POP!

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I. INTRODUCTION

For the IV 3 project, my team chose to explore bubbles popping using a high-speed camera. We were inspired by how beautiful bubbles are when they exist, and we were curious to learn more about the physics of when they pop. We were excited to have access to 2 different high-speed cameras through the university. We originally planned on taking photos of bubbles inside, but we found that high-speed cameras need very bright conditions to function well. Our first photos were taken inside at a measly 400 frames per second, and they were dark and hard to see. Further, they were taken with flimsy bubble soap, so they popped quickly.

II. PHENOMENON

a. Setup

Since the bubble soap we had didn't work particularly well, I found a recipe for bubble soap in an article called "Physicists determine the optimal soap recipe for blowing gigantic bubbles" from ARS Technica. To mix it, I followed the recipe they outlined using guar gum, baking powder, and isopropyl alcohol alongside the expected soap and water. The mixture settled for 20 hours before being used in our photography ventures.

After determining that the photo needed to be taken outdoors, I gathered a few extension cords, the Olympus I-Speed Camera, a monitor, and some bubble solution and brought it out to the loading dock at the Idea Forge. I ran an extension cord through a window to make sure we had enough reach. Then, I set up the camera so it was on the edge of the loading dock, which was about 2' above the ground. I focused the camera so it was focused on the bubble solution water bottle in the last bit of sunlight of the day. From there, my collaborator joined me and offered to pop bubbles for me. She sat next to the water bottle, just out of the camera's view, and I directed her to pop the bubble in a straight line to ensure the bubble and the pop would be in focus. I started the camera and blew some bubbles. When I saw that we had captured a pop, I rushed to turn the camera off. From there, I began the process of exporting the image which involves cutting the image size so it spans as little time as possible, to prevent exceptionally long loading times.

b. Flow

Although bubbles are perceived to be 'child's play,' they have been prominent in the field of physics since the 1800s, with a significant portion of study occurring related to surface tension (Ouellette). To calculate the surface tension in the bubble, I use the equation

$$P_i - P_o = \frac{4T}{r}$$

where P_i is the pressure inside of the bubble, P_o is the pressure outside of the bubble, T is the surface tension, and r is the radius. Estimating the radius to be 1.75", the pressure outside of the bubble to be 14.7000 psi according to the average pressure in Boulder, CO, and the inside pressure to be 14.7001 psi because it must be slightly higher than the outside pressure, the surface tension is likely approximately 0.000175 lbs/in (Barometric, "Surface Tension"). Additionally, the smallest aspect of the video is approximately 0.125" x 0.1" and this is seen in relation to the full field of view which is approximately 3' x 6'. Using this, the video covers about 3.5 decades. However, the smallest part of the physics is likely much smaller than the smallest part of the video, so the video is partially resolved in space.

More recently, bubbles popping has been tied to quantum physics. They release light in a quantized way, according to Alex Wilkins in New Scientist, which is an interesting tie to how light behaves as both a particle and a wave, even in a fluid (Wilkins). However, this experiment highlights how bubbles constructed with polymer chains react when popped. The special ingredient in the soap recipe highlighted above is guar gum, which acts as a thickening agent in food. It thickens food by creating polymer chains the longer it sits in a fluid and resting the soap for 20 hours before use ensured that long chains of guar gum had formed in the bubble fluid. This allowed us to create massive robust bubbles, which was especially important because the low Colorado humidity typically spells disaster for bubbles. As the bubble popped a long chain of gelatinous fluid fell to the ground: the remnants of the polymer chain. It took 1.5 minutes for the bubble to pop and fall to the ground in the unedited footage, only 10 seconds of which involve the actual popping of the bubble. The video was shot at 4000 frames per second. The actual speed of the bubble pop and fall to the ground was 0.0225 seconds, and just the bubble pop was 0.0025 seconds. This shows that the forces that cause the surface tension to dissolve are much faster than gravity. This means that the image is temporally resolved.

III. VISUALIZATION TECHNIQUES

The bubble inherently creates a boundary technique, because the boundary of the bubble is visible. Light from the sun shines off the bubble surface and creates beautiful colors that are picked up by the camera. Sunshine was the only light that we had access to that was bright enough to allow for the 4000 fps speed of the camera. There were a few clouds in the sky and the sun was beginning to set behind the building, but it was still very bright out. High-speed videography must be done in a very bright environment.

IV. PHOTOGRAPHIC TECHNIQUE

The field of view is 3’ x 6’, the bubble has a diameter of 3.5”, and the bubble is approximately 10’ away from the camera. The lens was the ‘TV lens’ that came with the Olympus i-Speed Camera set. The camera was a bit challenging to work with because it has seen heavy use since it first came out in 2004. Some of the buttons didn’t work which required some finessing to get around. I would recommend using a newer high-speed camera. The image was shot at 4000 frames per second and the actual bubble pop was played at 2x speed, while the rest of the video was played at 20x speed. Although I attempted to crop the video, I found that it lowered the quality so there is no ‘before’ video.

V. VIDEO

I think the video captures some spectacular physics. Although the camera was old and hard to use, it still managed to allow me to capture a bubble dissolving into a gelatinous blob. If I had had more light, I could have gotten a higher frames-per-second rate, but I think that 4000 was ample to get the information I needed out of the bubble. For future experiments, I would use a newer camera that had a start and stop button that worked well, and I would have a wider aperture to capture more in-focus bubbles. Additionally, I would have a tool to pop the bubbles instead of a finger.

VI. APPENDIX

a. Bibliography

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