Experiment #1: Refraction, Reflection, and Ray Tracing

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1 Purpose

In the first part of this lab, you will verify Snell's law of refraction and use it to measure the index of refraction of a glass block. In the second part of the lab, you will be verifying the law of reflection. In both cases you will be using ray tracing.

2 Safety

NEVER LOOK DIRECTLY INTO A LASER BEAM!!!

1. One of the easiest ways to prevent this from accidently occuring is to keep your head up (don't bend over).

2. To find a laser beam use a pin, your finger, a piece of white paper, or have it pass through a weakly scattering medium.

3. Use the pieces of gray PCV pipe as beamstops.

4. Use the curtains.

3 Preparation/General Instructions

To prepare for this lab, you should read the corresponding section in your textbook (pages 16-25 in Pedrotti[3]). Remember, the results from your experiment should not be manipulated so as to fit in with the theory. If your results contradict Snell's law, or the law of reflection, do not "adjust" them to make them fit. Instead, try to explain why you think your results are/are not reliable.

4 Procedure/Analysis

4.1 Ray tracing in ambient light

1. Place the glass block on a piece of white paper on top of the cork board as in Figure 1. Sketch the outline of the block.

2. To make a measurement position two pins on one side of the block $\sim$ 5 to 8 cm apart to define the direction of a light ray entering the plate. Look at the pins through the glass, edge on, as shown in Figure 2. Place two more pins on your side so that all four pins appear to be in a straight line *when sighted through the glass.* I suggest angles θ_1 between 20 and 60º, making 5 sets of measurements.
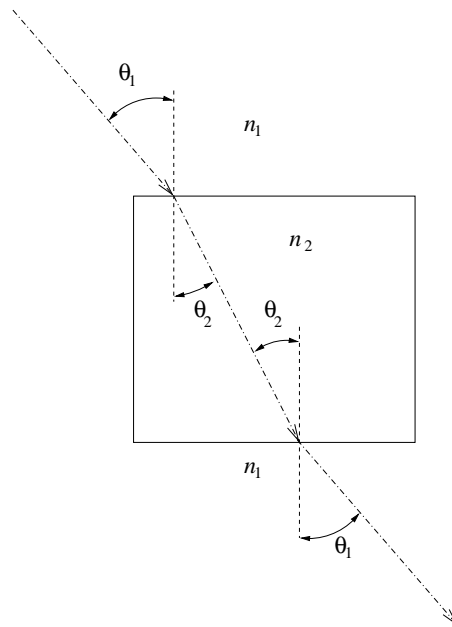
Figure 1: The ray diagram used to measure the index of refraction of the glass block. Use pins in medium 1 (air) to define the path of ambient light beams or the laser beam.

3. Remove the block and the pins. Using a ruler draw the implied paths of the light rays inside and outside the glass. You will be using a protractor with a radius of roughly 6 cm so make sure your rays are extended at least that much to measure angles. If you want to make direct measurements then you will also need to draw normals to the surfaces at the entrance/exit points. (The protractors don't seems to have "zero" as a number! Just offset your measurements by some convenient value, say, 10°. Don't guess at the location of "zero".)

4. Measure the angles of incidence and refraction, labeled as θ_1 and θ_2 in the figure, at *both* air-glass interfaces. Record the values on the paper and in your lab book in a neat table.

5. Make a plot of $\sin \theta_2$ versus $\sin \theta_1$. Include $(0,0)$. A straight line with zero intercept would support Snell's law. The reciprocal of the slope would be the index of refraction. Don't draw the line yet but with a ruler satisfy yourself that Snell's Law is verified.

4.2 Ray tracing using a laser beam

You will now reproduce the measurements above, but this time using a laser beam.

1. With a new piece of paper trace the outline of the glass block.

2. Turn on the laser. You might need to use a riser to bring the corkboard and glass block high enough for the standard laser mounts. As in Fig. 1 use the laser as your incoming ray. The exiting laser beam (i.e., out of the block) is the outgoing ray. When you have a pin in the path of the laser you can see the scattered laser light. Push the pin into the corkboard to trace out the incoming laser beam and outgoing beams. Assuming that you can keep track of the pinholes it is probably best to just use one pin and work your way along the path.

3. Try and use incident angles between $20^o$and 50°. Rather than stepping through, measure the extreme angles first.
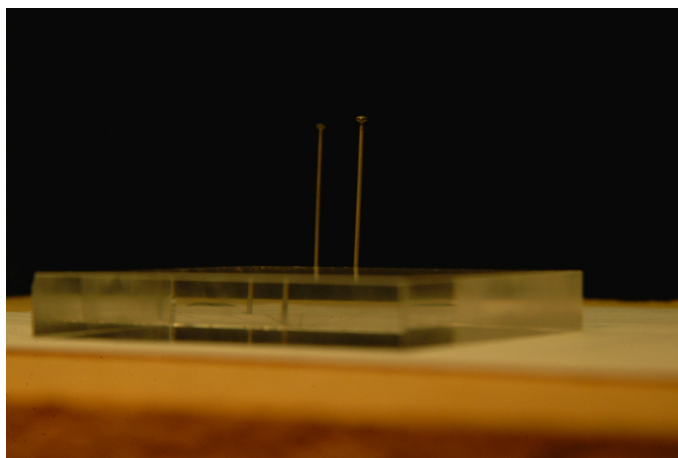
Figure 2: The apparent position of the pins is shifted to the left when looking through the glass block. This photo illustrates the shifting; in order to line everything up for ray tracing your viewing angle should move to the right.

4. You should measure the incident and refracted angles for at least 5 cases.

5. Put these points on the same graph as you used before. Are they consistent? If not try and figure out what might have gone wrong and possibly re-measure. Once you are satisfied find the slope that best fits both sets of data as well as the max and min slopes. Now determine the index of refraction and the uncertainties.

4.3 Critical angle and total internal reflection

If light is propagating from medium 2 to medium 1 where $n_2 > n_1$ Snell's law no longer has solutions for $\theta_2 > \theta_c$ where θ_c is the *critical angle* given by

$$\theta_c = \text{Sin}^{-1}\left(\frac{n_1}{n_2}\right) \tag{1}$$

If medium 1 is air then $\theta_c = \text{Sin}^{-1}(n_2^{-1})$. If the incident θ_2 exceeds θ_c then there is no transmitted beam and the beam is *totally internally reflected*[1]

1. Use the laser beam to provide an incident ray normal to the circumference of a semi-circular glass block as in Figure 3. You may be able to see the beam path by the weak scattering from inside the block.

2. Find the reflected and transmitted rays after they have exited the block.

3. Increase θ_{2i} and you should find that θ_{1t} increases quickly up to 90º until the scattered beam vanishes. Do your best to find the critical angle and make an estimate of the uncertainty. Now calculate n_2 and the uncertainty.

Why use a semi-circular block of glass, and not the block of glass from the previous experiments?

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[1]This can be explained from Maxwell's and the resulting Fresnel equations; Snell's Law doesn't work beyond θ_c.
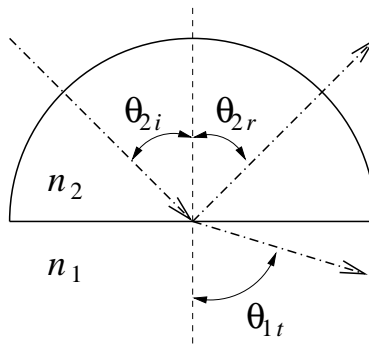
Figure 3: The ray diagram used to measure critical angle. θ_{2i} and θ_{2r} are the angles of incidence and reflection in medium 2 (the semi-circular glass block). θ_{1t} is angle of the transmitted beam in medium 1. Provided that the incident and reflected beams are normal to the circumference they should be undeflected.

4.4   Law of reflection with a mirror

1. Draw a straight line on a piece of paper and place a mirror on it.

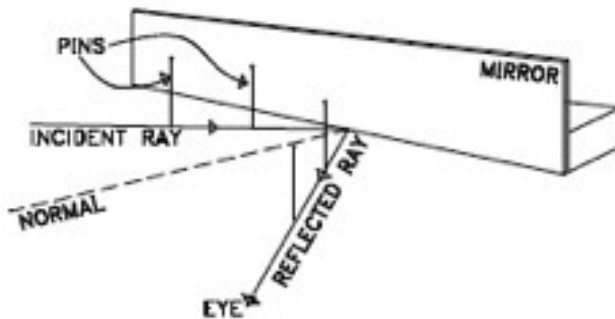2. Specify an incoming ray by placing two pins in front of the mirror. See Figure 4.

Figure 4: Verifying the law of reflection by ray tracing.

3. Find the reflected ray by looking into the mirror and moving your head until the images of the two pins appear exactly in-line.

4. Place two more pins between your eye and the mirror so they are lined up with the other two pins. This specifies the reflected ray.

5. Remove the mirror and the pins from the paper and draw the incoming and reflected ray using the pinholes in the paper.

6. Do the two rays intersect at the reflecting edge of the mirror?

7. Draw the normal to the mirror through the intersection vertex of the two rays.

8. Measure the incident and reflected angles relative to the normal.

9. Estimate a reasonable uncertainty for these angles, considering the technique used to construct and measure them.

10. Are the two angles equal within uncertainty?

11. What are the main errors in performing this experiment?

4.5   Law of reflection with a water tank.

A very direct way of verifying the law of reflection is to use the laser.

1. Using a water filled Plexiglas tank and laser beam as in Figure 5 observe that $\theta_i = \theta_r$. You can put the protractor under the water tank.
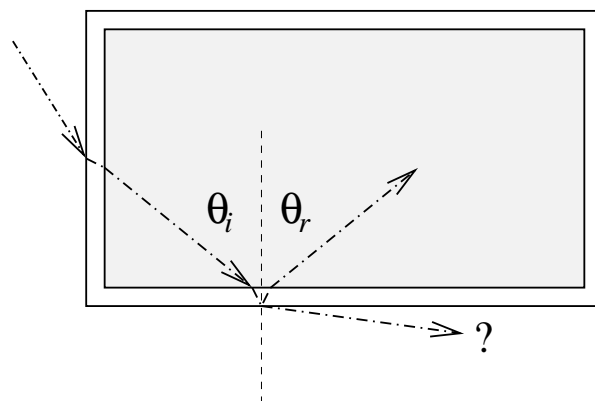
Figure 5: View from above of laser beam and watertank. A few drops of milk in the water makes it look really neat!

2. There is some ambiguity in these angles. Explain.

3. Make a measurement of the critical angle. Which media are involved?