Physics 476LW
Advanced Physics Laboratory
Polarization

In this lab you will study Malus’ law, optical rotation and the Fresnel equations.

Background
Light is a transverse electromagnetic wave, and may be found unpolarized, polarized or a combination of the two. Polarized light may be linearly polarized, circularly polarized or elliptically polarized. Additionally, unpolarized light may become polarized due to interactions with matter, via scattering and reflection. There are many phenomena that may rotate linearly polarized light. In this lab we will study one phenomenon, optical activity.

When light is reflected at an interface, the amount of reflected light is described by the Fresnel equations and is dependent upon the polarization of the light. We will study this too.

Experiments

Polarizers and Malus’ Law
Using light from the Ar⁺/Kr⁺ laser you will study linear polarizers and Malus’ law. Turn the laser on (it should be set for 676.4 nm) and place a polarizer in the beam path. Measure the power transmitted through the polarizer using the power meter. Find the maximum value by rotating the polarizer. Note both the polarizer angle and the meter reading. Now place the other polarizer in the beam path (in this position the polarizer is often called the analyzer) and measure the power transmitted through both the polarizer and the analyzer. Again, rotate the analyzer until the power transmitted is the maximum. Note this value. The ratio of the intensity after the analyzer and intensity after the polarizer is the maximum transmission of the linear polarizer. Repeat this for the other wavelengths of the Ar⁺/Kr⁺ laser, and make a plot of transmission versus wavelength. The Ar⁺/Kr⁺ laser can lase at the following wavelengths: 676.4, 647.1, 568.2, 530.9, 520.8, 514.5, 501.7, 496.5, 488.0, 482.5, 476.2, 468.0, 465.8, 457.9 and 454.6 nm.

Have the laser lase at 676.4 nm and again measure the power after the first polarizer. Place the power meter after the analyzer and measure the power as a function of the analyzer angle relative to the polarizer angle. Collect data every 5°. This should obey
Malus’ law, $I = I_0 \cos^2 \theta$. On the same graph, plot $I/I_0$ versus $\theta$, and also $\cos^2 \theta$ versus $\theta$. How do they compare? Plot $I/I_0$ versus $\cos^2 \theta$. Is it linear? Repeat this for at least 2 different wavelengths.

**Optical Rotation**

The electric field of linearly polarized light will undergo a rotation when light passes through certain materials. Some materials will produce a clockwise rotation (dextrorotary) of the electric field while others a counter-clockwise rotation (levorotary). (When the observer is viewing the beam coming towards him.) Many molecules (and crystals too) can exist in either of two forms, which are mirror images of one another. These are said to be enantiomorphs of one another. One enantiomorph will produce clockwise rotation while the other will produce counter-clockwise rotation, and it can be vitally important to know which enantiomorph is present.

In this lab you will study the optical activity of tap water and 3 sugar solutions. The angle of rotation of the electric field, $\beta$, passing through a solution of length $L$, with $d$ grams of sugar per cubic centimeter is given by:

$$\beta = \rho L d$$

where $\rho$ is known as the specific rotation of the material and is the amount of rotation due to a solution which is 10 cm thick and has a concentration of 1 gram per cubic centimeter (cc = ml) of solution. The specific rotation of sugar is 66.5° cc/(dm-g).

We will determine the concentration of sugar in each solution by measuring the rotation of the light passing through it. First fill the cell with tap water and place it between the polarizers. Rotate the analyzer until a maximum power is transmitted (see figure).

Empty the pure water out of the cell (into the sink) and place solution 1 into the cell. Then rotate the analyzer until a maximum power is transmitted through the analyzer. The difference between the angle of the analyzer for pure water and the present angle is $\beta$. The length of the cell is 94 mm. From this one should be able to determine how many grams of sugar per cubic centimeter are in solution A. Place solution 1 back into its original container (mason jar) and repeat this measurement for solutions B and C.

**Fresnel Equations**

The Fresnel equations describe the transmission and reflection of light from dielectrics, and depend upon the polarization of the light, the index of refraction of the medium and
the angle of incidence. For reflected light from an air/dielectric interface, the Fresnel equations are:

\[ r = \frac{E_r}{E} = \frac{\cos \theta - \sqrt{n^2 - \sin^2 \theta}}{\cos \theta + \sqrt{n^2 - \sin^2 \theta}}, \text{ for transverse electric (s polarization)} \]

\[ r = \frac{E_r}{E} = \frac{n^2 \cos \theta - \sqrt{n^2 - \sin^2 \theta}}{n^2 \cos \theta + \sqrt{n^2 - \sin^2 \theta}}, \text{ for transverse magnetic (p polarization)} \]

In this lab you will measure \( R = \left( \frac{I_r}{I} \right) = \left( \frac{E_r}{E} \right)^2 = r^2 \), where R is known as the reflectance and r is the reflection coefficient. A graph, with plots of R versus \( \theta \) for s and p polarization is shown below for n=1.5.

Select the 520.4 nm (green) light from the laser. Set up the prism labeled 1 as shown in the figure below, and orient it so the laser beam is reflected back upon itself. The prism is now oriented so that it is normal to the laser beam, and the angle of the rotation platform should be noted. Place a polarizer immediately after the laser to ensure that the beam is vertically polarized (s polarization). Measure the intensity of the laser beam after the polarizer. Now rotate the platform and measure the intensity of the reflected light as a function of the angle of incidence. Repeat this to as large an angle as you can go to. In regions where the reflected intensity changes markedly you should collect more closely spaced data. You have now collected all of the data so that you will be able to plot the
reflectance, \( R (=r^2) \) versus \( \theta \) and compare this with the Fresnel equation for reflected light for s-polarized light. You will now repeat these measurements for p-polarized light. To make p-polarized light, rotate the polarizer so that it is at \( \sim 45^\circ \). Place the second polarizer immediately after the first polarizer, and orient it at \( 90^\circ \), so the transmitted light is horizontally polarized (p-polarization for this instance). Measure the intensity of the light immediately after the second polarizer and repeat the experiment that you just did, measuring the intensity of the light reflected off of the front surface of the prism for a variety of angles. Calculate where you expect Brewster’s angle to be (Prism 1 has an index of refraction \( n(520.8 \text{ nm}) = 1.65 \)) and see if this agrees with your current data.

**Questions/Discussion Points**

1) Describe how a linear polarizer works.

2) A sugar solution and quartz are examples of materials that are optically active, and which rotate the polarization of light. There are other effects, which will cause linearly polarized light to be rotated, such as, Faraday rotation, the Pockels effect and the Kerr effect. Briefly describe how each of these work.

3) What are the sugar concentrations for solutions A, B and C?

4) In order to obtain p polarized light (to study the Fresnel equations) we have used a low cost method to rotate the polarization of the light by \( 90^\circ \). The advantage is that this is inexpensive, especially since we already have the polarizers. The most common way experimenters rotate the polarization of light by \( 90^\circ \) is by use of a 1/2-waveplate. What is the advantage of the 1/2-waveplate over our 2-polarizer method? How does a 1/2-waveplate work?

5) Insure that you make all of the graphs that are asked for in the manual and compare with theory. Comment on how well theory and experiment agree. What are some possible reasons for any disagreement between the two?

6) For normal incidence, what do the Fresnel equations give for the reflectance, \( R \), for s- and p- polarized light? Comment on this.