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ARTF 5200
Team Project #1

Combining Laser Light with Water as a Light Guide

Introduction

For the first team assignment I worked with Chris Francklyn, Lindsey Yarnell, Faith Batrack and David Gagne. We decided to try and capture images of water as a “lightguide” or “light pipe”. The basic setup we used has been displayed numerous times in physics classrooms and online, however we made some changes to the basic setup which made things a bit more interesting. The first step is to capture laser light propagating in a stream of water. We wanted to be able to visualize the internal reflection behind this phenomenon. To take this a bit further we wondered what would happen if multiple lasers and multiple streams were used. In particular we wanted to see if by combining different colored lasers in colliding streams we could combine the colors. As we went through the painstaking setup it became clear having two streams of water combine would not be trivial. Instead we decided to try and combine multiple lasers in a single stream of water. The resulting video clip and stills show the light reflecting within the stream and finally combining and dispersing in the white plastic bucket the water was pouring into. I created some freeze frames in the video to show the various colors displayed as the lasers dropped out of the stream due to the water level. The result was a multi-color laser light show that could only happen in the basement of a physics building.

Setup and Flow Apparatus

The basic setup consisted of a tank of water with a ¼” hole near the bottom of one side. Adjustable stands were used to place the lasers opposite the side with the hole and angled such that they would cast their beam into the flow. The hole had a rubber cork which was used as the target for the lasers. The outlet in the tank is a thin sheet of aluminum which minimizes the effect of the opening itself, encouraging a laminar flow.

Figure 1: Setup

Gravity is a major contributor to the flow observed and highlighted with the lasers. Gravity provides the force which creates the pressure which results in the stream of water. Further it causes the exponential curve of the stream as it curves toward the sink at the end of the table. The shape of this curve is important for the laser light to remain trapped within the water.

In some of the images two lasers are employed, while in others three are in use. The red, green and blue lasers used were of varying powers but appeared of similar strength to the naked eye. The red laser was placed at the same height as the hole in the tank. The result is that the beam starts out parallel with the stream of water before gravity takes effect. By examining a close up of the setup and utilizing Photoshops measurement tools, I determined the blue laser was placed above the red at an approximate angle of 7.2^o degrees and the blue above it at an approximate angle of 13.5^o degrees.

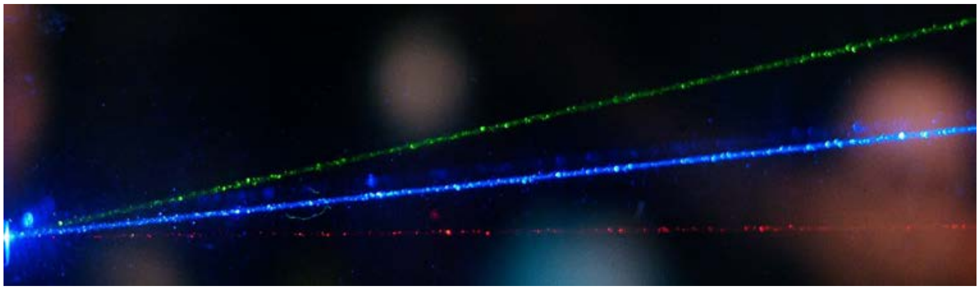

Figure 2: Image used to calculate angles of incidence

These angles are well below the critical angle needed to result in total internal reflection[1] which for an index of refraction of 1.333 in water can be calculated as:

$$\arcsin(1/1.333) \sim= 48^o$$

The varying angles of incidence for the lasers caused two interesting things to happen in the images. First, each laser reflected at a different location in the stream creating what appeared as twisting in some cases, although in reality they were just bouncing off the stream at different angles. Secondly, as the water lowered below the lasers entrance point from the back of the tank, they would be lost in the stream at different times. Since they were no longer entering from the back of the tank of water but instead from above, refraction caused them to bend down and no longer enter the flow of water exiting the tank. This caused different colors to be mixed at different times depending on which lasers were present in the flow. In order to highlight these various stages the video is held for a few seconds as the different colors are exhibited.

Visualization

The laminar flow of a stream of water falling from a tank into a sink isn't particularly interesting, what we wanted to capture was the interaction of the lasers within the water and the way they may combine. The solution used was a combination of water and a very small amount of pine sol (teammate David Gagne approximates as much as 1000:1) which provides larger colloidal particles for the lasers to reflect off, making the laser easier to see but not so large that most of the the beam is reflected or absorbed. The lighting in the room was made as dark as possible, there was an office in the corner emitting some light, otherwise the lasers were generating the rest of the visible light.

Photography and Video

The movie starts with a close up showing the three lasers internal reflection within the stream of water. The camera view angle for the video is approximately 55^{o} which from two feet away makes the field of view approximately 25". This footage was taken with my iPhone 5 when my Nikon DSLR ran out of batteries. When I back up to about eight feet away the field of view is approximately about 100". Whereas for the still image included the specs are as follows:

Shutter Speed	F-Stop	ISO	Field of View
1/13 sec.	f/1.8	800	10"

The stills were taken with my Nikon D40. The still was processed in Photoshop to increase contrast. When it was converted in iMovie the resolution for the still is greatly degraded compared to viewing the .NEF raw file.

Summary

The still image and first part of the video clearly show the total internal reflection of the lasers within the stream of water. The effect of the different angles of incidence into the stream can clearly be seen. The green and blue light bounce more times since they come in at a steeper angle. This appears to have an impact on the light being dispersed further down in the stream. As the friction from the air begins to create turbulence in the stream the lights which are bouncing more seem to become more prominent. Another thing which is revealed is how much light energy is carried by the water. When it splashes into the bucket the light disperses in the white plastic. The different colors remain separate in the stream as can be seen near the outlet and then combine to create new colors as they interact in the bucket. The video shows this clearly by freezing the frames with different colors being exhibited. Additionally you can see the diffraction occurring as the water level lowers below the point in which the lasers enter the back of the tank.

Ultimately this video reveals the different reflection points and the way the lasers interact in the water and ultimately the bucket. The quality of footage unfortunately is somewhat lacking particularly in this low light setting. The experimental setup made it somewhat tedious to iterate since the tank need to be manually filled each time. It would be nice to have a setup with a continuous flow to enable more experimentation of different angles and to further experiment with different combinations of light and how they may disperse in various materials. I also think it would be worth attempting again with multiple tanks as was part of the original plan but would require additional setup time.

In the end we were able to capture an interesting take on this classic physics experiment. It does seem there is room for additional variations on this setup to be explored. Special thanks to Michael Thomason for allowing us access to his lab and equipment!

[1] http://en.wikipedia.org/wiki/Total_internal_reflection