Chapter 9

Refraction and Polarization of Light

Name:___________  Lab Partner:___________  Section:______

9.1 Purpose

The purpose of this experiment is to demonstrate several consequences of the fact that materials have different indexes of refraction for light. Refraction, total internal reflection and the polarization of light reflecting from a nonmetallic surface will be investigated.

9.2 Introduction

Light can travel through many transparent media such as water, glass and air. When this happens the speed of light is no longer $c = 3 \times 10^8 \text{ m/s}$ (the speed in vacuum), but is less. This reduction in the speed depends on the material. This change in speed and direction is called refraction and is governed by Snell’s Law of Refraction.

$$ n_1 \sin \theta_1 = n_2 \sin \theta_2 $$ \hspace{1cm} (9.1)

The ratio of the speed of light in vacuum to that in the medium is called the index of refraction ($n$). The index of refraction is a number greater than or equal to one. The angles ($\theta_1$ and $\theta_2$) are measured with respect to the normal (perpendicular) to the interface between the two media (See Figure 9.1).

When light passes from a medium of higher index of refraction to a medium with a lower index of refraction, the light ray can be refracted at $90^0$. This phenomenon is called total internal reflection. For incident angles greater than $\theta_c$, there is no refracted beam. The transmission of light by fiber-optic cable uses this effect. The critical angle of incidence where total internal reflection occurs is given by:

$$ \sin \theta_c = \frac{n_2}{n_1} \quad n_1 > n_2 $$ \hspace{1cm} (9.2)

If this angle and the index of refraction of one of the two media is known, the index of refraction of the other medium can be found.
Figure 9.1: Snell’s Law for refraction showing the angles measured with respect to the normal.

Figure 9.2: Ray table setup for the Snell’s Law measurement.

When light strikes an interface between two media, the reflected light is partially (linearly) polarized. At one special angle, the light reflected from an interface between two media with indices of refraction $n_1$ and $n_2$ will be completely polarized. This is called the Brewster angle, $\theta_B$. The Brewster angle is given by:

$$\tan \theta_B = \frac{n_2}{n_1} \quad (9.3)$$

9.3 Procedure

In the Snell’s Law and total internal reflection portions of the experiment, the ray table and a laser are used to measure the index of refraction of the cylindrical lens. The ray table, laser, and cylindrical lens are shown in Figure 9.2.

Special Cautions:

- Never look directly into the laser.
- Be careful when moving around the darkened room for the last part of the experiment.
9.3.1 Snell’s Law

Here we will consider the laser beam to be a parallel beam, meaning its diameter is always the same. We will use the laser beam to calculate the index of refraction of Lucite. The Lucite under consideration is a semi-circular disk (cylindrical lens).

- Place the ray table and base on the optics bench. Align the cylindrical lens on the ray table as shown in Figure 9.3 with the flat side facing the incident laser beam. The flat face of the cylindrical lens should be aligned and centered on the ray table line labeled 'Component'.

- Align the laser so the beam passes horizontally through the cylindrical lens. The laser beam should be aligned with the line on the ray table labeled 'Normal'. The laser should be placed on spacer blocks for the correct vertical alignment. To help see the incident and refracted beam, use a strip of transparent plastic.

- Rotate the ray table so the angle of incidence is 10°. Record the angle of incidence and angle of refraction. Repeat the measurement for 10° steps of the incident angle up to 80°. Record the values in the data table.

- Calculate the index of refraction of the cylindrical lens assuming the index of refraction of air is 1.0 for the eight data points in the data table and record the results in the table. Show one example calculation below.

- Calculate the mean value of the index of refraction of the cylindrical lens for the eight measurements.
<table>
<thead>
<tr>
<th>$\theta_1$</th>
<th>$\theta_2$</th>
<th>index of refraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^\circ$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$20^\circ$</td>
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<td>$70^\circ$</td>
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</tr>
<tr>
<td>$80^\circ$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9.4: Ray table setup for the total internal reflection measurement

Mean value of index of refraction __________

• Compare your average value for the index of refraction to the standard value for Lucite (or Plexiglas) of 1.51, i.e., calculate the percentage error.

Percentage error __________

9.3.2 Total Internal Reflection.

• Align the cylindrical lens on the ray table as shown in Figure 9.4 with the **curved** (round) side facing the incident laser beam. Adjust the beam so the beam passes through the cylindrical lens with an incident angle of $0^\circ$. The beam should pass straight through the lens.

• With the incident laser beam remaining normal to the round part of the cylindrical lens, slowly rotate the table and observe the exiting beam.

• Continue rotating the table until the exiting beam is nearly parallel to the flat face of the lens. The beam may appear to suddenly jump from near parallel to the flat face to inside the lens. This angle is the critical angle, $\theta_c$. Record the critical angle.
Assuming the index of refraction of air to be 1.0, calculate the index of refraction of the cylindrical lens. Show the calculation below and record the value.

Calculated index of refraction

Calculate the percentage difference between the mean value of the index of refraction found in the Snell’s Law experiment and the index of refraction found in the total internal reflection experiment.

Percentage difference for index values

9.3.3 Polarization and Brewster’s Angle

Before beginning this part of the measurement, observe the effect on unpolarized ambient light with two polarizers. Look through the two polarizers. Rotate one polarizer with respect to the other polarizer. As you rotate you will notice the light intensity varies between almost complete transmission and complete extinction. The first polarizer allows the component of unpolarized light which is aligned along the polarization axis to pass through the polarizer. The transmitted light is then completely polarized. When the second polarizer’s axis is aligned with the axis of the first polarizer, the light is almost completely transmitted. When the second polarizer’s axis is perpendicular to the first polarizer’s axis, the light is blocked.

In this part of the experiment, we will generate polarized light by reflection at Brewster’s angle and show the light is polarized using a single polarizer. The apparatus is shown in Figure 9.5.
Figure 9.6: Arrangement for the Brewster’s angle measurement

- Turn off the laser and secure it in a safe place on the lab table. Place the light source on the optics bench with the 'parallel ray lens' on the front of the light source. Place the slit plate and single slit mask on a component holder.

- Arrange the ray table as shown in Figure 9.6. The flat side of the cylindrical lens should face the light source. Adjust the slit mask so a single ray of light passes through the center of the ray table along the normal line. The room should be darkened for this part of the experiment.

- Rotate the ray table until the angle between the reflected and refracted rays is 90°. Place a polarizer on a component holder. Arrange this component holder so it is in line with the reflected ray.

- Look through the polarizer at the light source as seen reflected from the cylindrical lens. Rotate the polarizer slowly through all angles. The intensity of the reflected light should vary as the polarizer is rotated.

- Record the angle of reflection.

Measured Brewster angle ($\theta_B$) ________

- What is the angle of polarization of the light i.e., where is the light most intense. Take 0° to be when the polarizer is oriented vertically, before you rotate it.

- Assuming the index of refraction for air is 1.00, calculate the index of refraction for the cylindrical lens from the Brewster angle ($\theta_B$).
Index of Refraction from $\theta_B$

- Calculate the percentage difference between the mean value of the index of refraction from the Snell’s Law experiment to the value found from the Brewster angle.

  Percentage difference

- Change the angle of reflection from the flat face of the cylindrical lens. Is the light completely polarized for other angles of reflection? Explain why.

9.3.4 Questions

1. Using Snell’s Law, derive the critical angle for total internal reflection given in the text.

2. What is the speed of light in the plastic you measured?

3. It is critical that the flat face of the cylindrical lens face the laser for the Snell’s Law experiment and the curved side face the laser for the total internal reflection measurement. Why?
9.4 Conclusion

Write a detailed conclusion about what you have learned. Include all relevant numbers you have measured with errors. Sources of error should also be included.