Wave Optics

Interference Of Light

Wave Theory
Light is a form of energy which travels through a medium in the form of tranverse wave motion. The speed of light in a medium depends upon the nature of medium.

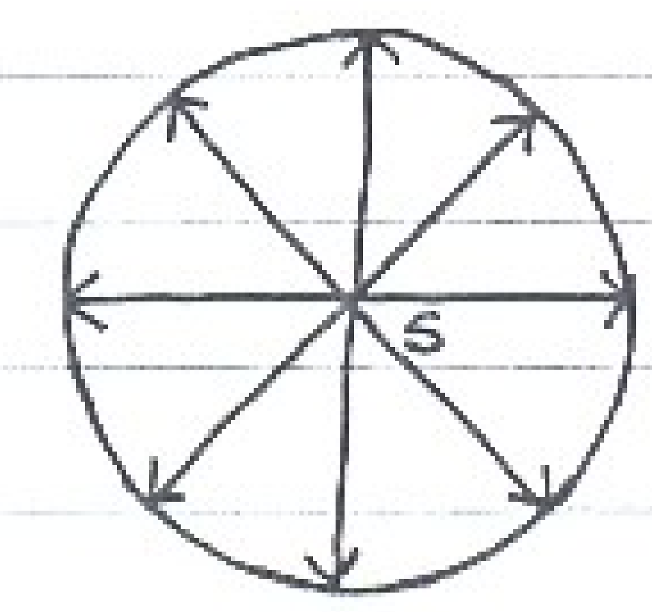
Wavefront
The locus of all the particles of the medium, which at any instant are vibrating in the same phase is called wavefront.

Types of wavefront

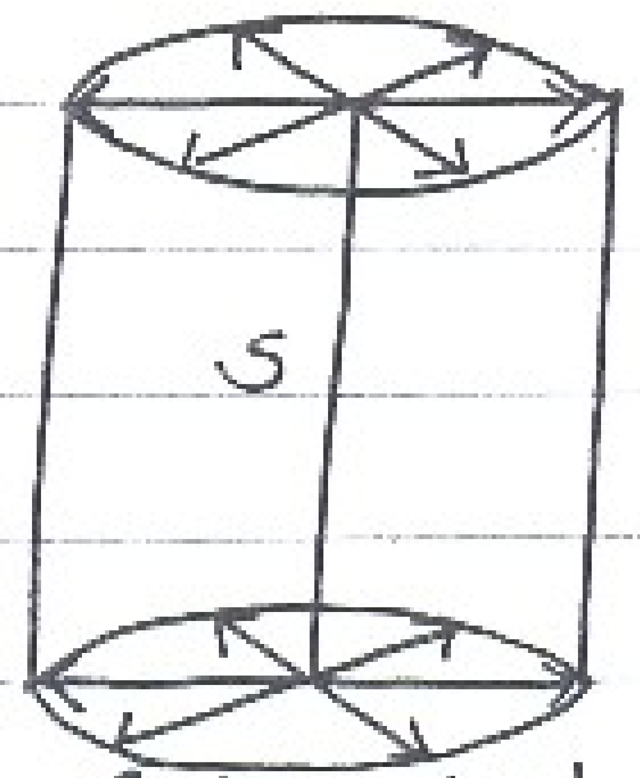
1. **Spherical wavefront**
When the source of light is a point source, the wavefront is a sphere, with centre at the source.

2. **Cylindrical wavefront**
When the source of light is linear (e.g. slit), the wavefront is cylindrical as all the points equidistant from the source lie on the cylinder.

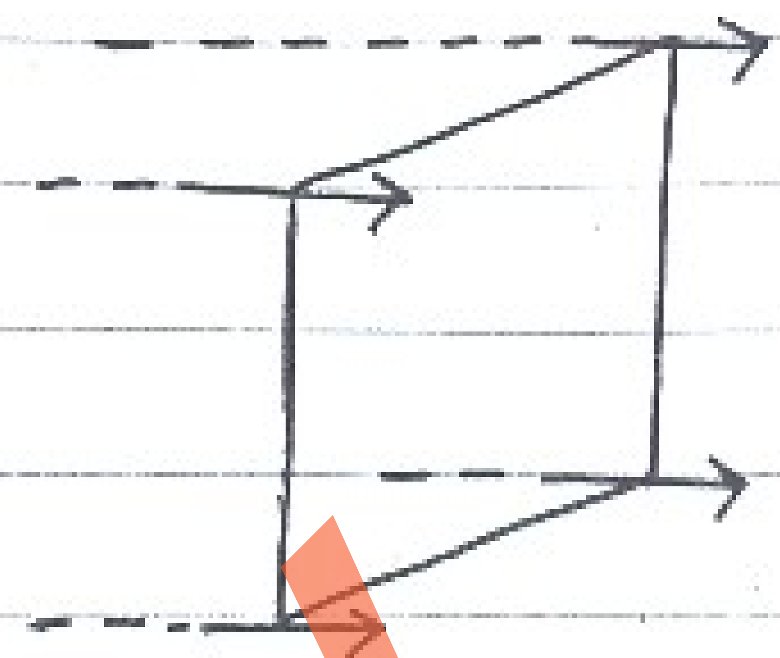
3. **Plane wavefront**
When the point or linear source of light is at very large distance, a small portion of spherical or cylindrical wavefront appears to be plane & is called as plane wavefront.



Spherical



Cylindrical

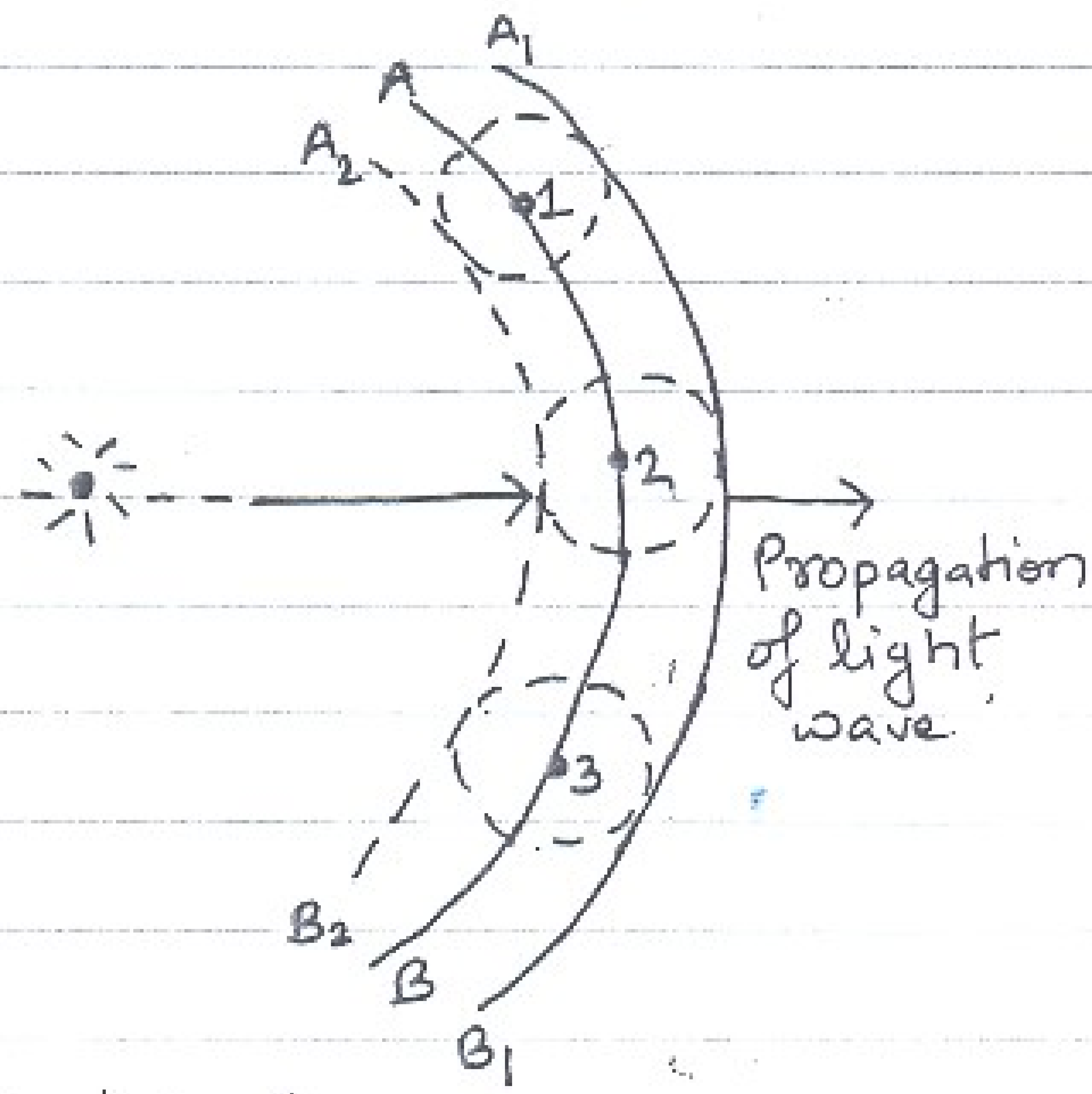


Plane

Huygen's Principle

① Every point on the given wavefront (primary wavefront) acts as a fresh source of new disturbance, called secondary wavelets, which travel in all directions with the velocity of light in the medium

② A surface touching these secondary wavelets, tangentially in the forward direction at any instant gives the new wavefront at that instant.



→ AB section of spherical wavefront (primary wavefront)

→ Distance travelled by light in 't' sec. = $c \times t$

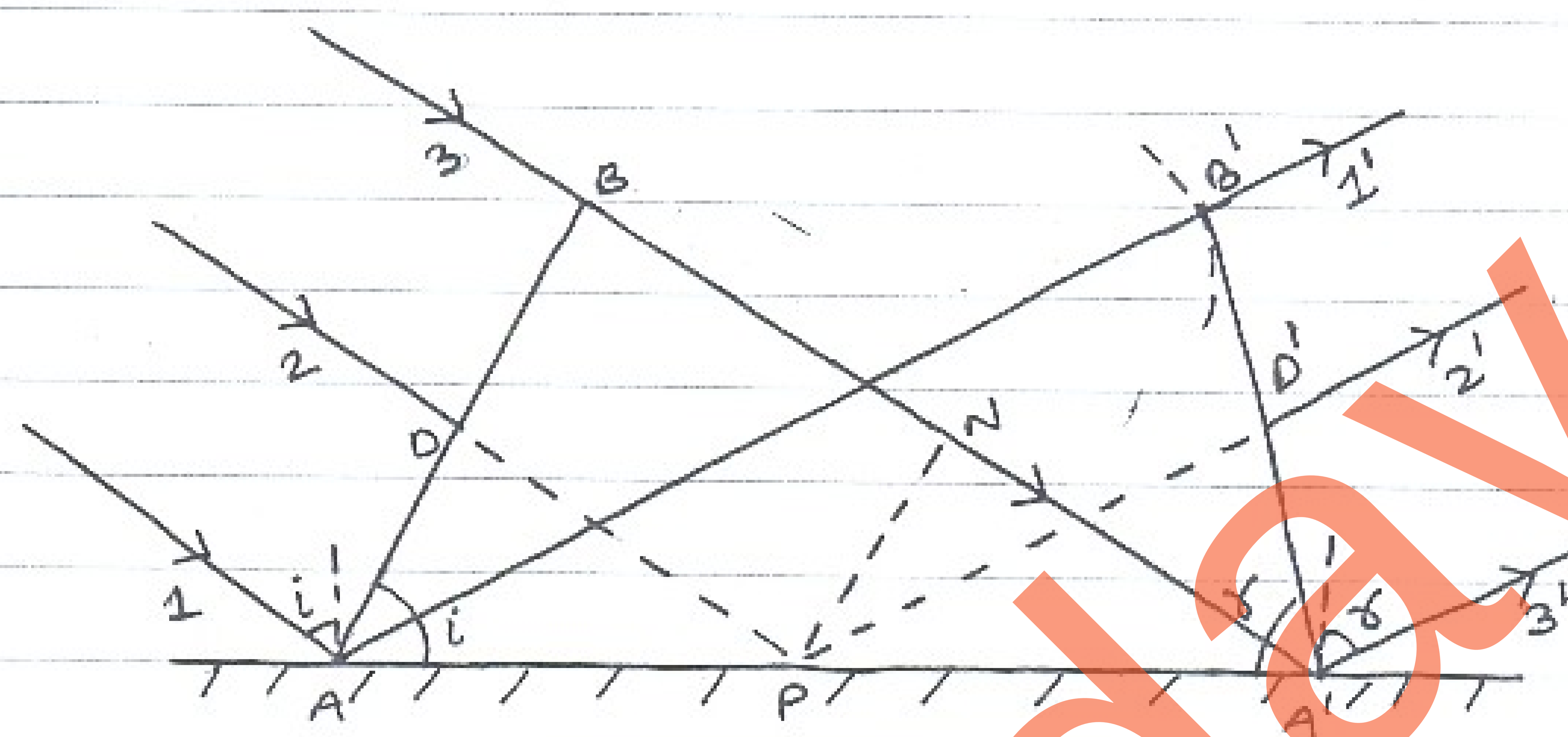
→ With $(c \times t)$ as radius & points 1, 2, 3 as centre draw spheres.

→ Draw A_1B_1 & A_2B_2

A_1B_1 - secondary wavefront

A_2B_2 - secondary wavefront in backward direction (which Huygen said is zero, also it is contrary to observation), So not to be considered.

Reflection on the basis of Wave Theory



Let AB be a plane wavefront incident on a plane mirror at $\angle BAA' = \angle i$

Acc. to Huygen's principle, every point on AB is a source of secondary wavelets.
Let the secondary wavelets from B strikes the mirror at A' in 't' seconds

$\therefore \quad BA' = c \times t$

The secondary wavelets from A will travel the same distance $(c\times t)$ in the same time. So, with A as centre and $(c \times t)$ as radius, draw an arc B'

From A', draw a tangent plane A'B' touching the arc at B'. So, A'B' is the secondary wavefront after 't' seconds.

In $\Delta AA'B$ & $\Delta AA'B'$

$AA' = AA'$ [common]

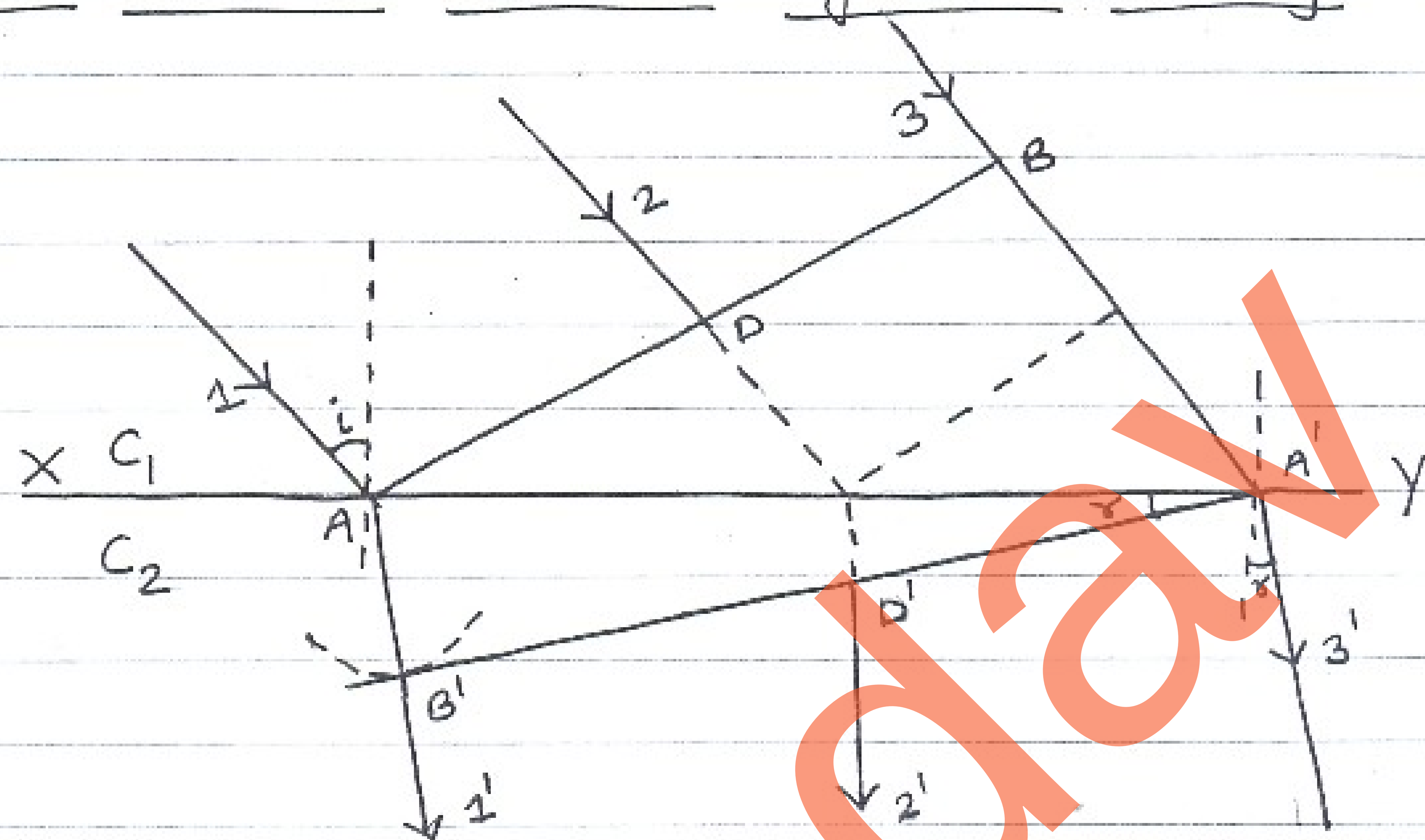
$\angle B = \angle B' = 90^\circ$

$BA' = AB' = c \times t$

$\therefore \quad \Delta AA'B \cong \Delta AA'B'$ [SAS congruence]

$\boxed{\angle BAA' = \angle B'A'A \Rightarrow \angle i = \angle r}$ [proved]

Refraction on the basis of Wave Theory



Let XY be a plane surface that separates a denser medium of refractive index μ from a rarer medium.

$$\mu = \frac{C_1 \text{ (speed of light in rarer medium)}}{C_2 \text{ (speed of light in denser medium)}}$$

Let AB be a plane wavefront incident on XY at $\angle BAA' = \angle i$.

Acc. to Huygen's principle, every point on AB is a source of secondary wavelets.

Let the secondary wavelets from B strikes XY at A' in t seconds so $BA' = c \times t$

The secondary wavelets from A travel in denser medium with velocity c_2 & would cover a distance $(c_2 \times t)$ in 't' seconds. So, with A as centre & radius $(c_2 \times t)$ draw an arc B'.

From A', draw a tangent plane touching the arc at B'. So, $A'B'$ is the secondary wavefront.

In $\Delta AA'B$, $\sin i = \frac{BA'}{AA'} = \frac{c_1 \times t}{AA'}$

In $\Delta AA'B'$, $\sin r = \frac{AB'}{AA'} = \frac{c_2 \times t}{AA'}$

$$\therefore \boxed{\frac{\sin i}{\sin r} = \frac{c_1}{c_2} = \mu}$$

Superposition Principle

When 2 or more wave motions travelling through a medium superimpose one another, a new wave is formed in which resultant displacement at any instant is equal to the vector sum of the displacements due to individual waves at that instant.

$$\vec{y} = \vec{y}_1 + \vec{y}_2 + \text{------}$$

Coherent Sources

The sources of light which emit continuous light waves of the same wavelength, same frequency & in same phase or having a constant phase difference are called coherent sources.

Conditions for obtaining two coherent sources

① Coherent sources of light should be obtained from a single source

[The coherent sources can be obtained by -

(i) source & its virtual image

(ii) 2 virtual images of same source.

(iii) 2 real " " "]

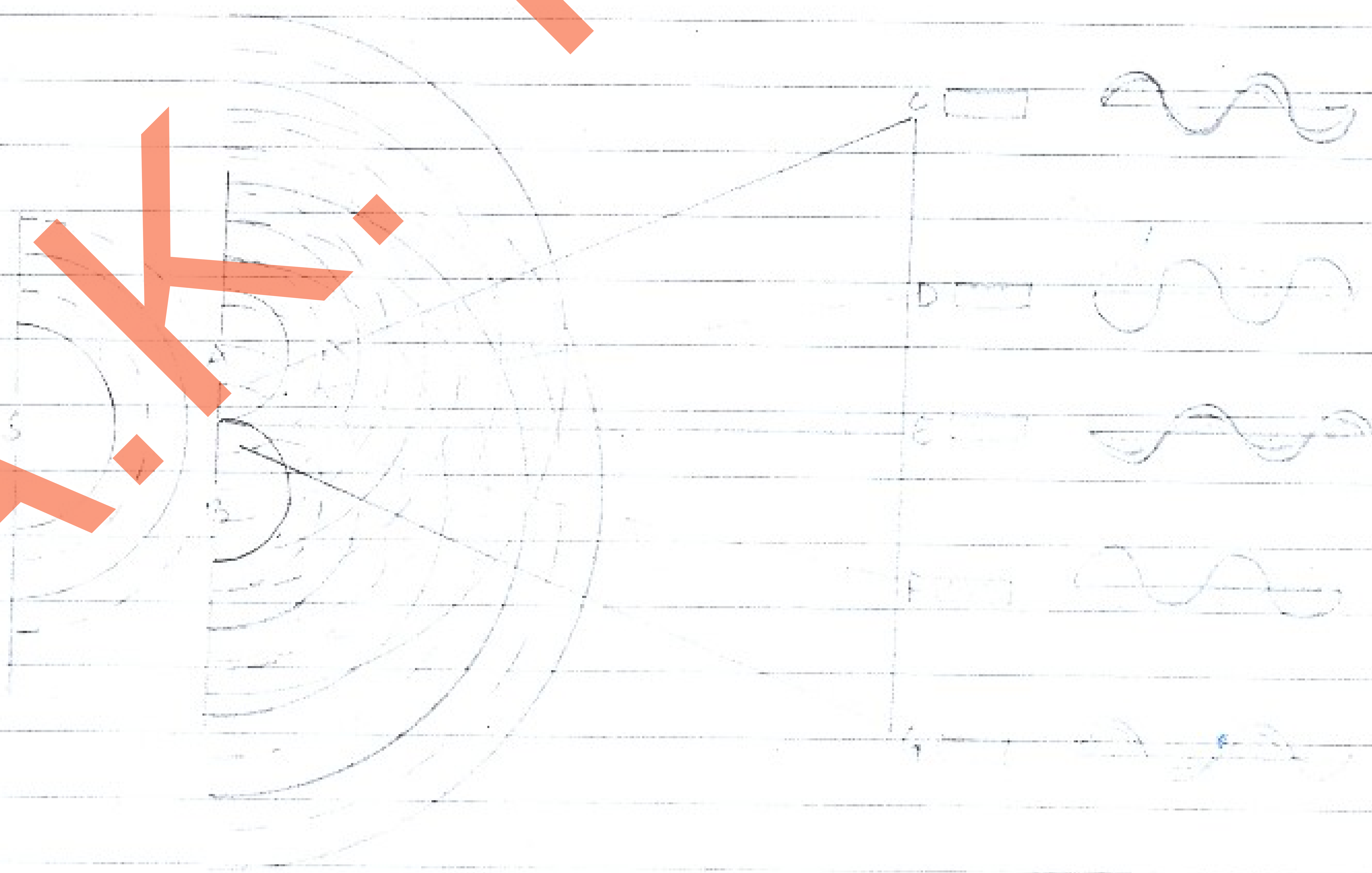
(2) The 2 sources should give monochromatic light.
(3) The path difference betⁿ light waves from two sources should be small.

Interference of Light

It is the phenomenon of redistribution of light energy in a medium on account of superposition of light from 2 coherent sources.

max. resultant intensity – constructive interference
min. " " – destructive "

Young's Double Slit Experiment



→ S is a narrow slit (≈ 1mm width) illuminated by a monochromatic source of light.

→ At a suitable distance (≈ 10 cm) from S, 2 fine slits A & B (0.5 mm apart) are placed symmetricall[y] parallel to S.

→ When a screen is placed at a large distance (≈ 2m) from A & B alternate bright & dark fringes running parallel to the lengths of slits appear on the screen

Explanation

Monochromatic source of light illuminated ~~by~~ S, sends out spherical wavefront.

solid arc – crest
dotted " – trough

↓

Wavefronts reach A & B simultaneously, becomes secondary wavelets

↓

So, 2 waves of same amplitude & same frequency with zero phase difference are given by A & B.

↓

These waves on superposition produce interference.

Constructive → 1. crest/trough of one wave falls on crest/trough of other.
2. resultant amplitude & intensity of light max.

Destructive → 1. crest of one wave on trough of other & vice versa
2. resultant amplitude & intensity of light min.

* If S (source of white light) – fringes coloured, width unequal

Conditions for constructive & destructive interference

Let the waves from 2 coherent sources of light be

$$y_1 = a \sin \omega t$$
$$y_2 = b \sin(\omega t + \phi)$$

where a, b - amplitude of the 2 waves
ϕ - constant phase angle.

Acc. to superposition principle, displacement of resultant wave is

$$y = y_1 + y_2$$

$$= a \sin \omega t + b \sin(\omega t + \phi)$$
$$= a \sin \omega t + b \sin \omega t \cos \phi + b \cos \omega t \sin \phi$$
$$y = \sin \omega t \,(a + b\cos\phi) + \cos \omega t \cdot b \sin \phi \quad \text{—(1)}$$

Let $a + b\cos\phi = R\cos\theta$ —(2)
$b\sin\phi = R\sin\theta$ —(3)

$$\therefore \quad y = \sin \omega t \cdot R\cos\theta + \cos\omega t \cdot R\sin\theta$$
$$= R[\sin \omega t \cos\theta + \cos\omega t \cdot \sin\theta]$$
$$\boxed{y = R\sin(\omega t + \theta)}$$

So, the resultant wave is a harmonic wave of amplitude R.

$(2)^2 + (3)^2$

$$R^2 = a^2 + b^2\cos^2\phi + 2ab\cos\phi + b^2\sin^2\phi$$

$$\boxed{R = \sqrt{a^2 + b^2 + 2ab\cos\phi}}$$

Now, Intensity $\propto$ (amplitude of wave)^2

So, $I_1 = Ka^2$

$I_2 = Kb^2$

$I_R = KR^2 = K(a^2 + b^2 + 2ab\cos\phi)$

$$\therefore \quad \boxed{I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi}$$

For constructive interference

I – max. if $\cos\phi = +1$ i.e. $\phi = 0, 2\pi, 4\pi \dots$

$$\boxed{\phi = 2n\pi} \quad , n = 0, 1, 2 \dots$$

If x is the path difference bet^n the 2 waves, so

$$x = \frac{\lambda}{2\pi}\phi = \frac{\lambda}{2\pi} \times 2n\pi = n\lambda$$

$$\boxed{x = n\lambda}$$

For destructive interference

I – min. if $\cos\phi = -1$, i.e. $\phi = \pi, 3\pi, 5\pi$

$$\boxed{\phi = (2n-1)\pi} \quad , n = 1, 2, \dots$$

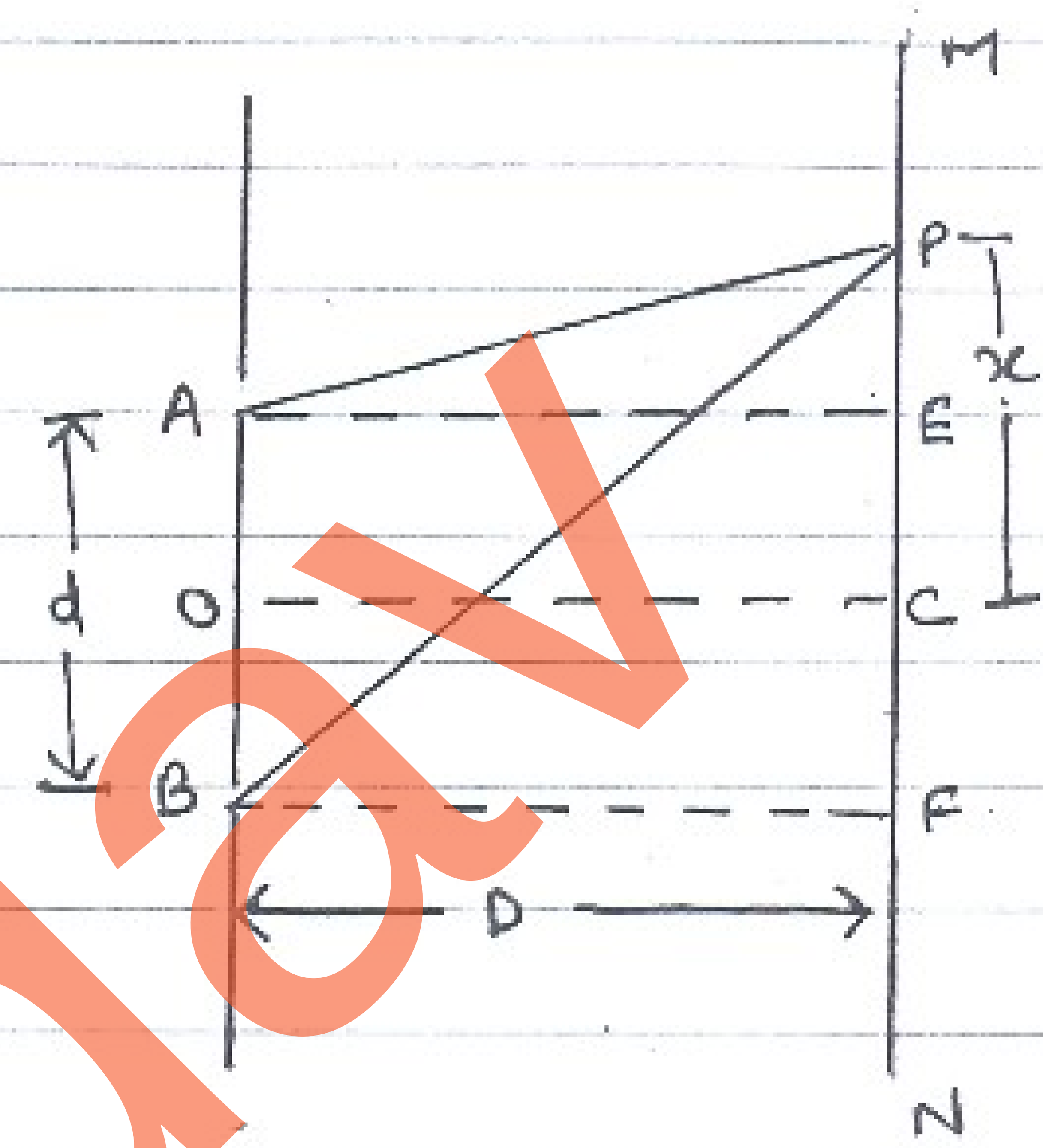
$$x = \frac{\lambda}{2\pi}\phi = \frac{\lambda}{2\pi}(2n-1)\pi$$

$$\boxed{x = \frac{(2n-1)\lambda}{2}}$$

* $\frac{I_{max}}{I_{min}} = \frac{(a+b)^2}{(a-b)^2}$

Expression for fringe width

Suppose A & B are 2 fine slits separated by a distance 'd' and illuminated by a strong source of monochromatic light of wavelength λ.



The 2 waves from A & B superimpose, resulting in a interference pattern on screen MN placed at a distance D from A & B.
Draw AE ⊥ MN, BF ⊥ MN & OC ⊥ MN.

Point C on screen, is equidistant from A & B, so the path difference betn 2 waves reaching C is zero & the pt. C is of maximum intensity called central maxima.

Consider a point P at a distance 'x' from C. The path difference betn 2 waves arriving at P is

path diff = BP − AP

In ΔBPF

$$BP = [BF^2 + PF^2]^{1/2}$$
$$= [D^2 + (x + d/2)^2]^{1/2}$$
$$= D\left[1 + \frac{(x+d/2)^2}{D^2}\right]^{1/2}$$
$$= D\left[1 + \frac{1}{2}\frac{(x+d/2)^2}{D^2}\right]$$

In ΔAPE

$$AP = [AE^2 + PE^2]^{1/2}$$
$$= [D^2 + (x - d/2)^2]^{1/2}$$
$$= D\left[1 + \frac{(x-d/2)^2}{D^2}\right]^{1/2}$$
$$= D\left[1 + \frac{1}{2}\frac{(x-d/2)^2}{D^2}\right]$$

$\therefore$ path diff $= D\left[1 + \frac{(x+d/2)^2}{2D^2} - 1 - \frac{(x-d/2)^2}{2D^2}\right]$

$$= \frac{1}{2D}\left[4x\frac{d}{2}\right]$$
$$= \frac{xd}{D}$$

for bright fringes, path diff $= n\lambda$

$$\frac{xd}{D} = n\lambda$$

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

$n = 0$, $x_0 = 0$ (at C) - central bright fringe

$n = 1$, $x_1 = \frac{\lambda D}{d}$ - 1^{st} " "

$n = 2$, $x_2 = \frac{2\lambda D}{d}$ - 2^{nd} " "

$n = n$, $x_n = \frac{n\lambda D}{d}$ - n^{th} " "

for dark fringes, path diffence $= (2n-1)\lambda/2$

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

$n=1$, $x_1' = \frac{\lambda D}{2d}$ — 1^{st} dark fringe

$=2$, $x_2' = \frac{3\lambda D}{2d}$ — 2^{nd} " "

$=n$, $x_n' = \frac{(2n-1)\lambda D}{2d}$ — n^{th} " "

Fringe width (β)

The separation bet^n the centres of two consecutive bright fringes is the width of a dark fringe or vice-versa

$$\beta = x_n - x_{n-1}$$

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

$$\boxed{\beta = \frac{\lambda D}{d}}$$

Similarly, $\beta' = x_n' - x_{n-1}' = \frac{\lambda D}{d}$

So, $\boxed{\beta = \beta' = \frac{\lambda D}{d}}$

Hence all bright & dark fringes are of equal width.

Conditions for Sustained Interference

The 2 sources of light must be

1. coherent
2. monochromatic

③ strong with least background
④ very close to each other
⑤ The 2 sources should be point sources.

Diffraction Of Light

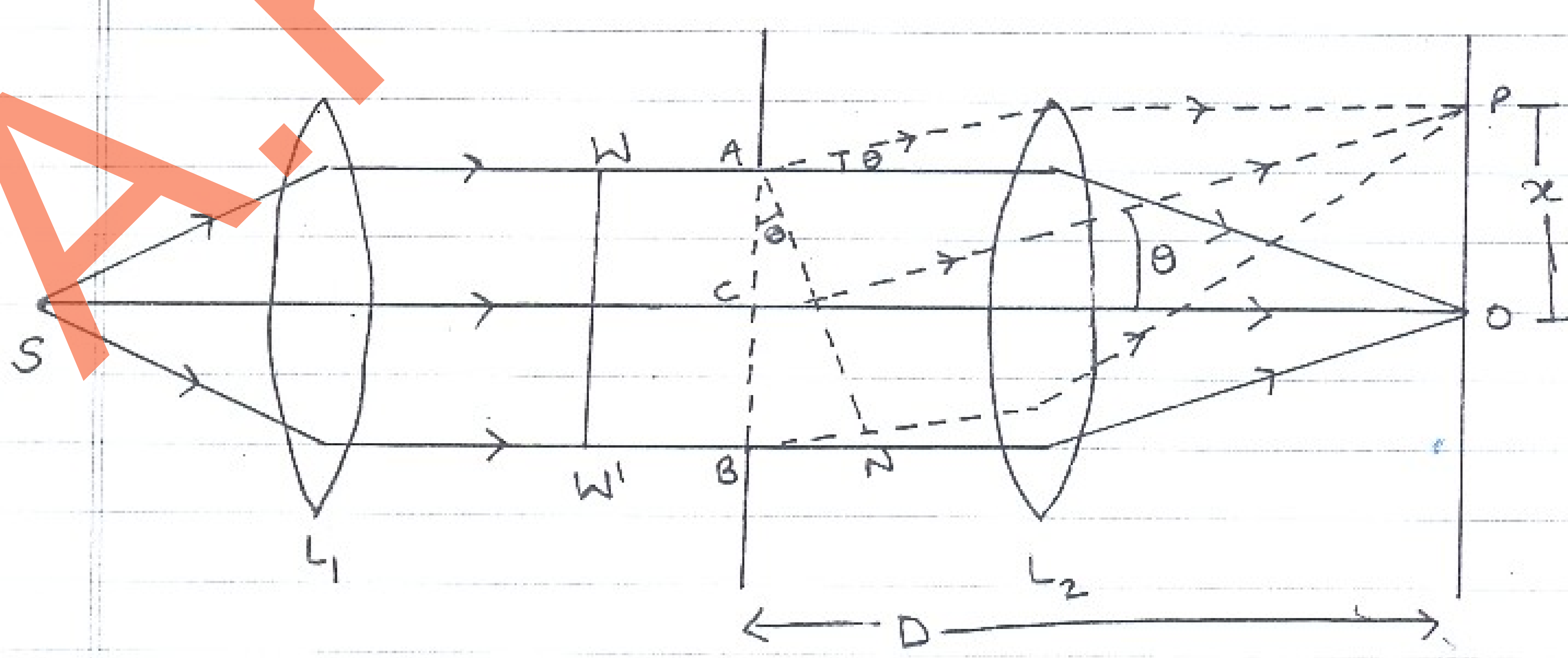
Diffraction

- It is the phenomenon of bending of light around corners of an obstacle in the path of light.
- The bending/deviation becomes much more pronounce when the dimensions of the obstacle are comparable (or less than) to the wavelength of light.
- Phenomenon of diffraction is common to all types of waves

sound/radio wave — wavelength is large, so obstacle of this size easily available so diffraction is observed readily

light wave — wavelength very small, obstacle of that size hardly available so diffraction not common.

Diffraction at a single slit



collimate - to make parallel

→ S is a monochromatic light source held at the focus of collimating lens L_1

→ A parallel beam of light from L_1 with a plane wavefront WW' is made to fall on single slit AB.

→ As width of AB (= a) is comparable to wavelength of light, diffraction occurs.

→ Diffraction pattern is focussed on screen (XY) with the help of L_2.

Theory

According to Huygen's principle, each point on AB sends out secondary wavelets in all directions.
The secondary waves from points lying in CA & CB travel the same distance in reaching O (so path diff = 0) resulting in max. intensity at O.

position of secondary minima

Consider secondary waves travelling in a direction making an angle θ with CO. All the secondary waves travelling in this direction reach a point P on the screen.
Draw AN ⊥ BK.

Path difference betn secondary waves reaching P from A & B is

$$x = BN = AB\sin\theta = a\sin\theta$$

If $x = \lambda$, then pt. P will be point of minimum intensity

If $x = \lambda$
path diff. betⁿ sec. waves from A & $C = \lambda/2$
" " " " " " B & $C = \lambda/2$
Destructive interference at $P \rightarrow$ 1st sec. minimum

Similarly, if $x = 2\lambda$ – pt. P will be the position of second secondary minimum.

In general $\boxed{a\sin\theta = n\lambda}$

<u>position of secondary maxima</u>

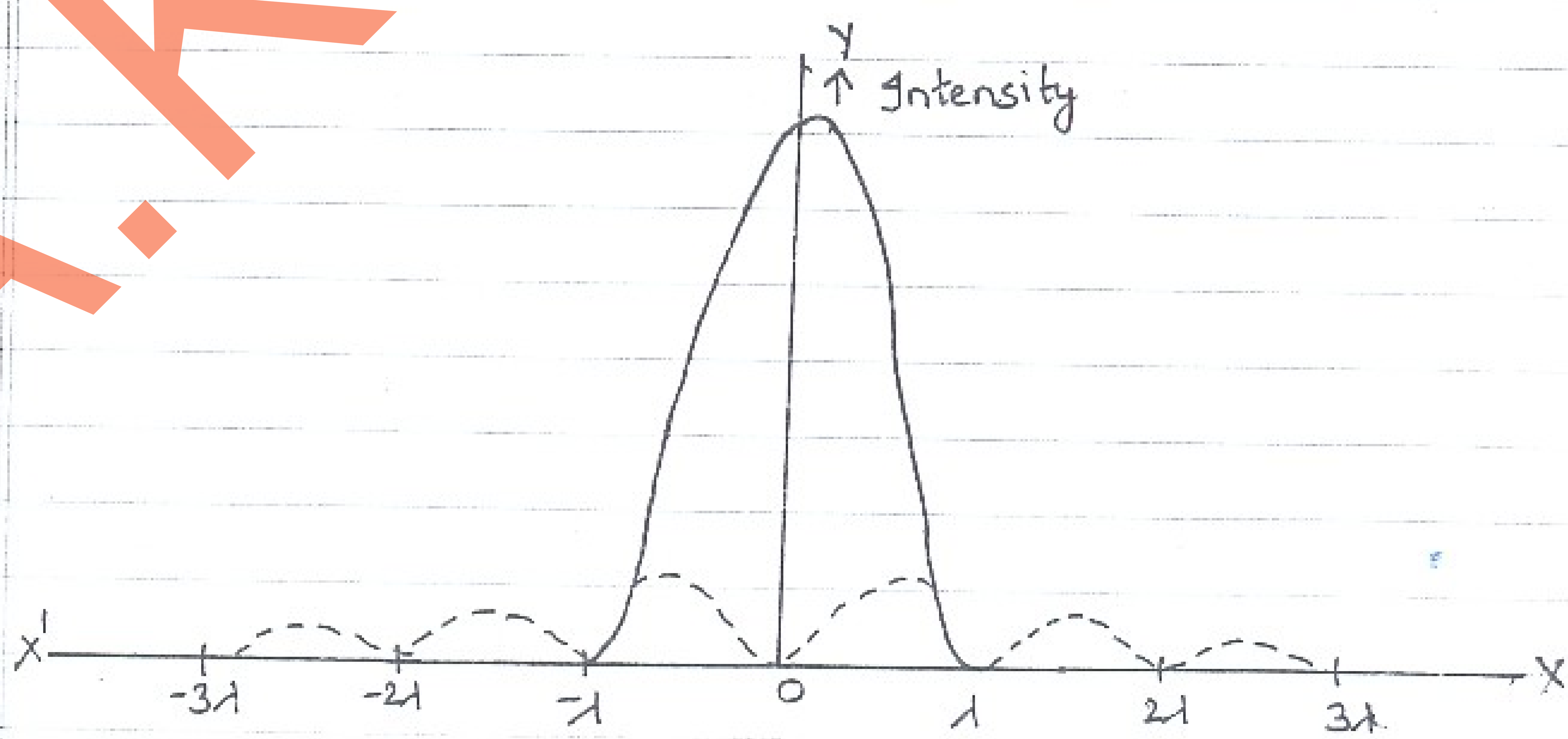
Consider a point P_1 (not in fig.) such that

$$x = BN = a\sin\theta = \frac{3\lambda}{2}$$

then P_1 will be the position of 1st sec. maximum
[AB divided into 3 parts having path diff. $\lambda/2$ each.
1st 2 parts cancel out, $\lambda/2$ remains which produce
1st secondary maximum]

Similarly $BN = \frac{5\lambda}{2}$, P_1 – position of 2nd sec. max.

In general $\boxed{a\sin\theta = (2n+1)\frac{\lambda}{2}}$



Path Difference ($a\sin\theta$)

Width of central maxima

It is the distance between first secondary minimum on either side of O.

If P is the position of 1st secondaly min. ($n=1$) & $OP = x$, then

$$a\sin\theta = 1 \times \lambda$$

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

If θ is small, $\sin\theta \approx \theta = \frac{x}{f} = \frac{x}{D}$

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

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

$$\boxed{\text{Width of central maxima} = 2x = \frac{2\lambda D}{a}}$$

* As 'a' increases, width of central maxima decreases (as shown in fig.)

*

Diffraction due to monochromatic light	Diffraction due to white light
1. Diffraction pattern consists of alt. bright & dark bands	1. pattern coloured
2. central bright fringe	2. white, other coloured
3. unequal widths	3. width of red band is more from violet

Difference betⁿ Interference & Diffraction

Interference	Diffraction
1. It is due to superposition of 2 distinct waves from 2 coherent sources.	1. It is due to superposition of secondary wavelets from different parts of same wavefront.
2. All bright fringes are of same intensity.	2. not of same intensity
3. Intensity of minima is 0 or very small.	3. never zero
4. Good contrast between bright & dark fringes.	4. poor contrast.
5. Width of fringes may or may not be equal.	5. always unequal.

Resolving Power

It is the power or ability of an instrument to produce distinctly separate images of two close objects.

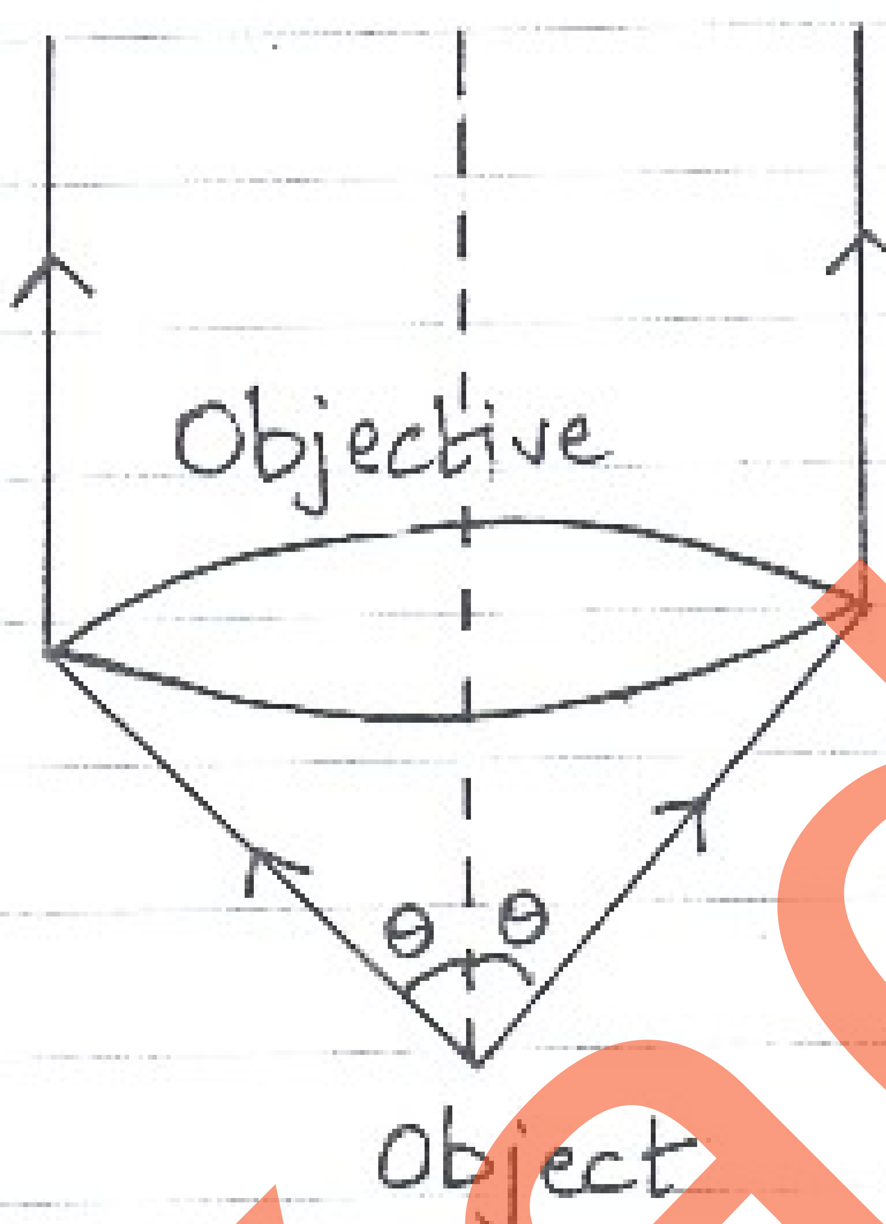
Limit of resolution (d)

The minimum distance bet^n 2 objects which can just be seen as separate by the optical instrument.

- Smaller the value of d, greater is its R.P.
- Resolving power of human eye is 1 min or $\frac{1}{60}$ degree. It means that if 2 distant objects subtends an angle $\geq \frac{1}{60}$ degree, their images are seen separate by the eye.

Resolving power of microscope

It is the ability of the microscope to show, as separate, the images of 2 point objects lying close to each other.



The limit of resolution is measured by the min. distance (d) betⁿ 2 point objects, whose images in the microscope are just seen as separate.

Now $d \propto \lambda$ (wavelength of light used)

$d \propto \dfrac{1}{2\theta}$ (cone angle of light rays)

So, $d \propto \dfrac{\lambda}{2\theta} \Rightarrow d = \dfrac{\lambda}{2\sin\theta}$

If medium betⁿ the object & objective lens of microscope is a transparent medium of refractive index μ, then

$$\boxed{d = \frac{\lambda}{2\mu\sin\theta}}$$

$$\boxed{\text{R.P. of microscope} = \frac{1}{d} = \frac{2\mu\sin\theta}{\lambda}}$$

$\mu\sin\theta$ - numeric aperture of microscope

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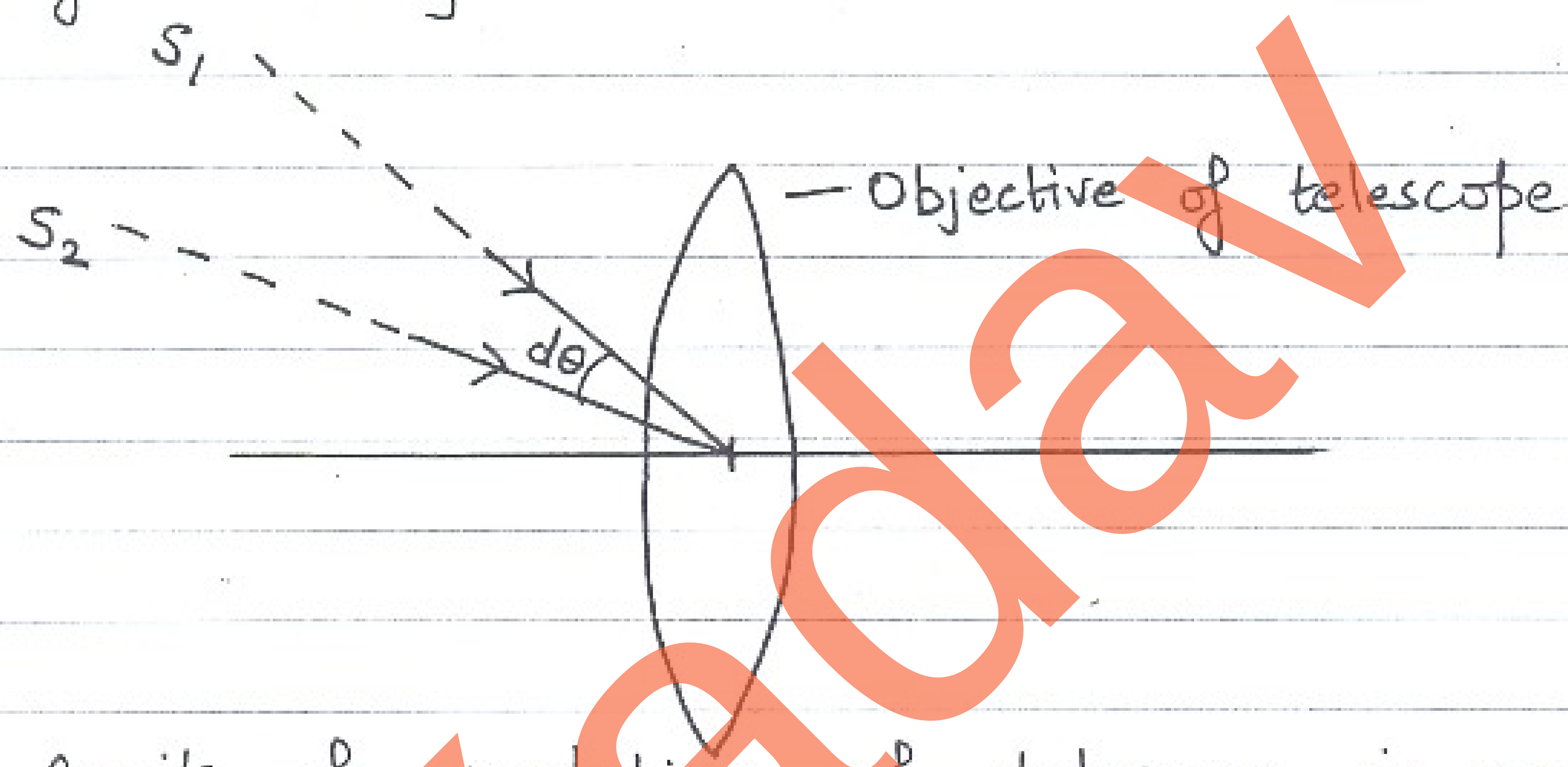
Resolving power of Telescope

It is the ability of the telescope to show distinctly the images of 2 distant objects lying closeby.



The limit of resolution of telescope is measured by the angle ($d\theta$) subtended at its objective by 2 distant objects.

$d\theta \propto \lambda$ (wavelength of light used)

$d\theta \propto \frac{1}{D}$ (aperture of objective lens) | aperture = diameter

$\therefore \quad d\theta \propto \frac{\lambda}{D}$

$$\boxed{d\theta = \frac{1.22\lambda}{D}}$$

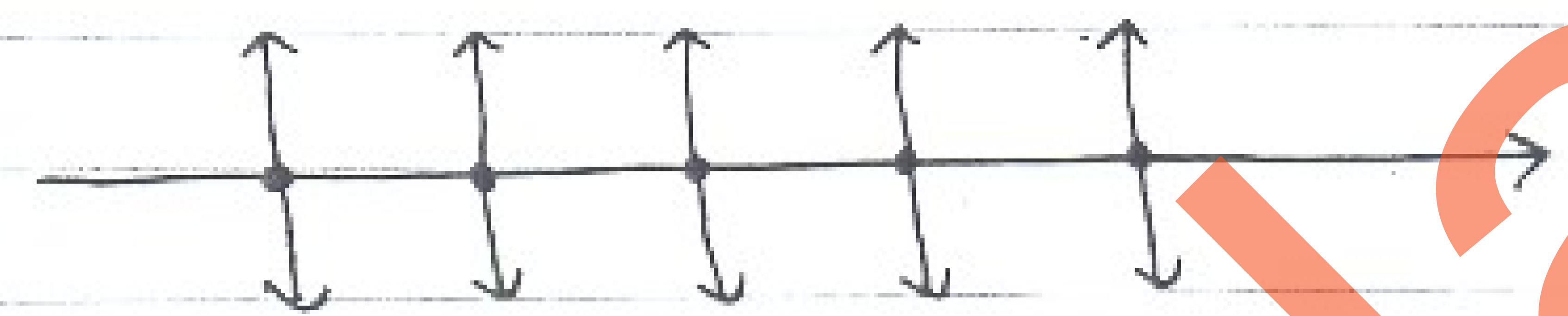
$$\boxed{\text{R.P. of telescope} = \frac{1}{d\theta} = \frac{D}{1.22\lambda}}$$

- Here we can't change λ (normally sunlight used so λ is out of bounds) so we have to change D.
- Extremely far away stars can be seen with telescope of large aperture (D).

Polarisation of Light

Unpolarised light

The ordinary ray of light, in which the vibrations are in all directions but perpendicular to the direction of propagation of light is called ordinary or unpolarised light.



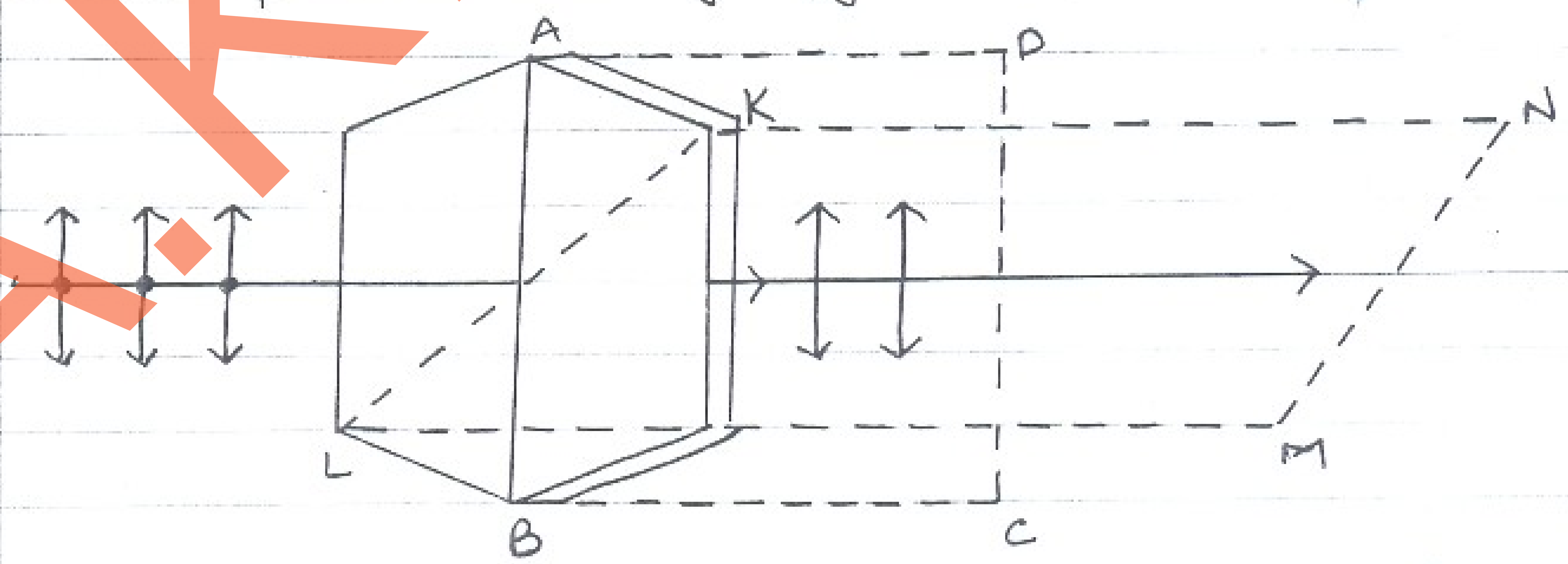
In this diagram

↕ → vibrations in the plane of paper

• → " in a direction $\perp^r$ to plane of paper.

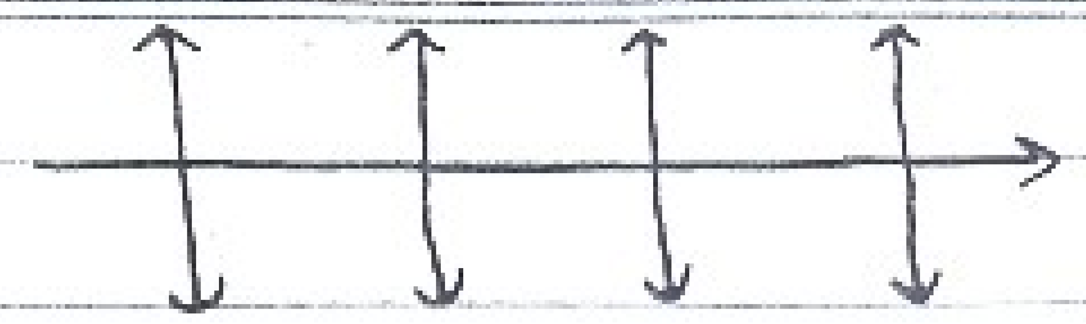
Polarisation

The phenomenon of restricting vibrations of light (electric vector) in a particular direction, $\perp^r$ to the direction of wave motion is called polarisation of light.



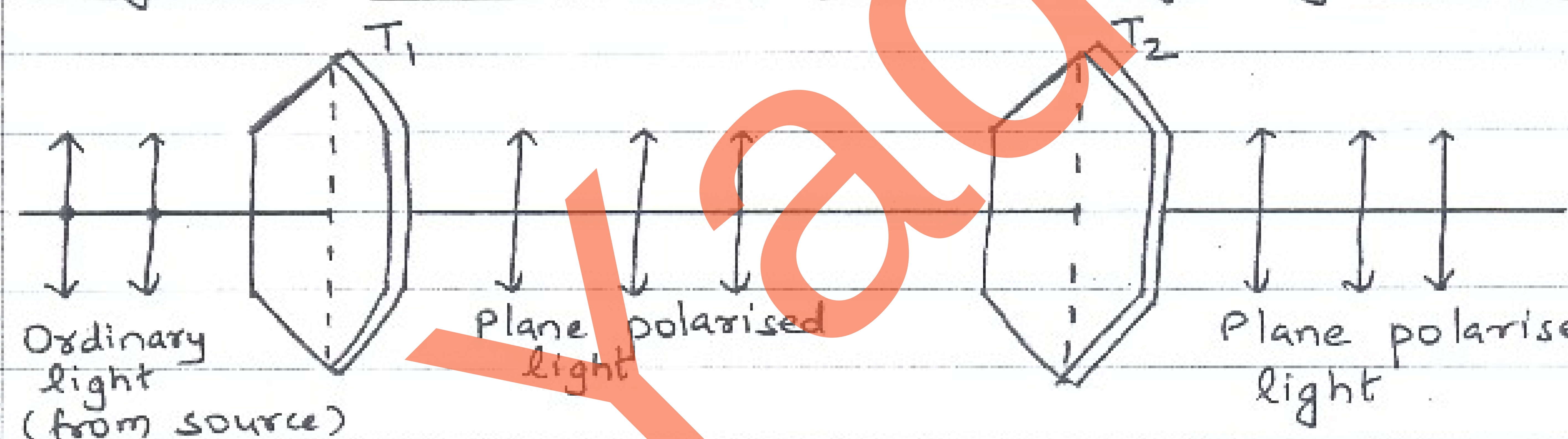
- Plane ABCD in which vibrations of polarised light are confined is called plane of vibration.
- Plane KLMN which is $\perp^r$ to the plane of vibration is called plane of polarisation.

- Plane polarised light having vibrations in the plane of paper.



- Plane polarised light having vibrations in a plane $\perp^r$ to the plane of paper.

Experimental Demonstration of polarisation of light & transverse nature of light waves

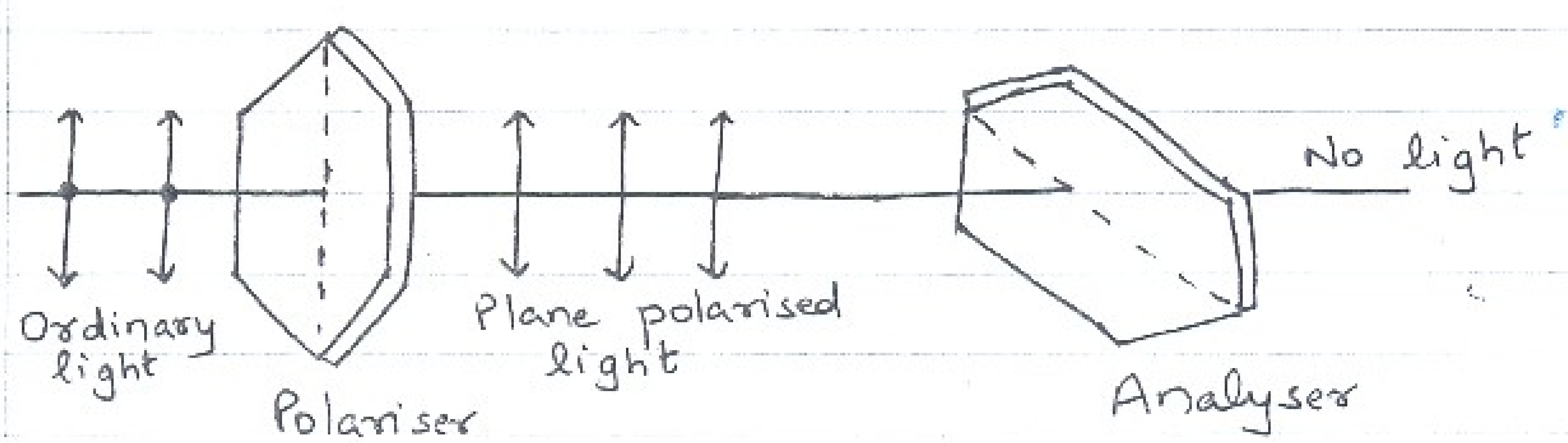


T_1, T_2 – thin plates of tourmaline

→ Light from source is passed through T_1 & T_2, the intensity of light remains same/unaffected/max. only when T_1 & T_2 are parallel (along their axis)

→ When T_2 is rotated gradually, intensity of light transmitted from T_2 goes on decreasing.

→ When the axes of T_1 & T_2 are $\perp^r$, light is completely cut off.



→ On rotating T_2 further, light reappears.
→ Intensity of light transmitted from T_2 starts increasing, till it is max. when axes of T_1 & T_2 are parallel again.
→ If both T_1 & T_2 are rotated with same angular velocity in same direction, no change in intensity of transmitted light is observed.

Explanation

- The phenomenon can be explained only when we assume that light waves are transverse.
- T_1 allows only those vibrations to pass through it which are parallel to its axis.
- When T_2 is introduced with its axis parallel to the axis of T_1, the vibrations of elector vector transmitted by T_1 are also transmitted through T_2.
- When axis of T_2 is $\perp^r$ to the axis of T_1, T_2 does not allow electric vectors to pass & hence eye receives no light.
- Since the intensity of polarized light on passing through a tourmaline crystal changes with the relative orientation of its axis with that of polariser, so light must consist of transverse waves.

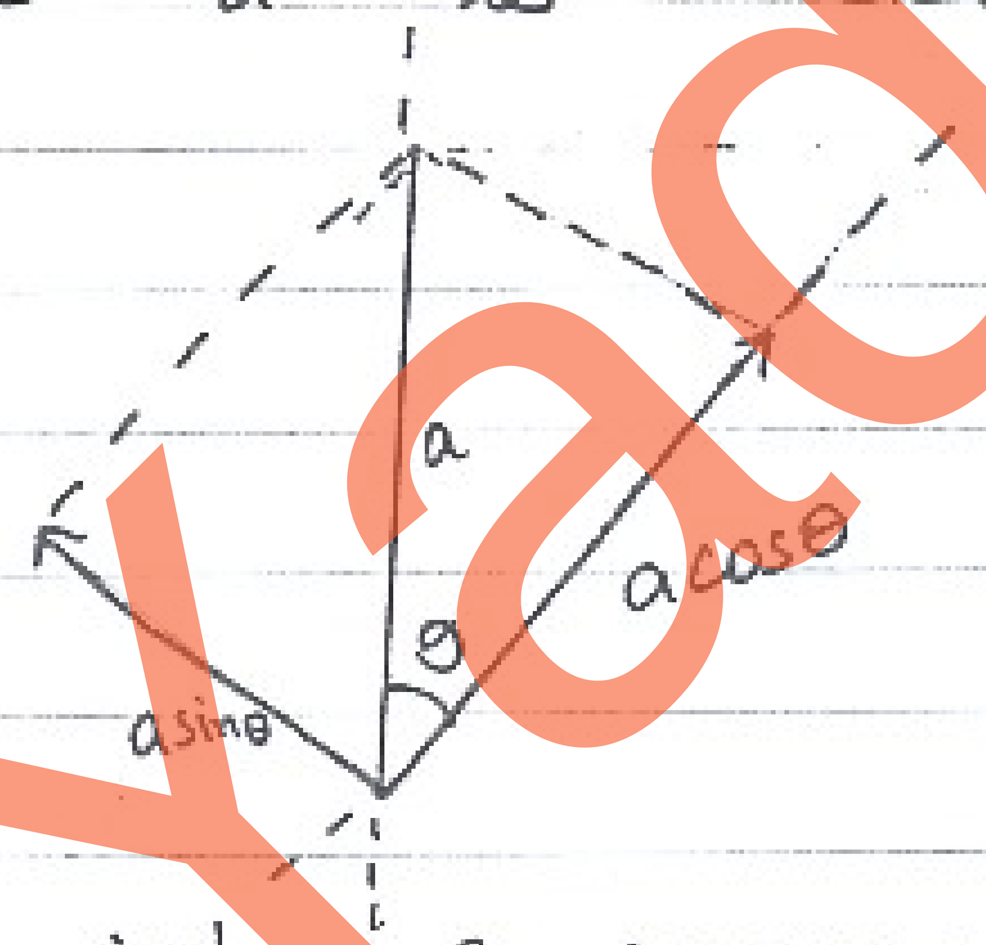
Nicol Prism

It is an optical device which is used for producing & analysing the plane polarised light.

Law of Malus

"When a completely plane polarised light beam is incident on an analyser, the intensity of emergent light varies as the square of the cosine of the angle betⁿ the planes of transmission of the analyser & the polariser."

Consider plane polarised light of intensity I_0 & amplitude 'a' is incident on the polariser



Resolving 'a' into 2 components

(i) $a\cos\theta$ – along the plane of transmission of analyser

(ii) $a\sin\theta$ – $\perp^r$ to " " " analyser

As the component transmitted through analyser is only $a\cos\theta$ so, intensity of light transmitted through analyser is

$$I = k(a\cos\theta)^2$$
$$= ka^2\cos^2\theta$$
$$\boxed{I = I_0\cos^2\theta}$$

where $I_0 = ka^2$

intensity of incident plane polarised light

$$\boxed{I \propto \cos^2\theta}$$ – Law of Malus

Discussion

(1) When $\theta = 0^\circ$ or 180°, $\cos\theta = \pm 1$

$$I = I_0 \quad (\text{max})$$

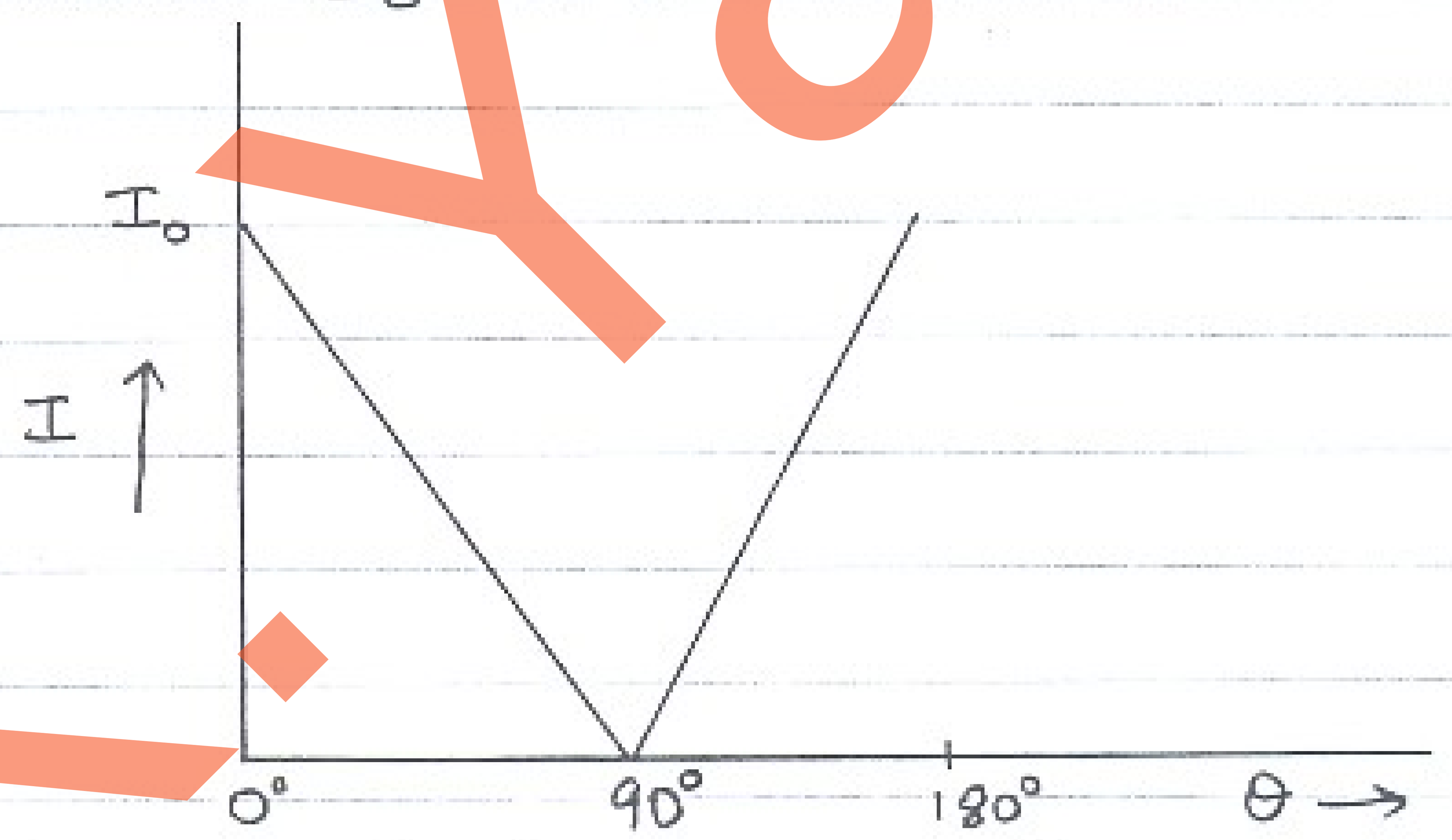
i.e. When polariser & analyser are parallel, the intensity of light transmitted from the analyser is same as that which falls on it from polariser.

(2) When $\theta = 90^\circ$, $\cos\theta = 0$

$$I = 0 \quad (\text{min.})$$

i.e. No light transmitted from analyser.

(3) Graph betn I_0 & θ



(4) If light incident on analyser is unpolarised

$$\cos^2\theta = \frac{1}{2}$$

$$\boxed{I = \frac{1}{2} I_0}$$

Q Discuss the intensity of transmitted light when a polaroid sheet sheet is rotated between 2 crossed polaroids.

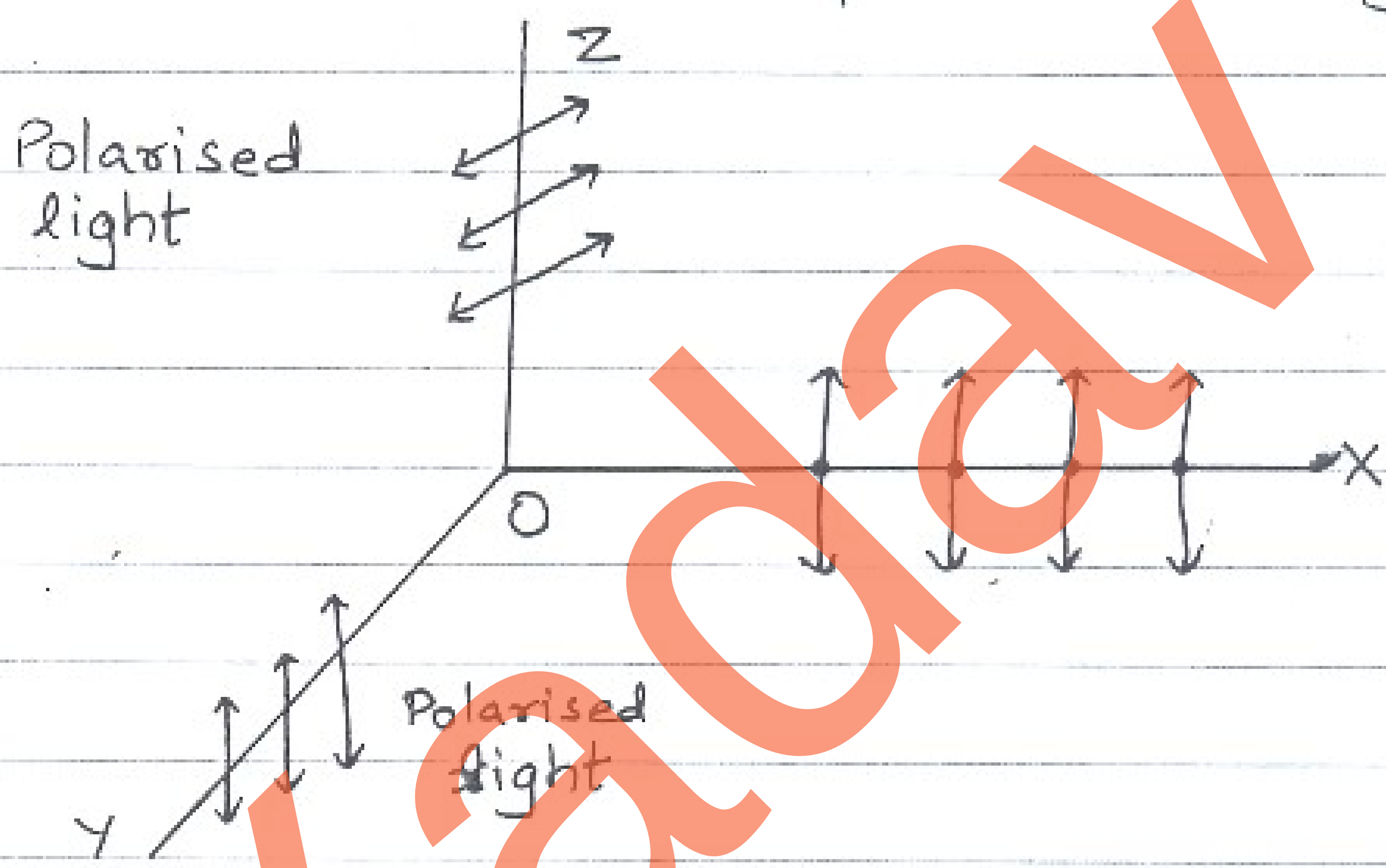
Ans $I = I_0 \cos^2\theta$ - Intensity of light from P_2

As the polariseds are crossed (P_1 & P_3) so

$I = I_0 \cos^2\theta \cos^2\left(\frac{\pi}{2} - \theta\right) = I_0 \cos^2\theta \sin^2\theta = \frac{I_0}{4} \sin^2 2\theta \Rightarrow I = I_0$ at θ =

Polarisation by scattering

When a scattered light is seen in a direction perpendicular to the direction of incidence, it is found to be plane polarised. The phenomenon is called polarisation by scattering.



Consider a beam of unpolarised light incident along Z-axis & let it get scattered at O.

Along X-axis

When we look along X-axis, then we only see the vibrations of electric vector which are parallel to Y-axis (or $\perp^r$ to X-axis)

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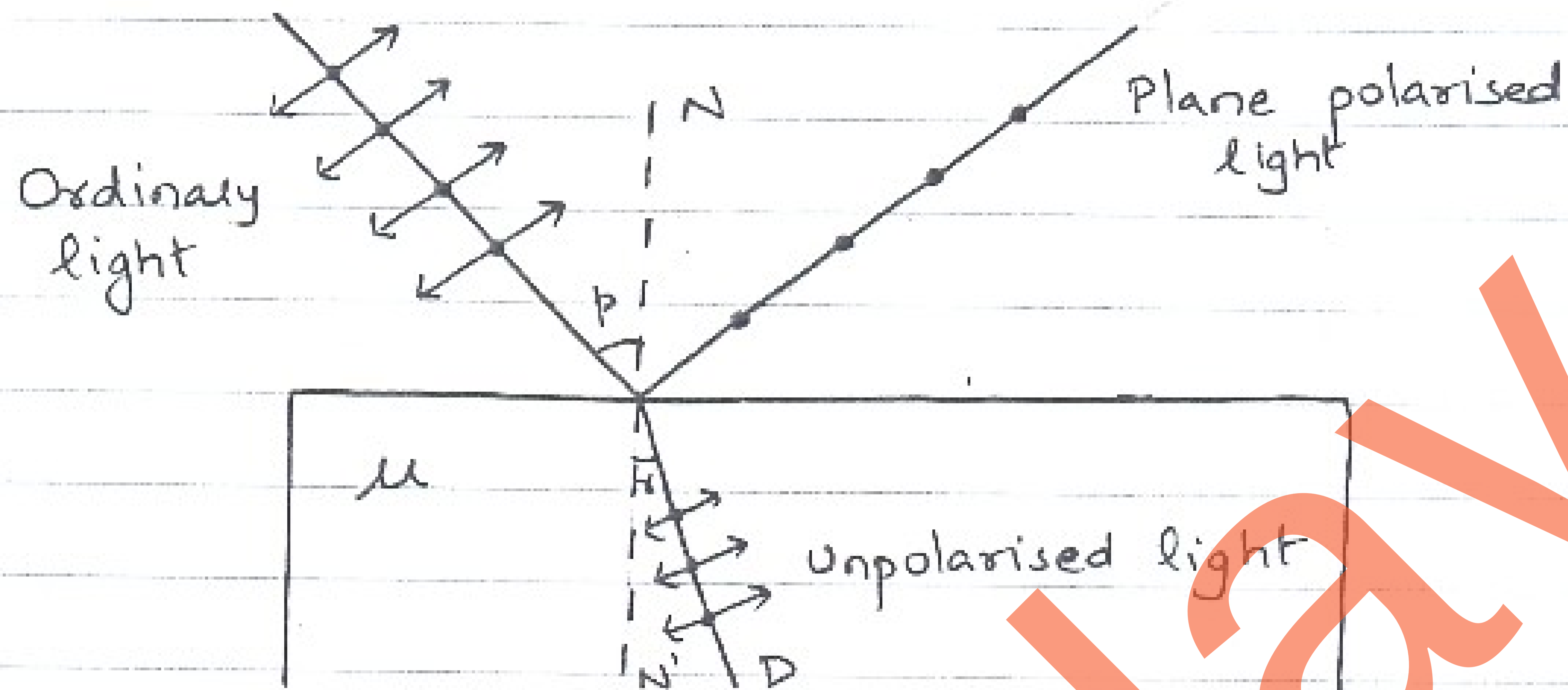
So, light scattered in a direction perpendicular to the incident light is always plane polarised.

Polarising angle (p)

The angle of incidence at which the reflected light is completely plane polarised is called polarising/ Brewster's angle.

Polarisation by reflection



- Ordinary light is incident along AB on the surface separating air from a medium of refractive index μ.
- Completely plane polarised light is obtained along BC (reflected light) & unpolarised light is obtained along BD (refracted light)

Explanation

(i) Unpolarised light has 2 electric field components
- • – perpendicular to the plane of incidence
- ↕ – parallel " " " " "

(ii) The vibrations $\perp^r$ to the plane of paper always remain parallel to the reflecting surface, whatever be the angle of incidence (think 3D, • is "$\perp^r$ to this page" & the diagram is "on the page")

(iii) So, the condition of reflection remains the same, even if angle of incidence is changed.

(iv) The other vibrations (↕) make different angles with the reflecting surface as the angle of incidence is changed.

(v) When light is incident at polarising angle (p), the vibrations perpendicular to the plane of paper are reflected along BC, & other vibrations are transmitted.

(vi) So, the reflected light is completely plane polarised in the

Brewster's Law

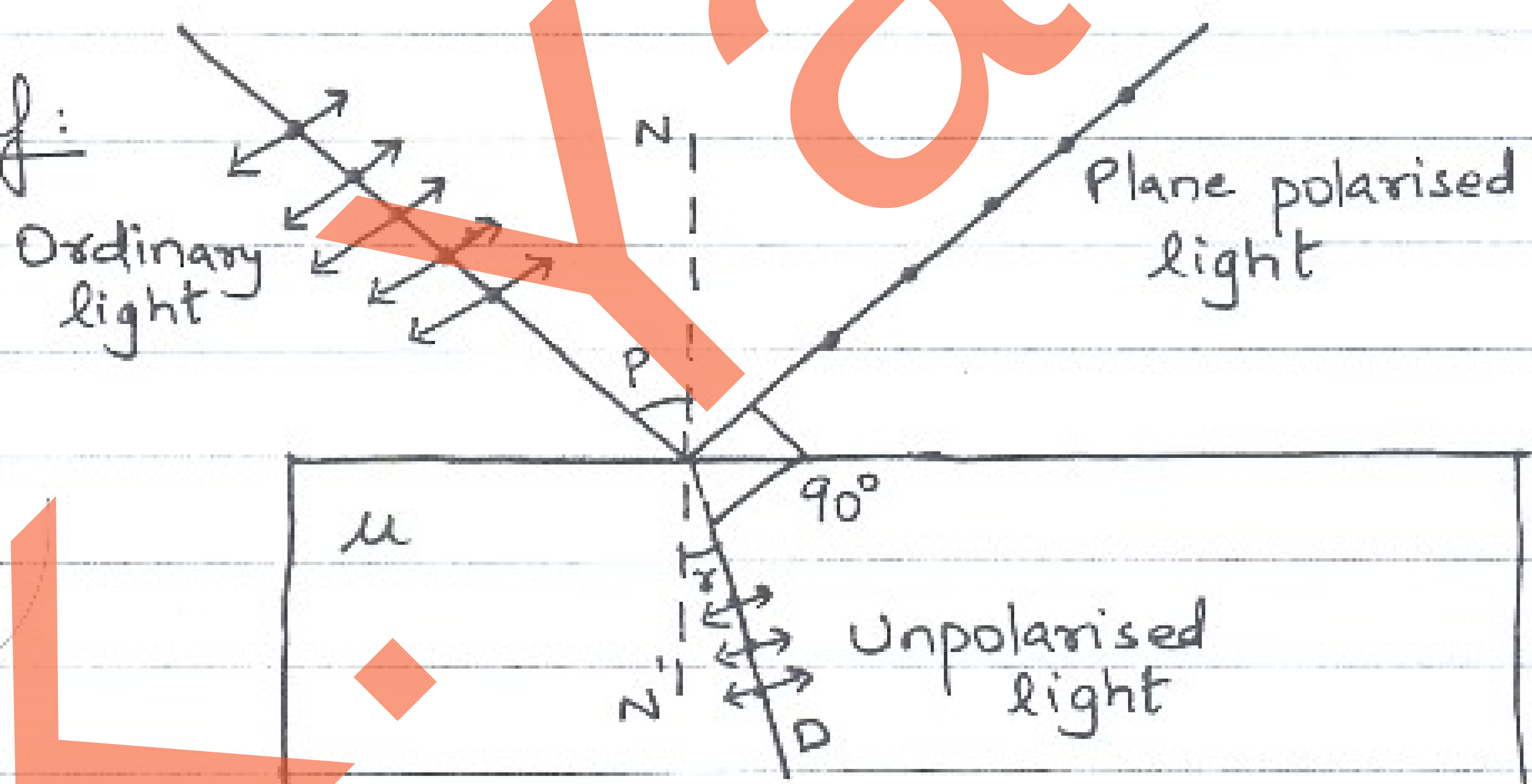
When light is incident at polarising angle at the interface of a refracting medium, the refractive index of the medium is equal to the tangent of the polarising angle.

$$\boxed{\mu = \tan p}$$

OR

When unpolarised light is incident at polarising angle on an interface separating air from a medium of refractive index μ, then the reflected light is fully polarised, provided $\mu = \tan p$

Proof:



When light is incident at polarising angle (p), the reflected component (along OB) & refracted component (along OC) are mutually $\perp^r$ to each other.

i.e. $$\angle BOY + \angle YOC = 90^\circ$$
$$(90^\circ - p) + (90^\circ - r) = 90^\circ$$
$$90^\circ - p = r$$

According to Snell's law

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin p}{\sin(90-p)} = \tan p$$

$$\boxed{\mu = \tan p}$$

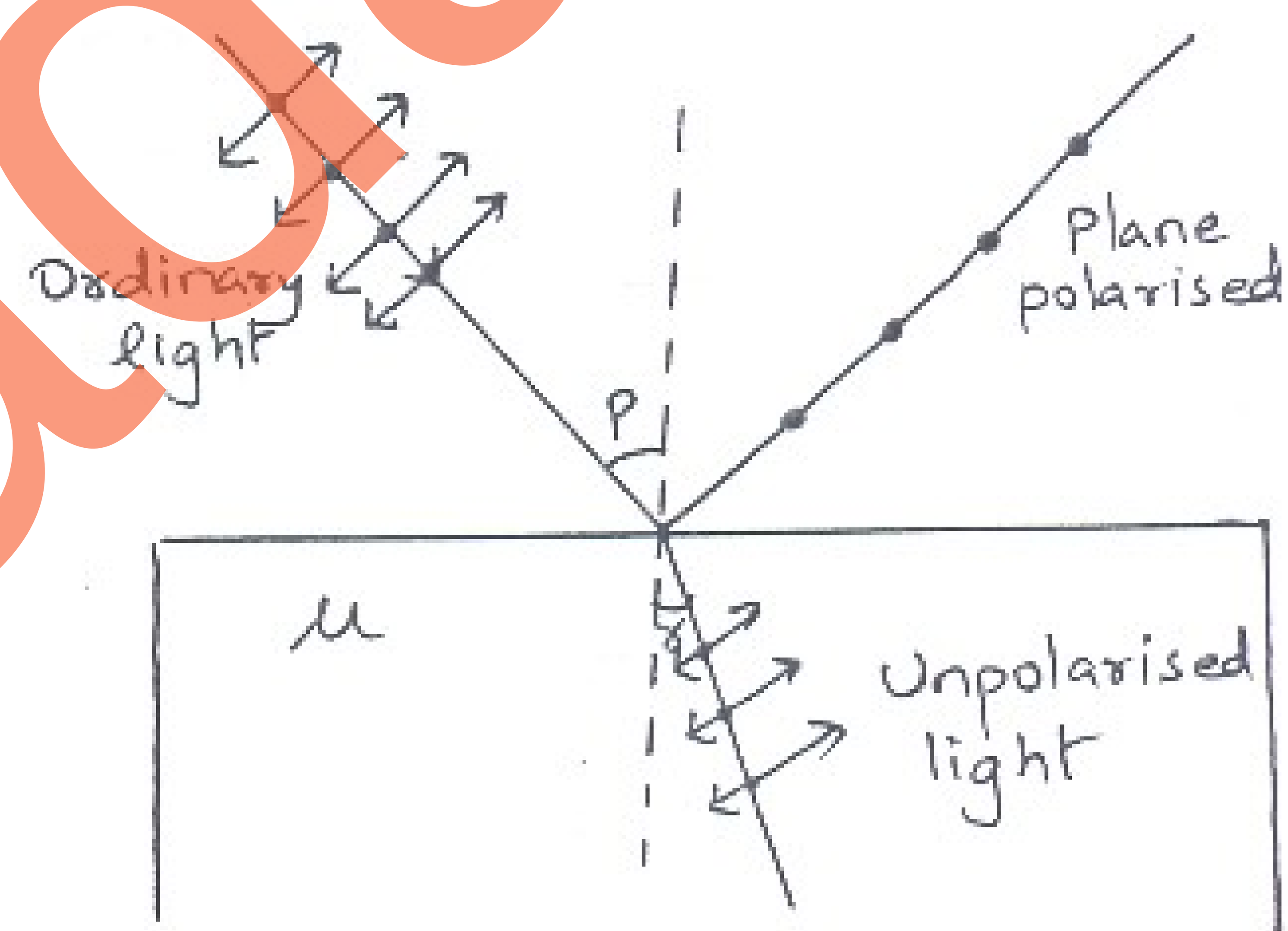
Q1. On what factor does polarising angle depends ?

Ans. wavelength of light

Complete polarisation can be obtained only with monochromatic light.

Q2. Prove that when a ray of light is incident at polarising angle, the reflected ray is at right angle to the refracted ray.

Ans.



Acc. to Snell's law

$$\mu = \frac{\sin p}{\sin r}$$

Acc. to Brewster's law

$$\mu = \tan p = \frac{\sin p}{\cos p}$$

$$\therefore \quad \frac{\sin p}{\sin r} = \frac{\sin p}{\cos p}$$

$$\sin r = \cos p$$

$$\sin r = \sin (90^\circ - p)$$

$$r = 90^\circ - p$$

$$\boxed{r + p = 90^\circ}$$

Hence proved.

Polaroids

A polaroid is a material which polarises light.

eg Tourmaline (natural polaroid)

Nicol prism

It is used to avoid the glare of light & in holography.

Q. Explain how polaroids help to avoid glare of light.

Ans. Most of the light reflected from glazed surfaces is partially plane polarised with vibrations in the horizontal plane.
When we use polarised sun glasses with their vibrations in the vertical plane, then most of the polarised light reflected from glazed surface is cut off.