10 Wave Optics

Lesson at a Glance

• Wavefront

It is the locus of all points having same phase or it is the surface of constant phase. The wave fronts are of three types.

• Interference

The term 'interference' in general refers to any situation where two or more waves overlap each other in the same region of space. But usually, interference refers to the superposition of two coherent waves of same frequency moving in the same direction.

• Condition for Constructive Interference

For intensity to be maximum at P,

$$\cos\phi = 1$$

∴ Phase difference, $\phi = \pm 2n\pi$

where $n = 0, 1, 2$...........

Now, $$\frac{2\pi}{\lambda}(\Delta x) = \Delta\phi = \pm 2\pi n$$

or, $$\Delta x = \pm n\lambda$$

where $n = 0, 1, 2$..........

and $$I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}$$

or, $$I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$$

or, $$I_{max} \propto (a_1 + a_2)^2$$

• Condition for Destructive Interference

Intensity will be minimum when

$$\cos\phi = \text{minimum} = -1$$

i.e., $$\phi = \pm\pi, \pm 3\pi, \pm 5\pi$$

or, $$\phi = \pm(2n-1)\pi \text{ with } n = 1, 2, 3\text{..............}$$

or, $$\frac{2\pi}{\pi}(\Delta x) = \pm(2n-1)\pi \qquad \left[\because \Delta\phi = \frac{2\pi}{\lambda}(\Delta x)\right]$$

or, $\Delta x = \pm(2n - 1)\lambda/2$ with $n = 1, 2, 3$..........

also, $I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$

or, $I_{min} \propto (a_1 - a_2)^2$

• Ratio of Intensity of Wave at Maxima and Minima

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

• Position of Bright Fringes

Position of bright fringes is given by

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

where $n = 0, 1, 2$..........

• Position of Dark Fringes

Position of dark fringes is given by

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

where, $n = 1, 2, 3$...........

• Fringe Width (ω)

The separation between two consecutive dark (or bright) fringes is known as fringe width (ω). It is also denoted by 'β'.

$$\therefore \quad \omega = Y_{n+1} - Y_n = (n+1)\frac{\lambda D}{d} - \frac{n\lambda D}{d}$$

$$\Rightarrow \quad \boxed{\omega = \frac{\lambda D}{d}}$$

Angular fringe width or angular separation between fringes is

$$\theta = \frac{\omega}{D}$$

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

• Coherent Waves

Two waves of same frequency are said to be 'coherent' if their phase difference does not change with time, *i.e.*, their phase difference is independent of time.

• Diffraction of Light

The flaring out or encroachment of light in the shadow zone as it passes around obstacles or through small aperture is called diffraction.

• Polarisation of Light

Light is an electromagnetic wave having electric and magnetic field vibrations perpendicular to each other as well as perpendicular to the direction of propagation. The phenomenon due to which the electric vectors of light are restricted in a particular direction is called polarisation. *Polarised light consists of individual photons whose electric field vectors are all aligned in the same direction.* Ordinary light is unpolarised because the photons are emitted in a random manner. When light passes through a polariser, the electric field vectors outreacts more strongly with molecules having certain orientation. This causes the incident beam to separate into two beams, whose electric vectors are perpendicular to each other. A horizontal filter absorbs photons whose electric vectors are vertical.

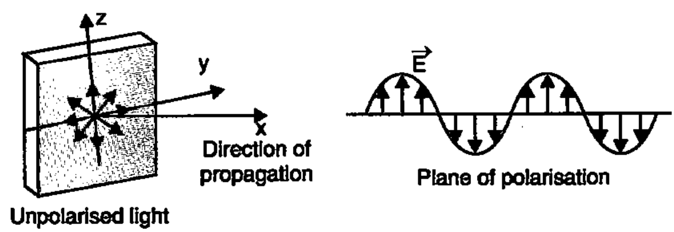

Fig. 10.1

• Brewster's Law

When light is incident at polarising angle at the interface of a refracting medium, the refractive index of the medium is equal to the tangent of polarising angle. In Fig. 10.2.

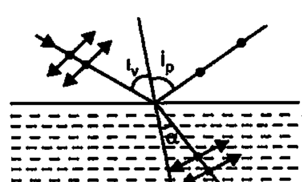

Fig. 10.2

Mathematically

$$\mu = \tan i_p \quad ...(I)$$

But from Snell's law

$$\mu = \frac{\sin e_p}{\sin r} \quad ...(II)$$

$$\Rightarrow \quad \frac{\sin i_p}{\sin r} = \frac{\sin i_p}{\cos i_p} \qquad \text{from I, II}$$

or $$\sin r = \cos i_p$$

or $$\sin r = \sin (90° - i_p)$$

or $$r = 90° - i_p$$

or $$r + i_p = 90°$$

Thus, the angle of refraction and angle of polarisation is complementary to each other. The reflected and refractive ray are perpendicular to each other.

• Scattering of Light

When light passes through heterogenous medium, it strikes to the heterogenous particles of the medium and spread out in all the directions. This phenomenon is called scattering of light.

• Resolving Power of Optical Instruments

The resolution power of an instrument is reciprocal of the resolving limit. The *smallest separation of two point objects at which they appear just separated is called the limit of resolution.*

Theory of diffraction of light shows that the radius of the central bright region is approximately given by

$$r = \frac{1.22\,\lambda f}{2d} = \frac{0.61\,\lambda f}{d}$$

where f is the focal length of the lens and $2d$ is the diameter of the circular aperture or the diameter of the lens, which is smaller. [Fig. 10.3]

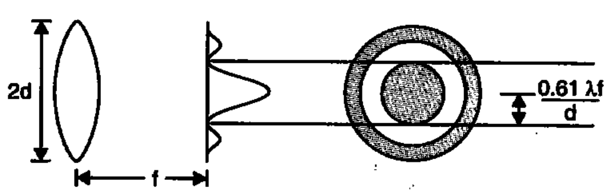

Fig. 10.3

• The resolving power of the microscope is reciprocal of the minimum separation of two points seen as distinct.

∴ *R.P.* of microscope

$$R.P. = \frac{2n \sin\beta}{1.22\lambda}$$

• Resolving Power of a Telescope

It is the reciprocal of the smallest angular separation between two distinct objects, so that they appear just separate when seen through telescope.

The least separation,

$$\theta = \frac{1.22\lambda}{2d}$$

∴ Resolving power $\frac{1}{\theta} = \frac{2d}{1.22\lambda}$

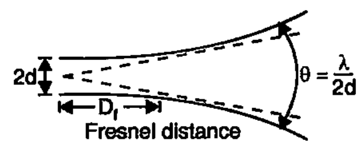

Fig. 10.4

$2d$ is the aperture of the objective lens.

TEXTBOOK QUESTIONS SOLVED

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.*

Sol. Given, $\lambda = 589$ nm $c = 3 \times 10^8$ m/s, $\mu = 1.33$

(*a*) For reflected light

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

$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{589 \times 10^{-9}} = 5.09 \times 10^{14} \text{ Hz.}$$

Speed $v = c = 3 \times 10^8$ m/s

(*b*) For refracted light

$$_a\mu_\omega = \frac{v_a}{v_\omega} \qquad _a\mu_\omega = \frac{v_a\lambda_a}{v_\omega\lambda_\omega}$$

∴ $v_a = v_\omega$

so $$\lambda_\omega = \frac{\lambda_a}{_a\mu_\omega} = \frac{589 \times 10^{-9}}{1.33} = 4.42 \times 10^{-7} \text{ m}$$

$$\lambda = \frac{\lambda}{\mu} = \frac{589 \times 10^{-9}}{1.33} = 4.42 \times 10^{-7}\text{m}$$

As frequency remains unaffected on entering another medium, therefore,

$$v_\omega = v_a = 5.09 \times 10^{14} \text{ Hz}$$

Speed, $$v' = \frac{v_a}{\mu_\omega} = \frac{3\times10^8}{1.33} = 2.25 \times 10^8 \text{ m/s.}$$

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.

Sol. (*a*) Spherical

(*b*) Plane

(*c*) Plane (Because a small area on the surface of a large sphere is nearly planar.)

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 ms^{-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?

Sol. (*a*) Refractive index, $$\mu = \frac{\text{speed of light in vacuum}}{\text{speed of light in the medium}}$$

$$\therefore \text{ Speed of light in glass} = \frac{\text{speed of light in vacuum}}{\mu_g}$$

$$= \frac{3.0\times10^6}{1.5} = 2.0 \times 10^6 \text{ ms}^{-1}.$$

(*b*) No, the refractive index and the speed of light in a medium depend on wavelength, *i.e.*, colour of light. We know that $\mu_v > \mu_r$. Therefore $v_{violet} < v_{red}$. Hence violet component of white light travels slower than the red component.

10.4. *In 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 m. Determine the wavelength of light used in the experiment.*

Sol. Given, $D = 1.4$ m, $d = 0.28$ mm $= 0.28 \times 10^{-3}$m

Fringe width, $$\omega = \frac{1.2}{4} = 0.3 \times 10^{-2} \text{ m}$$

(as the distance 1.2 m is of fourth fringe from central maxima)

Using formula,

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

$$\therefore \quad \lambda = \frac{\omega d}{D} = \frac{0.3\times10^{-2}\times0.28\times10^{-3}}{1.4}$$

$$= 0.06 \times 10^{-5} = 600 \times 10^{-9} = 600 \text{ nm.}$$

10.5. *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?*

Sol. Phase difference corresponding to λ is 2π and phase difference corresponding to λ/3 is 2π/3.

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

Let that $I_1 = I_2 = I_0$

In the first case, $K = I_0 + I_0 + 2I_0 \cos 2\pi = 4I_0$

In the second case, $K' = I_0 + I_0 + 2I_0 \cos\frac{2\pi}{3}$

$$= I_0 + I_0 - 2I_0\left(\frac{1}{2}\right) = I_0$$

Now, $\frac{K'}{K} = \frac{I_0}{4I_0} = \frac{1}{4}$ or $K' = \frac{K}{4}$.

10.6. *A beam of light consisting of two wavelength, 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?

Sol. Here, $\lambda_1 = 650 \text{ nm} = 650 \times 10^{-9}$ m

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

Suppose, d = distance between two slits

D = distance of screen from the slits.

(*a*) For third bright fringe, $n = 3$

$$x = n\lambda_1.\frac{D}{d}$$

$$= 3 \times 650 \times 10^{-7} \times \frac{120}{0.2}$$

$$= 0.117 \text{ cm} = 1.17 \text{ mm}$$

(*b*) Let *n* fringes of wavelength 650 nm coincide with (n + 1) fringes of wavelength 520 nm.

$$x = n\lambda_1 D/d = (n+1)\,\lambda_2\, D/d \times \lambda_2$$

or, $$x = n \times 650 = (n+1) \times 520$$

or, $$\frac{n+1}{n} = \frac{650}{520} = \frac{5}{4}$$

or, $$1+\frac{1}{n} = \frac{5}{4} \Rightarrow \frac{1}{n} = \frac{5}{4}-1 = \frac{1}{4} \quad \text{or} \quad n = 4$$

Hence, $$x = n\cdot\lambda_1 \frac{D}{d}$$

$$= 4 \times 650 \times 10^{-7} \times \frac{120}{0.2} = 1.56 \text{ mm.}$$

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 as 600 nm. What will be the angular width of the fringe if the entire experiment apparatus is immersed in water? Take refractive index of water to be 4/3.*

Sol. Angular fringe separation,

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

In water, $$d = \frac{\lambda'}{\theta'}$$

$\therefore$ $$\frac{\lambda}{\theta} = \frac{\lambda'}{\theta'}$$

or, $$\frac{\theta'}{\theta} = \frac{\lambda'}{\lambda} = \frac{1}{\mu} = 3/4 \qquad \left[\because\ {}_a\mu_\omega = \frac{\lambda_a}{\lambda_\omega}\right]$$

or, $$\theta' = \frac{3}{4}\theta = \frac{3}{4}\times 0.2^\circ = 0.15^\circ.$$

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

Sol. Given, $\mu = 1.5$

Using formula,

$$\tan i_p = \mu$$

or, $$i_p = \tan^{-1}(\mu)$$

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

Thus, $$i_p = 56.3^\circ.$$

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?*

Sol. The wavelength and frequency of the reflected light are the same as that of the incident light.

∴ Wavelength of reflected light = 5000 Å

Frequency of reflected light = c/λ

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

According to law of reflection, $i = r$

The reflected ray is normal to the incident ray.

$$i + r = 90°$$
$$i + i = 90°$$
$$2i = 90°$$

or, $$i = 45°.$$

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

Sol. Here, $a = 4 \text{ mm} = 4 \times 10^{-3}$ m

$\lambda = 400 \text{ nm} = 400 \times 10^{-9} \text{ m} = 4 \times 10^{-7}$ m

Ray optics is good approximation upto distances equal to Fresnel's distance (Z_F)

$$Z_F = \frac{a^2}{\lambda} = \frac{(4\times10^{-3})^2}{4\times10^{-7}} = 40 \text{ m}.$$

10.11. *The 6563 Å H_α line emitted by hydrogen in a star is found to be red-shifted by 15Å. Estimate the speed with which the star is receding from the Earth.*

Sol. $\lambda = 6563 \text{ Å} = 6563 \times 10^{-10}$ m

$\lambda' - \lambda = 15 \text{ Å} = 15 \times 10^{-10}$ m

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

$$V_s = \frac{c}{\lambda}(\lambda' - \lambda) = \frac{3.0\times10^8}{6563\times10^{-10}} \times 15 \times 10^{-10}$$

$$= 6.8566 \times 10^5 \text{ ms}^{-1}$$

or, $$V_s = 6.86 \times 10^5 \text{ ms}^{-1}.$$

10.12. *Explain how Newton's 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 the experimental determination of speed of light in water? If not, which alternative picture of light is consistent with experiment?*

Sol. According to Newton's Corpuscular theory of light, when corpuscles of light strike the interface XY, figure separating a denser medium from a rarer medium, the component of their velocity along XY remains the same:

If v_1 is velocity of light in rarer medium (air)

v_2 is velocity of light in denser medium (water)

i is angle of incidence,

r is angle of refraction,

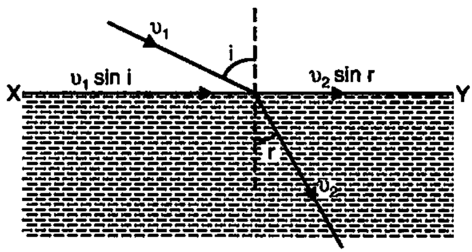

Fig. 10.5

Then component of v_1 along $XY = v_1 \sin i$

component of v_2 along $XY = v_2 \sin r$

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

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

As $\mu > 1 \quad \therefore \quad v_2 > v_1$

i.e., light should travel faster in water than in air. This prediction of Newton's theory is opposite to the experimental result.

Huygens wave theory predicts that $v_2 < v_1$, which is consistent with experiment.

10.13. *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.*

Sol. Let O be a point object in front of plane mirror XY at a normal distance OP from it. Spherical wavefront starts from it. A part RPQ of the wavefront touches the plane mirror at P. Whereas disturbance from R and Q continues moving forward along normals (rays) OR and OQ, that from P reflects back. When distur-bances from R and Q reach the mirror at A and C respectively, that from P reaches B'. This gives rise to reflected spherical wavefront $AB'C$. ABC is the virtual position (position in absence of mirror) of the wavefront.

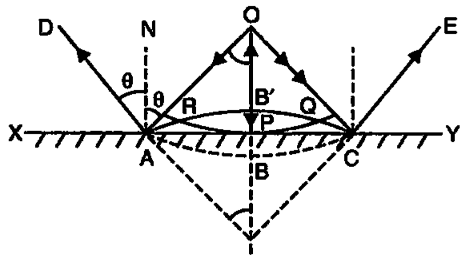

Fig. 10.6

The reflected wavefront $AB'C$, appears to start from I. I becomes virtual image for O as real point object.

Draw AN normal to XY, hence parallel to OP.

Now, OA is incident ray (being normal to incident wavefront ABC) and AD is reflected ray (being normal to reflected wavefront $AB'C$).

Hence, $\angle OAN = \angle DAN = \theta$ [$i = r$]

But $\angle OAN$ = alternate $\angle AOP$

and $\angle DAN$ = corresponding $\angle AIP$

$\angle AOP = \angle AIP$

Now, in ΔAIP and ΔAOP

$\angle AIP = \angle AOP$ (each θ)

$\angle API = \angle APO = 90°$ (each 90°)

AP is common to both

Δ_s become congruent

Hence, $PI = PQ$

i.e., normal distance of image from the mirror = normal distance of object from the mirror.

Thus, virtual image is formed as much behind the mirror as the object in front of it.

10.14. *Let us list some of the factors which could possibly influence the speed of wave propagation: (i) nature of source, (ii) direction of propagation, (iii) motion of 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,

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

Sol. (*a*) Speed of light in vacuum is an absolute constant, according to Einstein's theory of relativity. It does not depend upon any of the factors listed above or any other factor.

(*b*) The speed of light in a medium like water or glass

(*i*) does not depend upon the nature of the source.

(*ii*) does not depend upon the direction of propagation, when the medium is isotropic.

(*iii*) does not depend upon motion of the source w.r.t. the medium, but depends on motion of the observer relative to the medium.

(*iv*) depends on wavelength of light, being lesser for shorter wavelength and vice-versa.

(*v*) does not depend upon intensity of light.

10.15. *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 wave 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?

Sol. Sound waves require a medium for propagation. Thus, even though the situations (*i*) and (*ii*) may correspond to the same relative motion (between the source and the observer), they are not identical physically since the motion of the observer relative to the medium is different in the two situations. Therefore, we can not expect Doppler formulas for sound to be identical for (*i*) and (*ii*). For light waves in vacuum, there is clearly nothing to distinguish between (*i*) and (*ii*). Here only the relative motion between the source and the observer counts. The relativistic Doppler formula is the same for (*i*) and (*ii*). For light propagation in a medium, once again like for sound waves, the two situations are not identical and we should expect the Doppler formulas for this case to be different for the two situations (*i*) and (*ii*).

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

Sol. Angular fringe width, $\boxed{\beta_\theta = \frac{\lambda}{d}}$ $\Rightarrow$ $d = \frac{\lambda}{\beta_\theta}$

Now,

$$\lambda = 600 \times 10^{-9}\text{m}, \ \beta_\theta = 0.1^\circ = \frac{0.1 \times \pi}{180} \text{ radian}$$

$$= \frac{0.1 \times 3.14}{180} \text{ radian}$$

$$\therefore \quad d = \frac{600 \times 10^{-9} \times 180}{0.1 \times 3.14} \text{m} = 3.44 \times 10^{-4} \text{ m.}$$

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 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?*

Sol. (*a*) Width of central diffraction band = $2D\frac{\lambda}{d}$, so on doubling the width of the slit, the size of the central diffraction band reduces to half value. But the light amplitude becomes double, which increases the intensity four fold.

(*b*) The intensity of interference fringes in Young's double-slit experiment is modified by the diffraction pattern of each slit.

(*c*) Wave diffracted from the edge of the circular obstacle interface constructively at the centre of the shadow producing a bright spot.

(*d*) For diffraction or bending of waves by obstacles or apertures by a large angle, the size of the latter should be comparable to wavelength. If the size of the obstacle/aperture is much too large compared to wavelength, diffraction is by a small angle. Here the size of partition wall is of the order of a few meters. The wavelength of light is about 5×10^{-7} m, while sound wave of say 1kHz have wavelength of about 0.3 m. Thus, sound waves can bend around the partition while light waves cannot.

(*e*) Typical sizes of the apertures involved in ordinary optical instruments are much large than the wavelength of light. Consequently, the diffraction effects of light are negligibly small in these instruments. Hence, the assumption that light travels in straight lines can be safely used in the optical instruments.

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?*

Sol. Size of aperture, $a = 50$ m

Distance of aperture from tower, Z_F

$$= \frac{40}{2} = 20 \text{ km} = 20 \times 10^3 \text{ m.}$$

Fresnel distance, $\boxed{Z_F = \frac{a^2}{\lambda}}$

$$\Rightarrow \qquad \lambda = \frac{a^2}{Z_F} = \frac{(50)^2}{20 \times 10^3}$$

or, $\lambda = 125 \times 10^{-3}$ m = 12.5 cm.

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.*

Sol. Given, $D = 1$ m, $n = 1$

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

$\lambda = 500$ nm $= 500 \times 10^{-9}$ m $= 5 \times 10^{-7}$ m

Using formula,

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

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

or, $$d = \frac{1 \times 5 \times 10^{-7} \times 1}{2.5 \times 10^{-3}} = 2 \times 10^{-4} \text{ m} = 0.2 \text{ mm.}$$

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?*

Sol. (*a*) A low flying aircraft reflects the TV signal. The slight shaking on the TV screen may be due to interference between the direct signal and the reflected signal.

(*b*) Superposition principle follows from the linear character of the differential equation governing wavemotion. If y_1 and y_2 are solutions of the wave equation, so is any linear combination of y_1 and y_2. When amplitudes are large (*e.g.*, high intensity laser beams) and non-linear effects are important, the situation is for more complicated.

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.*

Sol. Let the slit width a be dividing into n equal parts of width a' so that

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

or,
$$a = na'$$

Then angle,
$$\boxed{\theta = \frac{n\lambda}{a}} = \frac{n\lambda}{na'}$$

or,
$$\theta = \frac{\lambda}{a'}$$

At this angle, each slit part will make first diffraction minimum. Hence, resultant intensity to all slits will be zero in that direction.

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