Reflection and Refraction
Snell's Law and the Index of Refraction

(Only a short report is required for this lab.)

Background
For many purposes we can consider light to travel in straight lines called rays. Geometric optics is the study of how light rays behave at the boundary between two different materials, and of how light rays form images.

Snell's law describes the transition of a light ray from a medium with index of refraction \( n_1 \) to a medium of index of refraction \( n_2 \). The angle of incidence and the angle of refraction are related by Snell's Law:

\[
\sin \theta_1 = \frac{n_2}{n_1} \sin \theta_2
\]

The angle of reflection is equal to the angle of incidence.

A more dense material usually has a larger refractive index than a less dense material. The refractive index of air is about 1.0003. For the purposes of this lab we can use \( n_{\text{air}} = 1 \).

A. The Index Of Refraction Of Water
The laws of reflection and refraction can be checked using a laser beam incident on the surface of water in a tank. The path of the laser beam in the water is made visible by the scattering of light from chalk dust in the water. Similarly, smoke from burning incense in the air above the water renders the light path in air visible. Use the protractor fixed to the side of the tank to measure the angles. There are 4 setups of this apparatus, to be shared. Make a few measurements by changing the angle of incidence of the laser. Please be careful that you stay out of the path of the laser beam and its reflections, and be careful that the laser doesn’t fall while you are making adjustments (it is quite heavy).

Are your measurements consistent with the law of reflection? Use your measurements to calculate the index of refraction of the water.

B. Total Internal Reflection
According to Snell's Law, the angle of refraction is given by \( \sin \theta_2 = \frac{n_1}{n_2} \sin \theta_1 \). If the ray is initially traveling in the more dense of the two media, the one with the larger refractive index, \( \sin \theta_2 \) will be larger than \( \sin \theta_1 \), and the calculated value of \( \sin \theta_2 \) could exceed unity. This is non-physical, and there is a critical angle of incidence, beyond which there is no refracted ray. This is
known as Total Internal Reflection. The critical angle is found from Snell's Law by setting $\sin \theta_2$ to unity, in which case $\sin \theta_1 = \sin \theta_c = n_2/n_1$. If the second medium is air, $\sin \theta_c = 1/n_1$.

We have a tank of water, with chalk dust and incense to observe the rays. The adjustable mirror on the bottom of the tank allows the angle of incidence in the water to be adjusted until Total Internal Reflection is observed. Vary the angle of incidence until the refracted ray just vanishes. Measure the critical angle, calculate the refractive index of water, and compare with Part A.

### C. Index of Refraction of Glass

In this part of the experiment you will test Snell's Law and measure the refractive index of a glass plate. Place the glass plate near the upper left corner of a sheet of paper. Outline the plate with a sharp pencil.

Insert a pin at point B. Insert another pin at point C, defining your line of sight. Do this such that A (the corner of the glass plate, as seen through the plate), B and C appear to be in a straight line. Line AO is the incident ray, and line OBC is the refracted ray. Repeat this with several other rays. Measure $\theta_1$ and $\theta_2$ for each.

Choose points B and C such that the distance BC is large, and OB is small. (Why?) Cover as large a range of angles as possible.

- Make a table of $\theta_1$, $\theta_2$, $\sin \theta_1$, $\sin \theta_2$, and $\sin \theta_2/\sin \theta_1$.
- Make a graph of $\sin \theta_1$ vs $\sin \theta_2$, and draw a straight line through it.
- Calculate the slope of the line.
- Determine the index of refraction of the glass from the slope of the line on your graph.

### D. Effect of Plate of Glass with Parallel Edges on Path of Light

Here we investigate the overall effect of a plate of glass with parallel edges on the path of light. Set up two pins A and B, then look through the plate and insert pins C and D such that ABCD all appear to lie in a straight line when viewed through the glass. Find the angle that AB makes with respect to the edge of the glass, and do the same for CD. Move pin A a few times so that the line AB makes a different angle with respect to the glass, and find the new angles for AB and CD. What is the relationship between the angles that AB and CD make with respect to the glass? Is this a property that you would expect to find in a lens? What does the glass do to the path of light (i.e. how does the presence of the glass change the position and angle of pins C and D compared to the case that there is no glass)?