Very Short Answer Questions (PYQ)

Q. 1. When monochromatic light travels from one medium to another, its wavelength changes but frequency remains the same. Explain. [CBSE Delhi 2011]

Ans. Frequency is the fundamental characteristic of the source emitting waves and does not depend upon the medium. Light reflects and refracts due to the interaction of incident light with the atoms of the medium. These atoms always take up the frequency of the incident light which forces them to vibrate and emit light of same frequency. Hence, frequency remains same.

Q. 2. Light of wavelength 5000 Å propagating in air gets partly reflected from the surface of water. How will the wavelengths and frequencies of the reflected and refracted light be affected? [CBSE Delhi 2015]

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

Reflected ray: No change in wavelength and frequency.

Refracted ray: Frequency remains same, wavelength decreases

$$\text{Wavelength} = \lambda' = \frac{\lambda}{\mu}$$

Q. 3. Why are coherent sources required to create interference of light? [CBSE (F) 2009]

Ans. Coherent sources are required for sustained interference. If sources are incoherent, the intensity at a point will go on changing with time.

Q. 4. Differentiate between a ray and a wave front. [CBSE Delhi 2009]

Ans. A wave front is a surface of constant phase. A ray is a perpendicular line drawn at any point on wave front and represents the direction of propagation of the wave.

Q. 5. What type of wave front will emerge from a (i) point source and (ii) distant light source? [CBSE Delhi 2009]

Ans. (i) Spherical wave front **(ii)** Plane wave front.

Q. 6. What will be the effect on interference fringes if red light is replaced by blue light? [CBSE Delhi 2013]

Ans.

$\beta = \frac{D\lambda}{d}$, *i.e.*, $\beta \propto \lambda$; the wavelength of blue light is less than that of red light; hence if red light is replaced by blue light, the fringe width decreases, *i.e.*, fringes come closer.

Q. 7. Unpolarised light of intensity I is passed through a Polaroid. What is the intensity of the light transmitted by the Polaroid? [CBSE (F) 2009]

Ans. Intensity of light transmitted through the Polaroid = $\frac{I}{2}$.

Q. 8. If the angle between the pass axes of a polariser and analyser is 45°. Write the ratio of the intensities of original light and the transmitted light after passing through the analyser. [CBSE Delhi 2009]

Ans. If I0 is intensity of original light, then intensity of light passing through the polariser = $\frac{I_0}{2}$.

Intensity of light passing through analyser

$$I = \frac{I_0}{2}\cos^2 45^\circ \quad \Rightarrow \quad \frac{I_0}{I} = \frac{2}{\cos^2 45^\circ} = \frac{4}{1}$$

Q. 9. Which of the following waves can be polarized (i) Heat waves (ii) Sound waves? Give reason to support your answer. [CBSE Delhi 2013]

Ans. Heat waves are transverse or electromagnetic in nature whereas sound wave are not. Polarisation is possible only for transverse waves.

Q. 10. At what angle of incidence should a light beam strike a glass slab of refractive index $\sqrt{3}$, such that the reflected and refracted rays are perpendicular to each other?
[CBSE Delhi 2009]

Ans. The reflected and refracted rays are mutually perpendicular at polarising angle; so from Brewster's law

$$i_B = \tan^{-1}(n) = \tan^{-1}(\sqrt{3}) = 60^\circ.$$

Q. 11. How does the fringe width of interference fringes change, when the whole apparatus of Young's experiment is kept in water (refractive index 4/3)?
[CBSE Delhi 2011] [HOTS]

Ans.

Fringe width, $\beta = \frac{D\lambda}{d} \Rightarrow \beta \propto \lambda$ for same D and d. When the whole apparatus is immersed in a transparent liquid of refractive index $n = 4/3$, the wavelength decreases to $\lambda' = \frac{\lambda}{n} = \frac{\lambda}{4/3}$. So, fringe width decreases to $\frac{3}{4}$ times.

Q. 12. In what way is the diffraction from each slit related to interference pattern in double slit experiment? [CBSE Bhubaneshwar 2015]

Ans. The intensity of interference fringes in a double slit arrangement is modulated by the diffraction pattern of each slit. Alternatively, in double slit experiment the interference pattern on the screen is actually superposition of single slit diffraction for each slit.

Q. 13. 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? [CBSE (AI) 2012]

Ans.

Angular separation is $\theta = \frac{\beta}{D} = \frac{D\lambda/d}{D} = \frac{\lambda}{d}$

Since θ is independent of D, angular separation would remain same.

Q. 14. 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? [CBSE (AI) 2012]

Ans. In single slit diffraction experiment fringe width is

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

If d is doubled, the width of central maxima is halved. Thus size of central maxima is reduced to half. Intensity of diffraction pattern varies with square of slit width. So, when the slit gets double, it makes the intensity four times.

Very Short Answer Questions (OIQ)

Q. 1. What are coherent sources of light?

Ans. Two sources of light having same frequency and zero or constant initial phase difference are called coherent sources.

Q. 2. State the importance of coherent sources in the phenomenon of interference.

Ans. If coherent sources are not taken, the phase difference between two interfering waves, meeting at any point will change continuously and a sustained interference pattern will not be obtained. Thus, coherent sources provide sustained interference pattern.

Q. 3. Can two identical and independent sodium lamps act as coherent sources? Give reason for your answer.

Ans. No, two independent sources of light cannot act as coherent sources.

Reason: The emission of light is due to millions of atoms. So phase difference between waves emitted from these atoms will change randomly and sustained interference will not be obtained.

Q. 4. In Young's double slit experiment, if the distance between the slits be less than λ (i.e., d < λ) what will be the effect on interference fringes?

Ans.

Fringe width $\beta = \frac{D\lambda}{d}$, if $d < \lambda$, so no fringe will be observed in the region of visibility.

Q. 5. What is the shape of the wave front on earth for sunlight?
[NCERT Exemplar]

Ans. Spherical with huge radius as compared to the earth's radius so that it is almost a plane.

Q. 6. When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the center of the shadow of the obstacle. Explain why.

Ans. Waves diffracted from the edges of the circular obstacle interfere constructively at the centre of the shadow producing a bright spot.

Q. 7. Why is the interference pattern not detected, when two coherent sources are far apart? [HOTS]

Ans. Fringe width of interference fringes, is given by $\beta = \frac{D\lambda}{d} \propto \frac{1}{d}$. If the sources are far apart; d is large; so fringe width (β) will be so small that the fringes are not resolved and they do not appear separate. That is why the interference pattern is not detected for large separation of coherent sources.

Q. 8. No interference pattern is detected when two coherent sources are infinitely close to each other. Why? [HOTS]

Ans. Fringe width of interference fringes is given by β = $\frac{D\lambda}{d} \propto \frac{1}{d}$. When d is infinitely small, fringe width β will be too large. In such a case even a single fringe may occupy the whole field of view. Hence, the interference pattern cannot be detected.

Q. 9. A Polaroid (I) is placed in front of a monochromatic source. Another Polaroid (II) is placed in front of this Polaroid (I) and rotated till no light passes. A third Polaroid (III) is now placed in between (I) and (II). In this case, will light emerge from (II)? Explain [NCERT Exemplar] [HOTS]

Ans. Only in the special cases when the pass axis of (III) is parallel to (I) or (II) there shall be no light emerging. In all other cases there shall be light emerging because the pass axis of (II) is no longer perpendicular to the pass axis of (III).

Q. 10. Give reason for the following:

The value of the Brewster angle for a transparent medium is different for lights of different colours. [HOTS]

Ans. Brewster's angle, $i_p = \tan^{-1}(n)$

As refractive index n varies as inverse value of wavelength; it is different for lights of different wavelengths (colours), therefore, Brewster's angle is different for lights of different colours.

Q. 11. State the essential condition for diffraction of light to take place.

Ans. The condition is "The width or sharpness of obstacle or aperture must be of the order of the wavelength of light used."

Q. 12. A parallel beam of monochromatic light falls normally on a single narrow slit. How does the angular width of the principal maximum in the resulting diffraction pattern depend on the width of the slit?

Ans. Width of central maximum, $\beta = \frac{2\lambda D}{a} \propto \frac{1}{a}$, where a is width of the slit.

That is angular width of principal maximum decreases with increase of width of the slit.

Q. 13. The polarising angle of a medium is 60°. What is the refractive index of the medium?

Ans. $\text{Brewster's law } n = \tan\ i_p = \tan\ 60^o = \sqrt{3} = 1.732$

Q. 14. The refractive index of a material is. What is the angle of refraction if the unpolarised light is incident on it at the polarising angle of the medium?

Ans.

From Brewster's law,

polarising angle $i_B = \tan^{-1}(n) = \tan^{-1}\sqrt{3} = 60^\circ$

Also $i_B + r = 90^o$

$\therefore$ Angle of refraction $= 90^\circ - i_B = 90^\circ - 60^\circ = 30^\circ$

Q 15. Among the following waves which can be polarised? Sound waves, radio waves, X-rays, cathode rays.

Ans. Only transverse waves can be polarised. Out of the given waves, radio waves and X-rays are electromagnetic and hence transverse. So, radio waves and X-rays can be polarised.

Q. 16. Does the polarising angle for any transparent medium depend on the wavelength of light?

Ans. Yes, Reason: Angle of polarisation $i_B = \tan^{-1}(n)$ and since refractive index varies as inverse of square of wavelength so angle of polarisation decreases with increase of wavelength.

Q. 17. Two Polaroids are placed with their optic axis perpendicular to each other. One of them is rotated through 45°, what is the intensity of light emerging from the second Polaroid if I0 is the intensity of unpolarised light? [CBSE Sample Paper 2017]

Ans.

$$I = \frac{I_0}{2}\cos^2(45)^\circ = \frac{I_0}{4}$$

Short Answer Questions – I (PYQ)

Q. 1. When are two objects just resolved? Explain. How can the resolving power of a compound microscope be increased? Use relevant formula to support your answer.
[CBSE Delhi 2017]

Ans. Two objects are said to be just resolved when, in their diffraction patterns, central maxima of one object coincides with the first minima of the diffraction pattern of the second object.

Limit of resolution of compound microscope

$$d_{\min} = \frac{1.22\lambda}{2n\ \sin\beta}$$

Resolving power of a compound microscope is given by the reciprocal of limit of resolution (d_{min}).

Therefore, to increase resolving power, λ can be reduced and refractive index of the medium can be increased.

Q. 2. Find the intensity at a point on a screen in Young's double slit experiment where the interfering waves of equal intensity have a path difference of (i) $\frac{\lambda}{4}$, and (ii) $\frac{\lambda}{3}$.
[CBSE (F) 2017]

Ans.

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

(i) If path difference $=\frac{\lambda}{4}$

$$\Rightarrow \quad \Delta x=\frac{2\pi}{\lambda}\times\Delta\phi$$

$$\Rightarrow \quad \Delta x=\frac{2\pi}{\lambda}\times\frac{\lambda}{4}=\frac{\pi}{2}$$

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

(ii) If $\Delta x=\frac{\lambda}{3}$

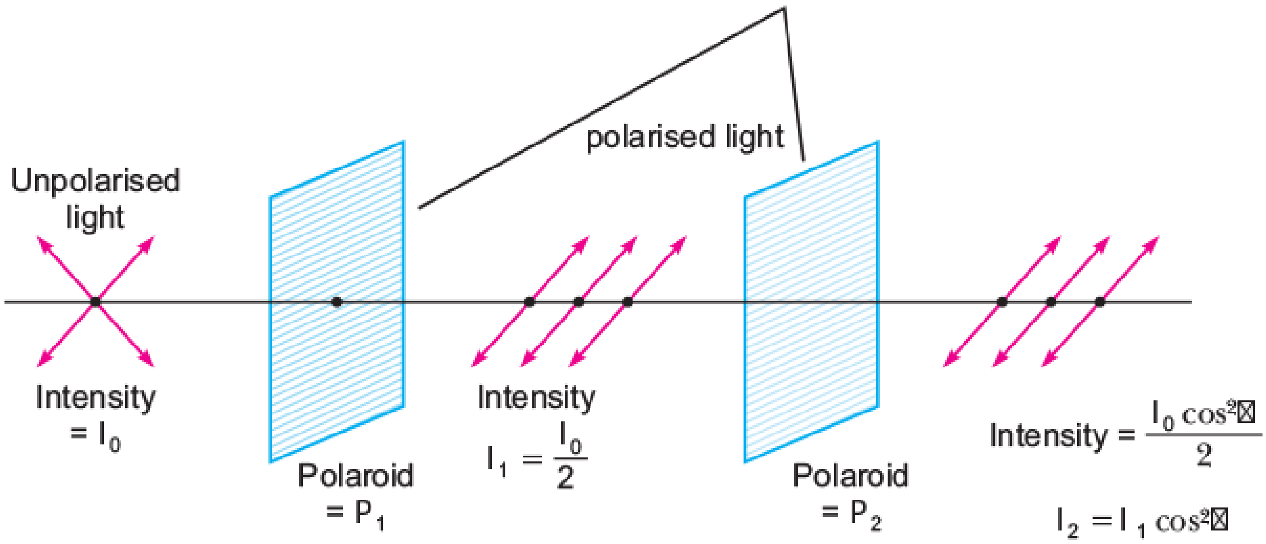
$$\Rightarrow \quad \Delta\phi=\frac{2\pi}{\lambda}\times\frac{\lambda}{3}=\frac{2\pi}{3}$$

$$\therefore \quad I=4I_0\cos^2\frac{\Delta\phi}{2}$$

$$=4I_0\cos^2\left(\frac{2\pi}{3\times2}\right)=I_0$$

Q. 3. 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 θ 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.
[CBSE (AI) 2017]

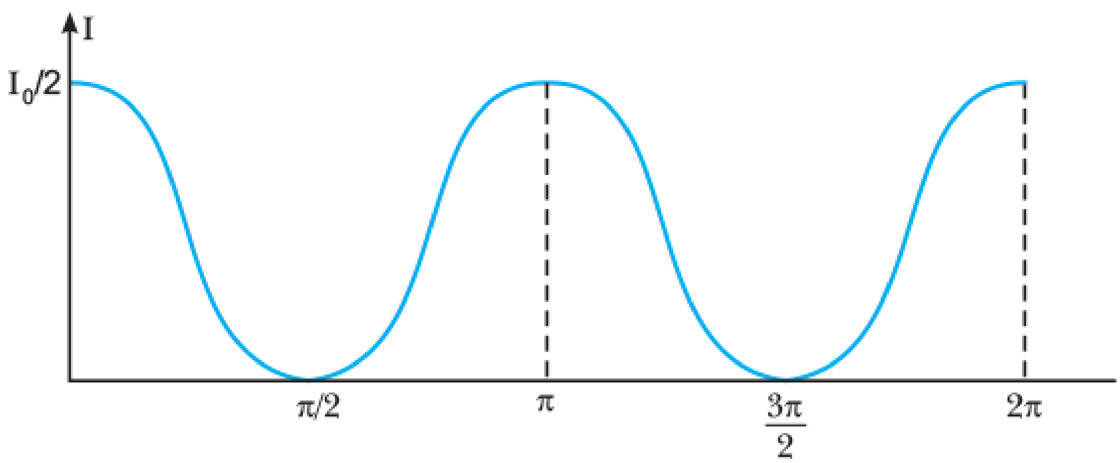
Ans.



Intensity is $\frac{I_0}{2}\cos^2$ (If I_0 is the intensity of unpolarised light)

Intensity is $I \cos^2 \theta$ (If I is the intensity of polarised light)

The required graph would have the form as shown in figure.



Short Answer Questions – I (OIQ)

Q. 1. Find the ratio of intensities at two points on a screen in Young's double slit experiment when waves from the two slits have a path difference of (i) 0 and (ii) $\frac{\lambda}{4}$.

Ans.

Intensity $I = a_1^2 + a_2^2 + 2a_1 a_2 \cos\varphi$

Let $a_1 = a_2 = a$ (say), then

$$I = a^2 + a^2 + 2a^2 \cos\varphi = 2a^2(1 + \cos\varphi)$$

$$\frac{I_1}{I_2} = \frac{1+\cos\phi_1}{1+\cos\phi_2}$$

When path difference is 0, phase difference $\varphi_1 = 0$

When path difference $\frac{\lambda}{4}$, is phase difference $\phi_2 = \frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \frac{\pi}{2}$

$\therefore$ $$\frac{I_1}{I_2} = \frac{1+\cos 0^\circ}{1+\cos\frac{\pi}{2}} = \frac{1+1}{1} = \frac{2}{1}$$

Q. 2. A parallel beam of light of wavelength 600 nm is incident normally on a slit of width 'a'. If the distance between the slit and the screen is 0.8 m and the distance of 2nd order maximum from the centre of the screen is 1.5 mm, calculate the width of the slit.

Ans. Given λ= 600 nm = 600×10^{-9} m = 6.0×10^{-7} m, D = 0.8 m,

y_2 = 1.5 mm = 1.5×10^{-3} m, n = 2, a =?

Position of n^{th} maximum in diffraction of a single slit

$$y_n = \left(n + \frac{1}{2}\right)\frac{\lambda D}{a} \quad \Rightarrow \quad a = \left(n + \frac{1}{2}\right)\frac{\lambda D}{y_n}$$

Substituting given values $a = \left(2 + \frac{1}{2}\right)\frac{6.0 \times 10^{-7} \times 0.8}{1.5 \times 10^{-3}}$

$$= \frac{5}{2} \times 4.0 \times 0.8 \times 10^{-4}\ m = 0.8 \times 10^{-3}\ m = 0.8\ \text{mm}$$

Q. 3. How does the resolving power of a compound microscope get affected on

(i) Decreasing the diameter of its objective?

(ii) Increasing the focal length of its objective?

Ans.

$$\text{Resolving limit of microscope} = \frac{\lambda}{2n \sin \theta}$$

$$\text{Resolving power} \propto \frac{1}{\text{Resolving limit}}$$

$$i.e., \text{ Resolving power} = \frac{2n \sin \theta}{\lambda}$$

(i) When diameter of objective lens decreases, θ and hence sin θ decreases; so the resolving power decreases.

(ii) The focal length of objective lens has no effect on resolving power of microscope.

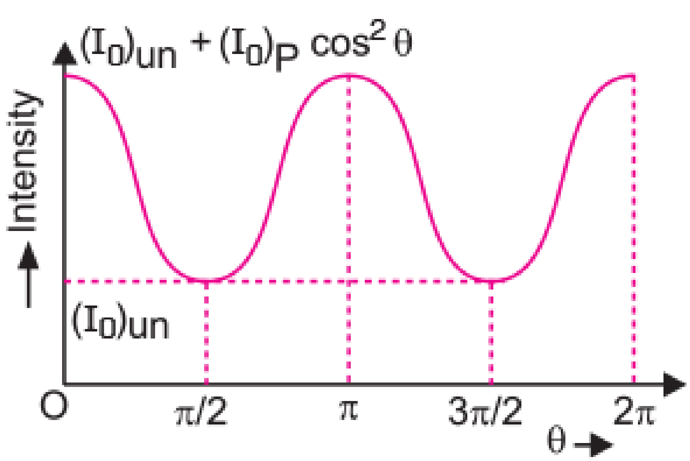
Q. 4. A partially plane polarised beam of light is passed through a Polaroid. Show graphically the variation of the transmitted light intensity with angle of rotation of the Polaroid.

Ans. The partially polarised beam consists of unpolarised plus polarised light. The intensity of unpolarised part varies according to

$(I)_p = (I_0)_p \cos^2 \theta$

$\therefore \quad I = (I_0)_{un} + (I_0)_p \cos^2 \theta$

The graph from θ = 0 to θ = 2π (full rotation) is shown in fig.



Q. 5. Two coherent waves of equal amplitude produce interference pattern in Young's double slit experiment. What is the ratio of intensity at a point where phase difference is $\frac{\pi}{2}$ to intensity at centre?

Ans.

$$I_{\pi/2} = a_1^2 + a_2^2 + 2a_1 a_2 \cos\varphi = a^2 + a^2 + 2a^2 \cos\frac{\pi}{2} = 2a^2$$

$$I_{\max} = (a_2 + a_2)^2 = (a + a)^2 = 4a^2$$

$$\therefore \quad \frac{I_{\pi/2}}{I_{\max}} = \frac{2a^2}{4a^2} = \mathbf{\frac{1}{2}}$$

Q. 6. Sketch a graph showing the variation of fringe width versus the distance of the screen from the plane of the slits (keeping other parameters same) in Young's double slit experiment. What information can one obtain from the slope of this graph?

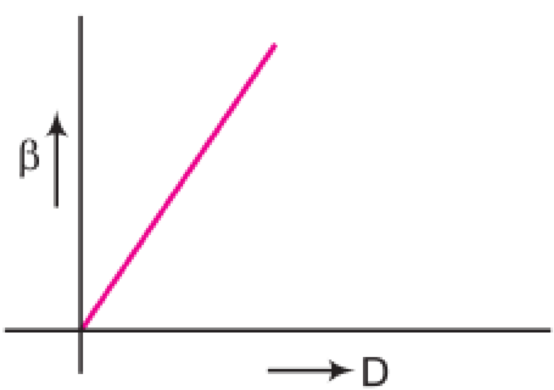
Ans. We know that the fringe width is given by

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

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

The graph between β and *D* is shown alongside

The slope of graph = $\frac{\lambda}{d}$



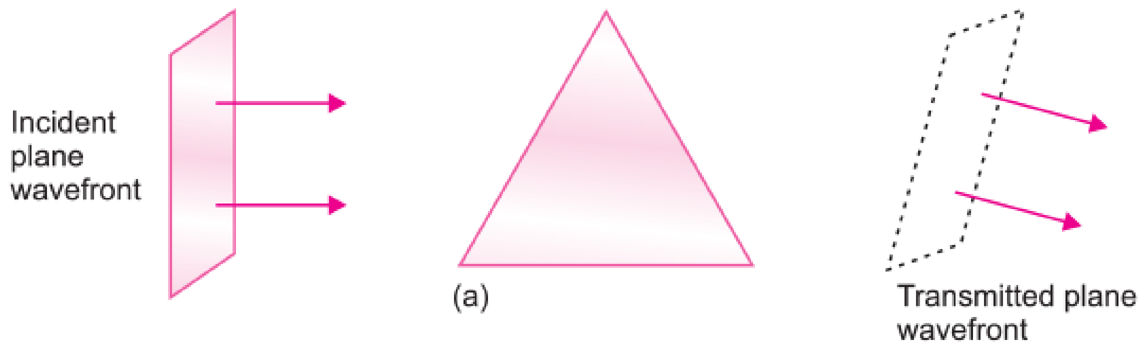
Knowing d, the wavelength of light used can be calculated to be

λ = Slope of graph × d

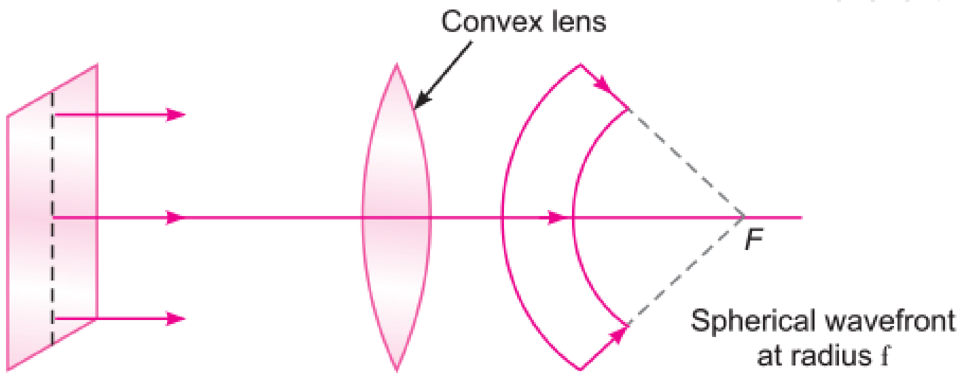
Short Answer Questions – II (PYQ)

Q. 1. Draw the diagrams to show the behaviour of plane wave fronts as they (a) pass through a thin prism, and (b) pass through a thin convex lens and (c) reflect by a concave mirror. [CBSE Bhubaneshwar 2015]

Ans. The behaviour of a thin prism and a thin convex lens are shown in figs. (a) and (b) respectively.

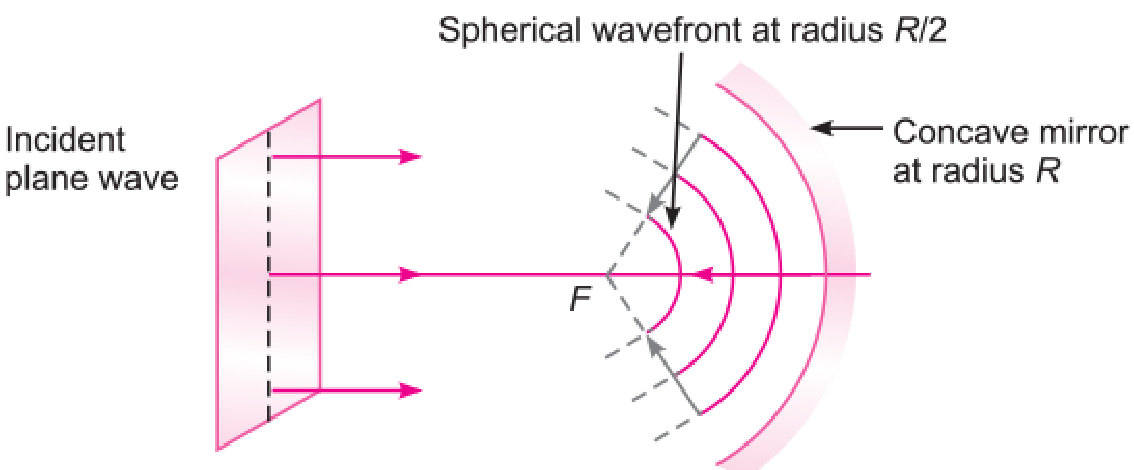


(a)



(b)

A plane wave front becomes spherical convergent after reflection



(c)

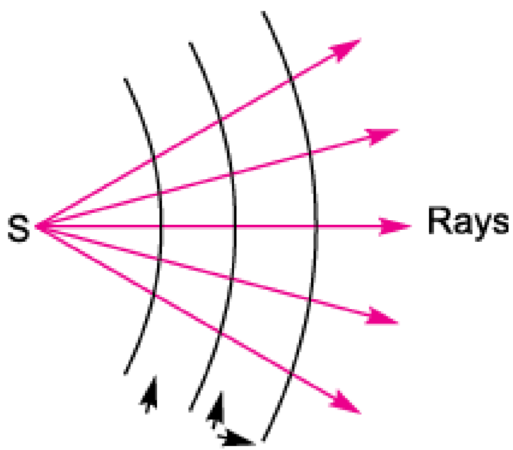
Q. 2. What is the shape of the wave front in each of the following cases: [CBSE Delhi 2009]

(i) Light diverging from a point source

(ii) Light emerging out of a convex lens when a point source is placed at its focus.

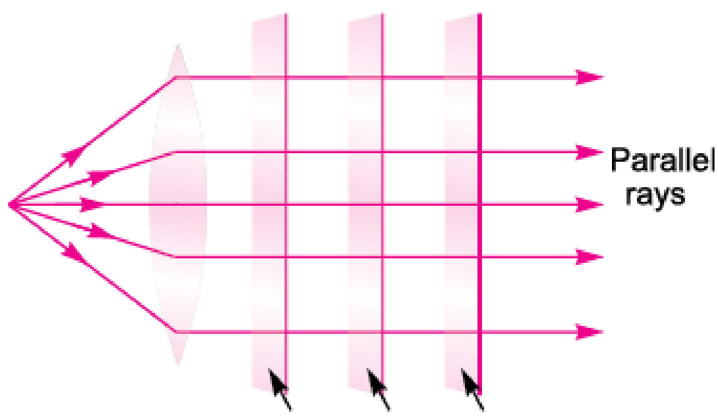
(iii) The portion of a wave front of light from a distant star intercepted by the earth.

Ans. (i) The wave front will be spherical of increasing radius, fig. (a).



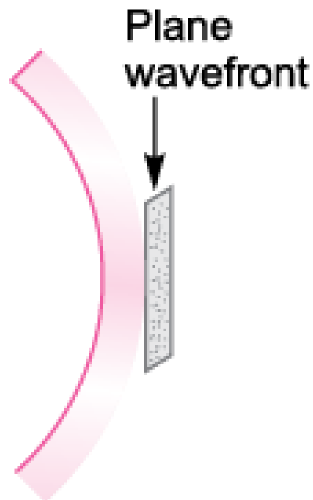
(a) Spherical wavefront

(ii) The rays coming out of the convex lens, when point source is at focus, are parallel, so wave front is plane, fig. (b).



(b) Plane wavefront

(iii) The wave front starting from star is spherical. As star is very far from the earth, so the wave front intercepted by earth is a very small portion of a sphere of large radius; which is plane (i.e., wave front intercepted by earth is plane), fig. (c).



(c) Plane wavefront

Q. 3. Explain the following, giving reasons: [CBSE Central 2016]

(i) When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency as the incident frequency.

(ii) When light travels from a rarer to a denser medium, the speed decreases. Does this decrease in speed imply a reduction in the energy carried by the wave?

(iii) In the wave picture of light, intensity of light is determined by the square of the amplitude of the wave. What determines the intensity in the photon picture of light?

Ans. (i) Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of the incident light. Hence frequency remains unchanged.

(ii) No; when light travels from a rarer to a denser media, its frequency remains unchanged. According to quantum theory of light, the energy of light photon depends on frequency and not on speed.

(iii) For a given frequency, intensity of light in the photon picture is determined by the number of photon incident normally on a crossing an unit area per unit time.

Q. 4. Answer the following questions [CBSE Patna 2015]

Write the necessary conditions to obtain sustained interference fringes.

(i) Also write the expression for the fringe width.

(ii) In Young's double slit experiment, plot a graph showing the variation of fringe width versus the distance of the screen from the plane of the slits keeping other parameters same. What information can one obtain from the slope of the curve?

(iii) What is the effect on the fringe width if the distance between the slits is reduced keeping other parameters same?

Ans. (1) Conditions for sustained interference:

(i) The interfering sources must be coherent i.e., sources must have same frequency and constant initial phase.

(ii) Interfering waves must have same or nearly same amplitude, so that there may be contrast between maxima and minima.

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

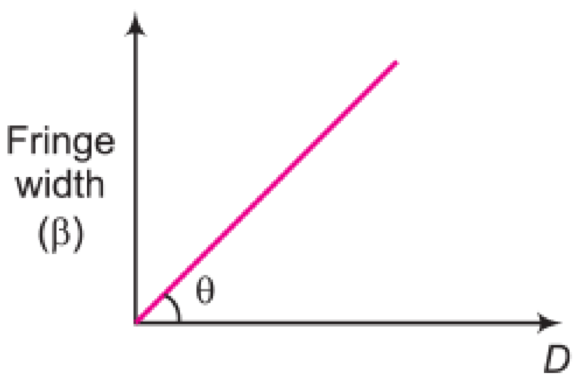
Where D = distance between slits and screen.

d = separation between slits.

λ = wavelength of light used.

(2) Information from the slope:

Wavelength, λ = Slope × d = d. tan θ



(3) Effect: From relation, $\beta = \frac{\lambda D}{d}$

Fringe width, $\beta \propto \frac{1}{d}$

If distance d between the slits is reduced, the size of fringe width will increase.

Q. 5. 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 $\frac{\lambda}{a}$. At the same angle of $\frac{\lambda}{a}$, we get a maximum for two narrow slits separated by a distance "a". Explain. [CBSE Delhi 2014]

Ans. Case I: The overlapping of the contributions of the wavelets from two halves of a single slit produces a minimum because corresponding wavelets from two halves have a path difference of $\lambda/2$.

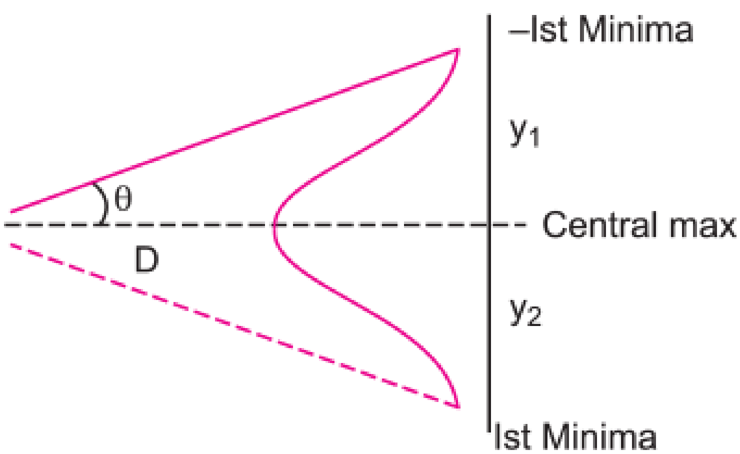
Case II: The overlapping of the wave fronts from the two slits produces first maximum because these wave fronts have the path difference of λ.

Q. 6. In the experiment on diffraction due to a single slit, show that [CBSE (F) 2011]

(i) The intensity of diffraction fringes decreases as the order (n) increases.

(ii) Angular width of the central maximum is twice that of the first order secondary maximum.

Ans. (i) The reason is that the intensity of central maximum is due to constructive interference of wavelets from all parts of slit, the first secondary maximum is due to contribution of wavelets from one third part of slit (wavelets from remaining two parts interfere destructively) the second secondary maximum is due to contribution of wavelets from one fifth part only and so on.



(ii)

For first minima $a\sin\theta = \lambda$ $\quad a\theta = \lambda$ $\quad \tan\theta = \frac{y}{D}$

$\Rightarrow \quad \theta = \frac{y_1}{D}$

$\Rightarrow \quad \frac{ay_1}{D} = \lambda \qquad y_1 = \frac{\lambda D}{a} = y_2$

Hence the angular width of central maximum $= \frac{2\lambda D}{a}$

Width of secondary maximum = Separation between nth and $(n+1)$th minima

For minima $\theta_n = \frac{n\lambda}{d} \qquad \theta_{n+1} = (n+1)\frac{\lambda}{d}$

Angular width of secondary maximum $= (n+1)\frac{\lambda}{d} - \frac{n\lambda}{d} = \frac{\lambda}{d}$

Hence β = Angular width × D = $(n+1)\frac{\lambda}{d} - \frac{n\lambda}{d} = \frac{\lambda}{d}$

Thus central maximum has twice the angular width of secondary maximum.

Q. 7. Answer the following questions

(i) Describe briefly, with the help of suitable diagram, how the transverse nature of light can be demonstrated by the phenomenon of polarisation of light. [CBSE (AI) 2014]

(ii) When unpolarised light passes from air to a transparent medium, under what condition does the reflected light get polarised? [CBSE Delhi 2011]

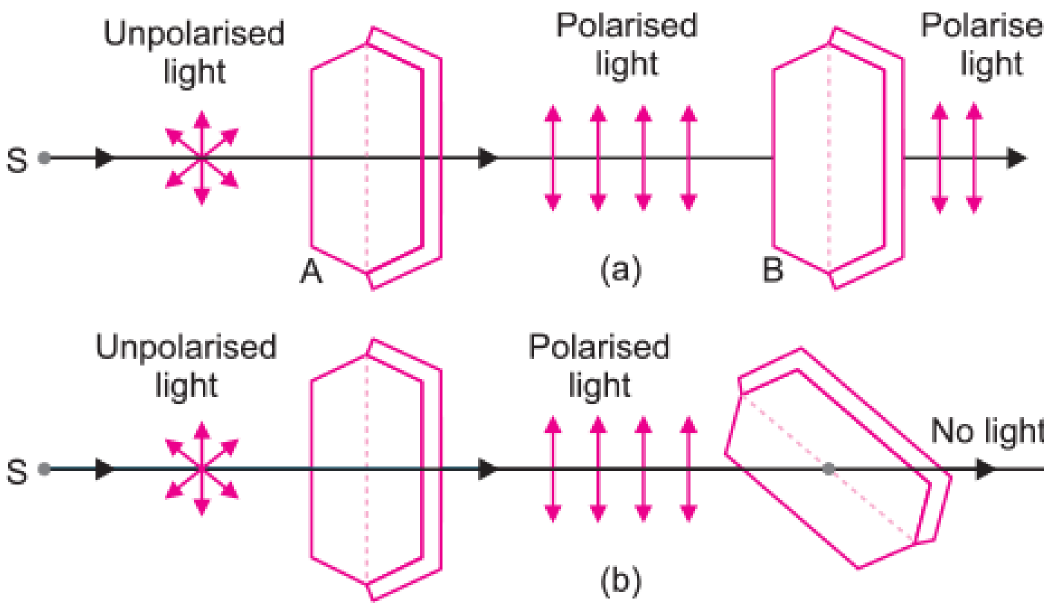
Ans. (i) Light from a source S is allowed to fall normally on the flat surface of a thin plate of a tourmaline crystal, cut parallel to its axis. Only a part of this light is transmitted through A.

If now the plate A is rotated, the character of transmitted light remains unchanged. Now another similar plate B is placed at some distance from A such that the axis of B is parallel to that of A. If the light transmitted through A is passed through B, the light is almost completely transmitted through B and no change is observed in the light coming out of B.

If now the crystal A is kept fixed and B is gradually rotated in its own plane, the intensity of light emerging out of B decreases and becomes zero when the axis of B is perpendicular to that of A. If B is further rotated, the intensity begins to increase and becomes maximum when the axes of A and B are again parallel.

Thus, we see that the intensity of light transmitted through B is maximum when axes of A and B are parallel and minimum when they are at right angles.

From this experiment, it is obvious that light waves are transverse and not longitudinal; because, if they were longitudinal, the rotation of crystal B would not produce any change in the intensity of light.



(ii) The reflected ray is totally plane polarised, when reflected and refracted rays are perpendicular to each other.

Q. 8. (a) The light from a clear blue portion of the sky shows a rise and fall of intensity when viewed through a Polaroid which is rotated. Describe, with the help of a suitable diagram, the basic phenomenon/process which occurs to explain this observation.

(b) Show how light reflected from a transparent medium gets polarised. Hence deduce Brewster's law.

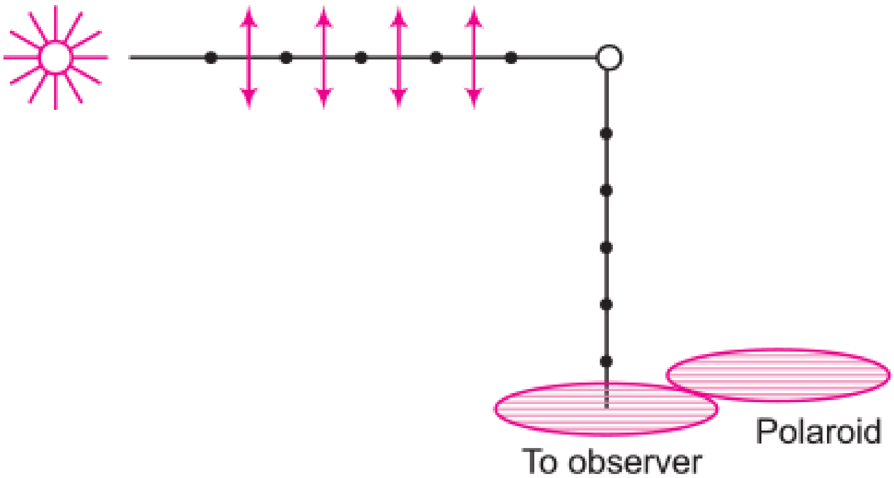
OR

An unpolarised light is incident on the boundary 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.
[CBSE Delhi 2014, Bhubaneshwar 2015]

Ans. (a) Sun emits unpolarised light, and represented as dots and double arrow. The dots stand for polarisation perpendicular to the plane and double arrow in the polarisation of plane.

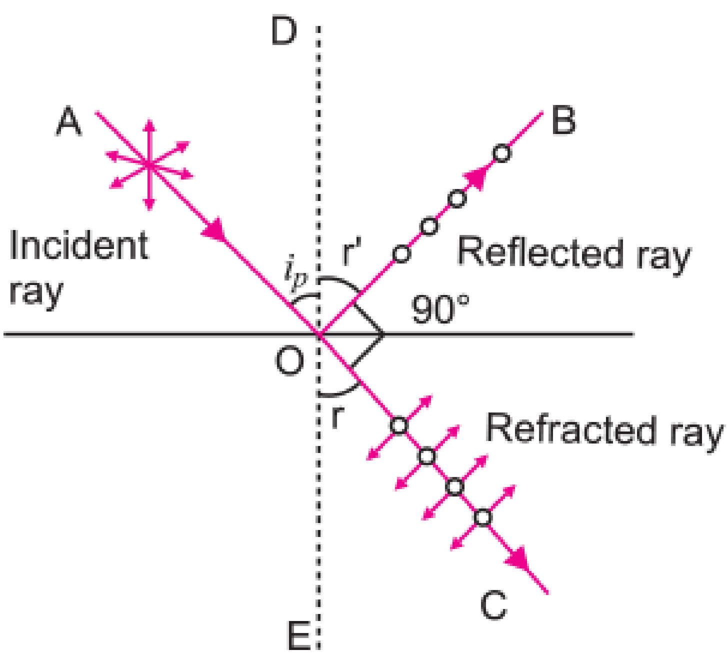
When the unpolarised light strikes on the atmospheric molecules, the electrons in the molecules acquire components of motion in both directions. The charge accelerating parallel to double arrow do not radiate energy towards the observer, so the component of electric field represented by dots radiate towards the observer.

If the scattered radiations represented by dots is viewed through an artificial Polaroid. It shows the variation in its intensity with the rotation of the Polaroid.



(b) Condition: The reflected ray is totally plane polarised, when reflected and refracted rays are perpendicular to each other.

$\angle BOC = 90°$



When reflected wave is perpendicular to the refracted wave, the reflected wave is a totally polarised wave. The angle of incidence in this case is called Brewster's angle and is denoted by i_B.

If r' is angle of reflection and r the angle of refraction, then according to law of reflection $i_B = r'$
and from fig. $r' + 90° + r = 180°$
$\Rightarrow i_B + r = 90°$ …(*i*)
$\Rightarrow r = (90° - i_B)$ …(*ii*)
From Snell's law, refractive index of second medium relative to first medium (*air*) say.

$$n = \frac{\sin i_B}{\sin r} = \frac{\sin i_B}{(90^\circ - i_B)} = \frac{\sin i_B}{\cos i_B}$$

$$\Rightarrow n = \tan i_B$$

This is known as Brewster's law.

Angle of incidence, iB = $\tan^{-1}$ (n).

Q. 9. State Brewster's law.

The value of Brewster angle for a transparent medium is different for light of different colours. Give reason. [CBSE Delhi 2016]

Ans. Brewster's Law: When unpolarised light is incident on the surface separating two media at polarising angle, the reflected light gets completely polarised only when the reflected light and the refracted light are perpendicular to each other.

Now, refractive index of denser (second) medium with respect to rarer (first) medium is given by

$\mu = \tan i_P$, where i_P = polarising angle.

Since refractive index is different for different colour (wavelengths), Brewster's angle is different for different colours.

Q. 10. Explain why the intensity of light coming out of a Polaroid does not change irrespective of the orientation of the pass axis of the Polaroid.
[CBSE East 2016]

Ans. When unpolarised light passes through a polariser, vibrations perpendicular to the axis of the Polaroid are blocked.

Unpolarised light have vibrations in all directions.

Hence, if the polariser is rotated, the unblocked vibrations remain same with reference to the axis of polariser.

Hence for all positions of Polaroid, half of the incident light always get transmitted. Hence, the intensity of the light does not change.

Q. 11. Answer the following questions [CBSE (F) 2011]

(i) Light passes through two Polaroids P_1 and P_2 with axis of P_2 making an angle with the pass axis of P_1. For what value of is the intensity of emergent light zero?

(ii) A third Polaroid is placed between P_1 and P_2 with its pass axis making an angle β with the pass axis of P_1. Find a value of β for which the intensity of light emerging from P_2 is $\frac{I_0}{8}$, where I0 is the intensity of light on the Polaroid P_1.

Ans. (i) At θ = 90°, the intensity of emergent light is zero.

(ii)

Intensity of light coming out from polariser $P_1 = \frac{I_0}{2}$

Intensity of light coming out from $P_3 = \left(\frac{I_0}{2}\right) \cos^2 \beta$

Intensity of light coming out from $P_2 = \left(\frac{I_0}{2}\right) \cos^2 \beta \ \cos^2 (90 - \beta)$

$$= \frac{I_0}{2} \cdot \cos^2 \beta . \sin^2 \beta = \frac{I_0}{2} \left[\frac{(2 \cos \beta . \sin \beta)^{\ 2}}{(2)^2}\right]$$

$$I = \frac{I_0}{8} (\sin \ 2\beta)^2$$

But it is given that intensity transmitted from P_2 is $I = \frac{I_0}{8}$

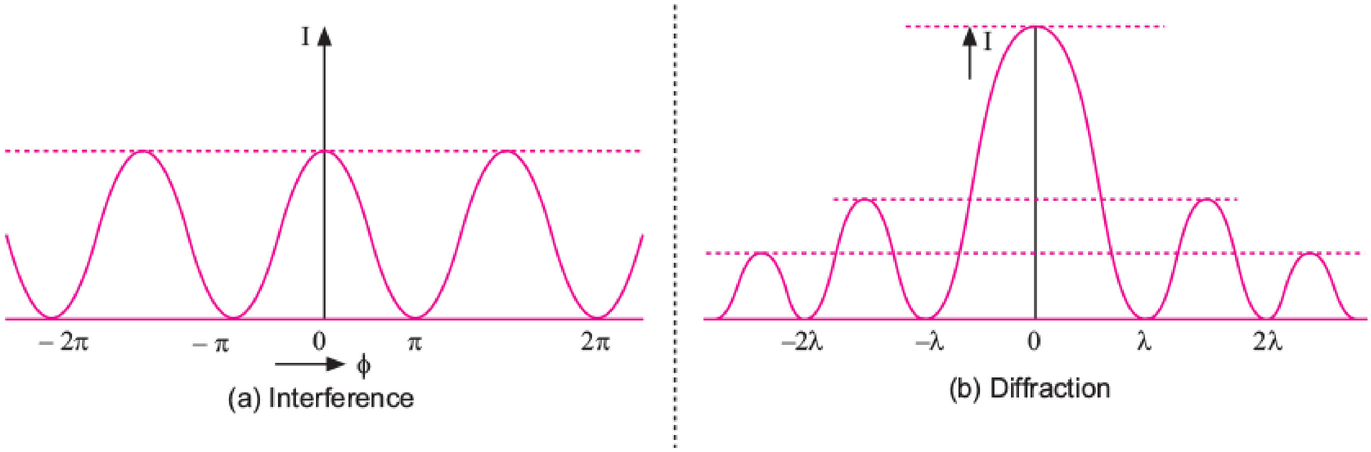
So, $\quad \frac{I_0}{8} = \frac{I_0}{8} (\sin \ 2\beta)^2$

or, $\quad (\sin 2 \beta)^2 = 1$

$$\sin \ 2\beta = \sin \frac{\pi}{2} \quad \Rightarrow \quad \beta = \frac{\pi}{4}$$

Q. 12. Draw the intensity distribution for (i) the fringes produced in interference, and (ii) the diffraction bands produced due to single slit. Write two points of difference between the phenomena of interference and diffraction. [CBSE (F) 2017]

Ans.



Intensity Patterns

Differences between interference and diffraction

Interference	Diffraction
(*i*) It is due to the superposition of two waves coming from two coherent sources.	(*i*) It is due to the superposition of secondary wavelets originating from different parts of the same wavefront.
(*ii*) The width of the interference bands is equal.	(*ii*) The width of the diffraction bands is not the same.
(*iii*) The intensity of all maxima (fringes) is same.	(*iii*) The intensity of central maximum is maximum and goes on decreasing rapidly with increase in order of maxima.

Q. 13. How does the refractive index of a transparent medium depend on the wavelength of incident light used? Velocity of light in glass is 2×10^8 m/s and in air is 3×10^8 m/s. If the ray of light passes from glass to air, calculate the critical angle.
[CBSE (F) 2015]

Ans. Refractive index of a transparent medium decreases with increase in wavelength of the incident light used.

Refractive index of glass with respect to air is given

$$\mu = \frac{\text{Speed of light in air}}{\text{Speed of light in glass}} = \frac{3\times10^8 \text{ m/s}}{2\times10^8 \text{m/s}} = 1.5$$

$$\text{Now,} \qquad \mu = \frac{1}{\sin\, i_c} \quad \Rightarrow \quad \sin\, i_c = \frac{1}{\mu}$$

$$i_c = \sin^{-1}\left(\frac{1}{\mu}\right) = \sin^{-1}\left(\frac{1}{1.5}\right) = \sin^{-1}\left(\frac{2}{3}\right).$$

Q. 14. Use Huygen's principle to explain the formation of diffraction pattern due to a single slit illuminated by a monochromatic source of light.

When the width of slit is made double the original width, how this affect the size and intensity of the central diffraction band? [CBSE Delhi 2012]

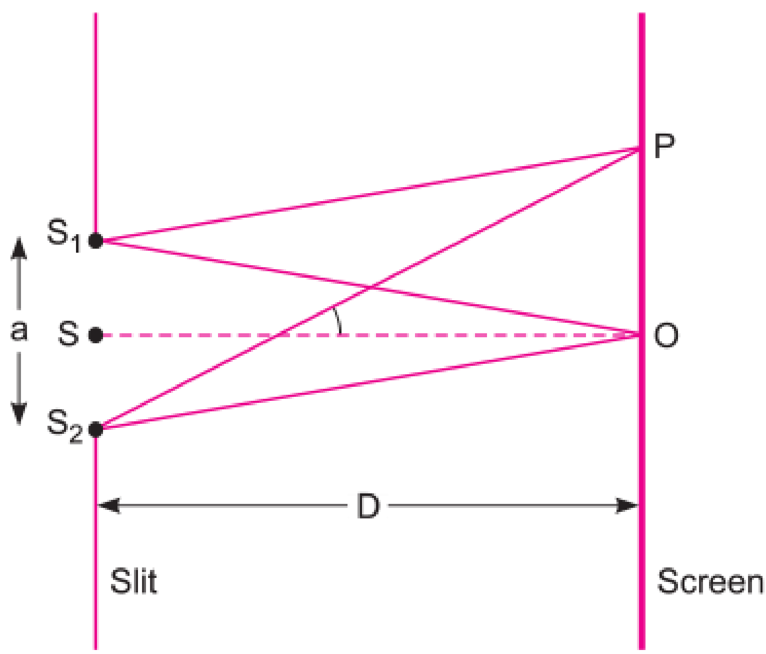
Ans. According to Huygen's principle, "The net effect at any point due to a number of wavelets is equal to sum total of contribution of all wavelets with proper phase difference.

The point O is maxima because contribution from each half of the slit S_1S_2 is in phase, i.e., the path difference is zero.

At point P

i. If $S_2P - S_1P = n\lambda$ $\Rightarrow$ the point P would be minima.

ii. If $S_2P - S_1P = (2n+1)\frac{\lambda}{2}$ $\Rightarrow$ the point would be maxima but with decreasing intensity.



The width of central maxima $= \frac{2\lambda D}{a}$

When the width of the slit is made double the original width, then the size of central maxima will be reduced to half and intensity will be four times.

Q. 15. (a) In Young's double slit experiment, two slits are 1 mm apart and the screen is placed 1 m away from the slits. Calculate the fringe width when light of wavelength 500 nm is used.

(b) What should be the width of each slit in order to obtain 10 maxima of the double slits pattern within the central maximum of the single slit pattern? [CBSE East 2016]

Ans.

Fringe width is given by $\beta = \frac{\lambda D}{d}$

$$<= \frac{500\times10^{-9}\times1}{10^{-3}} = 0.5 \text{ mm} = 0.5\times10^{-3}m = 5\times10^{-4}m$$

(b) $$\beta_0 = \frac{2\lambda D}{a} = 10\beta$$

$\Rightarrow$ $$a = \frac{2\times500\times10^{-9}\times1}{10\times5\times10^{-4}} = 2\times10^{-4}\ m$$

Q. 16. A beam of light consisting of two wavelengths, 800 nm and 600 nm is used to obtain the interference fringes in a Young's double slit experiment on a screen placed 1.4 m away. If the two slits are separated by 0.28 mm, calculate the least distance from the central bright maximum where the bright fringes of the two wavelengths coincide. [CBSE (AI) 2012]

Ans. Given λ_1 = 800 nm = 800×10^{-9} m

λ_2 = 600nm = 600×10^{-9} m

D = 1.4

d = 0.28 mm = 0.28×10^{-3}m

For least distance of coincidence of fringes, there must be a difference of 1 in order of λ_1 and λ_2.

As $\lambda_1 > \lambda_2$, $n_1 < n$

If $n_1 = n$, $n_2 = n + 1$

$\therefore \qquad (y_n)_{\lambda_1} = (y_n + 1)_{\lambda_2} \quad \Rightarrow \quad \frac{n\,D\,\lambda_1}{d} = \frac{(n+1)D\lambda_2}{d}$

$\Rightarrow \qquad n\lambda_1 = (n+1)\lambda_2$

$\Rightarrow \qquad n\lambda_1 = (n+1)\lambda_2$

$$y_{\min} = \frac{\text{nD}\,\lambda_1}{d} = \frac{3\times1.4\times800\times10^{-9}}{0.28\times10^{-3}} = 12000\times10^{-6} = 12\times10^{-3}\ m$$

Q. 17. Answer the Following questions [CBSE Guwahati 2015]

(i) Assume that the light of wavelength 6000 Å is coming from a star. Find the limit of resolution of a telescope whose objective has a diameter of 250 cm.

(ii) Two slits are made 1 mm apart and the screen is placed 1 m away. What should be the width of each slit to obtain 10 maxima of the double slit pattern within the central maximum of the single slit pattern?

Ans. (i) The limit of resolution of the objective lens in the telescope is

$$\Delta\theta = \frac{1.22\,\lambda}{D}$$

Since D = 250 cm = 2.5 cm and λ^2 = 6000 Å = 6×10^{-7} m

$\therefore \qquad \Delta\theta = \frac{1.22\times6\times10^{-7}}{2.5} = 2.9\times10^{-7}$ radian

(ii) If a is the size of single slit for diffraction pattern then, for first maxima

θ= λ a (n=1)

And angular separation of central maxima in the diffraction pattern

$$\theta' = 2\theta = \frac{2\lambda}{a} \qquad \ldots(1)$$

The angular size of the fringe in the interference pattern

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

If there are 10 maxima within the central maxima of the diffraction pattern, then

$$10\,\alpha = \theta'$$

$$10\left(\frac{\lambda}{d}\right) = \frac{2\lambda}{a} \quad \Rightarrow \quad a = \frac{d}{5}$$

The distance between two slits is 1 mm.

∴ Size of the single slit a = $\frac{1}{5}$ mm = 0.2 mm

Q. 18. Answer the following questions [CBSE Delhi 2012]

(i) Why are coherent sources necessary to produce a sustained interference pattern?

(ii) In Young's double slit experiment using monochromatic light of wavelength, the intensity of light at a point on the screen where path difference is, is K units. Find out the intensity of light at a point where path difference is.

Ans. (i) This is because coherent sources are needed to ensure that the positions of maxima and minima do not change with time.

If the phase difference between wave, reaching at a point change with time intensity will change and sustained interference will not be obtained.

(ii) We know

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

for path difference λ, phase difference $\varphi = 2\pi$

Intensity of light $= K$

Hence, $K = 4I_0 \cos^2 \pi = 4I_0$

For path difference $\frac{\lambda}{3}$, Phase difference $\phi = \frac{2\pi}{3}$

Intensity of light $I' = 4I_0 \cos^2 \frac{\phi}{2} = 4I_0 \cos^2 \frac{\pi}{3} = I_0$

$\Rightarrow \quad I' = \frac{K}{4}$

Q. 19. Distinguish between polarised and unpolarised light. Does the intensity of polarised light emitted by a Polaroid depend on its orientation? Explain briefly.

The vibrations in a beam of polarised light make an angle of 60° with the axis of the Polaroid sheet. What percentage of light is transmitted through the sheet? [CBSE (F) 2016]

Ans. A light which has vibrations in all directions in a plane perpendicular to the direction of propagation is said to be unpolarised light. The light from the sun, an incandescent bulb or a candle is unpolarised.

If the electric field vector of a light wave vibrates just in one direction perpendicular to the direction of wave propagation, then it is said to be polarised or linearly polarised light.

Yes, the intensity of polarised light emitted by a Polaroid depends on orientation of Polaroid. When polarised light is incident on a Polaroid, the resultant intensity of transmitted light varies directly as the square of the cosine of the angle between polarisation direction of light and the axis of the Polaroid.

$I \propto \cos^2 \theta$ *or* $I = I_0 \cos^2 \theta$

Where I_0 = maximum intensity of transmitted light;

θ = angle between vibrations in light and axis of Polaroid sheet.

or, $I = I_0 \cos^2 60^\circ = \frac{I_0}{4}$

Percentage of light transmitted $= \frac{I}{I_0} \times 100 = \frac{1}{4} \times 100 = 25\%$

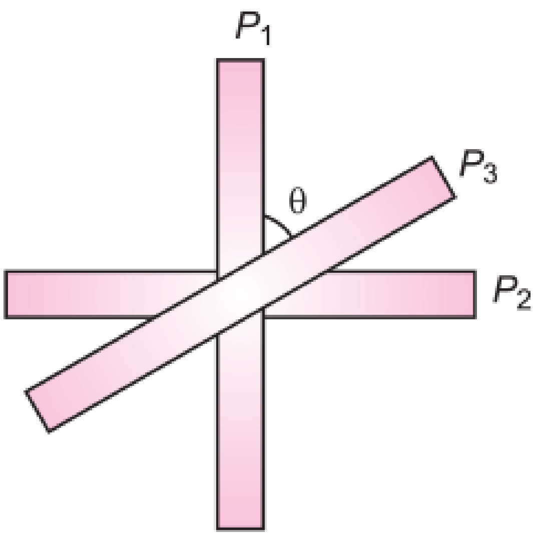
Q. 20. Find an expression for intensity of transmitted light when a Polaroid sheet is rotated between two crossed Polaroids. In which position of the Polaroid sheet will the transmitted intensity be maximum? [CBSE Delhi 2015]

Ans. Let P_1 and P_2 be the crossed Polaroids, and no light transmitted through Polaroid P_2.

Let I_0 be the intensity of the polarised light through Polaroid P_1.

If another Polaroid P_3 is inserted between P_1 and P_2, and Polaroid P_3 is at an angle θ with the Polaroid P_1.

Then intensity of light through Polaroid P_3 is



$I_3 = I_0 \cos^2 \theta$ …(1)

If this light I_3 again passes through the Polaroid P_2 then

$I_2 = I_3 \cos^2 (90 - \theta)$ …(2)

From equation (1) and (2), we get

$I_2 = I_0 \cos^2 \theta \,.\, \cos^2 (90 - \theta)$

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

For maximum value of I_2,

$$\sin 2\theta = \pm 1 \qquad \Rightarrow \qquad 2\theta = 90^\circ$$

$$\Rightarrow \quad \theta = 45^\circ$$

It is possible only when Polaroid P_3 is placed at angle 45° from each Polaroid P_1 (or P_2).

Q. 21. Two wavelengths of sodium light 590 nm and 596 nm are used, in turn, to study the diffraction taking place at a single slit of aperture 2 × 10^{-4} m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of the first maxima of the diffraction pattern obtained in the two cases.
[CBSE Delhi 2013]

Ans. For maxima other than central maxima

$$a.\theta = \left(n + \tfrac{1}{2}\right)\lambda \qquad and \quad \theta = \frac{y}{D}$$

$$\therefore \qquad a.\frac{y}{D} = \left(n + \tfrac{1}{2}\right)\lambda$$

For light of wavelength λ_1= 590 nm

$$2 \times 10^{-14} \times \frac{y_1}{1.5} = \left(1 + \tfrac{1}{2}\right) \times 590 \times 10^{-9}$$

$$y_1 = \frac{3}{2} \times \frac{590 \times 10^{-9} \times 1.5}{2 \times 10^{-4}} = 6.64 \text{ mm}$$

For light of wavelength =596 nm

$$2 \times 10^{-4} \times \frac{y_2}{1.5} = \left(1 + \tfrac{1}{2}\right) \times 596 \times 10^{-9}$$

$$\Rightarrow \qquad y_2 = \frac{3}{2} \times \frac{596 \times 10^{-9} \times 1.5}{2 \times 10^{-4}} = 6.705 \text{ mm}$$

Separation between two positions of first maxima

$\triangle y = y_2 - y_1 = 6.705 - 6.64 = 0.065$ mm

Q. 22. Answer the following questions [CBSE Central 2016]

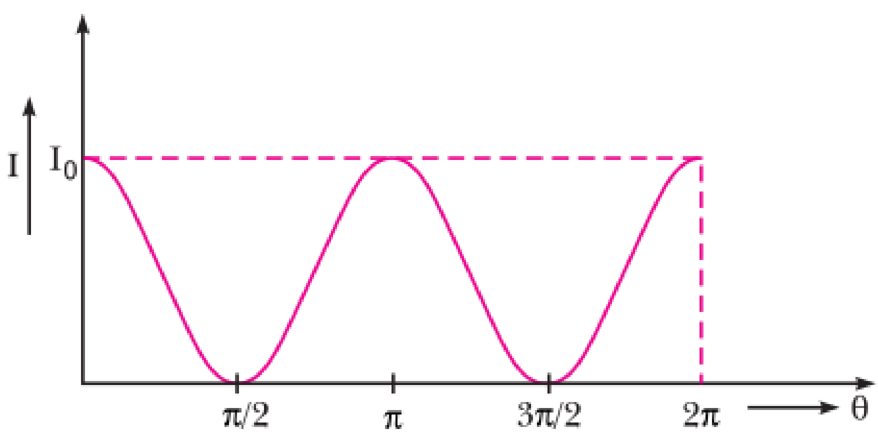
(i) State law of Malus.

(ii) Draw a graph showing the variation of intensity (I) of polarised light transmitted by an analyser with angle (θ) between polariser and analyser.

(iii) What is the value of refractive index of a medium of polarising angle 60°?

Ans. (i) Malus law states that when the pass axis of a polaroid makes an angle θ with the plane of polarisation of polarised light of intensity I_0 incident on it, then the intensity of the transmitted emergent light is given by $I = I_0 \cos^2 \theta$.

(ii)



(iii)

$$\mu = \tan i_\beta = \tan 60^\circ = \sqrt{3} = 1.7$$

Q. 23. The intensity at the central maxima (O) in a Young's double slit experiment is I0. If the distance OP equals one-third of the fringe width of the pattern, show that the intensity at point P would be $\frac{I_0}{4}$. [CBSE (F) 2011, 2012]

Ans.

$$\text{Fringe width } (\beta) = \frac{\lambda D}{d}$$

$$y = \frac{\beta}{3} = \frac{\lambda D}{3d}$$

$$\text{Path diff } (\Delta P) = \frac{\text{yd}}{D} \Rightarrow \Delta P = \frac{\lambda D}{3d} \cdot \frac{d}{D} = \frac{\lambda}{3}$$

$$\Delta\varphi = \frac{2\pi}{\lambda} \cdot \Delta P = \frac{2\pi}{\lambda} \cdot \frac{\pi}{3} = \frac{2\pi}{3}$$

$$\text{Intensity at point } P = I_0 \cos^2 \Delta\varphi$$

$$= I\ 0\ [\cos\ 2\pi\ 3]\ 2 = I\ 0\ (1\ 2)\ 2 = I\ 0\ 4$$

Short Answer Questions – II (OIQ)

Q. 1. In Young's double slit experiment, explain with reason in each case, how the interference pattern changes, when

(i) Width of the slits is doubled
(ii) Separation between the slits is increased and
(iii) Screen is moved away from the plane of slits.

Ans. (i) The fringe width β = $\frac{D\lambda}{d}$

(i) When the width of the slit is doubled; the intensity of interfering waves becomes four times, intensity of maxima becomes 16 times i.e., fringes become brighter.

(ii) When separation between the slits is increased the fringe width decreases, i.e., fringes come closer.

(iii) β ∝ D, when screen is moved away from the plane of the slits, the fringe width increases, i.e., fringes become farther away.

Q. 2. What are coherent sources of light? Why are coherent sources required to produce interference of light? Give an example of interference in everyday life.

Ans. Coherent Sources: Two sources giving light waves of same frequency and zero or constant initial phase are called coherent sources.

Necessity of coherent sources to produce interference of light: Intensity at any point in the region of superposition is $I = a_1^2 + \ a_2^2 \ + \ 2a_1 \ a_2 \ \cos \ f$

If the interfering sources are not coherent, then the phase difference at any point in the region of superposition will go on changing with time. Then we shall get time-averaged intensity which is equal to $I = a_1^2 + a_2^2 \ \ i.e.,$ sum of intensities of individual waves. This means that there will be no modifications in intensity in the region of superposition and hence no interference will be observed.

Example of Interference in Daily Life: The bubbles of colourless soap solution appear coloured in white light. This is due to interference of white light rays reflected from upper and lower surface of soap film. The colours of soap solution observed are those which satisfy the condition of maxima in reflected light.

Q. 3. Define resolving power of a compound microscope. How does the resolving power of a compound microscope change when

(i) Refractive index of medium between the object and objective lens increases.
(ii) Wavelength of radiation used is increased?

Ans. Resolving Power of a Microscope

The resolving power of a microscope is defined as its ability to form separate images of two close objects placed near the microscope.

The minimum distance between close objects for which microscope can just form separate images of the objects is called the limit of resolution of microscope. Smaller the limit, larger the resolving power

The angular resolving limit of microscope is $d\theta = \frac{\lambda}{2n \sin\theta}$,

Where n is the refractive index of medium between object and objective.

$$\text{Resolving power } \frac{1}{d\theta} = \frac{2n \ \sin \ \theta}{\lambda}$$

(i) Resolving power ∝ n; therefore resolving power of a compound microscope increases when refractive index (n) between the object and objective lens increases.

(ii) Resolving power $\propto \frac{1}{\lambda}$; therefore, resolving power of a compound microscope decreases with the increase of wavelength of light used.

Q. 4. Two identical coherent waves, each of intensity I, are producing an interference pattern. Find the value of the resultant intensity at a point of (i) constructive interference and (ii) destructive interference.

Ans. Resultant intensity at any point having a phase difference φ is

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

Here, $I_1 = I_2 = I$

$$\therefore\quad I_R = I + I + 2\sqrt{I.I.}\ \cos\varphi = 2I + 2I\cos\varphi$$

(i) At a point of constructive interference

$$\varphi = 2n\pi\ (n = 0, 1, 2, \ldots) \qquad \Rightarrow \qquad \cos\varphi = 1$$

$$\therefore \qquad I_{\max} = 2I + 2I = 4I$$

(ii) At a point of destructive interference

$$\Rightarrow \qquad \cos\varphi = 0$$

$$\therefore \qquad I_{\min} = 2I - 2I = 0$$

Q. 5. Two Polaroids are placed 90° to each other and the transmitted intensity is zero. What happens when one more Polaroid is placed between these two bisecting the angle between them. Take intensity of unpolarised light I0.

How will the intensity of transmitted light vary on further rotating the third Polaroid?

Ans. If ordinary unpolarised light of intensity I_0' is incident on first Polaroid (*A*, say)

Intensity of light transmitted from first Polaroid is $I_0 = \frac{I_{0'}}{2}$

Given angle between transmission axes of two polaroids A and B is initially 90°.

According to Malus law, intensity of light transmitted from second polaroid (B, say) is

$$I = I_0 \cos^2 \theta \quad \Rightarrow \quad I = I_0 \cos^2 90^\circ = 0$$

When one more polaroid (C say) is placed between A and B making an angle of 45° with the transmission axis of either of polaroids, then intensity of light transmitted from A is

$$I = I_0 \cos^2 \theta \quad \Rightarrow \quad I = I_0 \cos^2 90^\circ = 0$$

Intensity of light transmitted from C is

$$I_C = I_0 \cos^2 45^\circ = \frac{I_0}{2}$$

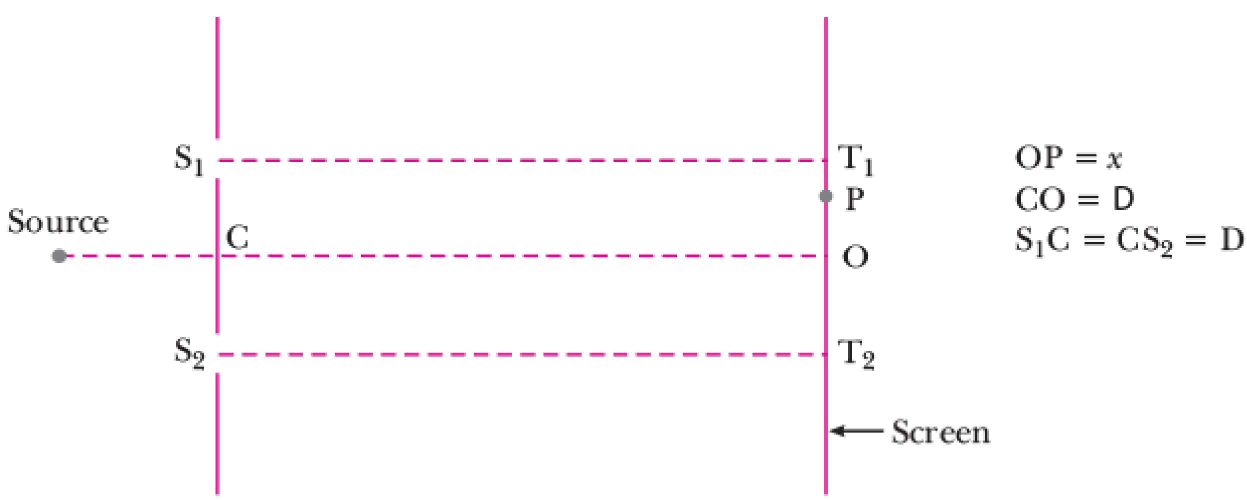
Intensity of light transmitted from polaroid B is

$$I_B = I_C \cos^2 45^\circ = \frac{I_0}{2} \times \frac{1}{2} = \frac{I_0}{4}$$

This means that the intensity becomes one-fourth of intensity of light that is transmitted from first Polaroid.

On further rotating the Polaroid C such that if angle between their transmissions axes increases, the intensity decreases and if angle decreases, the intensity increases.

Q. 6. Consider a two slit interference arrangements such that the distance of the screen from the slits is half the distance between the slits.



Obtain the value of D in terms of λ such that the first minima on the screen fall at a distance D from the centre O. [CBSE Sample Paper 2017]

Ans.

$T_2P = D + x,\ T_1P = D - x$

$$S_1P = \sqrt{(S_1T_1)^2 + (PT_1)^2} = \left[D^2 + (D - x)^2\right]^{1/2}$$

$S_2P = \left[D^2 + (D + x)^2\right]^{1/2}$

Minima will occur when

$$\left[D^2 + (D + x)^2\right]^{1/2} - \left[D^2 + (D - x)^2\right]^{1/2} = \frac{\lambda}{2}$$

If $x = D, (D^2 + 4D^2)^{1/2} - D = \frac{\lambda}{2}$

$$\Rightarrow \quad D(\sqrt{5} - 1) = \frac{\lambda}{2} \quad \Rightarrow \quad D = \frac{\lambda}{2(\sqrt{5} - 1)}$$

Q. 7. Define the term 'resolving power' of an astronomical telescope. How does it get affected on

(i) Increasing the aperture of the objective lens?
(ii) Increasing the wavelength of light used?
(iii) Increasing the focal length of the objective lens?

Justify your answer in each case.

Ans. Resolving Power of an Astronomical Telescope

The resolving power of an astronomical telescope is its ability to form separate images of two neighbouring astronomical objects (e.g. stars).

The least distance between two neighbouring objects for which astronomical telescope can form separate images is called the **resolving limit**. The angular limit of resolution is given by

$$\theta_{\text{min}} = \frac{1.22\lambda}{d}$$

Where λ is wavelength and d is diameter of aperture objective lens. Smaller the resolving limit, greater is the resolving power.

$\therefore$ $$\text{Resolving power} = \frac{d}{1.22\lambda}$$

(i) RP $\propto$ d, so by increasing aperture of objective lens, the resolving power of telescope increases.

(ii) RP $\propto \frac{1}{\gamma}$, so by increasing the wavelength of light, the resolving power of telescope decreases.

(iii) Resolving power of telescope is independent of its focal length, so there is no effect on resolving power if focal length of objective lens is increased.

Long Answer Questions

Q. 1. Using Huygens' Principle, draw a diagram to show propagation of a wavefront originating from a monochromatic point source. Explain briefly.

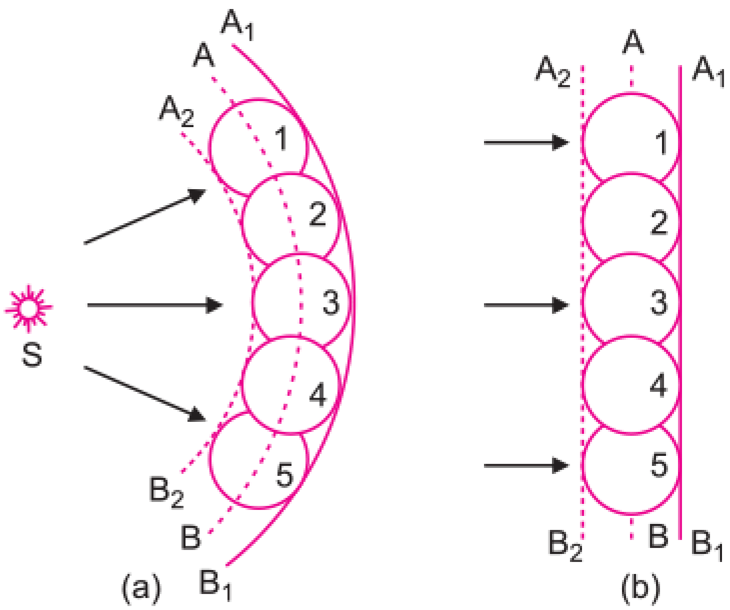
Ans. Propagation of Wavefront from a Point Source:

This principle is useful for determining the position of a given wavefront at any time in the future if we know its present position. The principle may be stated in three parts as follows:

(i) Every point on a given wavefront may be regarded as a source of new disturbance.

(ii) The new disturbances from each point spread out in all directions with the velocity of light and are called the secondary wavelets.

(iii) The surface of tangency to the secondary wavelets in forward direction at any instant gives the new position of the wavefront at that time.



Let us illustrate this principle by the following example:

Let *AB* shown in the fig. be the section of a wave front in a homogeneous isotropic medium at $t = 0$. We have to find the position of the wave front at time t using Huygens' Principle. Let v be the velocity of light in the given medium.

a. Take the number of points 1, 2, 3, … on the wave front *AB*. These points are the sources of secondary wavelets.
b. At time t the radius of these secondary wavelets is vt. Taking each point as centre, draw circles of radius vt.
c. Draw a tangent A_1B_1 common to all these circles in the forward direction.

This gives the position of new wave front at the required time *t*.

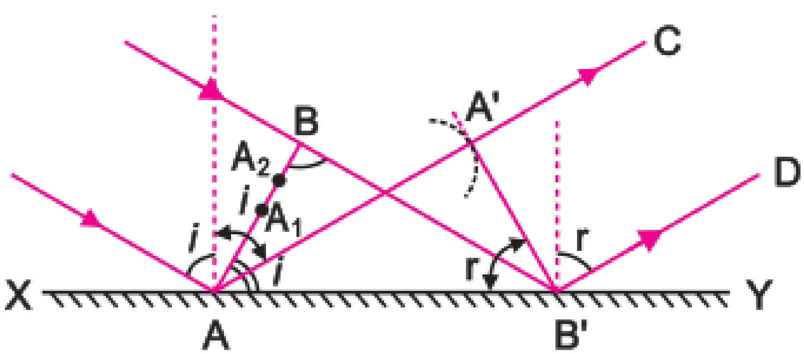
The Huygens' construction gives a backward wave front also shown by dotted line A_2B_2 which is contrary to observation. The difficulty is removed by assuming that the intensity of the spherical wavelets is not uniform in all directions; but varies continuously from a maximum in the forward direction to a minimum of zero in the backward direction

The directions which are normal to the wave front are called rays, *i.e.*, a ray is the direction in which the disturbance is propagated.

Q. 2. How is a wave front defined? Using Huygen's construction draw a figure showing the propagation of a plane wave reflecting at the interface of the two media. Show that the angle of incidence is equal to angle of reflection. [CBSE Delhi 2008]

Ans. Wave front: A wave front is a locus of particles of medium all vibrating in the same phase.

Law of Reflection: Let XY be a reflecting surface at which a wave front is being incident obliquely. Let v be the speed of the wave front and at time t = 0, the wave front touches the surface XY at A. After time t, the point B of wave front reaches the point B′ of the surface.



According to Huygen's principle each point of wavefront acts as a source of secondary waves. When the point *A* of wavefront strikes the reflecting surface, then due to presence of reflecting surface, it cannot advance further; but the secondary wavelet originating from point *A* begins to spread in all directions in the first medium with speed v. As the wavefront *AB* advances further, its points A_1, A_2, A_3 ... etc. strike the reflecting surface successively and send spherical secondary wavelets in the first medium.

First of all the secondary wavelet starts from point *A* and traverses distance *AA*' (= *vt*) in first medium in time *t*. In the same time *t*, the point *B* of wavefront, after travelling a distance *BB*', reaches point *B*' (of the surface), from where the secondary wavelet now starts. Now taking *A* as centre we draw a spherical arc of radius *AA*' (= *vt*) and draw tangent *A*'*B*' on this arc from point *B*'. As the incident wavefront *AB* advances, the secondary wavelets starting from points between *A* and *B*', one after the other and will touch *A*'*B*' simultaneously. According to Huygen's principle wavefront *A*'*B*' represents the new position of *AB*, *i.e.*, *A*'*B*' is the reflected wavefront corresponding to incident wavefront *AB*.

Now in right-angled triangles *ABB*' and *AA'B'*

∠*ABB*' = ∠*AA'B*' (both are equal to 90°)

side *BB*' = side *AA*' (both are equal to *vt*)

and side *AB*' is common.

i.e., both triangles are congruent.

∴ ∠ *BAB*' = ∠ *AB'A'*

i.e., incident wavefront *AB* and reflected wavefront *A'B'* make equal angles with the reflecting surface *XY*. As the rays are always normal to the wavefront, therefore the incident and the reflected rays make equal angles with the normal drawn on the surface *XY*, *i.e.*,

Angle of incidence i = Angle of reflection r

This is the second law of reflection.

Since *AB*, *A'B'* and *XY* are all in the plane of paper, therefore the perpendiculars dropped on them will also be in the same plane. Therefore we conclude that *the incident ray, reflected ray and the normal at the point of incidence, all lie in the same plane.* This is the first law of reflection.

Thus Huygen's principle explains both the laws of reflection.

Q. 3. (a) How is a wave front defined? Distinguish between a plane wave front and a spherical wave front. Using Huygens's constructions 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.

When a light wave travels from rarer to denser medium, the speed decreases. Does it imply reduction its energy? Explain. [CBSE Delhi 2008, 2013, (F) 2011, 2012]

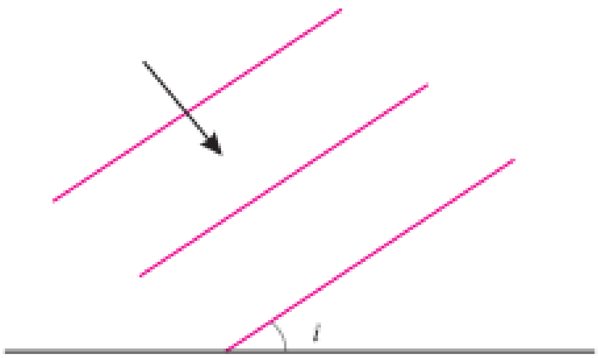
(b) When monochromatic light travels from a rarer to a denser medium, explain the following, giving reasons:

(i) Is the frequency of reflected and refracted light same as the frequency of incident light?

(ii) Does the decrease in speed imply a reduction in the energy carried by light wave?
[CBSE Delhi 2013]

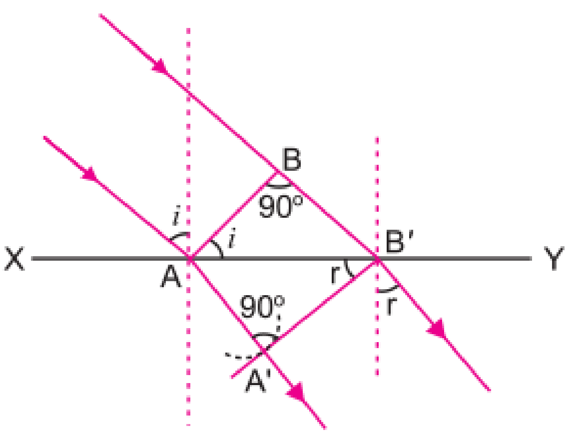
OR

A plane wave front propagating in a medium of refractive index 'μ_1' is incident on a plane surface making the angle of incidence 'i' as shown in the figure. It enters into a medium of refractive index 'μ_2' ($\mu_2 > \mu_1$). Use Huygens'



Construction of secondary wavelets to trace the propagation of the refracted wave front. Hence verify Snell's law of refraction. [CBSE (F) 2015]

Ans. Wave front: A wave front is a locus of all particles of medium vibrating in the same phase. **Huygen's Principle:** Refer point 18 of basic concepts. **Proof of Snell's law of Refraction using Huygen's wave theory:** When a wave starting from one homogeneous medium enters the another homogeneous medium, it is deviated from its path. This phenomenon is called **refraction**. In trans versing from first medium to another medium, the frequency of wave remains unchanged but its speed and the wavelength both are changed. Let XY be a surface separating the two media '1' and '2'. Let v_1 and v_2 be the speeds of waves in these media.



Suppose a plane wave front AB in first medium is incident obliquely on the boundary surface XY and its end A touches the surface at A at time $t = 0$ while the other end B reaches the surface at point B' after time-interval t. Clearly $BB' = v_1t$. As the wave front AB advances, it strikes the points between A and B' of boundary surface. According to Huygen's principle, secondary spherical wavelets originate from these points, which travel with speed v1 in the first medium and speed v2 in the second medium.

First of all secondary wavelet starts from A, which traverses a distance AA' (= v_2t) in second medium in time t. In the same time-interval t, the point of wave front traverses a distance BB' (= v_1t) in first medium and reaches B', from, where the secondary wavelet now starts. Clearly $BB' = v_1t$ and $AA' = v_2t$.

Assuming A as centre, we draw a spherical arc of radius AA' (= v_2t) and draw tangent $B'A'$ on this arc from B'. As the incident wave front AB advances, the secondary wavelets start from points between A and B', one after the other and will touch $A'B'$ simultaneously. According to Huygen's principle $A'B'$ is the new position of wave front AB in the second medium. Hence A'B' will be the refracted wave front. **First law:** As AB, $A'B'$ and surface XY are in the plane of paper, therefore the perpendicular drawn on them will be in the same plane. As the lines drawn normal to wave front denote the rays, therefore we may say that the incident ray, refracted ray and the normal at the point of incidence all lie in the same plane.

This is the first law of refraction. **Second law:** Let the incident wave front AB and refracted wave front $A'B'$ make angles i and r respectively with refracting surface XY. In right-angled triangle $AB'B$, $\angle ABB' = 90°$

$$\therefore \quad \sin i = \sin \angle BAB' = \frac{BB'}{AB'} = \frac{v_1 t}{AB'} \quad ...(i)$$

Similarly in right-angled triangle $AA'B'$, $\angle AA'B' = 90° \therefore$

$$\sin r = \sin \angle AB'A' = \frac{AA'}{AB'} = \frac{v_2 t}{AB'} \quad ...(ii)$$

Dividing equation (i) by (ii), we get

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant} \quad ...(iii)$$

As the rays are always normal to the wave front, therefore the incident and refracted rays make angles i and r with the normal drawn on the surface XY i.e. i and r are the angle of incidence and angle of refraction respectively. According to equation (iii):

The ratio of sine of angle of incidence and the sine of angle of refraction for a given pair of media is a constant and is equal to the ratio of velocities of waves in the two media. This is the second law of refraction, and is called the Snell's law.

(b) (i) If the radiation of certain frequency interact with the atoms/molecules of the matter, they start to vibrate with the same frequency under forced oscillations.

Thus, the frequency of the scattered light (Under reflection and refraction) equals to the frequency of incident radiation.

(ii) No, energy carried by the wave depends on the frequency of the wave, but not on the speed of the wave.

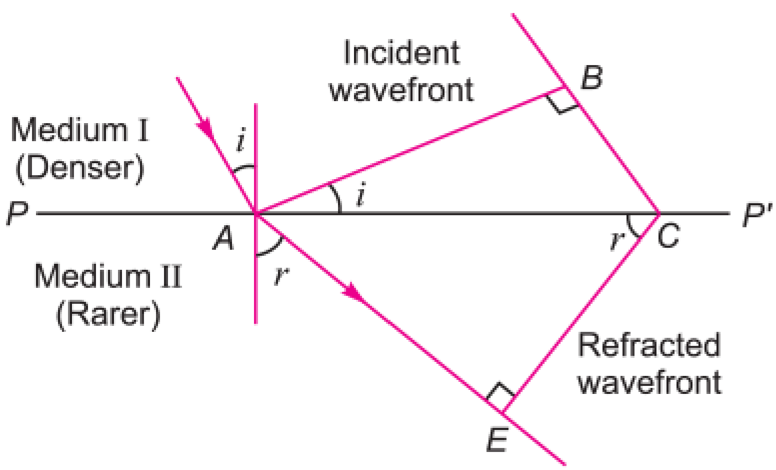
Q. 4. Use Huygens' Principle to show how a plane wave front propagates from a denser to rarer medium. Hence, verify Snell's law of refraction.
[CBSE Allahabad 2015, Sample Paper 2016]

Ans. We assume a plane wave front *AB* propagating in denser medium incident on the interface *PP*' at angle i as shown in

Fig. Let τ be the time taken by the wave front to travel a distance *BC*. If v_1 is the speed of the light in medium *I*.

So, $BC = v_1 \tau$

In order to find the shape of the refracted wave front, we draw a sphere of radius $AE = v_2 \tau$, where v_2 is the speed of light in medium II (rarer medium). The tangent plane *CE* represents the refracted wave front



In ΔABC, $\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$

and in ΔACE, $\sin r = \frac{AE}{AC} = \frac{v_2 t}{AC}$

$$\therefore \quad \frac{\sin i}{\sin r}\frac{BC}{AE} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} \quad \ldots(1)$$

Let c be the speed of light in vacuum

So, $\mu_1 = \frac{C}{v_1}$ and $\mu_2 = \frac{C}{v_2}$

$$\frac{\mu_2}{\mu_1} = \frac{v_1}{v_2} \quad \ldots(2)$$

From equations (1) and (2), we have

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

$\mu_1 \sin i = \mu_2 \sin r$

It is known as Snell's law.

Q. 5. Answer the following questions

(i) In Young's double slit experiment, deduce the conditions for (i) constructive, and destructive interference at a point on the screen. Draw a graph showing variation of the resultant intensity in the interference pattern against position 'X' on the screen.
[CBSE Delhi 2016, (AI) 2012]

(ii) Compare and contrast the pattern which is seen with two coherently illuminated narrow slits in Young's experiment with that seen for a coherently illuminated single slit producing diffraction.

Ans. (i) Conditions of Constructive and Destructive Interference:

When two waves of same frequency and constant initial phase difference travel in the same direction along a straight line simultaneously, they superpose in such a way that the intensity of the resultant wave is maximum at certain points and minimum at certain other points. The phenomenon of redistribution of intensity due to superposition of two waves of same frequency and constant initial phase difference is called the interference. The waves of same frequency and constant initial phase difference are called **coherent waves.** At points of medium where the waves arrive in the same phase, the resultant intensity is maximum and the interference at these points is said to be **constructive.** On the other hand, at points of medium where the waves arrive in opposite phase, the resultant intensity is minimum and the interference at these points is said to be **destructive.** The positions of maximum intensity are called **maxima** while those of minimum intensity are called **minima.** The interference takes place in sound and light both.

Mathematical Analysis: Suppose two coherent waves travel in the same direction along a straight line, the frequency of each wave is $\frac{\omega}{2\pi}$ and amplitudes of electric field are a1 and a2 respectively. If at any time t, the electric fields of waves at a point are y_1 and y_2 respectively and phase difference is φ, then equation of waves may be expressed as

$y_1 = a_1 \sin \omega t$ ...(*i*)

$y2 = a_2 \sin (\omega t + \varphi)$ ...(*ii*)

According to Young's principle of superposition, the resultant displacement at that point will be

$y = y_1 + y_2$ ...(*iii*)

Substituting values of y_1 and y_2 from (*i*) and (*ii*) in (*iii*), we get

$y = a_1 \sin \omega t + a_2 \sin (\omega t + \varphi)$

Using trigonometric relation

$\sin (\omega t + \varphi) = \sin \omega t \cos \varphi + \cos \omega t \sin \varphi$,

We get $y = a_1 \sin \omega t + a_2 (\sin \omega t \cos \varphi + \cos \omega t \sin \varphi)$

$= (a_1 + a_2 \cos \varphi) \sin \omega t + (a_2 \sin \varphi) \cos \omega t$ ...(*iv*)

Let $a_1 + a_2 \cos \varphi = A \cos \theta$ ...(*v*)

And $a_2 \sin \varphi = A \sin \theta$ ...(*vi*)

Where A and θ are new constants.

Then equation (*iv*) gives $y = A \cos \theta \sin \omega t + A \sin \theta \cos \omega t = A \sin (\omega t + \theta)$ ...(*vii*)

This is the equation of the resultant disturbance. Clearly the amplitude of resultant disturbance is A and phase difference from first wave is θ. The values of A and q are determined by (v) and (vi). Squaring (v) and (vi) and then adding, we get

$(a_1 + a_2 \cos \varphi)^2 + (a_2 \sin \varphi)^2 = A^2 \cos^2 \theta + A^2 \sin^2 \theta$

Or $a_1^2 + a_2^2 \cos^2 \varphi + 2a_1a_2 \cos \varphi + a_2^2 \sin^2 \varphi = A^2 (\cos^2 \theta + \sin^2 \theta)$

As $\cos^2 \theta + \sin^2 \theta = 1$, we get

$A^2 = a_1^2 + a_2^2 (\cos^2 \varphi + \sin^2 \varphi) + 2a_1a_2 \cos \varphi$

Or $A^2 = a_1^2 + a_2^2 + 2a_1a_2 \cos \varphi$

$$\text{Amplitude,} \qquad A = \sqrt{{a_1}^2 + {a_2}^2 + 2a_1a_2 \cos\varphi} \qquad \ldots(viii)$$

As the intensity of a wave is proportional to its amplitude in arbitrary units $I = A^2$

∴ Intensity of resultant wave

$I = A^2 = a_1^2 + a_2^2 + 2a_1a_2 \cos \varphi$ ...(ix)

Clearly the intensity of resultant wave at any point depends on the amplitudes of individual waves and the phase difference between the waves at the point.

Constructive Interference: For maximum intensity at any point $\cos \varphi = + 1$

Or phase difference $\varphi = 0, 2\pi, 4\pi, 6\pi$.........

$= 2n\pi$ ($n = 0, 1, 2, ...$) ...(x)

The maximum intensity,

$I_{max} = a_1^2 + a_2^2 + 2a_1a_2 = (a_1 + a_2)^2$ ...(xi)

Path difference

$$\Delta = \frac{\lambda}{2\pi} \times \text{Phase difference} = \frac{\lambda}{2\pi} \times 2n\pi = n\lambda$$
$$\ldots(xii)$$

Clearly the maximum intensity is obtained in the region of superposition at those points where waves meet in the same phase or the phase difference between the waves is even multiple of π or path difference between them is the integral multiple of λ and maximum intensity is $(a_1 + a_2)2$ which is greater than the sum intensities of individual waves by an amount 2a1a2.

Destructive Interference: For minimum intensity at any point cos φ = –1

Or phase difference, $\varphi = \pi, 3\pi, 5\pi, 7\pi$ ....

$= (2n - 1)\pi$, $n = 1, 2, 3$ ....(*xiii*)

In this case the minimum intensity,

$I_{min} = a_1^2 + a_2^2 - 2a_1a_2 = (a_1 - a_2)^2$ ...(*xiv*)

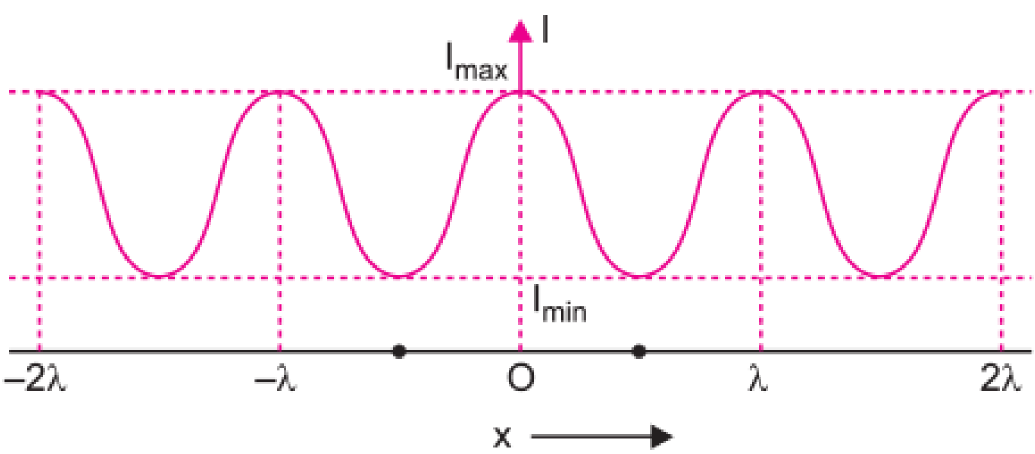
$$\text{Path difference, } \Delta = \frac{\lambda}{2\pi} \times \text{ Phase difference}$$

$$= \frac{\lambda}{2\pi} \times (2n - 1)\pi = (2n - 1)\frac{\lambda}{2} \qquad ...(xv)$$

Clearly, the minimum intensity is obtained in the region of superposition at those points where waves meet in opposite phase or the phase difference between the waves is odd multiple of π or path difference between the waves is odd multiple of $\frac{\lambda}{2}$ and minimum intensity $= (a_1 - a_2)^2$ which is less than the sum of intensities of the individual waves by an amount $2a_1a_2$.

For equations (*xii*) and (*xvi*) it is clear that the intensity $2a_1a_2$ is transferred from positions of minima to maxima. This implies that the ***interference is based on conservation of energy*** *i.e., there is no wastage of energy.*

Variation of Intensity of light with position x is shown in fig.



Q. 6. Two harmonic waves of monochromatic light

$y_1 = a \cos \omega t$ and $y_2 = a \cos(\omega t + \varphi)$

Are superimposed on each other. Show that maximum intensity in interference pattern is four times the intensity due to each slit. Hence write the conditions for constructive and destructive interference in terms of the phase angle φ. [CBSE South 2016]

Ans. The resultant displacement will be given by

$y = y_1 + y_2$

$= a \cos \omega t + a \cos(\omega t + \varphi)$

$= a [\cos \omega t + \cos(\omega t + \varphi)]$

$= 2a \cos(\varphi/2) \cos(\omega t + \varphi/2)$

The amplitude of the resultant displacement is $2a \cos(\varphi/2)$

The intensity of light is directly proportional to the square of amplitude of the wave. The resultant intensity will be given by

$$I = 4a^2 \cos^2 \frac{\varphi}{2}$$

$\therefore$ Intensity $= 4I_0 \cos^2\left(\frac{\varphi}{2}\right)$, where $I_0 = a^2$ is the intensity of each harmonic wave

At the maxima, $\varphi = \pm 2n\pi$

$$\therefore \qquad \cos^2 \frac{\varphi}{2} = 1$$

At the maxima, $I = 4I_0 = 4 \times$ intensity due to one slit

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

For constructive interference, I is maximum.

It is possible when $\cos^2\left(\frac{\varphi}{2}\right) = 1; \frac{\varphi}{2} = n\pi; \varphi = 2n\pi$

For destructive interference, I is minimum, *i.e.*, $I = 0$

It is possible when $\cos^2\left(\frac{\varphi}{2}\right) = 0; \frac{\varphi}{2} = \frac{(2n-1)\pi}{2}; \varphi = (2n \pm 1)\frac{\pi}{2}$

Q. 7. (a) What are coherent sources of light? State two conditions for two light sources to be coherent.

(b) Derive a mathematical expression for the width of interference fringes obtained in Young's double slit experiment with the help of a suitable diagram. [CBSE Delhi 2011, Panchkula 2015]

(c) If s is the size of the source and b its distance from the plane of the two slits, what should be the criterion for the interference fringe to be seen?

OR

(a) In Young's double slit experiment, describe briefly how bright and dark fringes are obtained on the screen kept in front of a double slit. Hence obtain the expression for the fringe width.

(b) The ratio of the intensities at minima to the maxima in the Young's double slit experiment is 9: 25. Find the ratio of the widths of the two slits. [CBSE (AI) 2014]

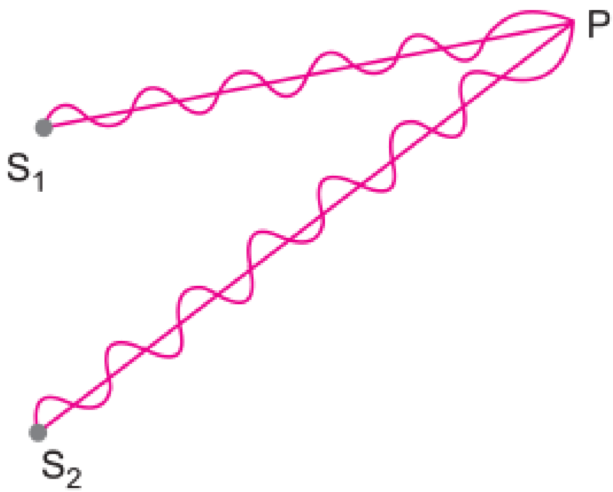
Ans. Coherent sources are those which have exactly the same frequency and are in this same phase or have a zero or constant difference.

Conditions:

(i) The sources should be monochromatic and originating from common single source.

(ii) The amplitudes of the waves should be equal.

(a) Condition for formation of bright and dark fringes.

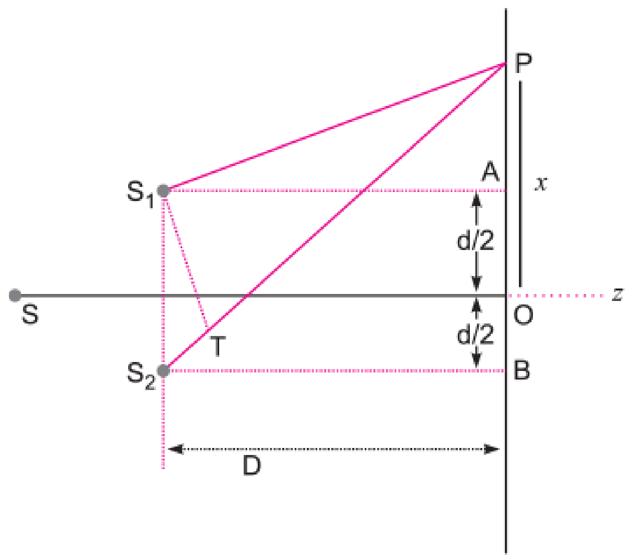


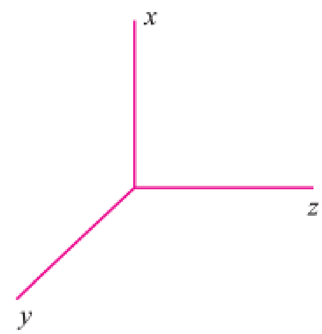
Suppose a narrow slit S is illuminated by monochromatic light of wavelength λ.

The light rays from two coherent sources S1 and S2 are reaching a point P, have a path difference (S2P - S1P).

(i) If maxima (bright fringe) occurs at point P, then $S_2P - S_1P = n\lambda$ (n = 0, 1, 2, 3 …)

(ii) If minima (dark fringe) occurs at point P, then $S_2P - S_1P = (2n+1)\frac{\lambda}{2}$ (n = 0, 1, 2, 3 …)





Light waves starting from S and fall on both slits S_1 and S_2. Then S_1 and S_2 behave like two coherent sources. Spherical waves emanating from S_1 and S_2 superpose on each other, and produces interference pattern on the screen. Consider a point P at a distance x from 0, the centre of screen. The position of maxima (or minima) depends on the path difference.

($S_2T = S_2P - S_1P$).

From right angled ΔS_2BP and ΔS_1AP,

$$(S_2P)^2 - (S_1P)^2 = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(x - \frac{d}{2}\right)^2\right] = 2\,\text{xd}$$

$$(S_2P + S_1P)(S_2P - S_1P) = 2\text{xd}$$

$$\Rightarrow S_2P - S_1P = \frac{2\,\text{xd}}{(S_2P + S_1P)}$$

In practice, the point P lies very close to O, therefore

$$S_2P \pm S_1P = 2\text{D}$$

$$S_2P - S_1P = \frac{2\,\text{xd}}{2D} = \frac{\text{xd}}{D} \ldots \text{(i)}$$

For constructive interference (Bright fringes)

Path difference, $\frac{\text{dx}}{D} = n\lambda$ where n = 1, 2, 3, …

For n = 0, $x_0 = 0$ Central bright fringe

For n = 1, $x_1 = \frac{D\lambda}{d}$ 1st bright fringe

For n = 2, $x_2 = \frac{2D\lambda}{d}$ 2nd bright fringe

For n = n, $x_n = \frac{\text{nD}\,\lambda}{d}$ nth bright fringe

The distance between two consecutive bright fringes is

$$\beta = x_n - x_{n-1}\ \beta' = (2n - 1)\frac{D\lambda}{2d} - \{2(n - 1) - 1\}\frac{D\lambda}{2d} = \frac{D\lambda}{d}$$

For destructive interference (dark fringes)

Path difference $\frac{\text{dx}}{D} = (2n - 1)\frac{\lambda}{2}$

$$x = (2n - 1)\frac{D\lambda}{2d} \quad \text{where } n = 1, 2, 3,$$

For $n = 1$, $x'_1 = \frac{D\lambda}{2d}$ for 1st dark fringe

For $n = 2$, $x'_2 = \frac{3D\lambda}{2d}$ for 2nd dark fringe

For $n = n$, $x'_n = (2n - 1)\frac{D\lambda}{2d}$ for nth dark fringe

The distance between two consecutive dark fringe is

$$\beta' = (2n - 1)\frac{D\lambda}{2d} - \{2(n - 1) - 1\}\frac{D\lambda}{2d} = \frac{D\lambda}{d}$$

The distance between two consecutive bright or dark fringes is called fringe width (w).

$\therefore$ Fringe width = $\frac{Dl}{d}$

The expression for fringe width is free from n. Hence the width of all fringes of red light are broader than the fringes of blue light.

(b) Intensity of light (using classical theory) is given as

I ∝ (Width of the slit)

∝ (Amplitude)2

$$\frac{I_{\max}}{I_{\min}} = \frac{(a_1+a_2)^2}{(a_1-a_2)^2} = \frac{25}{9} \Rightarrow \frac{a_1+a_2}{a_1-a_2} = \frac{5}{3} \Rightarrow \frac{a_1}{a_2} = \frac{4}{1}$$

Intensity ratio

$$\frac{I_1}{I_2} = \frac{w_1}{w_2} = \frac{a_1^2}{a_2^2} \Rightarrow \frac{I_1}{I_2} = \left(\frac{4}{1}\right)^2 = \frac{16}{1}$$

(c) The condition for the interference fringes to be seen is

$$\frac{s}{b} < \frac{\lambda}{d}$$

When s is the size of the source and b is the distance of this source from plane of the slit.

Q. 8. What is interference of light? Write two essential conditions for sustained interference pattern to be produced on the screen.

Draw a graph showing the variation of intensity versus the position on the screen in Young's experiment when (a) both the slits are opened and (b) one of the slits is closed.

What is the effect on the interference pattern in Young's double slit experiment when:

(i) Screen is moved closer to the plane of slits?
(ii) Separation between two slits is increased?

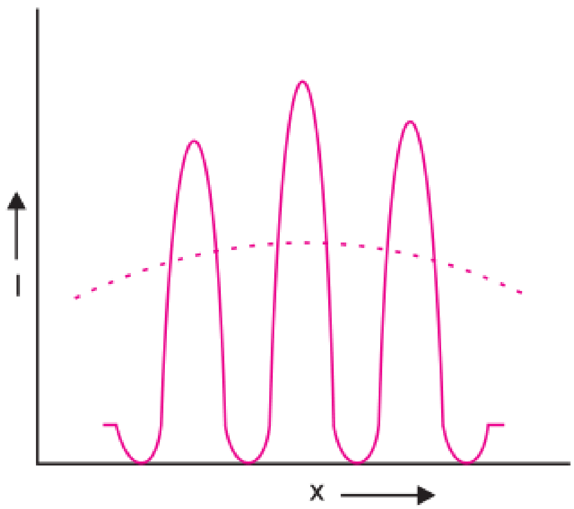
Explain your answer in each case.

Ans. Interference of light: When two waves of same frequency and constant initial phase difference travel in the same direction along a straight line simultaneously, they superpose in such a way that the intensity of the resultant wave is maximum at certain points and minimum at certain other points. This phenomenon of redistribution of energy due to superposition of two waves of same frequency and constant initial phase difference is called interference.

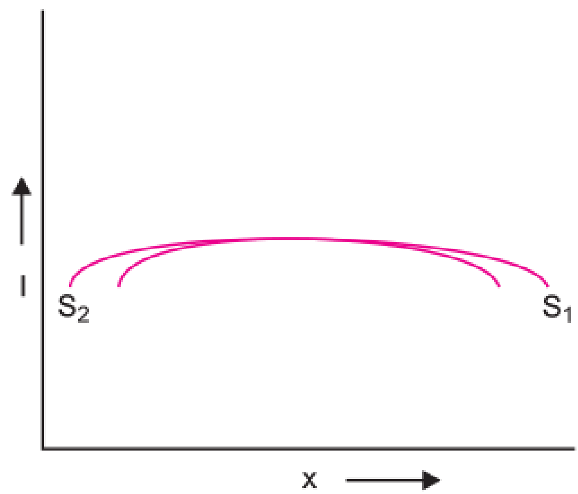
Conditions for Sustained Interference of Light Waves

To obtain sustained (well-defined and observable) interference pattern, the intensity must be maximum and zero at points corresponding to constructive and destructive interference. For the purpose following conditions must be fulfilled:

i. The two interfering sources must be coherent and of same frequency, i.e., the sources should emit light of the same wavelength or frequency and their initial phase should remain constant. If this condition is not satisfied the phase difference between the interfering waves will vary continuously. As a result the resultant intensity at any point will vary with time being alternately maximum and minimum, just like the phenomenon of beats in sound.
ii. The interfering waves must have equal amplitudes. Otherwise the minimum intensity will not be zero and there will be general illumination.



(a) When both the slits are opened. The dashed curve is the single slit intensity for comparison



(b) When one of the slits is closed.

The variation of intensity I versus the position x on the screen in Young's experiment. Fringe width, $\beta = \frac{D\lambda}{d}$.

(i) β ∝ D, therefore with the decrease of separation between the plane of slits and screen, the fringe width decreases.

(ii) On increasing the separation between two slits (d), the fringe separation decreases as β is inversely proportional to d (i.e.,β ∝ $\frac{1}{d}$.)

Q. 9. What is diffraction of light? Draw a graph showing the variation of intensity with angle in a single slit diffraction experiment. Write one feature which distinguishes the observed pattern from the double slit interference pattern. [CBSE (F) 2013]

How would the diffraction pattern of a single slit be affected when:

(i) The width of the slit is decreased?
(ii) The monochromatic source of light is replaced by a source of white light?

Ans. Diffraction of Light: When light is incident on a narrow opening or an obstacle in its path, it is bent at the sharp edges of the obstacle or opening. This phenomenon is called diffraction of light.

For graph refer point 23 of basic concepts.

In an interference pattern all the maxima have the same intensity while in diffraction pattern the maxima are of different intensities. For example in Young's double slit experiment all maxima are of the same intensity and in diffraction at a single slit, the central maximum have the maximum intensity and it falls rapidly for first, second orders secondary maxima on either side of it.

(i) When the width of the slit is decreased: From the relation sin θ = $\frac{\lambda}{a}$, we find that if the width of the slit (a) is decreased, then for a given wavelength, sin θ is large and hence θ is large. Hence diffraction maxima and minima are quite distant on either side of θ.

(ii) With monochromatic light, the diffraction pattern consists of alternate bright and dark bands. If white light is used central maximum is white and on either side, the diffraction bands are coloured.

Q. 10. Describe diffraction of light due to a single slit. Explain formation of a pattern of fringes obtained on the screen and plot showing variation of intensity with angle θ in single slit diffraction. [CBSE Delhi 2010, (F) 2013, (AI) 2014]

Ans. Diffraction of light at a single slit: When monochromatic light is made incident on a single slit, we get diffraction pattern on a screen placed behind the slit. The diffraction pattern contains bright and dark bands, the intensity of central band is maximum and goes on decreasing on both sides.

Explanation: Let *AB* be a slit of width '*a*' and a parallel beam of monochromatic light is incident on it. According to Fresnel the diffraction pattern is the result of superposition of a large number of waves, starting from different points of illuminated slit.

Let θ be the angle of diffraction for waves reaching at point *P* of screen and *AN* the perpendicular dropped from A on wave diffracted from *B*.

The path difference between rays diffracted at points *A* and *B*,

$\Delta = BP - AP = BN$

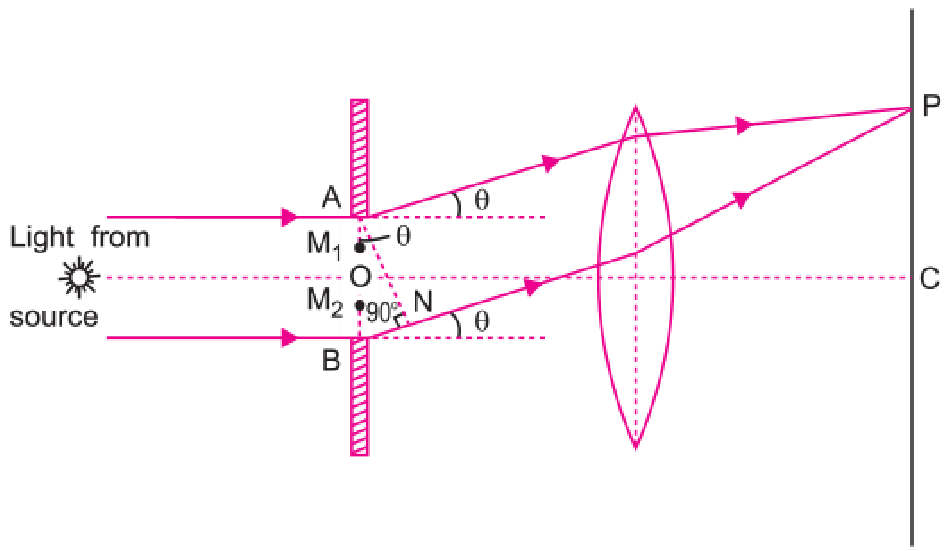
In $\Delta\, ANB$, $\angle ANB = 90°$ and $\angle BAN = \theta$

$$\therefore \quad \sin\theta = \frac{\mathrm{BN}}{\mathrm{AB}} \text{ or } \mathrm{BN} = \mathrm{AB}\sin\theta$$

As AB = width of slit = a

$$\therefore \text{ Path difference, } \Delta = a\sin\theta \qquad \ldots(i)$$

To find the effect of all coherent waves at P, we have to sum up their contribution, each with a different phase. This was done by Fresnel by rigorous calculations, but the main features may be explained by simple arguments given below:



At the central point C of the screen, the angle θ is zero. Hence the waves starting from all points of slit arrive in the same phase. This gives maximum intensity at the central point C.

Minima: Now we divide the slit into two equal halves AO and OB, each of width $\frac{a}{2}$. Now for every point, M_1 in AO, there is a corresponding point M_2 in OB, such that $\mathbf{M_1\, M_2} = \frac{a}{2}$; then path difference between waves arriving at P and starting from M_1 and M_2 will be $\frac{a}{2}\ \sin\theta = \frac{\lambda}{2}$..This means that the contributions from the two halves of slit AO and OB are opposite in phase and so cancel each other. Thus equation (2) gives the angle of diffraction at which intensity falls to zero. Similarly it may be shown that the intensity is zero for $\sin\theta = \frac{n\lambda}{a}$, with n as integer. Thus the general condition of minima is

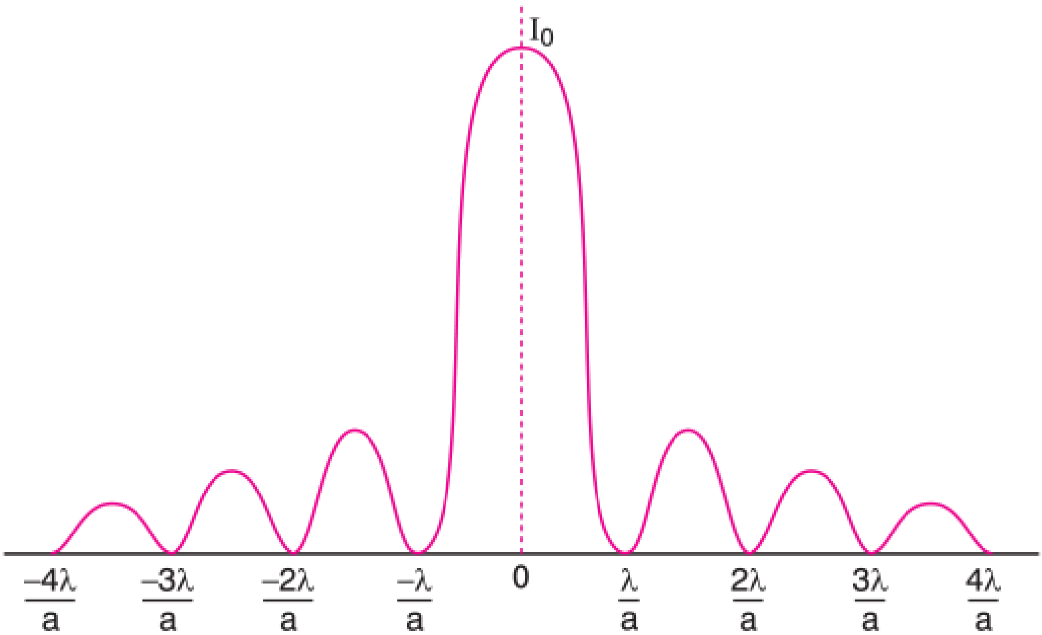
$$a \sin\theta = n\lambda \qquad ...(ii)$$

Secondary Maxima: Let us now consider angle θ such that

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

which is midway between two dark bands given by

$$\sin\theta = \theta = \frac{\lambda}{a} \quad \text{and} \quad \sin\theta = \theta = \frac{2\lambda}{a}$$



Let us now divide the slit into three parts. If we take the first two parts of slit, the path difference between rays diffracted from the extreme ends of the first two parts

$$\frac{2}{3}\, a\ \sin\ \theta = \frac{2}{3}a \times \frac{3\lambda}{2a} = \lambda$$

Then the first two parts will have a path difference of $\frac{\lambda}{2}$ and cancel the effect of each other. The remaining third part will contribute to the intensity at a point between two minima. Clearly there will be a maxima between first two minima, but this maxima will be of much weaker intensity than central maximum. This is called first secondary maxima. In a similar manner we can show that there are secondary maxima between any two consecutive minima; and the intensity of maxima will go on decreasing with increase of order of maxima. In general the position of nth maxima will be given by

$$a \sin\theta = \left(n + \tfrac{1}{2}\right)\lambda, \qquad [n = 1,2,3,4,....] \qquad ...(\text{iv})$$

The intensity of secondary maxima decreases with increase of order n because with increasing n, the contribution of slit decreases.

For n = 2, it is one-fifth, for n = 3, it is one-seventh and so on.

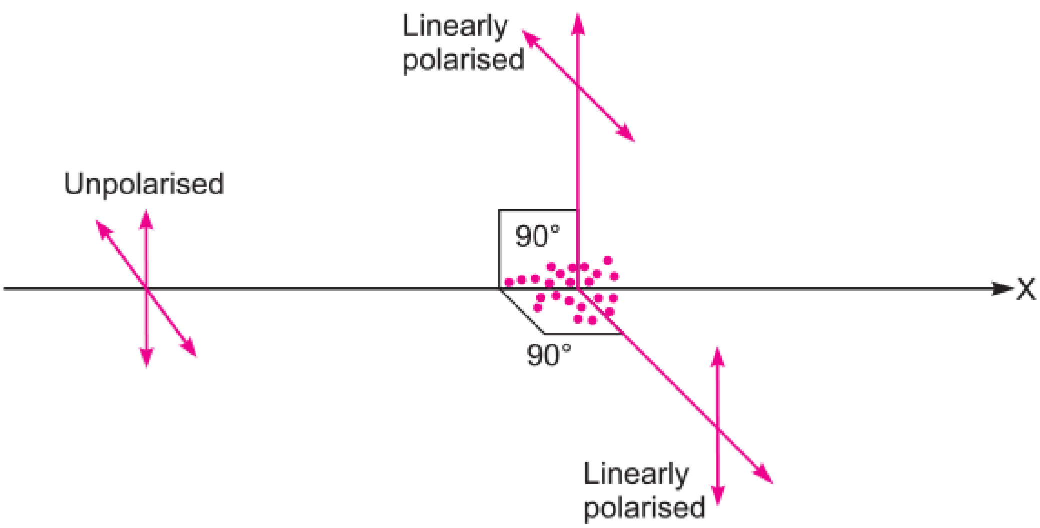
Q. 11. Answer the following questions [CBSE (AI) 2013]

(i) What is linearly polarized light? Describe briefly using a diagram how sunlight is polarised.

(ii) Unpolarised light is incident on a Polaroid. How would the intensity of transmitted light change when the polaroid is rotated? [CBSE (AI) 2013]

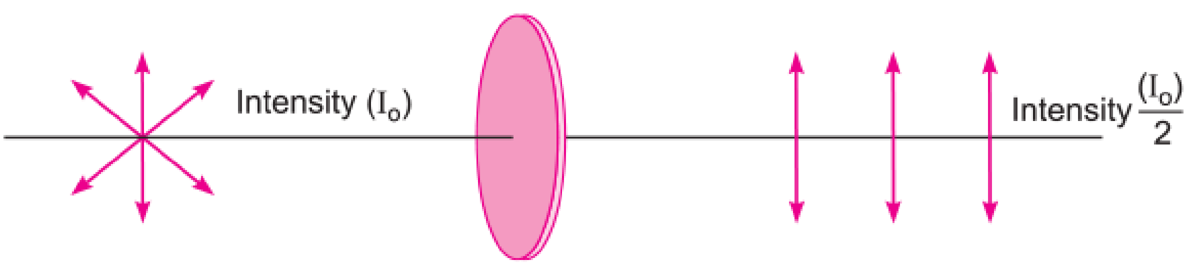
Ans. (i) Molecules in air behave like a dipole radiator. When the sunlight falls on a molecule, dipole molecule does not scatter energy along the dipole axis, however the electric field vector of light wave vibrates just in one direction perpendicular to the direction of the propagation. The light wave having direction of electric field vector in a plane is said to be linearly polarised.

In figure, a dipole molecule is lying along x-axis. Molecules behave like dipole radiators and scatter no energy along the dipole axis.



The unpolarised light travelling along x-axis strikes on the dipole molecule get scattered along y and z directions. Light traversing along y and z directions is plane polarised light.

(ii) In figure unpolarised light falls on the polaroid, and transmitted light has electric vibrations in the plane consisting of polaroid axis and direction of wave propagation as shown in Fig.

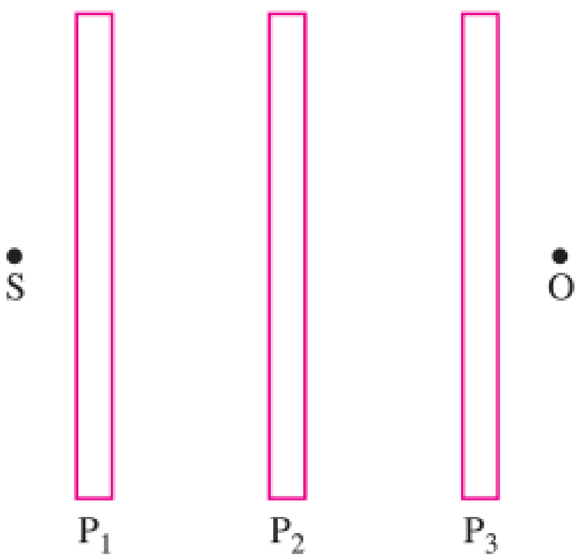


If polaroid is rotated the plane of polarisation will change, however the intensity of transmitted light remain unchanged.

Q. 12. Answer the following questions [CBSE North 2016]

(i) Why does unpolarised light from a source show a variation in intensity when viewed through a polaroid which is rotated? Show with the help of a diagram, how unpolarised light from sun gets linearly polarised by scattering.

(ii) Three identical polaroid sheets P_1, P_2 and P_3 are oriented so that the pass axis of P_2 and P_3 are inclined at angles of 60° and 90° respectively with the pass axis of P_1. A monochromatic source *S* of unpolarised light of intensity I_0 is kept in front of the polaroid sheet P_1 as shown in the figure. Determine the intensities of light as observed by the observer at O, when polaroid P_3 is rotated with respect to P_2 at angles θ = 30° and 60°.

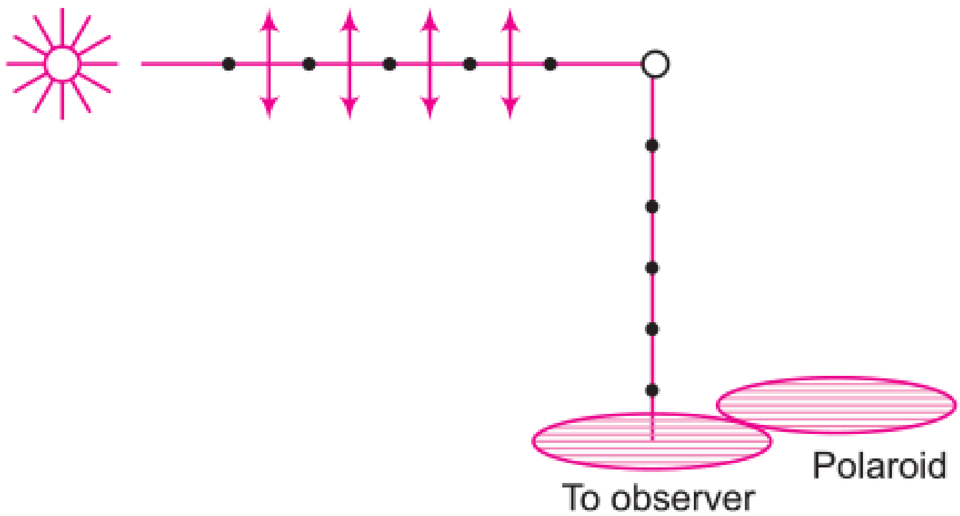


Ans. (i) According to Malus' law,

Transmitted intensity $I = I_0 \cos^2 \theta$

∴ The transmitted intensity will show a variation as per $\cos^2 \theta$.

Sun emits unpolarised light, and represented as dots and double arrow. The dots stand for polarisation perpendicular to the plane and double arrow in the polarisation of plane.



When the unpolarised light strikes on the atmospheric molecules, the electrons in the molecules acquire components of motion in both directions. The charge accelerating parallel to double arrow do not radiate energy towards the observer, so the component of electric field represented by dots radiate towards the observer.

If the scattered radiations represented by dots is viewed through an artificial polaroid, it shows the variation in its intensity with the rotation of the polaroid.

(ii) We have, as per Malus's law:

$I = I_0 \cos^2 \theta$

∴ If the intensity of light, incident on P_1 is I_0, we have

I_1 = Intensity transmitted through $P_1 = \frac{I_0}{2}$

I_2 = Intensity transmitted through $P_2 = \left(\frac{I_0}{2}\right)\cos^2 60^\circ = \frac{I_0}{8}$

For $\theta = 30^\circ$, we have

Angle between pass axis of P_2 and P_3

$= (30^\circ + 30^\circ) = 60^\circ \quad \Rightarrow \quad I_3 = \frac{I_0}{8}\cos^2 60^\circ = \frac{I_0}{32}$

or $\quad (30^\circ - 30^\circ) = 0^\circ \quad \Rightarrow \quad I_3 = \frac{I_0}{8}\cos^2 0^\circ = \frac{I_0}{8}$

$\therefore \quad I_3$ can be either $\frac{I_0}{32}$ or $\frac{I_0}{8}$.

For $\theta = 60^\circ$, we have

Angle between pass axis of P_2 and P_3]

$= (30^\circ + 60^\circ) = 90^\circ \quad \Rightarrow \quad I_3 = \frac{I_0}{8}\cos^2 90^\circ = 0$

or $(30^\circ - 60^\circ) = -30^\circ \quad \Rightarrow \quad I_3 = \frac{I_0}{8}\cos^2(-30^\circ) = \frac{3I_0}{32}$

$\therefore I_3$ can be either 0 or $\frac{3I_0}{32}$.

Q. 13. Answer the following questions [CBSE Delhi 2017]

(i) Distinguish between unploarised light and linearly polarised light. How does one get linearly polarised light with the help of a Polaroid?

(ii) A narrow beam of unpolarised light of intensity I_0 is incident on a Polaroid P_1. The light transmitted by it is then incident on a second Polaroid P_2 with its pass axis making angle of 60° relative to the pass axis of P_1. Find the intensity of the light transmitted by P_2.

Ans. (i) Unpolarised Light: The light having vibrations of electric field vector in all possible directions perpendicular to the direction of wave propagation is called the ordinary (or unpolarised) light.

Plane (or Linearly) Polarised Light: The light having vibrations of electric field vector in only one direction perpendicular to the direction of propagation of light is called plane (or linearly) polarised light.

When unpolarised light wave is incident on a polaroid, then the electric vectors along the direction of its aligned molecules get absorbed; the electric vector oscillating along a direction perpendicular to the aligned molecules, pass through. This light is called linearly polarised light.

(ii)

According to Malus' Law:

$$I = I_0 \cos^2$$

$$\therefore \quad I = \frac{I_0}{2}\cos^2\theta, \text{where } I_0 \text{ is the intensity of unpolarised light.}$$

Given, $\theta = 60^\circ$

$$I = \frac{I_0}{2}\cos^2 60^\circ = \frac{I_0}{2} \times \left(\frac{1}{2}\right)^2 = \frac{I_0}{8}$$

Q. 14. Answer the following questions [CBSE Delhi 2017]

(i) Explain two features to distinguish between the interference pattern in Young's double slit experiment with the diffraction pattern obtained due to a single slit.

(ii) A monochromatic light of wavelength 500 nm is incident normally on a single slit of width 0.2 mm to produce a diffraction pattern. Find the angular width of the central maximum obtained on the screen.

Estimate the number of fringes obtained in Young's double slit experiment with fringe width 0.5 mm, which can be accommodated within the region of total angular spread of the central maximum due to single slit.

Ans. (i) Differences between interference and diffraction

Interference	Diffraction
(a) It is due to the superposition of two waves coming from two coherent sources.	(a) It is due to the superposition of secondary wavelets originating from different parts of the same wave front.

(b) The width of the interference bands is equal.	(b) The width of the diffraction bands is not the same.
(c) The intensity of all maxima (fringes) is same.	(c) The intensity of central maximum is maximum and goes on decreasing rapidly with increase in order of maxima.

(ii)

Angular width of central maximum $= \frac{2\lambda}{a}$

$$= \frac{2\times500\times10^{-9}}{0.2\times10^{-3}}\text{radian} = 5\times10^{-3}\text{ radian}$$

Fringe width,

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

Linear width of central maxima in the diffraction pattern

$$\beta_0 = \frac{2\lambda D}{a}$$

Let 'n' be the number of interference fringes which can be accommodated in the central maxima

$$\therefore \quad n\times\beta = \beta_0$$

$$n = \frac{2\lambda D}{a}\times\frac{d}{\lambda D} \quad \Rightarrow \quad n = \frac{2d}{a}$$