OPTICS AND LASER PHYSICS LABORATORY #2
LINEAR POLARIZATION OF LIGHT

Polarization of an electromagnetic wave will be investigated in this laboratory. First measurement techniques for determining the polarization of the light will be demonstrated and then polarization via selective absorption (dichroism), reflection, and birefringence will be considered.

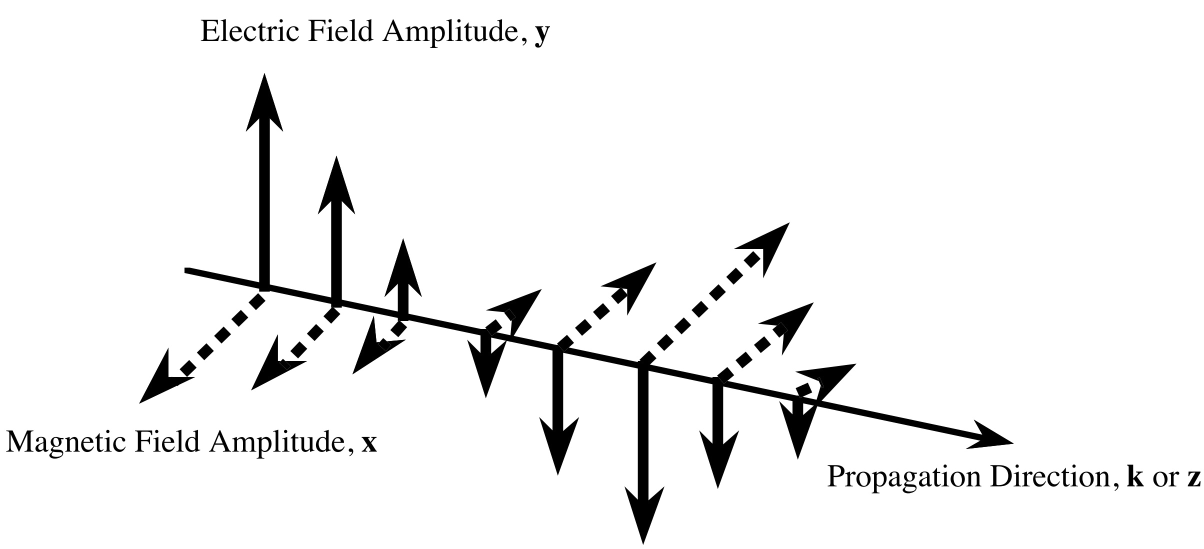

Figure 1: Linearly polarized light propagating in the **z** direction.

Polarization

The direction of polarization of an electromagnetic wave has traditionally been defined to lie along the direction of oscillation of the electric field. There are four possible states of polarization attributed to any light source -- unpolarized light, linear polarization, elliptically polarization or circular polarization. *Linearly polarized* light is the polarization most often brought to mind when polarization is mentioned. A plane wave exhibits linear polarization as its electric field vector always oscillates in a fixed direction in space while the magnetic field also oscillates at fixed right angles to the electric field. Linearly polarized light is emitted by a single dipole oscillator as viewed from the far field (a large distance away) or could be emitted by a collection of dipole oscillators radiating in synch with one another. In general, ordinary or natural light is *unpolarized*. Unpolarized light has an instantaneous polarization which fluctuates rapidly and in a random manner. This occurs because the source of most ordinary light is a large number of radiating atoms whose radiation is not synchronized, and as such the electromagnetic waves emanating from this light source do not maintain a constant direction of oscillation (as in linearly polarized light), nor does the direction of oscillation vary with any spatial regularity (as in elliptically polarized light).

Elliptical and *circular* polarizations occur when the electric field vector rotates at a particular frequency as it travels through space. If the amplitude of the electric field is constant throughout its rotation the associated light is said to be circularly polarized and if the amplitude oscillates while rotating the light is designated as elliptical. (Your textbook has several diagrams of the electric field and magnetic field vectors orientation during propagation for the various polarizations.) A beam of light consisting of both polarized and unpolarized light is said to be partially polarized.

Investigation of Polarization

The apparatus for this lab includes one He Ne laser (with mystery polarizing elements in front of them), as well as several dichroic polarizers, wave-plates and a detector. The only measurement which requires a photodiode detector is in the section on Polarization via Reflection, otherwise watch the beam on the screen. Use your eye to discriminate and estimate that 1/2, 1/3, 1/4 the light is getting through the polarizing elements. Polarizers are highly transmitting to one direction of electric field oscillation and highly absorbing to the other. This makes them good diagnostic tools.

1) How would you use polarizers to determine the polarization of a light source?

2) Determine the polarization of the laser.

3) Can you identify a circularly polarized source as opposed to an unpolarized source with dichroic sheets? Why or why not?

4) How might you determine if a light source were circularly polarized?

5) How might you determine if a light source were ellicptically polarized?

Producing Polarized Light via Light's Interaction with Matter

Light may be polarized when it interacts with certain media. For instance, if the response of a medium to light in figure 1 is different along the directions, **x** and **y**, which are transverse to the direction of propagation, **k**, then the light which exits the medium can become polarized. These asymmetric responses can arise in absorption, reflection, and transmission depending on the type of material interacting with the light.

OPTICS AND LASER PHYSICS LABORATORY #2

LINEAR POLARIZATION OF LIGHT

Polarization via Anisotropic Absorption -- Dichroism

One type of polarizer depends on a medium's ability to absorb one component of the electric field more strongly than the other, or dichroism. A dichroic polarizer selectively absorbs light with electric field oscillations in a specific direction and transmits electric field oscillation in the perpendicular direction, the transmission axis. The most commonly used dichroic polarizer is a Polaroid sheet invented by Edwin Land in 1938. When a sheet of this polyvinyl alcohol is stretched in one direction and heated, its hydrocarbon molecules align themselves in the same direction. Iodine is introduced to the sample in order to provide additional electrons to the molecules. This allows the material to absorb light and then to re-emit it so that it oscillates in the direction perpendicular to the elongated molecules. This is perhaps nonintuitive because one would expect the dipole in the elongated direction to be free to re-emit. It does so, however, the re-emission of an oscillating dipole is out of phase with the initial light and so destructive interference occurs for the component of the electric field vibrating in that elongated direction. Partial constructive interference in the direction perpendicular to the elongation permits the transmission of this component of the E-field with only a small loss in amplitude. (A good description of this dichroic behavior is found in *Introduction to Optics*, by Pedrotti and Pedrotti, Ch. 15-1, p.298 ff.)

1) Using the unpolarized HeNe laser and a dichroic polarizer, produce a polarized output. How has the power of the initial beam changed?

2) Cross a second polarizer with the first (place this polarizer's axis of transmission at 90^o to the first) and observe the transmission of the pair.

3) Place a flat piece of cellophane in between the two crossed polarizers and observe the resulting transmission. Try some balled-up cellophane. Can you explain your observations?

4) If you were to place a polarizer at 45^o to the first polarizer's transmitting axis and observe the output of the third polarizer, what would you expect to see? Try this and record observations. Rotate the intermediate polarizer to various positions. Predict the behavior of the output and record.

Polarization via Reflection

Another avenue for producing polarized light from unpolarized light is that of reflection from a dielectric surface. When unpolarized light is incident on a surface, its reflected beam is partially polarized in the TM mode, i.e. where the electric field is vibrating parallel to the plane of incidence.

Generally the degree of polarization in the reflection is dependent on the angle of incidence. Polaroid sunglasses are designed to have their transmitting axis in the vertical direction since the earth tends to polarize the light in the horizontal direction upon reflection. Equation 1 describes the reflection coefficient for light polarized in the TM mode. One sees that there exists an angle of incidence, θ, such that the coefficient R_{TM} is zero.

$$R_{TM} = \frac{\pm n^2 \cos\theta + \sqrt{n^2 \pm \sin^2\theta}}{n^2 \cos\theta + \sqrt{n^2 \pm \sin^2\theta}} \qquad \text{Eq. 1}$$

This angle is known as the Brewster angle or polarizing angle. The expression for determining the Brewster angle is given below. For light reflecting off of glass of index 1.5, one finds that the polarizing angle is 56.3^o. Note that one can find a polarizing angle for reflection within a medium as well, such as the Brewster angle for light traveling within the glass and undergoing internal reflection will be 33.7^o.

$$\theta_{pol} = \tan^{\pm 1}\left(\frac{n_2}{n_1}\right) \qquad \text{Eq. 2}$$

where n_2 is the medium into which the incident beam entering and n_1 is the medium in which the beam is initially traversing. A Brewster angle window is often incorporated into a laser cavity in order to produce a specific linear polarization in the laser beam.

A pile of dielectric plates can be employed in order to enhance the reflectivity of a polarizer as well as the degree of polarization. For instance, polarizing beam splitters are manufactured by treating the reflecting interface with many layers of dielectric thin film of a specific thickness. Then when unpolarized light is incident on the beam splitter, the reflected portion will have one polarization and the transmitted the opposite. The degree of polarization is defined as

$$\text{degree of polarization} = \frac{I_{max} \pm I_{min}}{I_{max} + I_{min}} \qquad \text{Eq. 3}$$

where the maximum and minimum I are found by rotating a polarizer in the beam of interest and measuring the corresponding power on the PIN photodiode.

OPTICS AND LASER PHYSICS LABORATORY #2

LINEAR POLARIZATION OF LIGHT

---

1) Place a glass slide at some angle to an unpolarized HeNe and view the reflected portion of the beam with a dichroic polarizer. What degree of polarization do you observe? (percentage of reflected light polarized) Use a photodiode detector to measure pertinent quantities.

2) Vary the angle of the glass slide and find the angle at which the maximum polarization is produced. Calculate the index of refraction of the glass slide.