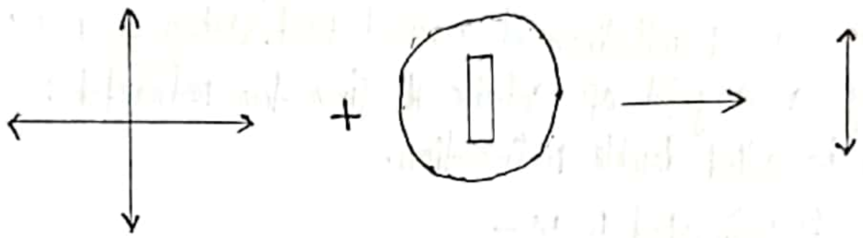
3 types of Polarization — Plane Polarization
— Circular "
— Elliptical "

Polarization

Polarization: If a beam of white light incident at a certain angle on the plane polished surface or ordinary glass. Then the Process of light vibration Confined into one vibration is called Polarization.

Polarized light: If the vibration of the beam of unpolarized light (Ordinary light) are confined to one plane, then the light is called polarized light.



Unpolarized light + Polaroid filter = Polarized light.

→ The arrowheads represents the vibrations of the Particle are parallel to the plane of the paper.

→ The dots represents the vibration of the particles are perpendicular to the plane of the paper.

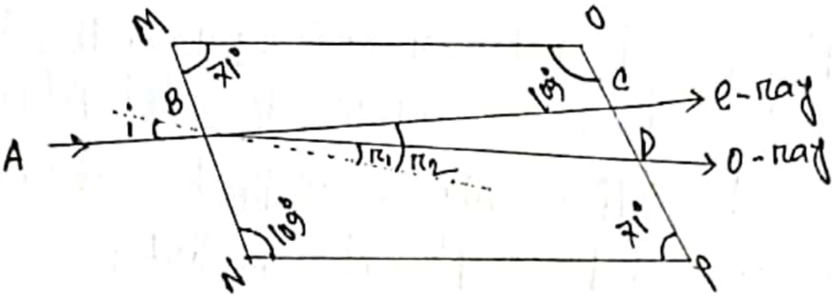
Define Polarizer and analyzer.

Polarizer: A Polarizer is an optical device that transforms unpolarized light into Polarized light. If it produces linearly Polarized light then it is called a linear polarizer.

Analyzer: An analyzer is an optical device that identify the direction of Vibration of linearly Polarized light.

Both the polarizer and analyzer are made in the same way and have the same effect on the incident light.

Double refraction:



In 1669 Erasmus Bertholinus discovered that, "When a ray of light is refracted by a crystal of calcite it gives two refracted rays. This phenomenon is called double refraction.

Two kinds of refracted rays –

1. Ordinary ray or O-ray;
2. Extra ray or e-ray.

Double refraction is also called Iceland spar.

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When a ray of light is refracted by calcite ($CaCO_3$) crystal, it gives two refracted rays. This phenomenon is called double refraction.

The two rays produced in double refraction are linearly polarized. One of the rays obeys Snell's law of refraction and is known as ordinary ray or O-ray. The other ray doesn't obey Snell's law of refraction and is known as extraordinary ray or E-ray.

A ray of light incident on the face MN of the crystal. The ray split into two rays, namely O and E rays. The E-ray travels through the crystal without deviation while O-ray is refracted at some angle. The ray emerged out parallel to the incident ray.

Optical activity: The ability to rotate the plane of vibration by certain crystals or substance is known as optical activity and the substance is known as optical active substance.

Example: Sugar solution, sugar crystals, Quartz, tartaric acid, tarpentine, sodium chlorate and cinabar are optically active substance.

But the calcite crystal is not optical active substance because it does not produce any change in the plane of vibration of the plane polarized light.

Specific rotation: The specific rotation is defined as the rotation produced by a decemetric (10 cm) long column of the liquid containing 1 gm of active substance in (1cc) the solution.

$$S_\lambda^t = \frac{10\,\theta}{LC}$$

Where, S_λ^t represents the specific rotation at temperature $t°C$ for wavelength of light λ, θ is the angle of rotation, C is the concentration of the solution.

Calculate the specific rotation if the plane of polarization is turned through 26.4°, travelling 20 cm length of 20% sugar solution.

Soln:

Here,

$\theta = 26.4°$

$L = 20$ cm

$C = 20\% = \frac{20}{100} = \frac{1}{5}$

We know,

$$S_\lambda^t = \frac{10\,\theta}{LC} = \frac{10 \times 26.4}{20 \times 1/5} = 66° \text{ /Ans.}$$

A 200 cm long tube and containing 48cc of sugar solution produces an optical rotation of 11° when placed in a saccharimeter. If the specific rotation of sugar solution is 66°. Calculate the quantity of sugar contained in the tube in the form of solution.

Soln: Here,

$V = 48\ cc = 48\ cm^3$

$L = 200\ mm = 20\ cm$

$\theta = 11^\circ$

$S = 66^\circ$

$m = ?$

We know,

$$S_\lambda^t = \frac{10\,\theta}{L\,C}$$

$$\Rightarrow C = \frac{10\,\theta}{L\,S_\lambda^t}$$

$$\Rightarrow C = \frac{10 \times 11}{20 \times 66}$$

$$\Rightarrow C = 0.083$$

and, $C = \frac{m}{V}$

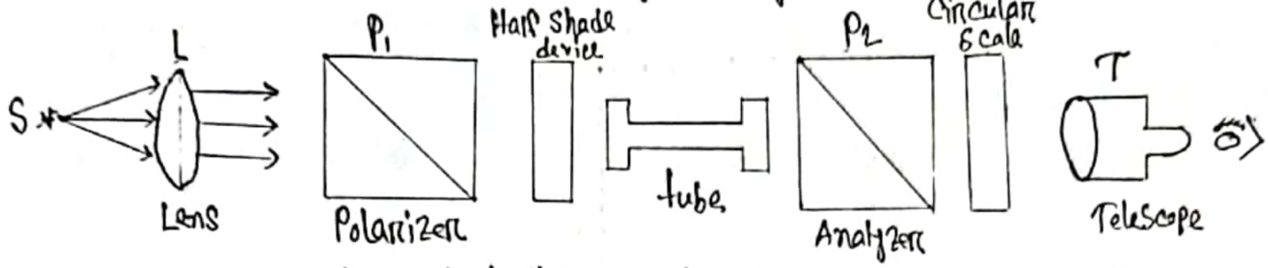
$$\Rightarrow m = CV$$
$$= 0.083 \times 48$$
$$\therefore m = 4\ gm$$ Ans.

Nicol Prism: It is an optical device used for producing and analyzing plane-polarized light. In 1828 William Nicol invented and he observed when a beam of light is transmitted through a calcite crystal, it breaks up into two rays, i) the ordinary ray which has vibrations perpendicular to the ~~Principal~~ Principle section of the crystal ii) the extra-ordinary ray which has its vibrations parallel to the principle section. According to his name it is called Nicol Prism.

The Nicol prism is made in such a way that it eliminated the ordinary ray by total internal reflection and only the extra-ordinary ray is transmitted through the prism.

Explain the function of Nicol Prism in Polarimeter to detect optical activity of sugar solution.

Fig. Working of Polarimeter.

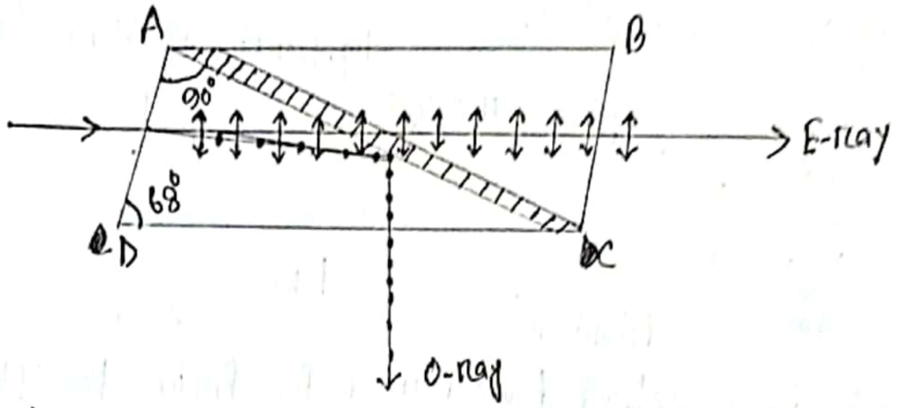


Polarimeter is an optical deviced used for finding the optical rotation of different solutions or concentration of solution.

A monocromatic beam of light passing through a convex lens create a parallel beam. Light after passing the polarizer becomes plane polarized with its vibrations. The plane polarized light now passes through the half shade device and through a tube containing optically active substance. The emerged light on passing through analyzer and view in telescope.

Plane polarized light emerged from polarizer and fall analyzer. Then the field of view is dark. But when optically substance liquid passes, the substances rotates the plane of vibration of light passing through it consequently the field of view was some bright. By rotating the analyzer is equal to the angle through which the plane of polarization is rotated by the substance.

Construction of Nicol Prism:



Let us consider ABCD is principle section of a calcite crystal whose length is three times its breath breadth. The diagonal AC represents the Canada balsam layer. It is made in such a way as if its angle of B and D is 68°.

Procedure: The layer canada balsam acts as a rarer medium for an ordinary ray and it acts as a denser medium for extra-ordinary ray. So when the ordinary ray passes from a portion of the crystal into the layer of Canada balsam it passes from a denser to a rarer medium. When the angle of incidence is greater than the critical angle, the ray is totally reflected and is not transmitted. The extra-ordinary ray is not affected and is transmitted through the prism.

The refractive index of calcite crystal for ordinary ray is $\mu_o = 1.658$ and refractive index of calcite crystal for extra-ordinary ray is $\mu_E = 1.486$. The refractive index of canada balsam layer is $\mu_B = 1.55$.

So, the refractive index for ordinary ray with respect to canada balsam,

$$\mu = \frac{\mu_o}{\mu_B} = \frac{1.658}{1.55}$$

$$\sin\theta = \frac{1}{\mu} = \frac{1.55}{1.658}$$

$$\therefore \theta = 69^\circ$$

If the angle of incidence for the o-ray is more than the critical angle, it is totally internally reflected and only the E-ray passes through the Nicol prism.

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Nicol Prism can be used as a Polarizer and as an analyzer :

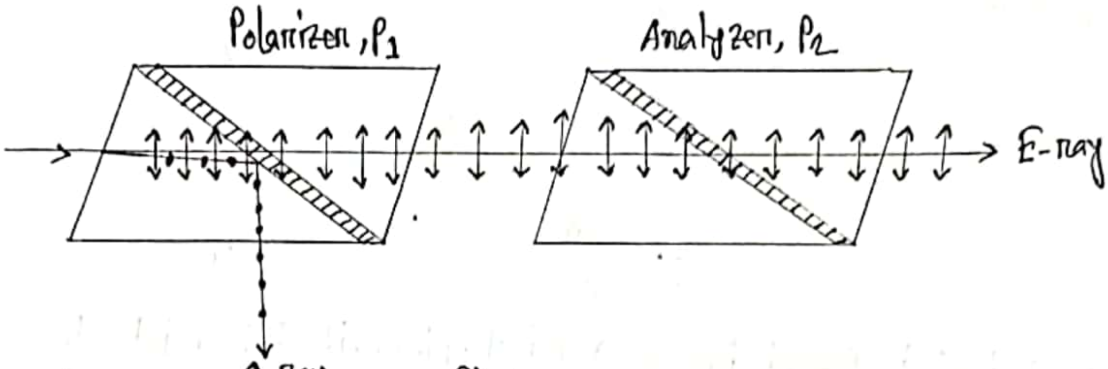


Fig.1

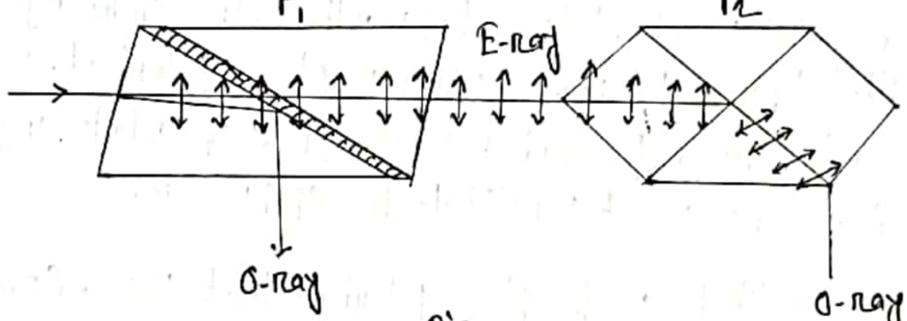
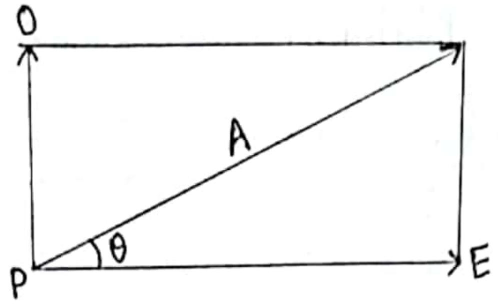


Fig.2

Nicol Prism can be used for the production and detection of the Plane Polarized light. When two Nicol Prism P_1 and P_2 are placed adjacent to each other as shown in fig.1
One of them act as a Polarizer and the other as analyzer. Figure 2 shows the Position of two parallel Nicols and only the extra-ordinary ray Passes through both the prism. If the second prism P_2 is gradually rotated, the intensity of the extra-ordinary ray decreases accordance with Malus law and when the two prisms are crossed (i.e., when they are right angles to each other) then no lights comes out of the Polarizer. When the Polarized E-ray enters the prism, P_2 in this position it acts as an ordinary ray and is totally internally reflected by the canada balsam Layer and so no light comes out of P_2. Thus, the Prism P_1 Produce plane Polarized light and the prism P_2 detect it.
Hence, P_1 and P_2 are respectively called the polarizer and analyzer.

Q: Established the theory elliptically and circularly plane Polarized light and explain it.



When a light is passed through a Nicol Prism, it divided into two Components E-ray and O-ray. The ordinary components is removed by total internal reflection from the Canada balsam layer. The extra-ordinary component is transmitted through the prism which is plane polarized. Now, the plane Polarized light is allowed to incident on the piece of calcite crystal, whose refracting faces are caught parallel to the optic axis.

Let, A is the amplitude of the plane polarized light wave. So, the amplitude of E-ray is, $A\cos\theta$ and that of O-ray is $A\sin\theta$. Where θ is the angle made by the plane polarized light wave with optic axis.

Let, δ is the Phase difference between E-ray and O-ray. So, the displacement equation for E-ray is, $x = A\cos\theta \sin(\omega t + \delta)$ —— (1)

And displacement equation for O-ray is, $y = A\sin\theta \cdot \sin\omega t$ —— (2)

Let, $A\cos\theta = a$ and $A\sin\theta = b$

$\therefore x = a\sin(\omega t + \delta)$ and $y = b\sin\omega t \Rightarrow \sin\omega t = \frac{y}{b}$

$\therefore \cos\omega t = \sqrt{1 - \frac{y^2}{b^2}}$

$$\Rightarrow \frac{x}{a} = \sin\omega t \cos\delta + \cos\omega t \sin\delta$$

$$\Rightarrow \frac{x}{a} = \frac{y}{b}\cos\delta + \sqrt{1 - \frac{y^2}{b^2}}\sin\delta$$

$$\Rightarrow \frac{x}{a} - \frac{y}{b}\cos\delta = \sqrt{1 - y^2/b^2}\sin\delta$$

$$\Rightarrow \frac{x^2}{a^2} + \frac{y^2}{b^2}\cos^2\delta - \frac{2xy}{ab}\cos\delta = \sin^2\delta - y^2/b^2 \sin^2\delta$$

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$$\Rightarrow \frac{x^2}{a^2} + \frac{y^2}{b^2}\left(\sin^2\delta + \cos^2\delta\right) - \frac{2xy}{ab}\cos\delta = \sin^2\delta$$

$$\therefore \frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\cos\delta = \sin^2\delta \qquad \text{——— (3)}$$

This is the general equation of an ellipse.

Special case:

i) When $\delta = \frac{\pi}{2}$, $a = b$ then equ. (3) becomes,

$$x^2 + y^2 = a^2$$

This represents the equation of circle of radius a. Thus the emerged light will be circular polarized.

ii) When $\delta = \pi/2$, $\cos\delta = 0$ but $\sin\delta = 1$ then equ. (3) becomes,

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

This represents the equation of ellipse. Thus the emerged light will be elliptically polarized.

Types of Polarization: There are three types of Polarization-

(i) Linear polarization.

(ii) circular polarization.

(iii) Elliptical polarization.

Plane/linear polarised light: When light travels along a certain direction the vibration take place in a direction at right angles to the direction of propagation. If the vibrations of the ether particles are linear and take place ~~along~~ parallel to a plane through the axis of the beam or the direction of propagation, light is said to be plane polarised.

Circularly polarised light: When the vibrations of the ether particles are circular having constant period and take place in the transverse plane, light is said to be circularly polarised. In this case, the amplitude of the ~~variations~~ vibrations remain constant but the direction changes only.

Elliptically polarised light: When the vibrations of the ether particles are elliptical, having a constant period, and take place in a plane perpendicular to the direction of propagation (transverse plane) light is said to be elliptically polarised. In this case, the amplitude of the vibrations change in magnitude as well as direction.

* Production and detection of Polarizers:

i) Plane polarised light:

<u>Production:</u> If a beam of monochromatic light is passed through a nicol Prism, it is split up into E-ray and O-ray. The O-ray is totally internally reflected at the canada balsam layer and is absorbed, while the E-ray passes through the nicol Prism, which is plane polarised.

<u>Detection:</u> A beam of monochromatic light is allowed to fall on a nicol Prism. The nicol Prism is rotated. If on rotating the nicol prism, light is completely extinguished twice (in each rotation of nicol Prism) the beam is plane polarized.

ii) Circular polarised light:

<u>Production:</u> Plane polarised light from a nicol prism is made to fall normally on a quarter wave plate such that its vibration makes an angle 45° with the direction of the optic axis of the quarter wave plate. This is broken into E and O vibrations of $\pi/2$ is introduced between them which results in the formation of a circular vibration and hence outgoing light is circularly polarised.

<u>Detection:</u> To confirm whether light emerging out of the quarter-wave plate is circularly polarised, it is first passed through another quarter-wave plate with optic axis in any position. The light on emergence from the second quarter-wave plate will become plane polarised. It is now examined through a nicol Prism. It will show variations of intensity with with zero minimum.

(ii) Elliptically polarised light:

Production: plane polarised light obtained from a nicol prism is made to fall normally on a quarter wave plate so that the plane of vibration of this light makes an angle other than 45° with the direction of the optic axis of the quarter wave plate. The vibration in passing through is split up into two components, the E-component with vibration parallel to the optic axis and the O-component with vibrations perpendicular to the optic axis. The amplitude of the E-component $a = A\cos\theta$ and that of the O-component is $b = A\sin\theta$ where A is the amplitude of the incident plane polarised vibration. On emergence through a quarter wave plate, a phase difference of $\pi/2$ introduced between the two components which combine resulting into elliptic vibration. Hence the outgoing light is ~~called~~ elliptical polarised.

Detection: To confirm if the light coming out of the quarter-wave plate is elliptically polarised, first examine it with a rotating nicol and adjust the position of the nicol for maximum intensity. Place another quarter-wave plate between the first quarter-wave plate and the analysing nicol such that the optic axis of the second quarter-wave plate is parallel to the principal section of the Nicol adjusted for maximum intensity. If the light was elliptically polarised it will now become plane polarised. If the nicol prism is now rotated variation of intensity from maximum to zero will be observed.

* **Plane of Polar Vibration:** The plane containing the optic axis in which the vibrations occur is known as the plane of vibration. Plane of vibration of a polarized light wave is generally unchanged in passing through a transparent material; it remains polarized in a similar plane.

* **Plane of Polarization:** The plane which is at right angles to the plane of vibration and which contains the direction of propagation of the polarized light is known as the plane of polarization. It is the plane in which the magnetic-vibration element of plane polarized electromagnetic radiation lies. The plane of polarization does not contains variations in it.