UNIT 7 WAVE OPTICS

Warm greetings:

Dear students

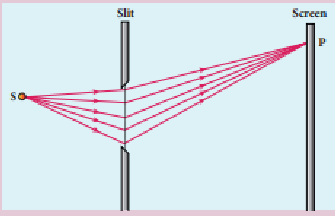
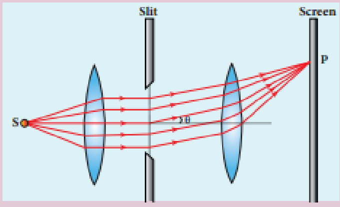
Welcome all. In this section of physics class you get to learn diffraction. Now we are going to discuss about the following topics.

- Diffraction
- Diffraction in single slit
- Fresnel's distance

DIFFRACTION:

- Diffraction is a characteristic of all waves, including sound waves. ***Diffraction*** **is bending of waves around sharp edges into the geometrically shadowed region.**
- This is a violation to the rectilinear propagation of light we have studied in ray optics. But, the diffraction is prominent only when the size of the obstacle is comparable to the wavelength of light.
- This is the reason why sound waves get diffracted prominently by obstacles like doors, windows, buildings etc. The wavelength of sound wave is large and comparable to the geometry of these obstacles.
- But the diffraction in light is more pronounced when the obstacle size is of the order of wavelength of light. **Fresnel and Fraunhofer diffractions.**
- Based on the type of wavefront which undergoes diffraction, it could be classified as Fresnel and Fraunhofer diffractions.
- The differences between Fresnel and Fraunhofer diffractions are shown in Table 7.1

Table 7.1 Difference between Fresnel and Fraunhofer diffractions

S.No.	Fresnel diffraction	Fraunhofer diffraction
1	Spherical (or) cylindrical wavefront undergoes diffraction	Plane wavefront undergoes diffraction
2	Light wave is from a source at finite distance	Light wave is from a source at infinity
3	Convex lenses need not be used for laboratory conditions	Convex lenses are to be used in laboratory conditions
4	Difficult to observe and analyse	Easy to observe and analyse
5		

As Fraunhofer diffraction is easy to observe and analyse, let us take it up for further discussions.

Diffraction in single slit:

- Let a parallel beam of light (plane wavefront) fall normally on a single slit AB of width *a* as shown in Figure 7.17.
- The diffracted beam falls on a screen kept at a distance *D* from the slit. The center of the slit is *C*.
- A straight line through C perpendicular to the plane of slit meets the center of the screen at *O*.
- Consider any point *P* on the screen. All the light reaching the point *P* from different points on the slit make an angle *θ* with the normal *CO*.
- All the light waves coming from different points on the slit interfere at point *P* (and other points) on the screen to give the resultant intensities.
- The point *P* is in the geometrically shadowed region, up to which the central maximum is spread due to diffraction as shown Figure 7.17.
- We need to give the condition for the point *P* to be of various minima. The basic idea is to divide the slit into even number of smaller parts.
- Then, add their contributions at *P* with the proper path difference to show that destructive interference takes place at that point to make it minimum.
- To explain maximum, the slit is divided into odd number of parts.

Condition for P to be first minimum:

Let us divide the slit *AB* into two halves *AC* and *CB*. Now the width of each part is *a*/2. We have different points on the slit which are separated by the same width *a*/2 called as *corresponding points.* This is shown in Figure 7.18.

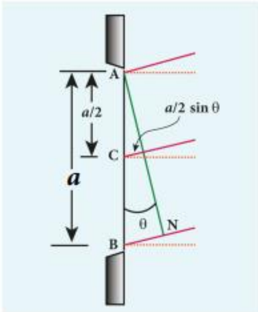


Figure 7.18 Corresponding points

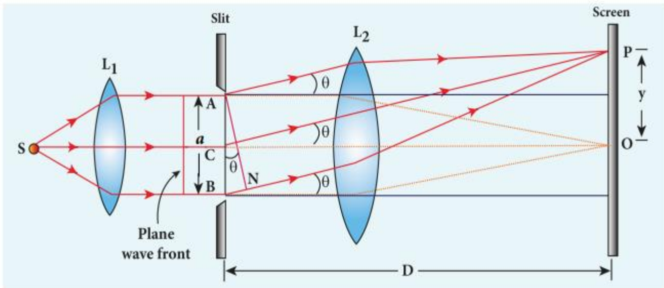


Figure 7.17 Diffraction at single slit

The light waves from different corresponding points meet at point P and interfere destructively to make it a minimum. The path difference *δ* between the waves from these corresponding points is, $\delta = a/2 \sin\theta$

The condition for P to be first minimum is, $\frac{a}{2}\sin\theta = \frac{\lambda}{2}$

$$a \sin\theta = \lambda \qquad (7.37)$$

Condition for P to be second minimum:

Let us divide the slit *AB* into four equal parts. Now, the width of each part is *a*/4. We have several corresponding points on the slit which are separated by the same width *a*/4. The path difference *δ* between the waves from these corresponding points is, $\delta = a/4 \sin\theta$.

The condition for *P* to be second minimum is, $\frac{a}{4}\sin\theta = \frac{\lambda}{2}$

$$a \sin\theta = 2\lambda \qquad (7.38)$$

Condition for P to be third minimum:

The same way the slit is divided in to six equal parts to explain the third minimum. The condition for *P* to be third minimum is, $a/6 \sin\theta = \lambda/2$.

$$a \sin \theta = 3\lambda$$

Condition for P to be nth minimum:

Dividing the slit into 2*n* number of (even number of) equal parts makes the light produced by one of the corresponding points to be cancelled by its counterpart. Thus, the condition for n^{th} minimum is,a/2n sinθ = λ/2.

$$a \sin \theta = n\lambda$$

Where, *n* = 1, 2, 3 ... is the order of diffraction minimum.

Condition for maxima:

For points of maxima, the slit is to be divided in to odd number of equal parts so that one part remains un-cancelled making the point *P* appear bright.

The condition for first maximum is,

$$\frac{a}{3}\sin\theta = \frac{\lambda}{2} \text{ (or) } a\sin\theta = \frac{3\lambda}{2} \quad (7.41)$$

The condition for second maximum is,

$$\frac{a}{5}\sin\theta = \frac{\lambda}{2} \text{ (or) } a\sin\theta = \frac{5\lambda}{2} \quad (7.42)$$

The condition for third maximum is,

$$\frac{a}{7}\sin\theta = \frac{\lambda}{2} \text{ (or) } a\sin\theta = \frac{7\lambda}{2} \quad (7.43)$$

In the same way, condition for n^{th} maximum is,

$$a\sin\theta = (2n+1)\frac{\lambda}{2} \text{ (}n^{th}\text{ maximum)} \quad (7.44)$$

Where, *n* = 0, 1, 2, 3, . . . , is the order of diffraction maximum.

The central maximum is called 0th order maximum. The points of the maximum intensity lie nearly midway between the successive minima.

Discussion on first minimum:

The equation for first minimum in single slit diffraction is, a sin $\theta = \lambda$. The angular spread for its first minimum in the diffraction pattern is, sin $\theta = \lambda / a$. The central maximum is found in between these first minima that occur on both the sides. We can discuss the following cases on the central maximum.

(i) If $a < \lambda$, then $\sin\theta > 1$ which is not possible. Hence, diffraction does not take place.

(ii) If $a = \lambda$, then $\sin\theta = 1$ i.e. $\theta = 90^\circ$. The first minimum is at 90°. Hence, the central maximum spreads fully into the geometrically shadowed region leading to the bending of the diffracted light by 90°.

(iii) If $a > \lambda$ and also comparable to λ, say $a = 2\lambda$, then $\sin\theta = \frac{1}{2}$ (or) $\theta = 30^\circ$. The diffraction is observed with a measurable spread. Hence, it is concluded that for observing the diffraction pattern, essentially the width of the slit a must be just few times greater than the wavelength of light λ.

(iv) If $a >> \lambda$, then $\sin\theta << 1$ i.e. The first minimum falls within the width space of the slit itself. Hence, the phenomenon of diffraction is not observed at all.

Fresnel's distance:

The rectilinear propagation of light is violated as there is bending of light in diffraction. But, this bending is not seen till the diffracted ray crosses the central maximum at a distance *z* from the slit as shown in Figure 7.19. Hence, **Fresnel's distance is the distance upto which the ray optics is obeyed and beyond which the ray optics is not obeyed; but, the wave optics becomes significant.**

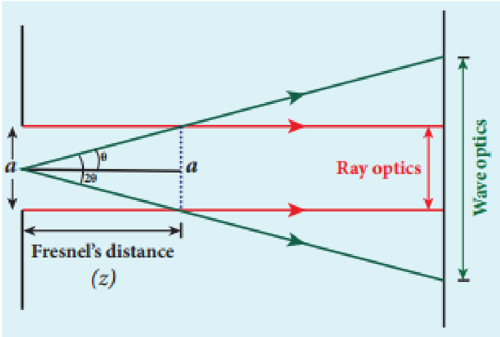


Figure 7.19 Fresnel's distance

The diffraction equation for first minimum is, $\sin\theta = \frac{\lambda}{a}$; when θ is small, $\theta = \frac{\lambda}{a}$

From the definition of Fresnel's distance,

$2\theta = \frac{a}{z}$ (or) $\theta = \frac{a}{2z}$

Equating the above two equation for θ gives, $\frac{\lambda}{a} = \frac{a}{2z}$

After rearranging, we get Fresnel's distance z as,

$$z = \frac{a^2}{2\lambda} \qquad (7.45)$$

Difference between interference and diffraction:

- It is difficult to find the difference between interference and diffraction as they both exhibit the wave nature of light.
- In both the phenomena, interference of light only produces maxima and minima on the screen and the diffraction of light only spreads light in the geometrically shadowed region.
- Nevertheless, in interference, the superposition is given importance and in diffraction, the bending of light is given importance.
- The difference between interference anddiffraction based on the appearance of their patterns are given in Table 7.2.

Table 7.2 Difference between interference and diffraction

S.No.	Interference	Diffraction
1	Equally spaced bright and dark fringes	Central bright is double the size of other fringes
2	Equal intensity for all bright fringes	Intensity falls rapidly for higher order fringes
3	Large number of fringes are obtained	Less number of fringes are obtained