Lab 6: Basic Optics—Reflection, Transmission and Polarization of Plane Waves

NAME_______________________NAME_______________________NAME_______________________

WARNING: SAFETY FIRST! ALWAYS WEAR SAFETY GOGGLES WHEN LASER IS ON. DO NOT ALLOW THE LASER BEAM, EITHER DIRECTLY OR AFTER REFLECTION FROM A SURFACE, TO ENTER ANYONE'S EYE. PERMANENT BLINDNESS MAY RESULT.

HANDLE ALL OPTICAL COMPONENTS WITH CARE. DO NOT TOUCH THE OPTICAL SURFACES WITH YOUR FINGERS.

Introduction:

In this lab you will examine reflection and transmission of a plane wave at a media interface, as well as its polarization properties using a He-Ne laser (Spectraphysics 155) as a source of electromagnetic waves (light) at a wavelength of 632.8 nm (red). You can also learn the construction of a He-Ne laser by examining the Electro Optics Associates LAS-101 He-Ne laser demo unit.

You will study Snell's law, total internal reflection, Brewster's angle and their polarization properties. The experiment setup is shown in the figure below.
A half-circular crystal lens with refractive index of 1.49 is placed on a rotational support centered on a circular plate. A cardboard labeled with angles is around the plate forming a wall. The He-Ne laser is placed outside the cardboard wall, emitting through a pinhole on the cardboard, where 0° is labeled inside. Make sure the cardboard is tightly attached to the plate, so that a nice circle is formed before you start the measurement.

**Procedure:**

1. Examine the LAS-101 He-Ne laser.

   Note the gas discharge tube in the middle, Brewster's angle windows at both ends of the tube and high reflectivity mirrors (for red light—emission wavelength 632.8 nm), which provide feedback, on both sides of the laser. Look against these mirrors. What color do you see, and why?

2. Linear Polarization

   Turn on the power button in the rear of the Spectraphysics 155 He-Ne laser. Switch the beam attenuator shutter open on the top front.

   Laser Beam Alignment:

   Direct the beam through the pinhole in the cardboard facing towards the rotating support. Rotate the support so that the crystal lens is not blocking the beam. Adjust the laser so that the beam is hitting the 180° line marked on the other side of the cardboard.

   Place polarizer P1 between the cardboard and the crystal lens. To determine whether the laser beam is linear polarized, observe the intensity of the transmitted beam on the cardboard as the polarizer is rotated within its holder. The polarizing direction is marked on the polarizer.

   Do you see intensity change as you rotate the polarizer? __________

   Is the laser beam polarized? __________

   Next place polarizer P2 behind P1, and use P2 to detect the polarization produced by P1.
Minimum intensity results when the polarizing directions of P1 and P2 are perpendicular or aligned?

Maximum intensity results when the polarizing directions of P1 and P2 are perpendicular or aligned?


An incident light wave at a media interface with refractive indices $n_1$ and $n_2$ will be reflected and transmitted. Snell’s law gives the angle relation between the incident wave and the transmitted wave as shown below.

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

Remove the polarizers. Rotate the support with the crystal lens so that the laser beam is incident on the flat surface of the lens. Rotate the support and verify Snell's law for the angles of incidence of 45° and 60°:

$\theta_1 = 45^\circ$, $\theta_2$ (measured) = _______ $\theta_2$ (Snell's law) = _______

$\theta_1 = 60^\circ$, $\theta_2$ (measured) = _______ $\theta_2$ (Snell's law) = _______

Insert P1 and vary the polarization. Does Snell's law depend on the polarization? _______

4. Total internal reflection.

Total internal reflection occurs when the light beam goes from a high refractive index medium to a low refractive index medium. When the angle of incidence reaches the critical angle $\theta_c$, at which the angle of refraction is 90°, no transmitted beam can be observed. For all $\theta_1 > \theta_c$, the transmitted beam disappears, and all incident wave energy is reflected.
Remove the polarizer. Rotate the support so that the laser beam is incident on the curved surface of the crystal lens as shown in the above figure. Rotate the support and observe the angles and the intensity of the waves transmitted and reflected from the flat surface of the lens. When the angle of incidence (on the flat surface) reaches the critical angle $\theta_c$, the transmitted wave emerges parallel to the flat surface of the lens. Measure the critical angle and compare it with the theoretical value calculated from Snell’s law:

$$\theta_c \text{ (measured)} = \phantom{000} \quad \theta_c \text{ (theory)} = \phantom{000}$$

Insert P1. Does the phenomenon of total internal reflection depend on the polarization?_______

5. Brewster's angle.

An incident beam contains two perpendicular polarizations, $s$ and $p$ as shown in the figure below. If the angle of incidence is equal to the Brewster’s angle $\theta_B$, the reflected beam will be purely $s$-polarized and the transmitted beam will be slight $p$-polarized (still contains a small fraction of $s$ polarization). Also, in this condition, the reflected and transmitted beam form a right angle.
Insert P1 between the cardboard and the crystal lens. Rotate P1 to align the polarization parallel to the table. Which polarization does the incident beam contain, s or p?

Rotate the support so that the laser beam is incident on the flat surface of the lens. Examine the reflected wave as you vary the angle of incidence by rotating the support. When the angle of incidence is equal to Brewster's angle, the reflected beam will vanish. Why?

Measure the Brewster's angle and compare with the calculated value.

\[ \theta_B (\text{measured}) = \quad \theta_B (\text{theory}) = \]

Rotate the polarizer by 90°. Which polarization does the incident beam contain now, s or p? Repeat the above measurement.

Is there a Brewster’s angle?____.

6) Diffraction Gratings

There are two diffraction gratings which are supplied, one with a relatively large rule spacing (18.4 lines per cm), grating 1, and one with a small rule spacing, grating 2. The rule spacing for grating 2 is unknown.

With the polarization oriented both along and across the rulings of the gratings and the gratings perpendicular to the light beam note the angles through which the beam is deflected by the gratings. In the second case there is only one visible angle.

Grating No. 1 (18.4 lines per cm)
First three scattering angles

\[ \Theta_1 = \]
\[ \Theta_2 = \]
\[ \Theta_3 = \]

Grating No. 2 (line spacing unknown)
\[ \Theta_4 = \]

Is there a polarization sensitivity? If so, what?
Using the grating equation

\[ \sin \theta_r = \sin \theta_i + n \left( \frac{\Delta}{\Lambda} \right) \]

where \( \lambda \) is the wavelength and \( \Lambda \) is the spatial period of the grating lines.

1) Calculate the three angles for the first grating using the given ruling (18.4 lines per cm)

\[ \theta_1 = \text{} \]
\[ \theta_2 = \text{} \]
\[ \theta_3 = \text{} \]

2) For the second grating calculate the ruling from the observed angle.

Calculated Ruling = \( \text{lines/cm} \)

3) Observe the scattering angles for an incident angle, \( \theta_i \), of approximately 20 degrees and check with the values calculated from the grating equation.

\[ \theta_1 = \text{} \]
\[ \theta_2 = \text{} \]
\[ \theta_3 = \text{} \]
\[ \theta_4 = \text{} \]

Observed

\[ \theta_1 = \text{} \]
\[ \theta_2 = \text{} \]
\[ \theta_3 = \text{} \]
\[ \theta_4 = \text{} \]

Calculated