CBSE Class 12 physics

Important Questions

Chapter 10

Wave Optics

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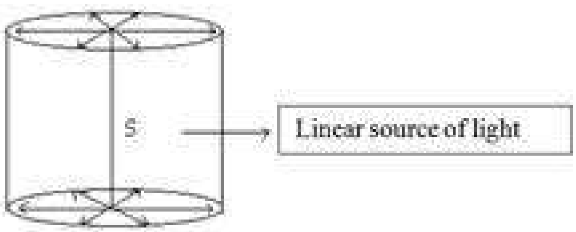
1 Mark Questions

1. Draw a diagram to show cylindrical wave front?

Ans.



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2. A light wave enters from air to glass. How will the following be affected:

(i) Energy of the wave

(ii) Frequency of the wave:

Ans. (1) A part of light is reflected back into the air. Thus energy of the wave will be lower in the glass.

(2) Frequency of the wave remains unchanged.

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3. What is the Brewster angle for air to glass transition? $(\mu g = 1.5)$

Ans. $\mu = \tan ip$

$1.5 = \tan ip$

$\Rightarrow ip = \tan^{-1}(1.5)$

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4. What is the shape of the wave front when light is diverging from a point source?

Ans. Spherical

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5. State the conditions that must be satisfied for two light sources to be coherent?

Ans. (1) They must emit waves continuously of same wavelengths.

(2) The phase difference between the waves must be zero or constant

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6. In young's double slit experiment. The distance between the slits is halved, what change in the fringe width will take place?

Ans. $\beta = \frac{\lambda D}{d} \;\; when \;\; d' = \frac{d}{2}$

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

$$\beta' = 2\beta$$

2 Mark Questions

1.Obtain an expression for the ratio of intensities at maxima and minima in an interference pattern.

Ans. Suppose $a_1 and\ a_2$ be the amplitudes and $I_1 and\ I_2$ the intensities of light waves which interfere each other

$$\text{Intensity } \alpha \text{ (Amplitude)}^2$$

$$\frac{I_1}{I_2} = \frac{a_1}{a_2}$$

After interference (applying superposition principle)

Amplitude at maxima = $a_1 + a_2$

Amplitude at minima = $a_1 - a_2$

$$\frac{\text{Imax}}{\text{Imin}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2}$$

$$\frac{\text{Imax}}{\text{Imin}} = \frac{\left(\frac{a_1}{a_2} + 1\right)^2}{\left(\frac{a_1}{a_2} - 1\right)^2} = \left(\frac{r+1}{r-1}\right)^2$$

$where\ \text{r} = \frac{a_1}{a_2} = \sqrt{\frac{I_1}{I_2}}$ = amplitude ratio of two waves.

2.A slit S is illuminated by a monochromatic source of light to give two coherent sources $P_1 and\ P_2$. These given bright and dark bands on a screen. At a point R, on the screen, there is a dark fringe. What relation must exist between the lengths $P_1R\ and\ P_2R$?

Ans. There will be a dark fringe at point R When path difference

$$= P_2R - P_1R$$

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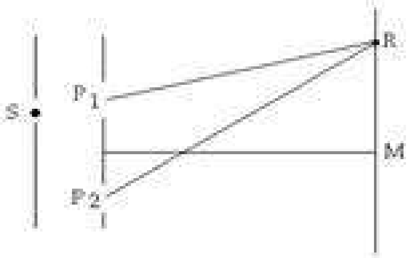
Where λ is the wavelength of the light and n = 0, 1, 2, 3 -----------



3.In young's double slit experiment how is the fringe width change when

(a) Light of smaller frequency is used

(b) Distance between the slits is decreased?

Ans. $\beta = \dfrac{D\lambda}{d}$

If light of smaller frequency is of higher wavelength is used the fringe width will increase.

(b) If distance between the slits is decreased

i.e $\beta \alpha \dfrac{1}{d}$. Fringe width will increase.

4.Write two points of difference between interference and diffraction?

Ans.

S.	Interference	Diffraction
1	Interference occurs due to superposition of light coming from two coherent sources.	It is due to the superposition of the waves coming from different parts of the same wave front.
2	All bright fringes are of equal intensity	The intensity of bright fringes decreases with increasing distance from the central bright fringes.

5.Consider interference between two sources of intensities I and 4I. What will be the intensity at points where phase differences is $(1)\frac{\pi}{2}\ \ (2)\pi$

Ans. $I = a^2 + b^2 + 2ab\cos\phi$

Where a and b are amplitudes of two coherent waves having phase difference of ϕ .

Here $a^2 = I$, $b^2 = 4I$

I = I + 4I + 2 $\sqrt{I}\sqrt{4I}\cos\phi$

I = 5I + 4I cos ϕ

(i) $When\phi = \frac{\pi}{2}$

$I = 5I + 4I\cos\frac{\pi}{2}$

I = 5I

(ii) Why $\phi = \pi$

I = 5I + 4I cos ϕ

I = 5I – 4I

I = I

6.Can white light produce interference? What is the nature?

Ans. White light produces interference but due to different colour present in white light interference pattern overlaps the central bright fringe for all the colours is at the position, so its colour is white. The white central bright fringe is surrounded by few coloured rings.

7.(a) The refractive index of glass is 1.5. What is the speed of light in glass? Speed of light in vacuum is 3.0×10^8 m s^{-1})

(b) Is the speed of light in glass independent of the colour of light? If not, which of the two colours red and violet travels slower in a glass prism?

Ans.(a) Refractive index of glass, μ = 1.5

Speed of light, c = 3×10^8 m/s

Speed of light in glass is given by the relation,

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

$$\frac{3 \times 10^8}{1.5} = 2 \times 10^8 m/s$$

Hence, the speed of light in glass is 2×10^8 m/s.

(b) The speed of light in glass is not independent of the colour of light.

The refractive index of a violet component of white light is greater than the refractive index of a red component. Hence, the speed of violet light is less than the speed of red light in glass. Hence, violet light travels slower than red light in a glass prism.

8.What is the Brewster angle for air to glass transition? (Refractive index of glass = 1.5.)

Ans. Refractive index of glass, $\mu = 1.5$

Brewster angle = θ

Brewster angle is related to refractive index as:

$$\tan\theta = \mu$$

$$\theta = \tan^{-1}(1.5) = 56.31^0$$

Therefore, the Brewster angle for air to glass transition is $56.31°$.

9.Estimate the distance for which ray optics is good approximation for an aperture of 4 mm and wavelength 400 nm.

Ans. Fresnel's distance (*ZF*) is the distance for which the ray optics is a good approximation. It is given by the relation,

$$Z_F = \frac{a^2}{\lambda}$$

Where,

Aperture width, *a* = 4 mm = $4 \times 10^{-3}\ m$

Wavelength of light, λ = 400 nm = $400 \times 10^{-9}\ m$ $Z_F = \frac{\left(4\times10^{-3}\right)^2}{400\times10^{-9}} = 40m$

Therefore, the distance for which the ray optics is a good approximation is 40 m.

10.Let us list some of the factors, which could possibly influence the speed of wave propagation:

(i) Nature of the source.

(ii) Direction of propagation.

(iii) Motion of the source and/or observer.

(iv) Wave length.

(v) Intensity of the wave. On which of these factors, if any, does

(a) The speed of light in vacuum,

(b) The speed of light in a medium (say, glass or water), depend?

Ans.(a) The speed of light in a vacuum i.e., $3 \times 10^8\ m/s$ (approximately) is a universal constant. It is not affected by the motion of the source, the observer, or both. Hence, the given factor does not affect the speed of light in a vacuum.

(b) Out of the listed factors, the speed of light in a medium depends on the wavelength of light in that medium.

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11. For sound waves, the Doppler formula for frequency shift differs slightly between the two situations: (i) source at rest; observer moving, and (ii) source moving; observer at rest. The exact Doppler formulas for the case of light waves in vacuum are, however, strictly identical for these situations. Explain why this should be so. Would you expect the formulas to be strictly identical for the two situations in case of light travelling in a medium?

Ans. No Sound waves can propagate only through a medium. The two given situations are not scientifically identical because the motion of an observer relative to a medium is different in the two situations. Hence, the Doppler formulas for the two situations cannot be the same.

In case of light waves, sound can travel in a vacuum. In a vacuum, the above two cases are identical because the speed of light is independent of the motion of the observer and the motion of the source. When light travels in a medium, the above two cases are not identical because the speed of light depends on the wavelength of the medium.

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12. In double-slit experiment using light of wavelength 600 nm, the angular width of a fringe formed on a distant screen is 0.1°. What is the spacing between the two slits?

Ans. Wavelength of light used, λ = 6000 nm = $600 \times 10^{-9}\ m$

Angular width of fringe, $\theta = 0.1^{0} = 0.1 \times \frac{\lambda}{180} = \frac{3.14}{1800} rad$

Angular width of a fringe is related to slit spacing (*d*) as:

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

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

$$= \frac{600 \times 10^{-9}}{\frac{3.14}{1800}} = 3.44 \times 10^{-4} m$$

Therefore, the spacing between the slits is $3.44 \times 10^{-4} m$.

13.In deriving the single slit diffraction pattern, it was stated that the intensity is zero at angles of $n\lambda / a$. Justify this by suitably dividing the slit to bring out the cancellation.

Ans. Consider that a single slit of width *d* is divided into *n* smaller slits.

$\therefore$ Width of each slit, $d' = \frac{d}{n}$

Angle of diffraction is given by the relation,

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

Now, each of these infinitesimally small slit sends zero intensity in direction θ. Hence, the combination of these slits will give zero intensity.

14.Answer the following questions:

(a) When a low flying aircraft passes overhead, we sometimes notice

a slight shaking of the picture on our TV screen. Suggest a possible explanation.

(b) As you have learnt in the text, the principle of linear superposition of wave displacement is basic to understanding intensity distributions in diffraction and interference patterns. What is the justification of this principle?

Ans.(a) Weak radar signals sent by a low flying aircraft can interfere with the TV signals received by the antenna. As a result, the TV signals may get distorted. Hence, when a low flying aircraft passes overhead, we sometimes notice a slight shaking of the picture on our TV screen.

(b) The principle of linear superposition of wave displacement is essential to our understanding of intensity distributions and interference patterns. This is because superposition follows from the linear character of a differential equation that governs wave motion. If y_1 and y_2 are the solutions of the second order wave equation, then any linear combination of y_1 and y_2 will also be the solution of the wave equation.

3 Mark Questions

1. State Brewster law? Using this law prove that, at the polarizing angle of incidence, the reflected and transmitted rays are perpendicular to each other?

Ans. according to Brewster law the longest of the angle of polarization for transparent medium is equal to the refractive index of the medium.

$i.e\ \mu = \tan i_p$

Proof. Using Snell's law

$$\mu = \frac{\sin i}{\sin r}$$

$$When\ \mathrm{i} = \mathrm{i}_p \quad \mu = \frac{\sin i_p}{\sin r_p} \text{ ---------(1)}$$

$$Also = \tan i_p = \frac{\sin i_p}{\sin i_p} \text{ -------(2)}$$

$$from\ (1) \& (2)$$

$$\frac{\sin i_p}{\sin r_p} = \frac{\sin i_p}{\cos i_p}$$

$$\sin r_p = \cos i_p$$

$$\sin r_p = \sin(90^\circ - i_p)$$

$$\Rightarrow rp + \ i_p = 90^\circ$$

2. In a single slit experiment, how is the angular width of central bright fringe maximum changed when

1) The slit width increased

2) The distance between the slit and the screen is increased.

3) Light of smaller wavelength is used.

Ans. In single slit diffraction

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

(a) When slit width'd' is increased. β decreases

(b) When 'D' is increased, width of central bright fringe will become maximum i.e

increase.

(c) When light of smaller wavelength is used, the width of central bright maximum

decrease.

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3. In a young's double slit experiment, the slit are repeated at 0.24mm. The screen is 1.2m away from the slits. The fringe width is 0.3cm calculate the wavelength of light used in the experiment?

Ans. $\beta = 0.3cm = 3.0\times10^{-3}\,m$

$D = 1.2m$

$d = 0.24mm = 2.4\times10^{-4}\,m$

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

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

$$\lambda = \frac{3.0\times10^{-3}\times2.4\times10^{-4}}{1.2}$$

$$\lambda = 6.0\times10^{-7}\,m$$

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4. Two coherent sources whose intensity ratio is 81:1 produce interference fringes. Calculate the ratio of intensity of maxima and minima in the interference pattern?

Ans $\frac{I_1}{I_2} = \frac{81}{1}$

Intensity α (Amplitude)^2

$$\frac{a_1}{a_2} = \sqrt{\frac{81}{1}} = \frac{9}{1} = r$$

$$\frac{\mathrm{I_{max}}}{\mathrm{I_{min}}} = \frac{(r+1)^2}{(r-1)^2} = \left(\frac{9+1}{9-1}\right)^2 = \left(\frac{10}{8}\right)^2$$

$$\frac{\mathrm{I_{max}}}{\mathrm{I_{min}}} = \frac{100}{64}$$

$$\frac{\mathrm{I_{max}}}{\mathrm{I_{min}}} = \frac{25}{16}$$

$$I_{max} : I_{min} = 25:16$$

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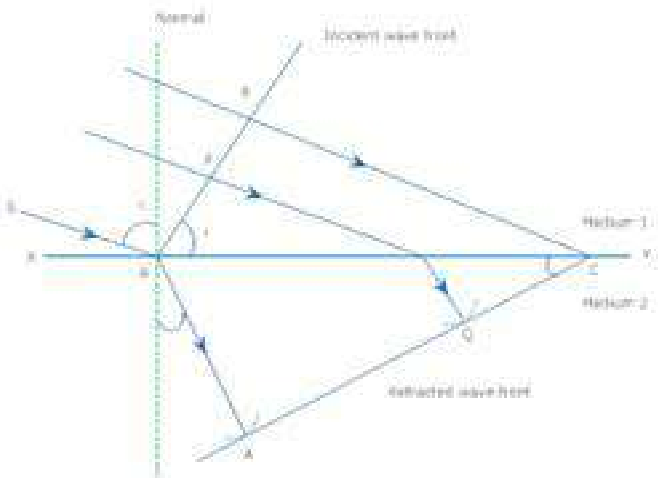
5. Using Huygens's principle deduce the laws of refraction?

Ans. According to Huygens's theory each point on AB given rise to new wave fronts give taken by the wavelets to reach from



$P \ to \ Q$

$t = \dfrac{PQ}{\vartheta^1} + \dfrac{OQ}{\vartheta^2}$ ------(1)

$In \ PAO$

$\sin i = \dfrac{PO}{AO}$

$PO = AO \sin i$

$\sin r = \dfrac{OQ}{OC}$

$OQ = OC \sin r$

Substituting in equation (1)

$$t = \frac{AO \sin i}{\upsilon_1} + \frac{(AC - AO)\sin r}{\upsilon_2}$$

$$t = AO\left(\frac{\sin i}{\upsilon_1} - \frac{\sin r}{\upsilon_2}\right) + \frac{AC \sin r}{\upsilon_2}$$

Since time is independent of equation

$\therefore$ Term containing AO must be zero.

$$i.e \frac{\sin i}{\upsilon_1} - \frac{\sin r}{\upsilon_2} = O \Rightarrow \frac{\sin i}{\upsilon_1} = \frac{\sin r}{\upsilon_2}$$

$$\frac{\sin i}{\sin r} = \frac{\upsilon_1}{\upsilon_2} = \mu\left(\because \mu = \frac{C}{\upsilon}\right)$$

Hence proved Snell's law

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6. A young's double slit experiment using light of wavelength 400 nm, interference fringes of width to 600nm, and the separation between the slits is halved. If one wants the observed fringe width on the screen to be the same in the two cases,find the ratio of the distance between the screen and the plane of the interfering

Ans. Let D_1 be the distance between the screen and the sources, when light of wavelength 400nm is used.

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

$$X = \frac{D_1 \times 400 \times 10^{-9}}{d}$$

In order to obtain the same fringe width

$$\frac{D_2 \times 600 \times 10^{-9}}{d} = \times \text{-------(2)}$$

From equation (1) and (2)

$$\frac{D_1}{D_2} = 1.5$$

$$\frac{D_1}{D_2} = \frac{600 \times 10^{-9}}{400 \times 10^{-9}}$$

sources in the two arrangements.

7. In young's double slit experiment while using a source of light of wavelength $5000 A^o$, the fringe width obtained is 0.6cm. If the distance between the slit and the screen is reduced to half, calculate the new fringe width?

Ans. $\lambda = 5000 A^o = 5\times 10^{-7} m$

$\beta = 0.6 cm = 0.6\times 10^{-2} m$

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

$$\frac{\beta}{\lambda} = \frac{D}{d} \Rightarrow \frac{D}{d} = \frac{0.6\times 10^{-2}}{5\times 10^{-7}}$$

$\frac{D}{d} = 1.2\times 10^{4}$ --------(1)

$\text{New Distance } D' = \frac{D}{d}$

New fringe width $\beta' = \frac{\lambda D'}{d} = \frac{\lambda D'}{2d}$

$$\beta' = \frac{5\times 10^{-7}\times 1.2\times 10^{4}}{2}$$

$\beta' = 3\times 10^{-3} m$

8. What is polarization of light? What type of waves show the property of polarization? Name any two methods to produce plane polarized light

Ans. The phenomenon of restricting the vibrations of a light vector in a particular direction in a plane perpendicular to the direction of propagation of light is called polarisation of light. Transverse waves show the property of polarisaiton.

Two methods to produce plane polarised light

(1)Polarisation by Reflection

(2) Polarization by scattering

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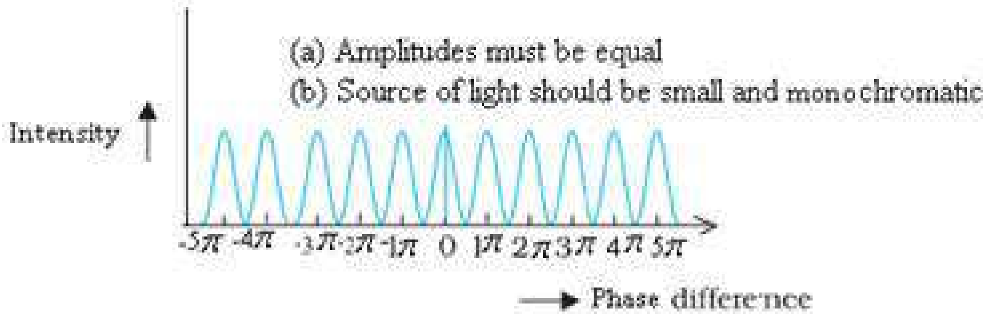
9. Draw the curve depicting, variation of intensity in the interference pattern in young's double slit experiment. State conditions for obtaining sustained interference of light?

Ans.



Conditions for sustained interference of light

(1) Two sources must be coherent sources of light.

(2)Two sources should exist light waves continuously. Intensity monochromatic

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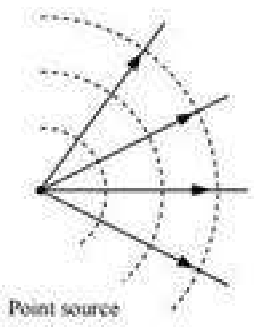
10. What is the shape of the wave front in each of the following cases:

(a) Light diverging from a point source.

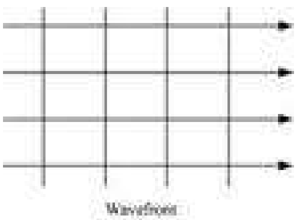
(b) Light emerging out of a convex lens when a point source is placed at its focus.

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

Ans. (a) The shape of the wave front in case of a light diverging from a point source is spherical. The wavefront emanating from a point source is shown in the given figure.



(b) The shape of the wavefront in case of a light emerging out of a convex lens when a point source is placed at its focus is a parallel grid. This is shown in the given figure.



(c) The portion of the wavefront of light from a distant star intercepted by the Earth is a plane.

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11. In a Young's double-slit experiment, the slits are separated by 0.28 mm and the screen is placed 1.4 m away. The distance between the central bright fringe and the fourth bright fringe is measured to be 1.2 cm. Determine the wavelength of light used in the experiment.

Ans. Distance between the slits, d = 0.28 mm = 0.28×10^{-3} m

Distance between the slits and the screen, D = 1.4 m

Distance between the central fringe and the fourth (n = 4) fringe,

u = 1.2 cm = 1.2×10^{-2} m

In case of a constructive interference, we have the relation for the distance between the two fringes as:

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

Where,

n = Order of fringes = 4

λ = Wavelength of light used

$$\therefore \lambda = \frac{ud}{nD}$$

$$= \frac{1.2 \times 10^{-2} \times 0.28 \times 10^{-3}}{4 \times 1.4}$$

$$= 6 \times 10^{-7}$$

$$= 600nm$$

Hence, the wavelength of the light is 600 nm.

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12. In a double-slit experiment the angular width of a fringe is found to be 0.2° on a screen placed 1 m away. The wavelength of light used is 600 nm. What will be the angular width of the fringe if the entire experimental apparatus is immersed in water? Take refractive index of water to be 4/3.

Ans. Distance of the screen from the slits, D = 1 m

Wavelength of light used, $\lambda_1 = 600nm$

Angular width of the fringe in $air, \theta_1 = 0.2^0$

Angular width of the fringe in water = θ_2

Refractive index of water, $\mu = \frac{4}{3}$

Refractive index is related to angular width as:

$$\mu = \frac{\theta_1}{\theta_2}$$

$$\theta_2 = \frac{3}{4}\theta_1$$

$$\frac{3}{4} \times 0.2 = 0.15$$

Therefore, the angular width of the fringe in water will reduce to $0.15°$.

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13. Light of wavelength 5000 $\overset{0}{A}$ falls on a plane reflecting surface. What are the wavelength and frequency of the reflected light? For what angle of incidence is the reflected ray normal to the incident ray?

Ans. Wavelength of incident light, λ = 5000 $\overset{0}{A}$ ¦ = 5000×10^{-10} m

Speed of light, $c = 3 \times 10^8\ m$

Frequency of incident light is given by the relation,

$$V = \frac{c}{\lambda}$$

$$= \frac{3 \times 10^8}{5000 \times 10^{-10}} = 6 \times 10^{14} Hz$$

The wavelength and frequency of incident light is the same as that of reflected ray. Hence, the wavelength of reflected light is 5000 $\overset{0}{A}$ ¦ and its frequency is $6 \times 10^{14}\ Hz$.

When reflected ray is normal to incident ray, the sum of the angle of incidence, $\angle i$ and angle of reflection, $\angle r$ is $90°$.

According to the law of reflection, the angle of incidence is always equal to the angle of reflection. Hence, we can write the sum as:

$$\angle i + \angle r = 90$$

$\angle i + \angle i = 90$

$$\angle i = \frac{90}{2} = 45^0$$

Therefore, the angle of incidence for the given condition is $45°$.

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14. The 6563 $\overset{0}{\mathrm{A}}$ H_0 line emitted by hydrogen in a star is found to be red shifted by 15 $\overset{0}{\mathrm{A}}$ ¦. Estimate the speed with which the star is receding from the Earth.

Ans. Wavelength of H_0 line emitted by hydrogen,

λ = 6563 $\overset{0}{\mathrm{A}}$ ¦

= $6563 \times 10^{-10}\ m$.

Star's red-shift, $\left(\lambda' - \lambda\right) = 15\overset{0}{A} = 15 \times 10^{-10}\, m$

Speed of light, $c = 3 \times 10^8\ m/s$

Let the velocity of the star receding away from the Earth be *v*.

The red shift is related with velocity as:

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

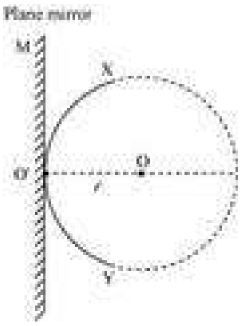
$$v = \frac{c}{\lambda} \times \left(\lambda' - \lambda\right)$$

$$= \frac{3 \times 10^8 \times 15 \times 10^{-10}}{6563 \times 10^{-10}} = 6.87 \times 10^5\ m/s$$

Therefore, the speed with which the star is receding away from the Earth is $6.87 \times 10^5\ m/s$.

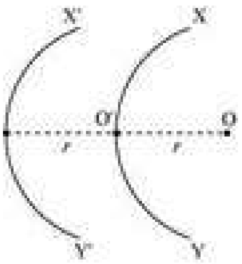
15. You have learnt in the text how Huygens' principle leads to the laws of reflection and refraction. Use the same principle to deduce directly that a point object placed in front of a plane mirror produces a virtual image whose distance from the mirror is equal to the object distance from the mirror.

Ans. Let an object at O be placed in front of a plane mirror MO' at a distance *r* (as shown in the given figure).



A circle is drawn from the centre (O) such that it just touches the plane mirror at point O'. According to Huygens' Principle, XY is the wavefront of incident light.

If the mirror is absent, then a similar wavefront X'Y' (as XY) would form behind O' at distance *r* (as shown in the given figure).



$X'Y'$ can be considered as a virtual reflected ray for the plane mirror. Hence, a point object placed in front of the plane mirror produces a virtual image whose distance from the mirror is equal to the object distance (*r*).

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

Ans. Wavelength of light beam, λ = 500 nm = $500 \times 10^{-9}\ m$ Distance of the screen from the slit, D = 1 m

For first minima, n = 1

Distance between the slits = d

Distance of the first minimum from the centre of the screen can be obtained as:

x = 2.5 mm = $2.5 \times 10^{-3}\ m$

It is related to the order of minima as:

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

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

$$\frac{1 \times 500 \times 10^{-9} \times 1}{2.5 \times 10^{-3}} = 2 \times 10^{-4}\ m = 0.2mm$$

Therefore, the width of the slits is 0.2 mm.

5 Mark Questions

1.(a) State Huygens's principle for constructing wavefronts?

(b) Using Huygens's principle deduce the laws of reflection of light?

(c) What changes in diffraction pattern of a single slit will you observe. when the monochromatic source of light is replaced by a source of white light?

Ans.(a) According to Huygens's principle

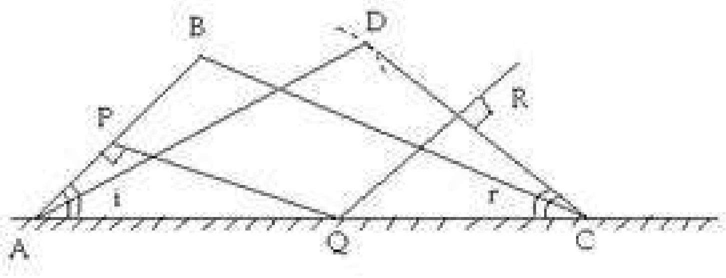
(1) Each source of light spreads waves in all directions.

(2) Each point on the wavefront give rise to new disturbance which produces secondary wavelets which travels with the speed of light.

(3) Only forward envelope which encloses the tangent gives the new position of wavefront.

(4) Rays are always perpendicular is the wavefront.

(b) A plane wave front AB incident at A hence every point on AB give rise to new waves. Time taken by the ray to reach from P to R



$$t = \frac{PQ}{v} + \frac{QR}{v} ------(1)$$

$$In\ \Delta PAQ \sin i = \frac{PQ}{AQ}$$

$$PQ = AQ \sin i$$

$$In\ \Delta RCQ \sin r = \frac{QR}{QC}$$

$$QR = QC \sin r$$

Substituting in equation (1)

$$t = \frac{AQ \sin i}{v} + \frac{QC \sin r}{v}$$

$$t = \frac{AQ \sin i}{v} + \frac{(AC - AQ)\sin r}{v}$$

$$t = \frac{AQ \sin i}{v} + \frac{QC \sin r}{v} - \frac{AQ \sin r}{v}$$

$$\frac{AQ(\sin i - \sin r)}{v} + \frac{AC \sin r}{v}$$

Since all the secondary wavelets takes the same time to go form the incident wavefront to the reflected wavefront so it must be independent of Q

i.e sin i– sin r = O

sin i = sin r

or i = r $\rightarrow$ law of Reflection of light

(c) (1) The diffracted light consists of different colours.

(2) It results in overlapping of different colours.

2.(a) Coloured spectrum is seen, when we look through a muslin cloth. Why?

(b) What changes in diffraction pattern of a single slit will you observe. when the monochromatic source of light is replaced by a source of white light?

Ans. (a) Muslin cloth consist of very fine threads which acts as fine slits and when light pass through it, light gets diffracted giving rise to a coloured spectrum.

(b) (i) Diffracted lights consist of different colours.

(ii) It results in overlapping of different colours.

3.A slit of width 'a' is illuminated by light of wavelength $6000\ A^o$. For what value of 'a' will the :-

(i) First maximum fall at an angle of diffraction of 30^o ?

(ii) First minimum fall at an angle of diffraction 30^o ?

Ans. $\lambda = 6000A^o = 6000\times10^{-10}\text{m}$

$\theta\ 1=30^\circ,\ \text{m}=1$

(1) For first maximum

$$\sin Q_m = \frac{\left(m+\frac{1}{2}\right)\lambda}{a}$$

$$\sin Q_1 = \frac{3\lambda}{2a}$$

$$or\ \text{a} = \frac{3\lambda}{2\sin\theta_1} = \frac{3\times6\times10^{-7}}{2\times\sin30^o}$$

(2) For first minimum

$$\sin Q_m = \frac{m\lambda}{a}$$

$$or \sin Q_1 = \frac{\lambda}{a}$$

$$a = \frac{\lambda}{\sin \theta_1}$$

$$a = \frac{6 \times 10^{-7}}{\sin 30^{\circ}}$$

$$A = 1.2 \times 10^{-6} m$$

4.(a) Derive all expression for the fringe width in young's double slit experiment?

(b) If the two slits in young's double slit experiment have width ratio 4:1, deduce the ratio of intensity of maxima and minima in the interference pattern?

Ans. Path difference between

$$S_1P \text{ and } S_2P$$

$$\Delta x = S_2P - S_1P$$ --------(A)

$$In\ \Delta S_2BP$$

$$(S_2P) = \left[(S^2B)^2 + (PB^2)\right]^{\frac{1}{2}}$$

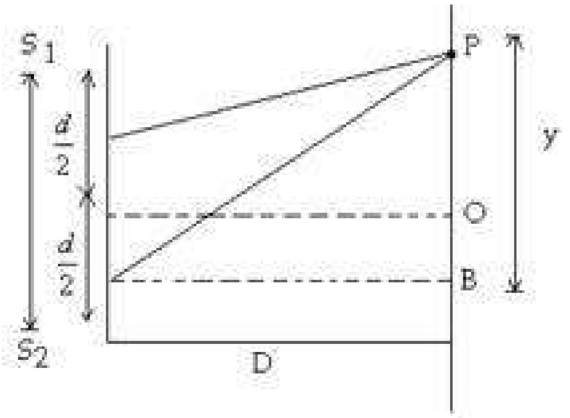
$$S_2P = D\left[1 + \frac{\left(y + \frac{d}{2}\right)}{D^2}\right]^{\frac{1}{2}}$$ -------(1)

Using Binomial theorem expand equation. (1) and neglect higher terms

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

Similarity $S_1P = D + \frac{\left(y - \frac{d}{2}\right)^2}{2D}$ ------(2)

Substituting equation (1) & (2) in equation (A)



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

$$\Delta x = \frac{y^2 + \frac{d^2}{4} + yd - y^2 - \frac{d^2}{4} + yd}{2D}$$

$$\Delta x = \frac{2yd}{2D}$$

$$\Delta x = \frac{yd}{D}$$

For bright fringes

Path difference = $x\lambda$

$$x\lambda = \frac{yd}{D}$$

$$i.e\ y = \frac{x\lambda D}{d}$$

form $=1 \quad y_1 = \frac{\lambda D}{d}$

$n = 2 \quad y_2 = \frac{\lambda D}{d}$

For fringe width

$$\beta = y_2 - y_1$$

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

(b) $\frac{a_1^2}{a_2^2} = \frac{w_1}{w_2} = \frac{4}{1}$

$$\frac{a_1}{a_2} = \frac{2}{1}$$

$$or\ a_1 = 2a_2$$

Using $\frac{I_{max}}{I_{min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2}$

$$\frac{I_{max}}{I_{min}} = \frac{(2a_1 + a_2)^2}{(2a_1 - a_2)^2} = \left(\frac{3a_2}{a_2}\right)^2$$

$$\frac{I_{max}}{I_{min}} = \frac{9}{1}$$

5.Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are the wavelength, frequency and speed of (a) reflected, and (b) refracted light? Refractive index of water is 1.33.

Ans. Wavelength of incident monochromatic light,

λ = 589 nm = $589 \times 10^{-9}\ m$

Speed of light in air, c = 3 × 108 m/s

Refractive index of water, μ = 1.33

(a) The ray will reflect back in the same medium as that of incident ray. Hence, the wavelength, speed, and frequency of the reflected ray will be the same as that of the incident ray.

Frequency of light is given by the relation,

$$V = \frac{c}{\lambda}$$

$$= \frac{3\times10^{8}}{5000\times10^{-10}} = 6\times10^{14}\,Hz$$

$$\angle i + \angle r = 90^{0}$$

$$\angle i + \angle i = 90^{0}$$

$$Z_F = \frac{\left(4\times10^{-3}\right)^2}{400\times10^{-9}} = 40m$$

$$\left(\lambda' - \lambda\right) = 15\overset{0}{A} = 15\times10^{-10}\,m$$

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

$$v = \frac{c}{\lambda}\times\left(\lambda' - \lambda\right)$$

$$\frac{v}{c}=\frac{\sin i}{\sin r}=\mu$$

$$\theta = 0.1^0 = 0.1\times\frac{\lambda}{180}=\frac{3.14}{1800}rad$$

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

$$=\frac{600\times10^{-9}}{\frac{3.14}{1800}}=3.44\times10^{-4}m$$

$$\therefore \lambda=\frac{a^2}{Z_P}$$

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

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

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

$$=\frac{3\times10^8}{589\times10^{-9}}$$

$$=5.09\times10^{14}Hz$$

Hence, the speed, frequency, and wavelength of the reflected light are 3×10^8 m/s, 5.09×10^{14} Hz, and 589 nm respectively.

(b) Frequency of light does not depend on the property of the medium in which it is travelling. Hence, the frequency of the refracted ray in water will be equal to the frequency of the incident or reflected light in air.

$\therefore$ Refracted frequency, $\nu = 5.09 \times 10^{14}$ Hz

Speed of light in water is related to the refractive index of water as:

$$V = \frac{c}{\mu}$$

$$V = \frac{3\times10^8}{1.33} = 2.26\times10^8\, m/s$$

Wavelength of light in water is given by the relation,

$$\lambda = \frac{V}{\nu}$$

$$= \frac{2.26\times10^8}{5.09\times10^{14}}$$

$$= 444.007\times10^{-9}\, m$$

$$= 444.01 nm$$

Hence, the speed, frequency, and wavelength of refracted light are $2.26 \times 10^8\ m/s$, $444.01 nm,\ and\ 5.09 \times 10^{14}\ Hz$ respectively.

6.In Young's double-slit experiment using monochromatic light of wavelength λ , the intensity of light at a point on the screen where path difference is λ , is *K* units. What is the intensity of light at a point where path difference is λ /3?

Ans. Let $I_1\ and\ I_2$ be the intensity of the two light waves. Their resultant intensities can be obtained as:

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

Where,

ϕ = Phase difference between the two waves

For monochromatic light waves,

$$I_1 = I_2$$

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

$$= 2I_1 + 2I_1\cos\phi$$

Phase difference = $\frac{2\pi}{\lambda} \times path\ difference$

Since path difference = λ ,

Phase difference, $\phi = 2\pi$

$$\therefore I' = 2I_1 + 2I_1 = 4I_1$$

Given,

I' = *K*

$$\therefore I' = \frac{K}{4} \quad ...(1)$$

When path difference $= \frac{\lambda}{3}$,

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

Hence, resultant intensity, $I_R' = I_1 + I_1 + 2\sqrt{I_1 I_1}\cos\frac{2\pi}{3}$

$$= 2I_1 + 2I_1\left(-\frac{1}{2}\right) = I_1$$

Using equation (1), we can write:

$$I_R = I_1 = \frac{K}{4}$$

Hence, the intensity of light at a point where the path difference is $\frac{\lambda}{3}$ is $\frac{K}{4}$ units.

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7. A beam of light consisting of two wavelengths, 650 nm and 520 nm, is used to obtain interference fringes in a Young's double-slit experiment.

(a) Find the distance of the third bright fringe on the screen from the central maximum for wavelength 650 nm.

(b) What is the least distance from the central maximum where the bright fringes due to both the wavelengths coincide? $\lambda_1 = 600nm$

Ans. Wavelength of the light beam, $\therefore x = 3 \times 650 \frac{D}{d} = 1950\left(\frac{D}{d}\right)nm$

$$n\lambda_2 = (n-1)\lambda_1$$

$$\lambda_1 = 650nm$$

$$\therefore n = 5$$

Wavelength of another light beam, $\lambda_2 = 520nm$

Distance of the slits from the screen = D

Distance between the two slits = d

(a) Distance of the nth bright fringe on the screen from the central maximum is given by the relation,

$$x = n\lambda_1\left(\frac{D}{d}\right)$$

For third bright fringe. N=3

$$\therefore x = 3 \times 650 \frac{D}{d} = 1950\left(\frac{D}{d}\right) nm$$

(b) Let the *n*th bright fringe due to wavelength λ_2 and (*n* - 1)th bright fringe due to wavelength λ_1 coincide on the screen. We can equate the conditions for bright fringes as:

$$n\lambda_2 = (n-1)\lambda 1$$

520n=650n-650

650=130n

$$\therefore n = 5$$

Hence, the least distance from the central maximum can be obtained by the relation:

$$x = \lambda_2 \frac{D}{d}$$

$$= 5 \times 520 \frac{D}{d} = 260 \frac{D}{d} nm$$

Note: The value of *d* and *D* are not given in the question.

8.Explain how Corpuscular theory predicts the speed of light in a medium, say, water, to be greater than the speed of light in vacuum. Is the prediction confirmed by experimental determination of the speed of light in water? If not, which alternative picture of light is consistent with experiment?

Ans. No; Wave theory

Newton's corpuscular theory of light states that when light corpuscles strike the interface of two media from a rarer (air) to a denser (water) medium, the particles experience forces of attraction normal to the surface. Hence, the normal component of velocity increases while the component along the surface remains unchanged.

Hence, we can write the expression:

C sin i=v sin r

C sin i=v sin r

Where,

i = Angle of incidence

r = Angle of reflection

c = Velocity of light in air

v = Velocity of light in water

We have the relation for relative refractive index of water with respect to air as:

$$\mu = \frac{v}{c}$$

Hence, equation (i) reduces to

$$\frac{v}{c} = \frac{\sin i}{\sin r} = \mu$$

But, $\mu > 1$

Hence, it can be inferred from equation (ii) that $v > c$. This is not possible since this prediction is opposite to the experimental results of $c > v$.

The wave picture of light is consistent with the experimental results.

9.Answer the following questions: (a) 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?

(b) In what way is diffraction from each slit related to the interference pattern in a double-slit experiment?

(c) When a tiny circular obstacle is placed in the path of light from a distant source, a

bright spot is seen at the centre of the shadow of the obstacle. Explain why?

(d) Two students are separated by a 7 m partition wall in a room 10 m high. If both light and sound waves can bend around obstacles, how is it that the students are unable to see each other even though they can converse easily.

(e) Ray optics is based on the assumption that light travels in a straight line. Diffraction effects (observed when light propagates through small apertures/slits or around small obstacles) disprove this assumption. Yet the ray optics assumption is so commonly used in understanding location and several other properties of images in optical instruments. What is the justification?

Ans.(a) In a single slit diffraction experiment, if the width of the slit is made double the original width, then the size of the central diffraction band reduces to half and the intensity of the central diffraction band increases up to four times.

(b) The interference pattern in a double-slit experiment is modulated by diffraction from each slit. The pattern is the result of the interference of the diffracted wave from each slit.

(c) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the shadow of the obstacle. This is because light waves are diffracted from the edge of the circular obstacle, which interferes constructively at the centre of the shadow. This constructive interference produces a bright spot.

(d) Bending of waves by obstacles by a large angle is possible when the size of the obstacle is comparable to the wavelength of the waves.

On the one hand, the wavelength of the light waves is too small in comparison to the size of the obstacle. Thus, the diffraction angle will be very small. Hence, the students are unable to see each other. On the other hand, the size of the wall is comparable to the wavelength of the sound waves. Thus, the bending of the waves takes place at a large angle. Hence, the students are able to hear each other.

(e) The justification is that in ordinary optical instruments, the size of the aperture involved is much larger than the wavelength of the light used.

10.Two towers on top of two hills are 40 km apart. The line joining them passes 50 m above a hill halfway between the towers. What is the longest wavelength of radio waves, which can be sent between the towers without appreciable diffraction effects?

Ans. Distance between the towers, *d* = 40 km

Height of the line joining the hills, *d* = 50 m.

Thus, the radial spread of the radio waves should not exceed 50 km.

Since the hill is located halfway between the towers, Fresnel's distance can be obtained as:

Z_P = 20 km = 2×10^4 m

Aperture can be taken as:

a = *d* = 50 m

Fresnel's distance is given by the relation,

$$Z_P = \frac{a^2}{\lambda}$$

Where,

λ = Wavelength of radio waves

$$\therefore \lambda = \frac{a^2}{Z_P}$$

$$= \frac{(50)^2}{2 \times 10^4} = 1250 \times 10^{-4} = .1250m = 12.5cm$$

Therefore, the wavelength of the radio waves is 12.5 cm.