General Physics I (PHYS 101)

Lecture 19

Polarization

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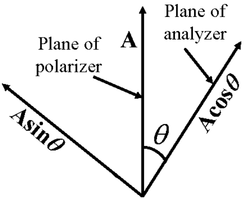
Outline

1. Law of Malus
2. Nicol prism as polarizer and analyzer
3. Optically active substance
   - Specific rotation

Law of Malus

When a beam of light polarized by reflection at one plane surface is allowed to fall on the second plane surface at the polarizing angle the intensity of the final reflected beam varies as the square of the cosine of the angle between the two planes of incidence.



This law may be stated as follows "The intensity of light emerging from the analyzer is proportional to the square of the cosine of the angle between the planes of transmission of the analyzer and the polarizer."

Let A be the amplitude of plane polarized light and θ be the angle between planes of polarizer and analyzer. Now we resolve A in to $A\cos\theta$ parallel to plane of analyzer and $A\sin\theta$ perpendicular to it as shown in figure. Only the

Law of Malus (contd.)

component $A\cos\theta$ is transmitted through the analyzer. So, intensity of transmitted beam is

$$I = (A\cos\theta)^2 = A^2\cos^2\theta = I_0\cos^2\theta$$

$$\therefore I \propto \cos^2\theta$$

where $I_0 = A^2$ is the intensity of incident plane polarized light.

When $\theta = 0$; we find $I = I_0$ (maximum intensity) and when $\theta = \frac{\pi}{2}$; we find $I = 0$ (minimum intensity). So, intensity of light transmitted from analyzer is maximum when the planes are parallel and minimum when they are perpendicular to each other.

Nicol prism as polarizer and analyzer

It is an optical device made up of calcite crystal and used for producing and analyzing plane polarized light. We know that when ordinary light is passed through calcite crystal, it splits up in to two rays; one is ordinary ray (O-ray) and the other is extraordinary ray (E-ray). The nicol prism is made in such a way that it eliminates one of the two rays by total internal reflection. It is found that the ordinary ray is eliminated and only the extraordinary ray is transmitted through the prism.

A calcite crystal is suitably cut in to two pieces and then cemented optically by a transparent material called Canada Balsam, whose refractive index lies between the refractive indices for ordinary and extraordinary rays for calcite. The numerical values of refractive indices are

Refractive index of calcite for ordinary ray, $\mu_o = 1.66$

Refractive index of Canada Balsam, $\mu = 1.55$

Refractive index of calcite for extraordinary ray, $\mu_e = 1.49$

Thus, we see that Canada Balsam is optically denser than calcite for E-ray and rarer for O-ray. So, O-ray is totally internally reflected and only E-ray is transmitted through the prism, which is plane polarized light. Hence nicol prism acts as polarizer.

Now to analyze the polarized ray, second nicol prism is placed adjacent to first as shown in figure 1 below.

Nicol prism as polarizer and analyzer (contd.)

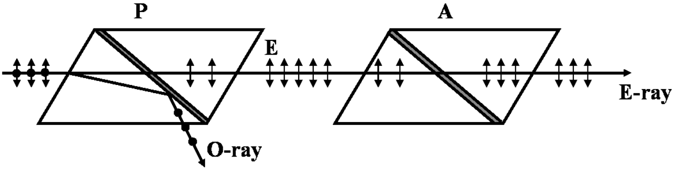


Figure 1

Here prism *P* acts as polarizer and prism *A* acts as analyzer. The planes of both prisms are parallel, so according to Malus law intensity of polarized ray transmitted from analyzer is maximum.

Nicol prism as polarizer and analyzer (contd.)

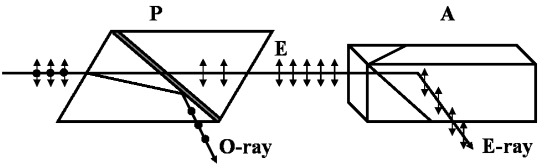


Figure 2

Now prism *A* is gradually rotated, the intensity of final transmitted E-ray decreases in accordance with Malus law and when planes of these prisms are crossed (perpendicular to each other), the intensity of light transmitted from analyzer is zero i.e. E-ray is totally internally reflected by analyzer.

Nicol prism as polarizer and analyzer (contd.)

Thus, nicol prism can be used both as polarizer and analyzer. The combination of P and A (i.e. two nicol prisms) is called a polarimeter.

Optically active substance

Some substances can rotate plane of vibration (or equivalently plane of polarization) of a plane polarized light when it passes through them. This phenomenon or property of rotating the plane of polarization is known as optical activity and the substance is known as optically active substance. If plane of polarization is rotated towards right, then such substance is called dextrorotatory or right handed and if plane of polarization is rotated towards left, then they are called laevorotatory or left handed.

Optically active substance

Specific rotation

Optically active substances can rotate the plane of polarization of plane polarized light. The angle through which the plane of polarization is rotated depends up on

1. the thickness of the medium
2. concentration of solution or density of active substance in solvent
3. wavelength of light used and
4. temperature

Optically active substance

Specific rotation (contd.)

The specific rotation is defined as the rotation produced by a decimeter (10 *c*m) long column of the liquid containing 1 gram of the active substance in one *cc* of the solution. Therefore,

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

Where S_{λ}^{t} is specific rotation at temperature $t^{o}C$ for a wavelength λ, θ is angle of rotation, l is length of the solution in cm and c is concentration of active substance in gm/cc.

Polarimeter is used to determine specific rotation and its study helps us to find out the amount of active substance in the given sample of solution.