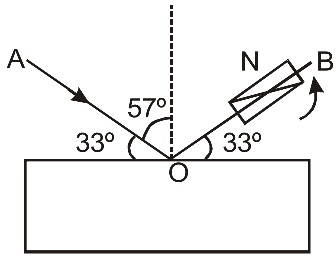
When the reflected and refracted rays are at right angle to each other, the angle of incident is known as angle of polarisation (i_p).

Here, θ = 60°, Using $\mu = \tan i_p$, we get

$\mu = \tan 60° = \sqrt{3} = 1.732$

Example 11 :

A beam of light AO is incident on a glass slab ($\mu = 1.54$) in a direction as shown in fig. The reflected ray OB is passed through nicol prism. On viewing through a nicol prism, we find on rotating the prism that



(a) the intensity is reduced down to zero and remains zero
(b) the intensity reduces down somewhat and rises again
(c) there is no change in intensity
(d) the intensity gradually reduces to zero and then again increases

Solution : (d)

For complete polarisation of reflected light

$\mu = \tan\phi$ (ϕ = Brewster's angle)

$\therefore \phi = \tan^{-1}\mu = \tan^{-1}(1.54) = 57^o$

From fig, angle of incidence $= 90° - 33^o = 57^o$

Hence the reflected light is completely polarised. When the plane polarised light is viewed through a rotating nicol prism, the intensity gradually reduces to zero and then again increases.

RESOLVING POWER OF AN OPTICAL INSTRUMENT

The resolving power of an optical instrument, is its ability to distinguish between two closely spaced objects.

Diffraction occurs when light passes through the circular, or nearly circular, openings that admit light into cameras, telescopes, microscopes, and human eyes. The resulting diffraction pattern places a natural limit on the resolving power of these instruments. For example, for normal vision, the limit of resolution of normal human eye is ~0.1 mm from 25 cm. (i.e., distances less than 0.1 mm cannot be resolved). For optical microscope the limit of resolution ~ 10^{-5} cm and for electron microscope ~5 Å or less.

The limit of resolution of a microscope $x = \frac{0.61\lambda}{a}$ where a is the aperture of the microscope.

DOPPLER'S EFFECT FOR LIGHT WAVES

(a) When the source moves towards the stationary observer or the observer moves towards the source, the apparent frequency.

$$\nu' = \nu\left(1 + \frac{v}{c}\right) \text{(Blue shift)}$$

(b) When the source moves away from the stationary observer or vice-versa, $\nu' = \nu\left(1 - \frac{v}{c}\right)$ (Red shift)

where ν' = apparent frequency, ν = active frequency

v = velocity of source, c = velocity of light

But in both cases, the relative velocity v is small.

Example 12 :

The time period of rotation of the sun is 25 days and its radius is 7×10^8 m. What will be the Doppler shift for the light of wavelength 6000 Å emitted from the surface of the sun?

Solution :

$$\text{Doppler's shift } d\lambda = \frac{v}{c} \times \lambda = R\,\omega\left(\frac{\lambda}{c}\right) = R\left(\frac{2\pi}{T}\right)\left(\frac{\lambda}{c}\right)$$

$$= \frac{7 \times 10^8 \times 2 \times 22}{25 \times 24 \times 60 \times 60 \times 7} \times \frac{6000}{3 \times 10^8}\text{Å} = 0.04\text{Å}$$

Example 13 :

How far in advance can one detect two headlights of a car if they are separated by a distance of 1.57 m ?

Solution :

The human eye can resolve two objects when the angle between them is 1 minute of arc. Thus, we have

$$D = \frac{x}{\theta}$$

Here $x = 1.57\text{ m}, \ \theta = 1' = \frac{1}{60} \times \frac{\pi}{180}\text{rad}$,

$$\text{Thus } D = \frac{1.57}{\frac{1}{60} \times \frac{\pi}{180}} = \frac{10800 \times 1.57}{3.14} = 5400 \text{ m} = 5.4 \text{ km}$$

Example 14 :

The numerical aperture of a microscope is 0.12, and the wavelength of light used is 600 nm. Then find its limit of resolution.

Solution :

The limit of resolution of a microscope is given by

$$x = \frac{0.61\,\lambda}{\mu \sin\theta}$$

It is given that $\lambda = 6 \times 10^{-7}$ m, and the numerical aperture $\mu \sin\theta = 0.12$.

$$\text{Therefore, } x = \frac{0.61 \times 6 \times 10^{-7}}{0.12} = 3.05 \times 10^{-6}\text{m} \approx 3\ \mu\text{m}$$

Example 15 :

A person wants to resolve two thin poles standing near each other at a distance of 1 km. What should be the minimum separation between them?

Solution :

Angular limit of resolution of eye θ = 1 minute of arc = 1/60 degree.

Therefore, the minimum separation should be such that

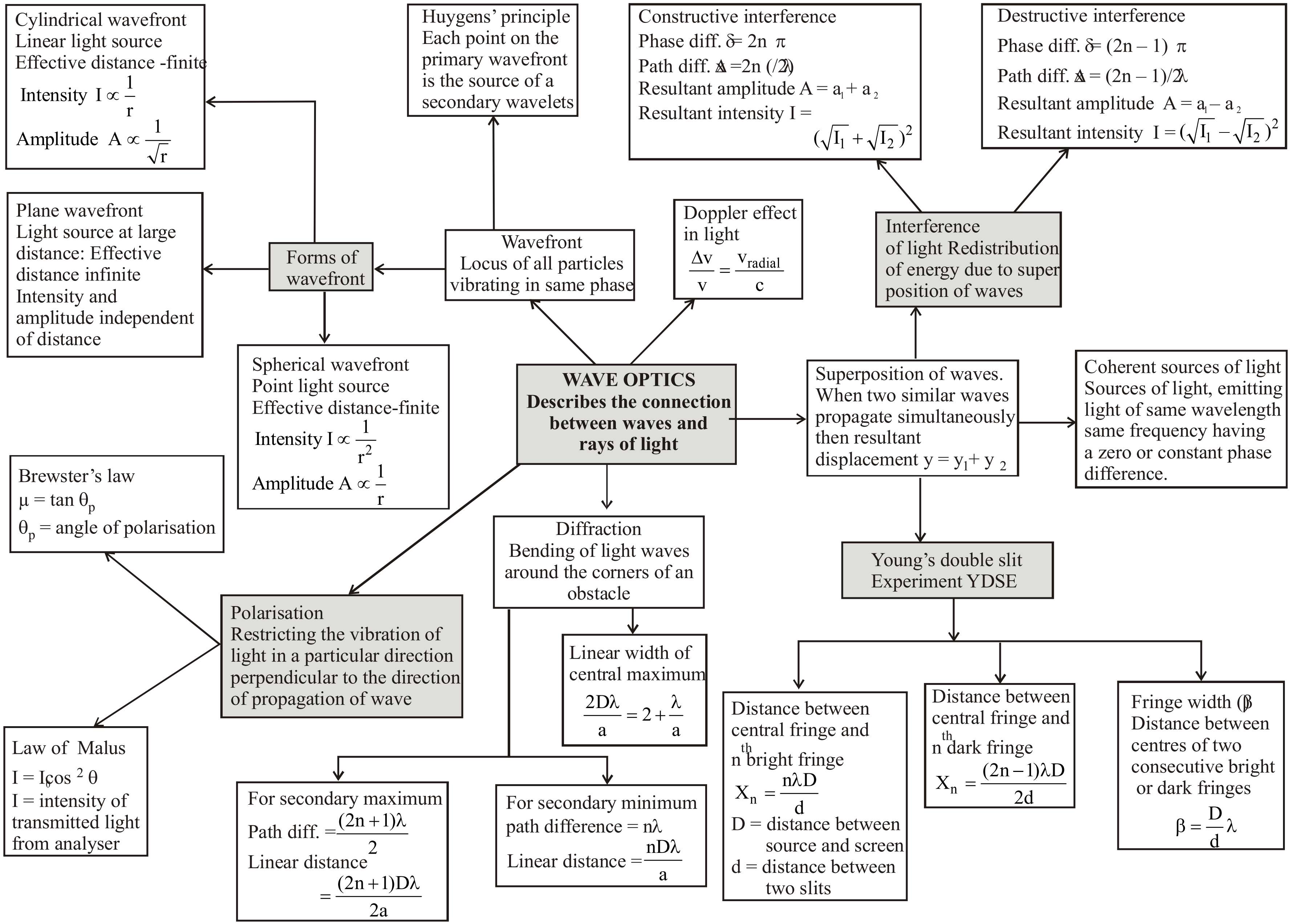
$$x = D\theta$$

with D = 1 km. = 10^3 m and $\theta = \frac{1}{60} \times \frac{\pi}{180}$ radian

$$\text{Thus } x = \frac{10^3 \times 3.14}{60 \times 180} = \frac{31.4}{108} = 0.29 \text{ m}$$

or $x \approx 30$ cm.

CONCEPT MAP



Cylindrical wavefront
Linear light source
Effective distance -finite
Intensity $I \propto \frac{1}{r}$
Amplitude $A \propto \frac{1}{\sqrt{r}}$
Huygens' principle
Each point on the primary wavefront is the source of a secondary wavelets
Constructive interference
Phase diff. $\delta = 2n\pi$
Path diff. $\Delta = 2n(\lambda/2)$
Resultant amplitude $A = a_1 + a_2$
Resultant intensity $I = (\sqrt{I_1} + \sqrt{I_2})^2$
Destructive interference
Phase diff. $\delta = (2n-1)\pi$
Path diff. $\Delta = (2n-1)\lambda/2$
Resultant amplitude $A = a_1 - a_2$
Resultant intensity $I = (\sqrt{I_1} - \sqrt{I_2})^2$
Plane wavefront
Light source at large distance: Effective distance infinite
Intensity and amplitude independent of distance
Forms of wavefront
Wavefront
Locus of all particles vibrating in same phase
Doppler effect in light
$\frac{\Delta v}{v} = \frac{v_{radial}}{c}$
Interference
of light Redistribution of energy due to super position of waves
Spherical wavefront
Point light source
Effective distance-finite
Intensity $I \propto \frac{1}{r^2}$
Amplitude $A \propto \frac{1}{r}$
WAVE OPTICS
Describes the connection between waves and rays of light
Superposition of waves.
When two similar waves propagate simultaneously then resultant displacement $y = y_1 + y_2$
Coherent sources of light
Sources of light, emitting light of same wavelength same frequency having a zero or constant phase difference.
Brewster's law
$\mu = \tan\theta_p$
θ_p = angle of polarisation
Diffraction
Bending of light waves around the corners of an obstacle
Young's double slit Experiment YDSE
Polarisation
Restricting the vibration of light in a particular direction perpendicular to the direction of propagation of wave
Linear width of central maximum
$\frac{2D\lambda}{a} = 2 + \frac{\lambda}{a}$
Law of Malus
$I = I_0\cos^2\theta$
I = intensity of transmitted light from analyser
Distance between central fringe and n^{th} bright fringe
$X_n = \frac{n\lambda D}{d}$
D = distance between source and screen
d = distance between two slits
Distance between central fringe and n^{th} dark fringe
$X_n = \frac{(2n-1)\lambda D}{2d}$
Fringe width (β)
Distance between centres of two consecutive bright or dark fringes
$\beta = \frac{D}{d}\lambda$
For secondary maximum
Path diff. $= \frac{(2n+1)\lambda}{2}$
Linear distance $= \frac{(2n+1)D\lambda}{2a}$
For secondary minimum
path difference $= n\lambda$
Linear distance $= \frac{nD\lambda}{a}$

EXERCISE - 1
Conceptual Questions

1. Which one of the following phenomena is not explained by Huygens construction of wavefront?
(a) Refraction (b) Reflection
(c) Diffraction (d) Origin of spectra

2. Which of the following phenomena is not common to sound and light waves ?
(a) Interference (b) Diffraction
(c) Coherence (d) Polarisation

3. Interference is possible in
(a) light waves only
(b) sound waves only
(c) both light and sound waves
(d) neither light nor sound waves

4. A single slit diffraction pattern is obtained using a beam of red light. If the red light is replaced by the blue light, then the diffraction pattern
(a) remains unchanged (b) becomes narrower
(c) becomes broader (d) will disappear

5. In Young's double slit experiment, if the slit widths are in the ratio 1 : 2, the ratio of the intensities at minima and maxima will be
(a) 1 : 2 (b) 1 : 3 (c) 1 : 4 (d) 1 : 9

6. If a wave can be polarized, it must be
(a) a transverse wave (b) a longitudinal wave
(c) a sound wave (d) a stationary wave

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

8. Angular width (B) of central maxima of a diffraction pattern of a single slit does not depend upon
(a) distance between slit and source
(b) wavelength of the light used
(c) width of slit
(d) frequency of light used

9. The phenomenon by which stars recedes from each other is explained by
(a) black hole theory (b) neutron star theory
(c) white dwarf (d) red shift

10. Which of the following does not support the wave nature of light?
(a) Interference (b) Diffraction
(c) Polarisation (d) Photoelectric effect.

11. The colours seen in the reflected white light from a thin oil film are due to
(a) diffraction (b) interference
(c) polarisation (d) dispersion

12. Which of the following cannot be polarised ?
(a) Radio waves (b) β rays
(c) Infrared rays (d) γ rays

13. The phenomenon of interference is shown by
(a) longitudinal mechanical waves only
(b) transverse mechanical waves only
(c) non-mechanical transverse waves only
(d) All of the above

14. The transverse nature of light is shown by
(a) interference of light (b) refraction of light
(c) polarization of light (d) dispersion of light

15. If the intensities of the two interfering beams in Young's double-slit experiment are I_1 and I_2, then the contrast between the maximum and minimum intensities is good when
(a) $|I_1$ and $I_2|$ is large (b) $|I_1$ and $I_2|$ is small
(c) either I_1 or I_2 is zero (d) $I_1 = I_2$

16. The idea of the quantum nature of light has emerged in an attempt to explain
(a) interference
(b) diffraction
(b) polarization
(d) radiation spectrum of a black body

17.. The contrast in the fringes in an interference pattern depends on
(a) fringe width
(b) wavelength
(c) intensity ratio of the sources
(d) distance between the slits

18. Polarisation of light establishes
(a) corpuscular theory of light
(b) quantum nature of light
(c) transverse nature of light
(d) all of the three

19. Huygens concept of wavelets is useful in
(a) explaining polarisation
(b) determining focal length of the lenses
(c) determining chromatic aberration
(d) geometrical reconstruction of a wavefront

20. When a compact disc is illuminated by small source of white light, coloured bands are observed. This is due to
(a) dispersion (b) diffraction
(c) interference (d) reflection

21. A nicol prism is based on the action of
(a) refraction (b) double refraction
(c) dichroism (d) both (b) and (c)

22. The deflection of light in a gravitational field was predicted first by
(a) Einstein (b) Newton
(c) Max Planck (d) Maxwell

23. When light passing through rotating nicol is observed, no change in intensity is seen. What inference can be drawn ?
(a) The incident light is unpolarized.
(b) The incident light is circularly polarized.
(c) The incident light is unpolarized or circularly polarized.
(d) The incident light is unpolarized or circularly polarized or combination of both.

24. In refraction, light waves are bent on passing from one medium to the second medium, because, in the second medium
(a) the frequency is different
(b) the coefficient of elasticity is different
(c) the speed is different
(d) the amplitude is smaller

25. Interference was observed in an interference chamber when air was present. Now, the chamber is evacuated and if the same light is used, a careful observation will show
(a) no interference
(b) interference with bright bands
(c) interference with dark bands
(d) interference in which breadth of the fringe will be slightly increased

EXERCISE - 2
Applied Questions

1. The width of a slit is 0.012 mm. Monochromatic light is incident on it. The angular position of first bright line is 5.2º. The wavelength of incident light is [sin 5.2º = 0.0906].
(a) 6040 Å (b) 4026 Å
(c) 5890 Å (d) 7248 Å

2. A ray of light is incident on the surface of a glass plate at an angle of incidence equal to Brewster's angel ϕ. If μ represents the refractive index of glass with respect to air, then the angle between the reflected and the refracted rays is
(a) $90° + \phi$ (b) $\sin^{-1}(\mu \cos \phi)$
(c) 90º (d) $90° - \sin^{-1}\left(\frac{\sin \phi}{\mu}\right)$

3. Light of wavelength 6.5×10^{-7} m is made incident on two slits 1 mm apart. The distance between third dark fringe and fifth bright fringe on a screen distant 1 m from the slits will be
(a) 0.325 mm (b) 0.65 mm
(c) 1.625 mm (d) 3.25 mm

4. The max. intensity produced by two coherent sources of intensity I_1 and I_2 will be
(a) $I_1 + I_2$ (b) $I_1^2 + I_2^2$
(c) $I_1 + I_2 + 2\sqrt{I_1 I_2}$ (d) zero

5. The path difference between two wavefronts emitted by coherent sources of wavelength 5460Å is 2.1 micron. The phase difference between the wavefronts at that point is
(a) 7.692 (b) 7.692π
(c) $\frac{7.692}{\pi}$ (d) $\frac{7.692}{3\pi}$

6. In Young's expt., the distance between two slits is $\frac{d}{3}$ and the distance between the screen and the slits is 3 D. The number of fringes in $\frac{1}{3}$m on the screen, formed by monochromatic light of wavelength 3λ, will be
(a) $\frac{d}{9D\lambda}$ (b) $\frac{d}{27D\lambda}$
(c) $\frac{d}{81D\lambda}$ (d) $\frac{d}{D\lambda}$

7. In Young's double slit expt. the distance between two sources is 0.1 mm. The distance of the screen from the source is 20 cm. Wavelength of light used is 5460 Å. The angular position of the first dark fringe is
(a) 0.08º (b) 0.16º
(c) 0.20º (d) 0.32º

8. The separation between successive fringes in a double slit arrangement is x. If the whole arrangement is dipped under water what will be the new fringe separation? [The wavelenght of light being used is 5000 Å]
(a) 1.5x (b) x
(c) 0.75x (d) 2x

9. Light of wavelength 6328 Å is incident normally on a slit having a width of 0.2 mm. The angular width of the central maximum measured from minimum to minimum of diffraction pattern on a screen 9.0 metres away will be about
(a) 0.36 degree (b) 0.18 degree
(c) 0.72 degree (d) 0.09 degree

10. A plane wave of wavelength 6250 Å is incident normally on a slit of width 2×10^{-2} cm. The width of the principal maximum on a screen distant 50 cm will be
(a) 312.5×10^{-3} cm (b) 312.5×10^{-3} m
(c) 312.5×10^{-3} m (d) 312 m

11. A ray of light strikes a glass plate at an angle of 60º. If the reflected and refracted rays are perpendicular to each other, the index of refraction of glass is
(a) $\frac{1}{2}$ (b) $\sqrt{\frac{3}{2}}$ (c) $\frac{3}{2}$ (d) 1.732

12. The wavelength of H_α line in hydrogen spectrum was found to be 6563 Å in the laboratory. If the wavelength of same line in the spectrum of a milky way is observed to be 6568Å, then recession velocity of milky way will be
(a) 105 m/s (b) 1.05×10^6 m/s
(c) 10.5×10^6 m/s (d) 0.105×10^6 m/s

13. A star is receding away from earth with a velocity of 10^5 m/s. If the wavelength of its spectral line is 5700 Å, then Doppler shift will be
(a) 200 Å (b) 1.9 Å
(c) 20 Å (d) 0.2 Å

14. A slit of width a is illuminated by red light of wavelength 6500 Å. If the first minimum falls at $\theta = 30°$, the value of a is
(a) 6.5×10^{-4} mm (b) 1.3 micron
(c) 3250 Å (d) 2.6×10^{-4} cm

15. Two beams of light of intensity I_1 and I_2 interfere to give an interference pattern. If the ratio of maximum intensity to that of minimum intensity is 25/9, then I_1/I_2 is

(a) 5/3 (b) 4
(c) 81/625 (d) 16

16. The condition for obtaining secondary maxima in the diffraction pattern due to single slit is

(a) $a\sin\theta = n\lambda$ (b) $a\sin\theta = (2n-1)\dfrac{\lambda}{2}$

(c) $a\sin\theta = (2n-1)\lambda$ (d) $a\sin\theta = \dfrac{n\lambda}{2}$

17. Light from two coherent sources of the same amplitude A and wavelength λ illuminates the screen. The intensity of the central maximum is I_0. If the sources were incoherent, the intensity at the same point will be

(a) $4I_0$ (b) $1I_0$ (c) I_0 (d) $I_0/2$

18. In Young's double slit experiment with sodium vapour lamp of wavelength 589 nm and the slits 0.589 mm apart, the half angular width of the central maximum is

(a) $\sin^{-1}(0.01)$ (b) $\sin^{-1}(0.0001)$
(c) $\sin^{-1}(0.001)$ (d) $\sin^{-1}(0.1)$

19. In Young's double slit experiment with sodium vapour lamp of wavelength 589 nm and the slits 0.589 mm apart, the half angular width of the central maximum is

(a) $\sin^{-1} 0.01$ (b) $\sin^{-1} 0.0001$
(c) $\sin^{-1} 0.001$ (d) $\sin^{-1} 0.1$

20. When the light is incident at the polarizing angle on the transparent medium, then the completely polarized light is

(a) refracted light
(b) reflected light
(c) refracted and reflected light
(d) neither reflected nor refracted light

21. In the phenomena of diffraction of light, when blue light is used in the experiment in spite of red light, then

(a) fringes will become narrower
(b) fringes will become broader
(c) no change in fringe width
(d) None of these

22. The wavefronts of a light wave travelling in vacuum are given by $x + y + z = c$. The angle made by the direction of propagation of light with the X-axis is

(a) 0^o (b) 45^o
(c) 90^o (d) $\cos^{-1}(1/\sqrt{3})$

23. In Fresnel's biprism expt., a mica sheet of refractive index 1.5 and thickness 6×10^{-6} m is placed in the path of one of interfering beams as a result of which the central fringe gets shifted through 5 fringe widths. The wavelength of light used is

(a) 6000 Å (b) 8000 Å
(c) 4000 Å (d) 2000 Å

24. Two sources of light of wavelengths 2500 Å and 3500 Å are used in Young's double slit expt. simultaneously. Which orders of fringes of two wavelength patterns coincide?

(a) 3rd order of 1st source and 5th of the 2nd
(b) 7th order of 1st and 5th order of 2nd
(c) 5th order of 1st and 3rd order of 2nd
(d) 5th order of 1st and 7th order of 2nd

25. A radar sends radiowaves of frequency v towards an aeroplane moving with velocity v_a. A change Δv is observed in the frequency of reflected waves which is higher than original frequency. The velocity of aeroplane is ($v_a << c$)

(a) $\dfrac{c\,\Delta v}{v}$ (b) $\dfrac{2c\,\Delta v}{\Delta v}$ (c) $\dfrac{c\,\Delta v}{2v}$ (d) $\dfrac{\Delta v}{2c\,v}$

26. In Young's double slit experiment, we get 10 fringes in the field of view of monochromatic light of wavelength 4000Å. If we use monochromatic light of wavelength 5000Å, then the number of fringes obtained in the same field of view is

(a) 8 (b) 10 (c) 40 (d) 50

27. With a monochromatic light, the fringe-width obtained in a Young's double slit experiment is 0.133 cm. The whole set-up is immersed in water of refractive index 1.33, then the new fringe-width is

(a) 0.133 cm (b) 0.1 cm
(c) 1.33×1.33 cm (d) $\dfrac{1.33}{2}$ cm

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

(a) 3250 Å (b) 6.5×10^{-4} cm
(c) 1.3 micron (d) 2.6×10^{-4} cm

29. The Fraunhoffer 'diffraction' pattern of a single slit is formed in the focal plane of a lens of focal length 1 m. The width of slit is 0.3 mm. If third minimum is formed at a distance of 5 mm from central maximum, then wavelength of light will be

(a) 5000 Å (b) 2500 Å
(c) 7500 Å (d) 8500 Å

30. Two points separated by a distance of 0.1 mm can just be inspected in a microscope, when light of wavelength 600Å is used. If the light of wavelength 4800 Å is used, the limit of resolution will become

(a) 0.80mm (b) 0.12mm (c) 0.10mm (d) 0.08mm

31. Unpolarised light of intensity 32 W m^{-2} passes through three polarizers such that the transmission axis of the last polarizer is crossed with that of the first. The intensity of final emerging light is 3 W m^{-2}. The intensity of light transmitted by first polarizer will be

(a) 32 W m^{-2} (b) 16 W m^{-2}
(c) 8 W m^{-2} (d) 4 W m^{-2}

32. A parallel beam of monochromatic unpolarised light is incident on a transparent dielectric plate of refractive index $\dfrac{1}{\sqrt{3}}$. The reflected beam is completely polarised. Then the angle of incidence is

(a) 30^o (b) 60^o
(c) 45^o (d) 75^o

33. Two nicols are oriented with their principal planes making an angle of 60°. Then the percentage of incident unpolarised light which passes through the system is
(a) 100 (b) 50 (c) 12.5 (d) 37.5

34. A beam of unpolarised light passes through a tourmaline crystal A and then through another such crystal B oriented so that the principal plane is parallel to A. The intensity of emergent light is I_0. Now B is rotated by 45° about the ray. The emergent light will have intensity
(a) $I_0/2$ (b) $I_0/\sqrt{2}$ (c) $I_0\sqrt{2}$ (d) $2I_0$

35. A rocket is receding away from earth with velocity 0.2 c. The rocket emits signal of frequency 4×10^7 Hz. The apparent frequency observed by the observer on earth will be
(a) 4×10^6 Hz (b) 3.2×10^7 Hz
(c) 3×10^6 Hz (d) 5×10^7 Hz

36. The heavenly body is receding from earth, such that the fractional change in λ is 1, then its velocity is
(a) c (b) $\frac{3c}{5}$ (c) $\frac{c}{5}$ (d) $\frac{2c}{5}$

37. Fluorescent tubes give more light than a filament bulb of same power because
(a) the tube contains gas at low temperature
(b) ultraviolet light is converted into visible light by fluorescence
(c) light is diffused through the walls of the tube
(d) it produces more heat than bulb

38. In young's double-slit experiment, the intensity of light at a point on the screen where the path difference is λ is I, λ being the wavelength of light used. The intensity at a point where the path difference is $\frac{\lambda}{4}$ will be
(a) $\frac{I}{4}$ (b) $\frac{I}{2}$ (c) I (d) zero

39. Aperture of the human eye is 2 mm. Assuming the mean wavelength of light to be 5000 Å, the angular resolution limit of the eye is nearly
(a) 2 minute (b) 1 minute
(c) 0.5 minute (d) 1.5 minute

40. If the polarizing angle of a piece of glass for green light is 54.74°, then the angle of minimum deviation for an equilateral prism made of same glass is
[Given, tan 54.74° = 1.414]
(a) 45° (b) 54.74°
(c) 60° (d) 30°

41. In Young's double slit experiment, the fringes are displaced by a distance x when a glass plate of refractive index 1.5 is introduced in the path of one of the beams. When this plate is replaced by another plate of the same thickness, the shift of fringes is (3/2) x. The refractive index of the second plate is
(a) 1.75 (b) 1.50
(c) 1.25 (d) 1.00

42. A single slit Fraunhoffer diffraction pattern is formed with white light. For what wavelength of light the third secondary maximum in the diffraction pattern coincides with the second secondary maximum in the pattern for red light of wavelength 6500 Å?
(a) 4400 Å (b) 4100 Å
(c) 4642.8 Å (d) 9100 Å

43. When the angle of incidence is 60° on the surface of a glass slab, it is found that the reflected ray is completely polarised. The velocity of light in glass is
(a) $\sqrt{2} \times 10^8 \text{ ms}^{-1}$ (b) $\sqrt{3} \times 10^8 \text{ ms}^{-1}$
(c) $2 \times 10^8 \text{ ms}^{-1}$ (d) $3 \times 10^8 \text{ ms}^{-1}$

44. A lens having focal length f and aperture of diameter d forms an image of intensity I. Aperture of diameter $\frac{d}{2}$ in central region of lens is covered by a black paper. Focal length of lens and intensity of image now will be respectively
(a) f and $\frac{I}{4}$ (b) $\frac{3f}{4}$ and $\frac{I}{2}$
(c) f and $\frac{3I}{4}$ (d) $\frac{f}{2}$ and $\frac{I}{2}$

45. In Young's double slit experiment, the slits are 2 mm apart and are illuminated by photons of two wavelengths λ_1 = 12000Å and λ_2 = 10000Å. At what minimum distance from the common central bright fringe on the screen 2 m from the slit will a bright fringe from one interference pattern coincide with a bright fringe from the other ?
(a) 6mm (b) 4mm (c) 3mm (d) 8mm

46. A parallel beam of fast moving electrons is incident normally on a narrow slit. A fluorescent screen is placed at a large distance from the slit. If the speed of the electrons is increased, which of the following statements is correct ?
(a) The angular width of the central maximum of the diffraction pattern will increase.
(b) The angular width of the central maximum will decrease.
(c) The angular width of the central maximum will be unaffected.
(d) Diffraction pattern is not observed on the screen in case of electrons.

DIRECTIONS for Qs. (47 to 50) : Each question contains STATEMENT-1 and STATEMENT-2. Choose the correct answer (ONLY ONE option is correct) from the following-
(a) Statement -1 is false, Statement-2 is true
(b) Statement -1 is true, Statement-2 is true; Statement -2 is a correct explanation for Statement-1
(c) Statement -1 is true, Statement-2 is true; Statement -2 is not a correct explanation for Statement-1
(d) Statement -1 is true, Statement-2 is false

47. **Statement 1 :** In YDSE, if a thin film is introduced in front of the upper slit, then the fringe pattern shifts in the downward direction.
Statement 2 : In YDSE if the slit widths are unequal, the minima will be completely dark.

48. **Statement 1 :** In YDSE, if $I_1 = 9I_0$ and $I_2 = 4I_0$ then $\frac{I_{max}}{I_{min}} = 25.$
Statement 2 : In YDSE $I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$ and $I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$.

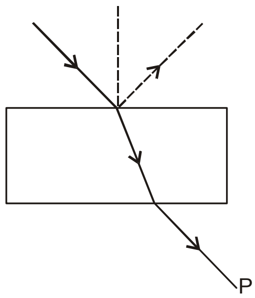
49. **Statement 1 :** In Young's double slit experiment if wavelength of incident monochromatic light is just doubled, number of bright fringe on the screen will increase.
Statement 2: Maximum number of bright lunge on the screen is inversely proportional to the wavelength of light used

50. **Statement 1 :** In YDSE number of bright fringe or dark fringe can not be unlimited
Statement 2 : In YDSE path difference between the superposing waves can not be more than the distance between the slits.

EXERCISE - 3
Exemplar & Past Years NEET/AIPMT Questions

Exemplar Questions

1. Consider a light beam incident from air to a glass slab at Brewster's angle as shown in figure.
A polaroid is placed in the path of the emergent ray at point P and rotated about an axis passing through the centre and perpendicular to the plane of the polaroid.



(a) For a particular orientation, there shall be darkness as observed through the polaroid
(b) The intensity of light as seen through the polaroid shall be independent of the rotation
(c) The intensity of light as seen through the polaroid shall go through a minimum but not zero for two orientations of the polaroid
(d) The intensity of light as seen through the polaroid shall go through a minimum for four orientations of the polaroid

2. Consider sunlight incident on a slit of width 10^4 Å. The image seen through the slit shall
(a) be a fine sharp slit white in colour at the centre
(b) a bright slit white at the centre diffusing to zero intensities at the edges
(c) a bright slit white at the centre diffusing to regions of different colours
(d) only be a diffused slit white in colour

3. Consider a ray of light incident from air onto a slab of glass (refractive index n) of width d, at an angle θ. The phase difference between the ray reflected bv the top surface of the glass and the bottom surface is

(a) $\frac{2\pi d}{\lambda}\left(1-\frac{1}{n^2}\sin^2\theta\right)^{1/2}+\pi$

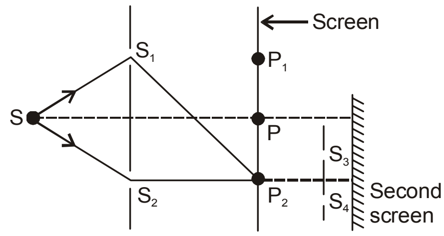
(b) $\frac{4\pi d}{\lambda}\left(1-\frac{1}{n^2}\sin^2\theta\right)^{1/2}$

(c) $\frac{4\pi d}{\lambda}\left(1-\frac{1}{n^2}\sin^2\theta\right)^{1/2}+\frac{\pi}{2}$

(d) $\frac{4\pi d}{\lambda}\left(1-\frac{1}{n^2}\sin^2\theta\right)^{1/2}+2\pi$

4. In a Young's double-slit experiment, the source is white light. One of the holes is covered by a red filter and another by a blue filter. In this case,
(a) there shall be alternate interference patterns of red and blue
(b) there shall be an interference pattern for red distinct from that for blue
(c) there shall be no interference fringes
(d) there shall be an interference pattern for red mixing with one for blue

5. Figure shows a standard two slit arrangement witn slits S_1, S_2, P_1, P_2 are the two minima points on either side of P (figure).



At P_2 on the screen, there is a hole and behind P_2 is a second 2-slit arrangement with slits S_3, S_4 and a second screen behind them.
(a) There would be no interference pattern on the second screen but it would be lighted
(b) The second screen would be totally dark
(c) There would be a single bright point on the second screen
(d) There would be a regular two slit pattern on the second screen

NEET/AIPMT (2013-2017) Questions

6. In Young's double slit experiment, the slits are 2 mm apart and are illuminated by photons of two wavelengths $\lambda_1 = 12000$Å and $\lambda_2 = 10000$Å. At what minimum distance from the common central bright fringe on the screen 2 m from the slit will a bright fringe from one interference pattern coincide with a bright fringe from the other ? ***[2013]***
(a) 6mm (b) 4mm
(c) 3mm (d) 8mm

7. A parallel beam of fast moving electrons is incident normally on a narrow slit. A fluorescent screen is placed at a large distance from the slit. If the speed of the electrons is increased, which of the following statements is correct ? ***[2013]***

(a) The angular width of the central maximum of the diffraction pattern will increase.
(b) The angular width of the central maximum will decrease.
(c) The angular width of the central maximum will be unaffected.
(d) Diffraction pattern is not observed on the screen in case of electrons.

8. In Young's double slit experiment the distance between the slits and the screen is doubled. The separation between the slits is reduced to half. As a result the fringe width

(a) is doubled ***[NEET Kar. 2013]***
(b) is halved
(c) becomes four times
(d) remains unchanged

9. A parallel beam of light of wavelength λ is incident normally on a narrow slit. A diffraction pattern is formed on a screen placed perpendicular to the direction of the incident beam. At the second minimum of the diffraction pattern, the phase difference between the rays coming from the two edges of slit is ***[NEET Kar. 2013]***

(a) $\pi\lambda$ (b) 2π
(c) 3π (d) 4π

10. A beam of light of $\lambda = 600$ 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 first dark fringes on either side of the central bright fringe is: ***[2014]***

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

11. In the Young's double-slit experiment, the intensity of light at a point on the screen where the path difference is λ is K, (λ being the wave length of light used). The intensity at a point where the path difference is $\lambda/4$, will be: ***[2014]***

(a) K (b) K/4
(c) K/2 (d) Zero

12. In a double slit experiment, the two slits are 1 mm apart and the screen is placed 1 m away. A monochromatic light wavelength 500 nm is used. What will be the width of each slit for obtaining ten maxima of double slit within the central maxima of single slit pattern ? ***[2015]***

(a) 0.1 mm (b) 0.5 mm
(c) 0.02 mm (d) 0.2 mm

13. For a parallel beam of monochromatic light of wavelength 'λ', diffraction is produced by a single slit whose width 'a' is of the wavelength of the light. If 'D' is the distance of the screen from the slit, the width of the central maxima will be: ***[2015]***

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

14. At the first minimum adjacent to the central maximum of a single-slit diffraction pattern, the phase difference between the Huygen's wavelet from the edge of the slit and the wavelet from the midpoint of the slit is : ***[2015 RS]***

(a) $\frac{\pi}{2}$ radian (b) π radian
(c) $\frac{\pi}{8}$ radian (d) $\frac{\pi}{4}$ radian

15. Two slits in Young's experiment have widths in the ratio 1 : 25. The ratio of intensity at the maxima and minima in the interference pattern, $\frac{I_{max}}{I_{min}}$ is: ***[2015 RS]***

(a) $\frac{121}{49}$ (b) $\frac{49}{121}$
(c) $\frac{4}{9}$ (d) $\frac{9}{4}$

16. In a diffraction pattern due to a single slit of width 'a', the first minimum is observed at an angle 30° when light of wavelength 5000 Å is incident on the slit. The first secondary maximum is observed at an angle of : ***[2016]***

(a) $\sin^{-1}\left(\frac{1}{4}\right)$ (b) $\sin^{-1}\left(\frac{2}{3}\right)$
(c) $\sin^{-1}\left(\frac{1}{2}\right)$ (d) $\sin^{-1}\left(\frac{3}{4}\right)$

17. The intensity at the maximum in a Young's double slit experiment is I_0. Distance between two slits is $d = 5\lambda$, where λ is the wavelength of light used in the experiment. What will be the intensity in front of one of the slits on the screen placed at a distance D = 10 d ? ***[2016]***

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

18. The ratio of resolving powers of an optical microscope for two wavelengths $\lambda_1 = 4000$ Å and $\lambda_2 = 6000$ Å is ***[2017]***

(a) 9 : 4 (b) 3 : 2
(c) 16 : 81 (d) 8 : 27

19. Young's double slit experment is first performed in air and then in a medium other than air. It is found that 8th bright fringe in the medium lies where 5th dark fringe lies in air. The refractive index of the medium is nearly ***[2017]***

(a) 1.59 (b) 1.69
(c) 1.78 (d) 1.25

20. Two Polaroids P_1 and P_2 are placed with their axis perpendicular to each other. Unpolarised light I_0 is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its axis makes an angle 45° with that of P_1. The intensity of transmitted light through P_2 is ***[2017]***

(a) $\frac{I_0}{4}$ (b) $\frac{I_0}{8}$
(c) $\frac{I_0}{16}$ (d) $\frac{I_0}{2}$

Hints & Solutions

EXERCISE - 1

1. (d) 2. (d) 3. (c) 4. (b)
5. (d) 6. (a) 7. (d)

8. (a) For single slit diffraction pattern $e\sin\theta = \lambda$ Angular width, e = slit width

$$\therefore \quad \theta = \sin^{-1}\left(\frac{\lambda}{e}\right)$$

It is independent of D, distance between screen and slit.

9. (d) Doppler effect in light explains the phenomenon of receding of stars and approaching of star by red shift and blue shift respectively.
10. (d) Photoelectric effect does not support the wave nature of light.
11. (b)
12. (b) Longitudinal waves cannot be polarised.
13. (d)
14. (c) 15. (d) 16. (d)
17. (c) 18. (c) 19. (d)
20. (b) The line rulings, each of 0.5 μm width, on a compact disc function as a diffraction grating. When a small source of light illuminates a disc, diffracted light forms coloured 'lanes' that are the composite of the diffraction patterns from the ruling.
21. (d) When a ray of light enters nicol prism, it splits into two plane polarised light in mutually perpendicular direction. One of this light undergoes total reflection and absorption whereas other comes out as a plane polarised light.
22. (b) Newton first predicted deflection of light by gravitational field.
23. (c)
24. (c) Speed of light is different in different media and different medium has different refractive index.

$${}^1\mu_2 = \frac{\text{Speed of light in medium 1}}{\text{Speed of light in medium 2}}$$

25. (d) As fringe width $\beta = \frac{D}{d}\lambda$

$$\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \ldots$$

$\mu_{Vacuum} < \mu_{Air}$ so $\lambda_{Vacuum} > \lambda_{Air}$
Therefore when chamber is evacuated fringe width β slightly increases.

EXERCISE - 2

1. (d) It is a one of Fraunhoffer diffraction from single slit. so for bright fringe where a is the width of slit.

$$a\sin\theta = (2n+1)\frac{\lambda}{2}$$

$$\lambda = \frac{2a\sin\theta}{2n+1} = \frac{2\times1.2\times10^{-5}\times0.0906}{2\times1+1}$$

$$= 7248\times10^{-10}\text{ m} = 7248\text{Å}.$$

2. (c) $\because i_p = \phi$, therefore, angle between reflected and refracted rays is 90°.

3. (c) $x_5 = n\lambda\frac{D}{d} = \frac{5\times6.5\times10^{-7}\times1}{10^{-3}} = 32.5\times10^{-4}\text{m}$

$$x_3 = (2n-1)\frac{1}{2}\frac{D\lambda}{d} = \frac{5\times6.5\times10^{-7}\times1}{2\times10^{-3}}$$

$$= 16.25\times10^{-4}\text{m}$$

$$x_5 - x_3 = 16.25\times10^{-4}\text{m} = 1.625\text{ mm}.$$

4. (c) As $R^2 = a^2 + b^2 + 2ab\cos\phi$

$$\therefore \quad I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos 0^\circ$$

$$= I_1 + I_2 + 2\sqrt{I_1 I_2}$$

5. (b) Phase diff. $= \frac{2\pi}{\lambda}x$

Path difference $= \frac{2\pi\times2.1\times10^{-6}}{5460\times10^{-10}} = 7.692\,\pi$ radian.

6. (c) $\beta = \frac{\lambda' D'}{d'} = \frac{3\lambda 3D}{d/3} = 27\frac{\lambda D}{d}$.

No. of fringes $= \frac{1/3}{\beta} = \frac{d}{81\lambda D}$.

7. (b) The position of n^{th} dark fringe. So position of first dark fringe in $x_1 = \lambda D/2d$.
$d = 20$ cm, $D = 0.1$mm, $\lambda = 5460$ Å, $x_1 = 0.16$
8. (c) When the arrangement is dipped in water;

$$\beta' = \beta/\mu = \frac{x}{4/3} = \frac{3}{4}x = 0.75x$$

9. (a) The angular width of central maxi. is

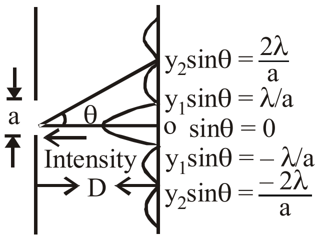
$$2\theta = 2\frac{\lambda}{a} = \frac{2\times6328\times10^{-10}}{2\times10^{-4}}\text{radian}.$$

$$= 6328\times10^{-6}\times\frac{180}{\pi}\text{degree} = 0.36^\circ$$

10. (a) Width of central maximum

$$= \frac{2\lambda D}{a} = \frac{2\times 6250\times 10^{-10}\times 0.5}{2\times 10^{-4}}$$

$$= 3125\times 10^{-6}\text{m} = 312.5\times 10^{-3}\text{ cm.}$$



Screen position of various minima for Fraunhoffer diffraction pattern of a single slit of width a.

11. (d) As reflected and refracted rays are perpendicular to each other, therefore, $i_p = i = 60°$, where i_p is called angle of polarisation.

$\mu = \tan i_p = \tan 60° = \sqrt{3} = 1.732.$

12. (b) $\upsilon = \frac{\Delta\lambda}{\lambda}\times c = \frac{(6586-6263)}{6563}\times 3\times 10^8$

$= 1.05\times 10^6\text{ m/s.}$

13. (b) $\Delta\lambda = \frac{\upsilon}{c}\times\lambda = \frac{10^5}{3\times 10^8}\times 5700 = 1.9\,\text{Å}.$

14. (b) According to principle of diffraction, a sin θ = nλ
where, n = order of secondary minimum
or, a sin 30° = 1 × (6500 × 10^{-10})
or, a = 1.3 × 10^{-6} m, or, a = 1.3 micron.

15. (d) $\frac{I_{max}}{I_{min}} = \frac{25}{9}$ or $\left(\frac{a_1+a_2}{a_1-a_2}\right)^2 = \frac{25}{9}$

where a denotes amplitude.

$\frac{a_1+a_2}{a_1-a_2} = \frac{5}{3}$ or $5a_1 - 5a_2 = 3a_1 + 3a_2$

or, $5a_1 - 5a_2 = 3a_1 + 3a_2$ or $2a_1 = 8a_2$

or, $\frac{a_1}{a_2} = 4$ or $\left(\frac{a_1}{a_2}\right)^2 = 16 = \frac{I_1}{I_2}.$

16. (b)

17. (d) For two coherent sources, $I_1 = I_2$

$I_{max} = (A_1 + A_2)^2 = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$

This is given as I_0 for maximum and zero for minimum. If there are two noncoherent sources, there will be no maximum and minimum intensities. Instead of all the intensity I_0 at maximum and zero for minimum, it will be just $I_0/2$.

18. (c) $\sin\theta = \frac{\lambda}{d} = \frac{589\times 10^{-9}}{0.589\times 10^{-3}} = 10^{-3} = \frac{1}{1000} = 0.0001$

19. (c) In Young's double slit experiment, half angular width (θ) is given by

$\sin\theta = \frac{\lambda}{d}$

$= \frac{589\times 10^{-9}}{0.589\times 10^{-3}} = 10^{-3}$

∴ $\theta = \sin^{-1} 0.001$

20. (b) When the light is incident at the polarising angle on the transparent medium, the reflected light is completely polarised.

21. (a)

22. (d) Let any $\vec{R}$ its components are

$\vec{R} = \vec{R}x + \vec{R}y + \vec{R}z$

with $|\vec{R}| = \vec{R} = |\vec{R}| = \vec{R} = \sqrt{Rx^2 + Ry^2 + Rz}$

& $\cos\theta_x = \frac{Rx}{R}$, $\cos\theta_y \frac{Ry}{R}$, $\cos\theta_z = \frac{Rz}{R}$

there $\cos\theta_x$, $\cos\theta_y$ and $\cos\theta_z$ one called direction cosines.

Hence $x + y + z = c\ \ (= \vec{R})$

So, magnitude of $c = \sqrt{I^2 + I^2 + I^2} = \sqrt{3}$

and $\cos\theta_x = \frac{1}{\sqrt{3}}$

23. (a) Where n is equivalent number of fringe by which the centre fringe is shifted due to mica sheet

$\lambda = \frac{(\mu-1)t}{n} = \frac{(1.5-1)6\times 10^{-6}}{5}$

$= 6\times 10^{-7}\text{m} = 6000\text{ Å}$

24. (b) Let nth fringe of 2500 Å coincide with (n – 2)th fringe of 3500Å.
∴ 3500 (n – 2) = 2500 × n
1000 n = 7000, n = 7
∴ 7th order fringe of 1st source will coincide with 5th order fringe of 2nd source.

25. (c) In Radar, the source & receiver are together, the receiver being turned for frequencies other than the source or radar frequency.

To measure the speed of helicopter

(i) The moving object of speed v_a receive a frequency

$\nu' = \nu\left(1 + \frac{v_a}{c}\right)$

(ii) The object which receives ν' frequency now acts as a moving source. The detector observes a frequency ν_0

$$\nu_0 = \nu'\left(\frac{1}{1-\frac{v_a}{c}}\right) = \left(\frac{1+\frac{v_a}{c}}{1-\frac{v_a}{c}}\right)$$

$$\Rightarrow (\nu_0 - \nu) = \Delta\nu = (\nu_0 + \nu)\frac{v_a}{c}$$

or $v_a = \dfrac{\Delta\nu c}{2\nu}$ $\left(\begin{array}{l}\therefore \nu_0 \approx \nu \\ \Rightarrow \nu_0 + \nu \approx 2\nu\end{array}\right)$

26. (a) As $\beta \propto \lambda$

$\therefore$ fringe width becomes $\frac{5}{4}$ times,

No, of fringes $= \frac{4}{5} \times 10 = 8$

27. (b) $\beta' = \frac{\beta}{\mu} = \frac{0.133}{1.33} = 0.1$ cm

28. (c) The position of n^{th} dark fringe in Fraunhoffer Diffraction from a single slit is
$a \sin\theta = n\lambda$

$$a = \frac{n\lambda}{\sin\theta} = \frac{1\times 6.5\times 10^{-7}}{\sin 30^\circ}, \text{(for first min. n = 1)}$$

$$= \frac{6.5\times 10^{-7}}{1/2} = 13\times 10^{-7}\,\text{m} = 1.3\,\mu\text{m}.$$

29. (a) $a\sin\theta = n\lambda$

$$\frac{ax}{f} = 3\lambda$$

(since θ is very small so $\sin\theta \approx \tan\theta \approx \theta = x/f$)

$$\text{or } \lambda = \frac{ax}{3f} = \frac{0.3\times 10^{-3}\times 5\times 10^{-3}}{3\times 1}$$

$$= 5\times 10^{-7}\,\text{m} = 5000\,\text{Å}.$$

30. (d) Limit of resolution $L.R \propto \lambda$

$$\therefore\ L.R' = L.R \times \frac{\lambda'}{\lambda} = 0.1\times\frac{4800}{6000} = 0.08\,\text{mm}.$$

$\therefore$ Resolution improves when light of lower wavelength is used.

31. (b) Intensity of polarised light transmitted from 1st polariser,
$I_1 = I_0 \cos^2\theta$

but $(\cos^2\theta)_{av} = \frac{1}{2}$

So $I_1 = \frac{1}{2} I_0 = \frac{32}{2} = 16\,\text{Wm}^{-2}$

32. (a) When angle of incidence i is equal to angle of polarisation i.e, then reflected light is completely plane-polarised whose vibration is perpendicular to plane of incidence.

33. (c) Suppose intensity of unpolarised light = 100.
$\therefore$ Intensity of polarised light from first nicol prism

$$= \frac{I_0}{2} = \frac{1}{2}\times 100 = 50$$

According to law of Malus,

$$I = I_0\cos^2\theta = 50\ (\cos 60^\circ)^2 = 50\times\left(\frac{1}{2}\right)^2 = 12.5$$

34. (a) According to law of Malus

$$\mathbf{I} = \mathbf{I}_0\cos^2\theta = \mathbf{I}_0(\cos 45^\circ)^2 = \mathbf{I}_0\left(\frac{1}{\sqrt{2}}\right)^2 = \frac{\mathbf{I}_0}{2}$$

35. (b) $\Delta\nu = \frac{\upsilon}{c}\times\nu = \frac{0.2c}{c}\times 4\times 10^7 = 0.8\times 10^7$ Hz

$\nu' = \nu - \Delta\nu = 4\times 10^7 - 0.8\times 10^7 = 3.2\times 10^7$ Hz.

36. (a) When planet or stars are receding away from earth. If f is frequency of vibration.

Then, $f = \frac{c}{\lambda}$

If v = velocity of body moving away
λ' = apparent wavelength to an observer on the earth

$\lambda' = \frac{(c+v)}{f}$ (c and v are in opposite to each other)

$$= \left(\frac{c+v}{c}\right)\lambda \qquad \lambda' = \left(1+\frac{v}{c}\right)\lambda$$

$$\frac{\lambda'-\lambda}{\lambda} = \frac{v}{c}$$

Fractional change in wavelength

$$\therefore \qquad 1 = \frac{v}{c} \Rightarrow v = c$$

37. (b) The fluorescent material present in the tube converts u.v. rays into visible light.

38. (b) For path difference λ, phase

$$\text{difference} = 2\pi\left(Q = \frac{2\pi}{\lambda}x = \frac{2\pi}{\lambda}.\lambda = 2\pi\right)$$

$\Rightarrow I = I_0 + I_0 + 2I_0\cos 2\pi$

$\Rightarrow I = 4I_0$ $\quad(\therefore \cos 2\pi = 1)$

For $x = \frac{\lambda}{4}$, phase difference $= \frac{\pi}{2}$

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

If $I_1 = I_2 = I_0$ then $I' = 2I_0 = 2.\frac{I}{4} = \frac{I}{2}$

39. (b) If the angular limit of resolution of human eye is R then

$$R = \frac{1.22\lambda}{a} = \frac{1.22\times5\times10^{-7}}{2\times10^{-3}} \text{ rad}$$

$$= \frac{1.22\times5\times10^{-7}}{2\times10^{-3}}\times\frac{180}{\pi}\times60 \text{ minute} = 1 \text{ minute}$$

40. (d) By principle of polarization, $\mu = \tan\theta_p$
or $\mu = \tan 54.74°$ or $\mu = 1.414$
For an equilateral prism, $\angle A = 60°$

$$\therefore \mu = \frac{\sin\left(\frac{A+\delta}{2}\right)}{\sin(A/2)} = \frac{\sin\left(\frac{60°+\delta}{2}\right)}{\sin(60°/2)}$$

or, $\frac{1.141\times1}{2} = \sin\left(\frac{60°+\delta}{2}\right)\left[\because 1.414 = \sqrt{2}\right]$

or, $\frac{\sqrt{2}}{2} = \sin\left(\frac{60°+\delta}{2}\right)$ or $\frac{1}{\sqrt{2}} = \sin\left(\frac{60°+\delta}{2}\right)$

or, $\sin 45° = \sin\left(\frac{60°+\delta}{2}\right)$ or $45° = \left(\frac{60°+\delta}{2}\right)$

41. (a)

42. (c) $x = \frac{(2n+1)\lambda D}{2a}$

For red light, $x = \frac{(4+1)D}{2a}\times6500Å$

For other light, $x = \frac{(6+1)D}{2a}\times\lambda Å$

x is same for each.

$\therefore 5\times6500 = 7\times\lambda \Rightarrow \lambda = \frac{5}{7}\times6500 = 4642.8\,Å.$

43. (b) ${}^a\mu_g = \tan\theta_P$ where θ_P = polarising angle.
or, ${}^a\mu_g = \tan 60°$

or, $\frac{c}{v_g} = \sqrt{3}$

or, $v_g = \frac{c}{\sqrt{3}} = \frac{3\times10^8}{\sqrt{3}} = \sqrt{3}\times10^8 \text{ ms}^{-1}$

44. (c) By covering aperture, focal length does not change. But intensity is reduced by $\frac{1}{4}$ times, as aperture diameter $\frac{d}{2}$ is covered.

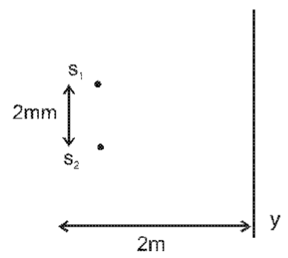
$\therefore I' = I - \frac{I}{4} = \frac{3I}{4}$

$\therefore$ New focal length = f and intensity $= \frac{3I}{4}$.

45. (a) $\because y = \frac{n\lambda D}{d}$

$\therefore n_1\lambda_1 = n_2\lambda_2$
$\Rightarrow n_1 \times 12000\times10^{-10} = n_2\times10000\times10^{-10}$
or, $n(12000\times10^{-10}) = (n+1)(10000\times10^{-10})$
$\Rightarrow n = 5$

$\left(\because \lambda_1 = 12000\times10^{-10}\text{m};\ \lambda_2 = 10000\times10^{-10}\text{m}\right)$

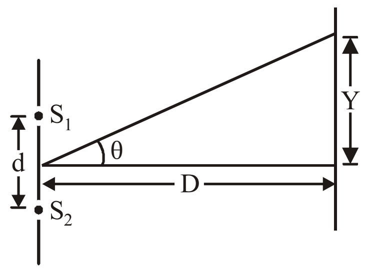


Hence, $y_{common} = \frac{n\lambda_1 D}{d}$

$= \frac{5(12000\times10^{-10})\times2}{2\times10^{-3}}$ $(\because d = 2\text{ mm and } D = 2\text{m})$

$= 5\times12\times10^{-4}$ m
$= 60\times10^{-4}$ m
$= 6\times10^{-3}$ m $= 6$ mm

46. (b)



Angular width, $\theta = \frac{Y}{D} = \frac{n\lambda D}{dD}\left[\because Y = \frac{D\lambda}{d}\right]$

so, $\theta = \frac{\lambda}{d}$, $v\uparrow \lambda\downarrow \theta\downarrow$ [For central maxima n = 1]

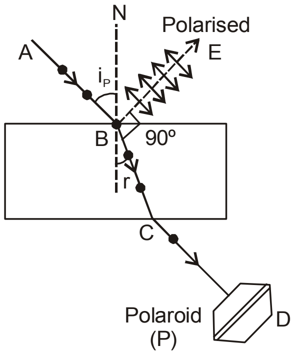
Hence, with increase in speed of electrons angular width of central maximum decreases.

47. (a) 48. (b) 49. (a) 50. (b)

EXERCISE - 3

Exemplar Questions

1. (c) Let us consider the diagram shown below the light beam incident from air to the glass slab at Brewster's angle (i_p). The angle between reflected ray BE and BC is 90°. Then only reflected ray is plane polarised represented by arrows.
As the emergent and incident ray are unpolarised, so, polaroid rotated in the way of CD then the intensity cannot be zero but varies in one complete rotation.



2. (a) As given that the width of the slit
$=10^4$ Å = 10000 Å
$= 10^4 \times 10^{-10}$ m $= 10^{-6}$ m = 1 μm
Wavelength of visible sunlight varies from 4000 Å to 8000 Å.
Thus the width of slit is 10000 Å comparable to that of wavelength visible light i.e., 8000 Å. So diffraction occurs with maxima at centre. Hence at the centre all colours appear i.e., mixing of colours form white patch at the centre.

3. (a) Let, us consider the diagram, the ray (P) is incident at an angle θ and gets reflected in the direction P' and refracted in the direction P' through O'. Due to reflection from the glass medium there is a phase change of π. The time difference between two refracted ray OP' and O'P'' is equal to the time taken by ray to travel along OO'.

$$\Delta t = \frac{OO'}{V_g} = \frac{d/\cos r}{c/n} = \frac{nd}{c\cos r}$$

From Snell's law, $n = \dfrac{\sin\theta}{\sin r}$

$$\sin r = \frac{\sin\theta}{n}$$

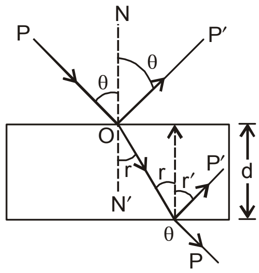
As we know that,

$$\cos r = \sqrt{1-\sin^2 r}\,,$$

so by putting sin r value in that relation.

So, $\cos r = \sqrt{1-\sin^2 r}$

$$\cos r = \sqrt{1-\frac{\sin^2\theta}{n^2}}$$



$$\therefore \quad \Delta t = \frac{nd}{c\left(1-\dfrac{\sin^2\theta}{n^2}\right)^{1/2}}$$

$$= \frac{nd}{c}\left(1-\frac{\sin^2\theta}{n^2}\right)^{-1/2}$$

Phase difference $= \Delta\phi = \dfrac{2\pi}{T} \times \Delta t$

$$= \frac{2\pi d}{\frac{1}{\nu}\cdot\nu\lambda}\left(1-\frac{\sin^2\theta}{n^2}\right)^{-1/2}$$

$$\Delta\phi = \frac{2\pi d}{\lambda}\left[1-\frac{\sin^2\theta}{n^2}\right]^{-1/2}$$

∴ Hence the net phase difference $= \Delta\phi + \pi$

$$= \frac{2\pi d}{\lambda}\left(1-\frac{1}{n^2}\sin^2\theta\right)^{-1/2} + \pi$$

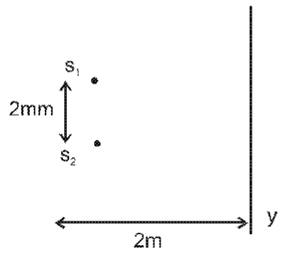
4. (c) For sustained interference pattern to be formed on the screen, the sources must be coherent and emits lights of same frequency and wavelength.
In a Young's double-slit experiment, when one of the holes is covered by a red filter and another by a blue filter. In this case due to filteration only red and blue lights are present which has different frequency. In this monochromatic light is used for the formation of fringes on the screen. So, in that case there shall be no interference fringes.

5. (d) Consider the given figure there is a hole at point P_2. By Huygen's principle, wave will propagates from the sources S_1 and S_2. Each point on the screen will acts as sources of secondary wavelets.
Wavefront starting from P_2 reaches at S_3 and S_4 which will again act as two monochromatic or coherent sources. Hence, there will be always a regular two slit pattern on the second screen.

Past Years (2013-2017) NEET/AIPMT

6. (a) $\because\ y = \dfrac{n\lambda D}{d}$
$\therefore\ n_1\lambda_1 = n_2\lambda_2$
$\Rightarrow\ n_1 \times 12000 \times 10^{-10} = n_2 \times 10000 \times 10^{-10}$
or, $n\,(12000 \times 10^{-10}) = (n+1)\,(10000 \times 10^{-10})$
$\Rightarrow\ n = 5$

$\left(\because \lambda_1 = 12000\times10^{-10}\text{m};\ \lambda_2 = 10000\times10^{-10}\text{m}\right)$



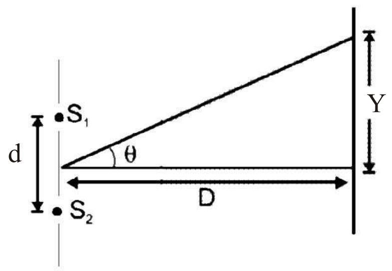
Hence, $y_{common} = \dfrac{n\lambda_1 D}{d}$

$= \dfrac{5\left(12000\times10^{-10}\right)\times2}{2\times10^{-3}}$

$(\because$ d = 2 mm and D = 2m$)$

$= 5\times12\times10^{-4}$ m
$= 60\times10^{-4}$ m
$= 6\times10^{-3}$ m $= 6$ mm

7. (b)



Angular width, $\theta = \dfrac{Y}{D} = \dfrac{n\lambda D}{dD}\ \left[\because Y = \dfrac{D\lambda}{d}\right]$

so, $\theta = \dfrac{\lambda}{d}$, $v\uparrow \lambda\downarrow \theta\downarrow$

[For central maxima n = 1]

Hence, with increase in speed of electrons angular width of central maximum decreases.

8. (c) Fringe width $\beta = \dfrac{\lambda D}{d}$;

From question $D' = 2D$ and $d' = \dfrac{d}{2}$

$\therefore \beta' = \dfrac{\lambda D^1}{d^1} = 4\beta$

9. (d) Conditions for diffraction minima are

Path diff. $\Delta x = n\lambda$ and Phase diff. $\delta\phi = 2n\pi$

Path diff. $= n\lambda = 2\lambda$

Phase diff. $= 2n\pi = 4\pi\ \ (\because n = 2)$

10. (d) Given: D = 2m; d = 1 mm $= 1\times10^{-3}$ m

$\lambda = 600$ nm $= 600\times10^{-6}$ m

Width of central bright fringe $(= 2\beta)$

$= \dfrac{2\lambda D}{d} = \dfrac{2\times600\times10^{-6}\times2}{1\times10^{-3}}$ m

$= 2.4\times10^{-3}$ m $= 2.4$ mm

11. (c) For path difference λ, phase difference $= 2\pi$ rad.

For path difference $\dfrac{\lambda}{4}$, phase difference $= \dfrac{\pi}{2}$ rad.

As $K = 4I_0$ so intensity at given point where path difference is $\dfrac{\lambda}{4}$

$K' = 4I_0\cos^2\left(\dfrac{\pi}{4}\right)\left(\cos\dfrac{\pi}{4} = \cos 45^\circ\right)$

$= 2I_0 = \dfrac{K}{2}$

12. (d) Here, distance between two slits,

$d = 1\text{mm} = 10^{-3}$m

distance of screen from slits, D = 1 m

wavelength of monochromatic light used,

$\lambda = 500\text{nm} = 500\times10^{-9}$m

width of each slit a = ?

Width of central maxima in single slit pattern $= \dfrac{2\lambda D}{a}$

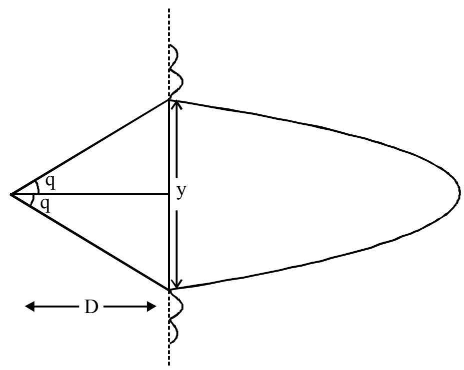
Fringe width in double slit experiment $\beta = \dfrac{\lambda D}{d}$

So, required condition $\dfrac{10\lambda D}{d} = \dfrac{2\lambda D}{a}$

$\Rightarrow a = \dfrac{d}{5D} = \dfrac{1}{5}\times10^{-3}\text{m} = 0.2\text{ mm}$

13. (d) Linear width of central maxima y

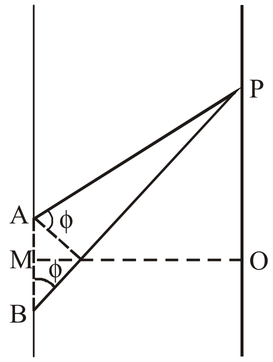
$= D(2q) = 2Dq = \dfrac{2D\lambda}{a}\quad \therefore q = \dfrac{\lambda}{a}$



14. (b) For first minima at P

$AP - BP = \lambda$

$AP - MP = \dfrac{\lambda}{2}$



So phase difference, $\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{2} = \pi$ radian

15. (d) The ratio of slits width = $\frac{1}{25}$ (given)

$\therefore \frac{I_1}{I_2} = \frac{25}{1}$

$I \propto A^2 \Rightarrow \frac{I_1}{I_2} = \frac{A_1^2}{A_2^2} = \frac{25}{1}$ or $\frac{A_1}{A_2} = \frac{5}{1}$

$\frac{A_{max}}{A_{min}} = \frac{A_1 + A_2}{A_1 - A_2} = \frac{5+1}{5-1} = \frac{6}{4} = \frac{3}{2}$

$\therefore \frac{I_{max}}{I_{min}} = \frac{A_{max}^2}{A_{min}^2} = \left(\frac{3}{2}\right)^2 = \frac{9}{4}$

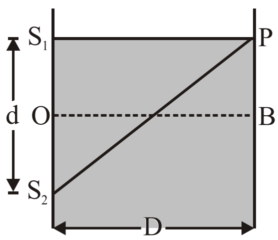
16. (d) For the first minima,

$\theta = \frac{\eta\lambda}{a} \quad \Rightarrow \quad \sin 30° = \frac{\lambda}{a} = \frac{1}{2}$

First secondary maxima will be at

$\sin\theta = \frac{3\lambda}{2a} = \frac{3}{2}\left(\frac{1}{2}\right) \quad \Rightarrow \quad \theta = \sin^{-1}\left(\frac{3}{4}\right)$

17. (d) Let P is a point infront of one slit at which intensity is to be calculated. From figure,



Path difference = $S_2P - S_1P$

$= \sqrt{D^2 + d^2} - D = D\left(1 + \frac{1}{2}\frac{d^2}{D^2}\right) - D$

$= D\left[1 + \frac{d^2}{2D^2} - 1\right] = \frac{d^2}{2D}$

$\Delta x = \frac{d^2}{2 \times 10d} = \frac{d}{20} = \frac{5\lambda}{20} = \frac{\lambda}{4}$

Phase difference,

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

So, resultant intensity at the desired point 'p' is

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

18. (b) Resolving power of a microscope = $\frac{2\mu \sin\theta}{\lambda}$

i.e., $R \propto \frac{1}{\lambda}$

or, $\frac{R_1}{R_2} = \frac{\lambda_2}{\lambda_1}$

Given that the two wavelengths,

$\lambda_1 = 4000Å$

$\lambda_2 = 6000Å$

$\therefore \frac{R_1}{R_2} = \frac{6000Å}{4000Å} = \frac{3}{2}$

19. (c) According to question

8^{th} bright fringe in medium = 5th dark fring in air

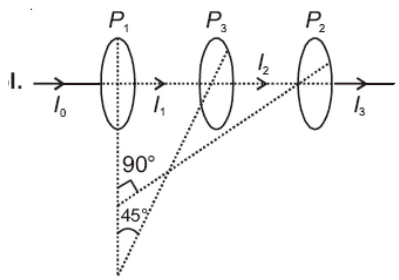
$Y_{8th\ bright} = 8\frac{\lambda D}{\mu d}$

$Y_{5th\ dark} = (2 \times 5 - 1)\frac{\lambda D}{2d} = \frac{9}{2}\frac{\lambda D}{d}$

$\Rightarrow \frac{9}{2}\frac{\lambda D}{d} = 8\frac{\lambda D}{\mu d}$

or, refractive index $\mu = \frac{16}{9} = 1.78$

20. (b)



According to malus law, $I = I_0 \cos^2\theta$

$I_1 = \frac{I_0}{2}$

$I_2 = \frac{I_0}{2}\cos^2 45° = \frac{I_0}{2} \times \frac{1}{2} = \frac{I_0}{4}$

$I_3 = \frac{I_0}{4}\cos^2 45°$

$I_3 = \frac{I_0}{8}$