CHAPTER 1 : POLARIZATION OF LIGHT WAVES & DOUBLE REFRACTION

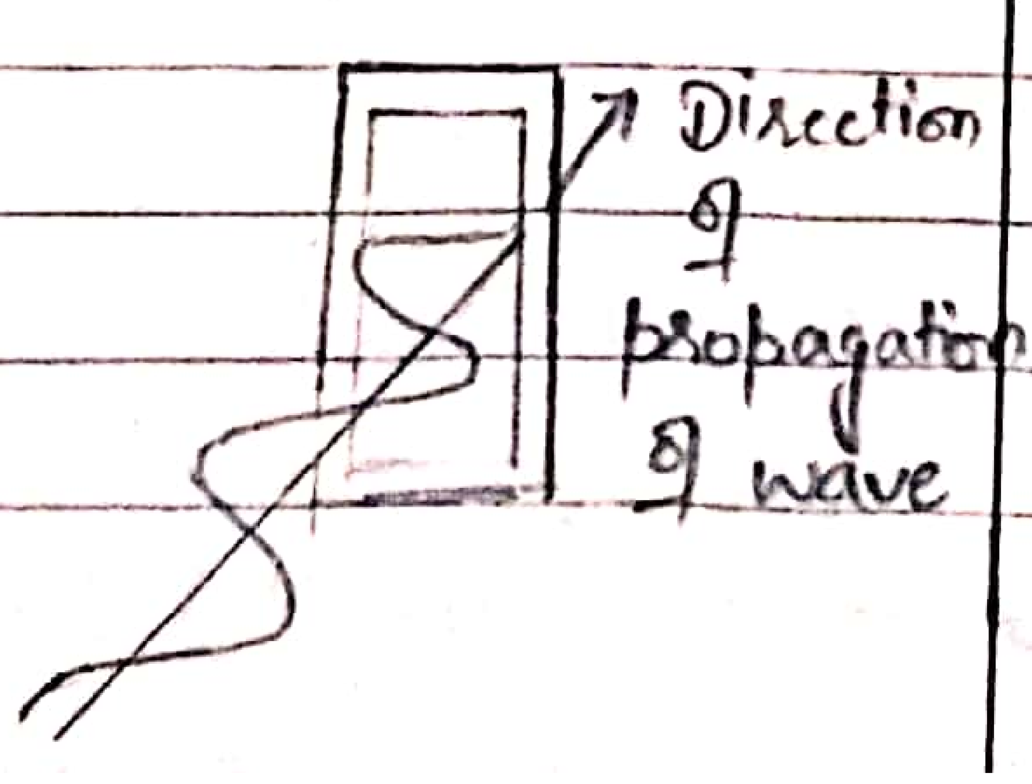
In last semester, experiments showed interference and diffraction of light but do not reveal about nature of light waves (i.e Whether light waves are longitudinal or transverse)
Reason :- Interference & diffraction can occur with both types of waves (But Polarization cannot shown in both)
example → Like Sound waves (mechanical waves) can also show both experiments and also light waves can show both the above phenomenon

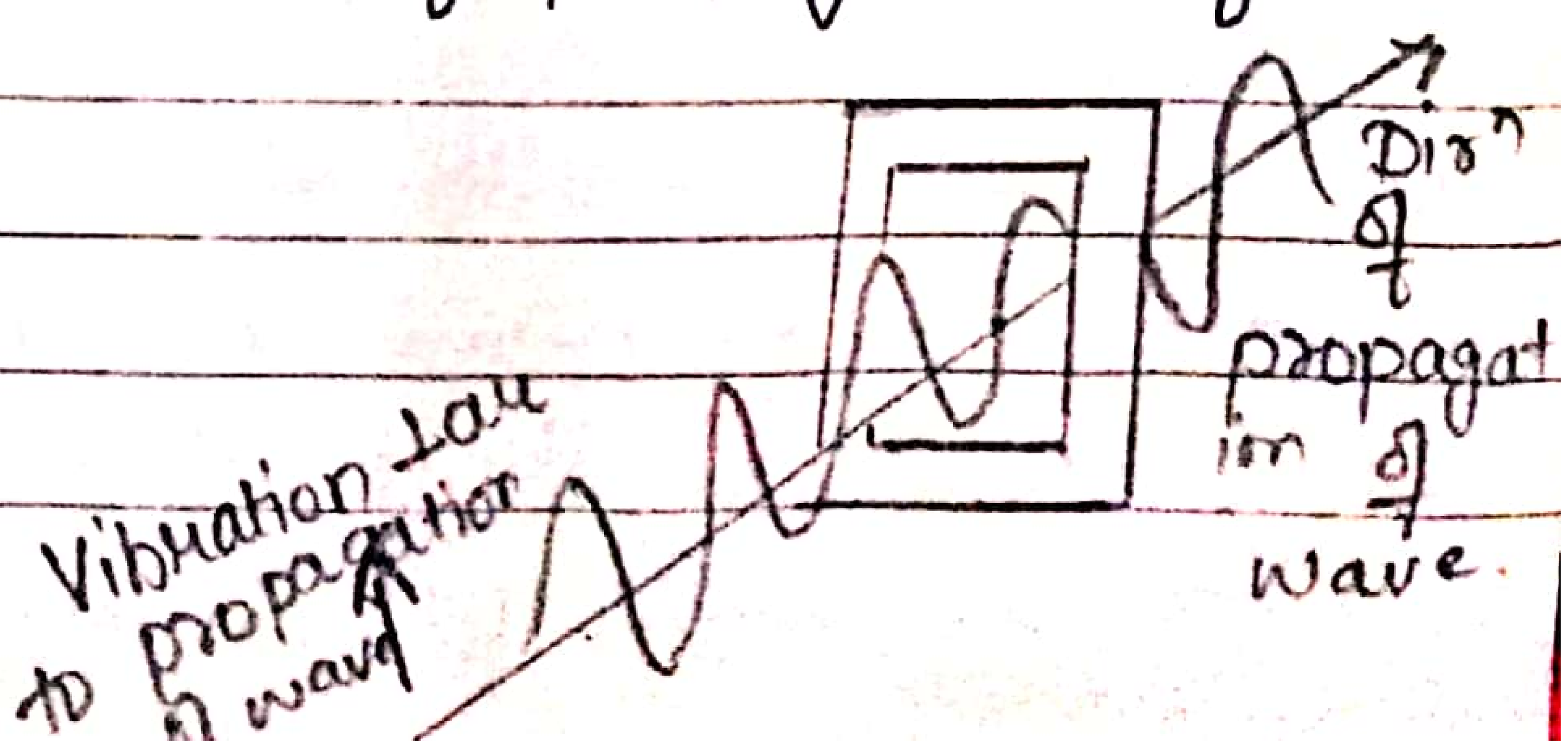
NATURE OF LIGHT WAVES :-

first of all, we define both types of waves i.e longitudina & transverse.

WAVES

Longitudinal Waves	Transverse Waves
It is a wave motion in which the particles of medium vibrate about their mean position in a direction parallel to the direction of propagation of wave.	It is a wave motion in which the particles of medium vibrate about their mean position in a direction perpendicular to the direction of propagation of wave



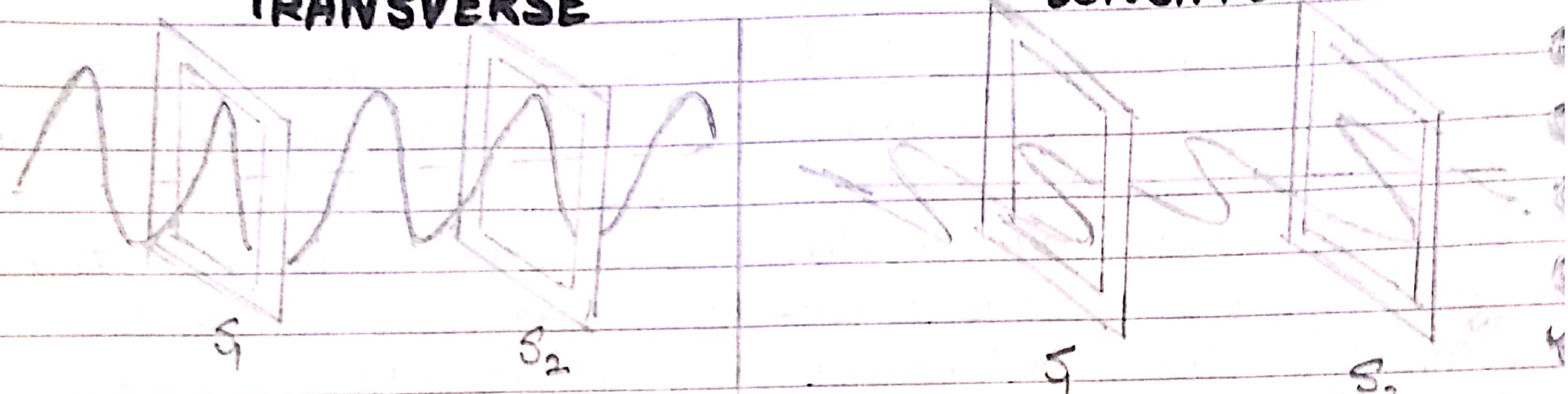


Now, let us illustrate wave nature (Light wave) by a simple method given below:-

Take a rope (or string) to pass through two slits S_1 & S_2

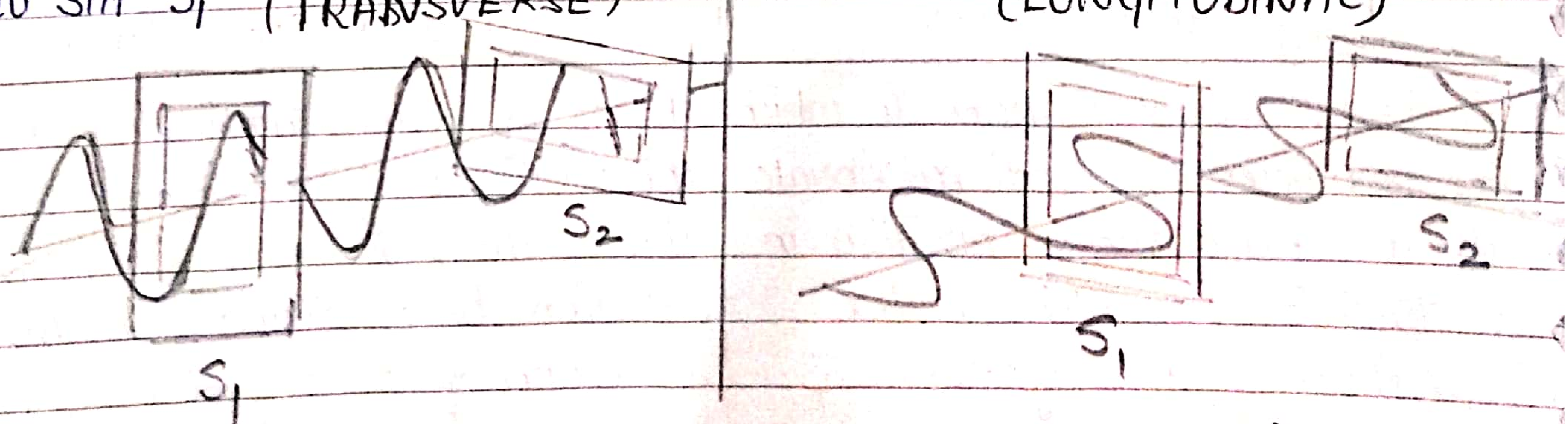
Case I:- When both slits are parallel to each other

TRANSVERSE LONGITUDINAL



It is shown that If we set up transverse wave with this rope and make it pass through the slits S_1 and S_2, the wave passes through slits undisturbed
Also If we set up longitudinal waves, It will also pass without being affected in both the slits. (ie. S_1 & S_2)

Case II:- When slit S_2 is rotated to become perpendicular to slit S_1 (TRANSVERSE) (LONGITUDINAL)



Now, we can see as we pass transverse wave from S_1 it passes undisturbed but not able to pass through S_2 with complete amplitude. But In case of longitudinal wave we can see wave passes undisturbed (completely) from both S_1 & S_2

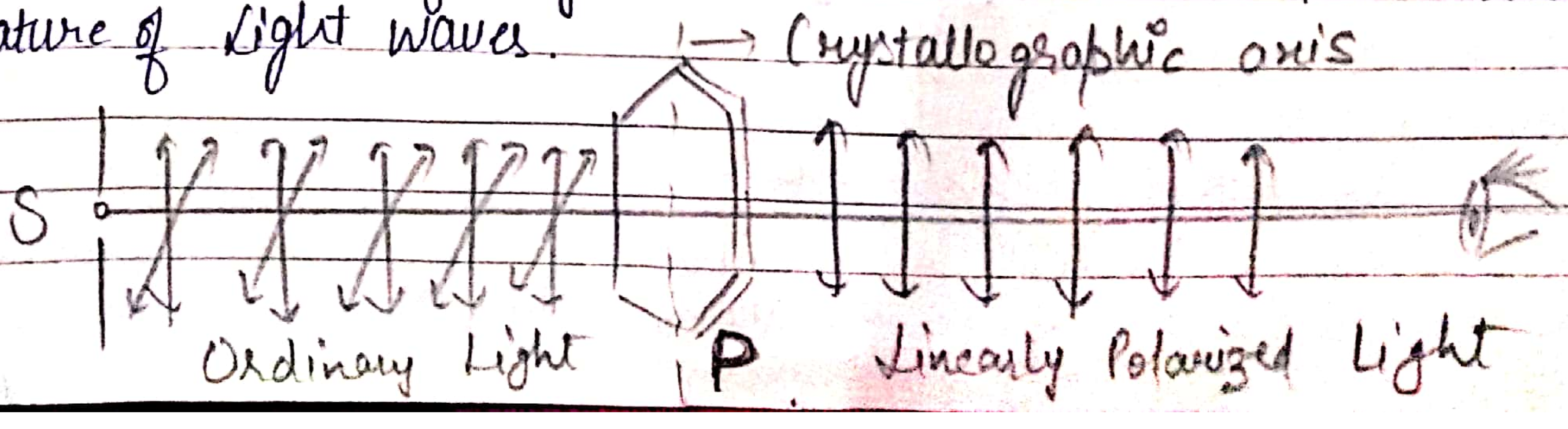
Polarization

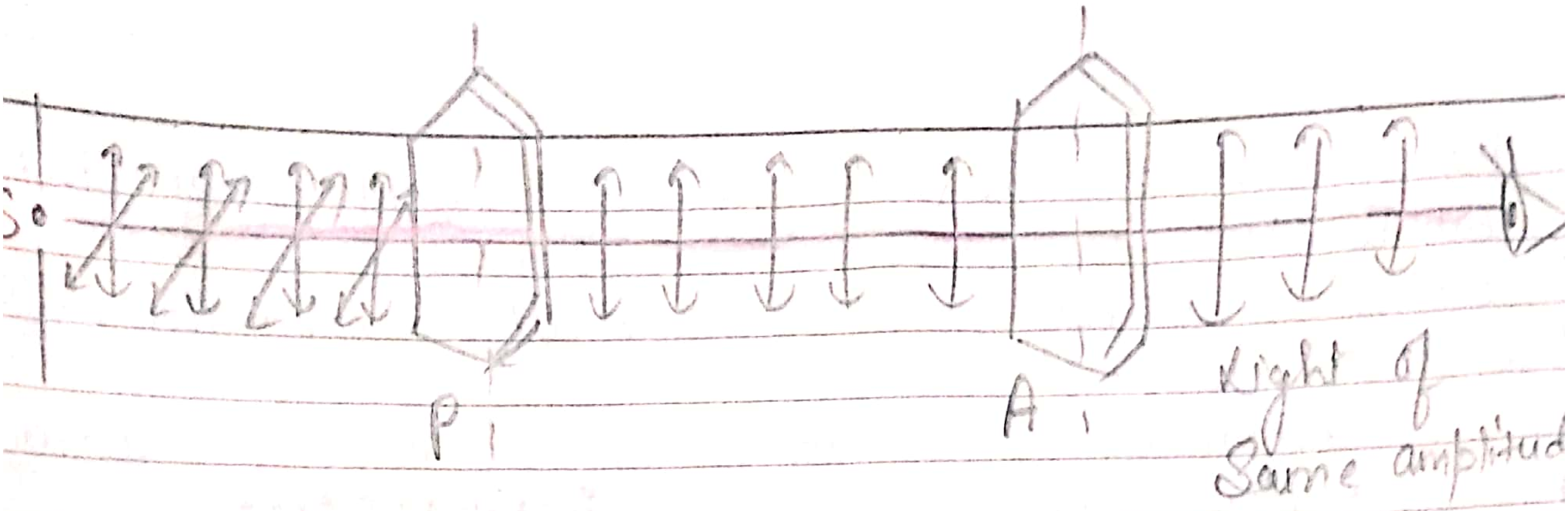
Thus, transverse waves have diffuent properties w.r.t the vertical plane as compared to other planes.
Such waves are said to be polarized after passing through first slit.
The Phenomenon of restricting the vibrations of a wave in a particular plane is known as **POLARIZATION.**

This example of rope helps us to determine the nature of light wave, because tourmaline (or any transparent crystalline substance) behave w.r.t light waves in exactly the same way as the slits do w.r.t transverse waves in the rope.

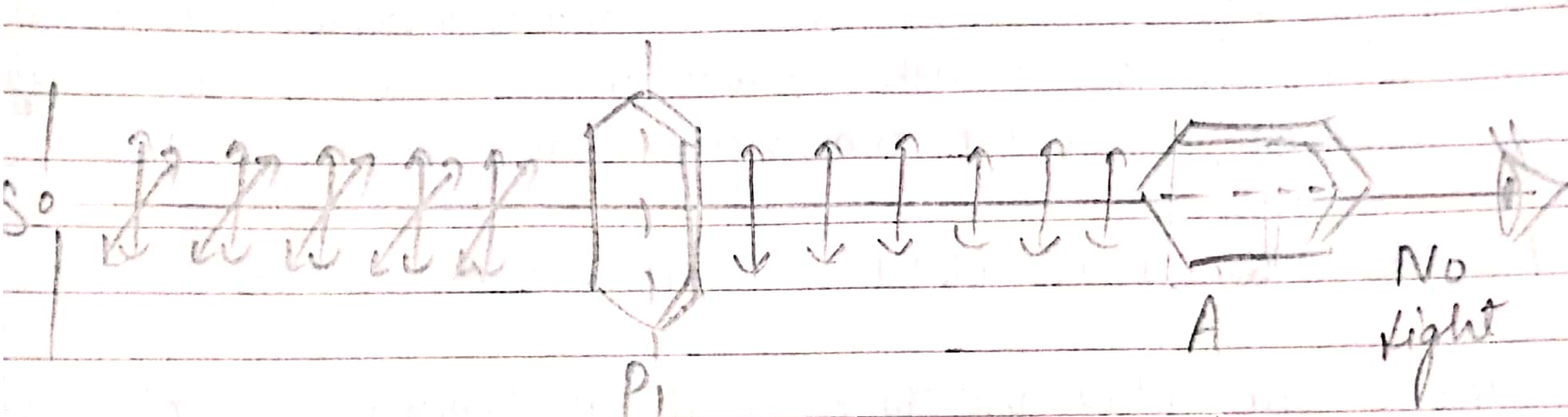
MECHANICAL EXPERIMENT SHOWING POLARIZATION

Take a Crystalline substance such as tourmaline & place it in front of light Coming out from Source S. Now you will notice some light coming out of crystal with reduced intensity of Source light (Because unpolarized light is now plane polarized i.e restricted to some plane i.e about crystalline axis of tourmaline). Before entering crystal, light is vibrating in all possible directions but after passing the crystal it is restricted to only single plane. How?
Now, take another crystal A (say), place it parallel to first Crystal (P say). You will find light of same intensity. But If you rotate crystal A, light intensity will gradually decrease and becomes zero when plane of crystal A becomes ⊥ar to plane of Crystal P. So this shows the transverse nature of Light waves.





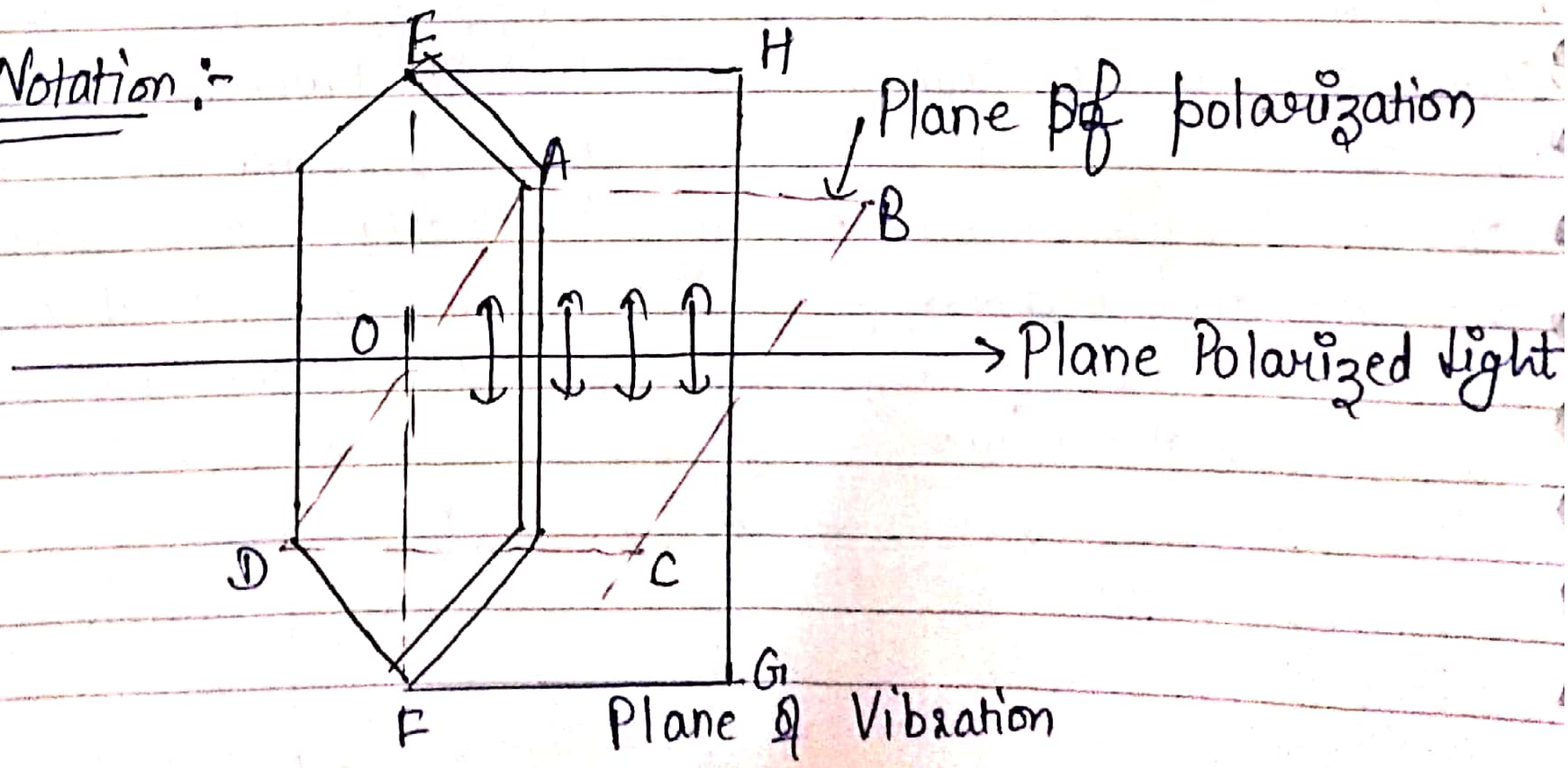
Case → Crystal Parallel



Case → Crystal Perpendicular.

Here the first Crystal will act as Polarizer (P) [जो किसी particular plane में Polarize करेगा] and second crystal 'A' will act as analyzer [जो check / prove करेगा, light कौन से plane में है].

Note :- Notation :-



After passing through crystal, light will Confined to a single plane and that plane will known as plane of VIBRATIONS. & light will be called plane polarized light. However plane perpendicular to plane of Vibration will be known as plane of polarization (ABCD) in fig.

Plane of Vibration (EFGH).

ORDINARY OR NATURAL LIGHT IS UNPOLARIZED

Now, As we know the nature of light waves are transverse and also light is an electromagnetic wave (According to Maxwell's electromagnetic theory). An electromagnetic wave consists of a vibrating electric and a vibrating magnetic field, both are perpendicular to each other and also perpendicular to propagation of waves.

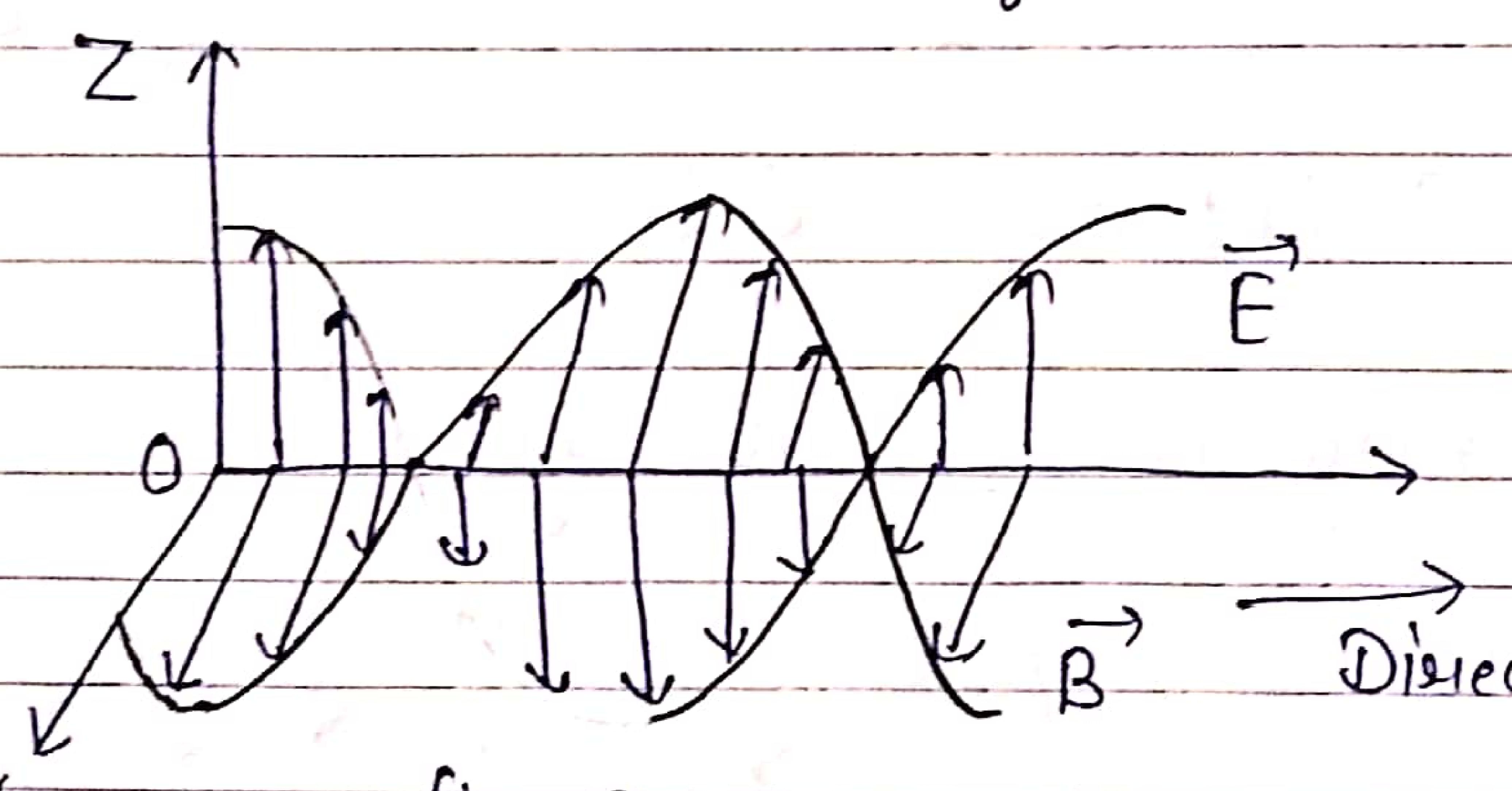


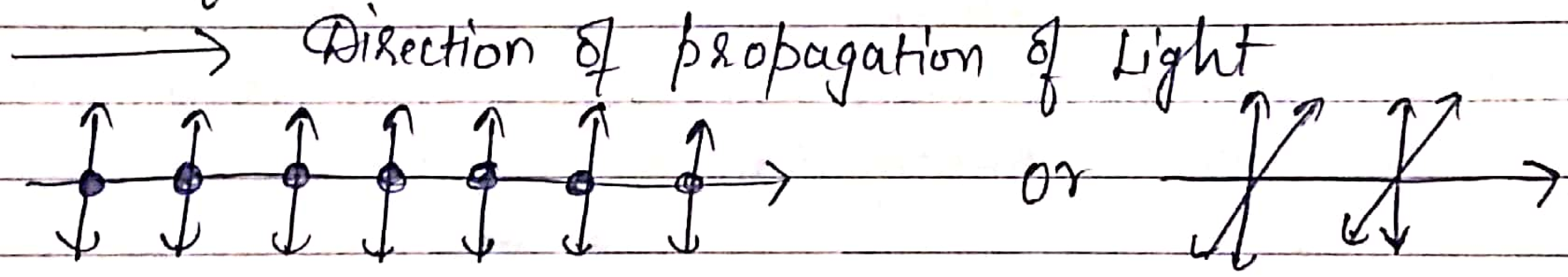
fig → Electromagnetic Waves

Among both the field vectors, only electric field vector $\vec{E}$ is responsible for optical effects. So, when we talk about vibration, it means only vibrations of electric vector $\vec{E}$. Now, as source light ~~emits~~ contain millions of atom giving light by exciting in all possible direction ⊥ar to propagation of wave. So, by single atom light being in any particular plane we have million of vibration (each polarized in any plane). So, for making whole light unpolarized

Simplicity, we resolve these all possible vibrations in two planes. One is in parallel to plane of paper shown by ↕ and other is ⊥ar to plane of paper shown by dot •
~~Therefore light i.e un~~

Representation of Unpolarized Light & Polarized Light.

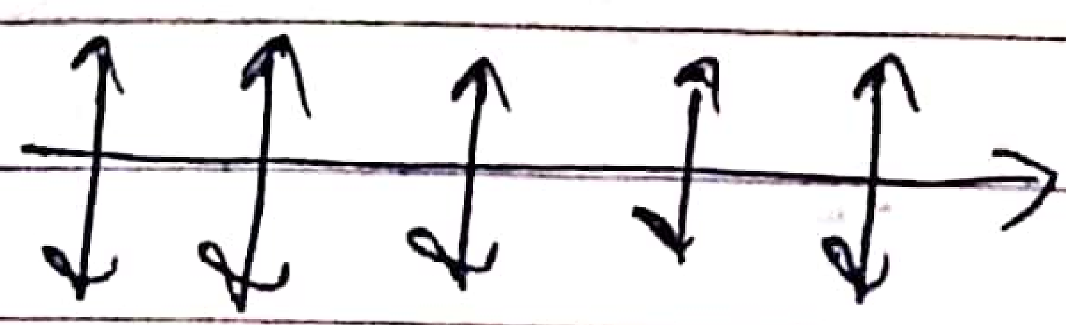
As Vibrations can be resolved into any two planes mutually perpendicular to each other. So, ordinary light may be shown by set of vibration, One in plane and other perpendicular to the plane of paper & both are ⊥ar to direction of propagation of wave also as shown in figure(a) below & known as unpolarized light.



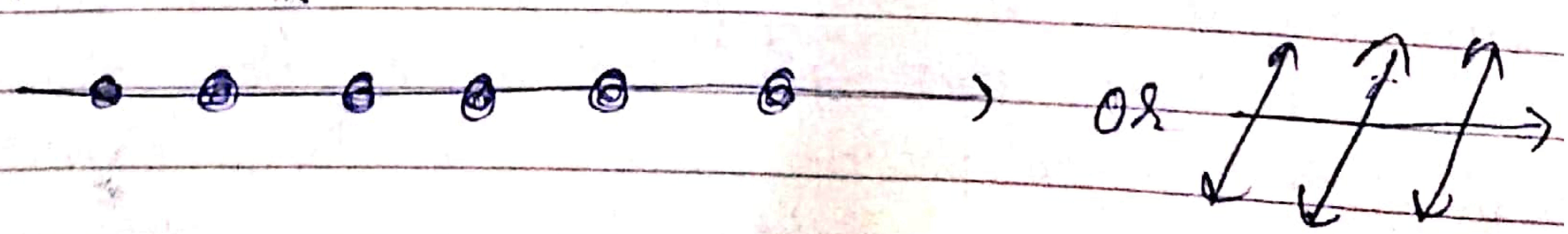
(a) Unpolarized Light

Polarised light may be of two types

⇒ polarized in plane of paper



⇒ polarized in a plane ⊥ar to plane of paper shown as by dot



METHODS FOR PRODUCTION OF POLARIZED LIGHT

① POLARIZATION BY REFLECTION

This is the simplest method for getting polarized light discovered by french scientist, Malus, in 1808.

According to his observation,
when a beam of ordinary light is reflected from the surface of a transparent medium like glass or water, the reflected light is partially polarized or almost polarized depending upon the angle of incidence.

The angle of incidence at which light is almost plane polarized is called polarizing angle / angle of polarization / Brewster's angle and denoted by 'ip'.
'ip' depends upon nature of medium & varies with wavelength of incident light. For glass ($i_p = 57.5°$)

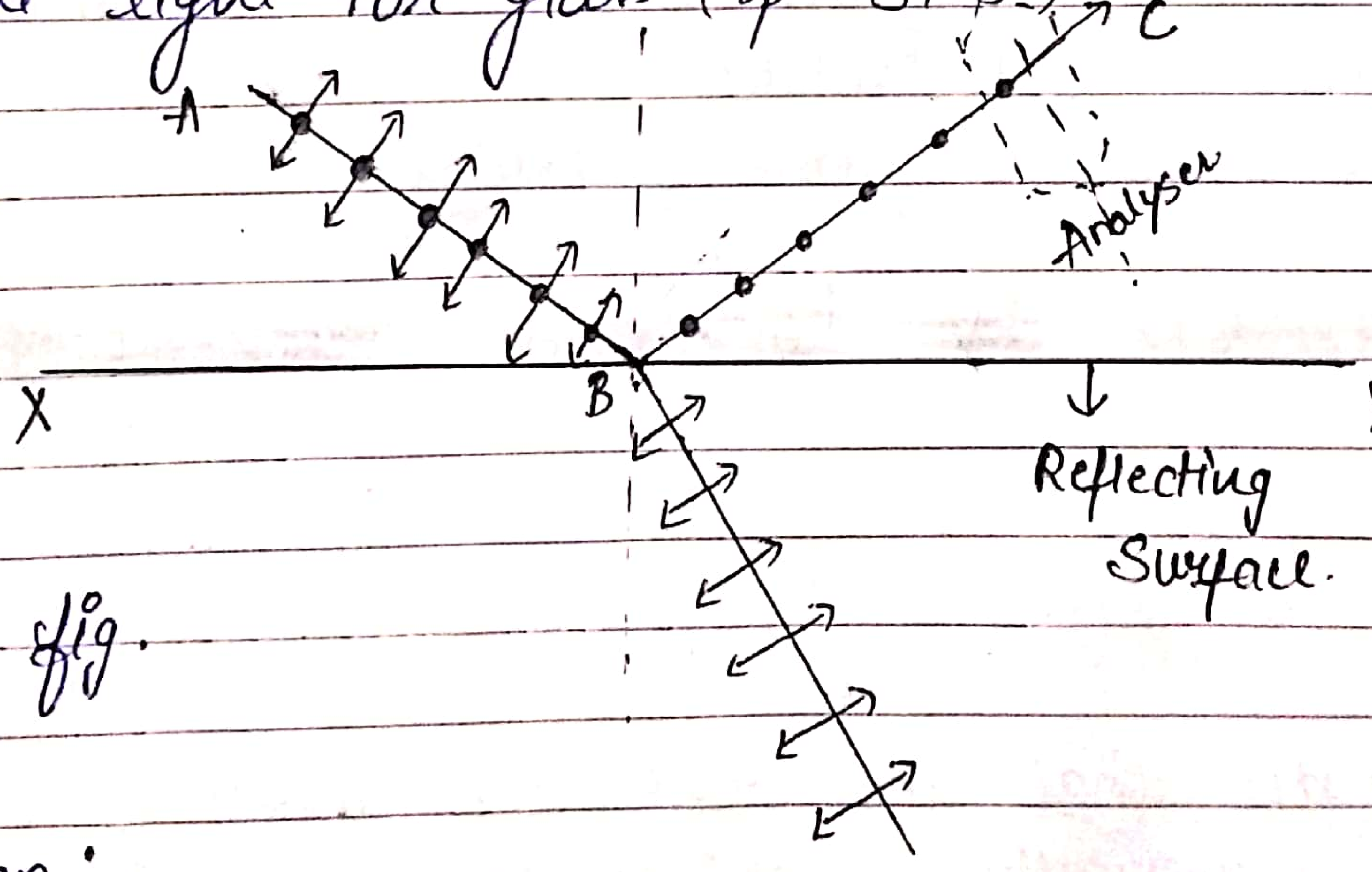


fig.

Explanation:

When a beam of ordinary light is incident on a reflecting surface, vibrations which are perpendicular to plane of incidence (represented by dot) remains always parallel to plane of reflecting surface. Therefore they will always get reflected whatever the angle of incidence be. But vibrations

which are parallel to plane of incidence (shown by ↕), may refuse to reflected by the surface at a particular angle called polarizing angle (for glass $i_p = 57.5°$). Thus transmitted ray is said to be polarized in plane perpendicular to plane of incidence.
Transmitted ray is however also contain some plane lar vibrations with plane parallel vibrations, thus it is partially polarized.

Detection of plane polarized reflected light.

For detection, we can place a tourmaline crystal in the path of reflected light. Rotate the crystal gradually about axis BC. Intensity of light will vary on rotation and you will find positions of crystal when intensity of reflected beam after transmission from crystal will be maximum & minimum twice in each rotation.
This indicate light is plane polarized.

[redacted] ([redacted])

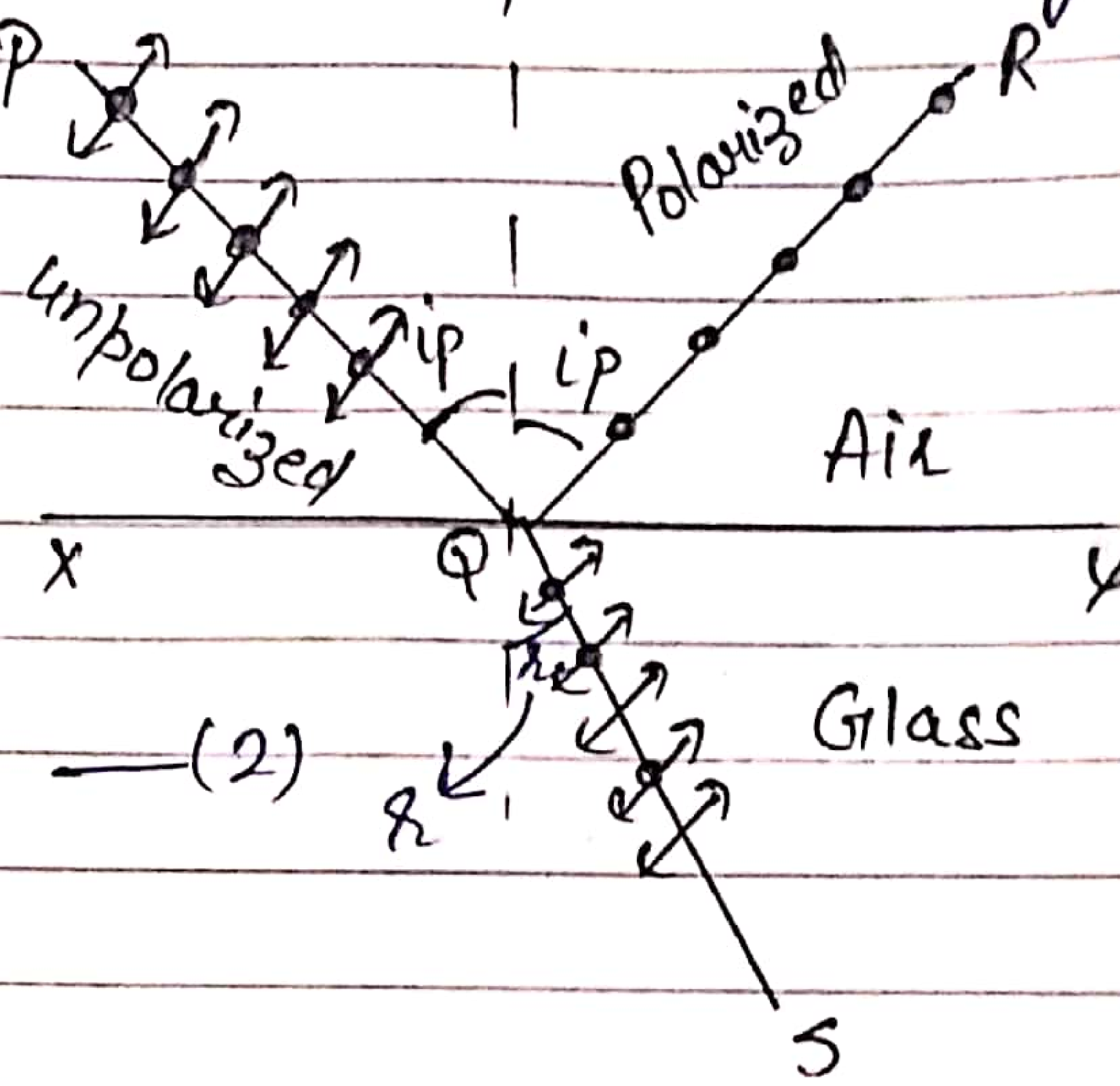
Brewster's Law

The law states that "the refractive index of refracting material is numerically equal to tangent of the angle of polarization 'ip'.

Mathematically, $\boxed{\mu = \tan i_p}$

Relation between i_p and angle of reflection 'r' in denser medium

Consider a reflecting surface XY seperating glass and air. Let PQ be the incident beam, incident at polarizing angle i_p shown in fig.
The reflected and refracted beam are represented by QR and QS.



from Snell's law, $\mu = \frac{\sin i_p}{\sin r}$ —— (1)

from Brewster's law,

$$\mu = \tan i_p = \frac{\sin i_p}{\cos i_p} \quad —— (2)$$

Comparing equation (1) & (2),

$$\sin r = \cos i_p$$
$$\Rightarrow \sin r = \sin(90° - i_p)$$
$$\Rightarrow r = 90° - i_p$$
$$\Rightarrow \boxed{r + i_p = 90°} \quad —— (3)$$

from Geometry, $i_p + \angle RQS + r = 180°$

$\angle RQS + 90° = 180°$ from (3)

$\angle RQS = 180° - 90° = 90°$

Hence at polarizing angle, the reflected ray is perpendicular to the refracted ray.