MCEN 4151
Flow Visualization

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Laser Light Trapped In Water

By: Faith Batrack

Co-Contributors: Chris Francklyn, David Gagne, Jeffrey Harriman, Lindsey Yarnell and Michael Thompson

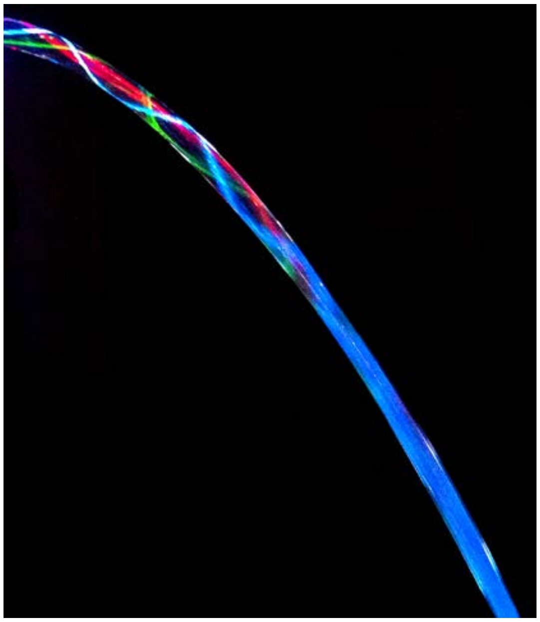

Figure 1: Trapped light in a stream of water

The image to the right, *Trapped Light*, is a submission for the first group assignment in the course Flow Visualization. The initial intent of the image was to create white light from colored beams of light. Once the group set up the apparatus it became apparent that a different setup was needed to fulfill that intent. The group then changed direction and focused in on the stream of water. The intent for the image in *Figure 1* was to capture the phenomena of light being trapped in a laminar stream of water and to witness the light's behavior while in the stream. This image was taken as part of a group effort in which the following people were involved: Chris Francklyn, David Gagne, Jeffrey Harriman and Lindsey Yarnell. The physics department provided the apparatus and equipment. A special thanks goes out to Michael Thompson of the physics department who provided the group with the space, equipment and help necessary for the creation of the image.

The setup for the apparatus can be seen in *Figure 2* below.

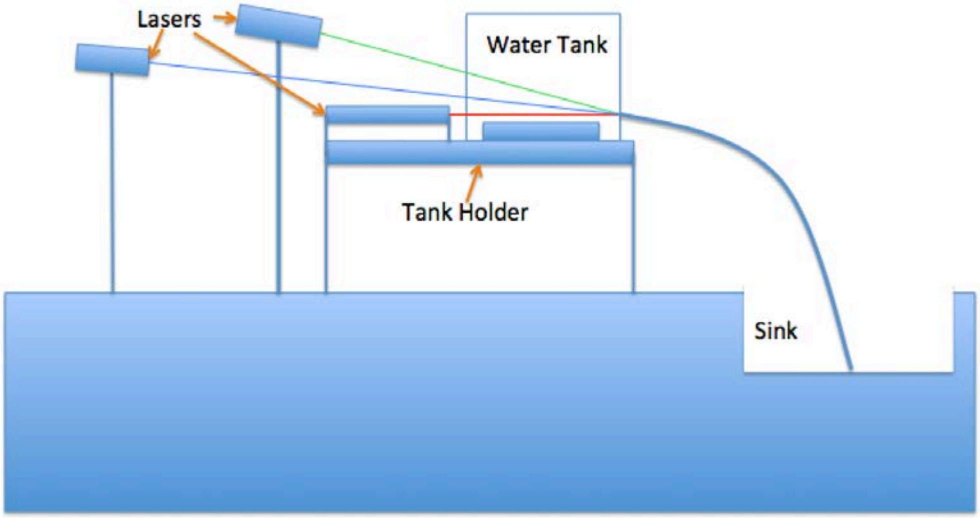

Figure 2: Schematic of the apparatus used for the image

As can be seen in *Figure 2*, three lasers were used: a red, green and blue laser. The three lasers were focused on the back of a rubber stopper, which plugs up the ½ inch hole the stream flows out of when unplugged. Focusing the lasers at the exit point in the tank helped to ensure the light get trapped in the stream. The red, blue and green laser were 0°, 15° and

30° from the horizontal (respectively). The tank itself was made of ½ inch acrylic epoxied together at the edges with the outer dimensions of 4" x 18" x 20", which is approximately one cubic foot in volume. The exit hole was placed an inch above the bottom of the tank. The water in the tank was mixed with approximately 1 ½ - 2 tablespoons of Pine Sol. This was done because pure water is extremely clear and the laser beam looks similar to a beam or light through air. The pine sol added colloidal particles to the water, which makes the beam more visible to the human eye because it gives the light something to "hit" (so-to-speak) and reflect off of.

In order for the light to get trapped into the free stream leaving the tank, the flow must be laminar. If the flow is not laminar (i.e. turbulent) then the light can (and will) escape the free stream. The flow must be laminar so that implies that the stream has a low Reynolds number. The Reynolds number is defined in *Equation 1*. Since the mixture in the image is mostly water, the density ρ, and the absolute dynamic viscosity μ [1] values will be taken from water's properties for the calculations done in this report.

Equation 1: Reynolds Number

$$Re = \frac{\rho_{water} V_{stream} L}{\mu_{water}}$$

Where V_{stream} is the velocity of the stream as it is exiting the tank and L is the radius of the hole in the tank the stream is exiting. If the assumption that the tank and fluid properties will remain the same throughout the specified time is made, then the following inequality can be deduced:

Equation 2: Condition for laminar flow

$$V_{max,stream} \leq V_{max,laminar}$$

Above, in *Equation 2*, it states that the maximum velocity of the stream has to be less than or equal to the maximum allowable velocity for the stream to be laminar. For the stream to be truly laminar, the Reynolds number should be less than 100. The maximum laminar velocity ($V_{max,laminar}$) can be back calculated using Equation 1, which comes out to being $V_{max,lamiar}$=620001.24 inches/second. The maximum stream velocity that will exit the tank can be calculated by first deriving an equation for the volumetric flow rate Q by use of the Bernoulli equation [1]. The greatest exiting velocity is calculated when the tank is full, so approximately 16 inches in height from the top of the hole. Once the volumetric flow rate is calculated, it can be divided by the area of the exiting hole to solve for the maximum velocity of the stream, which comes to be, $V_{max,stream}$=1132.623 inches/second. This satisfies the condition stated in *Equation 2* which supplies analytical proof on top of visual proof that the flow is laminar.

As previously stated, water with a little bit of Pine Sol was used to visualize beams of light getting trapped. Tap water (from Boulder County) was used to fill the tank, which was approximately one cubic foot in volume. Then 1 ½ to 2 tablespoons of Pine Sol were then added to water in the tank. A brush was then used to stir the contents in tank to make sure some of the Pine Sol particles reached the bottom of the tank. After stirring, the group waited for the water-Pine Sol mix to settle and be clear. This is a crucial step because the laser beams won't reach the rubber stopper due to the high concentration of the colloidal particles before settling occurs. For the image, minimal light was used. The flash was turned off on the camera and the lights in the room were turned off. The main light source came from the lasers themselves. Some ambient lighting from a near-by room may have interfered; however the intention was for the lasers to be the sole source of light.

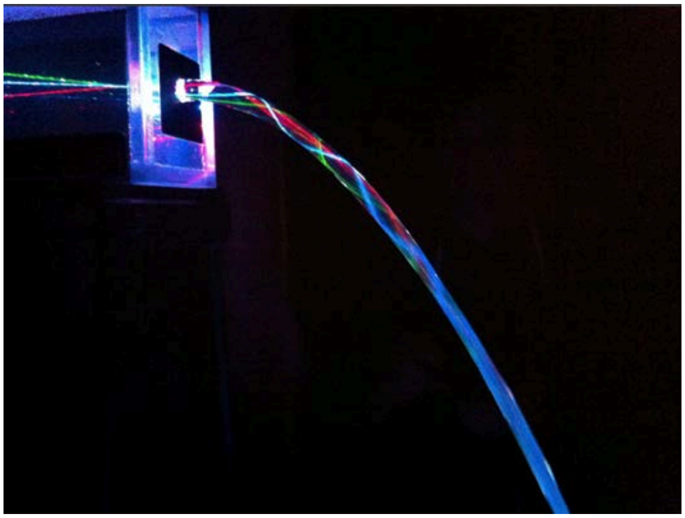
Figure 3: Original (un-edited) Image

For this image, a camera from an iPhone 4 was used. Several other cameras attempted to capture the flow phenomena; however they could not pick up on the red or green light as well as the iPhone 4 camera. There were multiple attempts of changing the settings (ISO, shutter speed and aperture) on the Nikon cameras, but the images did not come out as nicely as the iPhone photos. For the original image, which can be seen in *Figure 3*, the aperture was selected to be f/2.8 and the shutter speed was selected to be 1/15 s. The focal length of the camera was 3.9 mm. The original image's size is 2592 x 1936 pixels and the final edited image (in Figure 1) is 1378 x 1690 pixels. The camera was approximately two feet from the stream of water. The approximate size of the field of view is one foot in the y- direction and 1½ feet in the x- direction. The ISO was not specified on the camera or in its file information once uploaded. Since the image was taken in the dark, I assume a higher ISO was used to capture more light. During post process editing, the image was converted to a lossless file type, then contrast was enhanced to fully darken the background and finally the image was cropped so only the stream is visible. The editing software used was ViewNX 2, which is by Nikon.

The image reveals the physics of trapped light and is ultimately a clear demonstration of total internal reflection. I really like how the three light beams can be seen in the final image and I like how the light is bouncing back and forth within the stream without light straying from the stream. I dislike the graininess of the image and wish that it could be captured using a better camera. I would like to improve upon the image using different post-editing software, such as Photoshop. For future ideas, I think it would be cool to take a series of images that displays the different types of light interactions such as: reflection, refraction, diffusion, etc..

Sources:

[1] White, Frank M. *Fluid Mechanics*. 7th ed. New York, NY: McGraw Hill, 2011. Print.

[2] M. "Dynamic, Absolute and Kinematic Viscosity." *Dynamic, Absolute and Kinematic*

Viscosity. Engineering ToolBox, n.d. Web. 20 Mar. 2013. <http://www.engineeringtoolbox.com/dynamic-absolute-kinematic-viscosity-d_412.html>.