# Team Third: Ferrofluid


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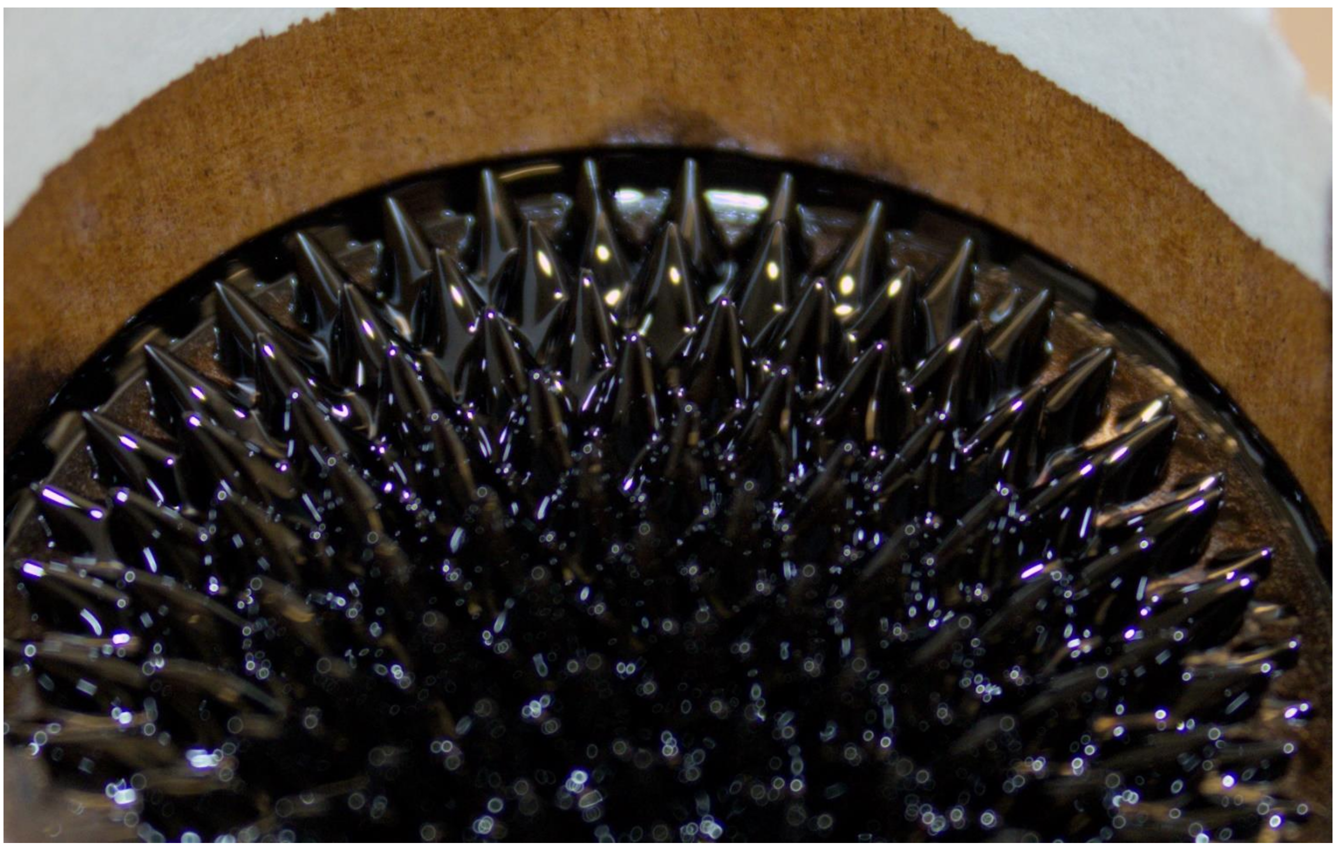

## I. Introduction and Background

The above image shows ferrofluid in a paper cup sitting above a cylindrical neodymium magnet. The image is cropped to only show a portion of the ferrofluid and cut out the majority of the paper cup and other surroundings. The repetition of the spike-like pattern dozens of times creates an image that's fairly homogenous; however, the reflection of light off the spikes serves to offer some contrast and differentiation to the image. Additionally, the focus throughout the frame, specifically the lack of focus at the bottom of the image helps provide a focal point to draw the viewer's attention. This also works in conjunction with the repetition of the spike shape to create the feeling that this image only captures a small subset of a much larger pattern.

My intent for this experiment was to play around with lighting and focus on a relatively simple experiment in an attempt to sharpen some of my photography skills. Initially, I had trouble getting the focus right since the camera does not easily focus on the black fluid. I also did have access to an external lighting source at the time of taking the image that could provide enough light to easily visualize the flow of the ferrofluid. However, I was able to use my camera's flash to provide enough light momentarily. This also is responsible for the way the light reflects off the spikes.

## II. Experimental Setup and Theoretical Calculations

Ferrofluid is a liquid with magnetic properties achieved by suspending magnetic nanoparticles in some sort of carrier fluid, generally oil. When placed above a magnet like in this experiment, the magnetic nanoparticles attempt to follow the direction of the magnetic field while the surface tension of the carrier fluid works against this expansion. These conflicting forces lead to the distinctive peak and valley formations, which is the most energetically favorable state of the fluid. This pattern is known as the normal-field instability or the Rosensweig instability.

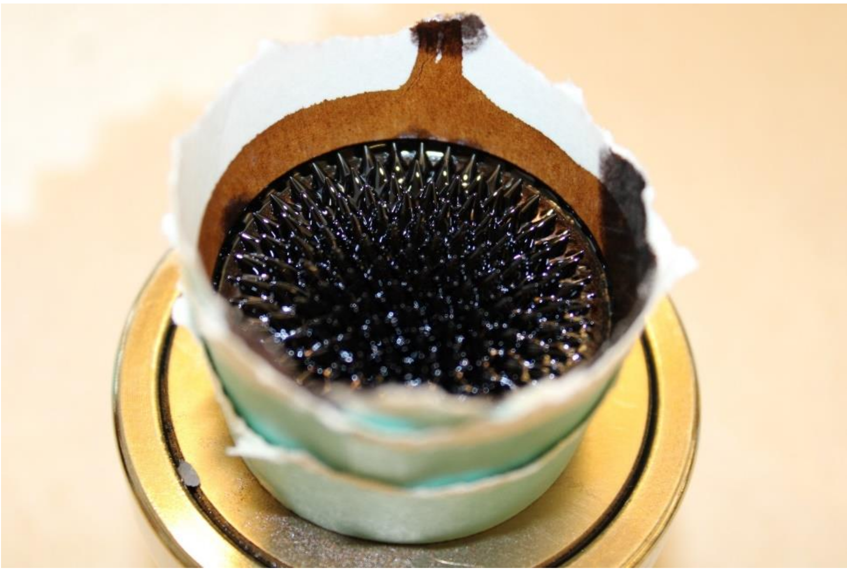

**Fig. 1:** Original (unedited) RAW picture

Figure 1 above shows the experimental setup better than the cropped image above. A cylindrical magnet, roughly disc-shaped with a large diameter of about 2.5 inches and short axial length, was placed on a flat surface. Then several paper cups which I cut down to length to easily view the ferrofluid were placed above the magnet. Multiple cups were stacked inside each other to prevent any of the fluid from soaking through the container. The base of the cups are roughly 1.5 inches in diameter. Approximately 25 mL of ferrofluid was then dispensed into this container using a pipet. Immediately, the fluid shifted into the normal-field instability orientation.

Because the magnet used was circular, the magnetic field was radially symmetric when passing through the ferrofluid. A visualization of this can be seen below in Fig. 2. This causes the normal-field instability in the ferrofluid to also be radially symmetric, a phenomenon that can be seen in Fig 1. While a traditional Reynolds number is not necessarily applicable to this case, there is a roughly equivalent quantity known as the magnetic Reynolds number, $R_m$. However, the field of magnetohydrodynamics is quite mathematically complex and generally concerned with large-scale systems such as the Sun. Therefore, there is a surprising lack of standardization and quantification of ferrofluid properties, meaning there aren't really any relevant dimensionless quantities that help describe the flow behavior.

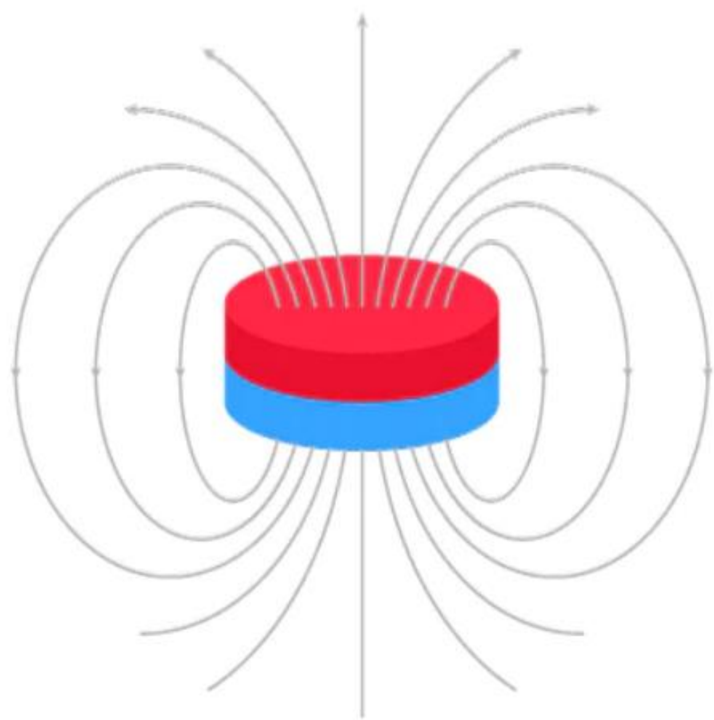

**Fig. 2:** Radially symmetric magnetic field lines of a circular magnet

## III. Visual Techniques and Camera Settings

The visual techniques used were quite simple. The picture was taken in a room with strong ambient lighting. However, the dark color of the fluid made it difficult to clearly photograph. By using my camera's flash, I was able to provide enough light to make out the shape of the flow. I initially attempted dying the fluid as I'd seen other groups do previously, but had trouble getting the fluid to accept the dye. In the end, I used a picture taken without dye as I liked the focus and reflection of light in this image.

This picture was taken with a Canon EOS Rebel 1500D and camera settings can be found below in Table 1. The original RAW image file has dimensions of 6020 x 4015 while the cropped, edited PNG image is 1718 x 1080 pixels. The image was edited in darktable, where I cropped down to focus on the fluid and slightly adjusted white balance and the tone curve to get my desired palette.

| | |
|---|---|
| Shutter Speed | 1/50 sec |
| Aperture | f/5 |
| ISO | ISO-800 |
| Focal Length | 41 mm |

**Table 1:** Camera Settings

## IV. Conclusion

I like how this image portrays the normal-field instability and how the varying focus and reflection of light create a sense of differentiation through the symmetric flow. However, I wish I had spent more time playing around with the experimental design. If I were to redo this experiment again, I would use a different container than the paper cups. Something with shorter walls and clear, like a petri dish, would be ideal. This would allow more light and making it much easier to photograph the fluid from multiple angles. Also, the oil carrier fluid began to soak into the paper cup walls, leading to the brown stains in the background of the image. I also wish the ferrofluid in this image had some dye in it; even if visualization was not enhanced I think color would brighten the image up and make it more visually appealing than the current black fluid. Additionally, it could be interesting to use different shaped magnets with different magnetic fields and see how this affects the resulting formations. Overall, playing with ferrofluid and magnets was a simple experiment and a fun visualization technique that can easily be expanded in new directions.

## References

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