

Q10.1 (a) Monochromatic light of wavelength 589 nm is incident from air on a water surface.

What are the wavelength, frequency and speed of (a) reflected. Refractive index of water is 1.33.

Answer:

Given a monochromatic light has a wavelength of  $589\text{nm}$  or  $589 \times 10^{-9}\text{m}$  .

And as we know the speed of the light in air is,  $c = 3 \times 10^8\text{m/s}$  .

Refractive index of water,  $\mu = 1.33$

Therefore we have now,

The ray is incident on the medium, and then it gets reflected back to the same medium therefore, the wavelength, speed, and frequency will be the same as that of the incident ray.

We have the frequency of light is given by the relation,

$$\begin{aligned}v &= \frac{c}{\lambda} \\&= \frac{3 \times 10^8\text{m/s}}{589 \times 10^{-9}} \\&= 5.09 \times 10^{14}\text{Hertz} = 5.09 \times 10^{14}\text{Hertz}\end{aligned}$$

Therefore the speed, frequency, and the wavelength of the reflected light are  $3 \times 10^8\text{m/s}$  ,  $5.09 \times 10^{14}\text{Hertz}$  , and  $589\text{nm}$  respectively.

Q10.1 (b) Monochromatic light of wavelength 589 nm is incident from air on a water surface.

What are the wavelength, frequency and speed of (b) refracted light? Refractive index of water is 1.33.

Answer:

Given,

The wavelength of the monochromatic light  $\lambda = 589\text{nm} = 589 * 10^{-9}\text{m}$

Refractive index of the water  $\mu_{\text{water}} = 1.33$

b) In the case of refraction, speed and wavelength will change as the medium is changing however, the frequency will remain the same because it doesn't change when the medium is changed,

so, frequency  $f = 5.09 * 10^{14}\text{Hz}$

Speed of rays: speed of rays in water with refractive index 1.33 is

$$v = \frac{c}{\mu_{\text{water}}} = \frac{3 * 10^8}{1.33} = 2.26 * 10^8 \text{m/s}$$

Now, the Wavelength of light

$$\lambda = \frac{v}{f} = \frac{2.26 * 10^8}{5.09 * 10^{14}} = 444.01 * 10^{-9}\text{m}$$

Hence the wavelength of light is 444.01nm, frequency is  $5.09 * 10^{14}\text{Hz}$  and speed is  $2.26 * 10^8\text{m/s}$ .

Q10.2 (a) What is the shape of the wavefront in each of the following cases:

(a) Light diverging from a point source.

Answer:

The shape of wavefront when light is diverging from a point source is Spherical since light travels in all direction.

Q10.2 (b) What is the shape of the wavefront in each of the following cases:

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

Answer:

The shape of light emerging out of a convex lens when a point source is placed at its focus is Parallel .when light rays come from infinity parallelly, they intersect at focus of convex lens and hence when light is emerging from the focus, the rays will get parallel to each other after coming out of the convex lens, because path of light rays are reversible.

Q10.2 (c) What is the shape of the wavefront in each of the following cases:

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

Answer:

The portion of the wavefront of the light from the distant star which is seen from earth is plane since a small area of a large sphere will nearly look like a plane.

Q10.3 (a) The refractive index of glass is 1.5. What is the speed of light in glass? (Speed of light in vacuum is  $3.0 \times 10^8 \text{ m s}^{-1}$ )

Answer:

Given,

Refractive index of the glass  $\mu_{\text{glass}} = 1.5$

Speed of light in vacuum  $c = 3 * 10^8 \text{ m/s}$

Now,

As we know,

Refractive index of a medium

$$\mu_{\text{medium}} = \frac{c}{v_{\text{medium}}} \text{ where } v_{\text{medium}} \text{ is the speed of light in that medium.}$$

so from here,

$$v_{\text{glass}} = \frac{c}{\mu_{\text{glass}}} = \frac{3 * 10^8}{1.5} = 2 * 10^8 \text{ m/s}$$

Hence the speed of light in water is  $2 * 10^8 \text{ m/s}$

Q10.3 (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:

No, the speed of light in glass is not independent of the colour. The colour of the light does influence the refractive index and speed of light in the medium. The refractive index of the violet light is greater than the refractive index of red light and hence red component of the white light travels faster in the glass than the red component of the light.

as

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

the more the refractive index, the lesser the speed.

Q10.4 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:

Given,

Distance between screen and slit  $D = 1.4m$

Distance between slits  $d = 0.28mm = 0.28 * 10^{-3}m$

Distance between central and fourth bright fringe  $u = 1.2cm = 1.2 * 10^{-2}m$

Now,

as we know, the distance between two fringes in a constructive interference is given by

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

where  $n$  = order of fringe (which is 4 here) and  $\lambda$  is the wavelength of light we are using.

so from here,

$$\lambda = \frac{ud}{nD} = \frac{1.2 * 10^{-2} * 0.28 * 10^{-3}}{4 * 1.4} = 6 * 10^{-7}m$$

Hence wavelength of the light is 600nm

Q10.5 In Young's double-slit experiment using monochromatic light of wavelength  $\lambda$ , the intensity of light at a point on the screen where path difference is  $\lambda$ , is K units. What is the intensity of light at a point where path difference is  $\frac{\lambda}{3}$  ?

Answer:

Given, in youngs double-slit experiment.

the wavelength of monochromatic light =  $\lambda$

The intensity of light when the path difference is  $\lambda = K$

Now,

As we know,

The phase difference  $\phi$  is given by

$$\phi = \frac{2\pi}{\lambda} (\text{Path Difference})$$

also

Total Intensity

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

$$\text{Let } I_1 = I_2 = I_0$$

Now, when path difference is  $\lambda$

the phase difference angle

$$\phi = \frac{2\pi}{\lambda} * \lambda = 2\pi$$

so,

$$I_0 + I_0 + 2\sqrt{I_0 I_0} \cos 2\pi = K$$

$$K = 4I_0$$

Now, when path difference is  $\frac{\lambda}{3}$

$$\phi = \frac{2\pi}{\lambda} * \frac{\lambda}{3} = \frac{2\pi}{3}$$

Intensity of light

$$K' = I_0 + I_0 + 2\sqrt{I_0 I_0} \cos \frac{2\pi}{3}$$

$$K' = I_0$$

Now comparing intensity at both cases

$$\frac{K'}{K} = \frac{I_0}{4I_0} = \frac{1}{4}$$

$$K' = \frac{K}{4}$$

Hence intensity will reduce to one-fourth of initial when path difference changes from  $\lambda$  to  $\frac{\lambda}{3}$ .

Q10.6 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.

Answer:

Given,

The wavelength of one light beam :

$$\lambda_1 = 650 \text{ nm} = 650 * 10^{-9} \text{ m}$$

The wavelength of another Light beam

$$\lambda_2 = 520\text{nm} = 520 * 10^{-9}\text{m}$$

Let, the distance between the two-slit be  $d$  and distance between slit and screen is  $D$

Now,

As we know, the distance  $x$  of  $n$ th bright fringe from central maxima is given by

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

so for 3rd fringe,

$$n = 3$$

$$x = n\lambda_1 \frac{D}{d} = 3 * 650 * 10^{-9} * \frac{D}{d} = 1950 \frac{D}{d} \text{nm}$$

Hence distance of 3rd fringe from central maxima is  $1950 \frac{D}{d} \text{nm}$ . Here value  $D$  and  $d$  are not given in the question.

Q10.6 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.

(b) What is the least distance from the central maximum where the bright fringes due to both the wavelengths coincide?

Answer:

Let the  $n$ th bright fringe due to wavelength,  $\lambda_2$  and  $(n - 1)$ <sup>th</sup> bright fringe due to wavelength  $\lambda_1$  coincide on the screen. We can equate the conditions for bright fringes as:



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

$$520n = 650n - 650$$

$$650 = 130n$$

$$n = 5$$

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

$$X = n \frac{\lambda_2 D}{d} = 5 * \frac{520 * 10^{-9} * D}{d}$$

Hence we can find out X if D and d are given.

Q10.7 In a double-slit experiment the angular width of a fringe is found to be  $0.2^\circ$  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:

Given

The angular width of the fringe when the medium is air

$$\theta_{air} = 0.2^\circ$$

The distance of the screen from the slit  $D = 1m$

The wavelength of light we are using  $\lambda = 600nm = 600 * 10^{-9}m$

Refractive index of water  $\mu_{water} = 4/3$

let angular width of fringe when the medium is water  $\theta_{water}$

Now, as we know the angular width is given by

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

so,

$$d = \frac{\lambda_{air}}{\theta_{air}} = \frac{\lambda_{water}}{\theta_{water}}$$

$$d = \frac{\lambda_{air}}{\lambda_{water}} = \frac{\theta_{air}}{\theta_{water}} = \mu$$

From here

$$\theta_{water} = \frac{\theta_{air}}{\mu_{water}} = \frac{3}{4} 0.2^{\circ} = 0.15^{\circ}$$

Hence angular width of the fringe in the water is  $0.15^{\circ}$ .

Q10.8 What is the Brewster angle for air to glass transition? (Refractive index of glass = 1.5.)

Answer:

Given,

Refractive index of glass  $\mu_{glass} = 1.5$

Now as we know,

$$\tan\theta = \mu$$

where  $\theta$  is the polarizing angle, also called the Brewster angle, and  $\mu$  is the refractive index.

so from here

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

Hence Brewster angle is  $56.31^\circ$ .

Q10.9 Light of wavelength  $5000 \text{ \AA}$  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:

Given,

$$\text{Wavelength of light } \lambda = 5000 \text{ \AA} = 5000 * 10^{-10} \text{ m}$$

$$\text{Speed of light } c = 3 * 10^8$$

Now,

Wavelength and frequency will be the same when the ray is reflected.

Frequency of reflected light

$$f = \frac{c}{\lambda} = \frac{3 * 10^8}{5000 * 10^{-10}} = 6 * 10^{14} \text{ Hz}$$

Hence wavelength and frequency of light is  $5000 * 10^{-10} \text{ m}$  and  $6 * 10^{14} \text{ Hz}$  respectively.

Now,

as per the law of reflection, angle of incidence  $i$  is always equal to angle of reflection  $r$ .

$$i = r$$

Now, when the reflected ray is perpendicular with incidence ray,

$$i + r = 90$$

$$i + i = 90$$

$$2i = 90$$

$$i = 45$$

Hence the angle of incidence is 45 for this condition.

Q10.10 Estimate the distance for which ray optics is good approximation for an aperture of 4 mm and wavelength 400 nm.

Answer:

Given

$$\text{Aperture } a = 4\text{mm} = 4 * 10^{-3}\text{m}$$

$$\text{Wavelength of light } \lambda = 400\text{nm} = 400 * 10^{-9}\text{m}$$

Now,

Distance for which ray optics is a good approximation also called Fresnel's distance:

$$Z_f = \frac{a^2}{\lambda} = \frac{(4 * 10^{-3})^2}{400 * 10^{-9}} = 40\text{m}$$

Hence distance for which ray optics is a good approximation is 40m.

NCERT solutions for class 12 physics chapter 10 wave optics additional exercises:

Q10.11 The 6563 Å H $\alpha$  line emitted by hydrogen in a star is found to be red-shifted by 15 Å.

Estimate the speed with which the star is receding from the Earth.

Answer:

Given,

wavelength H $\alpha$  line emitted by hydrogen:

$$\lambda = 6563 * 10^{-10}m$$

star is red-shifted by

$$\lambda' - \lambda = 15 * 10^{-10}m$$

let velocity of the star be  $v$

Now,

as we know,

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

from here

$$\lambda' - \lambda \frac{1}{c * \lambda} = v$$

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

Hence speed at which star is receding away is  $6.87 * 10^5 m/s$

Q10.12 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?

Answer:

According to corpuscular theory, when corpuscle of the light goes from rare medium to denser medium, the component of their velocity along the surface of the interface remains the same.

So we can write

$$v_1 \sin i = v_2 \sin r$$

$$\frac{v_2}{v_1} = \frac{\sin i}{\sin r} = \mu$$

As  $\mu > 1$ ,

$$v_2 > v_1$$

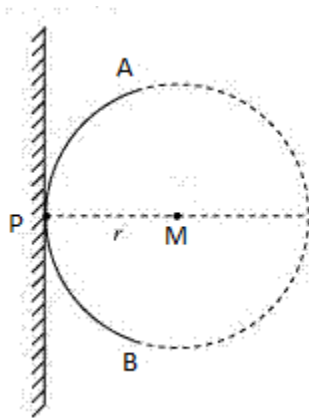
That is light should be faster in the dense medium than in rare medium. This is the opposite of what we see experimentally.

Huygens wave theory predicts that light is faster in a rare medium which matches with our experiments observation.

Q10.13 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.

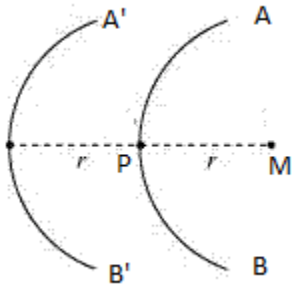
Answer:

Let an object M is placed in front of a plane mirror AB at a distance  $r$ .



A circle is drawn from the centre, such that it just touches the plane mirror at point P. according to the Huygens' principle, AB is the wavefront of the incident light .

If the mirror is absent then a similar wavefront A'B' would form behind M at a distance  $r$ .



A'B' can be considered as a virtual reflected ray for the plane mirror. Hence a point object placed in front of the plane mirror produces an image at the same distance as the object.

Q10.14 (a) 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) wavelength.

(v) intensity of the wave.

On which of these factors, if any, does

(a) the speed of light in vacuum depend?

Answer:

The speed of light in a vacuum is constant and independent of anything according to Einstein's theory of relativity.

Wave Optics Exercise: Additional Exercises



Question:

Q10.14 (b) 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) wavelength.

(v) intensity of the wave.

On which of these factors, if any, does

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

Answer:

The speed of light in any medium depends upon the wavelength of the light and does not depend on the nature of the source, direction of propagation, the motion of the source and/or observer, and intensity of the wave.

Q10.15 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?

Answer:

The sound wave requires a medium for propagation. so, even though both given situation may relate to the same relative motion, they are not identical physically since, the motion of the observer, relative to the medium is different in two situations. Hence, we cannot expect the Doppler formula to be identical in both given cases.

When light waves are in a vacuum, there is clearly nothing to distinguish between two cases.

for light propagation in a medium, two situations are not identical for the same reason as in the case of sound waves.

Q10.16 In double-slit experiment using light of wavelength 600 nm, the angular width of a fringe formed on a distant screen is  $0.1^\circ$ . What is the spacing between the two slits?

Answer:

Given,

Wavelength of light  $\lambda = 600\text{nm}$

Angular fringe width

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

$$d = \frac{\lambda}{B_\theta} = \frac{600 * 10^{-9} * 180}{0.1 * \pi} = 3.44 * 10^{-4}m$$

Hence spacing required between the two slits is  $3.44 * 10^{-4}m$  .

Q10.17 (a) Answer the following questions:

In a single slit diffraction experiment, the width of the slit is made double the original width.

How does this affect the size and intensity of the central diffraction band?

Answer:

As we know,

width of the central diffraction band is given by

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

where  $d$  is the width of the slit.

So when we double the width of the slit, the size of the central diffraction band reduces to half of its value. But, the light amplitude becomes double, which increase the intensity 4 times.

10.17 (b) Answer the following questions:

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

Answer:

When we have a width in the order of  $\lambda$ , the intensity of interference fringes in Young's double-slit experiment is modified by the diffraction pattern of each slit.

Q10.17 (c) Answer the following questions:

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?

Answer:

A bright spot is seen at the centre of the shadow of the obstacle because wave diffracted from the edge of a circular obstacle interfere constructively at the centre of the shadow producing the bright spot.

Q10.17 (d) Answer the following questions:

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.

Answer:

The size of obstacle should be comparable to the wavelength for diffraction of waves by obstacles, through a large scale.

This comes from

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

$$\sin\theta = \frac{10^{-7}}{10} = 10^{-8}$$

This implies  $\theta \rightarrow 0$

it means the light goes almost unbent and hence student are unable to see each other.

Q10.17 (e) Answer the following questions:

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?

Answer:

Typical size of the obstacle is much larger than the wavelength of light. Hence the diffraction effect is negligibly small. thus the assumption that light travels in a straight line can be safely used in day to day life.

Q10.18 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?

Answer:

Given,

Distance between two towers = 40km

size of aperture =  $a = 50m$

Now,

As we know

Fresnel's distance is equal to half of the distance between towers

$$Z_f = \frac{40}{2} = 20km$$

Also from the formula:

$$Z_f = \frac{a^2}{\lambda} = 20m$$

$$\lambda = \frac{a^2}{Z_f} = \frac{50^2}{20 * 10^3} = 12.5cm$$

Hence this is the required longest wavelength of the radio wave, which can be sent in between the towers without considerable diffraction effect.

Q10.19 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.

Answer:

Given

The distance of the screen from the slit,  $D = 1m$

The distance of the first minimum  $X_1 = 2.5mm = 10^{-3} = 2.5 * 10^{-3}mm$

The wavelength of the light  $\lambda = 500nm = 500 * 10^{-9}m$

Now,

As we know,

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

$$d = n \frac{\lambda D}{X_n} = 1 * \frac{500 * 10^{-9} * 1}{2.5 * 10^{-3}} = 2 * 10^{-4}m = 0.2mm$$

Hence, the width of the slit is 0.2 mm.

Q10.20 (a) Answer the following questions:

When a low flying aircraft passes overhead, we sometimes notice a slight shaking of the picture on our TV screen. Suggest a possible explanation.

Answer:

When a low flying aircraft passes overhead, we notice slight shaking in pictures of the TV. This is because aircraft interferes with signals and reflects it. So the shaking we see is the interference of direct signal and reflected signal.

Q10.20 (b) Answer the following questions:

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?

Answer:

The superposition principle comes from the linear character of the differential equation of wavemotion.that is if  $x_1$  and  $x_2$  are the solution of any wave equation, then linear combination of  $x_1$  and  $x_2$  is also the solution of the wave equation.

Q10.21 In deriving the single slit diffraction pattern, it was stated that the intensity is zero at angles of  $\frac{n\lambda}{a}$ . Justify this by suitably dividing the slit to bring out the cancellation.

Answer:

Let the width of the slit  $b$  be divided into  $n$  equal parts so that

$$b' = \frac{b}{n}$$

$$b = b'n$$

Now,

$$\theta = \frac{n\lambda}{b} = \frac{n\lambda}{b'n} = \frac{\lambda}{b'}$$

At this angle, each slit will make the first diffraction minimum. therefore the resultant intensity for all the slits will be zero at the angle of  $\frac{n\lambda}{b}$  .