Question 10.1:

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.]

Answer

Wavelength of incident monochromatic light,

$\lambda = 589\text{ nm} = 589 \times 10^{-9}\text{ m}$

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

Refractive index of water, $\mu = 1.33$

(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,

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

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

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

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:

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

$$v = \frac{3\times10^{8}}{1.33} = 2.26\times10^{8}\text{ m/s}$$

Wavelength of light in water is given by the relation,

$$\lambda = \frac{v}{\nu}$$
$$= \frac{2.26\times10^{8}}{5.09\times10^{14}}$$
$$= 444.007\times10^{-9}\,\text{m}$$
$$= 444.01\ \text{nm}$$

Hence, the speed, frequency, and wavelength of refracted light are 2.26 $\times10^{8}$ m/s, 444.01nm, and 5.09 $\times$ 10^{14} Hz respectively.

Question 10.2:

What is the shape of the wavefront in each of the following cases:

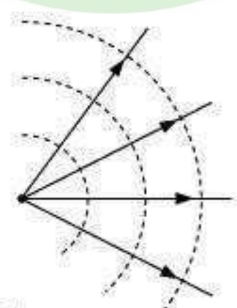
(a) Light diverging from a point source.

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

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

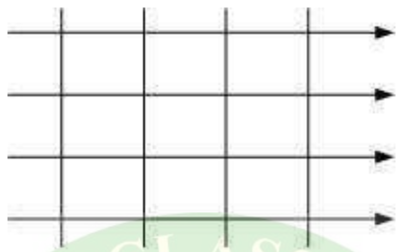
Answer

(a) The shape of the wavefront 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.



Point source

(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.

Question 10.3:

(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?

Answer

(a) Refractive index of glass, $\mu = 1.5$

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

Speed of light in glass is given by the relation,

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

$$= \frac{3\times10^8}{1.5} = 2\times10^8 \text{ m/s}$$

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.

Question 10.4:

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.

Answer

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

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

$$= \frac{1.2\times10^{-2}\times0.28\times10^{-3}}{4\times1.4}$$

$$= 6\times10^{-7}$$

$$= 600 \text{ nm}$$

Hence, the wavelength of the light is 600 nm.

Question 10.5:

In Young's double-slit experiment using monochromatic light of wavelengthλ, 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?

Answer

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,

$$I_1 = I_2$$

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

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

Since path difference = λ,

Phase difference, $\phi = 2\pi$

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

Given,

I' = K

$$\therefore I_1 = \frac{K}{4} \quad \text{... (1)}$$

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.

Question 10.6:

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? Answer

Wavelength of the light beam, $\lambda_1 = 650 \text{ nm}$

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

Distance of the slits from the screen = D

Distance between the two slits = d

(a) Distance of the n^{th} 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, $n = 3$

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

(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:

$$x = n\lambda_2 \frac{D}{d}$$
$$= 5 \times 520 \frac{D}{d} = 2600 \frac{D}{d} \text{ nm}$$

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

Question 10.7:

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.

Answer

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

Wavelength of light used, $\lambda_1 = 600 \text{ nm}$

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

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°.

uestion 10.8:

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

Answer

Refractive index of glass, $\mu = 1.5$

Brewster angle = θ

Brewster angle is related to refractive index as:

$$\tan\theta = \mu$$

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

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

Question 10.9:

Light of wavelength 5000 Å 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?

Answer

Wavelength of incident light, λ = 5000 Å = 5000 × 10^{-10} m

Speed of light, c = 3 × 10^{8} m

Frequency of incident light is given by the relation,

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

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

The wavelength and frequency of incident light is the same as that of reflected ray. Hence, the wavelength of reflected light is 5000 Å and its frequency is 6×10^{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:

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

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

$$\angle i = \frac{90}{2} = 45°$$

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

Question 10.10:

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

Answer

Fresnel's distance (Z_F) 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 = 4×10^{-3} m

Wavelength of light, λ = 400 nm = 400×10^{-9} m

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

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