# PHYSICS

## Class XII

## Chapter 10- Wave Optics

## 1 Mark Question

**Question 1.**
**How does the fringe width of interference fringes change, when the whole apparatus of Young's experiment is kept in a liquid of refractive index 1.3?**
Answer:

$$\beta_{air} = \frac{\lambda D}{d}$$

In water, $\lambda_\omega = \frac{\lambda_a}{1.3}$ ...where [$\lambda_\omega$ = wavelength in water and $\lambda_a$ = wavelength in air

$$\beta_{water} = \frac{\lambda_\omega D}{d} = \frac{\lambda_a D}{\mu d} = \frac{\beta_{air}}{1.3}$$

...where [$\mu$ = refractive index]

Fringe width becomes yL times of its initial value.

**Question 2.**
**How does the angular separation of interference fringes change in Young's experiment, if the distance between the slits is increased?**
Answer:

Angular separation, $\theta = \frac{\lambda}{d} \quad \therefore \ \theta \propto \frac{1}{d}$

When separation between two slits is increased, angular separation decreases.

**Question 3.**
**State the reason, why two independent sources of light cannot be considered as coherent sources.**
Answer:
Two independent sources of light cannot be coherent. This is because light is emitted by individual atoms, when they return to ground state. Even the smallest source of light contains billions of atoms which obviously cannot emit light waves in the same phase.

**Question 4.**
**How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced with red light?**
Answer:
We know that $\lambda_{red} > \lambda_{violet}$, therefore $\mu_{red} < \mu_{violet}$
and hence $\delta_{red} < \delta_{violet}$.
When incident violet light is replaced with red light, the angle of minimum deviation of a glass decreases.

**Question 5.**
**If the angle between the pass axis of polarizer and the analyser is 45°, write the ratio of the intensities of original light and the transmitted light after passing through the analyser.**
Answer:

$$I = \frac{I_0}{2} \cos^2 \theta$$

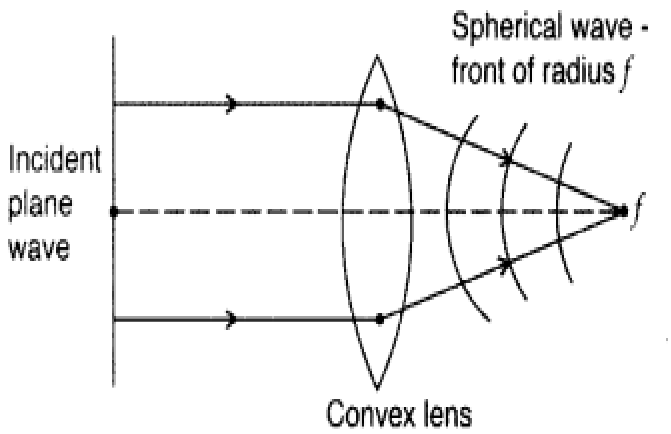
...where $\left[\begin{array}{l} I_0 \text{ is the original intensity and } \theta \text{ is the angle} \\ \text{between the axis of the polariser and the analyser} \end{array}\right.$

$$\therefore \quad \frac{I}{I_0} = \frac{\cos^2 \theta}{2} = \frac{1}{4} \qquad [(\because \theta = 45°, \cos^2 45° = 1/2)$$

**Question 6.**
**What type of wavefront will emerge from a**
**(i) point source, and**
**(ii) distant light source?**
Answer:
(i) Point source – Spherical wavefront
(ii) Distant light source – Plane wavefront.

**Question 7.**
**Unpolarized light is incident on a plane surface of glass of refractive index μ at angle i. If the reflected light gets totally polarized, write the relation between the angle i and refractive index μ.**
Answer:
$\mu = \tan i_p$.

**Question 8.**
**Draw a diagram to show refraction of a plane wave front incident in a convex lens and hence draw the refracted wave front.**
Answer:



**Question 9.**
**At what angle of incidence should a light beam strike a glass slab of refractive index 3–√, such that the reflected and the refracted rays are perpendicular to each other?**
Answer:
$\mu = \tan i_p$ under the given condition

$\therefore \quad i_p = \tan^{-1}(\sqrt{3}) = \frac{\pi}{3}$ **radian**

**Question 10.**
**Differentiate between a ray and a wave front.**
Answer:
Ray defines the path of light.
Wave front is the locus of points in the light wave' having the same phase of oscillation at any instant.

**Question 11.**
**How would the angular separation of interference fringes in Young's double slit experiment change when the distance between the slits and screen is doubled?**
Answer:
Angular separation θ=λd and is independent of slit-screen separation
∴ There will be no change

**Question 12.**
**How does the angular separation between fringes in single-slit diffraction experiment change when the distance of separation between the slit and screen is doubled?**
Answer:

$\theta = \frac{\lambda}{d}$ **where [θ is the angular separation.]**

When the distance D of seperation between the slits and the screen is doubled, the angular seperation θ remains unchanged.

**Question 13.**
**In a single-slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band.**
Answer:
If the width of the diffraction slit is doubled, the size of the central diffraction band will become half and its intensity will become four times of its original value.

**Question 14.**
**How does the fringe width, in Young's double-slit experiment, change when the distance of separation between the slits and screen is doubled?**
Answer:
If the distance between slits and screen (D) is doubled, the fringe width in double slit

experiment will become double as $x = \frac{D\lambda}{2d}$

$\Rightarrow \quad x \propto D$

**Question 15.**
**In what way is plane polarized light different from an unpolarized light?**
Answer:
In case of polarized light, the directions of electric field vector are restricted to only a particular / plane whereas in an unpolarized light the direction of $\vec{E}$ is in all possible directions in a plane perpendicular to the direction of propagation.

**Question 16.**
**In a single slit diffraction experiment, the width of the slit is reduced to half its original width. How would this affect the size and intensity of the central maximum?**
Answer:

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

$$\therefore \quad \beta' = \frac{\lambda D}{d} = \frac{2\lambda D}{d} = 2\beta$$

As width reduces to half, *i.e.,* $d' = \frac{d}{2}$

Size becomes twice and intensity $I = a^2$

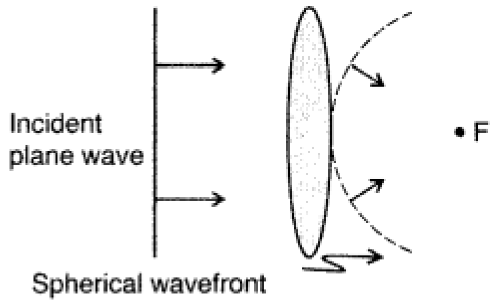
$$\therefore \quad I' = \left(\frac{a}{2}\right)^2 = \frac{1}{4}a^2 = \frac{1}{4}I$$

**Question 17.**
**Which of the following waves can be polarized**
**(i) Heat waves**
**(ii) Sound waves? Give reason to support your answer.**
Answer:
Heat waves can be polarized as they are transverse in nature.

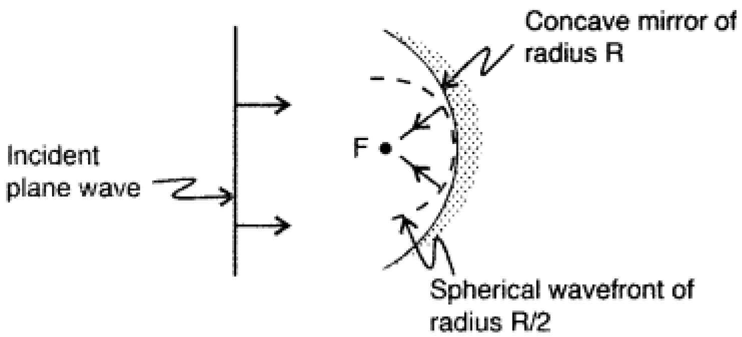
**Question 18.**
**Define the term 'coherent sources' which are required to produce interference pattern in Young's double slit experiment.**
Answer:
Two monochromatic sources, which produce light waves, having a constant phase difference are defined as coherent sources.

**Question 19.**
**Define the term 'wavefront'.**
Answer:
The wavefront is defined as the locus of all particles of a medium, which are vibrating in the same phase.

**Question 20.**
**Draw the shape of the wavefront coming out of a convex lens when a plane wave is incident on it.**
Answer:




**Question 21.**
**Draw the shape of the wavefront coming out of a concave mirror when a plane wave is incident on it.**
Answer:




**Question 22.**
**Why does Sun appear red at sunrise and sunset?**
Answer:
It is due to least scattering of red light as it has the longest wavelength.
[As per Rayleigh's scattering, the amount of light
scattered $\propto \frac{1}{\lambda^4}$]

**Question 23.**
**A beam of unpolarised light is incident, on the boundary between two transparent media, at an angle of incidence = $i_B$, the Brewester's angle. At what angle does the reflected light get polarised?**
Answer:
At an angle of incidence = iB, the reflected light gets polarised.

## 2 Mark Questions

**Question 1.**
**State one feature by which the phenomenon of interference can be distinguished from that of diffraction.**
**A parallel beam of light of wavelength 600 nm is incident normally on a slit of width 'a'. If the distance between the slits and the screen is 0.8 m and the distance of 2nd order maximum from the centre of the screen is. 15 mm, calculate the width of the slit.**
Answer:
(i) In interference all the maxima are of equal intensity.
In diffraction pattern central fringe is of maximum intensity while intensity of secondary maxima falls rapidly.
(ii) **Given :** $\lambda = 600 \text{ nm} = 6 \times 10^{-7}\text{m}$,
$D = 0.8\text{m}$, $\gamma_2 = 15 \times 10^{-3}\text{m}$
**To calculate :** Width of the slit '$d$'

**Calculations :** $\gamma_2 = \frac{5}{2} \times \frac{\lambda D}{d}$

$\Rightarrow d = \frac{5}{2} \times \frac{6 \times 10^{-7} \times 0.8}{15 \times 10^{-3}}$

$\therefore$ Distance, $d = 8 \times 10^{-5} =$ **80 μm**

**Question 2.**
**Define the term 'linearly polarised light'. When does the intensity of transmitted light become maximum, when a polaroid sheet is rotated between two crossed polaroids?**
Answer:
Linearly polarised light is one in which the
vibration of light is present in one line only.
***Law of Malus :*** $I = I_0 \cos^2\theta$, at $\theta = 0$, $\cos\theta = 1$,
Intensity is maximum.

**Question 3.**
**(i) State the principle on which the working of an optical fiber is based.**
**(ii) What are the necessary conditions for this phenomenon to occur?**
Answer:
(i) Working of an optical fibre is based on the principle of total internal reflection.
(ii) (a) Light should travel from a denser to rarer medium.
(b) Angle of incidence should be more than

critical angle given by $i_c = \sin^{-1}\left(\frac{1}{\mu}\right)$.

**Question 4.**
**(a) Why are coherent sources necessary to produce a sustained interference pattern?**
**(b) In Young's double slit experiment using mono-chromatic light of wavelength X, the intensity of light at a point on the screen where path difference is X, is K units. Find out the intensity of light at a point where path difference is 2λ3.**
Answer:
(a) Coherent sources have a constant phase difference and, therefore, produce a sustained interference pattern.
These sources are needed to ensure that the position of maxima and minima do not change with time.
(b) $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\phi$

Let $I_0$ be the intensity of either source, then

$$I_1 = I_2 = I_0 \text{ and } I = 2I_0(1+\cos\phi)$$

$$= 4I_0\cos^2\phi/2 \quad \Rightarrow I = 4I_0\cos^2\frac{\phi}{2}$$

When $p = \lambda$, $\phi = 2\pi$,
then $\quad I = 4I_0\cos^2\phi/2 = 4I_0\cos^2\pi = 4I_0 = K$

When $P = \frac{2\pi}{3}$, $\phi = \frac{4\pi}{3}$

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

$$\Rightarrow I = 4I_0\left(-\cos\frac{\pi}{3}\right)^2 = I_0 \therefore \mathbf{I} = \frac{\mathbf{K}}{\mathbf{4}}$$

**Question 5.**
**State two conditions required for obtaining co-herent sources.**
**In Young's arrangement to produce interference pattern, show that dark and bright fringes appearing on the screen are equally spaced.**
Answer:
Two conditions for obtaining coherent sources: (0 Two sources should give monochromatic light.
(ii) Coherent sources of light should be obtained from a single source by some device.
The fringe width (dark and bright) is given by

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

Hence, it is same for both dark and bright fringes So they are equally spaced on the screen.

**Question 6.**
**Laser light of wavelength 640 nm incident on a pair of slits produces an interference pattern in which the bright fringes are separated by 7.2 mm. Calculate the wavelength of another source of light which produces interference fringes separated by 8.1 mm using same arrangement. Also find the minimum value of the order 'n' of bright fringe of shorter wavelength which coincides with that of the longer wavelength.**
Answer:
Distance between two bright fringes = Fringe width

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

For same values of D and $d$, we have

$$\frac{\beta_1}{\beta_2} = \frac{\lambda_1}{\lambda_2} \quad \text{or} \quad \frac{7.2}{8.1} = \frac{640}{\lambda_2} \quad \text{or} \quad \frac{0.8}{0.9} = \frac{640}{\lambda_2}$$

or $0.8\lambda_2 = 576 \quad \therefore \lambda_2 = 720$ nm

Calculation of minimum value of order: for n to be minimum

$(n + 1)^{th}$ maxima of shorter wavelength should coincide with $n^{th}$ maxima of longer wavelength

coincide with $n^{th}$ maxima of longer wavelength

$$(n + 1)\ 640 = n \times 720 \quad \text{or} \quad 640\ n + 640 = 720\ n$$

or $640 = 720\ n - 640\ n$ *i.e.* $80\ n$

or $80\ n = 640$ or $n = 8$

$\therefore$ ***Minimum order of shorter wavelength***

$$= (n + 1) = (8 + 1) = \mathbf{9}$$

**Question 7.**

**Yellow light (λ = 6000Å) illuminates a single slit of width 1 x 10-4 m. Calculate**

**(i) the distance between the two dark lines on either side of the central maximum, when the diffraction pattern is viewed on a screen kept 1.5 m away from the slit;**

**(ii) the angular spread of the first diffraction minimum.**

Answer:

(i) Distance between two dark lines, on either

side of central maxima $= 2\dfrac{\lambda D}{a}$

$$= \frac{2 \times 6000 \times 10^{-10} \times 1.5}{1 \times 10^{-4}} = 18000 \times 10^{-6}$$

$$= 18 \times 10^{-3}\text{m} = \mathbf{18\ mm}$$

(ii) Angular spread of the first diffraction minimum (on either side)

$$= \theta = \frac{\lambda}{a} = \frac{6 \times 10^{-7}}{1 \times 10^{-4}} = \mathbf{6 \times 10^{-3}\ radians}$$

**Question 8.**

**A parallel beam of light of 500 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1 m away. It is observed that the first minimum is at a distance of 2.5 mm from the centre of the screen. Calculate the width of the slit.**

Answer:

Given, $\lambda = 500$ nm $= 500 \times 10^{-9}$ m, $\quad D = 1$

$x_n = 2.5$ mm $= 2.5 \times 10^{-3}$ m $\quad n = 1$

$$\frac{x_m d}{D} = n\lambda$$

$$d = \frac{n\lambda D}{x_n}$$

$$d = 1 \times (500 \times 10^{-9}) \times \frac{1}{2.5 \times 10^{-3}} = 2 \times 10^{-4}\ \text{m}$$

**Question 9.**

**A parallel beam of light of 600 nm falls on a narrow slit and the resulting diffraction pattern is observed on a screen 1.2 m away. It is observed that the first minimum is at a distance of 3 mm from the centre of the screen. Calculate the width of the slit.**

Answer:

$\lambda = 600 \text{ nm} = 600 \times 10^{-9}$ m, $D = 1.2$ m

First minima at $x_1 = 3$ mm $= 3 \times 10^{-3}$ m

Diffraction angle for first minima :

$$\theta_1 = \frac{x_1}{D}$$

$$\theta_1 = \frac{3 \times 10^{-3} \times 10}{12} = 2.5 \times 10^{-3} \text{ rad}$$

We know, $a \sin \theta_1 = n\lambda, \quad n = 1$

$a \sin \theta_1 = n\lambda$

Since angle is very small so $\sin \theta_1 \sim \theta$

$$a = \frac{\lambda}{\theta_1} = \frac{600 \times 10^{-9}}{2.5 \times 10^{-3}}$$

$$a = \frac{6}{2.5} \times 10^{-4} \text{ m} = 2.4 \times 10^{-4} \text{ m} = 0.24 \text{ mm}$$

$$\therefore \boxed{a = 0.24 \text{ mm}}$$

**Question 10.**

**Write the distinguishing features between a diffraction pattern due to a single slit and the interference fringes produced in Young's double slit experiment?**

Answer:

Difference between interference and diffraction of light

| | Interference | Diffraction |
|---|---|---|
| 1. | Interference is due to superposition of two distinct waves coming from two coherent sources. | Diffraction is due to superposition of the secondary wavelets coming from different parts of the same wavefront. |

| | | |
|---|---|---|
| 2. | Interference fringes may or may not be of the same width. | Diffraction fringes are not to be of the same width. |
| 3. | The intensity of minima is generally zero. | The intensity of minima is never zero. |
| 4. | All bright fringes are of uniform intensity. | All bright fringes are not of uniform intensity. |

**Question 11.**
**Answer the following questions :**
**(i) In what way is diffraction from each slit related to the interference pattern in a double slit experiment?**
**(ii) When a tiny circular obstacle is placed in the path of light from a distance source, a bright spot is seen at the centre of the shadow of the obstacle. Explain, why.**
Answer:
(i) Diffraction from each slit is related to interference pattern in a double slit experiment in the following ways :

- The intensity of minima for diffraction is never zero, while for interference it is generally zero.
- All bright fringes for diffraction are not of uniform intensity, while for interference, these are of uniform intensity

(ii) Waves from the distant source are diffracted by the edge of the circular obstacle and these diffracted waves interfere constructively at the centre of the obstacle's shadow produc¬ing a bright spot.

**Question 12.**
**(a) Write the conditions under which light sources can be said to be coherent.**
**(b) Why is it necessary to have coherent sources in order to produce an interference pattern?**
Answer:
(a) Coherent sources of light. The sources of light, which emit continuously light waves of the same wavelength, same frequency and in same phase are called Coherent sources of light.
Interference pattern is not obtained. This is because phase difference between the light waves emitted from two different sodium lamps will change continuously.

(b) Conditions for interference. The important conditions for obtaining interference of light are :

1. The two sources of light must be coherent. i.e. they should exist continuous waves of same wavelength or frequency.
2. The two sources should be monochromatic.
3. The phase difference of waves from two sources should be constant.
4. The amplitude of waves from two sources should be equal.
5. The coherent sources must be very close to each other.

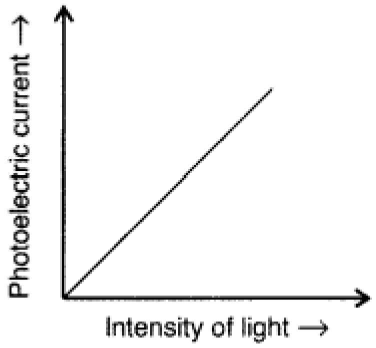
**Question 13.**
**(i) Monochromatic light of frequency $6.0 \times 10^{14}$ Hz is produced by a laser. The power emitted is $2.0 \times 10^{-3}$ W. Estimate the number of photons emitted per second on an average by the source.**
**(ii) Draw a plot showing the variation of photoelectric current versus the intensity of incident radiation on a given photosensitive surface.**
Answer:
(*i*) Given : $\nu = 6.0 \times 10^{14}$ Hz, $P = 2.0 \times 10^{-3}$ W
Energy of one photon
$= h\nu = (6.6 \times 10^{-34}) \times (6.0 \times 10^{14})$
Number of photons emitted per sec

$$= \frac{\text{Power}}{\text{Energy of one photon}}$$

$$n = \frac{2 \times 10^{-3}}{(6.6 \times 10^{-34}) \times (6.0 \times 10^{14})}$$

$\therefore$ $\boldsymbol{n = 5 \times 10^{15}}$

(*ii*)




**Question 14.**
**For a single slit of width "a", the first minimum of the interference pattern of a monochromatic light of wavelength λ occurs at an angle of λa .**
**At the same angle of λa, we get a maximum for a two narrow slits separated by a distance "a". Explain**
Answer:
For a single slit of width 'a',

the $n^{th}$ minimum, sinθn=nλa

or $\theta_n = \frac{n\lambda}{a}$ (when θ is small)

$\theta = \frac{\lambda}{a}$ (when $n = 1$ for the first minimum)

Now, the maximum of two narrow slits separated by a distance '$a$'

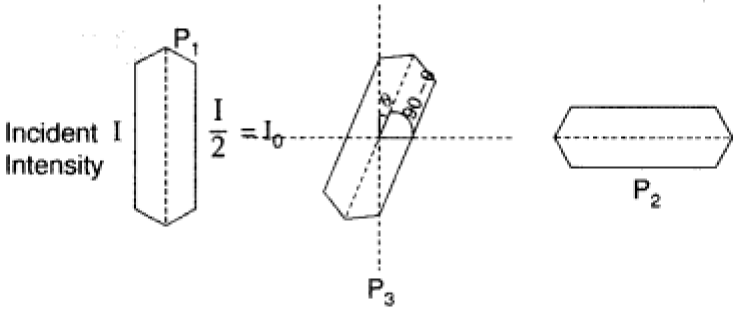
Path difference, $(x) = \frac{\lambda D}{d}$

angle $(\theta) = \frac{x}{D} = \frac{\lambda}{d}$ or $\frac{\lambda}{a}$ $(\because d = a)$

This is why, at the same angle $\frac{\lambda}{a}$, we get a maximum for two narrow slits separated by a distance '$a$'.

**Question 15.**
**Find an expression for intensity of transmitted light when a polaroid sheet is rotated between two crossed polaroids. In which position of the Polaroid sheet will the transmitted intensity be maximum?**

Answer:
Let the rotating Polaroid sheet make an angle θ with the first polaroid.
∴ angle with the other polaroid will be (90 – θ)




Applying Malus' law between $P_1$ and $P_3$

$I' = I_0 \cos^2\theta$

Between $P_3$ and $P_2$

$I'' = (I_0 \cos^2\theta)\cos^2(90 - \theta) = I_0 \cos^2\theta \sin^2\theta$

$= \frac{I_0}{4}(2\sin\theta\cos\theta)^2$

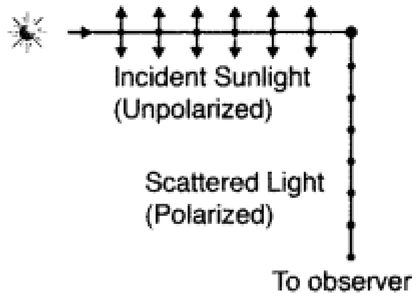
$I'' = \frac{I_0}{4}.\sin^2 2\theta$

$\because$ $\sin^2(2\theta) = 1$ or $2\theta = \frac{\pi}{2}$ or $\theta = \frac{\pi}{4}$

∴ Transmitted intensity will be maximum when $\theta = \frac{\pi}{4}$.

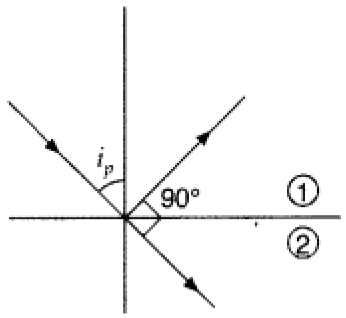
**Question 16.**
**Distinguish between unpolarised and a linearly polarised light. Describe, with the help of a diagram, how unpolarised light gets linearly polarised by scattering.**
Answer:
Unpolarized light : A light wave, in which the electric vector oscillates in all possible directions in a plane perpendicular to the direction of propagation is known as unpolarized light.
Linearly polarized light : If the oscillations of the electric vectors are restricted to just one direction, in a plane perpendicular to the direction of propagation, the corresponding light is known as linearly polarized light.

It is due to scattering of light by molecules of earth's atmosphere.



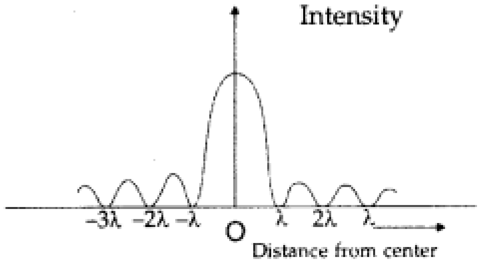

Under the influence of the electric field of the incident (unpolarized) wave, the electrons in the molecules acquire components of motion in both these directions. Charges, accelerating parallel to the double arrows, do not radiate energy towards the observer since their acceleration has no transverse component.
The radiation scattered by the molecules is therefore represented by dots, i.e., it is polarized perpendicular to plane of figure.

**Question 17.**
**State Brewster's law. The value of Brewster angle for a transparent medium is different for light of different colours. Give reason.**
Answer:
(i) Brewster's law : When unpolarised light is incident on the surface separating two media, the reflected light gets (completely) polarized only when the reflected light and refracted light become perpendicular to each other.
The refractive index of denser medium, with respect to rarer medium, is given by
$\mu = \tan i_p$



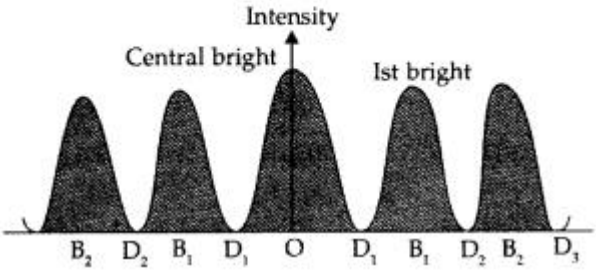

(ii) Since refractive index (μ) of a transparent medium is different for different colours, hence Brewster angle also is different for different colours.

**Question 18.**
**Draw the intensity pattern for single slit diffraction and double slit interference. Hence, state two differences between interference and diffraction patterns**
Answer:
(i) Intensity distribution in the diffraction due to single slit

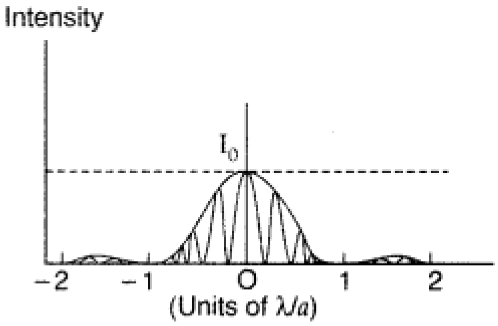


Intensity distribution in the diffraction due to single slit

(ii) Intensity pattern for double slit interference.



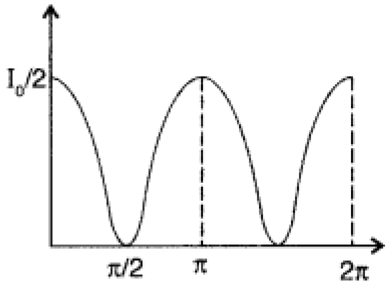

(iii) Difference between Interference and Difference Patterns:
Interference pattern and Diffraction pattern :
The diagram, given here, shows several fringes, due to double slit interference, 'contained' in a broad diffraction peak. When the separation between the slits is large compared to their width, the diffraction pattern becomes very flat and we observe the two slit interference pattern.




Basic features of distinction between interference and diffraction patterns :
(i) The interference pattern has a number of equally spaced bright and dark bands while diffraction pattern has a central bright maximum which is twice as wide as the other maxima.
(ii) Interference pattern is the superimposition of two waves slits originating from two narrow slits. The diffraction pattern is a superposition of a continuous family of waves originating from each point on a single slit.
(iii) For a single slit of width 'a' the first null of diffraction pattern occurs at an angle of λa. At the same angle of λa, we get a maxima for two narrow slits separated by a distance 'a'.

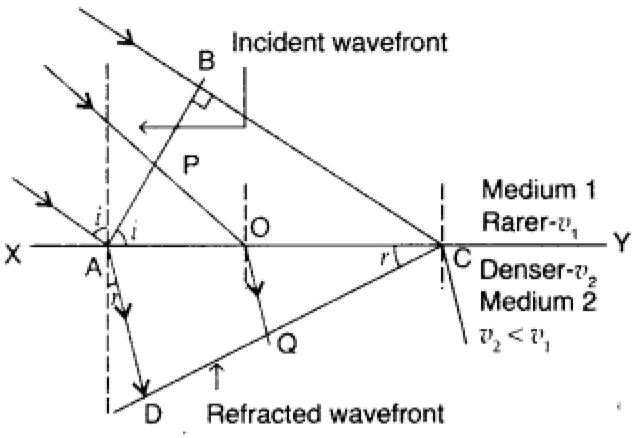
**Question 19.**
**Unpolarised light is passed through a polaroid $P_1$ When this polarised beam passes through another polaroid $P_2$ and if the pass axis of $P_2$ makes angle 6 with the pass axis of $P_1$, then write the expression for the polarised beam passing through $P_2$. Draw a plot showing the variation of intensity when θ varies from 0 to 2π.**
Answer:

Intensity is $\frac{I_0}{2}\cos^2\theta$ (If $I_0$ is the intensity of unpolarised light.)
Intensity is $I\cos^2\theta$ (If I is the intensity of polarised light)
*Graph showing the intensity :*




## 4 Mark Questions

**Question 1.**
**How is a wavefront defined? Using Huygen's construction draw a figure showing the propagation of a plane wave refracting at a plane surface separating two media. Hence verify Snell's law of refraction.**
Answer:
(i) Wavefront : Wavefront is defined as the continuous locus of all such particles of the medium which are vibrating in the same phase at any instant.



(ii) We take a plane wavefront AB incident at a plane surface XY. We use secondary wavelets starting at different times. We get refracted wavefront only when the time taken by light to travel along different rays from one wavefront to another is same. We take any arbitrary ray starting from point ‘P’ on incident wavefront to refracted wavefront at point ‘O’. Let total time be ‘t’.

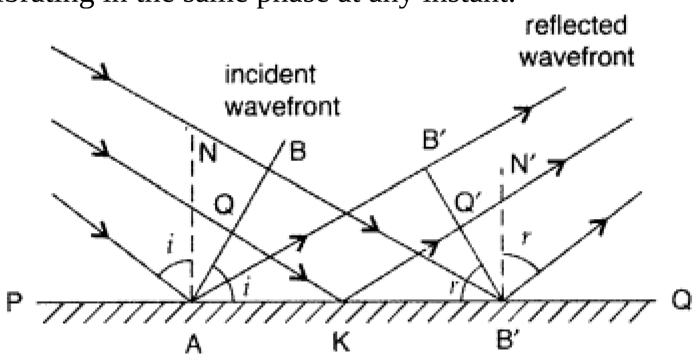
$$t = \frac{PO}{v_1} + \frac{OQ}{v_2} = \frac{AO\sin i}{v_1} + \frac{OC\sin r}{v_2}$$
$$= \frac{AO\sin i}{v_1} + \frac{(AC - AO)\sin r}{v_2}$$
$$= \frac{AC\sin r}{v_2} + AO\left(\frac{\sin i}{v_1} - \frac{\sin r}{v_2}\right)$$

As time should be independent of the ray to be considered
The coefficient of AO in the above equation should be zero

$$i.e. \quad \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2$$

Where ’$\mu_2$ is called refractive index of medium 2 w.r.t. medium 1. This is Snell’s law of refraction.

**Question 2.**
**How is a wavefront defined? Using Huygen’s construction draw a figure showing the propagation of a plane wave reflecting at the interface of the two media. Shpw that the angle of incidence is equal to the angle of reflection.**
Answer:
Wavefront : Wavefront is defined as the continuous locus of all such particles of the medium which are vibrating in the same phase at any instant.




We take any point Q on the incident wavefront. When disturbance from point B on the incident wavefront reaches point B’, the disturbance from point Q reaches Q’ via point K on the reflecting surface. Since B’A’ represents the reflected wavefront, time by light to travel from any point on incident wavefront to the corresponding point on the reflected wavefront should always be same. Let total time be ‘t’

$$t = \frac{QK}{v} + \frac{KQ'}{v} \qquad \text{...where } [v = C]$$
$$\text{or} \quad t = \frac{QK}{C} + \frac{KQ'}{C}$$
$$\text{or} \quad t = \frac{AK}{C}\sin i + \frac{(AB' - AK)\sin r}{C}$$
$$\therefore \quad t = \frac{AB'\sin r}{C} + \frac{AK}{C}(\sin i - \sin r)$$

As time of the ray to be considered should be independent, the coefficient of AK in the above equation

should be zero.
That is, sin i = sin r or i = r
Hence, angle of incidence is equal to angle of reflection.

## 7 Marks Questions

**Question 1.**
**Distinguish between unpolarised and plane polarised light. An unpolarised light is incident on the boundry between two transparent media. State the condition when the reflected wave is totally plane polarised. Find out the expression for the angle of incidence in this case.**
Answer:
(a) Unpolarised light: A beam of light in which electrical vector oscillates in all possible planes, in a direction normal to the direction of propagation of wave.

(b) Polarised light : A beam of light in which electrical vector oscillates in a direction normal to the direction of propagation of wave on a single plane only.
From Snell’s law.

$$\frac{\sin i_p}{\sin r} = \mu \qquad \Rightarrow \frac{\sin i_p}{\sin(90^\circ - i_p)} = \mu$$

$$\Rightarrow \frac{\sin i_p}{\cos i_p} = \mu \qquad \therefore \mu = \tan i_p$$

In a single slit diffraction experiment, when a tiny circular obstacle is placed in the path of light from a distance source, a bright spot is seen at the centre of the shadow of the obstacle. Explain why?
State two points of difference between the interference pattern obtained in Young’s double slit experiment and the diffraction pattern due to a single slit.
Wave diffracted from the edge of any circular obstacle undergoes constructive interference to form a bright spot at the centre of shadow.

| | Young’s double slit experiment | Single slit experiment |
|---|---|---|
| 1. | Light originating from two coherent sources. | Light originating from single source. |
| 2. | Fringes are of equal width. | Fringe width decreases with order. |

| | | |
|---|---|---|
| 3. | Intensity of all the bright fringes is the brightness is the same. | Intensity falls with increasing order. The brigtness of successive bright fringes goes on decreasing. |

**Question 2.**
**In Young's double slit experiment, monochromatic light of wavelength 630 nm illuminates the pair of slits and produces an interference pattern in which two consecutive bright fringes are separated by 8.1 mm. Another source of monochromatic light produces the interference pattern in which the two consecutive bright fringes are separated by 7.2 mm. Find the wavelength of light from the second source. What is the effect on the interference fringes if the monochromatic source is replaced by a source of white light?**
Answer:
Position of the n$^{th}$ bright fringe is given by nλDd from the central bright,
So the separation between two consecutive bright fringes is $\frac{\lambda D}{d}$

With $\lambda_1 = 630$ nm, we have $\frac{\lambda_1 D}{d} = 8.1$ mm ...(*i*)

With $\lambda_2$, we have $\frac{\lambda_2 D}{d} = 7.2$ mm ...(*ii*)

Dividing (*i*) by (*ii*), we have $\frac{\lambda_1}{\lambda_2} = \frac{8.1}{7.2}$

$$\Rightarrow \lambda_2 = \frac{7.2}{8.1} \times \lambda_1 = \frac{8}{9} \times 630 = \mathbf{560\ nm}$$

When the monochromatic light is replaced by a white light:

1. the central bright remains white and
2. all the other colours will form individual maximas with the least wavelength violet forming its bright close to the central bright.

**Question 3.**
**(a) In a single slit diffraction experiment, a slit of width 'd' is illuminated by red light of wavelength 650 nm. For what value of 'd' will**
**(i) the first minimum fall at an angle of diffraction of 30°, and**
**(ii) the first maximum fall at an angle of diffraction of 30°?**
**(b) Why does the intensity of the secondary maximum become less as compared to the central maximum?**
Answer:

(a) (i) I minimum at 30° satisfies the condition,

$d \sin\theta = \lambda$

$$d = \frac{\lambda}{\sin 30^\circ} = 2 \times \lambda = \mathbf{1300\ nm}$$

(ii) I maxima at 30° satisfies the condition,

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

$$\therefore \quad d = 3 \times \frac{\lambda}{2 \sin 30^\circ} \Rightarrow 3\lambda = 2d \sin 30^\circ$$

$$\Rightarrow \quad 3 \times 650 = 2d \sin 30^\circ$$

$$\Rightarrow \quad 2d \times \frac{1}{2} = 1950$$

$$\therefore \quad d = \mathbf{1950 \times 10^{-9}\ nm}$$

(b) As the order increases only $1/n^{th}$ (where n is an odd number) of the slit, will contribute in producing brightness at a point in diffraction. So the higher order maxima are not so bright as the central.

**Question 4.**

**In Young's double slit experiment, mono-chromatic light of wavelength 600 nm illuminates the pair of slits and produces an interference pattern in which two consecutive bright fringes are separated by 10 mm. Another source of monochromatic light produces the interference pattern in which the two consecutive bright fringes are separated by 8 mm. Find the wavelength of light from the second source. What is the effect on the interference fringes if the monochromatic source is replaced by a source of white light?**

Answer:

$\lambda_1 = 600$ nm, $\beta_1 = 10$ mm, $\beta_2 = 8$ mm

$$\text{Since } \beta = \frac{\lambda D}{d} \qquad \Rightarrow \frac{\beta_2}{\beta_1} = \frac{\lambda_2}{\lambda_1}$$

$$\Rightarrow \quad \lambda_2 = \frac{\beta_2}{\beta_1} \times \lambda_1 \qquad \Rightarrow \lambda_2 = \frac{8}{10} \times 600 = \mathbf{480\ nm}$$

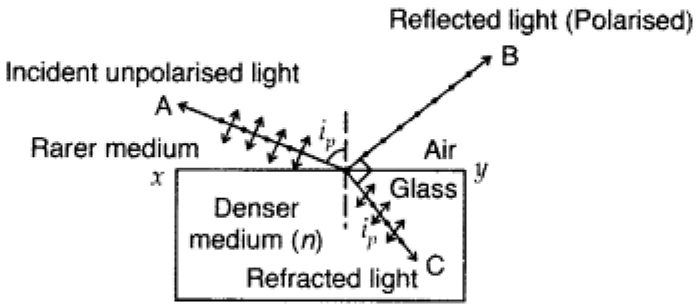
Effect: When the monochromatic light is replaced by a white light:

(i) the central bright remains white and

(ii) all the other colours will form individual maximas with the least wavelength violet forming its bright close to the central bright.

an unpolarized light  the help of suitable ray diagram how an unpolarized light can be polarized by reflection from a transparent medium. Write the expression for Brewster angle in terms of the refractive index of denser medium.

Unpolarized light: A light which has vibrations in all directions in a plane perpendicular to the direction of propagation is said to be unpolarized light.




When unpolarised light is incident on the boundary of two transparent media, the reflected light is polarised with electric vector perpendicular to the plane of incidence when the refracted and reflected rays make a right angle with each other.
Relation between Brewster angle i and refractive index (μ) is :
$\mu = \tan i_p$

**Question 3.**
**In Young's double slit experiment, the two slits 0. 15 mm apart are illuminated by monochromatic light of wavelength 450 nm. The screen is 1.0 m away from the slits.**
**(a) Find the distance of the second**
**(i) bright fringe,**
**(ii) dark fringe from the central maximum.**
**(b) How will the fringe pattern change if the screen is moved away from the slits?**
Answer:
**Given** : $d = 0.15$ mm $= 0.15 \times 10^{-3}$ m,
$\lambda = 450 \times 10^{-9}$ m and D = 1.0 m
(a) (i) Distance of the second bright fringe,

$$x_2 = \frac{2\lambda D}{d}$$

$$\therefore \quad x_2 = \frac{2 \times 450 \times 10^{-9} \times 1.0}{0.15 \times 10^{-3}}$$

$$= 2 \times 3 \times 10^{-3} = \mathbf{6\ mm}$$

(ii) Distance of the second dark fringe,

$$x_2 = \frac{3\lambda D}{2d} = \frac{3 \times 450 \times 10^{-9} \times 1.0}{2 \times 0.15 \times 10^{-3}}$$

$$= \mathbf{4.5\ mm}$$

(b) Linear width of a fringe, $\beta = \frac{\lambda D}{d}$

Angular width of a fringe, $\Delta Q = \frac{\lambda}{d}$

∴ With increase in the value of D linear width will increase, while the angular width will remain the same.

**Question 4.**
**(a) How does an unpolarised light get polarised when passed through a polaroid?In Young's double slit experiment, the two slits 0.12 mm apart are illuminated by monochromatic light of wavelength 420 nm. The screeen is 1.0 m away from the slits.**
**(a) Find the distance of the second**
**(i) bright fringe,**
**(ii) dark fringe from the central maximum.**
**(b) How will the fringe pattern change if the screen is moved away from the slits?**

Answer:
(a) In a polaroid a long chain of molecules is aligned in a particular direction. The electric vectors (of light waves) along the direction of . aligned molecules gets absorbed.
An unpolarised light wave incident on such a polaroid gets linearly polarised with the electric vector oscillating along a direction perpendicular to the aligned molecules. This direction is called pass-axis of the polaroid.
In Young's double slit experiment, the two slits 0.12 mm apart are illuminated by monochromatic light of wavelength 420 nm. The screeen is 1.0 m away from the slits.
(a) Find the distance of the second
(i) bright fringe,
(ii) dark fringe from the central maximum.
(b) How will the fringe pattern change if the screen is moved away from the slits?

**Given :** $d = 0.12 \text{ mm} = 0.12 \times 10^{-3} \text{ m}$
$= 12 \times 10^{-5} \text{ m}$
$\lambda = 420 \text{ nm} = 420 \times 10^{-9} \text{ m}, \ D = 1.0 \text{ m}$

(a) (i) Distance of the second bright fringe,

$$x_2 = \frac{2\lambda D}{d} \quad \ldots\left[\because x_n = \frac{n\lambda D}{d}\right.$$

$$= \frac{2 \times 420 \times 10^{-9} \times 1.0}{12 \times 10^{-5}}$$

$$= \mathbf{70 \times 10^{-4} = 7 \text{ mm}}$$

(ii) Distance of the second dark fringe,

$$x_2 = \frac{3\lambda D}{2d} \quad \ldots\left[\because x_n = (2n-1)\frac{\lambda D}{2d}\right.$$

$$= \frac{3 \times 420 \times 10^{-9} \times 1.0}{2 \times 12 \times 10^{-5}}$$

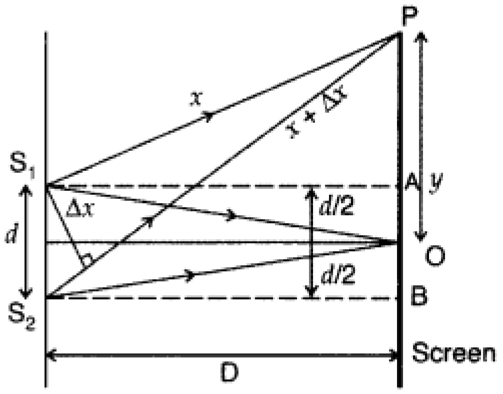
$$= 52.5 \times 10^{-4} \text{ m} = \mathbf{5.25 \text{ mm}}$$

(b) Linear width of a fringe, $\beta = \dfrac{\lambda D}{d}$

Angular width of a fringe, $\Delta Q = \dfrac{\lambda}{d}$

$\therefore$ With increase in the value of D linear width will increase, while the angular width will remain the same.

**Question 5.**
**Describe Young's double slit experiment to produce interference pattern due to a monochromatic source of light. Deduce the expression for the fringe width.**
Answer:
Consider two coherent sources $S_1$ and $S_2$ separated by a distance d. Let D be the distance between the screen and the plane of slits $S_1$ and $S_2$.
Light waves emitted from $S_1$ and $S_2$ reach point O on the screen after travelling equal distances. So path difference and hence phase difference between these waves is zero. Therefore, they meet at O in phase and hence constructive interference




takes place at O. Thus O is the position of the central bright fringe.
Let the waves emitted by $S_1$ and $S_2$ meet at point P and the screen at a distance y from the central bright fringe.
The path difference between these waves at P is given by

$$\Delta x = S_2P - S_1P \qquad \ldots(i)$$

From right angled triangle $S_2BP$,

$$S_2P = [S_2B^2 + PB^2]^{1/2}$$

$$\Rightarrow \quad S_2P = \left[D^2 + \left(y + \frac{d}{2}\right)^2\right]^{1/2} = D\left[1 + \frac{(y + d/2)^2}{D^2}\right]^{1/2}$$

$$\Rightarrow \quad S_2P = D\left[1 + \frac{(y + d/2)^2}{2D^2}\right]$$

$$\therefore \quad S_2P = D + \frac{(y + d/2)^2}{2D} \qquad \ldots(ii)$$

Similarly from right angled $\Delta S_1AP$,

$$S_1P = D + \frac{(y - d/2)^2}{2D} \qquad \ldots(iii)$$

Substituting these values in (i), we get

$$\Delta x = D + \frac{(y + d/2)^2}{2D} - D - \frac{(y - d/2)^2}{2D}$$

$$= \frac{(y^2 + d^2/4 + yd) - (y^2 + d^2/4 - yd)}{2D} = \frac{2yd}{2D} = \frac{yd}{D} \qquad \ldots(iv)$$

For constructive interference/maxima:

If path difference is an integral multiple of λ, then bright fringe will be formed at P

$$i.e., \frac{yd}{D} = m\lambda \quad \text{or} \quad y = \frac{m\lambda D}{d} \quad \ldots(v)$$

…where [m = 1, 2, 3 …
which is the position of mth bright fringe from the central bright fringe.
Fringe width (β) : The distance between any two successive bright fringes (or successive fringes) is called fringe width.

$$\beta = y_2 - y_1 = \frac{2\lambda D}{d} - \frac{\lambda D}{d} = \frac{\lambda D}{d}$$

Destructive interferencelMinima: If path difference is odd multiple of λ/2, then dark fringe is formed at P

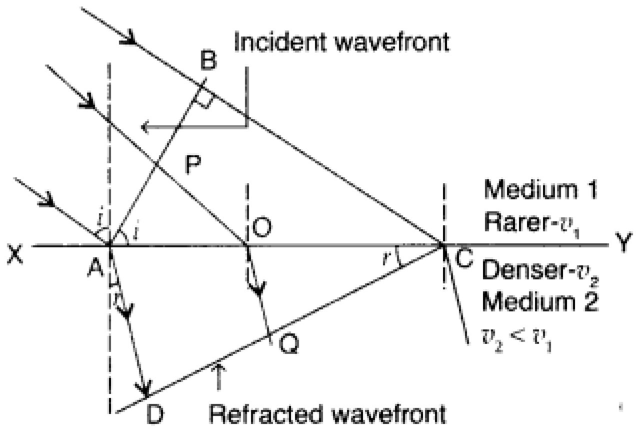
$$i.e., \frac{yd}{D} = \left(m + \frac{1}{2}\right)$$

$$\therefore \quad y = \frac{\left(m + \frac{1}{2}\right)\lambda D}{d} \quad \ldots\text{where } [m = 1, 2, 3 \ldots$$

Which is position of $m^{th}$ dark fringe from the central bright fringe.
β(fringe width) = $y_1 - y_0$

$$= \frac{3\lambda D}{2d} - \frac{\lambda D}{2d} = \frac{2\lambda D}{2d} = \frac{\lambda D}{d}$$

**Question 6.**
**Use Huygen's principle to verify the laws of refraction.**
Answer:
(i) Wavefront : Wavefront is defined as the continuous locus of all such particles of the medium which are vibrating in the same phase at any instant.




(ii) We take a plane wavefront AB incident at a plane surface XY. We use secondary wavelets starting at different times. We get refracted wavefront only when the time taken by light to travel along different rays from one wavefront to another is same. We take any arbitrary ray starting from point 'P' on incident wavefront to refracted wavefront at point 'O'. Let total time be 't'.

$$t = \frac{PO}{v_1} + \frac{OQ}{v_2} = \frac{AO\sin i}{v_1} + \frac{OC\sin r}{v_2}$$
$$= \frac{AO\sin i}{v_1} + \frac{(AC - AO)\sin r}{v_2}$$
$$= \frac{AC\sin r}{v_2} + AO\left(\frac{\sin i}{v_1} - \frac{\sin r}{v_2}\right)$$

As time should be independent of the ray to be considered
The coefficient of AO in the above equation should be zero

$$i.e. \quad \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2$$

Where $'\mu_2$ is called refractive index of medium 2 w.r.t. medium 1. This is Snell's law of refraction.

## Fill in the blanks

1. What is the geometric shape of the wavefront that originates when a plane wave passes through a convex lens-----------------**( Converging Spherical)**

2. How can the fringe width increase in Young's double-slit experiment------------

**(By decreasing the separation of slits)**

3. What is the locus of all particles in a medium vibrating in the same phase called**-------------( Wavefront)**

4. Which of the following factors does the intensity of light depend on-----------

**( Amplitude)**

## Multiple choice questions

1. Which of the following light phenomena confirms the transverse nature of light?

   a. Refraction of light
   b. Diffraction of light
   c. Dispersion of light
   d. Polarization of light

**Answer:** (d) Polarization of light

**Explanation:** Polarization of light confirms the transverse nature of light.

2. Polaroid glasses are used in sunglasses because

a. They are cheaper
b. They have a good colour
c. They look fashionable
d. They reduce the light intensity to half on account of polarization

**Answer:** (d) They reduce the light intensity to half on account of polarization

**Explanation:** Polaroid glasses are used in sunglasses because they reduce the light intensity to half on polarization.

3. Two light sources are said to be coherent when both the sources of light emit light of

a. The same amplitude and phase
b. The same intensity and wavelength
c. The same speed
d. The same wavelength and constant phase difference

**Answer:** (d) the same wavelength and constant phase difference

**Explanation:** Two light sources are said to be coherent when both light sources emit light of the same wavelength and constant phase difference.

4. Which of the following is an application of the Doppler Effect?

a. Doppler Radius
b. Doppler Spectrometer
c. Doppler Velocimeter
d. All of the above

**Answer:** (d) All of the above

**Explanation:** Doppler Radius, Doppler Spectrometer and Doppler Velocimeter are applications of the Doppler Effect.

5. Who discovered Poisson's bright spot?

a. Fresnel
b. Rayleigh
c. Fraunhofer
d. Poisson

**Answer:** (d) Poisson

**Explanation:** Poisson discovered Poisson’s bright spot.

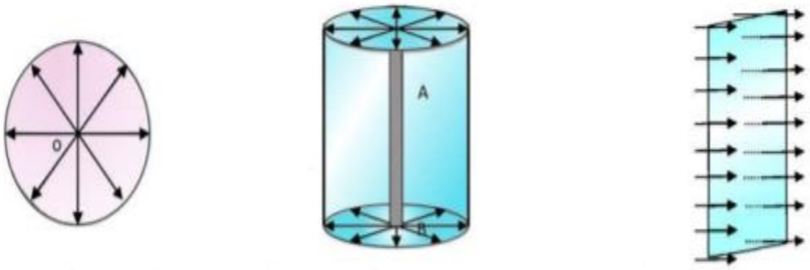
6. Which of the following is conserved when light waves interfere?

a. Intensity
b. Amplitude
c. Phase
d. None of the above

**Answer:** (d) None of the above

**Explanation:** Intensity, amplitude, and phase are not conserved when light waves interfere.

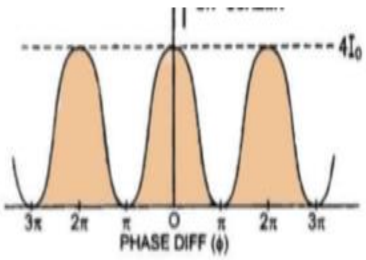
# Diagrams



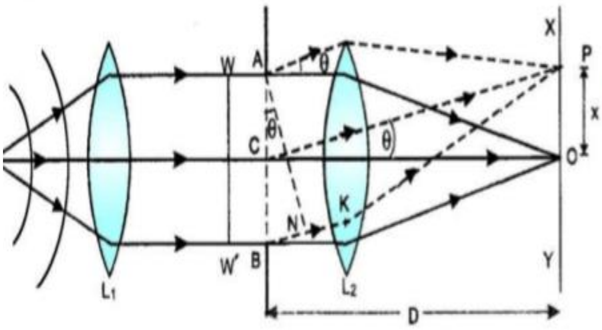

(i) Spherical Wavefront (ii) Cylindrical Wave front (iii) Plane Wavefront

## Interference of Light

$$I = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\phi$$
$$a^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi$$



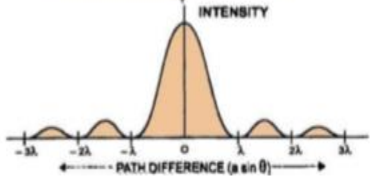

## Diffraction of Light at a single slit



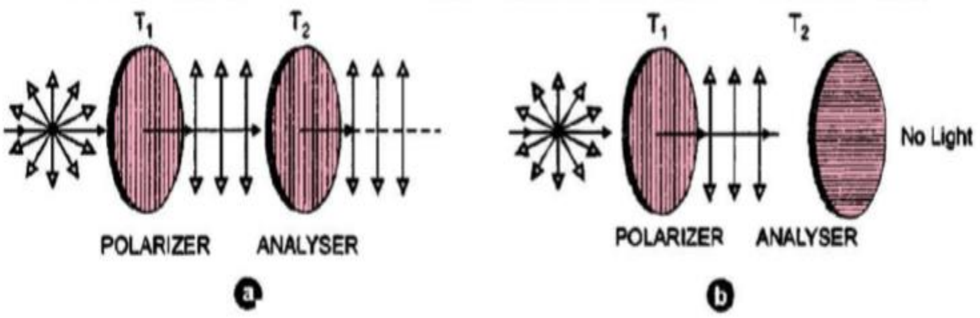

$$\boxed{a\sin\theta = n\lambda}$$

Position of Secondary Maxima

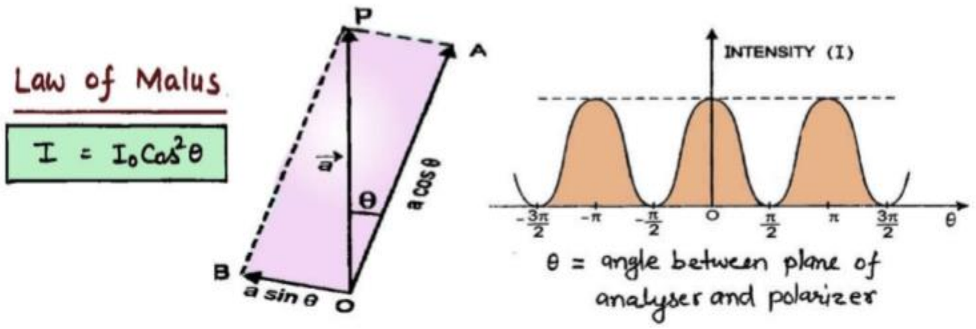
$$\boxed{a\sin\theta = (2n+1)\frac{\lambda}{2}}$$



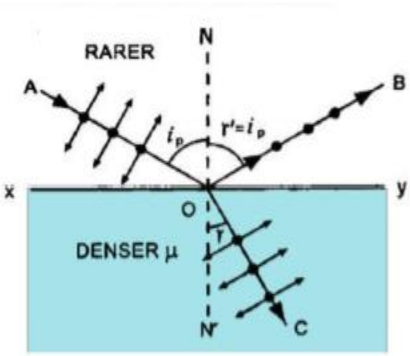
## Experimental Demonstration of polarization




## Low of Malus




## Polarization by Reflection




**Brewster's Law**

$$\mu = \tan i_p$$

## SUMMARY

- **Wave front:**
  It is the locus of points having the same phase of oscillation.
- **Rays:**
  Rays are the lines perpendicular to the wave front, which show the direction of propagation of energy.
- **Time Taken:**
  The time taken for light to travel from one wave front to another is the same along any ray.
- **Huygens' Principle:**
  a) According to Huygens' Each point on the given wave front (called primary wave front) acts as a fresh source of new disturbance, called secondary wavelet, which travels in all directions with the velocity of light in the medium.
  b) A surface touching these secondary wavelets, tangentially in the forward direction at any instant gives the new wave front at that instant. This is called secondary wave front,
- **Principle of Huygens' Construction:**
  a) It is based on the principle that every point of a wave front is a source of secondary wave front.
  b) The envelope of these wave fronts i.e., the surface tangent to all the secondary wave front gives the new wave front.
- **Snell's law of refraction:**

$$ {}_1\mu_2 = \frac{c_1}{c_2} = \frac{\text{Speed of light in first medium}}{\text{Speed of light in second medium}} $$

- **Refraction and Reflection of Plane Waves Using Huygens' Principle:**
  The law of reflection (i = r) and the Snell's law of refraction

$$ \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1} = \mu_{21} $$

  can be derived using the wave theory. (Here v1 and v2 are the speed of light in media 1 and 2 with refractive index $\mu_1 and \mu_2$ respectively).
- **Relation between Frequency and Speed:**
  The frequency $v$ remains the same as light travels from one medium to another. The speed v of a wave is given by

$$ v = \frac{\lambda}{T} $$

  Where $\lambda$ is the wavelength of the wave and $T(=1/v)$ is the period of oscillation.

- **Doppler Effect:**
  It is the shift in frequency of light when there is a relative motion between the source and the observer. The effect can be used to measure the speed of an approaching or receding object.
- **Change in Frequency:**
  For the source moving away from the observer $v < v_0$, and for the source moving towards the observer $v > v_0$, . The change in frequency is

$$\Delta v = v - v_0 = -\frac{v}{c} v_0$$

So, finally,

$$\frac{\Delta v}{v_0} = -\frac{v}{c}$$

- **Coherent and Incoherent Addition of Waves:**

a) Two sources are coherent if they have the same frequency and a stable phase difference.

b) In this case, the total intensity $I$ is not just the sum of individual intensities $I_1$ and $I_2$ due to the two sources but includes an interference term,

$$I = I_1 + I_2 + 2k.E_1.E_2$$

Where $E_1$ and $E_2$ are the electric fields at a point due to the sources.

c) The interference term averaged over many cycles is zero if

i) The sources have different frequencies or

ii) The sources have the same frequency but no stable phase difference.

d) For such coherent sources,

$$I = I_1 + I_2$$

e) According to the superposition principle when two or more wave motions traveling through a medium superimpose one another, a new wave is formed in which resultant displacements due to the individual waves at that instant.

f) The average of the total intensity will be

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

Where $\phi$ is the inherent phase difference between the two superimposing waves.

g) The significance is that the intensity due to two sources of light is not equal to the sum of intensities due to each of them.

h) The resultant intensity depends on the relative location of the point from the two sources, since changing it changes the path difference as we go from one point to another.

i) As a result, the resulting intensity will vary between maximum and minimum values, determined by the maximum and minimum values of the cosine function. These will be

$$\bar{I}_{MAX} = \bar{I_1} + \bar{I_2} + 2\sqrt{\left(\bar{I_1}\right)\left(\bar{I_2}\right)} = \left(\sqrt{\bar{I_1}} + \sqrt{\bar{I_2}}\right)^2$$

$$\bar{I}_{MIN} = \bar{I_1} + \bar{I_2} - 2\sqrt{\left(\bar{I_1}\right)\left(\bar{I_2}\right)} = \left(\sqrt{\bar{I_1}} - \sqrt{\bar{I_2}}\right)^2$$

- **Young's Experiment**

  Two parallel and very close slits $S_1$ and $S_2$ (illuminated by another narrow slit) behave like two coherent sources and produce on a screen a pattern of dark and bright bands – interference fringes.

  For a point P on the screen, the path difference

  $$S_2P - S_2P = \frac{y_1 d}{D_1}$$

  Where d is the separation between two slits, $D_1$ is the distance between the slits and the screen and y1 is the distance of the point of *P* from the central fringe.

  For constructive interference (bright band), the path difference must be an integer multiple of $\lambda$ , i.e.,

  $$\frac{y_1 d}{D_1} = n\lambda \text{ or } y_1 = n\frac{D_1\lambda}{d}$$

  The separation $\Delta y_1$ between adjacent bright (or dark) fringes is,

  $$\Delta y_1 = \frac{D_1\lambda}{d}$$

  using which $\lambda$ can be measured.

- **Young's Double Slit Interference Experiment:**

  Fringe width, $w = \frac{D\lambda}{d}$

  where D is the distance between the slits & the screen d is the distance between the two slits

- **Constructive Interference:**

  a) Phase difference : $\Delta\phi = 2\pi n$ where n is an integer

  b) Path difference: $\Delta X = n\lambda$ where n is an integer

- Destructive interference:

  a) Phase difference : $\Delta\phi = \left(n + \frac{1}{2}\right)2\pi$ , where n is an integer

  b) Path difference: $\Delta X = \left(n + \frac{1}{2}\right)\lambda$ , where n is an integer

- **Diffraction due to Single Slit:**

  a) Angular spread of the central maxima $= \frac{2\lambda}{d}$

  b) Width of the central maxima: $\frac{2\lambda D}{d}$

  Where D is the distance of the slit from the screen d is the slit width

- **Condition for the Minima on the either side of the Central Maxima:**
  - $d\sin\theta = n\lambda$ , where n = 1,2,3,….

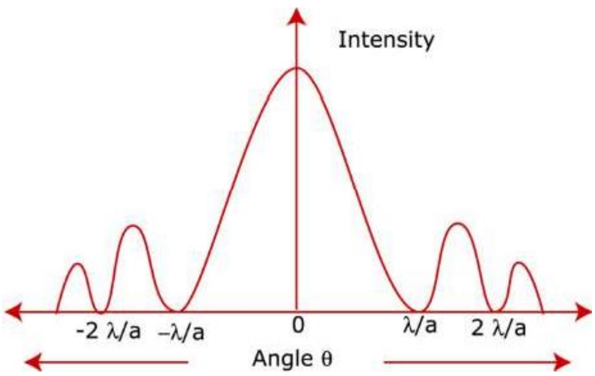
- **Relation between phase difference & path difference:**
  - $\Delta\phi = \frac{2\pi}{\lambda}.\Delta X$

  Where $\Delta\phi$ is the phase difference & $\Delta X$ is the path difference

- **Diffraction:**

  a) It refers to light spreading out from narrow holes and slits, and bending around corners and obstacles.

  b) The single-slit diffraction pattern shows the central maximum $(at\theta = 0)$, zero intensity at angular separation $\theta = \pm(n + 1/2)\ldots\ldots\lambda\ldots\ldots(n \neq 0)$




- **Different Parts of the Wave Front at the Slit act as Secondary Sources:**

  a) Diffraction pattern is the result of interference of waves from these sources.

  b) The intensity plot looks as follows, with there being a bright central maximum, followed by smaller intensity secondary maxima, with there being points of zero intensity in between, whenever

  $d\sin\theta = n\lambda, n \neq 0$

- **Emission, Absorption and Scattering:**

  a) These are the three processes by which matter interacts with radiation. In emission, an accelerated charge radiates and loses energy.

  b) In absorption, the charge gains energy at the expense of the electromagnetic wave.

  c) In scattering, the charge accelerated by incident electromagnetic wave radiates in all direction.

- **Polarization:**

  a) It specifies the manner in which electric field E oscillates in the plane transverse to the direction of propagation of light. If E oscillates back and forth in a straight line, the wave is said to be linearly polarized. If the direction of E changes irregularly the wave is unpolarized.

  b) When light passes through a single polaroid $P_1$ light intensity is reduced to half, independent of the orientation of $P_1$. When a second Polaroid $P_2$ is also included, at one specific orientation w.r.t $P_1$, the net transmitted intensity is reduced to zero but is transmitted fully when $P_1$ is turned $90^0$ from that orientation. This happens because the transmitted polarization by a polaroid is the component of E parallel to its axis.

c) Unpolarized sunlight scattered by the atmosphere or reflected from a medium gets (partially) polarized.

- **Optical Activity:**
  Linearly polarized light passing through some substances like sugar solution undergoes a rotation of its direction of polarization, proportional to the length of the medium traversed and the concentration to the substance. This effect is known as optical activity.
- **Intensity of the Light due to Polarization:**
  $$I = I_0 \cos^2 \theta$$
  Where I is the intensity of light after polarization Io is the original intensity, $\theta$ is the angle between the axis of the analyzer & the polarizer
- **Brewster's Law:**
  When an incident light is incident at the polarizing angle, the reflected & the refracted rays are perpendicular to each other. The polarizing angle, also called as Brewster's angle, is
  $$\tan\theta_p = \mu$$
- **Polarization by Scattering:**

a) Light is scattered when it meets a particle of similar size to its own wavelength. The scattering of sunlight by dust particles is an example of polarization by scattering.

b) Rayleigh showed that the scattering of light is proportional to the fourth power of the frequency of the light or varies as $\frac{1}{\lambda^4}$ where $\lambda$ is the wavelength of light incident on the air molecules of size 'd' where $d << \lambda$ . Hence blue light is scattered more than red. This explains the blue colour of the sky.