Biennial Conference on Chemical Education
Demo Grand Prix Symposium

Using a liquid prism to demonstrate index of refraction

Abstract: The use of two parallel lasers shined onto a plastic prism filled with liquid media having varying indexes of refraction, which effectively demonstrates how the beam paths are altered by the different media. The use of different lasers at different wavelengths can also demonstrate the wavelength dependence of index of refraction. By making simple measurements the index of refraction for any media can be calculated.

Chemical Concepts: The concept of the index of refraction can be a difficult one to illustrate quantitatively. Students have seen light bending due to refraction in everyday life, but they probably have not experimentally calculated a refractive index. Within the context of general education or high school courses, this demonstration can be a good introduction to first visualizing and then calculating the bending of light due to changes in refractive indices. Finally, different wavelength lasers can illustrate how the index of refraction within a medium is wavelength dependant.

Addressing the Concepts: The demonstration described below illustrates the index of refraction both qualitatively and quantitatively. The degree to which the different properties are to be addressed and calculated is up to the instructor. The experiment set-up with two parallel lasers illuminating media with different refractive indices permits visual and qualitative insight into refraction. From measurements of the laser bending, the exact index of refraction of the different media can be calculated. Students can compare a calculated value to literature values they look up.

Preparing the Demonstration:
Materials needed: Two low-powered lasers (i.e. diode, or HeNe) a lab jack for supporting the lasers, a prism shaped container (available from Edmund Scientific:#3038421), powdered milk, non-water soluble liquid with high index of refraction (glycerol, linseed oil, etc.), chalk dust, white cardboard for a screen, rulers for making measurements.

Set-up: A day or two prior to the demonstration, prepare the liquid prism. The total volume of the prism from Edmund Scientific is approximately 670 mL. For the demonstration, the prism should be one-third filled with a high index of refraction medium (glycerol) and one-third filled with water. The final portion remains empty.

Begin by mixing a small amount of chalk dust (about 1 teaspoon) with 220 mL of glycerol. Pour the suspension into the prism. Then mix a small amount of powered milk with 220 mL of water. Carefully pour the powered milk solution into the prism, trying to make a layer on top of the denser glycerol layer. Some mixing may occur, but if allowed to settle for a day or two, distinct layers will form (see Figure 1). Note: The addition of the

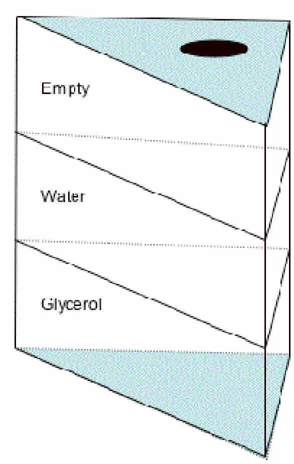

Figure 1. Solution layers in the liquid prism.

powered milk and chalk dust is for enhanced visibility of the laser beams that will be used in the demonstration.

On top of a lab jack, mount two lasers so their beams are displaced vertically by about 2 inches and parallel to each other. Verify correct laser placement by shining the beams onto a cardboard screen with a straight vertical line (see Figure 2).

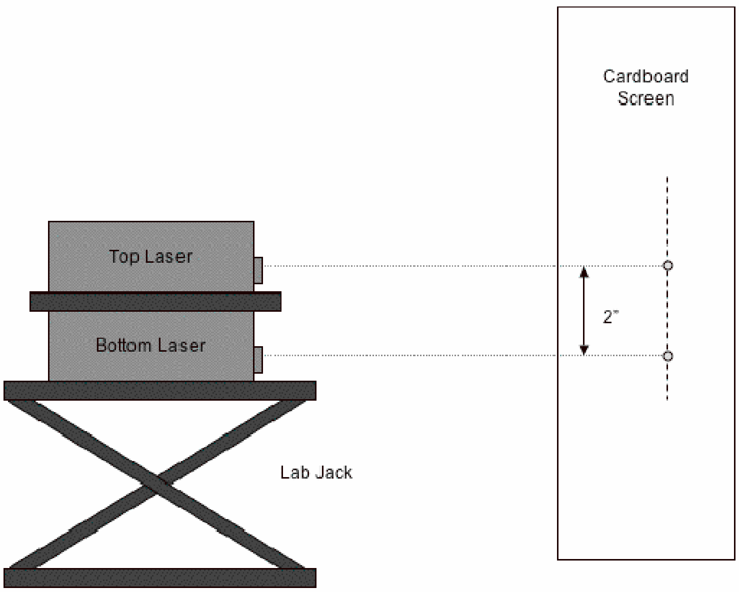

Figure 2. Checking the alignment of the stacked lasers.

The lab jack should be raised so the height of the top laser shines through the empty portion of the prism, and the lower laser shines through the water. Gently push the prism into the path of the laser beam. The refraction of the lower beam should be readily visible in the water with powdered milk. A spot can be drawn on the screen to quantify the amount of displacement of the laser beam compared to the other laser going through the empty portion.

Next, lower the lab jack slowly. Depending on the height of the lasers, you may lower to a region where both lasers are going through the water solution (see Figure 3). The students can look closely at the prism to see how much refraction is occurring from the first air/water interface, and how the beam path travels when reaching the second interface.

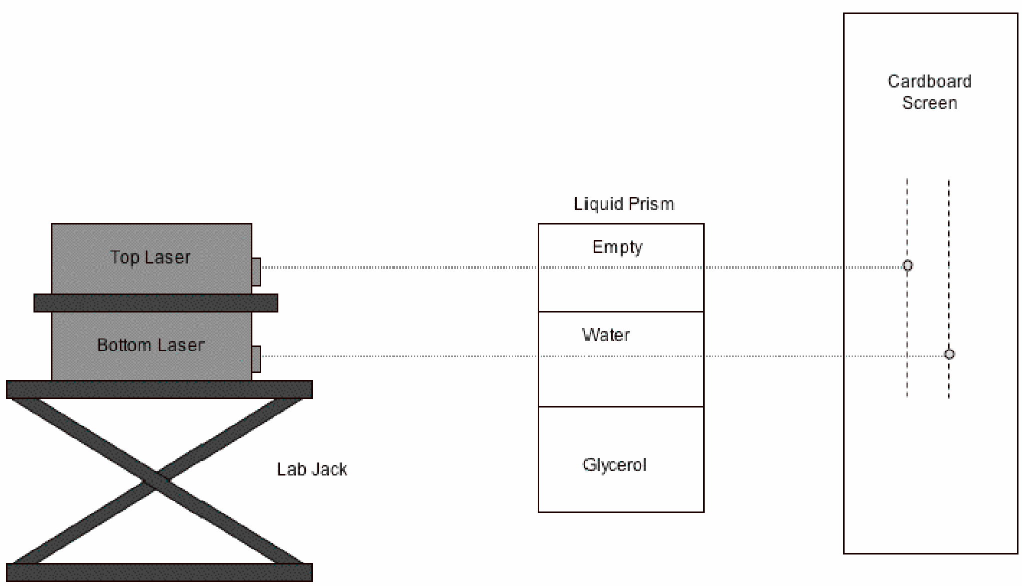

Figure 3: Demonstrating refraction by the displacement of parallel laser beams from a liquid prism.

Lower the jack even further so now the lower laser travels through the glycerol layer, and the upper one still shines through the aqueous layer. A second mark on the screen can be made to indicate the laser beam displacement caused by the glycerol layer. The students can inspect the prism to see the difference in the beam paths in the two layers. By sliding the prism perpendicularly to the lasers, the path length of the laser light in the prism can be changed. One can demonstrate that this change in path length has little effect on the amount of beam displacement seen on the screen.

<u>Measurements</u>: The students can calculate the index of refraction of water and glycerol by making a few simple measurements and using a few approximations. However, because the entire geometry of the system is known, no approximations are needed, and the index of refraction can be calculated exactly. This is a more involved calculation, and will not be presented here. Detailed below is the simplified calculation with the required approximations.

With approximations, the only measurements needed are the amount the laser beam is displaced through the medium compared to the beam traveling through the empty portion of the prism, and the distance between the laser an the screen on which the amount of deflection is recorded. This displacement is simply the distances between the lines drawn on the cardboard screen.

To solve for the index of refraction, the relationship between the angle of incidence and the angle of refraction is used. Here we will focus only on the change of the index of refraction that comes from exiting the prism, making the approximation that the distance the beams travel in the prism is very small compared to the distance traveled after the prism. The geometry of the second interface reduces to:

$$refractive\ index = \frac{Sin\theta(incident)}{Sin\phi(refraction)} \qquad \text{(Equation 1)}$$

Now take the ratio of two refractive indices:

$$\frac{refractive\ index1}{refractive\ index2} = \frac{\frac{Sin\theta_1}{Sin\phi_1}}{\frac{Sin\theta_2}{Sin\phi_2}} \qquad \text{(Equation 2)}$$

where θ is the angle of incidence, and ϕ is the angle of refraction. If we are comparing the angles of the top laser to that of the lower laser, we assume that angles of incidence are nearly equal, as the beams are parallel. The equation reduces to:

$$\frac{refractive\ index1}{refractive\ index2} = \frac{Sin\phi_2}{Sin\phi_1} \qquad \text{(Equation 3)}$$

Using geometry it is possible to solve for sin ϕ_1 and sin ϕ_2 (see figure 4).

$$sin\ \phi_1 = \frac{x}{\sqrt{x^2+d^2}} \text{ and } sin\ \phi_2 = \frac{x+\Delta x}{\sqrt{(x+\Delta x)^2+d^2}} \qquad \text{(Equation 4,5)}$$

Where *d* is the distance between the prism and the screen, *x* is the amount of displacement seen in the first measurement (i.e. aqueous layer), and Δ*x* is the displacement of the second measurement relative to the first.

The final equation becomes:

$$\frac{refractive\ index1}{refractive\ index2} = \frac{x + \Delta x}{\sqrt{(x + \Delta x)^2 + d}} \cdot \frac{\sqrt{x^2 + d^2}}{x} \qquad \text{(Equation 6)}$$

Thus if the refractive index of one medium is known, and the amount of displacement from the incident beam caused by each medium is measured, it is possible to calculate the refractive index of the second medium.

Safety & Disposal: The use of low powered lasers (Class II) minimizes any optical damage from laser radiation. Students should be reminded of basic laser safety, and instructed not to stare at an incident laser beam. All chemicals and solvents used in this demo are non-toxic and can be safely disposed down the drain.

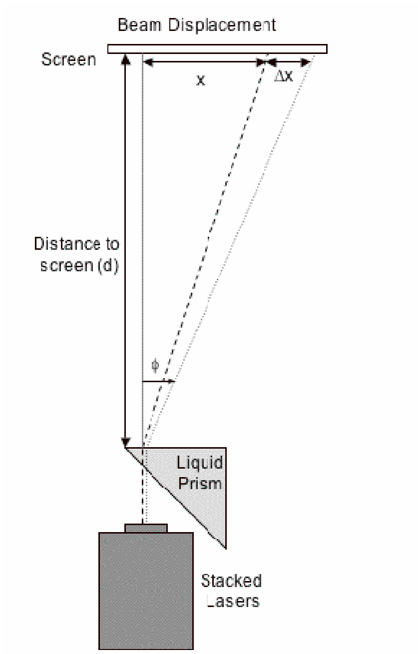

Figure 4. Top view of the refraction demo, showing the geometry of the set-up and the measurements.

Use of the demonstration: This demonstration was prepared for a general education chemistry course. This course happened to have a theme of art in chemistry, and thus the principle of refractive index was a course topic. Ideally, the instructor would present the concept of refractive index and the bending of light due to the change in the speed of light in different media. Then the equations involving in calculating the refractive index (Equation 1) would be presented on the board. The demonstration would be used to illustrate experimentally the principles of how light changes path in different media. If the course were being taught at a level where quantitative calculations would be insightful, experimental measurements can be made and the derivation of the approximate formula can be shown. Or, if time permits, the entire geometry of the system can be carefully recorded, and the exact index of refraction can be measured.