6) DIFFRACTION AND POLARISATION

1. The phenomenon of bending of light waves around the sharp edges of opaque obstacles or aperture and their encroachment in the geometrical shadow of obstacle or aperture is defined as diffraction of light.
2. The phenomenon resulting from the superposition of secondary wavelets originating from different parts of the same wavefront is defined as diffraction of light.
3. Greater the wavelength of wave higher will be its degree of diffraction i.e., more deviation from its rectilinear path.
4. The phenomenon of diffraction of light waves takes place in the near vicinity of the edge geometrical shadow of the obstacle only whereas the diffraction of sound waves is observed in other parts of geometrical shadow also.
5. Due to low degree of diffraction of light waves, it appears to be propagating in straight lines where as due to high degree of diffraction, sound waves do not travel in straight lines.

6. The phenomenon of diffraction was first discovered by Grimaldi in the year 1665. Its experimental study was done by Newton and Young. But the systematic explanation was given by Fresnel on the basis of Huygen's wave theory of light.

7. Dependence of diffraction of waves – The phenomenon of diffraction depends on (a) the size of the obstacle (b) the wavelength of waves.

8. Necessary conditions of diffraction of waves – The size of the obstacle must be of the order of the wavelength of the waves i.e., $\frac{a}{\lambda} \le 1$.

9. The condition for observing the diffraction at an object (obstacle, narrow slit) on a screen is $D \approx \frac{d^2}{4\lambda}$ where D is the distance between screen and object, d is the size o the object and λ is wavelength of light.

10. The wavelength of sound waves is large (1.65 cm to 16.5 m). Hence the diffraction of sound can be observed in our daily life which occurs due to large obstacles like windows, doors, walls, stem, branches of tree etc.

11. The wavelength of audible sound waves is of order of one metre, hence these are diffracted by ordinary obstacles.

12. The wavelength of ultrasonic waves is of the order of 1 cm. Hence these are not diffracted by ordinary obstacles.

13. The wavelength of light (4800 Å – 8000 Å) is very small. Hence its diffraction is not observed in daily life. But diffraction of light waves can be observed in the laboratory under special circumstances.

14. The wavelength or radio waves is very large (2.5 m – 250 m), hence their diffraction can take place due to large building and small hills. The wavelength of telephone waves is comparatively very small ($\approx$0.3 m), hence their diffraction cannot occur due to large buildings and hills.

15. If the size of the obstacle as compared to the wavelength of the wave is

i) very small (i.e., $a \ll \lambda$) then the waves will undergo reflection and not diffraction.

ii) very large (i.e., $a \gg \lambda$) then its distinct geometrical shadow will be formed and the wave will not be diffracted.

iii) almost equal (i.e, $a \approx \lambda$) then the waves spread maximum in the geometrical shadow and hence undergo maximum diffraction.

16. Consequences of diffraction in daily life :

a. Sound produced in one room can be heard in the nearby room.

b. When an intense source of light is viewed with the partially opened eye, colours are observed in the light.

c. Appearance of a shining circle around the section of sun just before sunrise.

Rectilinear propagation of light :

17. When the diffraction effect is negligible then the law of rectilinear propagation of light is quite valid. i.e., when $a >> \lambda$ then the law of rectilinear propagation is obeyed.

18. When the size of the obstacle or aperture is of the order of wavelength of light then the diffraction effect takes place and light encroaches in the region of geometrical shadow of obstacles thereby deviating from its straight path. Under this condition the rectilinear propagation of light is approximate.

19. The diffraction effect is observed near the edge of the obstacle or the aperture, hence rectilinear propagation is approximately obeyed in this region. Inside the region of geometrical shadow, diffraction effect is not observable and hence the law of rectilinear propagation is perfectly obeyed.

20. Diffraction can be explained by Huygen's –Fresnel principle. According to this principle each point on a wavefront, which is unobstructed, acts as a source of secondary waves. Diffraction is due to interference of secondary waves coming from same primary wavefront.

21. Condition for observing diffraction :

a) If $\frac{d^2}{D\lambda} << 1$, Fraunhofer diffraction is observed.

b) If $\frac{d^2}{D\lambda} \approx 1$, Fresnel diffraction is observed.

c) If $\frac{d^2}{D\lambda} >> 1$, the approximation of geometrical optics is applicable.

22. **DIFFRACTION AT A STRAIGHT EDGE:**

a. Fresnel diffraction occurs when a cylindrical wave front strikes the straight edge and diffraction pattern forms on the screen in front of it.

b. The intensity at any point on the screen will be maximum when odd number of Fresnel zones are present between straight edge and pole of wave front and minimum when even number of zones are present.

c. If light exhibits rectilinear propagation the region on the screen below the point "p" i.e. , geometrical shadow region must be completely dark. But this region is illuminated with decreasing intensity as the distance from the point "p" increases.

d. The intensity of illumination in the geometrical shadow decreases gradually as more and more half period zones are cut off with increasing distance from the point p.

e. The encroachment of light in geometrical shadow shows that light undergoes diffraction and rectilinear propagation of light is only approximately true.

f. **Diffraction due to single slit:** The diffraction pattern due to a single slit consists of a central bright band having alternate dark and weak bright bands of decreasing intensity on both sides.

g. The condition for nth secondary minimum is that path difference $= a\sin\theta_n = n\lambda,$ where n = 1,2,3… and the condition for nth secondary maximum is that path difference $= a\sin\theta_n = (2n+1)\frac{\lambda}{2}$; where n = 1,2,3…

h. Width of central maximum is $2x = \frac{2D\lambda}{a} = \frac{2f\lambda}{a}$

i. Here, a is width of slit and D is distance of screen from the slit; f is focal length of lens for diffracted light.

j. For small angles $\sin\theta_n = \theta_n$

k. Distance of n^{th} dark fringe from centre, $x_{dark} = \frac{n\lambda D}{a}$

l. Distance of n^{th} bright fringe from centre, $x_{bright} = \frac{(2n+1)\lambda D}{2a}$

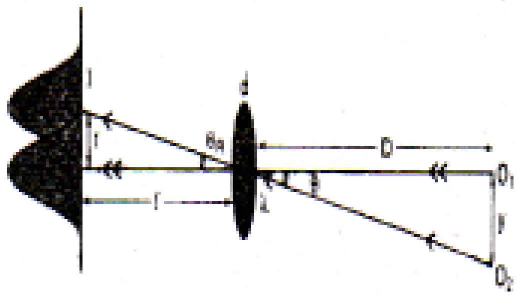
m. Diffraction is supposed to be due to interference of secondary wavelets from the exposed portion of wave front from the slit.

n. Whereas in interference, all bright fringes have same intensity, in diffraction, bright bands are of decreasing intensity.

23 Resolving Limit and Resolving Power :

A. Telescope :

Smallest angular separations (d_θ) between two distant objects, whose images are separated in the telescope is called resolving limit.



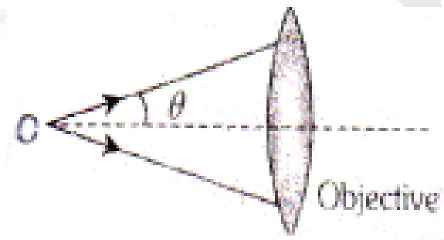
Resolving limit $d_\theta = \frac{1.22\lambda}{a}$ and resolving power

(RP) = $\frac{1}{d\theta} = \frac{a}{1.22\lambda} \Rightarrow R.P \propto \frac{1}{\lambda}$

where a = aperture of objective.

B.Microscope:

The resolving power of an optical instrument is defined as the reciprocal of smallest angular separation between two neightbouring objects whose images are just distinctly formed by the instrument. The smallest angular seperation is called the limite of resolution.



$R.L = \frac{\lambda}{2\mu \sin\theta}$ and $R.P. \frac{2\mu \sin\theta}{\lambda} \Rightarrow R.P \propto \frac{1}{\lambda}$

λ = Wavelength of light used to illuminate the object,

μ = Refractive index of the medium between object and objective

θ = Half angle of the cone of light from the point object, $\mu \sin \theta$ = Numerical aperture

POLARIZATION

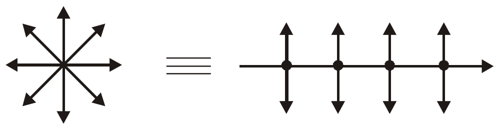
1. Light waves :Light propagates as transverse electromagnetic waves.
2. Description of light waves :The magnitude of electric field vector is much larger as compared to the magnetic field vector. (E=cB where c=speed of light).

Also, the eye is mainly affected by electric vector, Therefore, we generally prefer to describe light as electric field oscillations.

3. Representation of polarized light :

Unpolarized light consists of a very large number of vibrations in all planes with equal probability at right angles to the direction of propagation. Hence unpolarized light is represented by star.

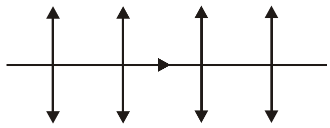
4. Unpolarized light :



a) In polarized light the vibrations of electric vector are confined to only one direction perpendicular to the direction of wave propagation.

5. Polarized light :

a) The light having oscillations only in one plane is called polarized or plane polarized.

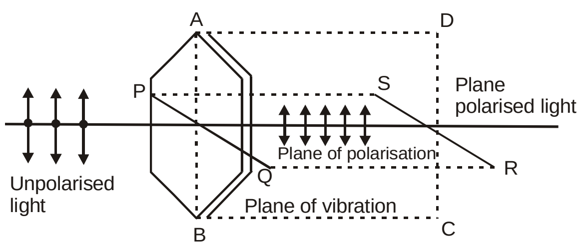


b) If the vibration of electric vector are parallel to the plane of paper then polarized light is represented by arrow lines. They are referred as π components.

c) If the vibrations of electric vector are perpendicular to the plane of paper, then polarized light is represented by dots. They are referred as σ components.

6. If unpolarized light is incident on a Polaroid, the transmitted light is plane polarized as shown below.

Here, the vertical oscillations are transmitted because the transmission axis is also vertical. The horizontal oscillations are not transmitted. That is why, on the right hand side there are no dots at the intersection of lines.



7. Plane of vibration – The imaginary plane in a crystal containing the vibrations of electric vector in polarized light as well as the direction of propagation of light wave, is defined as the plane of vibration.

8. Plane of polarization – The imaginary plane in a crystal containing the direction of propagation of light wave and which is perpendicular to the plane of vibration is defined as the plane of polarization.

9. Optic axis – The imaginary axis in a crystal (polarizer), parallel to which the vibrations of electric vector in unpolarized light pass through it, is defined as the optic axis of the crystal.

10. Light can be polarized by transmitting through certain crystals such as tourmaline or polaroids.

11. Polaroids are thin films of ultramicroscopic crystals of quinine idosulphate with their optic axes parallel to each other.

12. Quinine idosulphate is also called herpathite.

13. Polaroids allow the light oscillations parallel to the transmission axis pass through them.

14. The intensity of the transmitted light should be 50% of the incident light. However, in actual practice it is found to be about 35% of the incident light.

15. The crystal or Polaroid on which unpolarized light is incident is called polarizer.

16. Crystal or Polaroid on which polarized light is incident is called analyzer.

17. If the transmission axes of the polarizer and analyzer are parallel, then whole of the polarized light passes through the analyzer.

18. If the transmission axis of the analyzer is perpendicular to that of polarizer, then no light passes through the analyzer.

    Such polarizer and analyzer are said to be crossed.

19. Malus Law :

    If I_0 be the intensity of the polarized light incident on the analyzer and θ be the angle between the transmission axes of the polarizer and analyzer, then the intensity of the light transmitted through the analyzer is given by : $I=I_0\cos^2\theta$

20. If A be the amplitude of the light transmitted through the analyzer and A_0 be the amplitude of the polarized light incident on it, then

    $A^2=A_0^2\cos^2\theta$ or $A=A_0\cos\theta$

21. If Ii be the intensity of the unpolarized light incident on the polarizer and I be the intensity of the light transmitted through the analyzer, then

    $I_i=\frac{I_i}{2}\cos^2\theta$

Here $I_0 = I_i/2$

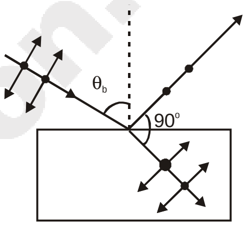
22. In the above expressions θ is also angle between the plane of oscillation of the polarized light and the transmission axes of the analyzer.

23. For the crossed polarizer and analyzer, $\theta = 90^o$ hence : $I = I_0 \cos^2 90^o = 0$.

24. Polarization confirms the transverse nature of the light waves.

25. Light can be polarized by the following methods (i) reflection, (ii) refraction, (iii) double refraction, (iv) dichorism, (v) scattering.

26. Polarization by reflection :



a) If the light is incident on a surface at a certain angle known at Brewster's angle (θ_b), then the reflected light is completely polarized having oscillations perpendicular to the plane of incidence. The Brewster's angle is also called polarizing angle.

b) The refracted ray is partially polarized.

c) When the reflected ray is completely polarized, the angle between the reflected ray and refracted ray is 90^o. Also, the refractive index of the material on which the light is incident is given by $\mu = \tan\theta_b$. Because

$\mu = \frac{\sin i}{\sin r} = \frac{\sin\theta_b}{\sin(90-\theta_b)} = \tan\theta_b$ This equation is called Brewster's law.

d) The polarizing angle θ_b depends on nature of material and wavelength of incident light.