Question 10.16:

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

Answer

Wavelength of light used, λ = 6000 nm = 600 × 10^{-9} m

Angular width of fringe, $\theta = 0.1° = 0.1 \times \dfrac{\pi}{180} = \dfrac{3.14}{1800}$ rad

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

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

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

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

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

Question 10.17:

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?

Answer

(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.

Question 10.18:

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

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

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

$$= \frac{(50)^2}{2 \times 10^4} = 1250 \times 10^{-4} = 0.1250 \text{ m} = 12.5 \text{ cm}$$

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

Question 10.19:

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

Wavelength of light beam, λ = 500 nm = 500×10^{-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 = 2.5×10^{-3} m

It is related to the order of minima as:

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

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

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

Therefore, the width of the slits is 0.2 mm.

Question 10.20:

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?

Answer

(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.

Question 10.21:

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.

Answer

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

∴ Width of each slit, $d' = \dfrac{d}{n}$

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.

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