Arif ce17

POLARIZATION

EEE-112(13)

[Interference and diffraction have been able to established firmly the wave nature of light; however, both these phenomenon, fail to establish whether light waves are longitudinal or transverse.]

Longitudinal wave : The particles of the medium execute a to and fro periodic motion about their mean positions along the direction of the propagation of the waves.

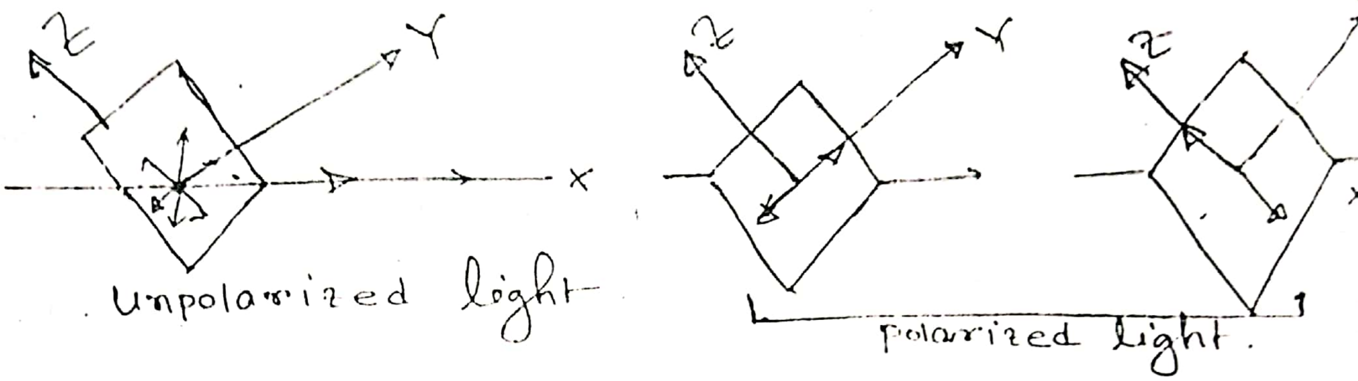
Transverse : The vibration of the particles is perpendicular to the direction of propagation of the wave.

* Light is emitted in the form of wave-trains by individual atoms when in an excited state.

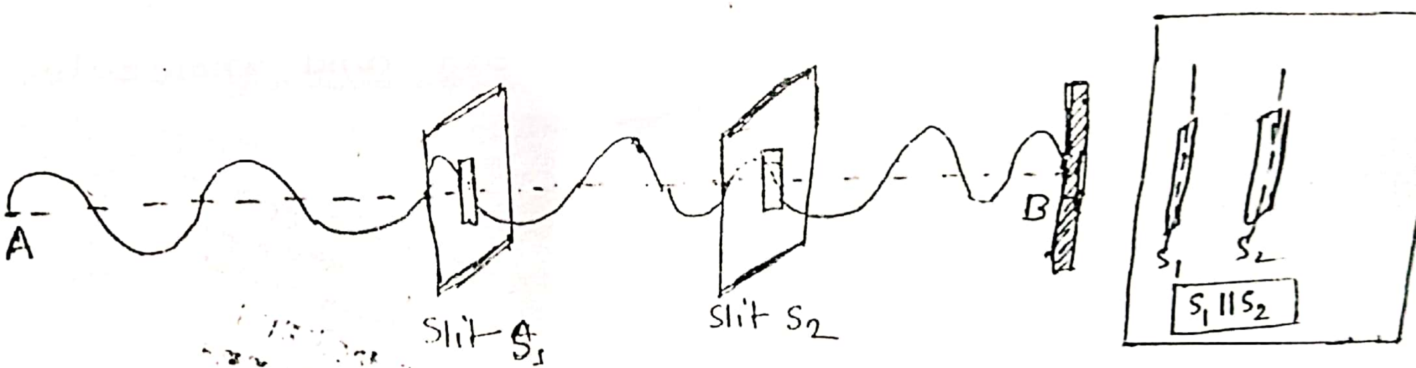
A beam of natural light consists of millions of such wave-trains emitted by a very large number of randomly oriented radiating atoms and molecules in the light source.

Q. Why do you need to study polarization ?

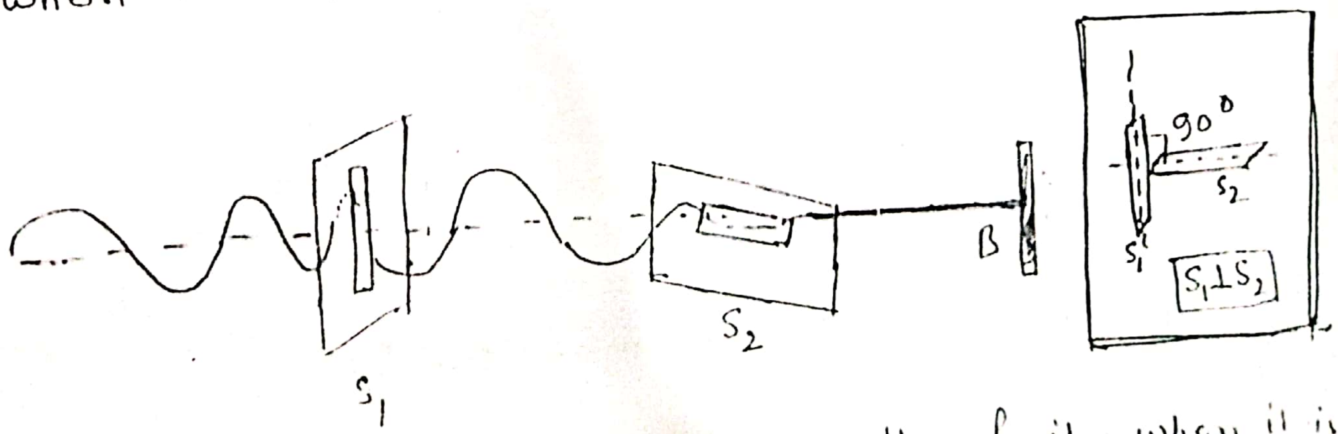
[4] Polarization: The process by which vibrating in different planes can be made to vibrate in a particular plane is called polarization of light.



[5] Polarization of Transverse wave:



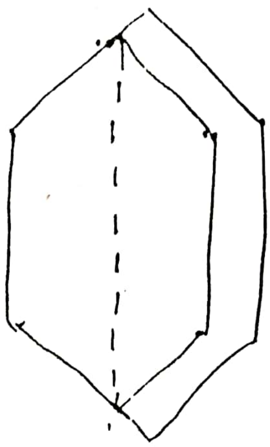
When string AB is moved up & down a transverse wave will produce. The slit S_2 allows the wave to pass through it when it is parallel to S_2.

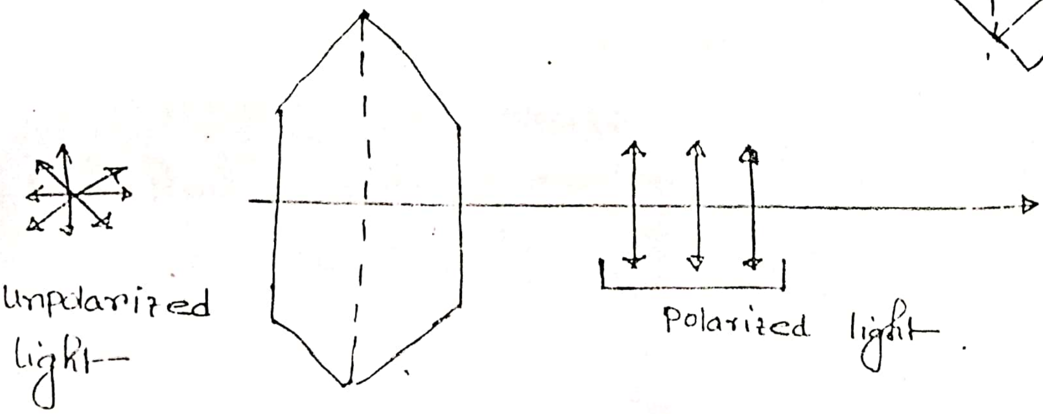


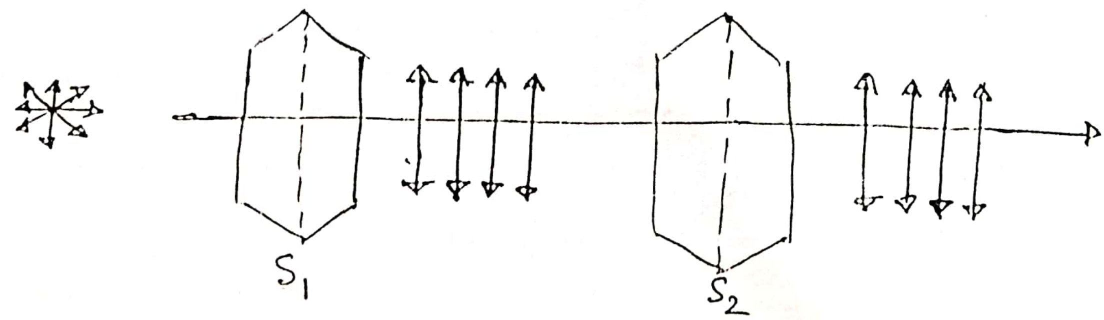
The slit S_2 does not allow to pass through it when it is ...

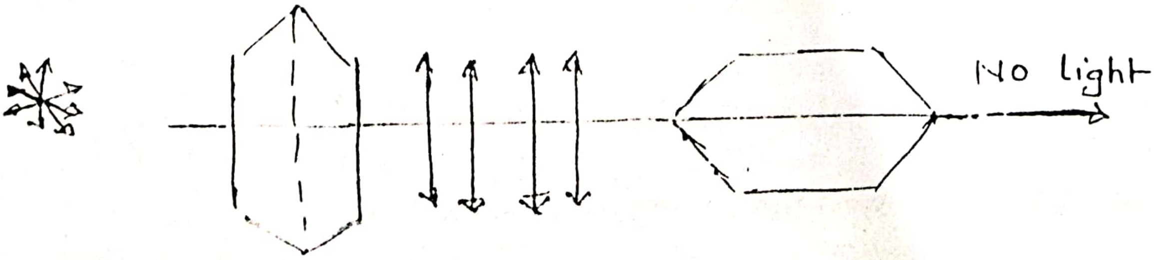
sion phenomenon has been observed in light when it passes through a tourmaline crystal.

__Tourmaline crystal:__ Tourmaline crystal is a transparent crystal of light green colour having six sides. The maximum diagonal is called the optic axis.









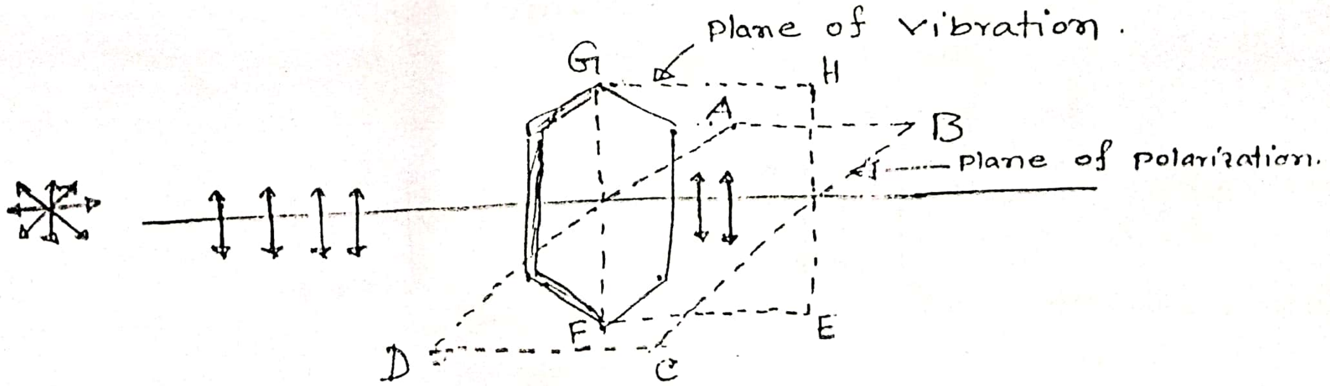
[1] Plane of polarization and plane of vibrations :

Plane of polarization : The plane of polarization is that plane in which no vibrations occur.

plane of vibrations : The plane of vibrations is that plane in which vibrations occur.

Plane of polarization ⊥ plane of vibrations,

When ordinary light is passed through a tourmaline crystal, the light is polarized and vibrations are confined to only one direction perpendicular to the direction of propagation of light. This is plane polarized light and it has acquired the property of one sidedness.



Plane ABCD → plane of polarization.

plane EFGH → Plane of vibration.

natural unpolarized light may be looked upon as a mixture of waves in all possible transverse directions. This is referred to as perfect symmetry.

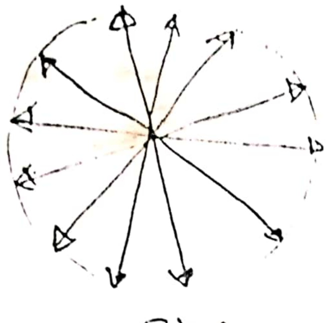


Fig.1

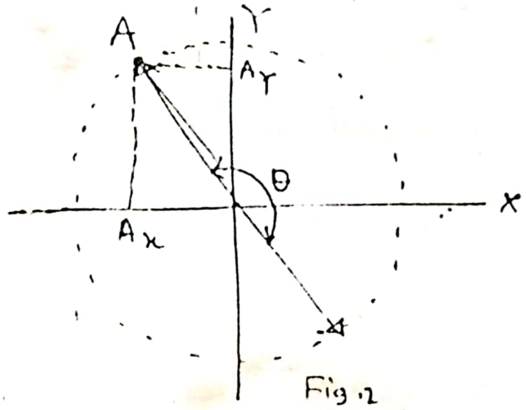
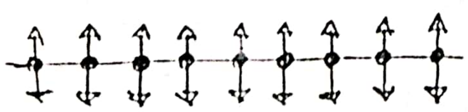


Fig.2

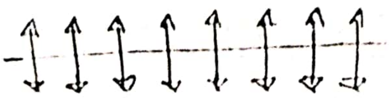
As light are transverse in nature, each vibration of Fig.1 can be resolved into two component vibrations along two planes at right angles to each other and also perpendicular to the direction of vibrations. Thus a beam of ordinary unpolarized light may be regarded as being made up of two kinds of vibration only.

1) One Half the vibration vibrating in a vertical plane, say along the plane of the paper, referred to as parallel vibration and represented by double headed arrows (↕)

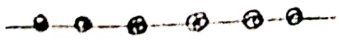
2) Other half vibrating perpendicular to the plane of the paper, referred to as perpendicular vibrations and represented by dots (•)



(ordinary unpolarized light)



(vibrations parallel to the pale of the paper)



(vibrations perpendicular to the plane of the paper)

[5] Methods of producing plane-polarized light (G.U.A. 1309)

There are three important methods for producing plane-polarized light. These are:

i) by reflection (Malus – 1808)

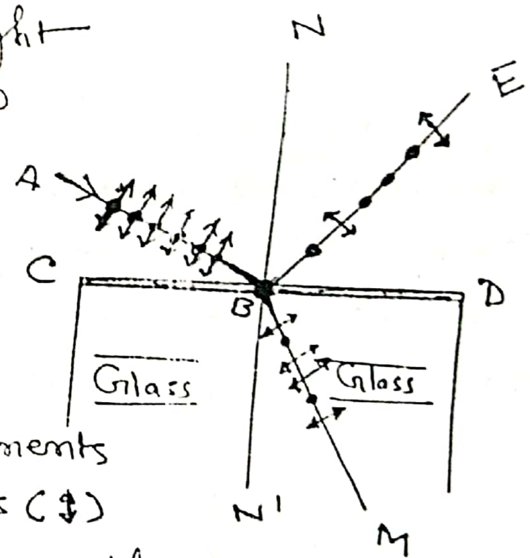
2) by refraction (Brewster – 1812)

3) by double refraction (Bartholinus – 1669) (Huygens – 1690).

Besides this three methods, polarization may also be produced by selective absorption and scattering of light.

[5] Polarization by reflection:

Let a beam AB of natural light is incident on glass surface CD



Both the reflected light along BE and transmitted light along BM are partially polarized. The reflected light consists mostly of dot (•) components along with few arrow components (↕) Similary the transmitted light mostly consists of arrow components along with dot components.

This is true for all angles of incident except one particular angle.

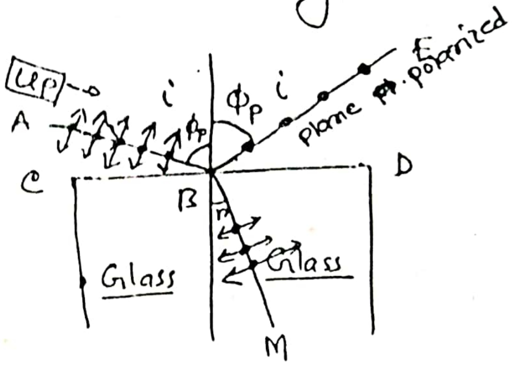
At is particular angle of incident, none of the arrow components is reflected, they are all transmitted.

The dot component that is reflected about 15% is the case of glass surface (Depends on refractive index) red being transmitted along with the arrow components.

The reflected light, although weak but polarized.
The refracted light is strong but partially polarized.

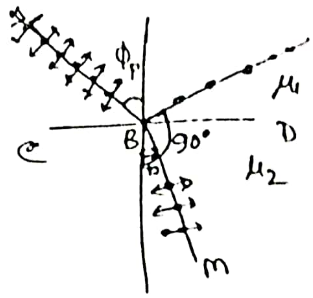
[i] Polarizing angle: The particular angle of incident for which the reflected light becomes completely polarized is known as the polarizing angle.
For glass this angle is 57°.

[UP] → unpolarized light.



[i] Brewster's law:

i) The tangent of the polarizing angle is equal to the refractive index of the reflecting material with respect to its surrounding.



ii) The reflected and refracted rays are perpendicular to each other.

Let
μ_1 is the absolute refractive index of the surrounding & μ_2 is the absolute refractive index of the reflecting material.
ϕ_p the polarizing angle, then Brewster's law.

$$\tan\phi_p = \frac{\mu_2}{\mu_1} = {}_1\mu_2$$

Here ${}_1\mu_2$ is the refractive index of the reflecting material with respect to its surrounding medium we know from snell's law.

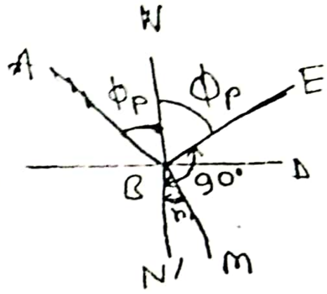
$$\frac{\sin\phi_p}{\sin r} = {}_1\mu_2 \quad \text{------ (1)}$$

According to Brewster's law

$$\tan\phi_p = \frac{\sin\phi_p}{\cos\phi_p} = {}_1\mu_2 \quad \text{------ (2)}$$

From equation (1) & (2)

$$\cos\phi_p = \sin r$$



or $\sin(90° - \phi_p) = \sin r$ [$\cos\phi_p = \cos(90° - r)$]

$$90° - \phi_p = r$$

or $r + \phi_p = \pi/2$

* Polarizer : The crystal which is used to produce plane polarized light is called polarizer.

* Analyser : The device by which the direction of polarization of a beam of light can be detecteds is called analizer.

Malus Law: The intensity of the polarized light transmitted throug the analyser varies as the square of the cosine of the angle between the plane of transmission of the analyser and the plane of ~~polarization~~ polarizer.

Let $OP = a$ be the amplitude of the vibrations transmitted or reflected by the polarizer and θ is the angle between the planes of the polarizer and the analyser.

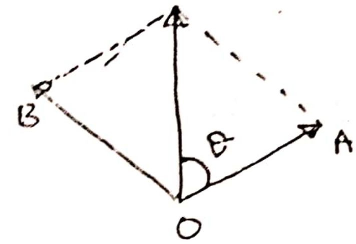


Fig. 1

From Fig. 1 OP resolve into two components:

i) $a\cos\theta$ along OA and
ii) $a\sin\theta$ along OB.

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

$\therefore$ Intensity of the transmitted light throug the analyser,

$$E_1 = (a\cos\theta)^2 = a^2\cos^2\theta, \quad \text{But } E = a^2$$

where E is the intensity of incident polarized light.

$$\therefore E_1 = E\cos^2\theta \quad \& \quad E_1 \propto \cos^2\theta .$$

when $\theta = 0$ i.e

$E_1 = E$ — two planes are parallel.

when $\theta = \pi/2$ i.e

(Brijlal - 572)

→ [I] <u>Double refraction</u> : When a ray of light is refracted by a crystal of calcite it gives two refracted rays. This phenomenon is called double refraction.

[II] Optic Axis : (Brijlal -- Page - 572) (see yourself)

...icol prism : (Brijlal page 574)

...t is an optical device used for producing and analysing plane polarized light. when a beam of light is transmitted through a calcite crystal, it breaks up into two rays.

1) The ordinary ray (o - wave)
   (its vibrations perpendicular to the principal section of the crystal)

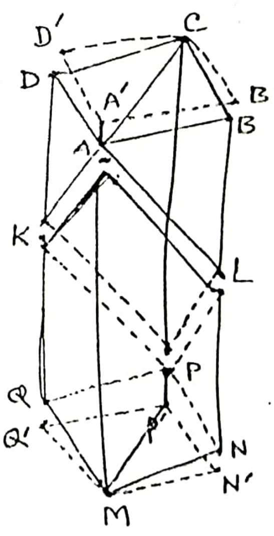
2) The extraordinary ray (E - wave)
   (its vibrations parallel to the principal section)

(GUA – Page -1320)

Construction: A calcite crystal is one of the form Nicol prism. Whose length is three times its breadth is taken let A′B′C D′M N′P′Q′ represents such a crystal.

A′ and P′ are the blunt corners of the crystal where the three obtuse angles of the three faces meet.

An imaginary plane through the edges A′M and P′C contain the optics axis of the crystal, therefor A′MP′C is one of the principal section of the crystal with the angle ∠A′CP′ = ∠P′MA′ = 71°. The faces A′B′CD′ and MN′P′Q′ are then ground so as to form the new faces ABCD and MNPQ in such a way that the angles ∠ACP and ∠PMA = 68° instead of 71°. The crystal is then cut along the plane AKPL passing through A and P perpendicular to the shorter diagonal of the end faces AC and PM. The two cut surfaces are then ground and polished to optical flatness and cemented together with a thin layer of canada balsam whic is transparent; non-doubly refracting plaster with an index of refraction intermediate between the refractive indices for the ordinary and extra ordinary rays for calcite.



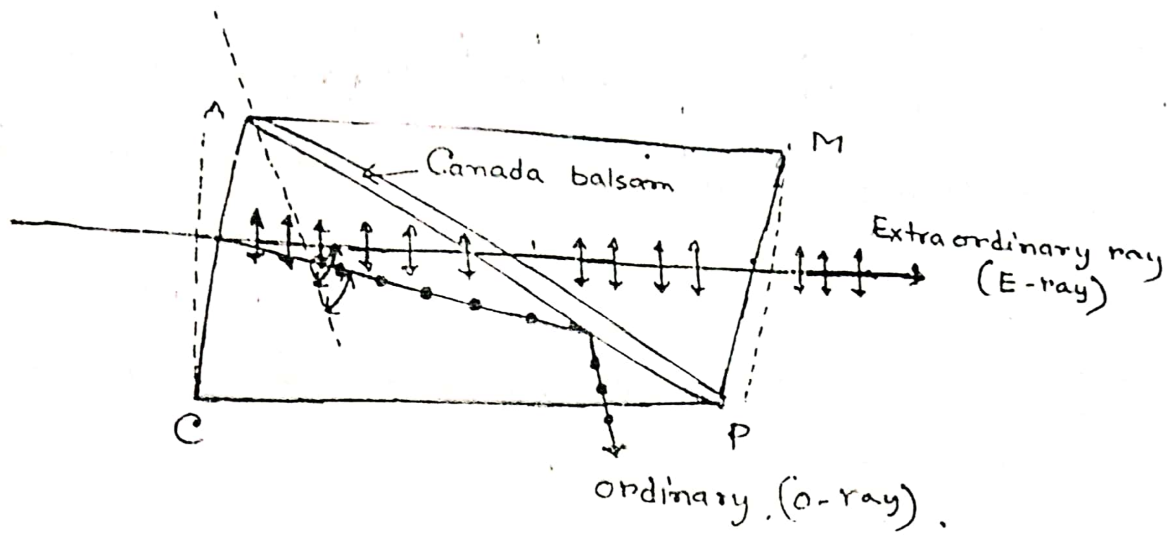
Refractive index for ordinary ray, $\mu_o = 1.658$

Refractive index for canada balsam $\mu_B = 1.55$

Refractive index for the extraordinary $\mu_E = 1.486$.

$$\mu_E < \mu_B < \mu_o$$

Action :



In the Fig. ACPM is the section of the crystal.

The diagonal AP represents the canada balsam layer in the plane ALPK. A ray of unpolarized light incident on one of the end faces of Nicol prism AC in a direction parallel to CP, splits up into E-ray and O-ray. The O-ray passes from calcite to Canada balsam travels denser to rarer medium and will suffer total internal reflection, if the angle of incident is greater than the critical angle. This totally reflected ray is absorbed by the backened side of Nicol prism.

The E-ray is transmitted as it is travelling from rarer to denser medium. When it is transmitted trough the balsam, simply suffering a slight deviation in its path. The E-ray finally emerges out of the prism parallel to the original direction bul slightly displaced Laterally.

Thus if the angle of incidence of the O-ray on the balsam is greater than the critical angle, a ray of unpolarized light on passing through the Nicol prism becomes plane-polarized light.

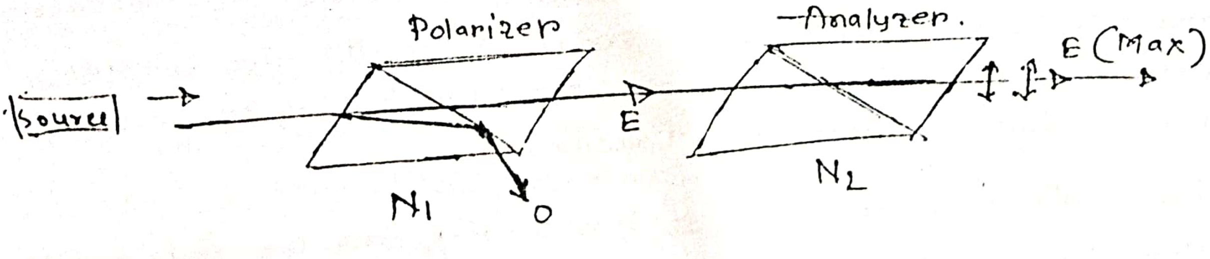
The critical angle, $c = \sin^{-1}\left(\frac{\mu_{cb}}{\mu_o}\right) = \sin^{-1}\left(\frac{1.55}{1.658}\right) = 69°$.

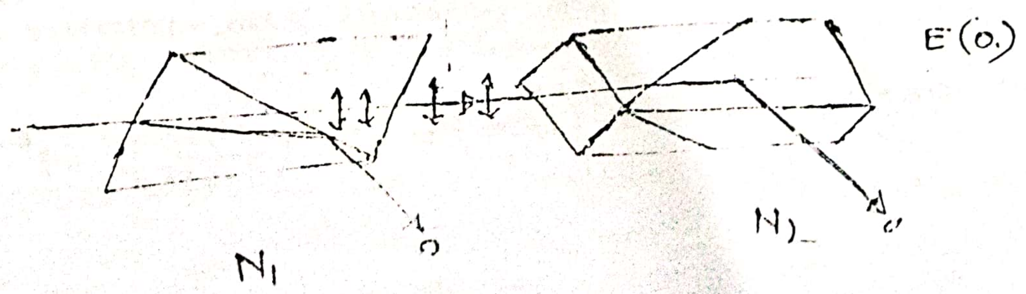
Uses: Nicol prism can be used to analyze polarized light when two Nicol prism are arranged coaxially. First prism produces polarized light is known as polarizer second prism analyses the polarized light known as analyzer.

Polariscope: The combination of two Nicol prism is called polariscope.

When principal section of two Nicol prism are parallel to each other. the vibrations of E-ray are in the plane of polarizer are also in the plane of analyzer. Therefor E-ray from the polarizer freely transmitted by the analyzer, so intensity of emergent light is maximum.

When the analyzer is rotated, the intensity of emergent light decreases. when principal section of Nicol prisms are perpendicular, then no light emerges from analyzer. In this position vibrations of E-ray, which are in the principal section of polarizer, become perpendicular to the principal section of analyzer. Hence it is totally reflected back by canada balsam layer and so no light comes out of analyzer.





Optical activity: The phenomenon or the property of rotating the plane of vibration of plane polarized light about its direction of propagation possessed by certain crystals or substances is known as optical activity.

The substance which exhibit the phenomenon of optical activity is called optically active substance.

Explain: (Page - 1332)

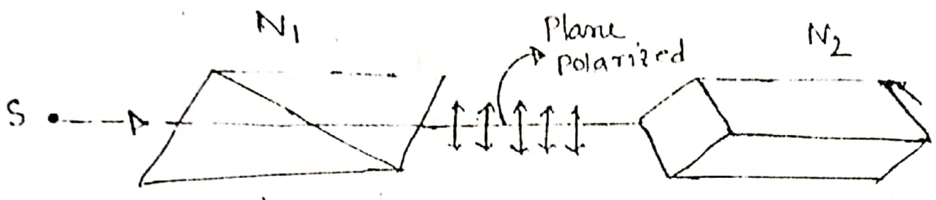


Fig. 1

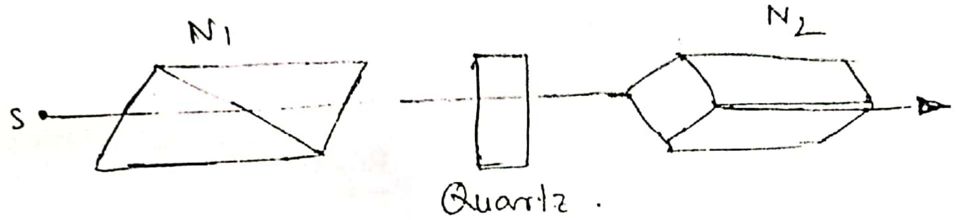


Fig. 2

When a polarizer and analyser are cross no light emerges out of analyser (Fig. 1). If now a quartz plate, cut with its faces parallel to the optic axis, is introduced between the two nicol prism so that polarized light from the Nicol N_1 falls normally on it, light emerges out of N_2. What happens is that as polarized light travels through the quartz crystal, its plane of vibration is slowly rotated about its direction of propagation and it emerges out vibrating in some other plane. This action of turning the plane of vibration occurs not on the surface of the crystal but inside the body of the crystal and the amount of rotation depends upon the thickness of the plate. If the thickness is such that it rotates the plane polarized light through 90°, the ~~br~~ vibrations are bought in the principal section of the analyzer which then transmits it freely. If the quartz plate is removed, then no light is transmitted by the analyzer in the crossed position.

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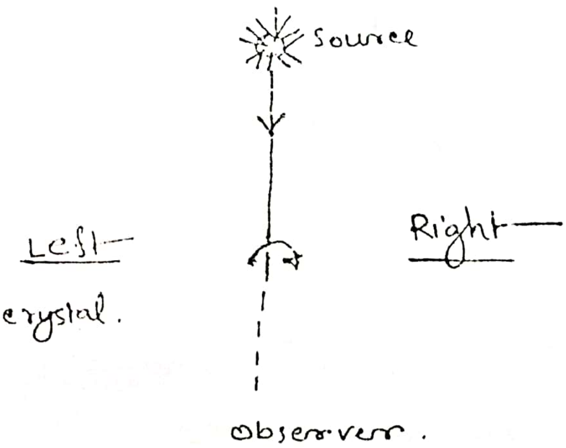
There are two kinds of optically active substances :

1) dextro - rotatory or right handed.
2) laevo - rotatory or left handed.

1) dextro- rotatory or right handed : ~~which~~ The substances that rotate the plane of vibration to the right. From the observer's point of view, a right-handed rotation means that is looking towards the light travelling towards him, the plane of vibration is rotated in a clock wise rotation.

* S.R ⟶ (+)



Example : Some quartz crystal.

2) Laevo - rotator : The substances that rotate the plane of vibration to the left. *S.R ⟶ (−)

Example : Except some quartz crystals are all laevo-rotatory substances.

Example of optically active substances :

i) sugar crystal, ii) sugar solution, iii) turpentine, iv) sodium chlorate & v) cinnabar.

[9] Specific rotation :

$$S = \frac{\text{rotation produced by 1 decimeter length of the solution}}{\text{density of the solution in gms per c.c}}$$

$$= \frac{\theta}{l/10} \div C = \frac{100}{C}$$

where l = length of the substance in decimeters (In meters $l/10$)

C = concentration (gm/cm^3) of the solution.

[9] Polarimeters : (Important)

*** 1) Laurent Half shade polarimeter (see yourself Book – Brij Lal – page – 611)