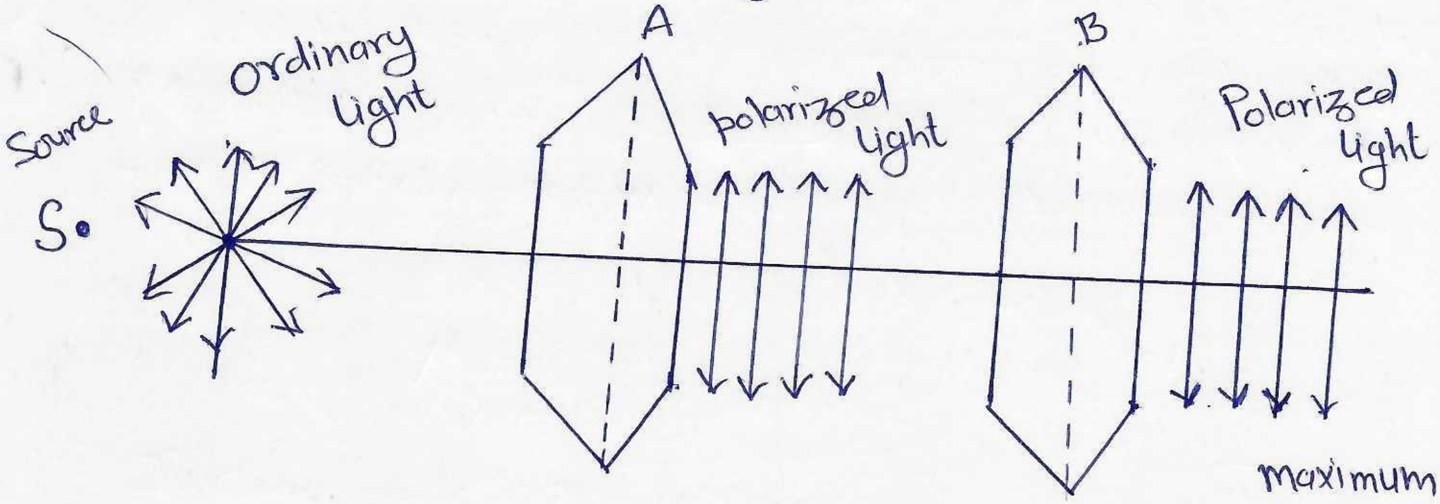
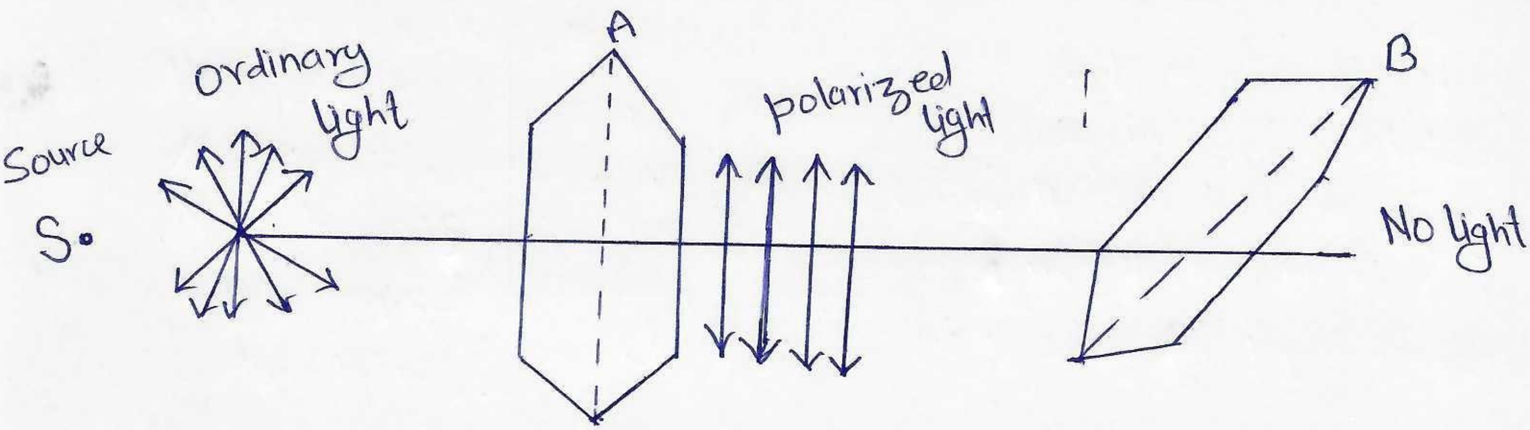
Polarization

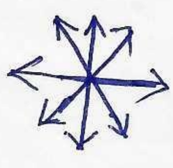
Polarization — The process of transforming unpolarised light wave to polarized light wave called the polarization of light.



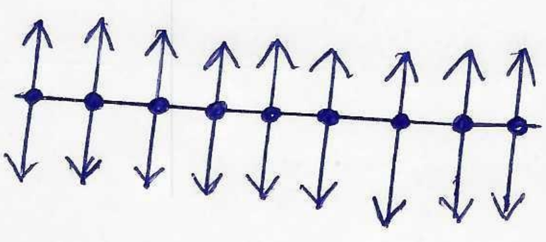


When ordinary light is incident normally on a pair of parallel tourmaline Crystal plate A and B Cut parallel to their Crystallographic axis the Emergent light Shows a Variation as B is rotated. The intensity is maximum When the axis of B is parallel to that of A and minimum when at right angle. This Shows that the light emerging from A is not Symmetrical about the direction of propagation of light, but its Vibrations are confined only a Single line in a plane perpendicular to direction of propagation. Such light is Called plane polarized light.

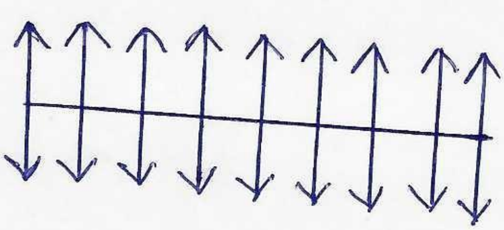
Pictorial Representation of light Vibrations



unpolarized light



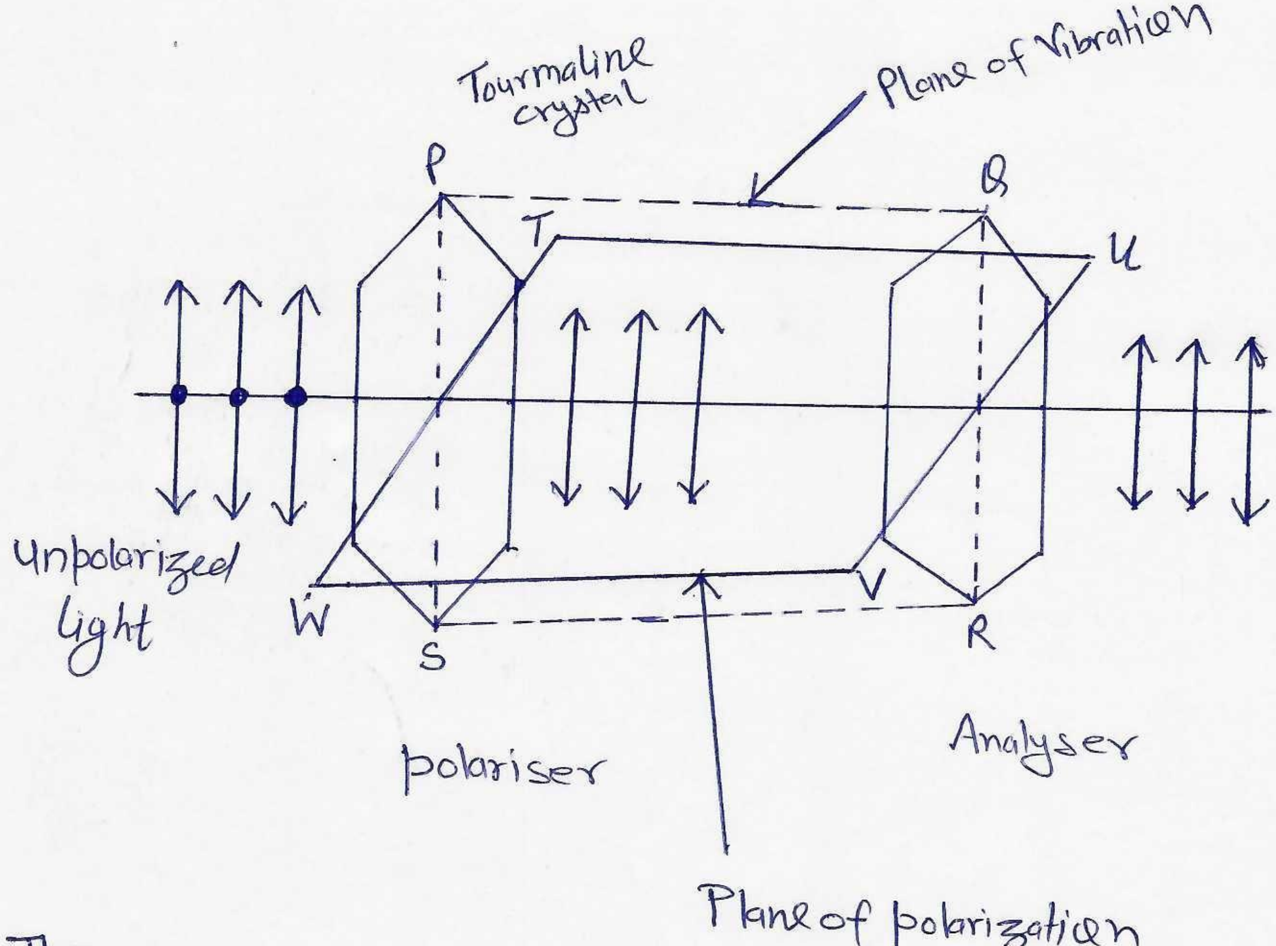
Unpolarized light



plane polarized Vibrations perpendicular to plane of paper

plane polarized light Vibrations paralle to plane of

Plane of Vibration and Plane of Polarization



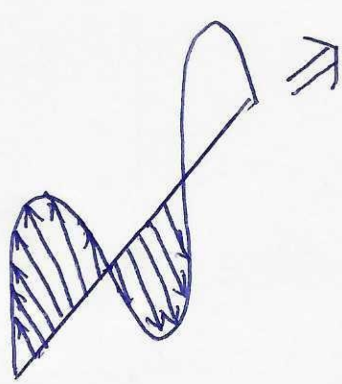
The plane in which the vibrations take place i.e. the plane containing the direction of vibration and the direction of propagation, is called plane of vibration. Plane PQRS is the plane of vibration.

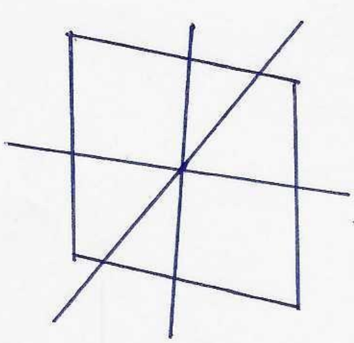
A plane perpendicular to the plane of vibration is called the plane of polarization. Thus the plane of polarization is the plane passing through the direction of propagation and contain no vibrations. The plane TUVW is the plane of polarization.

Types of polarization —

1- Plane polarized light
2- Circularly polarized light
3- Elliptically polarized light

Plane polarized light — If in a polarized light, the electric Vector Vibrates in a fixed Straight line perpendicular to direction of propagation of light, it is Said to be plane polarized light (PPL).

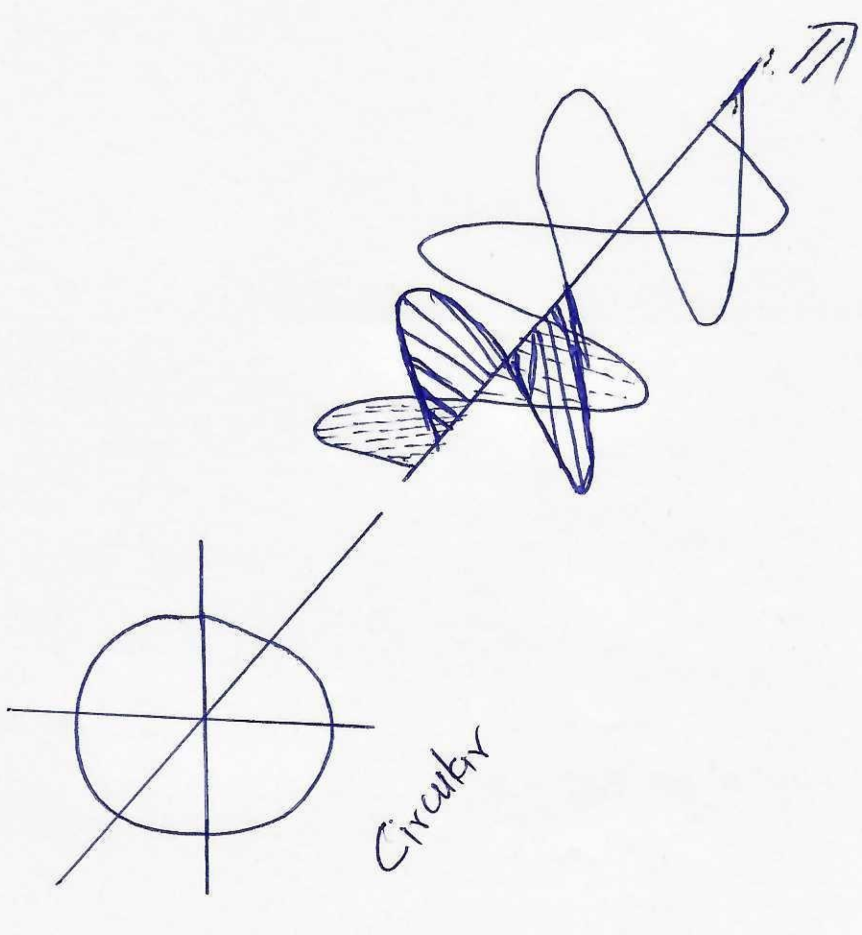




Plane

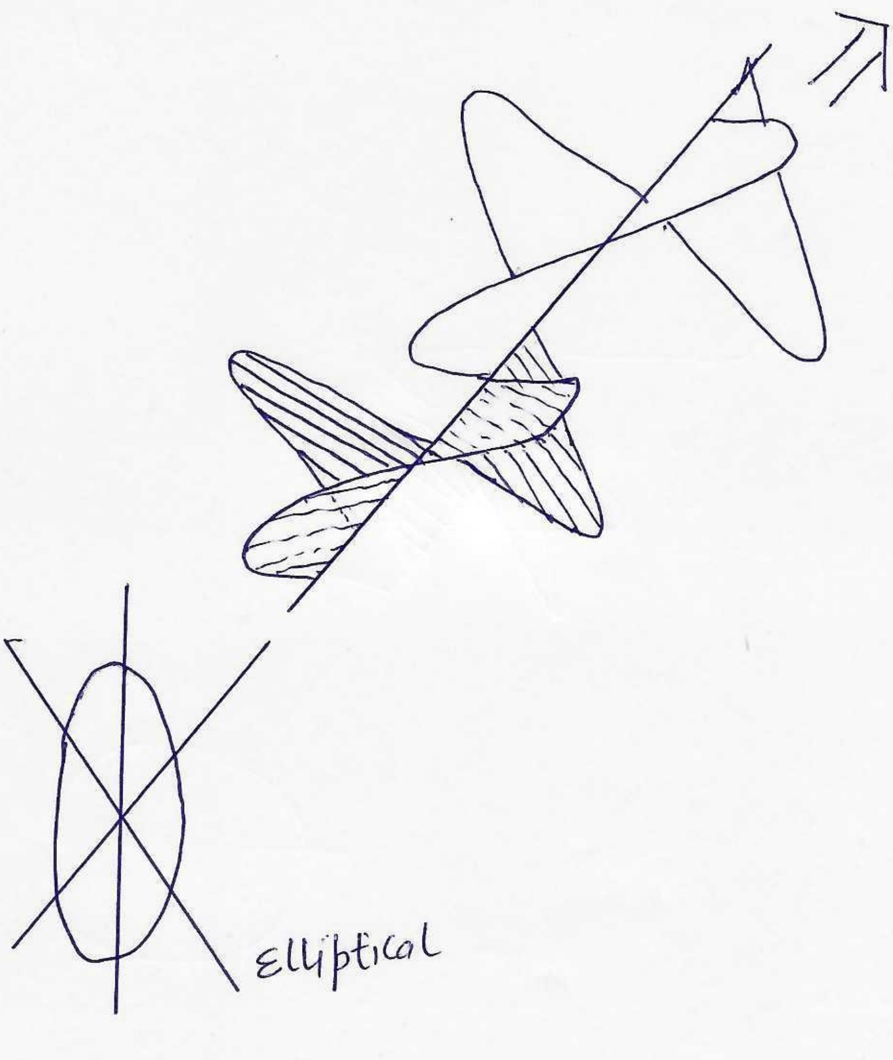
Circularly polarized light —

When two plane polarised light waves are superimposed Under Certain Conditions, the resultant light Vector rotates with a Constant magnitudes in a plane perpendicular to the direction of propagation of light; the tip of a Vector Space traces a Circle and the light is Said to be Circularly polarised light. Circularly polarised light Consists of two perpendicular electromagnetic plane Waves of Equal amplitude and with 90° difference in Phase.

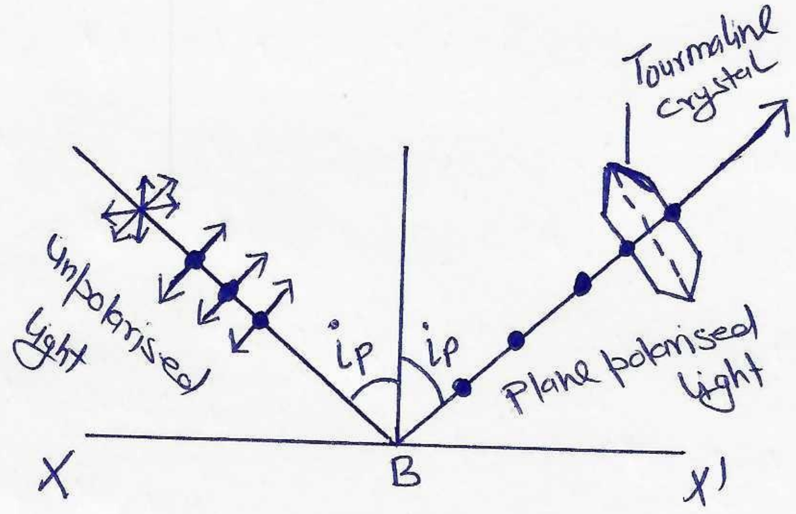


Elliptically polarized light—

Whe two plane polarised light waves are Superimposed, then under Certain Condition, the resultant light vector rotates the a plane perpendicular to the direction of propagation of light; the tip of vector traces an ellipse and the light is Said to be elliptically polarised light. Elliptically polarised light Consists of two perpendicular Waves of unequal amplitude which differ in phase by 90°.



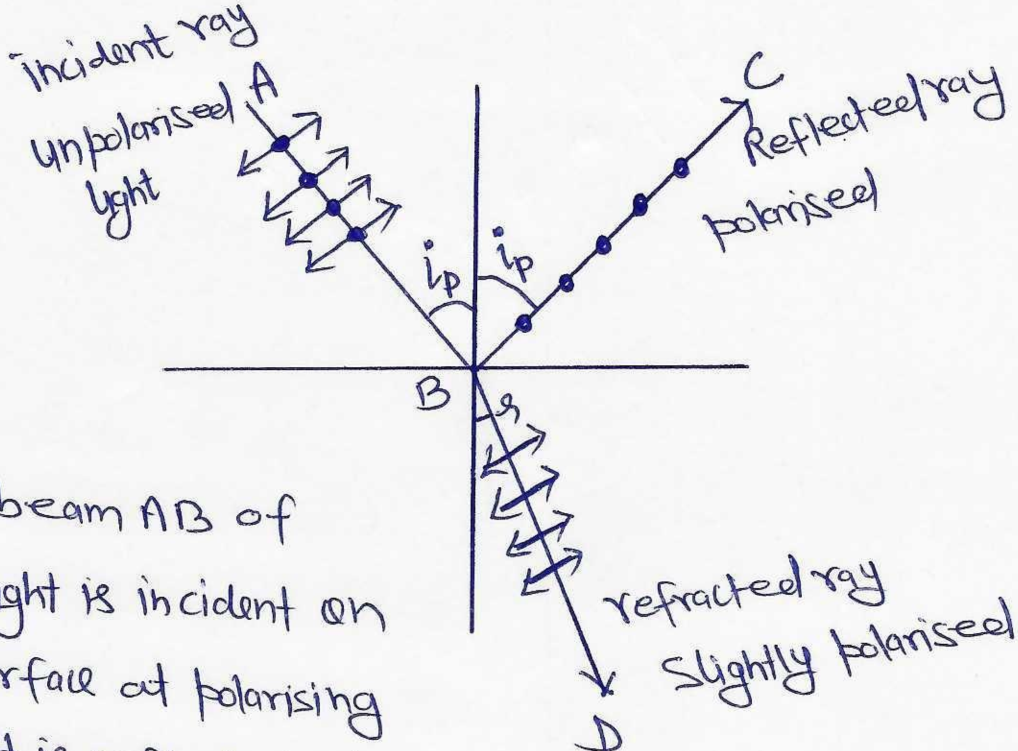
Polarisation by Reflection —



Ordinary light when reflected from a plane sheet of glass gets partially polarised. The degree of polarisation varies with angle with incidence. At a particular angle (i_p) known as angle of polarisation. The percentage of polarisation is maximum. The angle of polarisation slightly depends upon the nature of reflecting surface and wavelength of light.

Brewster's Law — Brewster performed number of experiments to study the polarisation of light by reflection. He found that at a perticular angle i_p the light is completely polarised in the plane of incident ray. He also found that the value of (i_p) depend upon the refractive index of reflecting medium. He discovered a relation

Which is known as Brewster's law. It also came into picture that reflected and refracted rays are perpendicular to each other.



Suppose a beam AB of unpolarised light is incident on the glass surface at polarising angle i_p. It is reflected along BC and refracted along BD. Then from Brewster's law

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

From Snells Law

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

$$\frac{\sin i_p}{\cos i_p} = \frac{\sin i_p}{\sin r}$$

$$\frac{\sin i_p}{\sin\left(\frac{\pi}{2} - i_p\right)} = \frac{\sin i_p}{\sin r}$$

$$\frac{\pi}{2} - i_p = r$$

$$i_p + r = \frac{\pi}{2}$$

As $i_p + \angle CBD + r = \pi$

$$\angle CBD = \pi - (i_p + r)$$

$$= \pi - \frac{\pi}{2}$$

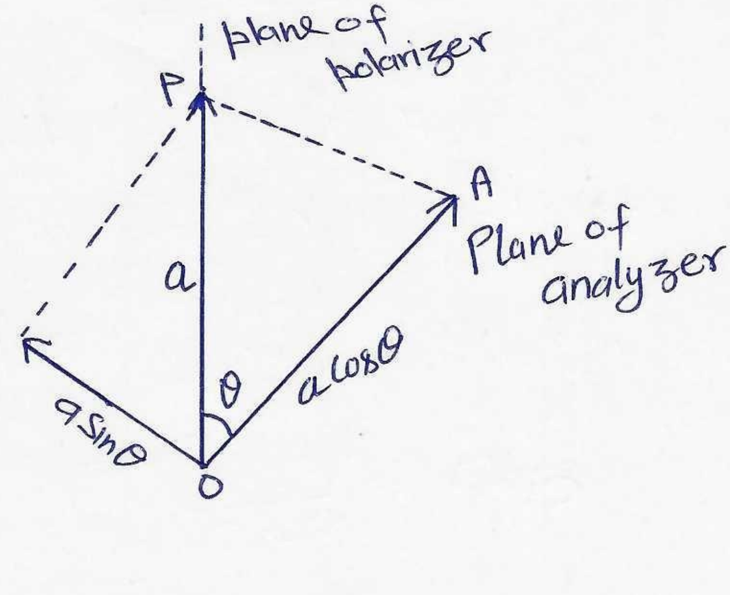
$$\boxed{\angle CBD = \frac{\pi}{2}}$$

i.e the reflected ray is at right angle to the refracted ray.

Polarisation by Refraction —

It is found that when ordinary light get refracted through any transparent medium, the refracted ~~ray~~ ray is partially ~~polarised~~ polarised. In order to obtain completely polarised light it is refracted through piles of plates which consists of adequate number of glass plates separated by airgaps. after multiple refraction through this arrangement the emerging light gets completely polarised.

<u>Malus's Law</u> — According to Malus when a completely plane polarised light is incident on an analyser, the intensity of the emergent light varies as the square of cosine of the angle between the plane of transmission of analyser and the polariser.



Let $OP = a$ be the amplitude of the incident plane polarised light from a polariser and θ is the angle between plane of polariser and plane of analyser.

So the amplitude of incident plane polarised light can be resolved into two components one parallel to the plane of transmission of analyser ($a\cos\theta$) and other perpendicular to it ($a\sin\theta$)

The component $a\cos\theta$ is transmitted through the analyser.

The intensity of transmitted light through analyser

$$I = (a\cos\theta)^2 = a^2\cos^2\theta$$

If I_0 be the intensity of incident polarised light then $I_0 = a^2$

$$So,\ I = I_0\cos^2\theta$$

or $\boxed{I \propto \cos^2\theta}$

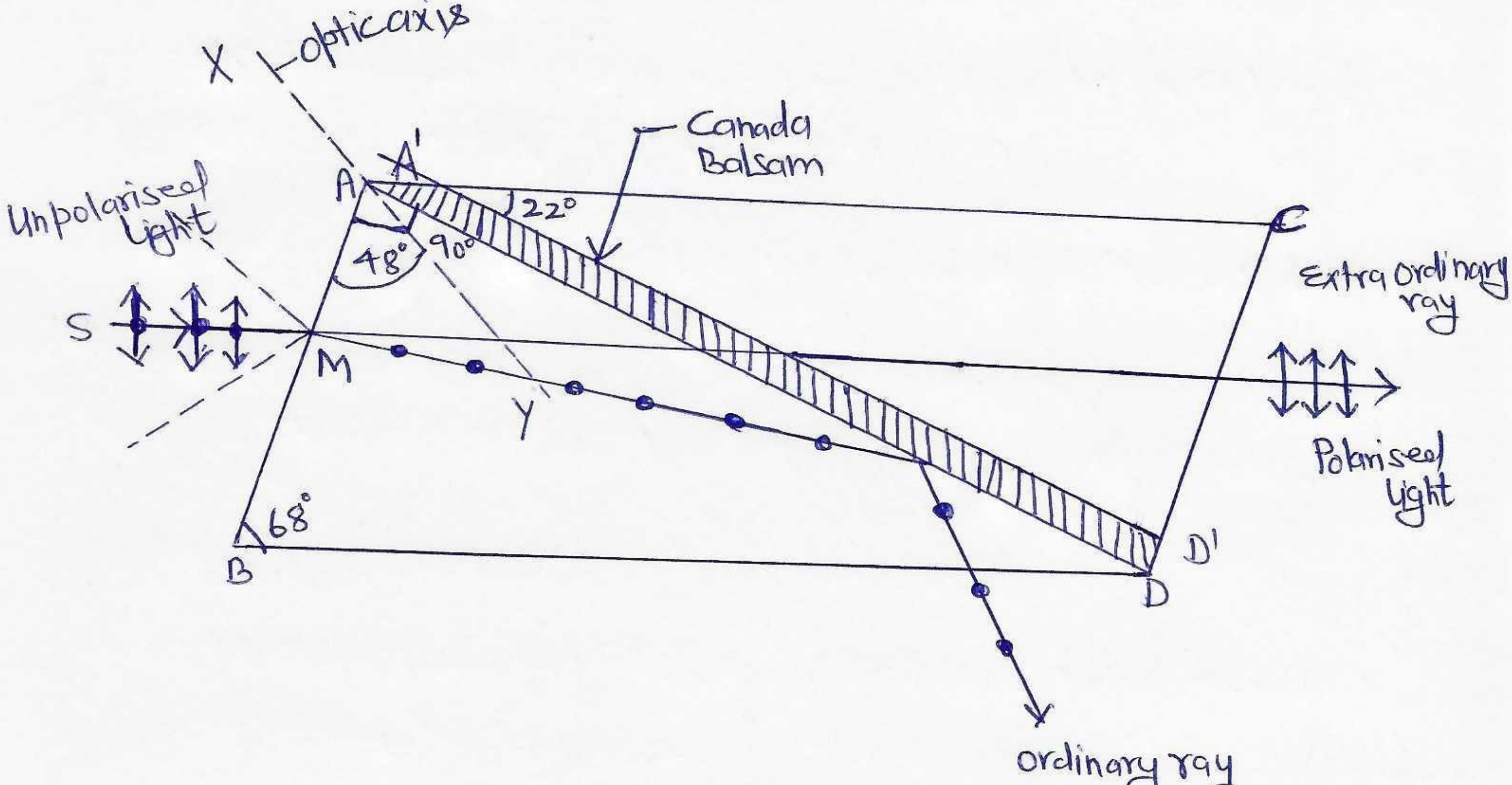
1) When $\theta = 0°$, two planes are parallel.

$$I = I_0$$

2) When $\theta = 90°$, two planes are perpendicular

$$I = 0$$

Nicol Prism — Nicol Prism is an optical device, invented by William Nicol for producing and analysing Plane polarised light.



Principle — It is based on the phenomenon of double refraction. When an Unpolarised light is passed through a doubly refracting Uniaxial Crystal, it is broken up into two rays.

1) ordinary ray

2) Extraordinary ray.

Both are polarised, having their Vibrations at right angle to each other. If by any suitable means one of the two rays is eliminated, the remaining ray coming out from the Crystal will be plane polarised.

Construction — Nicol prism is constructed from a calcite crystal whose length is nearly three times of its width ($l:b = 3:1$). The end faces of the crystal are cut down so as to reduce the angle of the principal section to a more acute angle of 68° The crystal is then cut along a diagonal and the two cut surfaces after polishing, cemented back together with a special cement called Canada balsam, which is transparent substance. It is optically more denser than calcite for the e-ray and less denser for o-ray

for Sodium light $\mu_o = 1.6583$

$\mu_{cb} = 1.55$

$\mu_e = 1.486$

Action — A ray of light SM is incident nearly parallel to BD' on the face A'B of the Nicol prism, it split into e-ray and o-ray whose vibrations are respectively, perpendicular and parallel to the principal section of the Nicol prism. The o-ray suffers total internal reflection at the Canada balsam surface for nearly normal incidence, because Canada Balsam is optically more denser than calcite for the e-ray and less denser than calcite for the o-ray.

The e-ray is refracted through Canada balsam and is transmitted but o-ray, moving from a denser calcite medium to the rarer of incidence greater than the Critical angle.

The Value of Critical angle i_c for the o-ray for Calcite to Canada balsam is

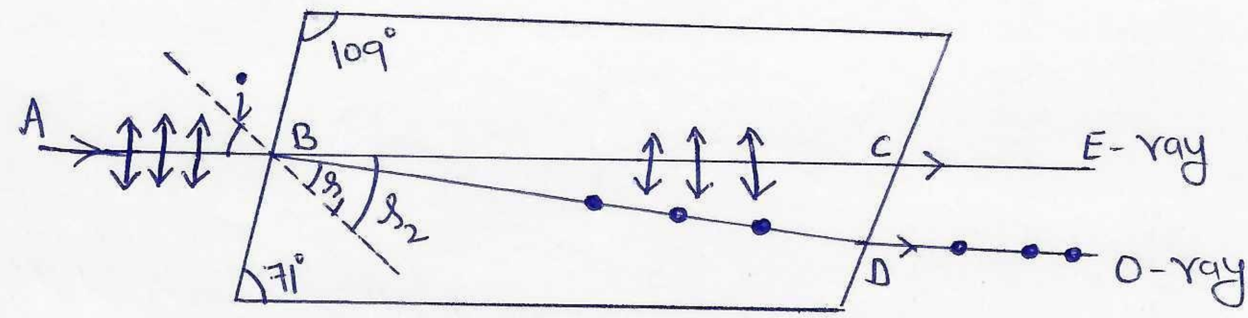
$$i_c = \sin^{-1} \frac{1.550}{1.658} = 69^\circ$$

Limitation — The Nicol prism works only when the incident ray is slightly convergent or slightly divergent.

1) If the incident ray makes an angle much smaller than $\angle BMS$ with the surface $A'B$ the o-ray will strike the Canada balsam layer at an angle less than the Critical angle and hence will be transmitted and light emerging from the Nicol prism will not be plane polarised.

2) If the incident ray make an angle greater than $\angle BMS$, the e-ray become more and more parallel to the optic axis and hence its refractive index will become nearly equal to the Calcite for the o-ray. This will suffer total internal reflection like o-ray. Hence no light will emerge out of the Nicol prism,

Double Refraction



When a beam of ordinary Unpolarised light is passed through a Calcite Crystal, the refracted light is split up into two refracted rays. The one which always obeys the ordinary Laws of refraction and having Vibrations perpendicular to the principal Section is known as ordinary ray. the other, doesnot obey the Laws of refraction and having Vibrations in the principal Section is Called as extra ordinary ray. Both the rays are plane polarised. This phenomenon is known as double refraction. The Crystals Showing this phenomenon are Called ~~double~~ doubly refracting Crystals.

There are two types of doubly refracting Crystals! 1) Uniaxial and 2) biaxial. In Uniaxial Crystal there is Only one direction (optic axis) along which the two refracted rays travel with the Same ~~veloci~~ Velocity (Exp. Calcite, tourmaline and quartz). ~~In biaxial~~ In biaxial Crystals there are two Such directions along which the

Consider a beam AB of unpolarised light incident on the Calcite Crystal at an angle of incident i. Inside the Crystal the ray breaks up into ordinary and extraordinary rays. The ordinary ray travelling along BD makes an angle of refraction (r_1) while the Extraordinary travelling along BC makes an angle of refraction (r_2). Since the two opposite faces of the Crystal are always parallel, both the rays emerge parallel to the incident rays The refractive index of ordinary and extraordinary rays can be expressed as

$$\mu_o = \frac{\sin i}{\sin r_1} \quad \text{and} \quad \mu_e = \frac{\sin i}{\sin r_2}$$

In Case of Calcite $\mu_o > \mu_e$ because $r_1 < r_2$, Therefore the velocity of light for ordinary ray inside the Crystal will be less than the extraordinary ray. It is observed that μ_o is same for all the angle of incidence while μ_e varies with angle of incidence. Therefore, ordinary ray travels with the same speeds in all directions while extraordinary has different speeds in different directions.

Negative Crystals and Positive Crystals

Negative Crystals —

In Crystals Such as Calcite the angle of refraction for ordinary ray (r_o) is less than the angle of refraction for Extra-Ordinary ray (r_e) hence the refractive index for ordinary ray (μ_o) is greater than the refractive index for Extraordinary ray (μ_e) and Velocity of ordinary ray is less than the Velocity of Extra ordinary ray. Such Crystals are Called negative Crystals. The ordinary image remains Stationary and e-image revolves around the o-imge.

Positive Crystals —

In positive Crystals $r_o > r_e$, hence $\mu_o < \mu_e$ and $v_o > v_e$. In Such Crystals the ordinary image remains fixed but the extraordinary image revolves in between the ordinary image, the line joining the two being parallel to the longer diagonal of the Emergent Face i.e. quartz Crystal

Retarders/Wave Plates

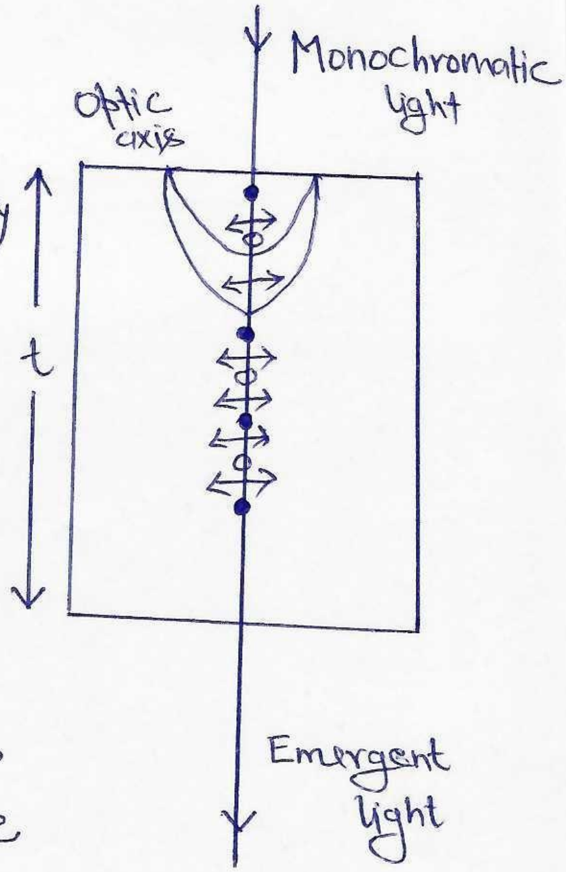
Retardation Plates —

The Simplest device for producing and detecting Circularly and Elliptically polarised light is Known as retardation plate. A plate cut from a doubly refracting Crystal So as to produce a definite ~~Valueof~~ Value of path difference or phase diffrence between e-ray and o-ray is Known as retardation plate. In generally, a retarding plate is cut from a doubly refracting Crystal with its face parallel to the optic axis. There are two types of retarding plates.

1) Quarter Wave Plate 2) Half Wave Plate

Quarter Wave Plate — A Plate of doubly refracting Uniaxial Crystal cut with its optic axis parallel to the refracting faces and Capable of producing a path difference of $\lambda/4$ or a phase difference of $\pi/2$ between the ordinary and extraordinary ~~rays~~ waves is Called a quarter wave plate or $\lambda/4$ plate.

When a beam of Monochromatic light of wavelength λ is incident normally on such a plate, it is broken up into o-wave and e-wave inside the plate. Both these waves travel in the same direction perpendicular to the faces but with different velocity



If 't' is the thickness of the plate, then the path t in the crystal plate is equivalent to $\mu_o t$ and $\mu_e t$ for o- and e-rays.

Hence the path difference between the two waves on emerging in case of negative crystal is

$$\Delta = \mu_o t - \mu_e t$$

$$\Delta = (\mu_o - \mu_e)t \quad \text{——— } ①$$

If the plate acts as a quarter wave plate, the path difference must be equal to $\lambda/4$.

$$\Delta = \lambda/4$$

$$(\mu_o - \mu_e)t = \lambda/4$$

$(\mu_o > \mu_e)$

$$t = \frac{\lambda}{4(\mu_o - \mu_e)} \quad \text{——— } ② \text{ for negative crystal}$$

For +ve crystal

A quarter wave plate is used in the production of circularly and Elliptically polarised light. If the angle of incidence of plane polarised light is 45° with optic axis the emergent light is circularly polarised. If the incident plane polarised light meets the optic axis at an angle not equal to 45° then the emergent ray is Elliptically polarised.

<u>Half Wave plate</u> — A plate of doubly refracting uniaxial crystal cuts with its optic axis parallel to the refracting faces and capable of producing a path difference of $\lambda/2$ and Phase difference of π between e- and o-rays is called Half wave plate or $\lambda/2$ plate.

If 't' is the thickness of such a plate, the in case of negative crystal ($\mu_o > \mu_e$) the path difference between o-ray and e-ray is

$$\Delta = (\mu_o - \mu_e)t = \lambda/2$$

$$t = \frac{\lambda}{2(\mu_o - \mu_e)} \quad \text{—— (1)}$$

for positive crystal, $\mu_e > \mu_o$

$$t = \frac{\lambda}{2(\mu_e - \mu_o)} \quad \text{—— (2)}$$