

S.Y.B.Sc.

Physics-I

POLARIZATION OF LIGHT

Unit-V

1. Define the following terms:

- **Unpolarized Light :**

Light in which the vibrations are taking place in every possible direction perpendicular to the direction of propagation is called 'Unpolarized Light'.

- **Polarization Light:**

It is the phenomenon of symmetry of vibrations of light about the direction of propagation of light. [OR] It is the phenomenon which restricts the wave oscillations to a particular plane.

- **Polarized Light :**

The light which acquires property of one-sidedness is called polarized light.

- **Plane Polarized Light:**

Light in which the vibrations are restricted to some definite plane passing through the direction of propagation.

- **Plane of Vibration :**

The plane which contains the direction of propagation and the direction of vibration of a plane polarized beam of light.

- **Plane of Polarization :**

The plane passing through the direction of propagation and perpendicular to the direction of vibration of plane polarized light.

- **Polarizer :**

A device such as nicole prism or a tourmaline crystal when used for obtaining plane polarized light from unpolarized light is called a Polarizer.

- **Analyzer:**

A device (such as nicole etc) used to testing the nature of lights as regards polarization.

- **Anisotropic medium:**

A medium whose physical and optical properties are different in different directions.

2. **State the laws:**

- **Brewster's Law:**

It states that the tangent of the polarizing angle is equal to the refractive index of the material with respect to the medium in which the incidence takes place.

The Brewster's relation is $\tan\theta = \mu$

- **Malu's Law:**

Since the intensity of the the wave is proportional to the square of the amplitude.

The relation is $I = I_0 \cos^2\theta$

3. **What is meant by 'Polarization of light'? Explain it briefly.**

Ans: Polarization of Light :

It is the phenomenon of symmetry of vibrations of light about the direction of propagation of light.

It can explained as follows:

- Light is electromagnetic (EM) in nature and it consist of varying mutually perpendicular electric and magnetic fields.
- In the EM wave i.e. light is transverse waves. The direction of polarization of the EM wave is the direction of the electric field.
- Electric field vector explains the optical phenomenon in EM waves.
- Thus the transverse nature of light wav is demonstrated by polarization.
- Polarized light acquires the property of one-sidedness.
- When the vibration constituting the beam of light are restricted in only one definite plane, it is called plane polarized light.
- Polarization of light provides the evidence for the wave theory of light and also the evidence for the transverse nature of light waves.

4. **Write a short note on the WIRE -GRID Polarizer**

Ans: The E-M waves are transverse waves and it can be demonstrated by using a WIRE-GRID POLARIZER.

- The wire-grid polarizer produces linearly polarized light waves.
- It consists of large number of thin gold and copper wires.
- These wires are parallel to each other.

- When un-polarized EM wave is propagated through the wire grid polarizer, then the component of electric vector along the length of wire is absorbed.
- The component of electric vector (Perpendicular) passes without much attention through it.
- This leads to obtained linearly polarized light.
- The wire-grid polarizer with the thick wires and with large spacing has very poor results.
- A thick wire allows some flow of current transversely across the individual wires. As a result the required component of light wave is absorbed to some level.
- Instead of long, thin wire grid polarizer, a long chain polymer molecule that contains atoms can be used.
- Since due to high conductivity of molecules, the E.M. wave parallel to molecules get absorbed and perpendicular component passes through with very little absorption.
- Following methods produces linearly polarized light from un-polarized light :
a)Reflection b)Refraction c)Scattering d)Selective absorption e)Double refraction.

5. Explain Polarization by REFLECTION

Ans: The un-polarized light can be converted into polarized by various methods such as :

- By reflection from non-metallic surfaces
- By transmission through a pile of plane (i.e. by REFRACTION).
- By using tourmaline crystals
- By using Polaroid.
- By using Nicole prism.
- By scattering
- By selective absorption
- By double refraction

By observing the reflection of the sun from a window pane through a calcite crystal Scientist MALU found the two images obtained by double refraction varied in relative intensities as the crystal was rotated about the line of sight.

- The direct sunlight or light from an ordinary lamp (Un-polarized light) is allowed to fall on the surface of transparent substance (glass or a plane surface of water)
- Let XY be the plane boundary that separates the two media (e.g. air and glass).
- Let PO be the incident beam. OR be the reflected beam and NOM be normal to XY at O.

It has been found that :

- When an Un-polarized light is incident on the surface of any transparent material, the reflected and refracted beams are partially plane polarized.
- For Brewster's angle, the reflected beam becomes completely plane polarized with the plane of vibration perpendicular to the plane of incidence.

If $\theta_i = \theta_p$ represents angle of incidence i.e. equal to angle of polarization.

θ_2 represents the angle of refraction for a refracted ray then according to the Snell's law.

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$
$$= \frac{\sin\theta_p}{\sin\theta_2}$$

Where n_2 is the absolute refractive index of the reflecting surface and n_1 is the refractive index of the surrounding medium.

But according to Brewster' law.

$$\theta_2 = \left(\frac{\pi}{2} - \theta_p\right)$$

$$\frac{n_2}{n_1} = \frac{\sin\theta_p}{\sin\left(\frac{\pi}{2} - \theta_p\right)}$$

$$\frac{n_2}{n_1} = \frac{\sin\theta_p}{\cos(\theta_p)}$$

$$\frac{n_2}{n_1} = \tan\theta_p$$

$$\theta_p = \tan^{-1}\left(\frac{n_2}{n_1}\right)$$

Thus, if the angle of incidence θ_1 is equal to θ_p satisfies Brewster's law then polarized component of incident light will not be reflected at all.

6. Explain Polarization by DOUBLE REFRACTION

- Ans:**
- Light can be polarized by passing it through a doubly refracting crystal.
 - The optical phenomenon of double refraction or birefringence in calcite crystal was observed in 1669.
 - Calcite was found as very large transparent crystals.
 - If natural light or un-polarized light is incident on the calcite crystal, in a direction different from that of its optic axis, the light will split into two components and emerge as two parallel beams.
 - These components are known as the ordinary rays (O-rays) and Extra-ordinary rays (E-rays).
 - If the crystal is examined through an analyzer, it will be found that the ordinary and extra-ordinary rays are linearly polarized at right angles to each other.
 - O-ray is in the plane of incidence.

7. Explain the phenomenon of DOUBLE REFRACTION

- Ans:**
- A ray of Un-polarized or natural light incident on a calcite crystal or quartz gives rise to two refracted rays instead of one as expected according to laws of refraction.
 - The phenomenon in which two refracted rays are produced corresponding to a single incidence ray of light is called Double refraction or birefringence.
 - One of the refracted rays follows ordinary laws of refraction and hence is called Ordinary ray (O-ray).
 - The other refracted ray does not follow the ordinary laws of refraction and is called extra-ordinary (E-ray).
 - A medium or substance in which optical properties are same in all direction is called isotropic medium.
 - A medium or substance in which optical properties as well as other physical properties are different in different directions is called anisotropic or birefringent medium.
 - Double refraction is the phenomenon found only in anisotropic medium.

Applications:

1. It is used to study the crystal structure.
2. Nicol prism which shows this property is used to produce plane polarized light.
3. Construction of wave plate; half plate and quarter wave plate
4. Photo elasticity.
5. Kerr effect.

8. Explain QUARTER WAVE PLATE

Ans:

- One application of crystalline birefringent material is to the production and detection of plane polarized light (circularly and elliptically too).
- For this purpose a crystal plate of suitable doubly refracting material and of suitable thickness “d” is employed.
- It is a plate doubly refracting uniaxial crystals such as quartz or calcite.
- The plate is with its optics axis parallel to the refracting faces produce a phase

difference of $\frac{\pi}{2}$ or a path difference of $\frac{\lambda}{4}$ between the o-and e-ray.

- If a beam of plane -polarized monochromatic light of wavelength λ is incident on a crystal of such type normally then according to theory it splits into O and E-components.
- Both of these travel along the same direction but with different velocities.
- If the thickness of the plate is ‘t’ and the refractive indices for O and E components are μ_0 and μ_E respectively.
- Therefore the resultant optical path difference(Δ) between these two components will be:

$$\Delta = t(\mu_0 - \mu_E) \dots \text{For -ve crystals.}$$

$$\Delta = t(\mu_E - \mu_0) \dots \text{For +ve crystals.}$$

- For a wavelength λ , since the phase changes by 2π .
- Then for phase difference of $\frac{\pi}{2}$ between the components of O and E-ray it is

necessary to introduce a path difference of $\frac{\lambda}{4}$. Then

$$\frac{\lambda}{4} = t(\mu_0 - \mu_E)$$

$$t = \frac{\lambda}{4(\mu_0 - \mu_E)} \dots \text{For -ve crystals.}$$

$$t = \frac{\lambda}{4(\mu_E - \mu_0)} \dots \text{For +ve crystals.}$$

- Above equation gives the thickness of a quarter wave plate.
- It can produce as well as defeat a circularly polarized light.
- If a -ve polarized light is incident on a quarter wave plate then the emergent light is circularly polarized.

To produce elliptically or circularly polarized light a quarter wave plate is used.

9. Explain HALF WAVE PLATE

- Ans.**
- Half wave plate is made from a uniaxial doubly refracting crystal like calcite or quartz.
 - The plates is cut with its axis parallel to its optics axis to introduce a phase difference of π or a path difference of $\frac{\lambda}{2}$ between the ordinary and extra-ordinary ray.
 - If a beam of plane -polarized monochromatic light of wave length λ is incident on a crystal of such type, then it splits into O and E-components.
 - Both travel along the same direction but with different velocities.
 - If the thickness of the plate is 't' and the refractive indices for O and E components are μ_0 and μ_E respectively.

- Therefore the resultant optical path difference(Δ) between these two components will be:

$$\Delta = t(\mu_0 - \mu_E) \dots\dots \text{For -ve crystals.}$$

$$\Delta = t(\mu_E - \mu_0) \dots\dots \text{For +ve crystals.}$$

- Since path difference $\Delta = \frac{\lambda}{2}$, therefore the thickness of a half-wave plate is:

$$\frac{\lambda}{2} = t(\mu_0 - \mu_E)$$

$$t = \frac{\lambda}{2(\mu_0 - \mu_E)} \dots\dots\dots \text{For -ve crystals.}$$

$$t = \frac{\lambda}{4(\mu_E - \mu_0)} \dots\dots\dots \text{For +ve crystals.}$$

- A half wave plates is used in the construction of Laurent's half-shade device

used in a polarimeter.

- If a plane-polarized light is incident on a half-wave plate such that it makes an angle of 45° with the optic axis the plate introduces a path difference of $\frac{\lambda}{2}$ between the E and O-rays, the emergent light is plane-polarized.
- The direction of polarization of linear incident light is rotated through 90° .

Thus if the incident light makes an angle of 45° with the optic axis of half-wave plate, the half-wave plate rotates the azimuth of a beam of plane-polarized light.