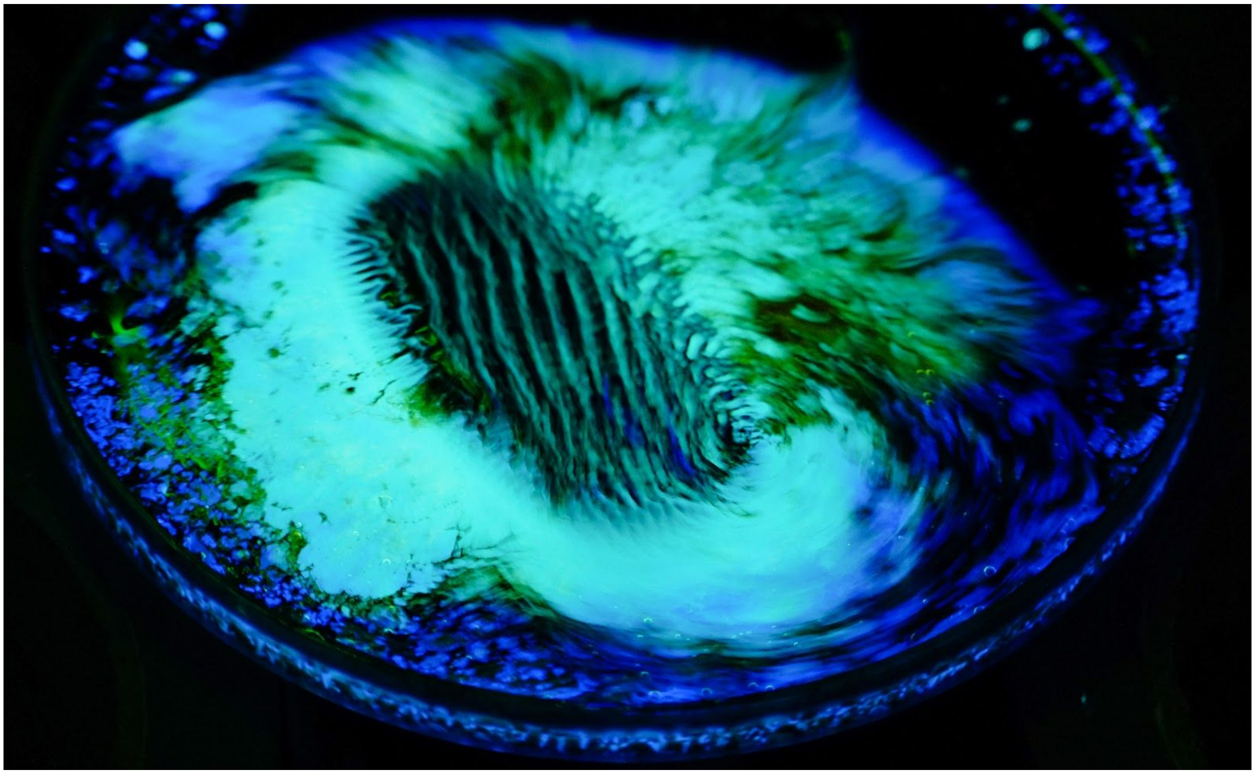

Figure 1

Glow Sticks and Ferrofluid

Report and Images by Summer Thompson for Team Second Project with collaboration from team members Abby Rastatter, Brandon Toves, Zach Hinck, and Garrett Wolcott. Photos and Report by Summer Thompson for the 2018 Spring Flow Visualization Class at CU Boulder.

For this assignment, my team and I borrowed ferrofluid from professor Herzberg's lab to capture the effect of a magnetic field on ferrofluid. To visualize this and create a unique aesthetic image, we decided to use glow stick fluid. The idea was inspired by a youtube video (https://www.youtube.com/watch?v=RtBtD0_KZ9o). We performed this experiment in a large room with the shades drawn. The experiment was done in a quart container lid with a label on it, which provided a reflector for light emitted from the glow stick fluid and created a opaque background beneath the flow. The quart lid was supported with three rolls of tape in order to allow Brandon to hold a magnet underneath the ferrofluid. We first added about a tablespoon of ferrofluid to the quart lid and used a 2 inch bar magnet underneath the container to create a ferrocell. Zach then poured the contents of 3 glowsticks, two blue, one green, onto the cell while Garrett, Abby, and I took photos of the flow. Brandon held the magnet and moved it in different ways while we took photos.

In Figure 1 Brandon was rotating the magnet along its horizontal axis while holding it horizontal to the container. The shutter speed was ¼ of a second, so the ferrofluid reacting to the change in magnetic field can be seen through motion blur around the ferrocell. The aperture was 1.4 and the iso was 2500. These settings allowed me to capture the flow in a dark room, and use the glow sticks as the only light source. I chose this image because it was essentially a light painting, made by the ferrocell and brandon's agitation of it.

The method of visualization used was glow sticks, which illuminated the valleys between cones of the ferrocell, creating a pattern matching the structure at that moment. Glow Sticks contain an ampoule of hydrogen peroxide and phthalic ester surrounded by phenyl oxalate ester and fluorescence anthracene dye. When the center ampoule is cracked, the phenyl oxalate ester and hydrogen peroxide react to form phenol and carbon dioxide. The oxidation (loss of an electron) of diphenyl oxalate allows an electron transfer reaction with the fluorescent dye. The subsequent excitement of an electron in the hybrid orbital shell of the conjugated dye molecule result in the emission of a photon within the visible spectrum. [1]

Ferrofluid is made with a 10% surfactant, 5% nanoparticles of magnetic solids and a 85%carrier liquid by volume. The surfactant has a polar head and nonpolar tail, which absorbs to the nanoparticle. The polar head orients out around the particles creating a micelle forming a

[1] Lightsticks - Chemiluminescence. NCSU Dept. of Chemistry. https://projects.ncsu.edu/project/chemistrydemos/Light/Lightsticks.pdf

colloid of surfactant and nanoparticles in the carrier fluid. When ferrofluid is exposed to a strong vertical magnetic field, the surface forms rising peaks with the vertical force lines.[2] The effect is known as the Rosensweig or normal-field instability.

The glow stick fluid settled in the valleys, between the peaks. The fluids did not mix because of the Rayleigh-Taylor instability which occured when the less dense, glow stick fluid was poured on top of the denser ferrofluid.

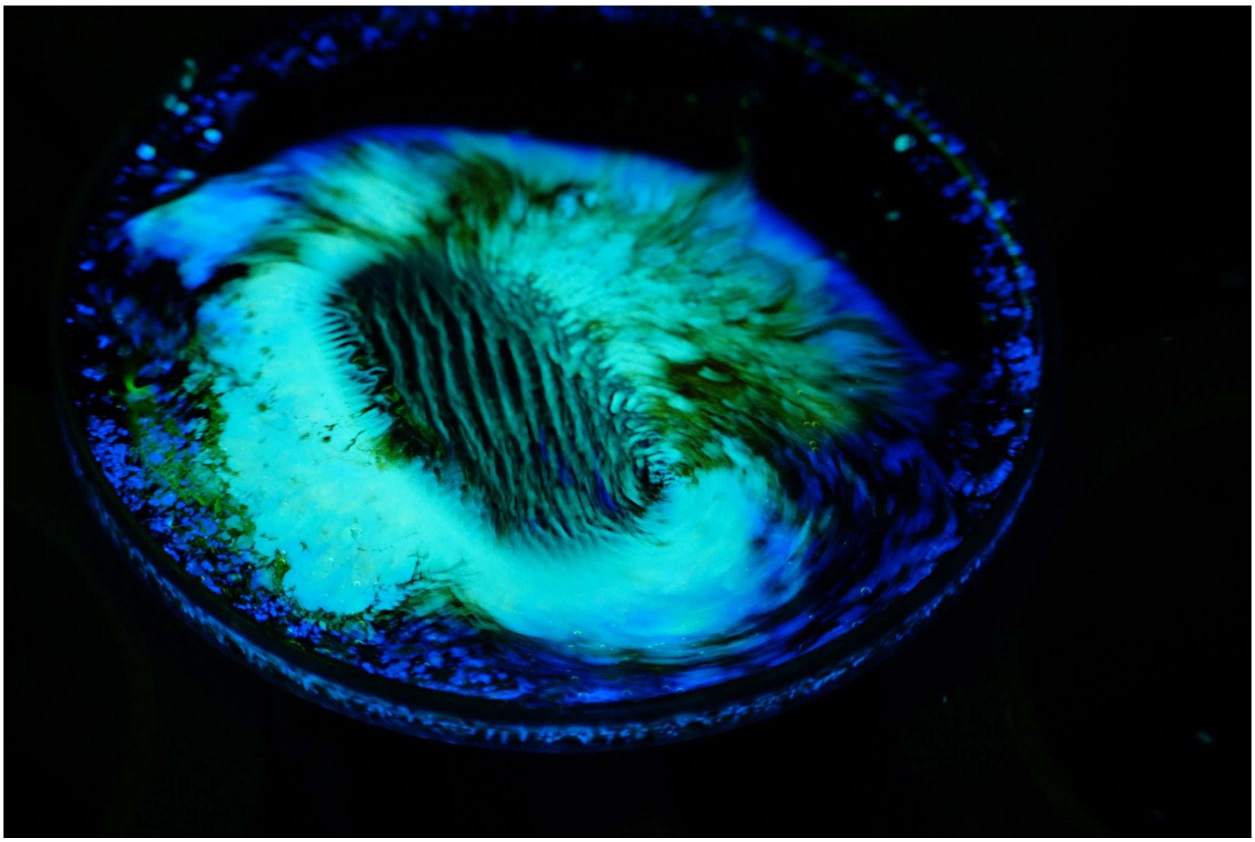

Figure 2. Photo of Glow Sticks and ferrofluid

To capture the images above, I used my Fujifilm X-pro 1 with a X2 Makinon teleconverter, a Nikon to Fujifilm-x mount converter, and a 50mm Nikkor 1:1.4 lens with a minimum focussing distance of 2 feet. I think using the teleconverter allowed a greater amount

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[2] Berger, Patricia, et al. "Preparation and Properties of an Aqueous Ferrofluid." *Journal of Chemical Education*, vol. 76, no. 7, 1 July 1999, pubs.acs.org/doi/abs/10.1021/ed076p943.

of detail between the ferrofluid and the glowsticks. I used a tripod and stood about 2 feet from the plastic lid when I took the images. The lid was six inches in diameter and field of view was approximately eight inches wide. My X-pro 1 is a cropped sensor mirrorless camera and the image dimensions were 3456 by 2304 pixels. The edits I made to this shot were cropping and boosting the shadows and blacks to give more detail in the final image. The cropped photos dimensions are 2913 by 1787 pixels but were compressed as a jpg.

The image reveals how ferrofluid reacts to a shift in the magnetic creating its shape. The glowsticks create an inverse image of this as they highlight the space left between spikes caused by the magnetic field. The swirls of motion blur in this image show the normal field instability shifting with the movement of the magnet. I am really proud of this project and more than satisfied with the aesthetic results of the images. If I were to do this project again, I would want to make a video of the initial pour of the glow stick fluid, illuminating the ferrocell in the dark. I would want to try to better capture the structure/pattern of the cones and play with abstract compositions of the fluid. I think I would start this by setting up a white backdrop behind the container. I would also want to use a different lens and a smaller aperture along with less movement to capture the silhouette of the ferrocell.