Possibility 1/Result 1: If there is *complete extinction* (i.e. darkness) at two positions during rotation – then the beam is ***plane polarized light***.

Possibility 2: If there is *no variation in intensity* – then the beam is either unpolarized light or circularly polarized light or mixture of unpolarized and circularly polarized light.

Possibility 3: If there is *variation of intensity* – then the beam is either elliptically polarized or mixture of unpolarized and plane polarized light or mixture of unpolarized and elliptically polarized light.

STEP II: We now introduce a quarter wave plate in the path followed by Nicol prism, as shown in Figure 21. Then;

In **possibility 2**, any of the following three results can be obtained.

Result 2: If there is *no variation in intensity* – then the beam is ***unpolarized light***.

Result 3: If there is *complete extinction* (i.e. darkness) at two positions during rotation – then the beam is ***circularly polarized light***.

Result 4: If there is *variation of intensity* – then the beam is ***mixture of unpolarized*** and ***circularly polarized light***.

In **possibility 3**, any of the following three results can be obtained.

Result 5: If there is *complete extinction* (i.e. darkness) at two positions during rotation – then the beam is ***elliptically polarized light***.

Result 6: If there is *variation of intensity*, but the position of maximum occurs at the same position as before – then the beam is ***mixture of unpolarized*** and ***plane polarized light***.

Result 7: If there is *variation of intensity*, but the position of maximum occurs at a different position as before – then the beam is ***mixture of unpolarized*** and ***elliptically polarized light***.

3.8 OPTICAL ACTIVITY

When a beam of plane polarized light is propagated through a crystal of quartz along its optic axis, the plane of vibration gradually undergoes rotation about its optic axis, as the beam penetrates deeper and deeper into the crystal. Finally, it emerges with the plane of vibration inclined to the plane of incident vibrations (Figure 22). This phenomenon is known as ***optical activity*** or *rotatory polarization*. The substances which exhibit this phenomenon are said to be *optically active* substances.

There are two types of optically active substances. The substances which rotate the plane of vibration of the incoming beam in the clockwise direction are called ***dextrorotatory*** or *right-handed*. For example; quartz (dextrorotatory), sugar solution, camphor solution etc.. The substances which rotate the plane of vibration of the incoming beam in the anti-clockwise direction are called ***levorotatory*** or *left-handed*. For example; quartz (levorotatory), $NaClO_3$, $NaBrO_3$, cinnabar, turpentine etc..

(a) Specific Rotation

Liquids made of an optically active substance and an optically inactive solvent are found to produce a rotation proportional to the amount of the active substances present. For a given wavelength of light at constant temperature*, the* ***specific rotation*** *or rotatory power is defined as the rotation produce by a* 10 *cm (or one decimeter) column of liquid containing one gm of active substance in one cubic centimeter of solution, i.e. concentration is* 1 *gm/cc*. This may be written as,

$$S = \frac{10\theta}{Cl}$$

where S is the specific rotation, C is the concentration of optically active solution in gm/cc, l is the length of solution in cm and is the angle of rotation produce.

In general, the rotation produced by crystals are quite large, therefore *the specific rotation for crystal is taken as the angle change for a one mm path of beam in crystal*.

(b) Fresnel's Explanation of Optical Activity

It is based on assumption that circularly polarized light is propagated along the optic axis without any change. It is based upon an idea that any SHM along a straight line can be described as the resultant of two opposite circular motion.

1. When plane polarized light enters into a crystal along optic axis, it splits into two circularly polarized vibrations rotating in opposite direction with the same frequency.
2. In an optically inactive crystals like calcite, these two circular motion R and L travels with the same speed. Since both vibrations arrive simultaneously at any given point, their resultant will be a SHM in the incident plane of vibration (Figure 23a). Thus, a plane polarized wave along the optic axis is propagated with its vibrations always in the same plane.
3. In an optically active crystal like quartz, the two circular vibrations move forward with slightly different velocities. In right handed (dextrorotatory) quartz, the clockwise motion and in left handed (levorotatory) quartz the anticlockwise motion travels faster, if looked against the light. Thus, in travelling from the crystal face at P to the point Q, the plane of vibration has been rotated through an angle $\delta/2$, where δ is the angle between R and L circular motion, as shown in Figure 23b. Therefore, the plane of vibration rotates continuously as the light penetrates deeper and deeper into the crystal. The angle of rotation would be proportional to the thickness of the crystal.

Let n_R and n_L be the refractive indices for the right and left handed circularly polarized lights and t is the thickness of the crystal, then the path difference introduced will be

$$\Delta = (n_L - n_R)t$$

So the phase difference is

$$\delta = \frac{2\pi}{\lambda}\Delta$$

$$\delta = \frac{2\pi}{\lambda}(n_L - n_R)t$$

As discussed above, the angle of rotation is given by $\theta = \delta/2$, i.e.

$$\theta = \frac{\pi}{\lambda}(n_L - n_R)t$$

3.9 POLARIMETER

The optical device which measures the angle through which the plane of vibration of a plane polarized beam is rotated by any optically active solution is called a **polarimeter.** They are of type,

(a) Laurent's half shade polarimeter
(b) Biquartz polarimeter

By measuring the angle of rotation θ, the specific rotation S produced by any optically active solution can be determined, if concentration C and length l of the solution are known.

When the polarimeters are used to determine the quantity of sugar in a solution, they are called as ***saccharimeter***.

Construction: The scheme of the polarimeter using half shade or biquartz is almost same except the light source, which should be *monochromatic* for half shade plate and *white light* for biquartz polarimeter.

The arrangement inside the polarimeter is shown in Figure 24. The S is the source of light. The lens L is used to collimate light on to the Nicol prism N_1, which serves as the polarizer. Just behind the polarizer, according to the type of polarimeter, the half shade plate or biquartz plate P is kept.

The optically active liquid is filled in the glass tube O provided with plane transparent glass windows at the ends. The analyzer Nicol prism N_2 is mounted co-axially just after glass tube. It can be rotated and its orientation can be read on the circular scale. At the end, there is short focus telescope T focused on plate P and mounted coaxially.

3.9.1 LAURENT'S HALF SHADE PLATE

Construction: It consists of a semi-circular piece CAD, which is actually a half wave plate of quartz Q cut parallel to the optic axis, CD. It can introduce a phase difference of π between the *e-ray* and *o-ray* during their passage through it. Another semi-circular piece CBD of glass G, of same thickness, is joined along CD so as to make a composite circular plate CADB (Figure 25).

Action: Let the vibration plane of the light incident on this be parallel to OP, inclined at an angle θ to the optic axis CD. The vibrations of light transmitted through glass half will remain in the same plane. But the change in plane occurs in the quartz half. Therefore, the vibration plane of the light emerging from glass half G is OP. While vibration plane of the light emerging from the quartz half is OQ making the same angle θ with the optic axis as does OP. If the principal section of the analyzer Nicol N_2 is;

1. parallel to AOB, the component OL and OM of the vibrations emerging out of the two halves will be equal and therefore they will appear ***equally bright***.
2. rotated by a small angle in the clockwise direction, the vibration from glass half will be completely cut-off, while component OM of the vibrations emerging out of quartz half will be transmitted. Thus, the glass plate will be less bright compared to quartz half.
3. rotated by a small angle in the anticlockwise direction, the vibration from quartz half will be completely cut-off, while component OL of the vibrations emerging out of glass half will be transmitted. Thus, the quartz plate will be less bright compared to glass half.

Thus, if the analyzer is rotated through even a small angle with respect to AOB, a change in intensity of the two halves is observed. Therefore, there is only two sharp position of analyzer for which both halves will be equally bright.

Determination of specific rotation of sugar: The tube is filled with pure water and the analyzer is turned to obtain the condition of *equal brightness* of the two halves. Then, the sugar solution of known concentration C is now filled in the tube and the process is repeated to obtain the second reading of the analyzer. The difference in the two reading gives the rotation produced by solution. Knowing the length l of the tube the specific rotation S can be calculated.

3.9.2 BIQARTZ

Construction: It consists of two semi-circular pieces of the levo-rotatory quartz CAD and the dextro-rotatory CBD cut perpendicular to the optic axis and joined together along the diameter CD to make a composite circular plate. The thickness of each plate is same and is such that each rotates the plane of vibration of yellow light through $\pi/2$ (Figure 26).

Action: When a beam of white plane polarized light incident normally on the biquartz plate, it rotates the different wavelengths of white light to different angle, thus rotatory dispersion occurs in each plate. The CAD plate rotates the plane of vibration in anticlockwise, while CBD in clockwise direction. The red rays are rotated the least, whereas the violet ray the most and others will be intermediate between these two (yellow ray rotates through $\pi/2$), as shown in Figure 26. If the principal plane of the analyzer is;

1. parallel to CD, the yellow portion will be completely cut off, only a mixture of red and blue (grayish violet), which is called the *tint of passage*, can be transmitted equally from the two halves.
2. turned through a small angle in the clockwise direction the right half will appear reddish while the left half will appear bluish.
3. turned through a small angle in the anticlockwise direction the right half will appear bluish while the left half will appear reddish.

The *tint of passage* is a very sensitive position and the analyzer can be set in this position with greater accuracy. There is only two sharp position of analyzer for which tint of passage can be observed.

Determination of specific rotation of sugar: The tube is filled with pure water and the analyzer is turned to obtain the condition of *tint of passage*. Then, the sugar solution of known concentration C is now filled in the tube and the process is repeated to obtain the second reading of the analyzer. The difference in the two reading gives the rotation produced by solution. Knowing the length l of the tube the specific rotation S can be calculated.

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