

Lab 2 : Index of Refraction, Total Internal Reflection, and Critical Angle

I. Objective

To measure the index of refraction of materials and to observe the effect of a total internal reflection.

II. Theory:

In class you learned that when light crosses from one medium to another, the rays “bend” or refract at the interface between the two mediums. Refraction of the light by a medium is the basis of lenses which can redirect light rays to a focus, for example. Lenses and refraction are used in everything from eyeglasses to correct vision to microscopes and telescopes. In this lab, you will observe refraction of light and from these measurements determine the index of refraction of the medium.

A. Refraction through a glass plate

Consider an incident beam of light and its refraction through a block of glass. The incoming light makes an angle of θ relative to the normal to the surface of the glass. The angle at which the light propagates in the glass is given by Snell’s Law or Refraction:

$$\sin \theta = n \sin \theta_r \quad (1)$$

where n is the index of refraction of the glass and the index of refraction of air is taken to be unity. When the beam of light crosses the second boundary of glass it refracts again. If the two surfaces of the glass are parallel to each other, the light beam emerges from the glass at the same angle θ but it is laterally displaced from its initial position by a distance d . Your goal in the lab is to measure the deviation d as a function of incident angle θ .

From the geometry of Figure 1, we can deduce the following geometric relations:

$$\theta = \alpha + \theta_r \quad (2)$$

$$d = L \sin \alpha \quad (3)$$

$$w = L \cos \theta_r \quad (4)$$

where L is the distance that the beam travels in the glass and the identity

$$\sin(A - B) = \sin A \cos B - \cos A \sin B \quad (5)$$

Combining these Equations, one can derive the equation

$$d = w \sin \theta \left(1 - \frac{\cos \theta}{\sqrt{n^2 - \sin^2 \theta}} \right) \quad (6)$$

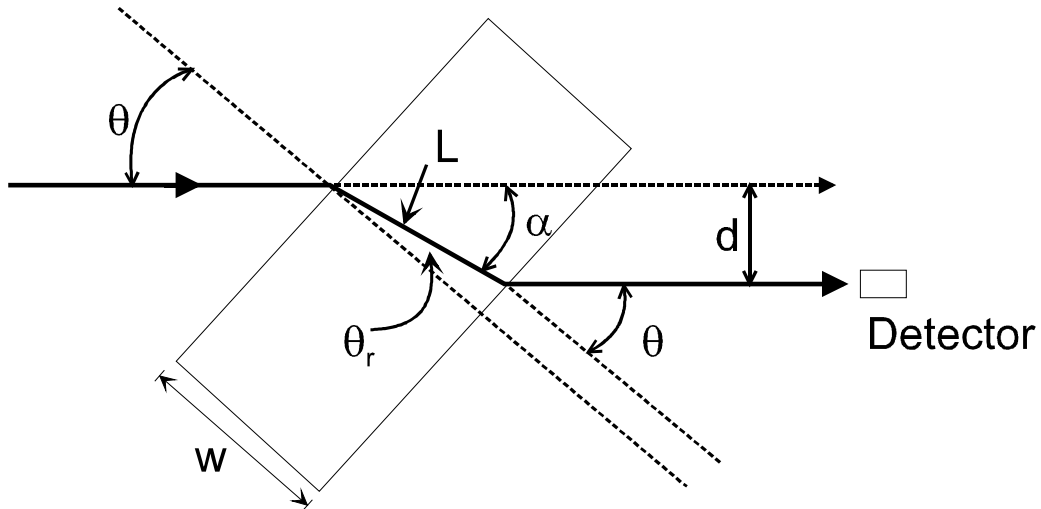


Figure 1: Geometry of refraction through a medium with parallel faces.

B. Refraction and Total Internal Reflection in a Prism

Total internal reflection can only occur when a beam of light is traveling from an optically denser medium to a less dense medium. In other words, the beam must travel from a medium of a larger index of refraction to a medium with a smaller index of refraction. In the case of the right angle prism (see Figure 2), the geometry is arranged so that total internal reflection occurs at the **SECOND** interface corresponding to the hypotenuse of the triangular prism. In total internal reflection there is no refracted ray, so from Snell's law we may calculate the "critical" angle, $\sin(\theta_c) = n_1/n_2$ where n_2 is the index of refraction of the denser material. In our case the less dense material is air, so $n_1 = 1$.

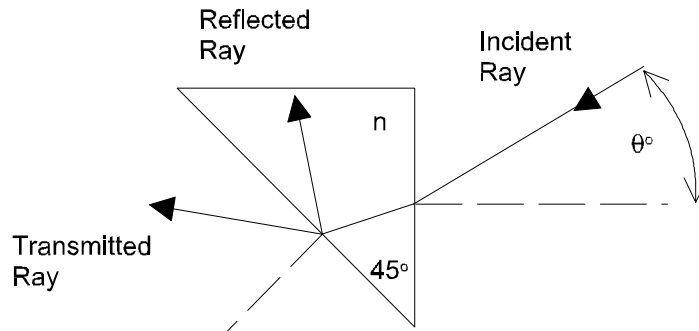


Figure 2: Geometry for measuring the index of refraction using total internal reflection in a prism.

For total internal reflection at the **SECOND** air/glass interface, (hypotenuse of the triangular prism), the transmitted ray of Figure 2 vanishes. By similar geometrical arguments as in Part II.B it can be shown:

$$n^2 = \sin^2(\theta_o) + (\sqrt{2} + \sin(\theta_o))^2 \quad (7)$$

where θ_o is the critical angle defined in Figure 2.

III. Procedure

A. Parallel Plate

- 1) Set up the experiment as shown in Figure 3. Make sure the laser beam is parallel to the tabletop and along one of the lines of screw holes after the second mirror (m2). To ensure this, measure the height of the beam after the second steering (m2) mirror making sure that the beam enters the photodetector at this height.
- 2) The photodetector should be placed in a horizontal translation stage. The stage should translate perpendicular to the direction of the incoming laser beam.
- 3) Measure the size of the photodetector element. In some cases, there will be black tape covering the front of the photodetector to make the effective area smaller. You will need this measurement for the discussion questions.
- 4) Measure the thickness of the glass plate. You will need this measurement for the discussion questions.
- 5) Now place the glass sample on the rotation stage. To start the measurements, you need to determine the relative rotation of the rotation stage for which the incoming laser beam is perpendicular to the air/glass interface. To ensure the normal incidence, adjust the rotation of the sample until the small reflection from the front surface of the glass is retroreflected back upon the mirror M2.
- 6) Make sure that the detector is linear. To do this, use the knowledge you gained from Lab 7. Place neutral density filter(s) in front of the beam before it reflects from mirror M1. Temporarily place a 0.3 neutral density filter in front of the detector. If the detector is linear, the voltage reading on the lock-in be half of the value before inserting the 0.3 ND filter. Try different neutral density filters until you are certain that the detector responds linearly.
- 7) Find the position of the undeflected beam by adjusting the position of the detector with the translation stage and locate the position of the peak reading on the lock-in. Record the current position of the translation stage.
- 8) Record the deflection of the beam as a function of the angle of incidence. Make sure that you are recording the net deviation from the “undeflected” position, i.e. the position MINUS the position recorded in Part III.A.5. Obtain about 10 different data points between 0° and 80° .

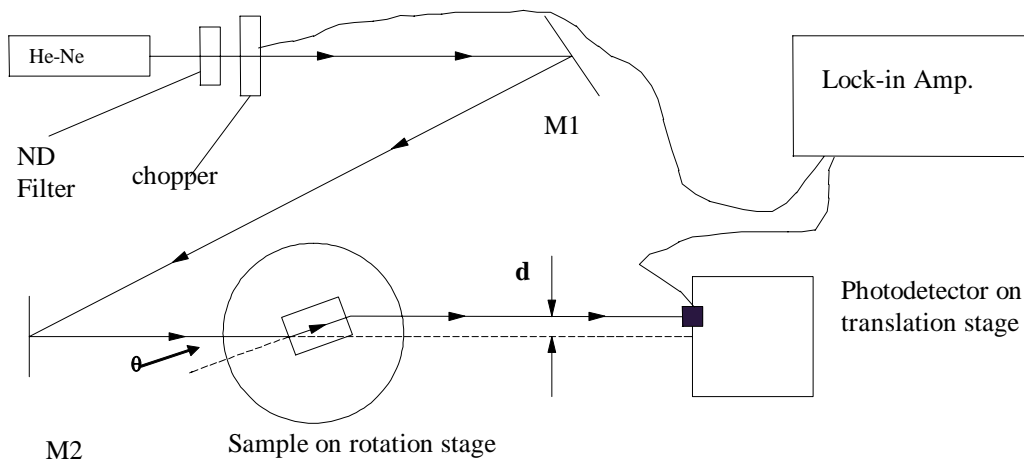


Figure 3: Experimental setup for determining deviation and index of refraction of light passing through a parallel plate of glass.

B. Prism

- 1) Leave everything in place except the piece of glass. Mount a right angle prism on the rotation stage as with the incoming laser beam oriented as illustrated in Figure 2.
- 2) Record the angle of the rotation stage for which an incoming laser beam is reflected from the first Air/Glass interface directed back on its incoming path. This will define the angle at which the incoming laser beam is perpendicular to the first interface. This corresponds to $\theta_o=0$ in Figure 2.
- 3) Adjust the angle of rotation of the stage so that the transmitted ray of Figure 2 just disappears. The NET rotation from the perpendicular (Part III.B.3) is the critical angle.

IV Discussion and Data Analysis

- 1) Using Equations (1) through (5), derive Equation (6), the measured deviation as a function of incident angle and refractive index of the glass. HINT: Divide Equation (3) by Equation (4) to eliminate L . Then use Equation (2) to eliminate α . Use Equation (5) to expand $\sin(\theta - \theta_r)$. Finally, use $\cos^2 A = 1 - \sin^2 A$ and Equation (1) to eliminate θ_r .
- 2) Using Matlab or a similar program, fit your experimental data to Eq. (6). For this fit, use your measured thickness of the plate for w . From your fit to the data, you will extract the value of n which gives the best fit to the data. When you plot your data in your report, plot the experimental data as individual symbols, with no lines connecting the symbols. Plot of the same graph your BEST FIT plot as a SOLID line.
- 3) From your analysis above, what is the index of refraction of the glass?
- 4) How does the physical size of the photo detector element compare with d ? How would your results change if the physical size of the photodetector element were larger than the maximum displacement d ?
- 5) Use the critical angle you measured for the prism and Equation (7) to calculate the index of refraction. Compare this with the value for crown glass.

INSTRUCTOR NOTES:

Equipment required:

Glass plate
45 degree prism
He-Ne or Diode Laser
Chopper
Mirrors and mounts (2)
ND filter set and mount
Horizontal rotation stage
Translation stage with micrometer
Photodetector and mount
Lock-in Amplifier
BNC coaxial Cables