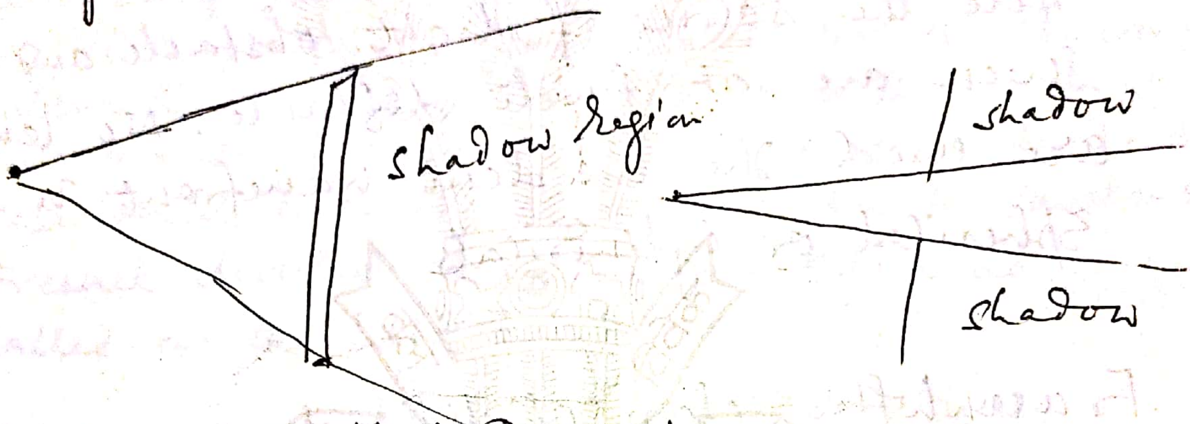
Q. What is diffraction? Distinguish between Freshel diffraction and Fraunhoffer diffraction. Explain Freshel's half Period zone theory of diffraction.

Deffraction.

It is a matter of common experience that there is a shadow region behind an obstacle or if a light passes through a slit, there is also shadow region below & above the aperture.



It is well explained in terms of rectilinear propagation of light according to Corpuscular theory. When the size of the obstacle or hole is made smaller (of the order of wavelength of light), some enchroachment of light in the shadow region was observed. It is due to bending of light round the corner of an obstacle in the shadow region and is called diffraction of light. Actually some fringe pattern was observed in the shadow region due to bending. This was later on explained by wave theory of light. We may call diffraction as the special case of interference.

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The phenomenon of diffraction was studied first by Fresnel & then by Fraunhoffer. So it is of two kinds: Fresnel class of diffraction and Fraunhoffer class of diffraction.

Fresnel class of diffraction —

Here the source of light, obstacle and the screen are at finite distance. No lenses are used. The incident wavefront is either spherical or cylindrical

Fraunhoffer class of diffraction —

Here the source of light, obstacle (slits) and the screen are infinite distances. This is done by placing the source and the screen in the focal planes of two lenses. The incident wavefront is plane. The diffraction pattern must be observed in the plane which is conjugate to the plane in which source of light lies.

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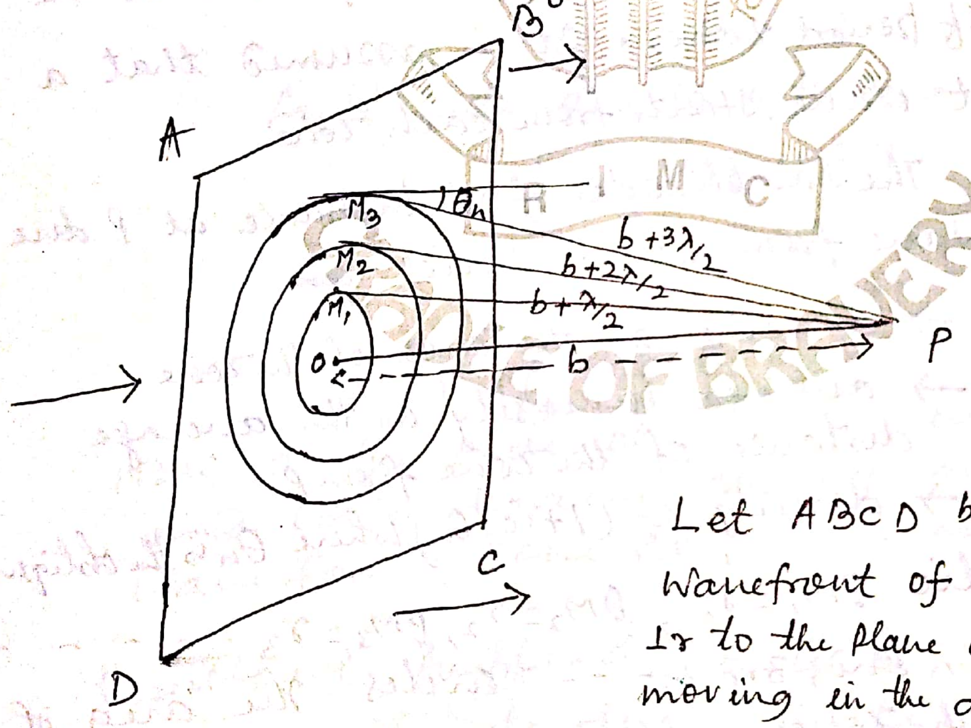
Fresnel's Half Period zones

According to wave theory of light, each point in a light source sends out waves in all directions. The continuous locus of particles vibrating in same phase is called the wave front. Each point of the wavefront is the source of secondary wavelets. Fresnel assumed that these wavelets are in a position to interfere and that the resultant intensity of light at any point is the result of interference of these wavelets. In order to find out the resultant intensity at a point due to wavefront, Fresnel divided the wavefront into a no. of zones called as the half period zones



Let ABCD be a plane wavefront of wavelength λ $\perp$r to the plane of the paper & moving in the direction from O to P

Let P be an external point at which the ~~entire~~ effect of the entire wavefront is to be found.

In order to achieve this, Fresnel sub-divided the wavefront into a no. of half-period zones as follows.

Let us draw a $\perp r$ Po on the wavefront from P. The Point O is the Pole of the wavefront w.r.to P. let PO=b, with P as centre and radii: $PM_1 = b+\lambda/2$, $PM_2 = b+2\lambda/2$, $PM_3 = b+\frac{3\lambda}{2}$ ... and so on draw a series of spheres. The sections of these spheres by the Plane of the wavefront are Concentric circles with O as Common centre. The area of the first circle is the first half period zone. The area between 2nd & first circle is the second half period zone and so on. The secondary wavelets originating from O & M_1 and reaching at P will have a path diff. of $\lambda/2$ or a time diff. of half period. It is why the zones are called half period zones. It is assumed that a resultant wave starts from each zone

The amplitude of disturbance at P due to the wave from a zone varies ~~as~~

→ directly as the area of the zone

→ ~~average~~ inversely as the average distance of the zone from P

→ directly as $(1+\cos\theta_n)$ where θ_n is the obliquity.

let radii $PM_1 = r_1$, $PM_2 = r_2$, $PM_3 = r_3$. - - - - of first, 2nd, 3rd . - - - circles. The area of the n th zone

$$= \pi r_n^2 - \pi r_{n-1}^2$$

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$$= \pi\left[\left\{\left(b+\frac{n\lambda}{2}\right)^2 - b^2\right\} - \left\{\left(b+(n-1)\lambda/2\right)^2 - b^2\right\}\right]$$

$$= \pi\left[\cancel{\theta}\, bn\lambda + \frac{n^2\lambda^2}{4} - b(n-1)\lambda - (n-1)^2\frac{\lambda^2}{4}\right]$$

$$= \pi\left[b\lambda + \frac{\lambda^2}{4}\left\{n^2-(n-1)^2\right\}\right]$$

$$= \pi\left[b\lambda + \frac{\lambda^2}{4}(2n-1)\right]$$

$$= \pi b\lambda \text{ approx.}$$

because b is quite large in comparison to λ so λ^2 is neglected. In this way the area of each zone is approximately the same

Further the average distance of nth zone from P is

$$\frac{\left[b+\frac{n\lambda}{2} + b + (n-1)\lambda/2\right]}{2} = b+(2n-1)\lambda/4$$

$\therefore$ Amplitude due to nth zone

$$\propto \frac{\pi\left[b\lambda+(2n-1)\lambda^2/4\right]}{b+(2n-1)\lambda/4}(1+\cos\theta_n)$$

$$\propto \pi\lambda(1+\cos\theta_n)$$

Now as the order of the zone increases, θ_n increase and $\cos\theta_n$ decreases. Thus; the amplitude of the wave from a zone at P decreases as n increases.

Resultant Amplitude — If $R_1, R_2, R_3 \ldots$ be the amplitude due to the 1st, 2nd, 3rd ... zones respectively at P, then the resultant amplitude is given by

$$R = R_1 + R_2 + R_3 + \ldots + R_n$$

if n is odd (if n is even, the last term is $-R_n$)

Now R_1 is slightly greater than R_2 & R_2 than R_3 and so on, they may be taken to form an arithmetic progression and hence we may write

$$R_2 = \frac{R_1 + R_3}{2}, \quad R_4 = \frac{R_3 + R_5}{2} \quad \text{--- and so on}$$

$$\therefore R = \frac{R_1}{2} + \left[\frac{R_1}{2} - R_2 + \frac{R_3}{2}\right] + \left[\frac{R_3}{2} - R_4 + \frac{R_5}{2}\right] + \cdots$$

The various terms within brackets reduce to zero because $R_2 = \frac{R_1}{2} + \frac{R_3}{2}$ & $R_4 = \frac{R_3}{2} + \frac{R_5}{2}$ ...

$$\therefore R = \frac{R_1}{2} + \frac{R_n}{2}, \text{ if } n \text{ is odd}$$

and $R = \frac{R_1}{2} + \frac{R_{n-1}}{2} - R_n$ if n is even

If n is quite large, R_n and R_{n-1} are almost ineffective on account of the distance and obliquity factor. Hence resultant amplitude at P due to the whole wave ~~front~~, whether n is odd or even, is

$$R = R_1/2$$

Thus, the resultant amplitude is only one half of that which would be produced by the first half period zone.

As the intensity $I \propto (\text{Amplitude})^2$

therefore $I = R_1^2/4$

Thus the intensity at P due to the whole wavefront is only one fourth of that due to the first half period zone alone.