

## Polarisation

**19.1. Polarisation.** Light is a kind of transverse wave motion. In ordinary light the vibrations take place in all directions perpendicular to the direction of propagation. Such light has the same properties in all directions and is known as *unpolarised light*. When light is passed through crystals, like tourmaline, quartz etc., it acquires the property of one-sidedness *i.e.*, the vibrations take place only in one plane. In such a case light is said to be *plane-polarised*. An arrangement for producing polarised light is called a *polariser*. A nicol prism is generally used for the purpose.

**19.2. Nicol prism.** It is an optical device made from calcite and is used in many instruments for producing and analysing plane polarised light.

When light is passed through a doubly refracting crystal it is split up into an *ordinary* and an *extraordinary ray*. Both these rays are plane polarised. In the nicol prism one of these rays is cut off by total internal reflection.

**Construction.** A calcite crystal about three times as long as it is wide is taken. The principal section  $ABCD$  is shown in Fig. 19.1. Its end faces are cut down so as to reduce the angles at  $B$  and  $D$  from  $71^\circ$  to  $68^\circ$  with principal section. The crystal is then cut apart along  $A'C'$  perpendicular both to the principal plane and the end faces such that  $A'C'$  makes an angle of  $90^\circ$  with the ends  $A'B$  and  $C'D$ . The two cut surfaces are ground, polished optically flat and cemented together with canada balsam which is a clear transparent cement whose refractive index lies midway between the refractive indices of calcite for the ordinary and extraordinary rays. The sides of the prism are blackened to absorb the totally reflected ray.

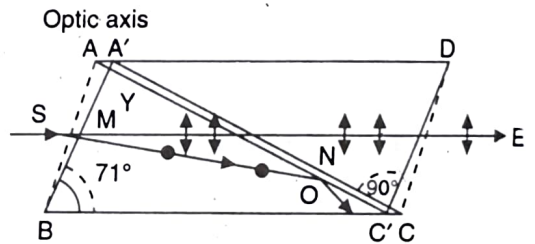


Fig. 19.1

A ray  $SM$  incident on the face of the prism is split up into the ordinary and the extraordinary rays. The ordinary ray is totally reflected at  $N$  whereas the extraordinary ray passes through giving rise to plane polarised light having vibrations in the principal plane.

The nicol prism can be used both as a polariser as well as an analyser. When the principal section of the two nicols are parallel as shown in Fig. 19.2, the extraordinary ray is transmitted through the analyser. If one of the nicols is rotated the intensity of the transmitted beam decreases and finally no light is transmitted.

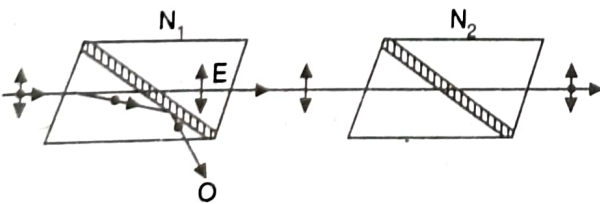


Fig. 19.2

The extraordinary ray for the first nicol forms an ordinary ray for the second and is thus totally

reflected. In this position the two nicols are said to be *crossed* as shown in Fig. 19.3. The first nicol polarises the light and is called the **polariser**, whereas the second nicol analyses the light and is called the **analyser**.

Again when the analyser is further rotated the two nicols are in parallel position and *E*-ray is again transmitted as shown in Fig. 19.4.

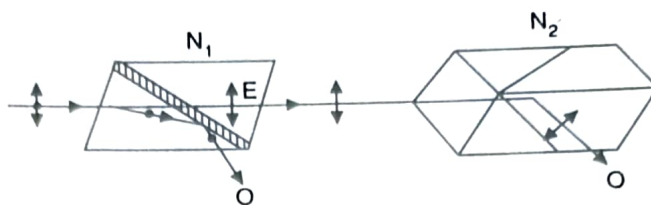


Fig. 19.3

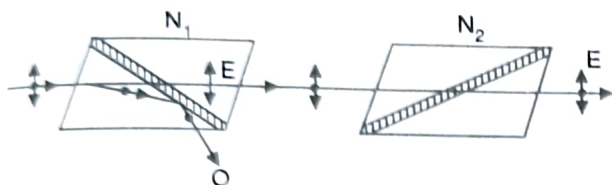


Fig. 19.4

**19.3. Specific rotation.** Certain substances like quartz, turpentine and sugar solution rotate the plane of polarisation of a plane polarised light passing through them. Such substances are called *optically active*. There are two types of substances.

(i) *Dextro-rotatory or right-handed.*

These produce the rotation of the plane of polarisation towards the right *i.e.* in the clockwise direction on looking towards the source.

(ii) *Laevo-rotatory or left-handed.* These produce the rotation of the plane of polarisation towards the left *i.e.*, in the anti-clockwise direction on looking towards the source.

The angle through which the plane of polarisation is rotated depends upon

- (i) thickness of the substance,
- (ii) concentration of the solution or the density of the material,
- (iii) wavelength of light, and
- (iv) temperature.

*Specific rotation for the given wavelength of light at a given temperature is defined as the rotation produced by one decimetre (10 centimetre) length of the solution of unit concentration.*

If  $\theta$  is the rotation produced by  $l$  decimetre of a solution and  $c$  is the concentration in gram per c.c., then specific rotation  $S$  at a given temperature and corresponding to a wavelength  $\lambda$  is given by

$$[S]_{\lambda}^t = \frac{\theta}{lc} = \frac{\text{Rotation in degrees}}{\text{Length in decimetres} \times \text{concentration in gm/c.c.}}$$

**19.4. Laurent's half-shade polarimeter.** It is an instrument used for finding the optical rotation of certain solutions. When used for finding the optical rotation of sugar it is called a saccharimeter. If the specific rotation of sugar is known, the concentration of the sugar solution can be determined.

**Construction.** The optical parts of a polarimeter are shown in Fig. 19.5 in which  $S$  is a source of monochromatic light usually a sodium lamp.

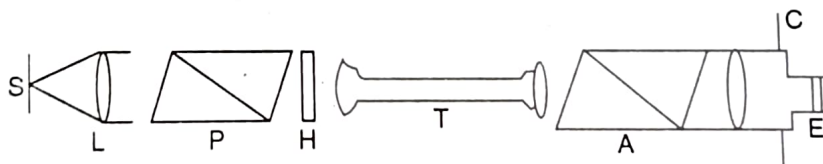


Fig. 19.5

The light from the source after passing through a narrow slit is rendered into a parallel beam by the lens  $L$ . The light is made plane polarised by the nicol prism  $P$  and after passing through the half-shade device  $H$  (described later), a glass tube  $T$  containing the solution is made to fall on the analysing nicol  $A$ . The light is viewed through a Galilean telescope  $E$ . The analysing nicol  $A$  can be rotated about the axis of the tube and its rotation can be measured on the graduated circular scale  $C$  divided in degrees, with the help of a vernier.

The position of the analyser is adjusted so that the field of view is completely dark. The tube  $T$  is filled with the required solution and placed in position. The field now becomes illuminated. Darkness can again be achieved by rotating the analysing nicol  $A$  through a certain angle which gives the optical rotation for the solution.

It is found that when the nicol  $A$  is rotated, the total darkness of the field of view is attained rather gradually and hence it is difficult to find the exact position correctly for which complete darkness is achieved. Laurent devised an ingenious method to achieve this. The arrangement is known as *Laurent's half-shade device*.

**Laurent's half-shade device.** It consists of a semi-circular plate  $ADB$  of glass cemented to a semi-circular plate  $ACB$  of quartz. The quartz plate is cut with its optic axis parallel to the line of separation  $AOB$ . The thickness of the quartz plate is such that it introduces a phase difference of  $\pi$  between the ordinary and the extraordinary vibrations. In other words it is a *half-wave plate*. The thickness of the glass plate is such that it absorbs the same amount of light as is done by the quartz plate.

Suppose that light after passing through the polariser  $P$ , is incident normally on the half-shade plate and has vibrations along  $OP$ . On passing through the glass half the vibrations will remain along  $OP$  but on passing through the quartz half, these will be split up into  $E$  and  $O$  components. The vibrations of the  $O$  component are along  $OD$  and those of  $E$ -component along  $OQ$ .

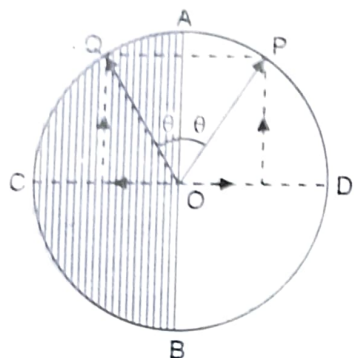


Fig. 19.6

On passing through the quartz plate a phase difference of  $\pi$  is introduced between the two vibrations. The  $O$ -vibration will advance in phase by  $\pi$  and will take place along  $OC$  instead of  $OD$ . The resultant vibration on emergence from the quartz plate will be along  $OQ$ , so that

$$\angle POA = \angle QOA.$$

If the analysing nicol is fixed with its principal plane parallel to  $OP$ , the plane polarised light through glass will pass and hence it will appear brighter than the quartz half from which light is partially obstructed.

If the principal plane of the nicol is parallel to  $OQ$  the quartz half will appear brighter than the glass half due to the same reason.

When the principal plane of the analysing nicol is parallel to  $AOB$ , the two halves will appear **equally bright**. It is because the vibrations emerging out of the two halves are equally inclined to its principal plane and hence the two components have equal intensities.

When the principal plane of the analyser is at right angles to  $AOB$ , again the components of  $OP$  and  $OQ$  are of equal intensity. The two halves are again equally illuminated but as the intensity of the component passing through is small as compared to those in the previous case, the two halves are said to be **equally dark**.

The eye can easily detect a slight change when the two halves are equally dark. The readings are, therefore, taken for this position.

**19.5. Bi-quartz** A bi-quartz is a simple and sensitive device which can be used in place of a half shade arrangement in a polarimeter. It consists of two semi-circular quartz plates  $ACB$  and  $ADB$  each 3.75 mm thick, one of left handed  $L$  and the other of right handed  $R$  quartz cut with their optic axes perpendicular to their refracting faces. These are cemented together along  $AB$  to form a circular plate as shown in Fig. 19.7 (a).

When plane polarised white light is incident normally on the plate each half of this plate will rotate each colour equally in opposite directions. For yellow light this rotation is about  $90^\circ$ . If  $POQ$

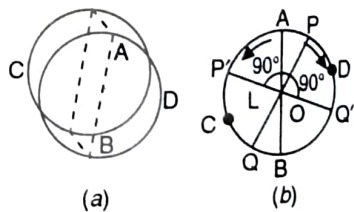


Fig. 19.7

is the direction of incident vibration, then for yellow light it will be along  $OQ'$  in the right handed half and along  $OP'$  in the left handed half. Hence the vibration of yellow light will be along the direction  $P'OQ'$  perpendicular to the direction  $POQ$ . Thus if the principal plane of the analysing nicol is parallel to  $POQ$  yellow light will be quenched in both halves of the field, while other colours will be present in the same proportion thereby giving the same tint of greyish violet colour to both the halves. This is known as the tint of passage. If the analyser is rotated to one side from this position one half of the field of view appears blue while the other half appears red. If the analyser is rotated in the opposite direction, the first half which was blue earlier appears red and the second half which was red earlier appears blue. As the transition from red to blue is very rapid, the zero position can be obtained very accurately.

**Experiment 19.1.** To determine the specific rotation of sugar using Laurent's half-shade polarimeter.

**Apparatus.** Laurent's half-shade polarimeter, a sodium lamp, sugar, a balance, a weight box, a graduated cylinder, two beakers, filter paper, a funnel, an eye-piece, a pipette and a glass rod.

**Theory.** If  $\theta$  is the optical rotation produced by  $l$  decimetres of a solution and  $c$  the concentration in gram per c.c., then specific rotation  $S$  at a given temperature  $t$  and corresponding to a wavelength  $\lambda$  is given by

$$[S]_{\lambda}^t = \frac{\theta}{lc} = \frac{\text{Rotation in degrees}}{\text{Length in decimetres} \times \text{concentration in gm/c.c.}}$$

**Procedure.** 1. *Preparation of 20% solution.* Taken a clean dry beaker and weigh it. Add about 20 gram of sugar in it and weigh again. Calculate the volume of solution to have a 20% strength as follows :—

$$\text{Volume required} = \frac{m \times 100}{20} \text{ c.c.}$$

where  $m$  is the mass of sugar in the beaker.

Add nearly half this volume of water in the beaker and stir well till the whole of sugar is dissolved. Add more water, if necessary taking care that the volume of solution is *less* than the calculated value of the volume.

Transfer the solution into a graduated cylinder. Rinse the beaker with a small quantity of water and add to the cylinder. Make the required volume by adding more water little by little with a pipette. Filter the solution in a clean beaker and cover it.

2. **Setting.** Find the vernier constant of the circular scale. Place the polarimeter so that the aperture is in front of the sodium lamp (or a sodium flame). Look through the telescope and adjust the position of the eye-piece so that the two halves of the half shade device are clearly in focus.

3. Remove the brass caps of the polarimeter tube. Clean the tube as well as the glass windows. Now replace one of the caps in position *taking care that no strain is exerted on the glass window*. Hold the tube in a vertical position and fill it with water. Slip the second glass window gently on the tube taking care *that no air bubbles are left underneath it*. Screw the cap gently *taking care that no strain is exerted on the glass window*.

4. Place the tube in position in the polarimeter and cover it. Rotate the analysing nicol by rotating the circular scale till the *two halves of the half shade device are in equally dark position*. In this position there will be an abrupt change in the intensity of the two halves when slight rotation on either side is given. Note the reading on the scale.

Turn through  $180^\circ$ , set the analyser again for equally dark position and note the reading on the scale.

**Note.** If the instrument is properly set, there is no strain on the glass windows, and water is free from optically active impurities, the scale reading will be 0 and 180 in the two positions respectively.

5. Now fill the tube with 20% sugar solution prepared as explained above. Place it in position and note the scale readings when the two halves are in equally dark position. Repeat by turning through  $180^\circ$ .

6. Take 30 c.c. of the 20% sugar solution and make the volume to 60 c.c. so as to reduce the strength to one-half (10%). Fill the tube with this 10% solution and take the readings as explained above.

7. Similarly repeat with 5% and 2.5% solutions.

**Observations.** Weight of the beaker = gm

Weight of beaker + sugar = gm

Weight of sugar  $m =$  gm

Volume of solution required  $= \frac{m}{20} \times 100$  c.c. =

Vernier constant =

Sl. No.	Strength of solution in g/m		Scale readings through solution		Rotation		Mean $\theta$	$\frac{\theta}{c}$
	per 100 c.c.	per c.c. (c)	1st pos.	2nd pos.	1st pos.	2nd pos.		
1	Zero							
2	20							
3	10							
4	5							
5	2.5							

Length of the tube  $l =$  decimetre

Mean  $\theta/c =$

$\therefore$  Specific rotation  $\frac{\theta}{lc} =$

Temperature of water  $t = ^\circ\text{C}$

Value of specific rotation from tables at  $t^\circ\text{C} =$

Percentage error =

Laevo-rotatory or dextro rotatory =

**Precautions.** 1. The tube and the glass windows should be clean.

2. There should be no air bubble in the glass tube when the tube is filled with the solution.

3. The caps should be screwed in such a manner that there is no leakage. These should not be made very tight so as to strain the glass windows. Explain why?

4. The reading should be taken in the equally dark position and not in the equally bright position.

5. Before filling the tube with a solution the tube should be rinsed with the same solution.

**Experiment 19.2.** Plot a graph between the concentration and rotation for various lengths of sugar solution and hence find (a) the specific rotation and (b) the concentration of the given sugar solution.

**Apparatus** Same as in Expt. 19.1.

**Theory.** If we plot a graph between concentration of sugar solution  $c$  taken along X-axis and corresponding rotation of plane of polarisation  $\theta$  along the Y-axis, the graph is a straight line as shown Fig. 19.8.

The slope of the graph gives the value of  $\theta/c$  from which we have specific rotation  $= \frac{1}{l} \frac{\theta}{c}$  where  $l$  is the length of the polarimeter tube in decimetre. To find the concentration of the given solution

the tube is filled with this solution and the corresponding value of rotation  $\theta$  is observed. The value of concentration against this value of  $\theta$  is noted from the graph.

**Procedure** 1. Find the rotation for 20%, 10% and 5% solution of sugar as explained in **Expt. 19.1**.

2. Now take 40 c.c of the original 20% sugar solution and add water to make the volume 50 c.c. This will make a 16% solution. Now find the angle of rotation for 16%, 8% and 4% as explained in **Expt. 19.1**.

3. Taking concentration in gm/c.c. along the X-axis and rotation  $\theta$  along Y-axis, plot a graph. The graph is a straight line.

4. To find the concentration of the given sugar solution take a point A on the Y-axis corresponding to the value of rotation  $\theta$  produced by this solution. Draw AB parallel to X-axis cutting the graph at the point B. Draw BC perpendicular to X-axis, then the value of concentration corresponding to the point C on the X-axis is the concentration of the given sugar solution.

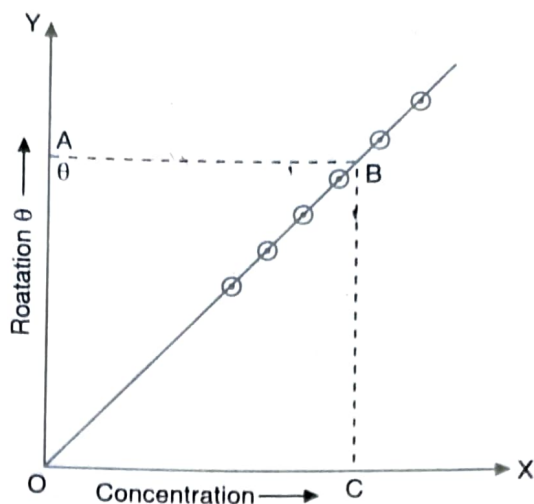


Fig. 19.8

5. The graph passes through the origin O. The slope of the graph  $\frac{BC}{OC}$  gives the mean value of

$\frac{\theta}{c}$ .

**Observations** Vernier constant =

S.No.	Strength of solution in gm		Scale reading through solution		Rotation		Mean rotation $\theta$
	per 100 cc	per cc(c)	1st position	2nd position	1st position	2nd position	
1	Zero						
2	20						
3	10						
4	5						
5	16						
6	8						
7	4						
8	Unknown	$x$					

Value of  $\theta$  corresponding to unknown concentration  $x = \theta =$

$\therefore$  [value of concentration  $x$  from the graph corresponding to the point C] = gm/cc. =

$$\text{Slope of the graph} = \frac{BC}{OC} = \frac{\theta}{c}$$

Length of the polarimeter tube  $l$  = decimetre

$$\therefore \text{Specific rotation} = \frac{1}{l} \frac{\theta}{c} = \frac{1}{l} \frac{BC}{OC} =$$

**Precautions :** Same as in **Expt. 19.1**.

**Exercise 2.** Find the specific rotation of turpentine.

## Oral Questions

**1. Polarisation.** (i) What is polarisation of light? (ii) What is plane polarised light? (iii) How do you obtain plane polarised light? Give various methods. Which method is the best and why? (iv) What is a Nicol prism and how it is prepared? (v) Can you use a transparent cement other than canada balsam? (vi) What is the plane of polarisation of light emerging out of the Nicol prism? (vii) What is a quarter wave plate? What is a half wave plate? (viii) Give various applications of polarisation. (ix) Explain the working of a biquartz.

**2. Specific rotation.** (i) Define specific rotation. On what factors does it depend? (ii) What are dextro-rotatory and laevo-rotatory substances? (iii) What are the various parts of the polarimeter? (iv) Explain the construction and action of a half-shade device. In which position is it most sensitive and why? (v) What type of telescope is used in a polarimeter?