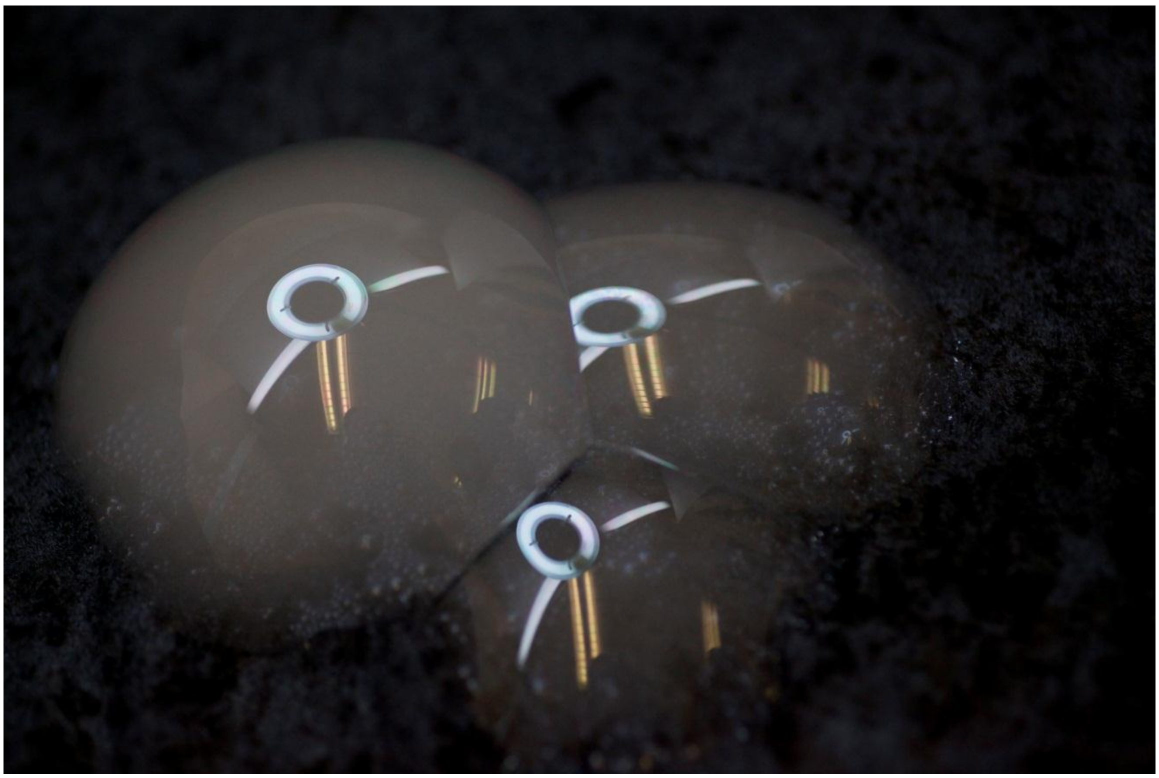
Spooky Science



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Flow Visualization
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Purpose:

This image was capture for the first team project for the class titled *Flow Visualization.* The group worked on the project in the basement of the Fleming Law building at the University of Colorado at Boulder. Using dry ice, cold water, soap and a hose, we created bubbles known in the scientific world as "Boo Bubbles" which are essentially a denser form of normal bubbles as they contain the carbon dioxide gas exuded through the hose from the dry ice and hot water mixture. This image was realized with the specific help of Elizabeth Crumb, Shea Zmerzlikar, Pat Cotter and Jon Horneber; all students from the University of Colorado.

Apparatus:

The apparatus used to capture the flow was a simple set up. It included a container that could be sealed off with a lid and a hose with an end that could be dipped in the soap solution. The hose was inserted into the container. The container is where the reaction between the hot water and dry ice takes place. The hose funnels the carbon dioxide gases into the nozzle where the soap of film is present; the result is a "Boo Bubble." The finished apparatus can be seen in Figure 1.

Figure 1: Bubble Apparatus Used for Capture

Flow:

To get to the root of the flow phenomenon occurring here we first comment on the dry ice. Dry ice is frozen Carbon Dioxide which is a gas. At room temperature, Carbon Dioxide wants to be a gas so it pulls heat from its surrounding in order to achieve this state [1]. The quickest way to heat up the dry ice is by submerging it in hot water so that the dry ice has an excess amount of heat to pull from its surroundings. Once submerged, the dry ice immediately begins to pull heat from the water; which in turn melts the dry ice. Since there is no intermediate stage, due to the fact that Carbon Dioxide is a gas and has no liquid form, the melting dry ice releases itself in the form of Carbon Dioxide gas. This creates the dense vapor that is funneled into the hose and through the soap film in order to create the "Boo Bubbles" that are seen in this image.

The physics of these bubbles are very interesting and differ greatly from standard bubbles that breath is used to make. The difference comes from the fact that carbon dioxide creates a cold dense fog that contains both condensed water and the carbon dioxide as it comes off of the dry ice. The condensed water comes from the water vapor above the water getting cooled as the carbon dioxide pulls heat from it. Standard bubbles usually only contain the carbon dioxide that you exhale after your body uses the oxygen from the air. As an example, we will say that one of the bubbles contains 10% water condensation and 90% carbon dioxide gas. Estimating the radius of the bubble to be 1 inch or .025 meters we have a volume of:

$$V = \frac{4}{3}\pi r^3 = 6.54 \ x \ 10^{-5} \ m^3$$

And using the approximation that 10% of the bubble is composed of condensed water and the other 90% of the bubble is composed of carbon dioxide, we can calculate the mixed density of the bubble:

$$\rho_{mix} = .1\rho_{H2O} + .9\rho_{CO2} = 101.78 \ \frac{kg}{m^3}$$

And show the density of a normal bubble with just carbon dioxide:

$$\rho_{CO2} = 1.98 \ \frac{kg}{m^3}$$

Finally, we calculate the masses of the two different bubbles so we can comment and compare on their severe differences:

$$m_{mix} = \rho_{mix}V = .0067 \ kg$$

$$m_{CO2} = \rho_{CO2}V = 1.290 \ x \ 10^{-4} \ kg$$

Calculating the differences between the two different bubbles, we say that the "Boo Bubble" is approximately 52 times heavier than that of the standard carbon dioxide bubble. This explains why the "Boo Bubble" drops so much more aggressively than that of a standard bubble. This is due to the fact that the density of air is 1.225 kg/m^3 [2]. The density of carbon dioxide as shown above is relatively close to the density of air so the bubble appears to float as it drops casually while the density of the "Boo Bubble" is much greater than that of air, causing the bubble to fall fast with no suspension [3].

Visualization Technique:

One of the more important aspects of the visualization technique used was the felt backdrop used to catch the bubbles. Other materials were too gristly to catch the bubbles without popping them so a black felt backdrop became necessary but also added a nice degree of texture to the foreground and background of the image. It was important to me that I achieve an image that was symmetrical across the y-axis, meaning that the image was centered and not skewed towards either side. Another important realization was to ensure that a certain amount of the fog (carbon dioxide) was visible in each bubble so that it became possible to see and explain the physics happening. The specific dilution of the soapy solution was approximately 50% soap and 50% water. Increasing the soap concentration in turn increases bubble surface tension. The lights reflecting off of the bubbles were not initially in the intent for the image but since they added a certain color and did not detract from the flow, I deemed them beneficial to the picture. The bubbles were lit by a retractable fluorescent light place 2 feet above, and were backlit by a row of fluorescent tube lights, recessed 3 feet in the background of the picture.

Photographic Technique:

The field of view of this image is approximately 6 inches and was taken with a Canon EOS 5D Mark II camera. The lens was approximately 4 inches from the bubbles. See Table 1 for the exposure specifications.

Table 1: Camera Settings/Specifications

Lens focal length	90 mm
Aperture	f/3.5
Shutter Speed	1/800 sec
ISO	400

The pixel count of the image is 5616 x 3744 and since there was no processing on the image, the pixel count remained the same in the final image. With respect to resolution, you can see that every part of the image is sharp besides the edge of the bubbles. Designating the lines of the bubbles to be at most 2 pixels wide we can say that the image could have used one more decade of resolution. Meaning that the details in the second and third decade of resolutions are sharp and you see no blurring lines but on the smaller scale, in the first decade, you see the blurring lines of the bubbles thus dignifying the possibility for enhanced resolution by adding another decade of fine details.

Concluding Remarks:

This image reveals the common phenomenon that people see all the time in dry ice. It shows the difference between regular bubbles and “Boo Bubbles” and helps to inform people on simple science that is informational as well as intriguing. I do wish that the edges of the bubbles were a little sharper but it doesn’t detract from the image on a large scale. My intent to capture a telling image of the fluid phenomenon known as “Boo Bubbles,” was very well realized. I really wish that I could have captured usable footage of the bubbles bouncing off of each other due to their increased surface tension. In the future I would look to use a high-speed camera to capture not only the bouncing of the bubbles but also to capture a bubble popping and releasing the fog as it hits a rough surface. This would tell more about the physics and would make for a very interesting piece.

References:

[1] web.chem.ucsb.edu Website. Accessed March 18th, 2013
http://web.chem.ucsb.edu/~outreach/station1.htm

[2] engineeringtoolbox.com. Website. Accessed March 18th, 2013
http://www.engineeringtoolbox.com/gas-density-d_158.html

[3] "General Properties and Uses of Carbon Dioxide, Good Plant Design and Operation for Onshore Carbon Capture Installations and Onshore Pipelines". Energy Institute. Accessed March 18th, 2013.