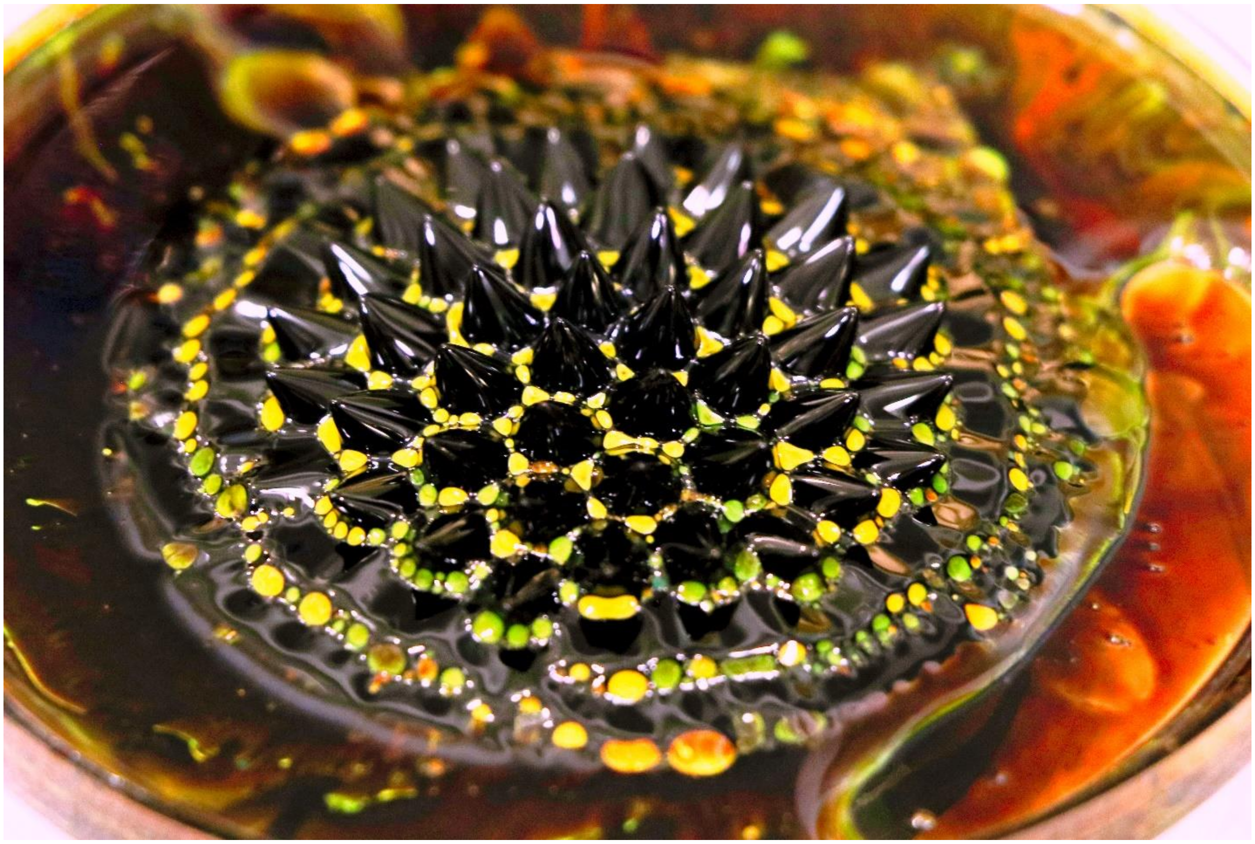

Team Third Image Report

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This photo was taken for the Team Third image. I set out to try and capture the beauty of a ferrofluid under the influence of a magnetic field. A ferrofluid is a fluid that has magnetic properties so when it interacts with a magnetic field it forms very interesting shapes and spikes. I wanted this image to really capture the spikes clearly and in an artistic way while invoking interest in the viewer into the science behind them.

To capture this image, we used EFH1 type ferrofluid that used light mineral oil as its carrier fluid and strong disk shaped magnets. We placed two of these magnets underneath of a petri dish and then poured the ferrofluid into the dish. We then poured some India ink around the outside and on top of the ferrofluid to add some artistic value. The India ink is water soluble which explains why the ink did not mix with the ferrofluid. A sketch of the setup can be found below in Figure 1.

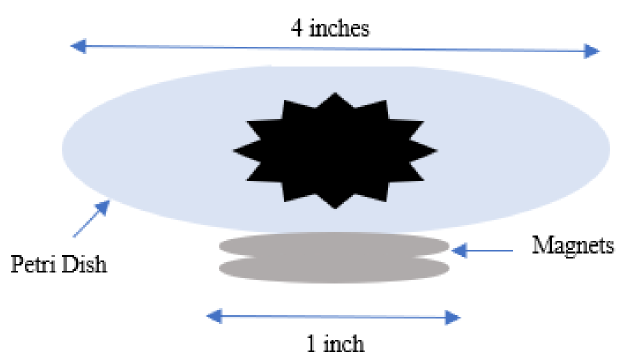

Figure 1: Apparatus

A ferrofluid is just a magnetic fluid. This is achieved by suspending ferromagnetic nano particles in a carrier fluid. When ferrofluid is subjected to a vertical magnetic field, as it was in this experiment, that is above a certain strength Normal Field Instabilities, also known as Rosenswieg Instabilities, form. This instability results in the spiky shapes on the surface of the ferrofluid. Three main forces contribute to the instability. The surface tension and gravitational energy stored in the fluid contribute to stabilizing the ferrofluid keeping a flat surface and the energy stored in the magnetic field that is interacting with the ferrofluid acts as a destabilizing force (Rosensweig 185). The interactions of these three factors directly leads to the instability. When subject to a sufficient magnetic field, the total energy of the system and of the magnetic field is minimized when the ferrofluid forms the repeating spikes seen in the image. This has to do with why the energy of the magnetic field is minimized in this orientation of the ferrofluid. Below in Figure 2 is a diagram that visually shows how the magnetic energy is minimized. The image was taken from Ferrohydrodynamics by Rosensweig. The magnetic field is focused along the crests of the ferrofluid (Rosensweig 188). This concentration of magnetic flux, the magnetic energy per unit area, is at a maximum where the peaks occur and at a minimum where the troughs are. This result is obtained by balancing the contribution of the aforementioned forces and jumping through some quite complicated mathematical hoops as shown throughout Ferrohydrodynamics by Rosenswieg in chapter 7. Rosenswieg also shows that different patterns of spikes appear depending on the strength of the magnetic field (Rosensweig 183). The shapes of the spikes can also change, most take on the shape of hexagons or squares. In the image it appears given the condition, the ferrofluid formed hexagonal spikes. It is also worth noting that the spikes protrude from the body of the fluid in the direction of the magnetic field lines. Generally, this instability can be thought of as the result of the surface tension, gravity and magnetic forces balancing and forming an orientation of the fluid that minimizes energy (Rosensweig 178)

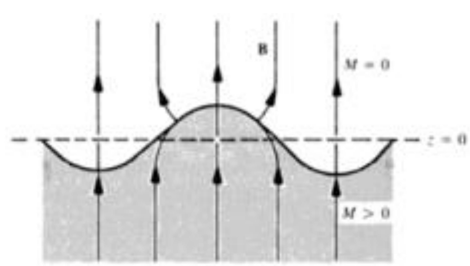

Figure 2: Visualization of the magnetic field through the ferrofluid

The flow visualization technique here was just capturing the spikes clearly by taking the photo at angle that minimized the reflection on the ferrofluid. India ink was also used to help visualize the hexagonal shape of the spikes. The lighting used was just the fluorescent lights that were present in the room the image was taken in.

The image was taken on a Canon EOS 80D. The f-stop was 5.6, the exposure time was 1/60th of a second, the ISO was 1600 and the focal length was 113 mm. The original dimensions of the image were 6000 x 4000 pixels. The edited image's dimensions were 4643 x 3109 pixels. For reference the unedited image is shown below in Figure 3. The camera was around 5 inches from the subject when the image was taken. When edited the image I increased the contrast and saturation to make the colors pop more. I also brought out the black in the ferrofluid to help keep its shape sharp and crisp.

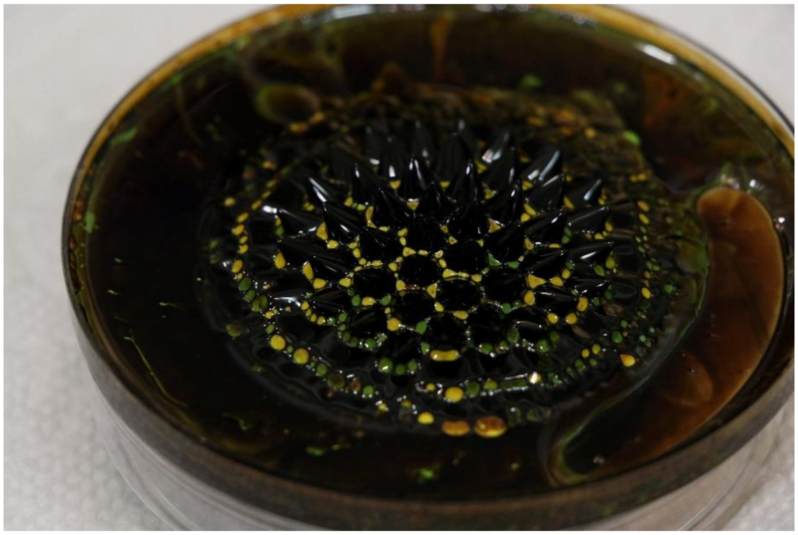

Figure 3: Unedited Image

I am very pleased with how the image came out. I was able to capture the image from very close up while still keeping the spikes of the ferrofluid in focus still. I also though the India ink added some much needed color to the image as well. If I could go back and make any changes, I would try some different colors of India ink and try to get the ferrofluid to not cover them up as much in the petri dish. The shape of the ferrofluid was almost unreal to see in person and was very interesting to work with.

Works Cited

"Theoretical Predictions." *Ferrohydrodynamics*, by Ronald E. Rosensweig, Dover Publications, 2018, pp. 178–190.