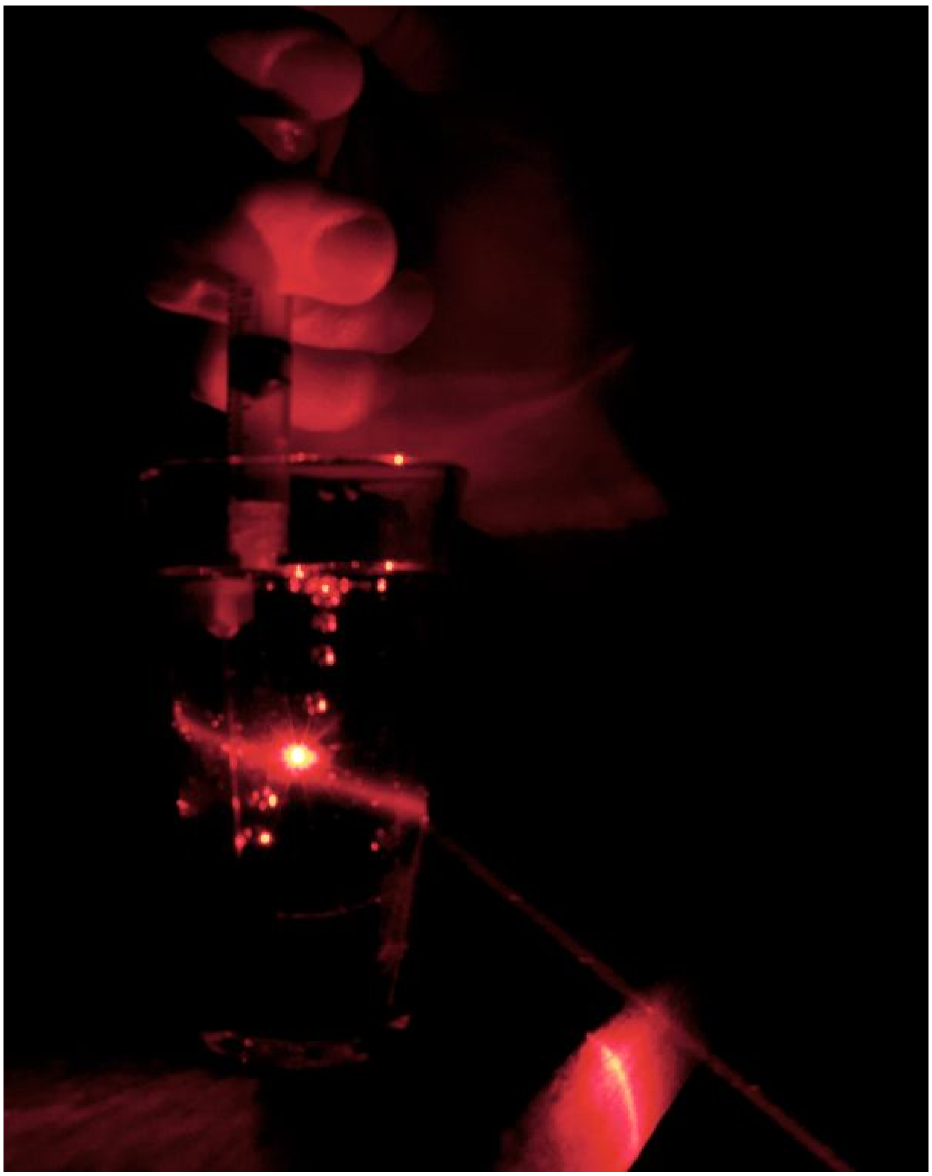
Team Image 3:

Laser, Syrup and Bubbles

Hamed Yazdi

Team members: Samuel Sommers, Joshua Hecht, Ernesto Grossman, Mitchell Stubbs

MCEN 5151: Flow Visualization



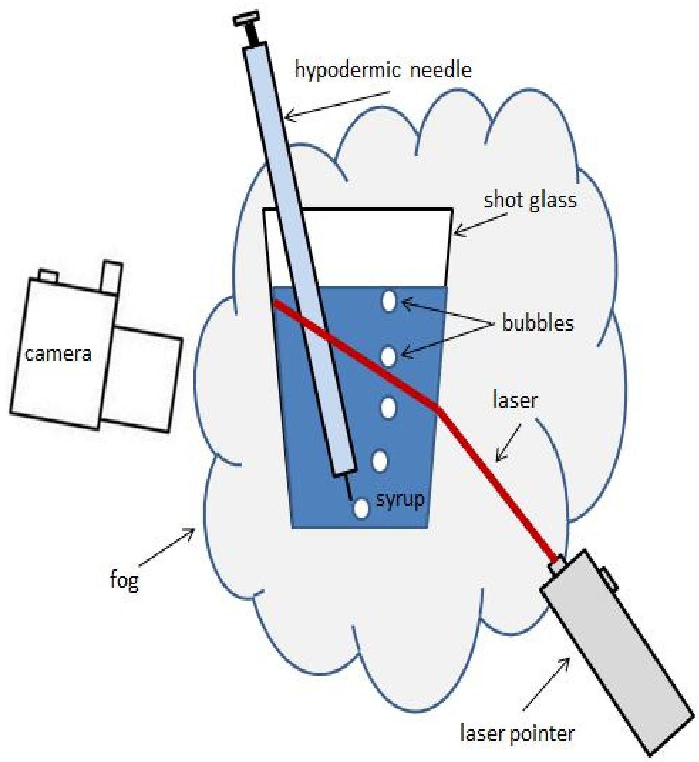
Date of image: 4/23/12

Purpose:

The purpose of this image is to capture the physics of the diffraction of light as a laser passes through a different medium from an angle. The two mediums that the laser passes through in this image are air and Kroger syrup. Bubbles were created in the syrup using a hypodermic needle for an additional aesthetic effect.

Apparatus:

The equipment used for this setup included a shot glass, syrup, a hypodermic needle full of air, a red laser, and a fog machine. The laser pointer was held about 8 inches from the shot glass at an angle of approximately 40 degrees from the horizontal (table). This image was taken in a dark room and there was no lighting other than that provided by the laser. The laser is a model rlf18130, class IIIb laser.



Once the fog machine warmed up and we had an ample amount of fog in the room, I held the laser in an appropriate distance and angle from the shot glass. I then submerged the hypodermic needle into the syrup and pushed out air into the syrup, which formed small bubbles.

The camera was held about 10 inches away from the shot glass. A burst of about 10 images was taken as the bubbles rose.

Flow Phenomena Observed:

The essential phenomenon observed in my image is the refraction of light as it passes two different mediums. Note that this report will not be focusing on the bubble, as they were added only for an artistic effect. The following image is a representation of refraction and the important variables used to analyze it:

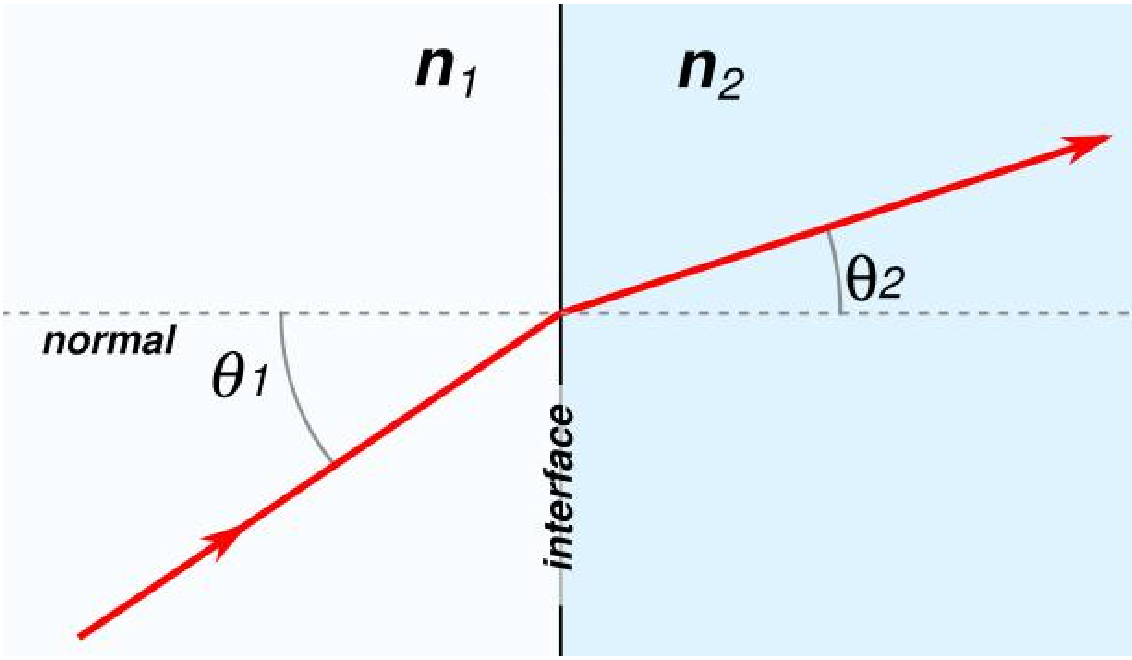


Figure 1: Visual Representation of Light Refraction
Image taken from http://phelafel.technion.ac.il/~lk/

http://www.physicsclassroom.com/class/refrn/u14l1e.cfm

Refraction is the bending of the path of a light wave as it passes across the boundary separating two media.[1] It is caused by a change in speed that a wave experiences as it passes through a different medium, and behaves differently depending on the optical density of the material. When light speeds up as it crosses the boundary (passes a less dense medium), it refracts away from the normal, and when it slows down (passes through a more dense medium, as in my image), it refracts toward the normal. It is actually possible to have a negative index of refraction, which will not be discussed in this report.[2]

The index of refraction is a basic property of optical materials and is a measure of how much light slows down when it enters a medium.[3] The index of refraction of a substance is equal to the ratio of the velocity of light in a vacuum to its speed in that substance. Its value determines the extent to which light is refracted when entering or leaving the substance.[4] In other words,

$$n = \frac{c_{vac}}{v_{mat}} \qquad \text{eq. (1)}$$

Where *n* is the index of refraction, c is the speed of light through a vacuum (3 E 8 m/s), and v is the velocity of light through a particular material.[5] Notice that a slower velocity of light corresponds to a higher index of refraction. Also note that a vacuum has an index of refraction of 1.

---

[1] http://www.physicsclassroom.com/class/refrn/u14l2b.cfm
[2] M. C. K. Wiltshire, "Bending Light the Wrong Way," Science, Vol. 292 no. 5514, 2001, 60
[3] Ibid.
[4] http://www.thefreedictionary.com/index+of+refraction
[5] E. Hecht: *Physics: Calculus (2nd ed.)* Brooks/Cole 2000

The index of refraction is related to the electrical and magnetic properties of the atoms and molecules that make up a material.[6] Basically, as a beam of light enters a transparent material, it interacts with the atoms that make up the material. Atoms bond together and form molecules. Every medium is made up of molecules. The optical density of a material is determined based on the number of molecules that exist in a finite volume of a medium. These molecules are usually quite close together and construct a uniform substance. As wavelets of light from the laser beam pass through this substance, both constructive and destructive interference will occur.

All the molecules of a medium are composed of atoms that contain electrons. The specific index of refraction of a material depends on the arrangement of the atoms as well as its electron distribution. Because light rays are electromagnetic, the electrons oscillate as they are illuminated by the laser beam. If a light wave moves through a vacuum, it does not interfere with any other electromagnetic waves, and thus moves at a speed of c, which is 3.00E8 m/s. However, the light waves that do encounter any kind of matter transmit energy. This transmission set the electrons in a vibrational motion. The movement of electrons generates a field, which causes the transmitted wave to change. The result is that the charges in the medium will start to move at the same frequency as the vibration of the electrons in the electromagnetic field. In other words, they resonate at the same frequency. Consequently, the charges radiate their own electromagnetic wave at the same frequency, but with a phase delay. This wave is a wave with the same frequency but shorter wavelength than the original one, which causes the wave's phase speed to slow down. [7] This can be clearly seen in the following formula:

$$v = \lambda f \qquad \text{eq. (2)}$$

Where *v* is velocity, λ is the wavelength, and *f* is the frequency.

On a microscopic level, the photons travel through the material, in between the atoms, until they encounter another particle within the material, which repeats the process and produces a new wave. This process results in a time delay for the photons to travel between the void spaces between atoms and causes a net decrease in the speed of light as it passes through the material.[8] As mentioned before, the time delay depends on the optical density of the material through which the light passes.

One value that can be calculated for analyzing my image is the index of refraction, *n*, for the syrup. This can be done using Snell's law, which is defined as:

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \qquad \text{eq. (3)}$$

Where n_1 is the index of refraction of the first material through which the light passes, n_2 is the index of refraction of the second material, θ_1 is the incident angle (with respect to the normal), and $\theta_2$is the

[6] http://www.utc.edu/Faculty/Tatiana-Allen/labbook282lab1a.html
[7] http://en.wikipedia.org/wiki/Refractive_index
[8] http://laser.physics.sunysb.edu/~jennifer/reference/index/indexrefraction.html

angle of refraction.[9] Please refer to figure 1 for a visual representation of the variables used in Snell's law.

Using a protractor, the incident angle is 50 below the horizontal. After the laser beam enters the syrup, its angle of refraction becomes 23 degrees above the horizontal. The first medium through which the laser beam passes is air, which has an index of refraction of approximately 1. Thus, we can calculate the index of refraction of the syrup by using eq. (1):

$$n_a \sin(\theta_a) = n_s \sin(\theta_s) \rightarrow n_s = \frac{n_a \sin(\theta_a)}{\sin(\theta_s)} = \frac{1 \times \sin(50)}{\sin(23)} \rightarrow n_s = 1.96$$

Based on my calculations, the index of refraction of syrup is 1.96. Unfortunately, I was not able to find an accepted value for the index of refraction of syrup to compare my result to.

<u>Possible Sources of Error:</u>

Although I do not have a value to compare my result to, I can think of a few items that may contribute to errors for my analysis. First of all, the shot glass has a round surface that the laser beam enters before it refracts. In my analysis, I considered that the laser beam transitions from air to syrup directly, and did not consider the effect of the material or shape of the shot glass. Taking those in consideration may have changed my results a bit. Furthermore, I did not consider the effects of the bubbles on the refraction of the laser beam. The laser beam in my image did pass through a bubble, which technically, should be treated as a different medium (air), but I neglected that in my analysis. Other than those two issues, I am confident that my analysis is quite accurate because the laser beam is very visible and the angles created are well-defined and easy to measure.

<u>Imaging Techniques:</u>

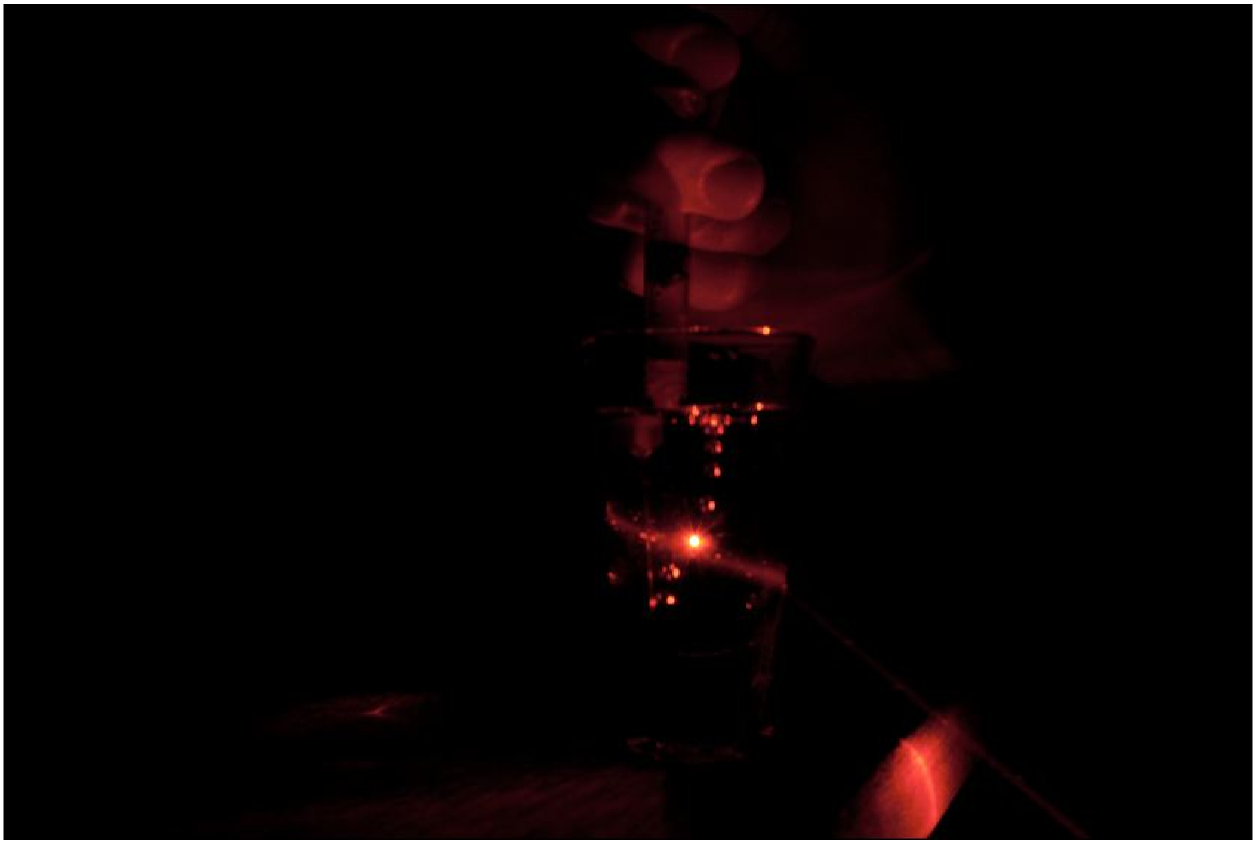
For this image, I used very simple photographing techniques. The lighting was supplied only by the laser, as the image was taken in a dark room. It was taken with a Canon EOS Digital Rebel XT. The photo was taken on the manual program with an 18-135 mm eddy lens. The shutter speed was 1/6 s and the ISO was 200. The ISO was low because there wasn't much movement in the image other than the bubbles which weren't moving too fast. The low shutter speed was used in order to make sure there was enough light from the laser, given the low ISO. The focal length and aperture were 18 mm and f/8, respectively. The image was originally 3456 pixels wide and 2304 pixels high. After cropping, the final image was 607 x 765 pixels.

For the final image, I made some simple manipulations using Photoshop. The first thing I did was crop the image to contain the part of the flow I wanted the user to focus on; namely, the laser diffraction on the shot glass and bubbles. After that, I made a few modifications to make the image more visible, as it was quite dark originally. To do so, I first used the auto color and auto tone options. After that, I used the curves option to bring out the parts of the image that weren't completely dark. Finally, I increased

---

[9] E. Hecht: *Physics: Calculus (2nd ed.)* Brooks/Cole 2000

the brightness and contrast a bit. The following is the original image before any Photoshop manipulations:



Analysis and Conclusions:

As mentioned earlier, the main intent of this image was to show the phenomenon of light refraction. I believe that this image clearly communicates that with the vivid laser. The fog really helps one see the laser beam, and the Photoshop techniques also amplify its effect. Although I am generally satisfied with the image, the one thing I would like to have done differently is to use a different medium other than syrup to slow down the movement of the bubbles, which would have allowed me to use a lower shutter speed to allow more light for the original image, or use the same shutter speed with less blur in the bubbles. Also, it would have been nice to use a medium that had a well-known value for its index of refraction for me to compare my results to.

I wonder what effects would show if there were multiple layers of different materials for the light beam to go through. It would be interesting to analyze that, and perhaps even more interesting to create a negative index of refraction. The most interesting part of this project to me was understanding the science behind the phenomenon of light refraction. Although refraction is not something new to me, this project really made me think a lot about the details of what causes it to happen.