Optical Activity:

In 1811, the French physicist Arago first observed that the plane of vibration of a beam of linearly polarized light underwent a continuous rotation as it propagated along the optic axis of a quartz plate.

About the same time, Biot saw the same effect while using both the vaporous & liquid forms of various natural substances like turpentine.

Any material that causes the $\bar{E}$-field of an incident linearly polarized wave to rotate is said to be optically active.

The amount of rotation was found to depend on the distance travelled inside the medium & on the wavelength of light.

If while looking in the direction of the source (i.e., against the oncoming light), the plane-of-vibration appears to have rotated clockwise, the substance is said to be dextrorotatory, or right-handed.

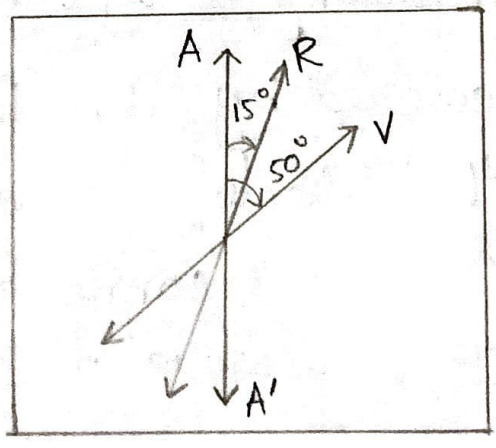
If $\bar{E}$ appears to have been rotated counterclockwise, the material is levorotatory or left-handed.

In 1822, it was discovered by Sir Herschel, an English astronomer, that the left-handed or right-handed behaviour in quartz corresponds to two different crystallographic structures. Crystal

quartz can be either right- or left-handed, depending on the arrangement of the molecules, SiO_2.
Externally, the two crystals are mirror images of each other & are said to be enantiomorphs of each other.
Molten quartz is not crystalline & not optically active.
All transparent enantiomorphic substances are optically active.
Naturally occuring substances like sugar, tartaric acid & turpentine are optically active in solution or in the liquid state.

ROTARY DISPERSION :

It was observed that light of diff. colours are rotated by diff. amounts by a given optically active substance.
These measurements were first made by Biot, who found that the amount of rotation is very nearly proportional to the inverse square of the wavelength of light.
This can be viewed as a rotatory dispersion, where violet being rotated more than the red light.

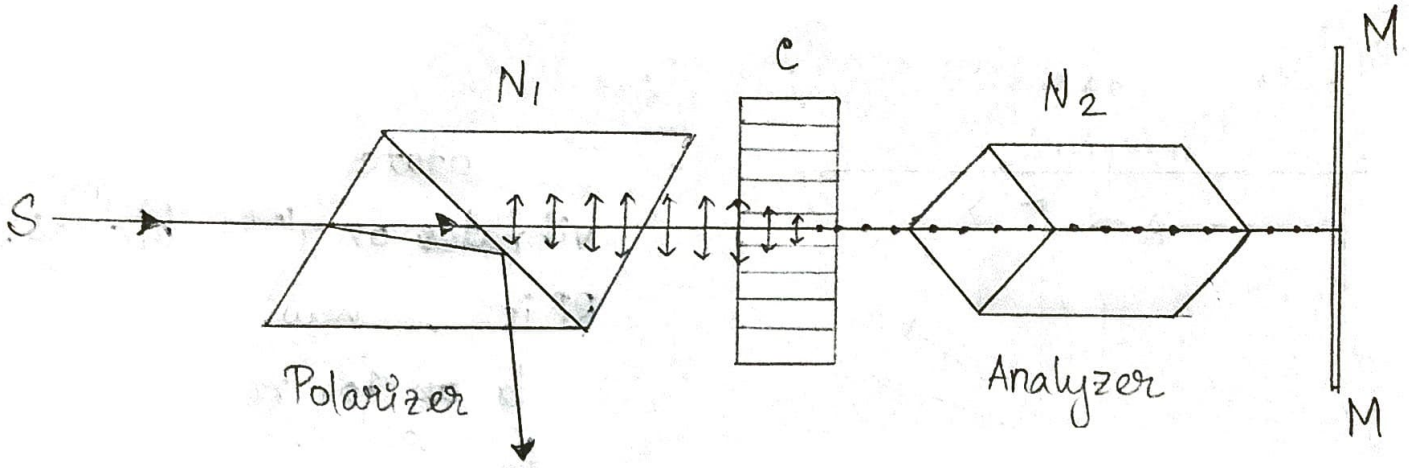


AA' → plane polarized white light.
Upon passing through a quartz plate of 1mm thickness, the violet

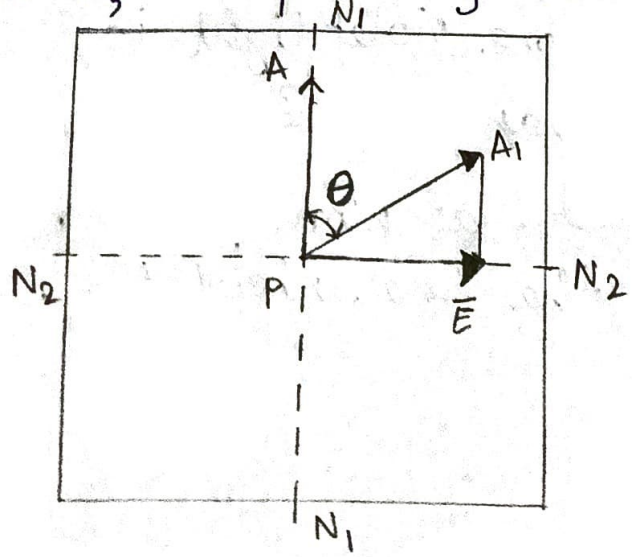
light is seen to be rotated by about 50° & the red by about 15° & other colours by intermediate amounts.

This is known as Biot's inverse-square law of rotatory polarization.

The ~~tan~~ law was later found to be approximately true.



A quartz crystal is inserted b/w crossed analyzer & polarizer. For a monochromatic source, S, it was seen that some light gets through the analyzer & is incident on the screen MM. This was because in passing through the quartz crystal along the optic axis, the plane of vibration has been rotated.



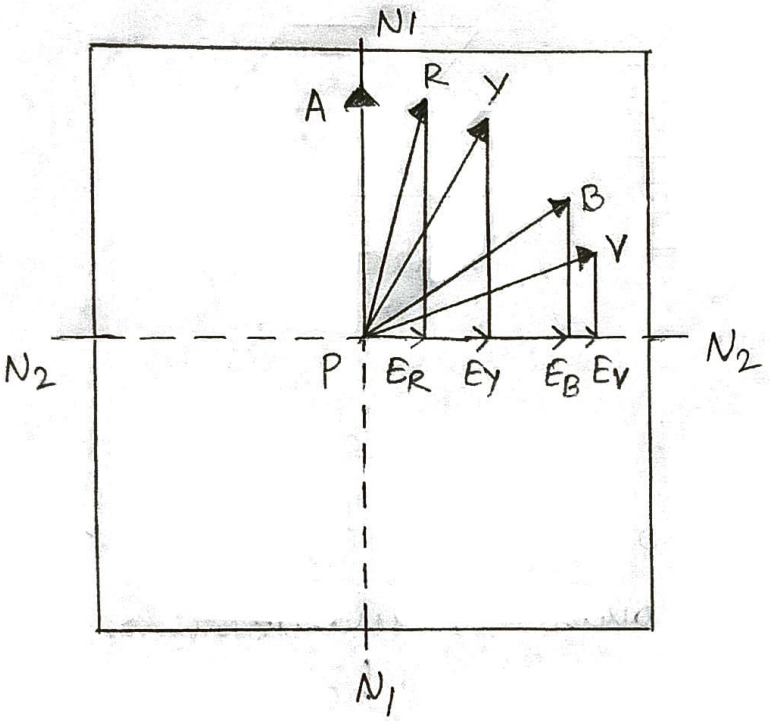
Let the incident vibration on the calcite be on the plane AP. This gets rotated by an angle θ to be on the plane A_1P, when emerges from the calcite.

$EP = A_1P \sin\theta$ is the component

which gets through the analyzer oriented along N_2N_2.

If N_2 is made parallel to A_1P, all the rotated light will be transmitted, & if N_2 is made normal to A_1P, no light will be transmitted by ~~the~~ N_2.

If white light is used, then upon passing through the crystal the different colours are rotated by diff. amounts.



The rotated lights now vibrates on diff. planes. RP is the new plane of vibration for red & VP is that for violet.

The two components E_R for red & E_V for violet get through the analyzer N_2.

Component of violet light getting through has larger magnitude than that of red, indicating more violet light is transmitted by the analyzer than red. So the image on screen MM will be coloured, as more of the red light has been eliminated in the 2nd nicol, N_2.

FRESNEL'S THEORY OF OPTICAL ROTATION:

We have seen that a linearly polarized wave can be represented as a superposition of two oppositely polarized circular waves.

* Acc. to Fresnel's 1st assumption, the plane-polarized light entering a crystal along the optic axis is decomposed into two circularly polarized vibrations rotating in opposite directions with the same freq.

* Acc. to the 2nd assumption, in an optically active crystal, the two circular vibrations move forward with very slightly diff. velocities.
In a right-handed quartz, the right-handed motion travels faster, & in the left-handed ~~crysta~~ quartz, the left-handed motion travels faster. So an active material shows circular birefringence, i.e., it possesses two RIs, one for right-handed vibrations (n_r) & the other for left-handed vibrations (n_L).

As the light travels through the active material, the two circular waves would get out-of-phase & the resultant linear wave would appear to have rotated from its original direction.

Consider a RCP beam propagating in the +z direction,

$$\left.\begin{aligned} E_x^r &= E_0 \cos(k_r z - \omega t) \\ E_y^r &= -E_0 \sin(k_r z - \omega t) \end{aligned}\right\} \quad -(1)$$

where $k_r = \frac{\omega}{c} \cdot n_r$ or, $k_r = k_0 n_r$.

Similarly, a LCP beam propagating in the +z direction,

$$\left.\begin{aligned} E_x^l &= E_0 \cos(k_l z - \omega t) \\ E_y^l &= E_0 \sin(k_l z - \omega t) \end{aligned}\right\} -(2)$$

where $k_l = k_0 n_l = \frac{\omega}{c} n_l$

Then the resultant electric field components are,

$$E_x = E_x^r + E_x^l$$

$$= E_0 [\cos(k_r z - \omega t) + \cos(k_l z - \omega t)]$$

$$= 2E_0 \cos\left[\tfrac{1}{2}(k_l - k_r) z\right] \cos\left[\omega t - \tfrac{1}{2}(k_l + k_r) z\right]$$

$$= 2E_0 \cos\left[\tfrac{1}{2}(k_l - k_r) z\right] \cos[\omega t - \theta(z)] \quad -(3)$$

$$E_y = E_y^r + E_y^l$$

$$= E_0 [-\sin(k_r z - \omega t) + \sin(k_l z - \omega t)]$$

$$= 2E_0 \sin\left[\tfrac{1}{2}(k_l - k_r) z\right] \cos\left[\omega t - \tfrac{1}{2}(k_l + k_r) z\right]$$

$$= 2E_0 \sin\left[\tfrac{1}{2}(k_l - k_r) z\right] \cos[\omega t - \theta(z)] \quad -(4)$$

where $\theta(z) = \frac{1}{2}(k_l + k_r) z$

Thus the resultant wave is always a linearly polarized one.

At the point where the wave enters the active medium, let that be $z=0$ plane, then

$$E_x(z=0) = 2E_0 \cos \omega t$$

$$E_y(z=0) = 0$$

So, it is linearly polarized along the x-axis.

Let, $\phi(z) = \frac{1}{2}(k_l - k_r)z$.

or, $\phi(z) = \frac{1}{2}k_0(n_l - n_r)z = \frac{\omega}{2c}(n_l - n_r)z$

or, $\phi(z) = \frac{\pi}{\lambda}(n_l - n_r)z = \frac{\omega}{2c}(n_l - n_r)z$ — (5)

where λ is the free space wavelength.

The resultant direction of vibration makes an angle $\phi(z)$ with the x-axis, which is a fn. of z.

If, $n_l > n_r$ ⟶ the substance is right-handed
⟶ $\phi(z)$ is +ve for +ve z direction.

If, $n_l < n_r$ ⟶ the substance is left-handed.
⟶ $\phi(z)$ is −ve for +ve z direction.

If, $n_l = n_r$ ⟶ $\phi(z) = 0$ ⟶ no optical rotation.
⟶ optically inactive.
⟶ isotropic substance.