Wave optics

Lecture Notes on Polarization

Introduction to Polarization:

Polarization refers to the orientation of the oscillations of a wave, especially electromagnetic waves such as light. While light waves can oscillate in various directions perpendicular to the direction of propagation, polarization restricts these oscillations to specific planes.

In everyday light sources (like the sun or a light bulb), light waves oscillate in all directions, and this is called **unpolarized light**. When the light is restricted to oscillate in a particular direction, it is called **polarized light**.

Types of Polarization:

1. **Linear Polarization:**
    - In linear polarization, the electric field oscillates in a single plane. For example, if light is polarized vertically, the electric field vibrates only in the vertical plane as it propagates forward.
    - **Example**: Light passing through a polarizing filter (like polarized sunglasses) is linearly polarized because the filter blocks all oscillations except for those in a specific direction.
2. **Circular Polarization:**
    - In circular polarization, the electric field vector rotates in a helical pattern as the wave propagates. The tip of the electric field vector describes a circle in a plane perpendicular to the direction of wave propagation.
    - Circular polarization can be **right-handed** or **left-handed**, depending on the rotation direction (clockwise or counterclockwise).
3. **Elliptical Polarization:**
    - This is the most general form of polarization, where the electric field vector traces an ellipse. Elliptical polarization occurs when two perpendicular components of light waves are out of phase but not equal in amplitude.
4. **Unpolarized Light:**
    - Unpolarized light consists of waves vibrating in multiple planes. Natural light sources, such as the sun and incandescent bulbs, emit unpolarized light.

Polarization by Various Methods:

1. **Polarization by Absorption:**
   - This is the most common method of producing polarized light, where light passes through a polarizer that allows only the oscillations in one plane to pass through.
   - Example: **Polaroid filters** are commonly used in sunglasses and cameras to reduce glare by allowing only light polarized in a certain direction to pass.

2. **Polarization by Reflection:**
   - When light reflects off a non-metallic surface (like water, glass, or road), it can become partially or completely polarized. The degree of polarization depends on the angle of incidence.
   - **Brewster's Law**: At a specific angle known as Brewster's angle, the reflected light becomes fully polarized. This angle is given by:

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

     where θ_B is Brewster's angle, and n_1 and n_2 are the refractive indices of the two media.

3. **Polarization by Scattering:**
   - When sunlight passes through the atmosphere, it gets scattered by air molecules. This scattered light is partially polarized, which is why the sky appears blue and why polarized sunglasses can reduce the intensity of the scattered light (glare).
   - The polarization effect is strongest at 90° from the direction of the incoming sunlight.

4. **Polarization by Double Refraction (Birefringence):**
   - Certain crystals, such as calcite, split an incoming light wave into two rays — an ordinary ray and an extraordinary ray — that are polarized in mutually perpendicular directions. This phenomenon is called **birefringence**.
   - Example: In a calcite crystal, a single beam of unpolarized light is split into two polarized beams, one that follows Snell's law (ordinary ray) and one that does not (extraordinary ray).

5. **Polarization by Dichroism:**
   - Dichroic materials selectively absorb one plane of polarization while allowing the perpendicular plane to pass through. This leads to light being polarized by absorption in specific crystals or materials.
   - Example: Tourmaline crystals exhibit this type of polarization.

Mathematical Representation of Polarization:

The electric field vector of polarized light can be represented in terms of its components along the x- and y-axes.

- **Linearly Polarized Light**: The electric field in the x-direction can be written as:

  $$E_x = E_0 \cos(\omega t)$$

  And the electric field in the y-direction as:

$$E_y = 0$$

Hence, the total electric field vector lies entirely along the x-axis.

- **Elliptically Polarized Light**: If the components in both the x- and y-directions are present but out of phase, the electric field can be written as:

$$E_x = E_{0x} \cos(\omega t)$$

$$E_y = E_{0y} \cos(\omega t + \delta)$$

Where δ is the phase difference between the two components. This describes an ellipse.

Applications of Polarization:

1. **Sunglasses:**
   - Polarized sunglasses reduce glare by blocking horizontally polarized light reflected from surfaces like roads or water.
2. **Optical Instruments:**
   - Polarization is used in microscopes and cameras to reduce unwanted reflections and enhance contrast.
3. **3D Movies:**
   - Special glasses with polarizing filters are used in 3D movies to give the illusion of depth by presenting two slightly different images to each eye, each polarized differently.
4. **Communication Technology:**
   - Polarization is used in satellite and radio communications to reduce interference by transmitting signals with specific polarizations.
5. **Stress Analysis:**
   - Polarized light is used in materials testing to detect stress patterns in transparent objects through a method known as **photoelasticity**.

Brewster's Angle and Polarization by Reflection:

- **Brewster's Law** states that when unpolarized light strikes a surface at a specific angle, called Brewster’s angle, the reflected light is completely polarized perpendicular to the plane of incidence.
- The angle is given by:

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

where θ_B is the Brewster’s angle, and n_1 and n_2 are the refractive indices of the two media involved.

At Brewster’s angle, the refracted and reflected light beams are at 90° to each other, and the reflected light is fully polarized.

Important Points to Remember:

- Polarization can occur through absorption, reflection, scattering, and refraction.
- Light can be linearly, circularly, or elliptically polarized.
- Polarization by reflection is used in many optical applications to reduce glare and improve visibility.
- In Brewster’s Law, the reflected light becomes completely polarized at a specific angle known as Brewster’s angle.

Summary:

Polarization is a key property of light that restricts the direction of wave oscillations. While natural light is unpolarized, many techniques can be used to polarize light for various practical applications, including reducing glare, improving contrast in optical devices, and studying stress patterns in materials.
