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Fraunhoffer Single slit diffraction:

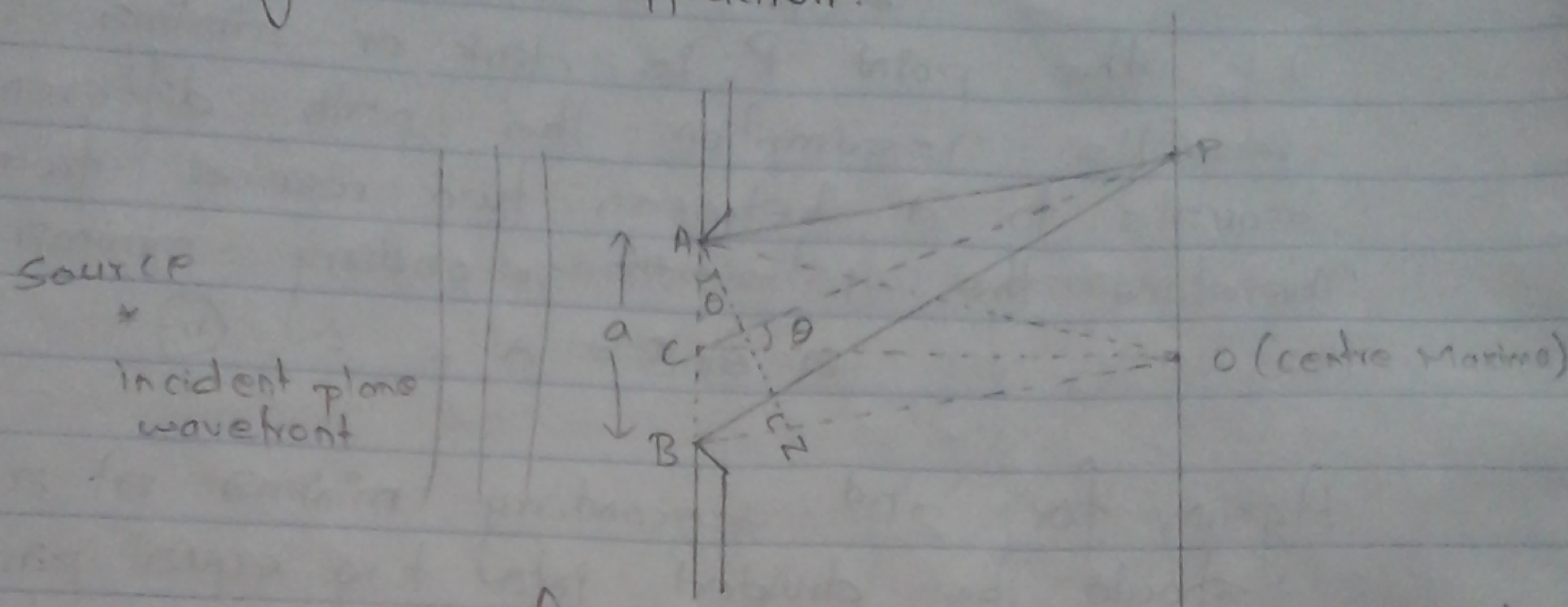


fig ①: Diffraction of light to know the fresnel assumption

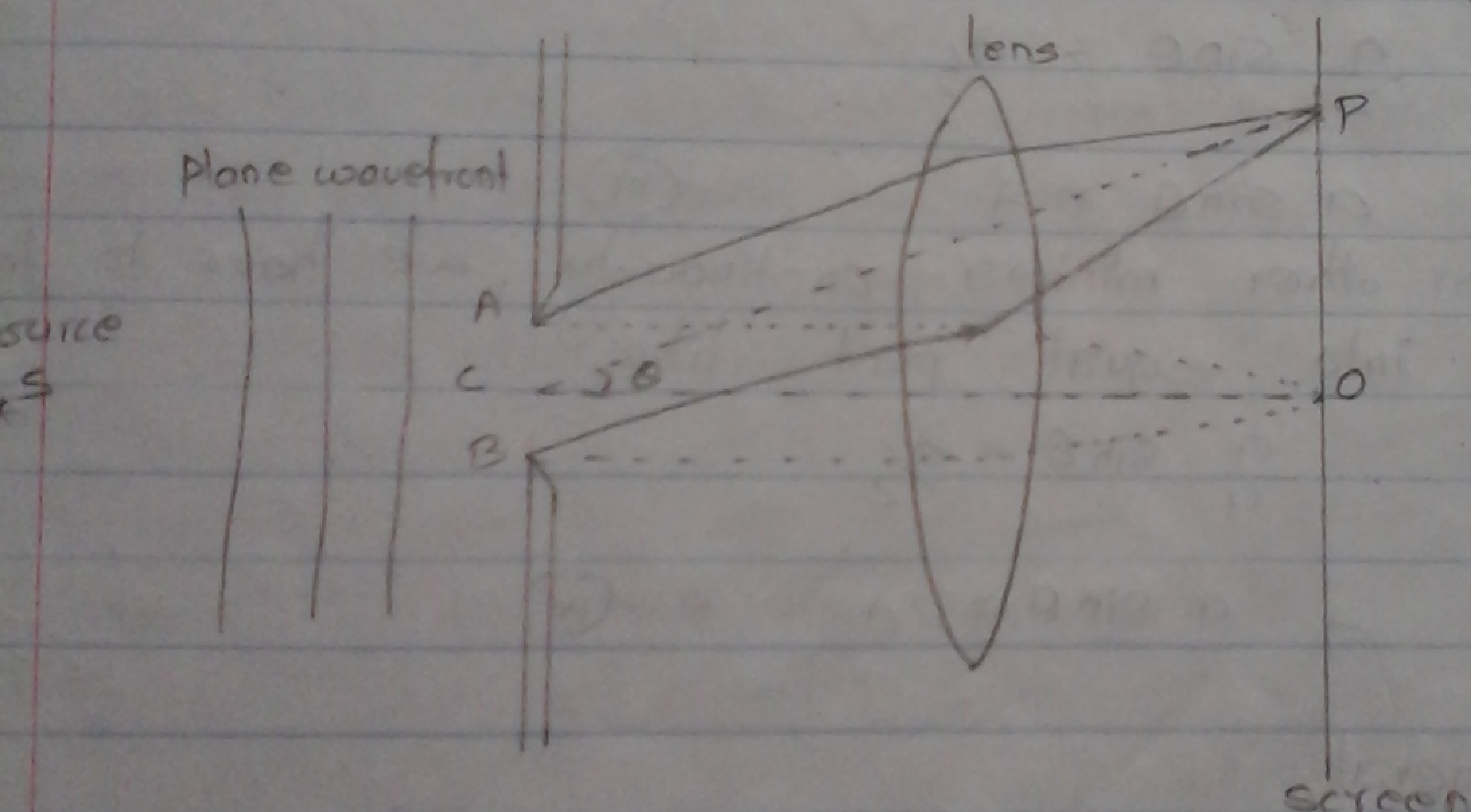
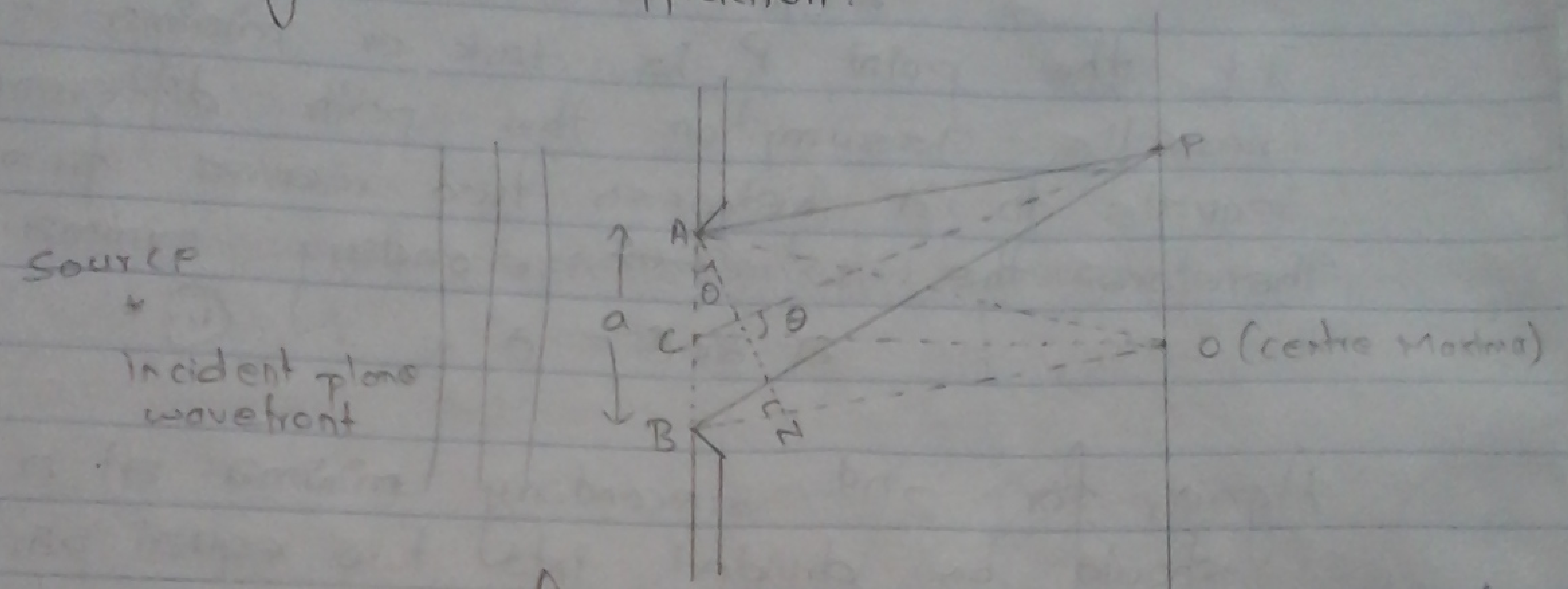


fig ①. fraunhoffer diffraction single slit

When the parallel wavefront incident on a slit of width 'a'. A set of incident disturbance propagated from the point A and B along centre O. Both waves from A & B

ii) Fraunhoffer diffraction: In this diffraction the source, obstacle (opaque) and screen are at infinite distance with the plane incident wavefront. The incident waves are modified by using lenses or mirror.

Fraunhoffer Single slit diffraction:



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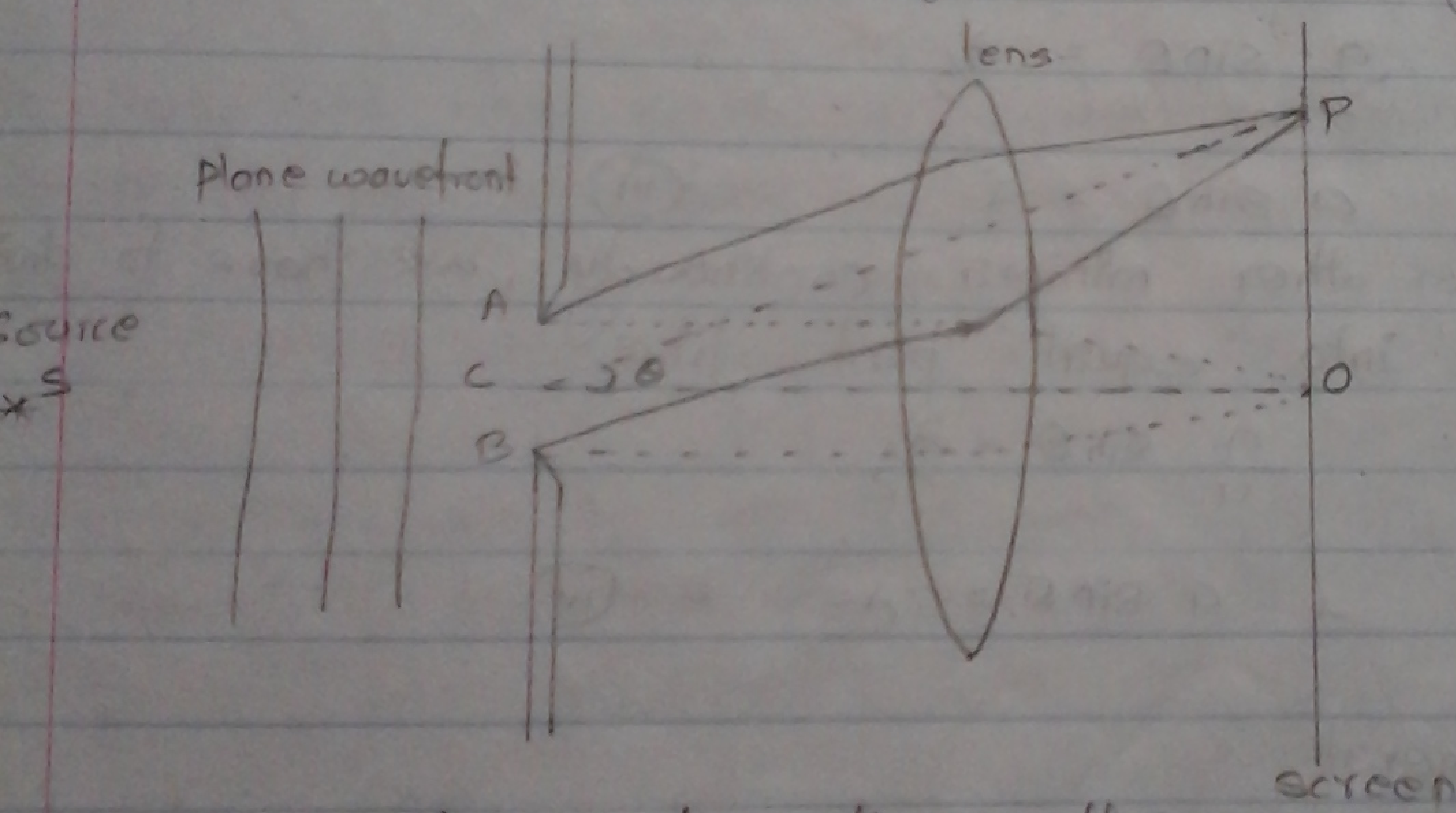


fig ①: fraunhoffer diffraction single slit

When the parallel wavefront incident on a slit of width 'a'. A set of incident disturbance propagated from the point A and B along centre O. Both waves from A & B superimposed at a point O. Therefore it's centre is maxima. When another set of wave makes an angle θ, propagate along P. it may be maxima or minima depends on the path difference between disturbance from A & B. ~~Draw~~ At

Draw $AN \perp BP$ we get path difference

$$BN = a \sin\theta \quad \ldots (i)$$

If the point P is dark or minima according to fresnel's assumption the path difference should be equals to λ between two waves from A and B. Therefore the 1st ~~2nd~~ secondary minima at P,

$$a \sin\theta = \lambda \quad \ldots (ii)$$

Again, for 2^{nd} secondary minima at a point, the slit should be divided into two equal parts then the path difference betn them is $\lambda/2$. Therefore,

$$\frac{a}{2} \sin\theta = \lambda/2$$

$$a \sin\theta = \lambda \quad \ldots (iii)$$

Also, for other minima, continously, we have to divide the slit into equal part like,

$$\frac{a}{4} \sin\theta = \lambda/2$$

$$\Rightarrow a \sin\theta = 2\lambda \quad \ldots (iv)$$

$\therefore$ In general,

$$a \sin\theta = n\lambda \quad (n = 1, 2, 3 \ldots)$$

is required expression for secondary minima.

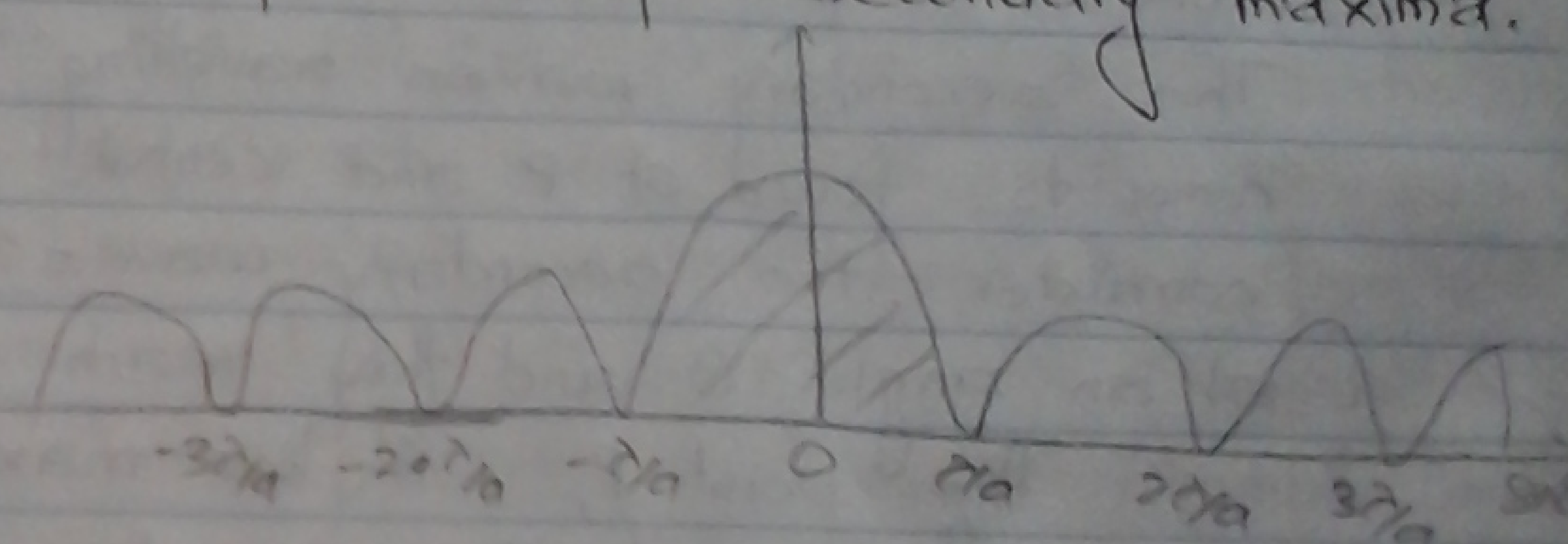
Again, for the secondary maxima (constructive)
If the angle betn two sets of incident wave is slightly increased the path difference between them changed into $3\lambda/2$

i.e. $a \sin\theta = 3\lambda/2$ . . . (vi)

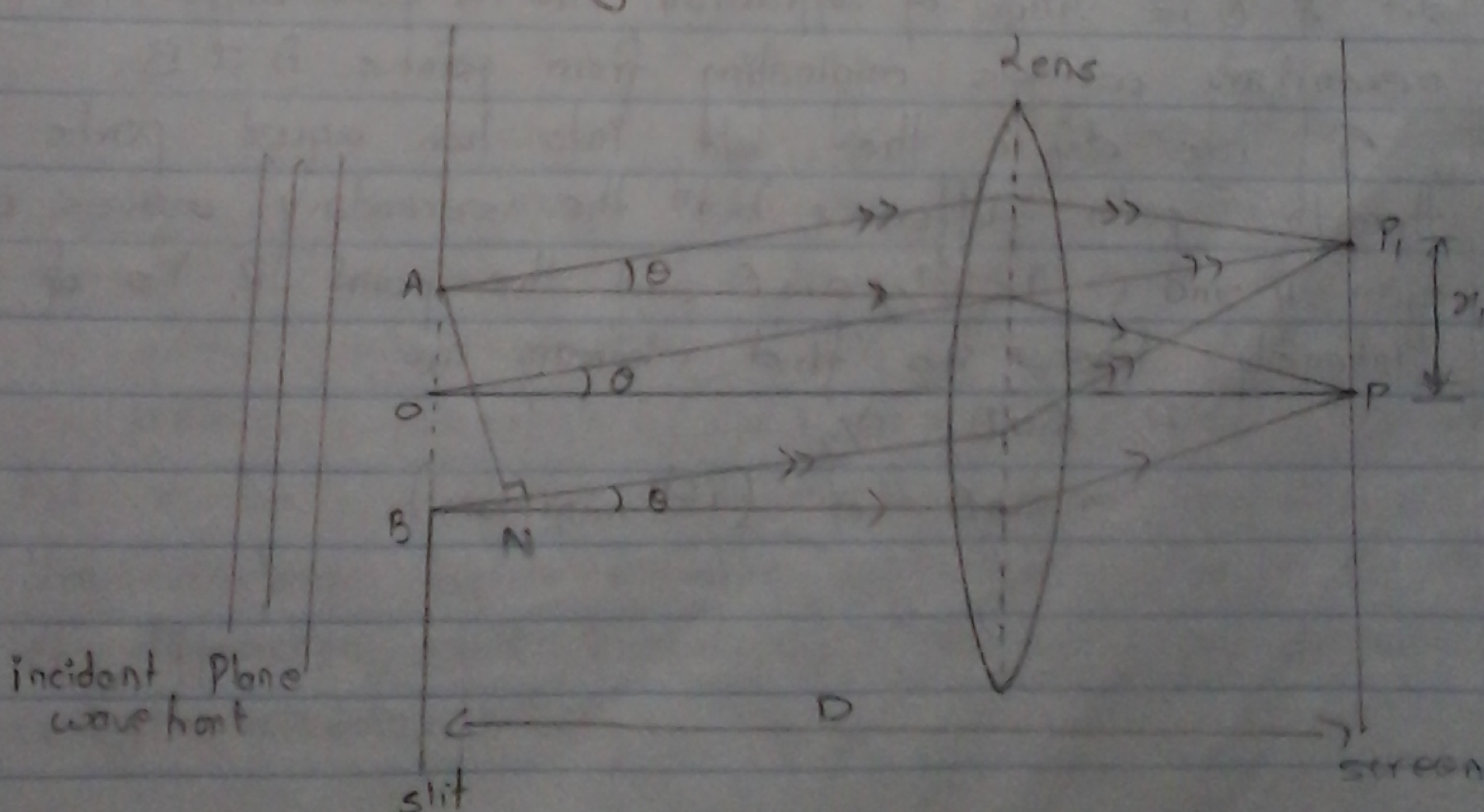
and so on

$a \sin\theta = (2n+1)\lambda/2 \quad (n = 1, 2, \ldots)$

It is required expression for secondary maxima.



show that the width of central maxima is twice of width of secondary maxima.



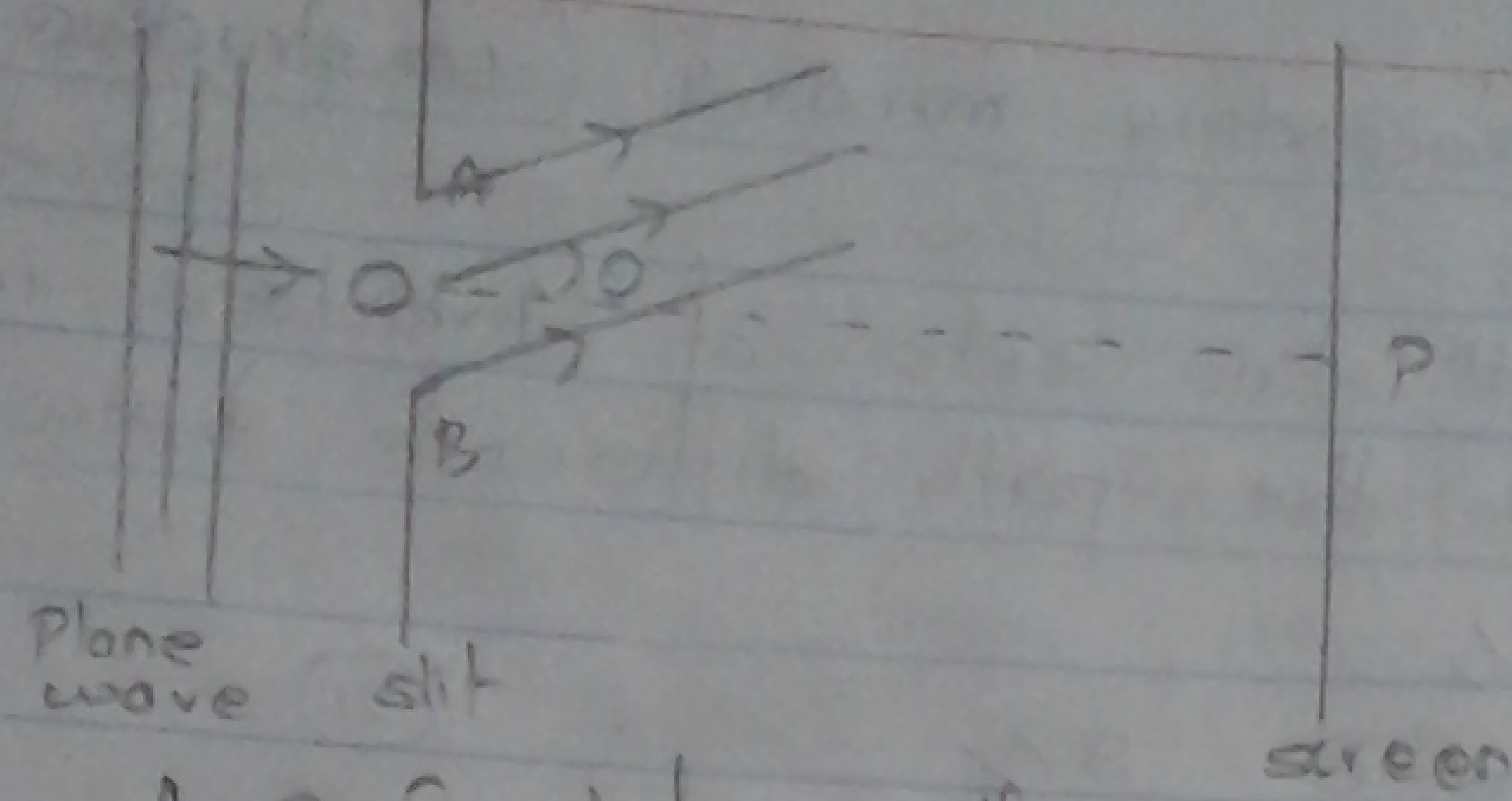


fig ①: Fraunhofer diffraction through single slit, θ as the angle of diffraction

A plane wavefront is incident on the slit AB and each point on this wavefront reacts as a source of secondary disturbance. The secondary waves travelling in the direction parallel to OP come to focus at P and central maximum is observed. Now, consider the secondary waves travelling in the direction inclined at an angle θ and they reach at point P_1 on the screen.

The point P_1 will be maxima or minimum depending on the path difference betn secondary waves originating from corresponding points of the wavefront.

From fig ①; in ΔANB, $BN = a\sin\theta$, where a is the width of slit & θ is angle of diffraction. BN is path difference, betn the secondary waves originating from points A & B.

If we divide the slit into two equal parts of width $a/2$ then the path difference betn the secondary waves emanating from A and O is $\frac{a}{2}\sin\theta$ and the point P_1 is of maximum intensity known as first minimum ie.

$$\frac{a}{2}\sin\theta = \frac{\lambda}{2}$$

$$a\sin\theta = \lambda \quad (1^{st}\text{ minimum})$$

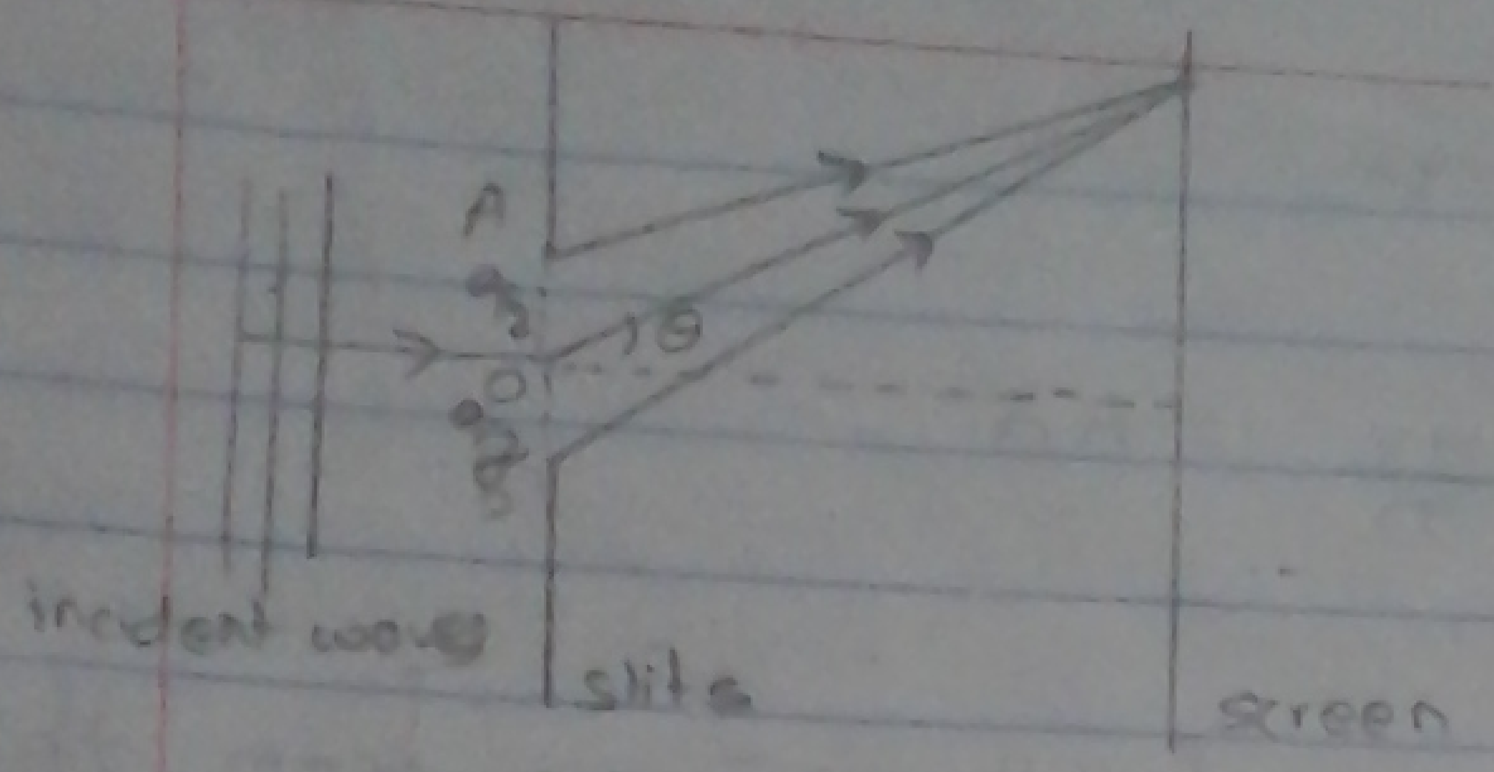


fig (11) P_1 as first minimum on the screen

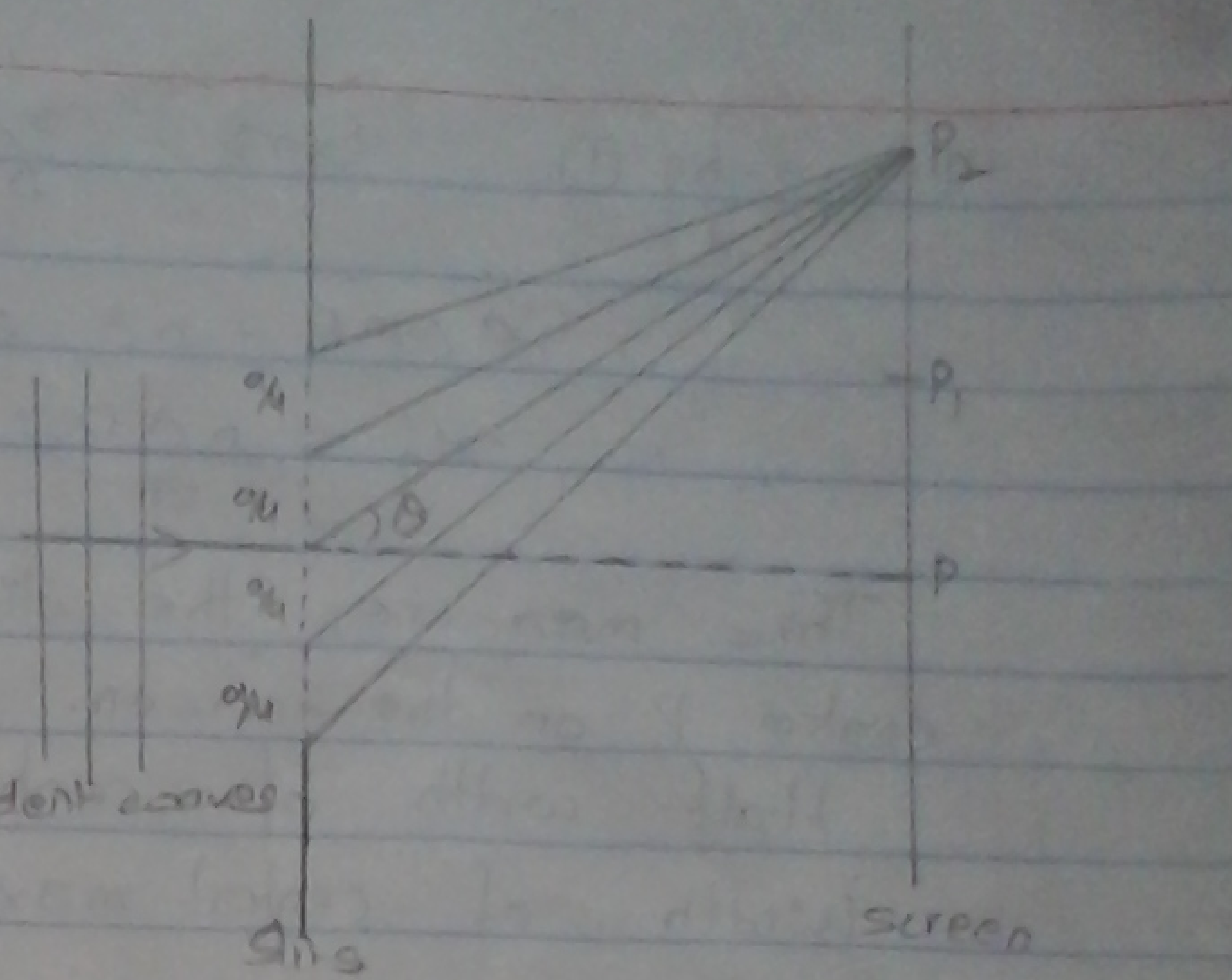


fig (11) P_2 as second minimum on the screen

Again let us divide the slit into 4 equal parts of width $a/4$. The rays coming from each zone meet at P_2. The path difference betn the secondary waves emanating from any two consecutive zones will be $\frac{a}{4}\sin\theta$ which is equal to $\lambda/2$ as defined by Fresnel. Here, point P_2 corresponds to 2^{nd} secondary minimum, i.e. $\frac{a}{4}\sin\theta = \lambda/2$

$$a \sin\theta = 2\lambda \quad (2^{nd} \text{ minimum})$$

Similary, slit is divided into $2n$ number of zones to get n^{th} minimum so that

$$\frac{a}{2n}\sin\theta = \lambda/2$$

$$a\sin\theta = n\lambda, \; (n = 1, 2, 3 \ldots) \quad (\text{minima - dark fringes})$$

Hence in between the secondary minima, the consecutive secondary maxima can be found for which the path difference is odd number multiple of $\lambda/2$

$$a\sin\theta = (2n+1)\lambda/2, \; (n = 1, 2, 3 \ldots) \quad (\text{secondary maxima - bright fringes})$$

let x_1 be the half-width of the central maximum = PP_1 D is the distance between slits and the screen. θ is the angle of diffraction and known as the half angular width of the central maximum.

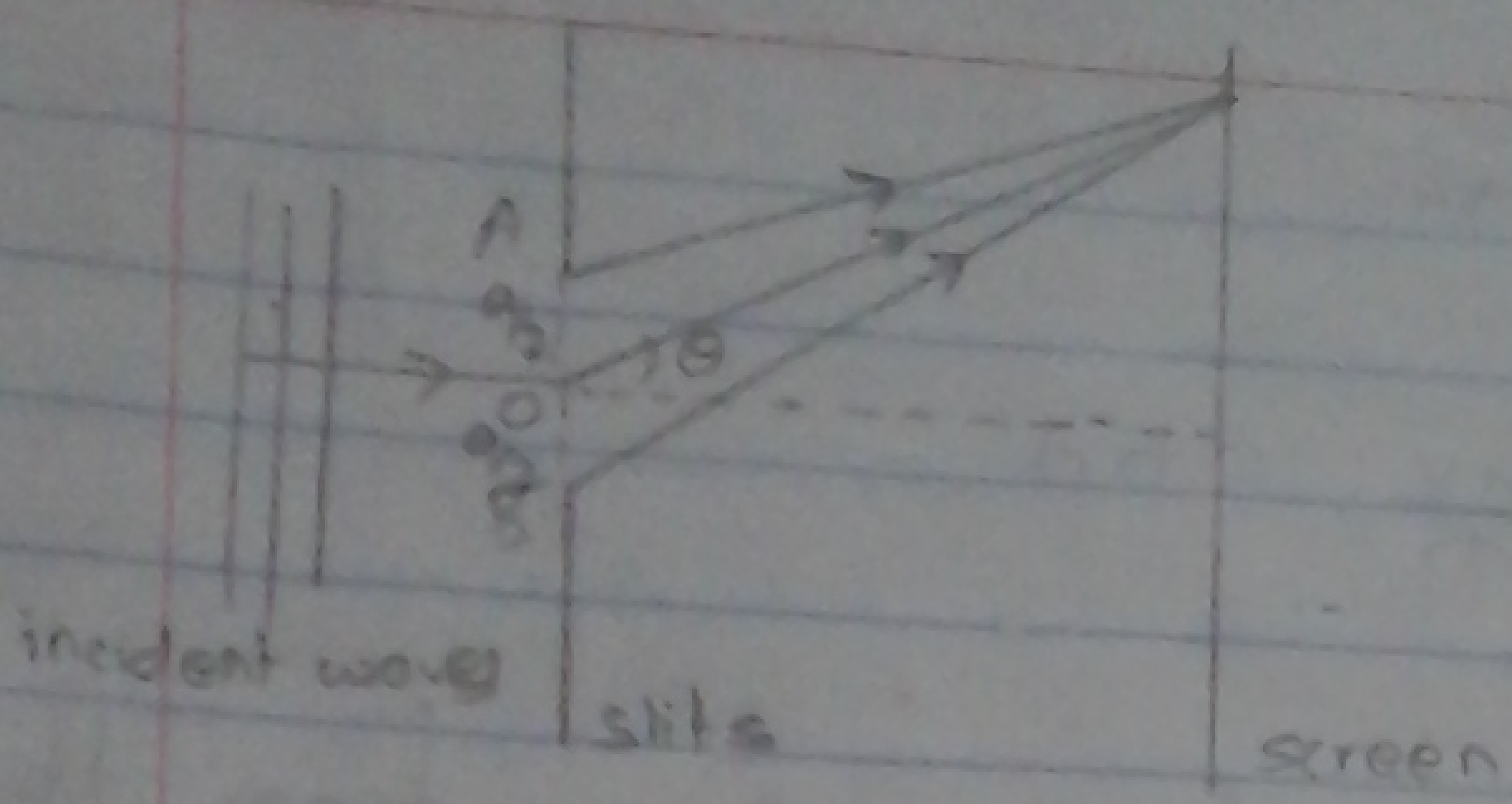
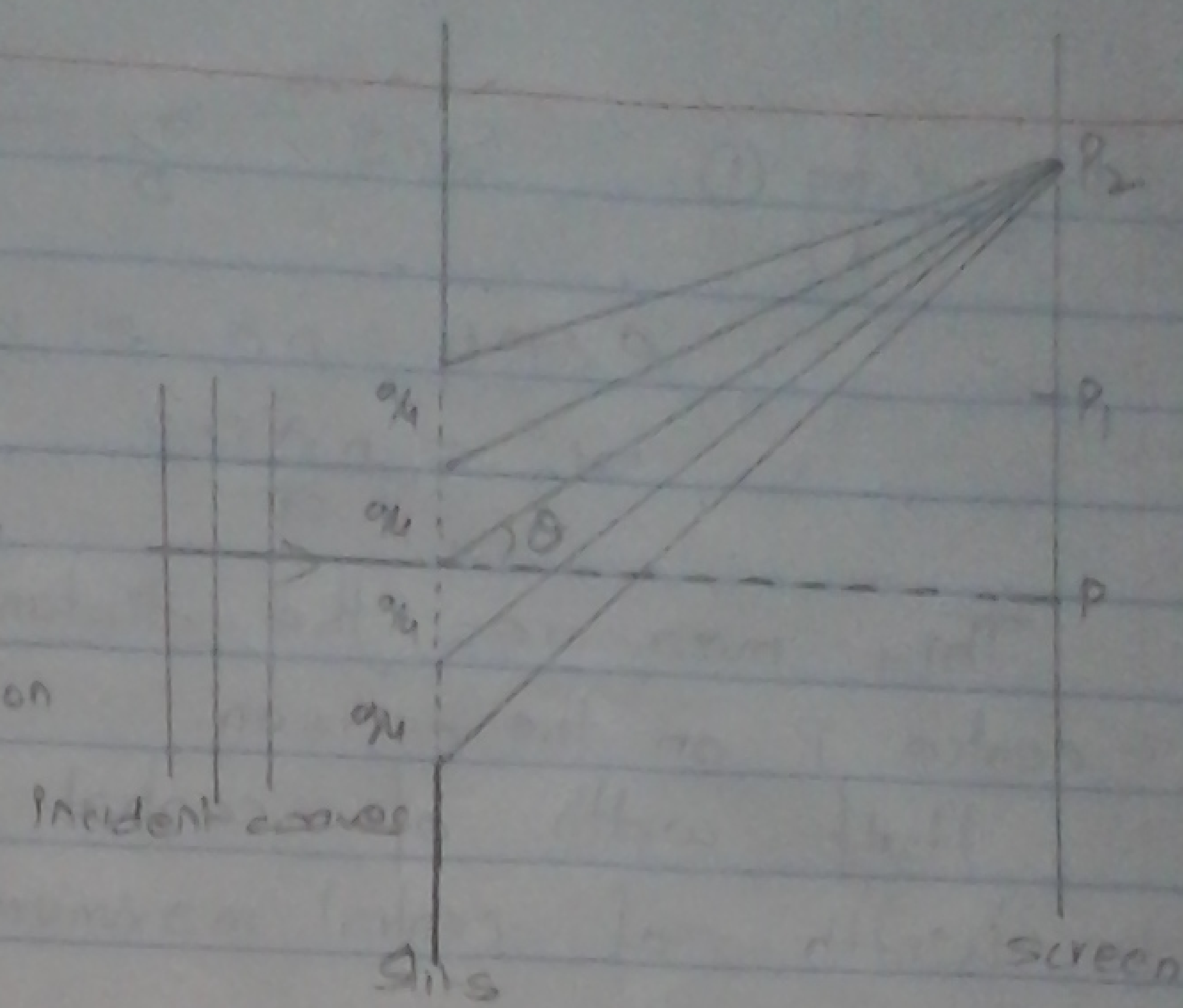


fig (ii) P_1 as first minimum on the screen



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let x_1 be the half-width of the central maximum $= PP_1$, D is the distance between slits and the screen. θ is the angle of diffraction and known as the half angular width of the central maximum.

From fig (1) $\sin\theta \approx \frac{x}{D}$

$$a\sin\theta = n\lambda = \frac{ax}{D} = n\lambda$$

$$x_n = \frac{n\lambda D}{a}$$

This measures the distance of n^{th} minimum from the centre P on the screen.

Half width of central maximum $= x_1 = \frac{\lambda D}{a}$

Width of central maximum $= 2x_1 = \frac{2\lambda D}{a}$

Also, angular width of central maximum $= 2\theta$

Width of secondary maxima $= \beta = x_{n+1} - x_n$

$$= \frac{\lambda D}{a}$$

Thus, the width of central maximum is double of the width of any other secondary maximum.

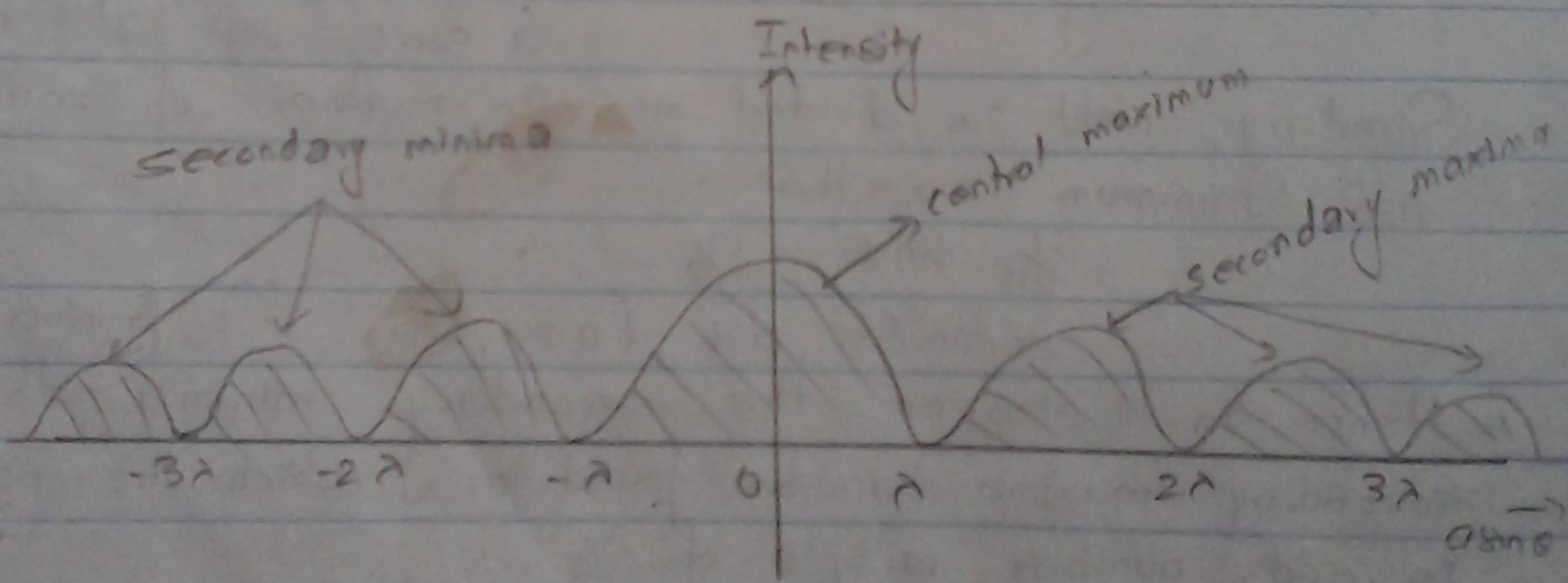

fig (iv) Intensity distribution (Intensity

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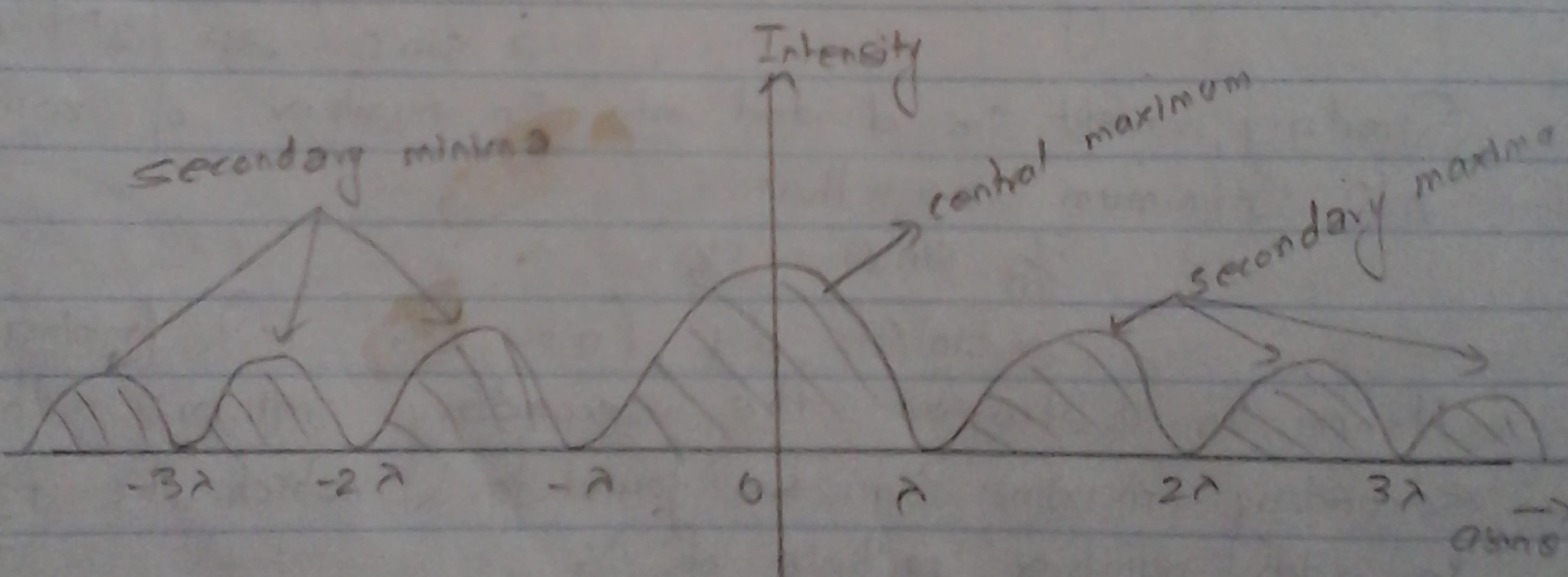
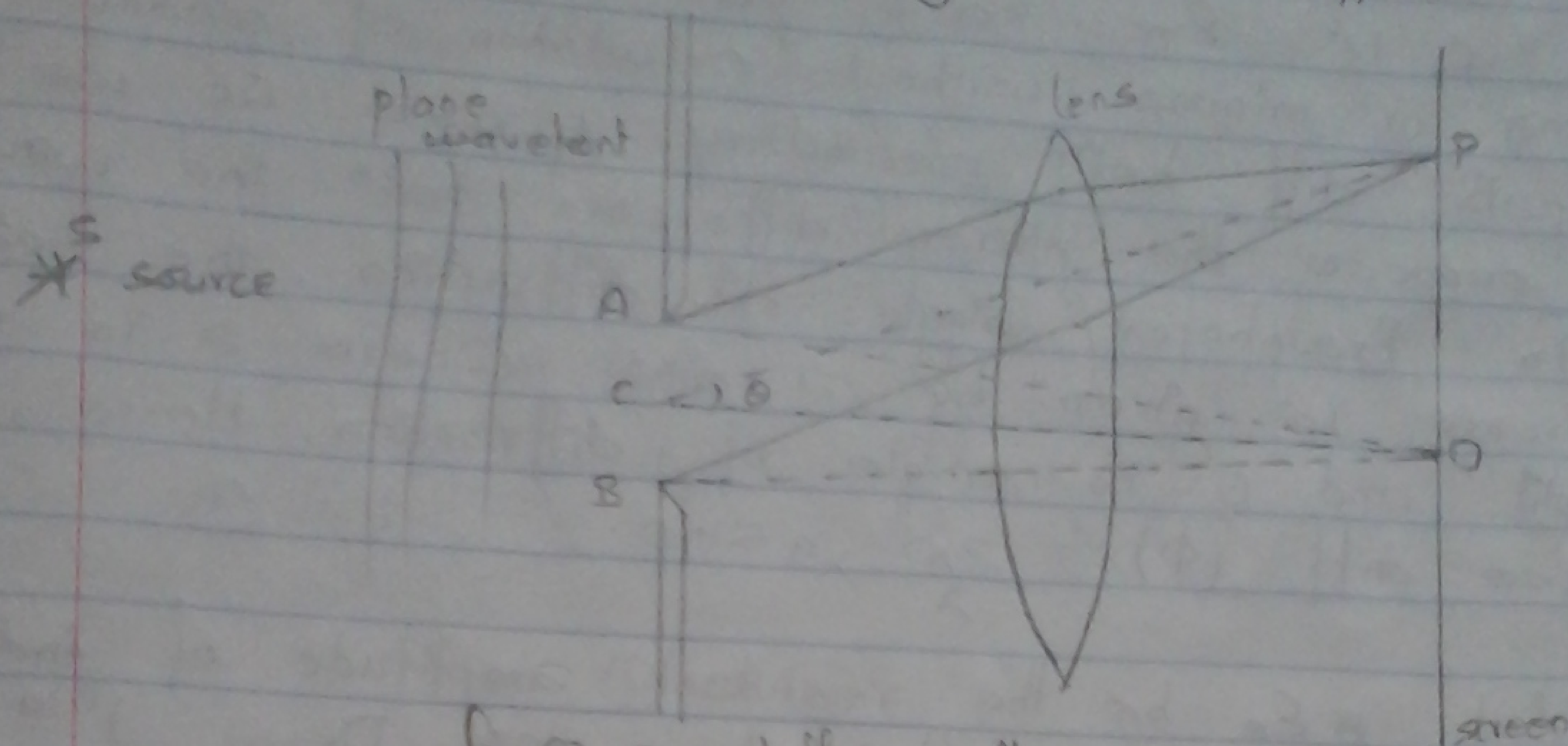
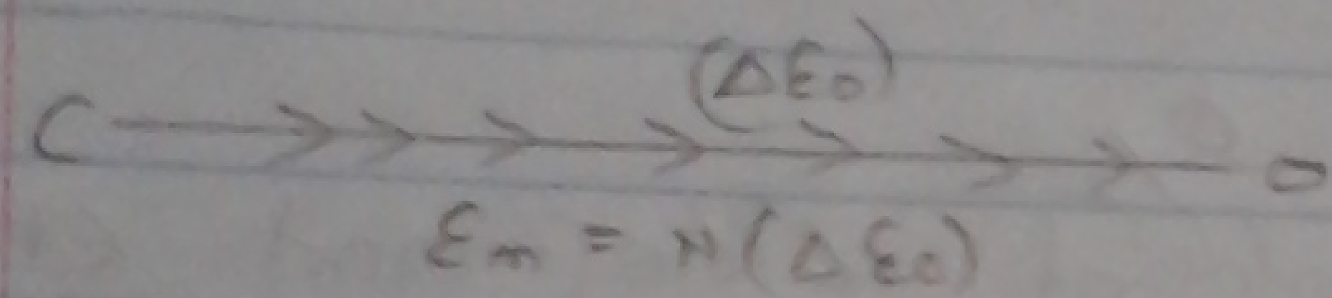


fig (iv) Intensity distribution / Intensity

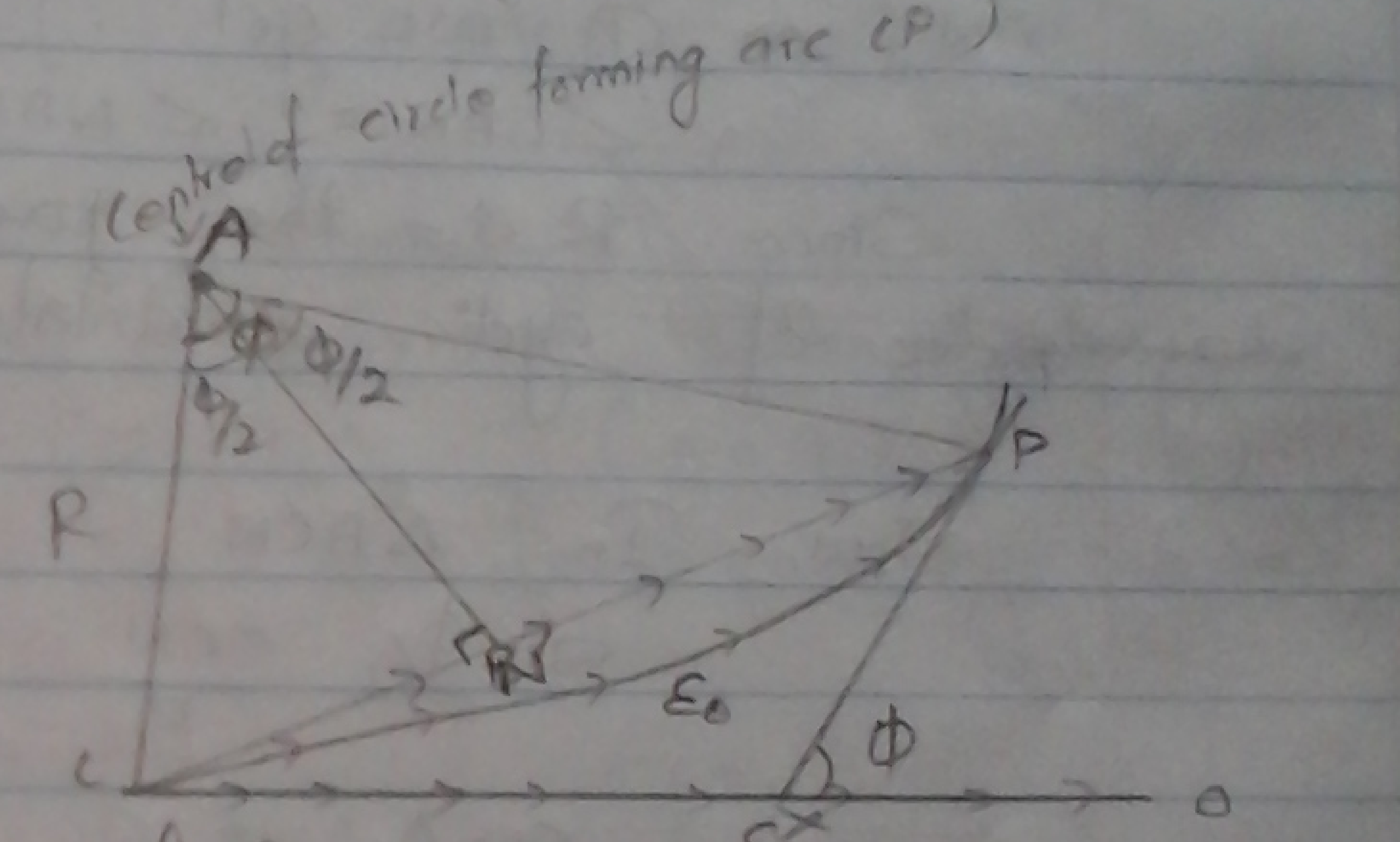
Intensity in Single slit diffraction :



fig① Fraunhoffer diffraction single slit



fig②: Symbolical representation of amplitude of waves



fig③

$\sin \frac{\phi}{2} = \frac{CB}{R}$

$\sin \frac{\phi}{2} = \frac{E_0}{2R}$

$E_0 = 2R \sin \frac{\phi}{2}$

$\angle A = \angle E_m$ (angle of cyclic quad)

$E_m \rightarrow$ amplitude of maxima

[path diff = $a \sin\theta$]

Light transferse in the form of quanta from one point to another in vaccum or medium. Let us consider the amplitude of each quanta be ΔE_m. Therefore, the total amplitude at any point is given by $E_m = N \cdot \Delta E_m$

Imp

Intensity in Single slit diffraction:

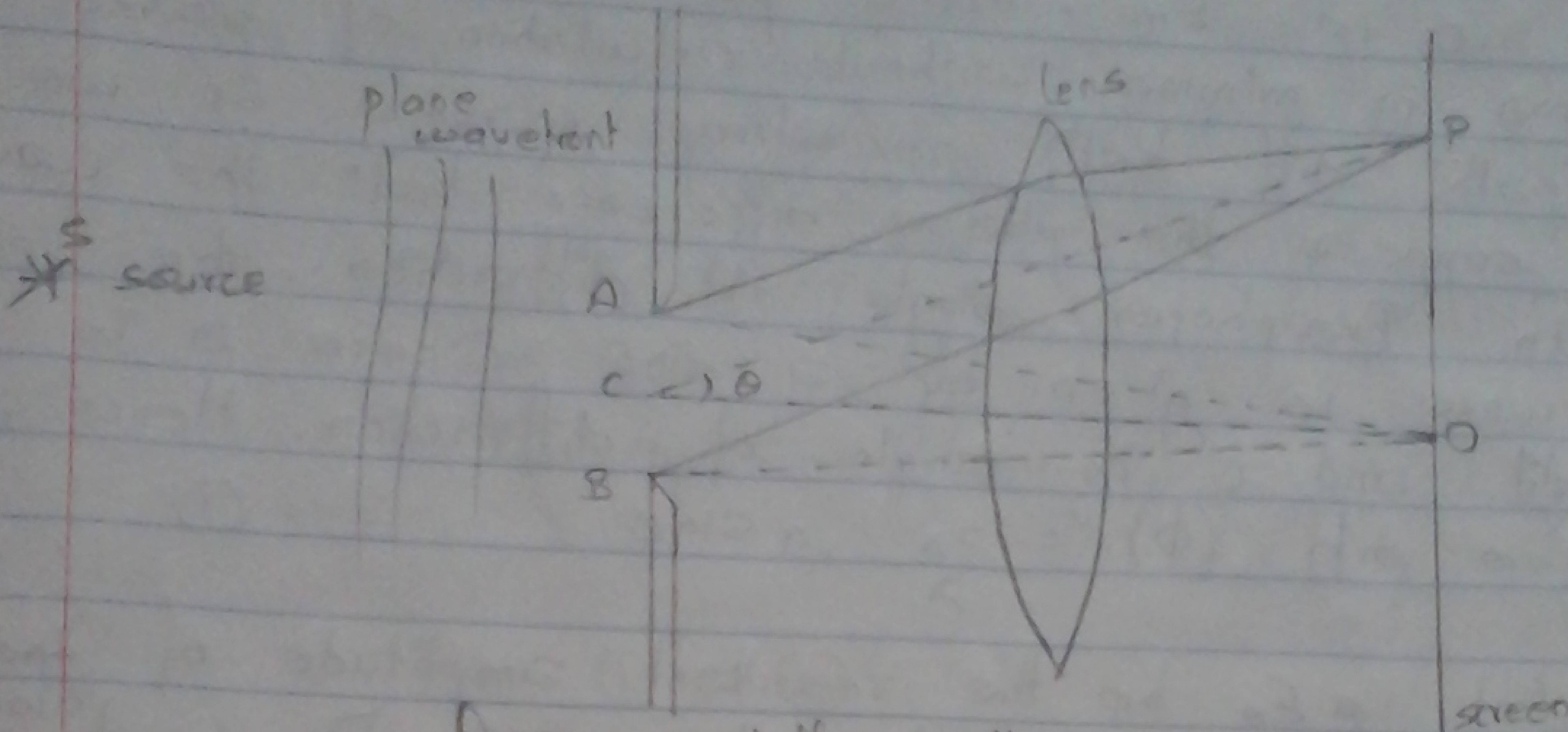
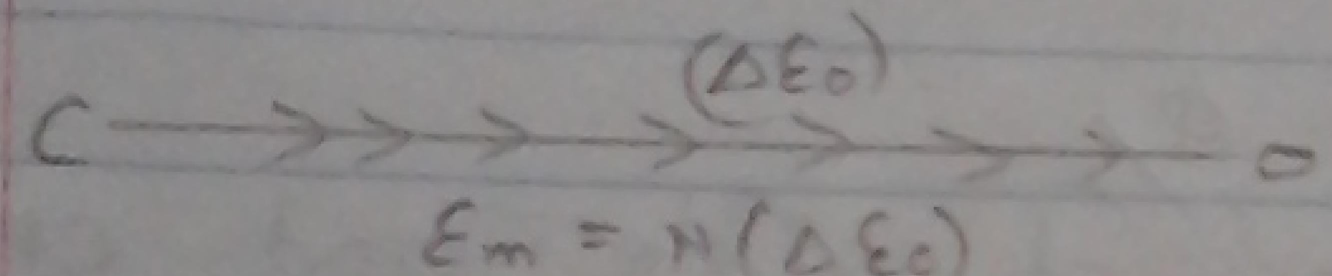


fig ① Fraunhoffer diffraction single slit



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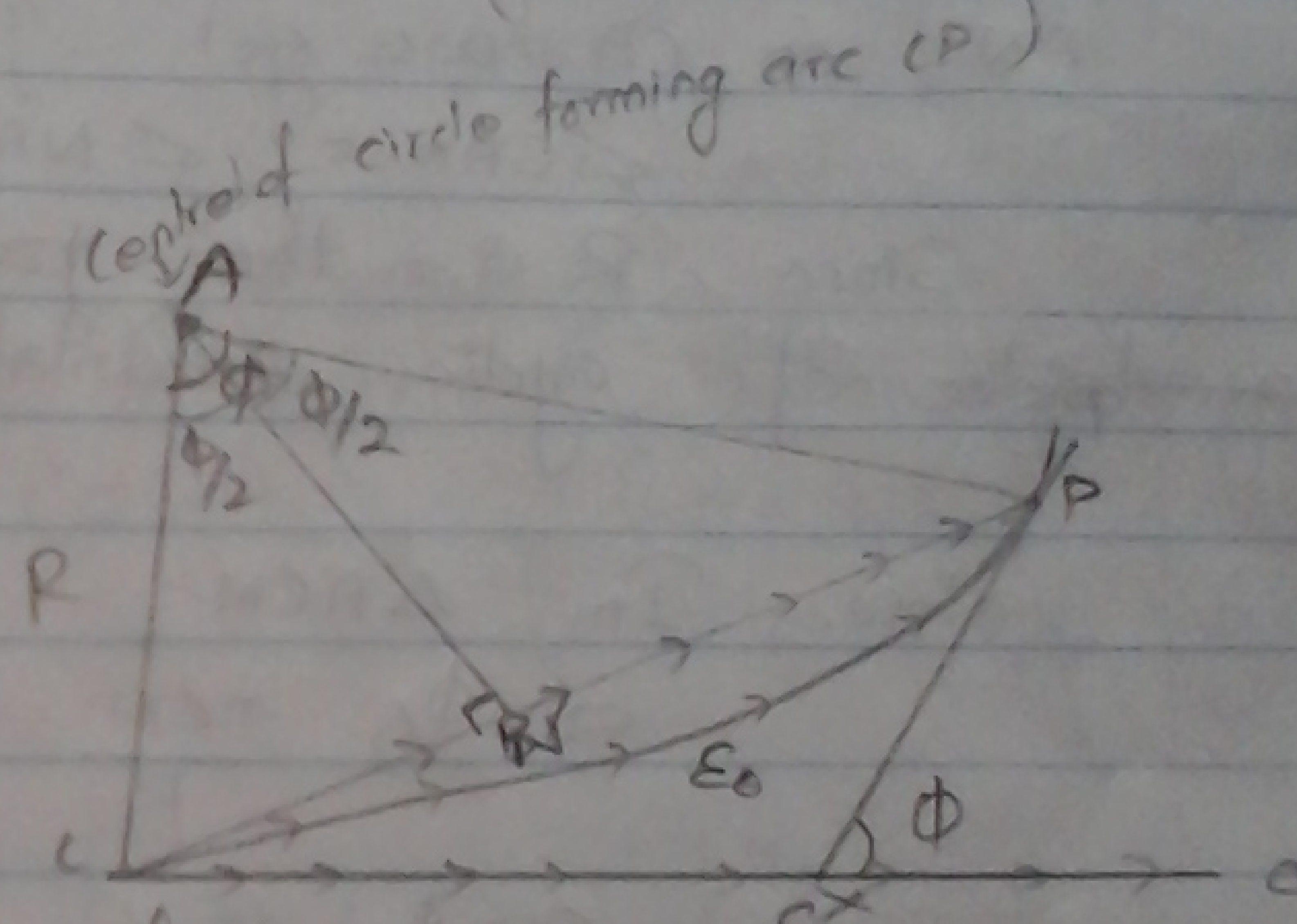

fig ③

$\angle A = \angle E_m$ (angle of cyclic quad.)

$E_m \to$ amplitude of maxima

[path diff = a sin θ]

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Light transfers in the form of quanta from one point to another in vaccum or medium. Let us consider the amplitude of each quanta be ΔE_m. Therefore, the total amplitude at any point is given by $E_m = N . \Delta E_m$

~~Fo~~ For the central maxima, the amplitude is maximum along CO i.e. $\mathcal{E}_m$. For a point P, we can't say the maxima or minima without calculation of phase diff or path diff betn secondary waves. So, we have to suppose the phase difference both the waves be ϕ. In Fraunhofer single slit diffraction, the path difference is given by $a \sin\theta$ where a is width of slit and θ is angle of diffraction. Hence, the phase diff $(\phi) = \frac{2\pi}{\lambda} \times a \sin\theta$ - - - - (1)

Let $\mathcal{E}_0$ be the resultant amplitude of ~~ind~~ individual amplitude of each quanta along CP. Draw $\perp$ular bisector AN on CP we get

$$\angle CAN = \angle NAP = \phi/2$$

Since R is the radius of circle and CP is the ~~diagonal side~~ of cyclic quadrilateral.

Now, In ΔACN

$$\sin\phi/2 = \frac{CN}{R}$$

$$\sin\phi/2 = \frac{\mathcal{E}_0}{2R} \quad \text{- - - (ii)}$$

and in sector ACP

$$\phi = \frac{\mathcal{E}_m}{R}$$

$$R = \frac{\mathcal{E}_m}{\phi} \quad \text{- - - (iii)}$$

From (ii) & (iii)

$$\sin\phi/2 = \frac{\mathcal{E}_0 \phi}{2 \times \mathcal{E}_m}$$

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From (ii) & (iii)

$$\sin \phi/2 = \frac{\mathcal{E}_0 \phi}{2 \times \mathcal{E}_m}$$

$$\frac{\varepsilon_0}{\varepsilon_m} = \frac{\sin \phi/2}{\phi/2}$$

Sq. on both sides:

$$\left(\frac{\varepsilon_\theta}{\varepsilon_m}\right)^2 = \left(\frac{\sin \phi/2}{\phi/2}\right)^2$$

$$\frac{I_\theta}{I_m} = \left(\frac{\sin \phi/2}{\phi/2}\right)^2$$

$$I_\theta = I_m \left(\frac{\sin \phi/2}{\phi/2}\right)^2 \quad \text{- - - (iv)}$$

From (1) & (iv)

$$I_\theta = I_m \left[\frac{\sin \frac{\pi}{\lambda} a \sin\theta}{\frac{\pi}{\lambda} a \sin\theta}\right]^2$$

Case (I) For central maxima, $\theta = 0$

$$\Rightarrow I_\theta = I_m \text{ (maximum Intensity) - - (v)}$$

Also, $a \sin\theta = (2n+1)\lambda/2$ $(n = 1, 2, 3 \ldots)$

for secondary maxima

Case (II): if ~~n = 1~~

$$I_\theta = I_m \left[\frac{\sin \frac{\pi(2n+1)}{2}}{\frac{\pi(2n+1)}{2}}\right]^2$$

a) if $n = 1$,

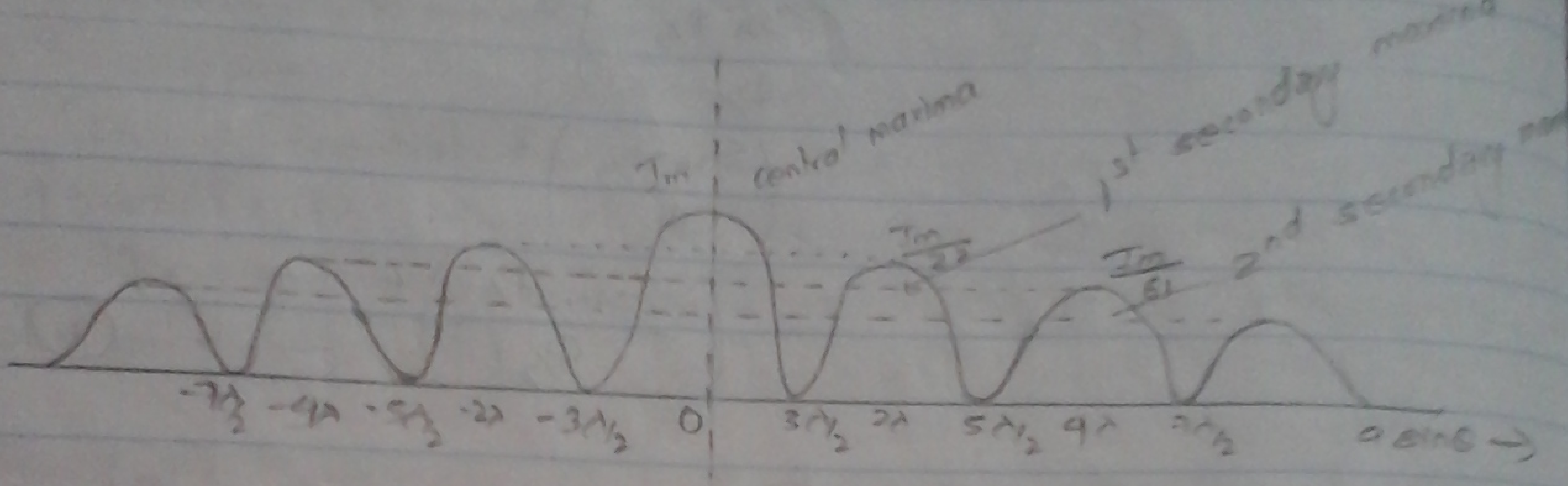
$$I_\theta = I_m \left(\frac{\sin 3\pi/2}{3\pi/2}\right)^2$$

$$I_\theta = \frac{I_m}{22} \quad \text{- - - (vi)}$$

b) if $n = 2$

$$I_\theta = I_m \left[\frac{\sin \frac{5\pi}{2}}{\frac{5\pi}{2}}\right]^2 = \frac{I_m}{61} \quad \text{- - - (vii)}$$

and so on, the intensity of diffracted light is decreas from the central maxima. It is the shown in below



Diffraction grating:

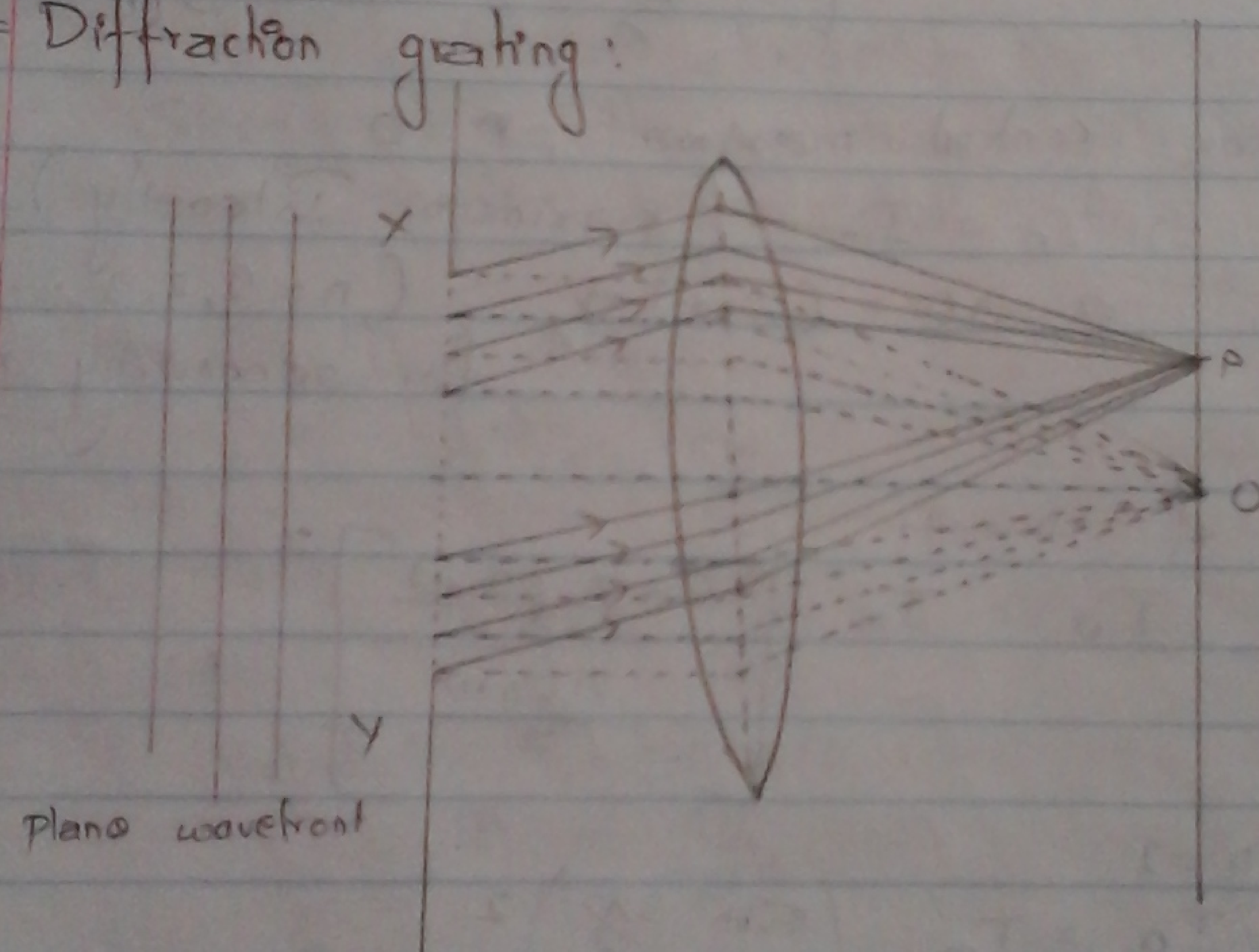
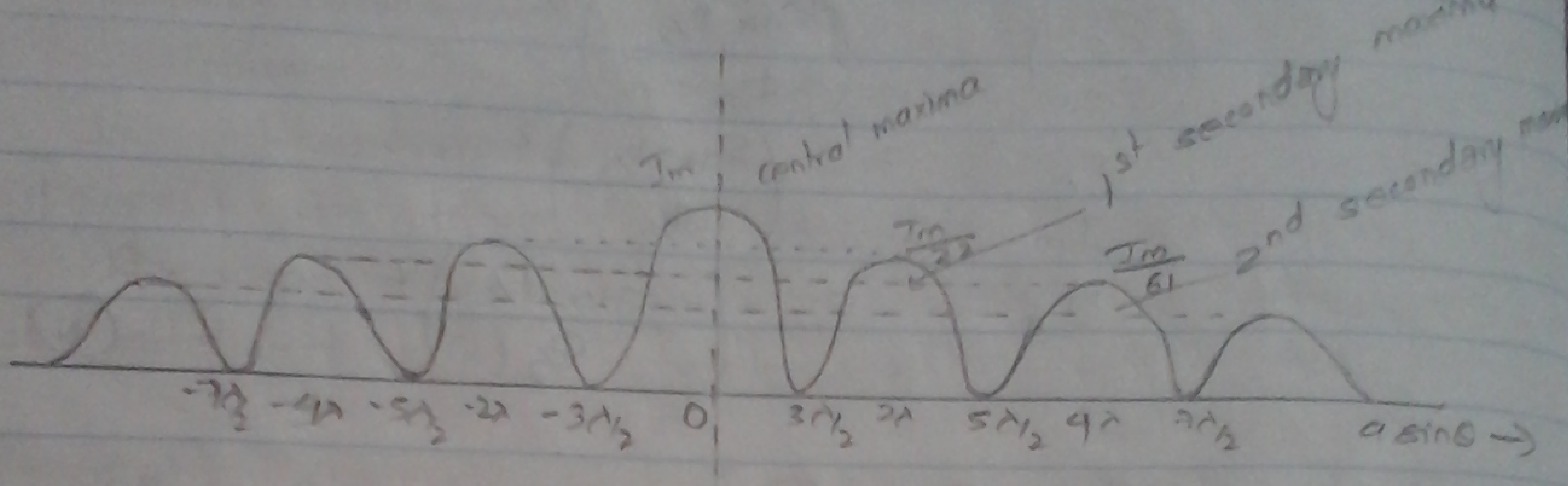


fig ① transparent and opaque portions are in alternative in a glass plate due to the sharp ruling of diamond (transmitted diff grating XY) and so on, the intensity of diffracted light is decreasing from the central maxima. It is the shown in below



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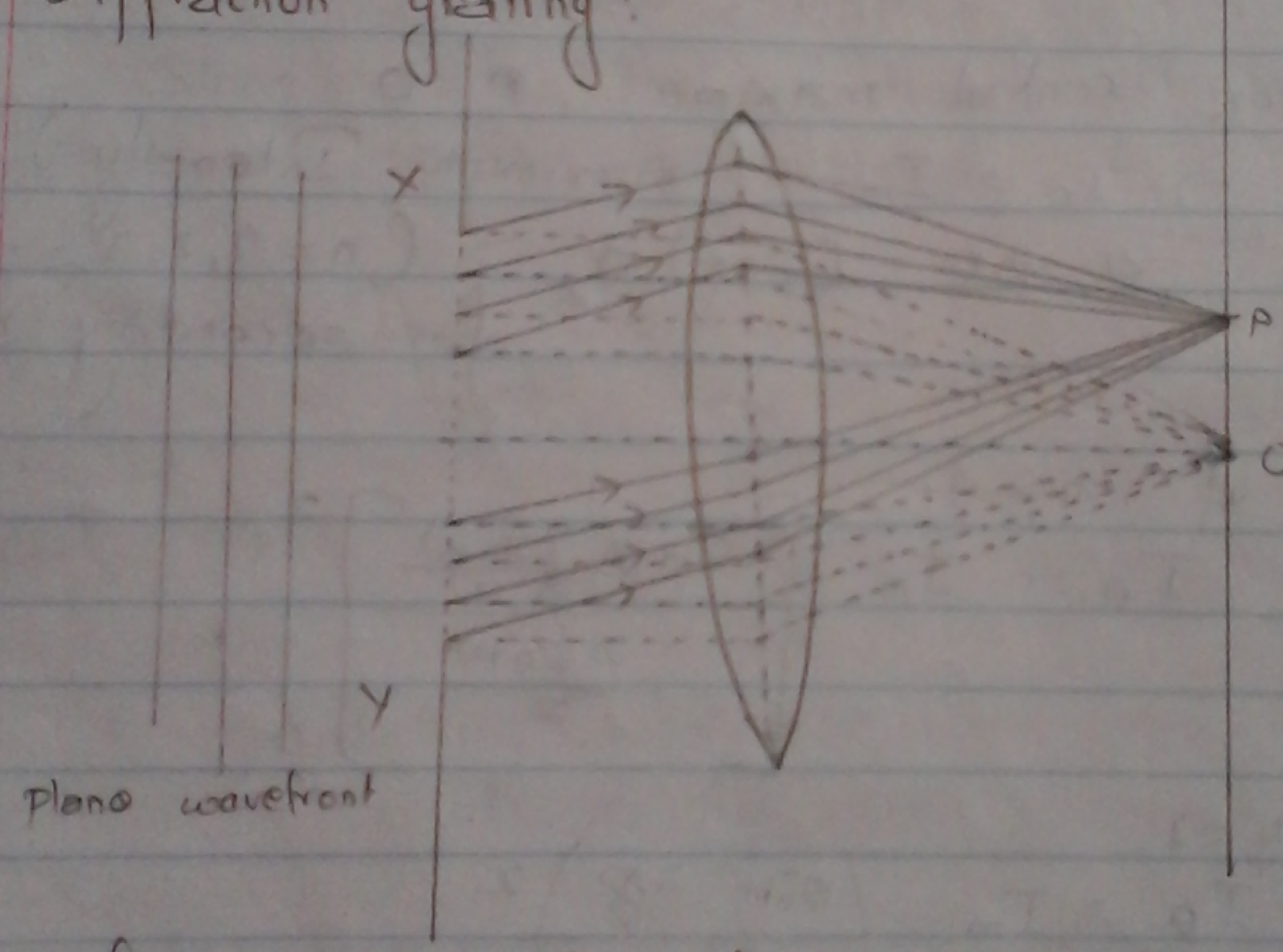

fig ① transparent and opaque portions are in alternative in a glass plate due to the sharp ruling of diamond (transmitted diff grating XY)

An optical device in which the alternative opaque and transparent portions are present and gets the diffractio is known as diffraction grating. The diamond sharp line act the opaque and in between the line the transparent ~~acts~~ portion acts to refraction of light.

There are two types of diffraction grating

1) Plane transmission diffraction grating:

In this grating the glass surface is coated by sharp line of diamond and the diffraction ~~to~~ takes place due to the transmission of light. ~~th~~ The width of transparent and opaque is known as grating element. ~~A~~ 'a' is denoted as width of transparent and 'b' is denoted as the width of opaque. Therefore (a+b) is the difraction grating element. Mostly,

$$a+b = \frac{2.54}{N} \text{ cm}$$

where N is the no. of lines per inch.

2) Reflected grating:

In this grating, the metal surface is coated by metal oxide and ~~tat~~ diffraction pattern takes due to reflection of light.

In the transmission grating path diff

$$= (a+b)\sin\theta$$

The ray of ~~e~~ light diffracted from upper wedge, transparent and lower wedge, one of the ray is cancelled out then the diffraction pattern is maximum ~~is~~ at P if path diff $= n\lambda$

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∴ For bright or maxima,

$(a+b) \sin\theta = n\lambda \quad (n = 1, 2, 3 \ldots)$

Similarly, for dark diffraction or minima

$(a+b) \sin\theta = (2n+1)\lambda/2$

where $(n = 1, 2, 3 \ldots)$.

Q.1) In Fraunhofer diffraction due to a narrow slit a screen is placed 2m away from the lens to obtain the pattern. If the slit width is 0.2mm and the 1st minima lie 5mm on either side of the ~~max~~ central maxima. Find the wavelength of light. (500)

Q.2) Diffraction pattern of a single slit of width 0.5cm is formed by a lens of focal length 40cm. Calculate the distance betn the 1st dark and next bright fringe from the axis ($\lambda = 5000 A^\circ$)

[Ans: 1.6×10^{-2} mm]

Q.3) The path difference between the two intensities at a point on the screen is $\frac{1}{8}$ of the wavelength. Find the ratio of intensity at this point to that at centre of central maxima. [Ans: 95%]

Q.4) A grating width 15000 ruling per inch is eliminated normally with white light extending from $4000 A^\circ$ - $7000 A^\circ$. show that only the 1st order spectrum is isolated but 2nd and third order overlap.

Q.5) Light is incident on a grating of total ruled width 5×10^{-3} m ~~lines~~ with 2500 lines in all. Find the angular seperation of sodium lines in the first order spectrum. Wavelength of lines are 589 nm and 5896 nm. Can they be seen distinctly?

Q.1 ⇒ Soln;

$D = 2m$

$a = 0.2m = 0.2 \times 10^{-3}$

$x = 5mm = 5 \times 10^{-3}$

$\lambda = ?$

We have;

$$x = \frac{\lambda D}{a}$$

$$5 \times 10^{-3} = \frac{\lambda \times 2}{0.2 \times 10^{-3}}$$

$$\therefore \lambda = 5000 A^{\circ}$$

Q.2 ⇒ Soln;

$$\frac{x_1}{f} = \frac{\lambda}{a} \quad (1^{st} \text{ minimum})$$

$$x_1 = \frac{f\lambda}{a} = \frac{0.4 \times \cancel{5}000 \times 10^{-10}}{\cancel{5} \times 10^{-3}}$$

$$= 400 \times 10^{-7} m$$

For 1^{st} secondary maxima : $x_2 = \frac{3f\lambda}{2a}$ $\left(\because a \sin\theta_n = (2n+1)\lambda/2 \right.$

$$\therefore x_2 = \frac{3}{2} \times 400 \times 10^{-7} = 600 \times 10^{-7} m$$

Now, $x_2 - x_1 = (600 - 400) \times 10^{-7} m$

$= 200 \times 10^{-7} m$

Q.3 ⇒ Solⁿ;

Here,

$$I_o = I_m \left(\frac{\sin\alpha}{\alpha}\right)^2 \quad \text{--- (1)}$$

We know,

$$\alpha = \frac{\pi}{\lambda} a \sin\theta$$

$$= \frac{\pi}{\lambda} \times \frac{\lambda}{8} \quad \left(\text{as it is } \frac{1}{8}^{th} \text{ of the wavelength}\right)$$

$$\therefore \alpha = \pi/8$$

Now, putting the value of α in eqⁿ (1)

$$\frac{I_o}{I_m} = \left(\frac{\sin \pi/8}{\pi/8}\right)^2$$

$$= 95\%$$

∴ The ratio of two intensities is 0.95

Q.4) ⇒ Solⁿ,

rulings per inch ~~(a+b) 15000~~ $= \frac{2.54}{15000}$ cm

Here, we find the highest order for the spectrum (4000 - 7000) A° for which max value of

$$\sin\theta_n = 1$$

We know,

$$(a+b) = n_1\lambda_1$$

$$n_1 = \frac{(a+b)}{\lambda_1} \quad (\text{for } \lambda_1 = 4000\ A^\circ)$$

$$= \frac{2.54}{15000} \times \frac{1}{4000 \times 10^{-8}} = 4$$

Again,

$$(a+b) = n_2 \lambda_2$$

$$n_2 = \frac{(a+b)}{\lambda_2} \quad (\text{for } \lambda_2 = 7000\,A^\circ)$$

$$= \frac{2.54}{15000} \times \frac{1}{7000 \times 10^{-8}}$$

$$= 2$$

Hence; the orders in the visible range are 2 and 4 but ~~Q.5) Soln~~, the first order is isolated.

Since the range of λ (4000-7000) A°, 4000 A° is exclusive so it's corresponding 4th diffraction order is isolated & remaining 2nd & 3rd are common for the wavelengths. Hence 2nd & 3rd order overlapp in between (4000-7000) A°

Q.5) ⇒ Soln,

Here,

$$N = 2500 \text{ lines}/0.5\text{cm}$$

$$a+b = \frac{1}{N} = \frac{1}{5000}\text{ cm}$$

$$(a+b)\sin\theta_1 = n\lambda_1 \quad (n = 1,\ \lambda_1 = 589\text{ mm})$$

$$\sin\theta_1 = 1 \times 0.589 \quad \therefore \theta_1 = 36.08^\circ$$

$$(a+b)\sin\theta_2 = n\lambda_2 \quad (n_2 = 1,\ \lambda_2 = 589.6\text{ mm})$$

$$\therefore \sin\theta_2 = 1 \times 0.5896$$

$$\theta_2 = 36.12^\circ$$

$$\therefore \text{Angular seperation} = \theta_2 - \theta_1$$

$$= 36.12 - 36.08$$

$$= 0.04^\circ$$

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

$$\lambda_1 = 589\text{mm} = 589 \times 10^{-3}\text{m}$$

$$\lambda_2 = 589.6\text{mm} = 589.6 \times 10^{-3}\text{m}$$

$$\lambda = \frac{\lambda_1 + \lambda_2}{2} = 589.3 \times 10^{-3}\text{ m}$$

$$d\lambda = 0.6 \times 10^{-3}\text{ m}$$

$$N' = \frac{589.3 \times 10^{-3}}{0.6 \times 10^{-3}}$$

$$= 982.16 \text{ lines/m}$$

Since $N' < N$

⇒ can't see distinctly.

Again,

$$(a+b) = n_2 \lambda_2$$

$$n_2 = \frac{(a+b)}{\lambda_2} \quad (\text{for } \lambda_2 = 7000\,A^\circ)$$

$$= \frac{2.54}{15000} \times \frac{1}{7000 \times 10^{-8}}$$

$$= 2$$

Hence; the orders in the visible range are 2 and 4 but ~~Soln~~, the first order is isolated.

Since the range of λ (4000-7000) A°, 4000 A° is exclusive so it's corresponding 4th diffraction order is isolated & remaining 2nd, 3rd are common for the wavelengths. Hence 2nd & 3rd order overlapp in between (4000-7000) A°

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Dispersive and Resolving Power :

Dispersive power of grating is the rate of change of angular diffraction per change in wavelength of the incident ray of light.

i.e.

$$\text{Dispersive power} = \frac{d\theta}{d\lambda}$$

We have,

$$(a+b)\sin\theta = n\lambda \quad (\text{for secondary Maxima})$$

or, $$(a+b)\cos\theta \frac{d\theta}{d\lambda} = n$$

$$\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta}$$

$$\therefore \frac{d\theta}{d\lambda} = \frac{n}{(a+b)\sqrt{\frac{(a+b)^2 - n^2\lambda^2}{(a+b)^2}}}$$

Resolving power :

The resolving power of grating is the ability to resolve the nearest wavelength of the different light (comparison of nearest wavelength of light). Mathematically, it can be resolved as,

$$\text{resolving power} = \frac{\lambda}{d\lambda} = Nm$$

where λ means mean of two wave's wavelength and $d\lambda$ is the difference between them.

N = No. of lines per cm

m = order of diffraction

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