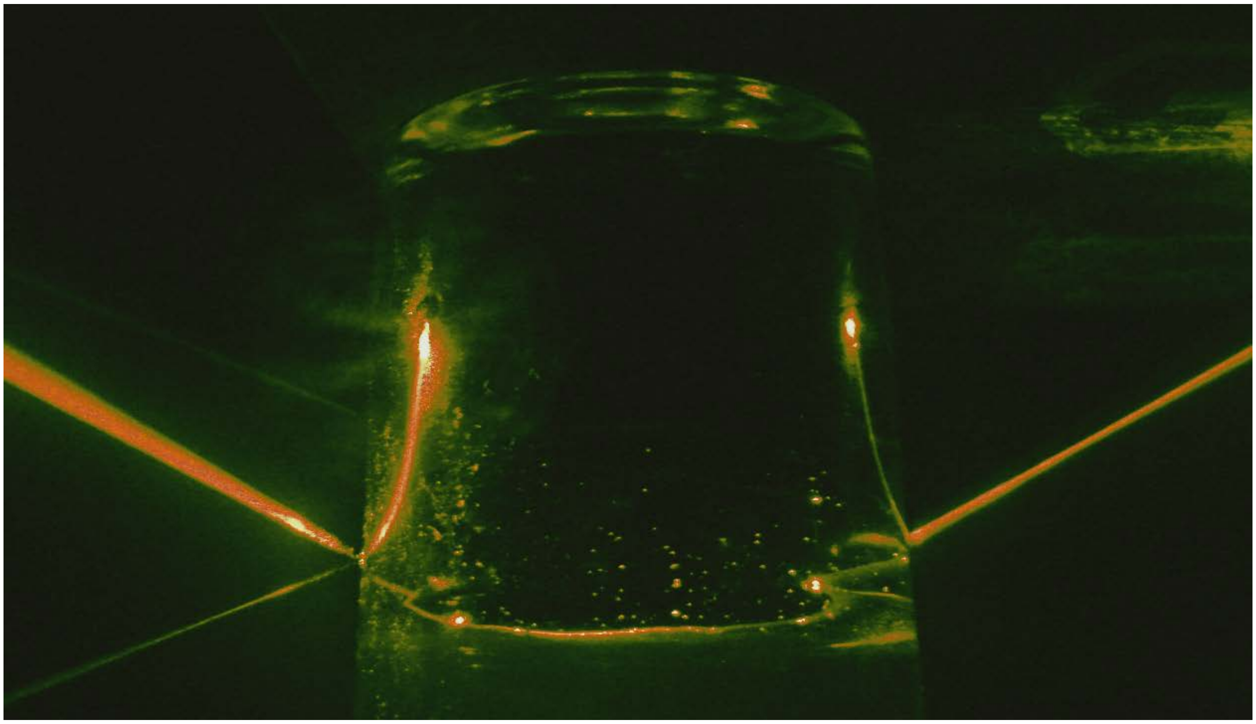
Team Image Report 3

Joshua Hecht

Submitted 5/1/12

MCEN 5151

Flow Visualization



The Flow Visualization class at the University of Colorado is a course where students learn about flow dynamics and photography techniques by capturing photos of fluid phenomenon. The sixth assignment in the class involved a group of four to five students working in a team to capture a complex dynamic flow by working together. For this assignment, the photographer -- Joshua Hecht-- was placed on a team with Mitch Stubbs, Hamed Yazdi, Ernesto Grossman, and Sam Sommers.

The team obtained a very high power red laser pointer, and used it to capture the image above. The laser pointer was used with various fluid interfaces to see how the liquid would alter the path of the laser beam. A shot glass was used to stack up liquids of different densities for the laser to pass through. Corn syrup was at the bottom of the glass, topped with kitchen soap as the next layer, followed by water, and finally vegetable oil. Usually, as the laser passed through the different layers, the laser would refract to a different angle (more description below) due to the change in indices between layers. In this case however, the laser pointer was positioned so that the beam pointed between the water and soap layer upon entering the side of the glass, and the laser did not refract upwards as expected. Rather, the laser followed the contour of the two liquids so that it exited the other side of the shot glass at the same angle that it came in. This phenomenon was photographed, and presented for analysis.

The experimental apparatus was set up fairly simplistically. A clear, three centimeter tall shot glass was filled up with layers of liquid. First, a centimeter of clear corn syrup was put at the bottom of the glass. The corn syrup was then covered up by a centimeter of orange dish soap. Another centimeter of blue water was poured on top of the soap. Lastly, a centimeter of oil was placed on the top of the water. Due to the density difference of these different layers, the liquids did not mix, and remained in their layered form. The layers primarily involved in the dynamics, soap and water, have densities of 1.03 g/cm^3 and 1.00 g/cm^3, respectively.

The laser was attached to a tripod, which allowed the light source to be held steady at any desired angle. The laser was set up so that the beam lined up with the water/soap layer. The shot glass had to be set-up on top of a book to achieve the desired angle. The lights in the room were turned off for best visibility. A fog machine was used as well so that the laser could be seen as it passed through the air. Once the phenomenon started to occur, the camera was held approximately seven centimeters away from the shot glass, and a photograph was taken. The overall set up is shown below in Figure 1:

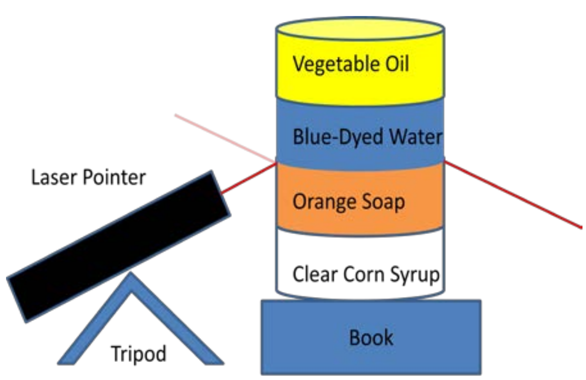


Figure 1: Experimental Test Set Up

The laser is visible through the air due to a fog machine being used at the time of the shot. The fog machine vapor has small particulates ejected into the atmosphere that are small enough so that the aerodynamic forces cancel out gravitational forces, allowing the fog to disperse out around the experiment (Khajehnajafi, 2011). The particulates are visible due to scattering of the laser as it hits the individual particles. When the light hits the particles floating around in the air, the light is diffused away in multiple directions, making the path of the laser visible (Bohren, 2007). The same is true of the visibility in the fluid. The soap and the water are both dyed, which act to scatter a bit of the light as the laser is passing through the two layers.

Along with the scattering through the fluid, as the laser pointer shines on the shot glass, a portion is reflected off the slide. The laser can also be seen entering the shot glass at the same angle that it comes out on the other side. The laser also highlights the interior glass portions of the shot glass in the soap region of liquid, and appears to stop as it reaches the corn syrup layer.

The dynamics occurring with the laser motion in this image have to do with optics. Optics physics is a function of the two layers' indices of reflection, and the angle at which the light hits the interface between the two. This can be visualized in Figure 2:

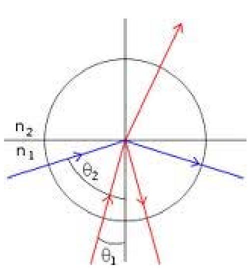


Figure 2: Light Interaction Between Two Interfaces (http://en.wikipedia.org/wiki/Total_internal_reflection)

In Figure 2, n1 and n2 are refractive indexes on the two different layers, with n1 being a higher index than n2. A higher refractive index will reduce the speed and the wavelength of the light passing through, and generally occurs due to a higher atmospheric density (Born, 1959). Θ1 and Θ2 are two different angles at which the light strikes the normal interface between the two layers.

The red line in Figure 2 shows a light beam hitting the interface between two layers, where a portion of the light reflects off the boundary between the two layers, and another portion of the light passes through. This is what occurs as the laser beam hits the side of the shot glass in the photograph. The laser passes from the air environment to the glass interface. A portion of the light is reflected off, and a portion is refracted through the glass.

The portion that is refracted through the glass approaches the boundary between the soap and the water layer. The light enters into the liquid with a very low incidence angle as it passes from the glass into the layered liquid, meaning the angle doesn't change much as it enters into the liquid. The light traveling through the liquid passes through a very slight amount of the soap layer, before hitting the bottom of the water layer at a very high incidence angle. With high incidence angles between two layers, the light may only reflect off the second layer, and will not refract at all. This occurs if the incidence angle is greater than the critical angle (Born, 1959).

As the light bounces off the water layer, it comes back down towards the soap layer at the same angle. This same angle is still higher than the critical angle, which means that the light again bounces up, and does not refract through the soap. This continual bouncing is defined as “total internal reflection” and occurs along the entire interface between the soap and the water (Axelrod, 1984). This phenomenon is essentially how fiber optic cables work.

As the light hits the other side of the shot glass, the laser is incoming at the same angle that it entered through the liquid in the first place. Therefore, as the light travels through the glass, and out into the air, the angle is the same as when it entered. The angle is flipped around 180 degrees however, due to the 180 degree curvature flip of the liquid as the surface tension of the shot glass pulled the sides of the liquid layers up. The total laser path and interface phenomenon is shown below in Figure 3:

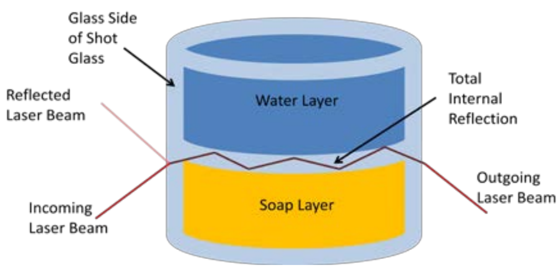


Figure 3: Refraction of Light Passing Through Two Mediums

In terms of visualization scale, the smallest viewable flow phenomenon was approximately ten pixels across. The entire field of view for the flow phenomenon in the photograph is 3072 pixels. Therefore, with the following equation, the scale of the resolution can be determined:

$$Resolution = \frac{Entire\ field\ of\ view}{Smallest\ viable\ flow}$$

$$Resolution = \frac{3072\ pixels}{10\ pixels} = 307.2$$

$$Resolution = 3.07e2$$

Therefore, since the resolution is in the hundreds, the scale of resolution is two decades, which is well resolved for the flow shown in the video.

When it came to capturing the flow itself, the visualization technique was fairly simple. The room was darkened entirely from outside light by shading the windows and turning off the lights. A fog machine was used to fill the surrounding air with smoke, allowing the laser to be seen as it passed through the air. The laser and shot glass were positioned according to Figure 1. The camera was aimed at the configuration from approximately 7 centimeters away, and was lined up with the layer between the water and the soap. The lighting source was from the laser pointer. As the laser traveled through the various mediums, scattering of light allowed the laser to be visualized by the camera.

The photographic technique involved setting a suitable ISO, focusing the lens for a narrow depth of field, and holding the camera still while taking the photo. A narrow depth of field was more or less required during the shot, since the shutter speed was fairly long in the dark environment. However, since the dynamics were primarily two dimensional, a wide depth of field was not needed to catch any extra phenomenon. The narrow depth of field still allowed for the different fluid layers to be clearly visualized along with the laser.

The picture was taken at an ISO of 320, a focal length of 6.3 millimeters, an f stop value of 2.8, and a shutter speed of 1/8 seconds. The image was captured in jpeg format with 7.1 megapixel resolution (the maximum resolution for the Sony Cybershot DSC-S700) with a width of 2304 pixels, and a length of 3072 pixels. The original image can be viewed in the Appendix. The picture was cropped down to 1244 pixels by 2618 pixels, and Gimp© was used for editing.

In editing, the image was flipped around 180 degrees, so that the laser was coming in from the upper right, rather than the lower left. The brightness was increased to show more details of the reflection, and to bring out some background details. The contrast was turned down to allow the details in the glass to enhance. Lastly, the colors were altered in great detail to turn the image from red-based, to green based. The highlights were altered to bring out a heavy amount of blue and yellow, while reducing the red highlights by a huge amount.

In the end, the photographic edits allowed for the shot glass to appear as a catfish face, with a full fin on the left side, and a half fin on the right side. The lights reflecting up the sides of the shot glass are highlighted as eyes, and the internally reflected laser looks like the smiling mouth of a fish. This was an artistic choice that adds a surreally familiar visual to the fluid dynamic phenomenon. I believe these edits make the image look more approachable, and at the same time, allows the phenomenon to be more clearly visualized.

Overall, the image reveals interesting dynamics of fluids’ affect on light. The fluids themselves were stable, and not interacting during the shot. However, the fluids did not have to react to demonstrate phenomenon that is allowed through proper placement of a light source. The soap and water layer created a pathway for the light to travel down, by having the light continuously bounce through the boundary layer in total internal reflection.

This is essentially the way fiber-optic cables work. I find it very exciting that I was able to catch this cutting edge technology with a couple of household items, and a light source. Learning how advanced technology works though the application of a household replica is a tremendous way to gain a fundamental understanding of the process. I am quite pleased that I was able to learn about the whole process.

In retrospect, I wish that the photo had come out with more detail. The image is well resolved, but the point and shoot camera quality cannot compare to the quality obtained from the high end cameras my partners used during the photography session. However, I really like what I was able to accomplish with the editing, and the overall picture was quite effective in carrying out a complicated fluid phenomenon in an approachable way. In the end, I feel that I learned quite a bit from this project, and I am pleased with the end result.

Bibliography:

Axelrod, D. Burghardt, T. Thompson, J. (1984). Total Internal Reflection Florescence. *Annual Review of Biophysics and Bioengineering*. 13, 274-268.

Bohren, C. Huffman, D. (2007). Absorption and Scattering of Light by Small Particles. WILEY-VCH Verlag GmbH & Co. KGaA.

Born, M. Wolf, E. (1959). Principles of Optics (7th ed.) Pergamon Press Ltd.

Khajehnajafi, S. Pourdarvish, R. Shah, H. (2011). Modeling dispersion and exposition of smoke generated from chemical fires. *Process Safety Progress*. 30, 2, 168-177.

Appendix:

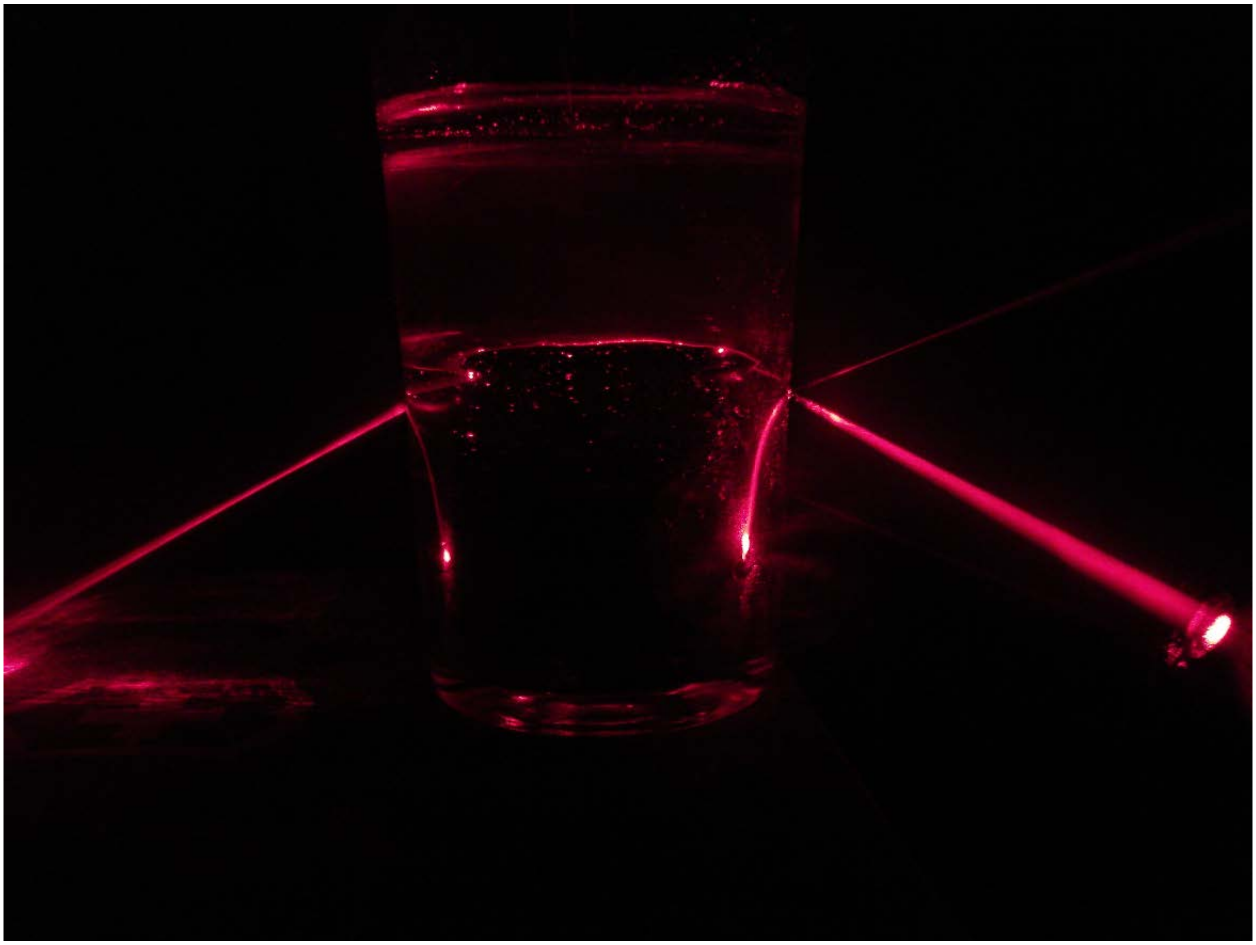


Photo with no edits