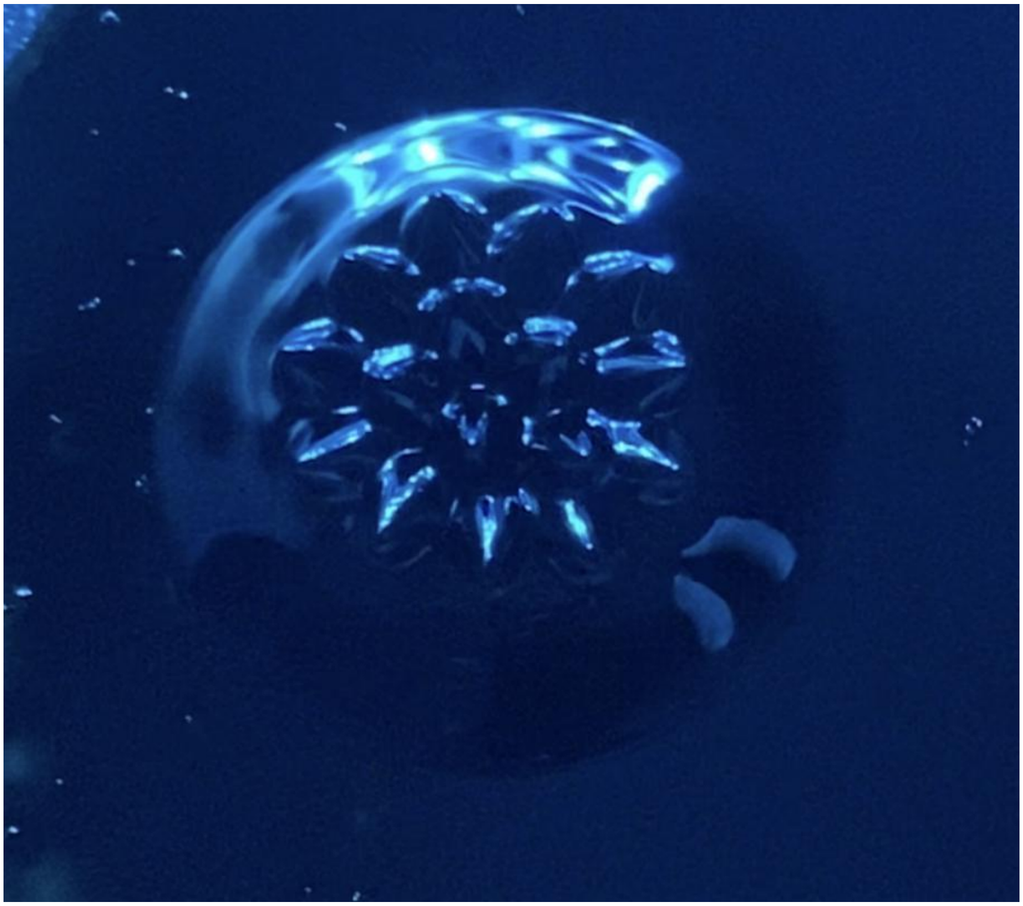

Figure 1: Snapshot of a ferrofluid’s Normal Field instability

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Introduction

The image presented in Figure 1 corresponds to the Team Third assignment for the course MCEN 5151, Flow Visualization. The picture shows a snapshot from a video showing a ferrofluid's normal field instability while subjected to different lighting conditions. Normal field instability refers to a ferrofluid being exposed to a strong magnetic field, forming a regular pattern of peaks and troughs [1]. This effect is also known as Rosensweig and is common in many magnetic fields [2]. A more in-depth analysis of the fluid dynamics will be performed in the following section. The experiment, as well as capturing the images was made possible by the help and support of Sierra Greeley and Jonathan Gruener.

Fluid Dynamics

Ferrofluids are colloidal suspensions containing nanoscale magnetic particles dispersed in a carrier fluid, often oil or water [2]. These fluids show intriguing behaviors due to the presence of these magnetic nanoparticles. One phenomenon associated with ferrofluids is known as "normal field instability," which refers to their response to an external magnetic field.

When a ferrofluid is affected by a magnetic field, the magnetic nanoparticles align themselves along the field lines due to their inherent magnetization [2]. At low magnetic field strengths, the particles align uniformly, producing a smooth surface and stable behavior. However, when the strength of the magnetic field exceeds a critical point, the balance between magnetic and interparticle forces is disrupted [3]. At this critical point, the magnetic forces between the nanoparticles overcome the stabilizing forces like Brownian motion or interparticle repulsion, which leads to instability in the fluid's structure.

The nanoparticles start forming chains or peaks along the field lines due to magnetic attraction, causing surface deformations and creating surface corrugations known as spikes or peaks [2]. The patterns can manifest as spikes, columns, or surface corrugations due to the cooperative alignment of magnetic particles along the magnetic field lines. These shapes represent a compromise between minimizing magnetic energy (by aligning with the field) and minimizing the system's surface energy (by reducing surface area or curvature changes) [1].

Simultaneously, the creation of peaks and valleys is countered by gravitational force and surface tension. Energy is needed to displace fluid from the low points to the high points and to expand the fluid's surface area [1]. Essentially, the appearance of these ridges and troughs elevates the liquid's surface free energy and gravitational potential energy but diminishes the magnetic energy. These patterns materialize only beyond a specific threshold of magnetic field strength, where the decrease in magnetic energy surpasses the rise in surface and gravitational energy factors [2].

Visualization Method

The visualization techniques used in this experiment to take the photograph in Figure 1 were the following. First, the ferrofluid was placed on a 3-inch circular mirror. The idea behind this was to make the ferrofluid stand out and to reflect the light evenly. Then, a magnet was placed under the mirror, generating the necessary magnetic field to produce normal field instability. The experiment took place inside a dark room to reduce unwanted light as much as possible. A light strip capable of producing a wide range of colors was placed over the ferrofluid. The colors changed periodically. The magnet was then moved around, making the ferrofluid shift in shape, size, and location.

Photographic Method

The image was taken using an iPhone 12. The lens focal length was 22mm and $f/1.6$ aperture. The distance from the object to the lens was around 3 inches with a field of view of around 1.5 inches. The camera's settings were as follows: ISO 3000, focal length 15 mm, 720p, and 4 k resolution with 30 fps. The overall length of the video shot was around 2 minutes. The original video had a pixel size of 1200px width x 720px height, which was cropped to 800px width x 400px height. The reason for this crop was to reduce some unnecessary background and to center the ferrofluid. Other postprocessing procedures were adding music, "Big B" by Alvin Risk & Team Ezy, increasing contrast between colors, slowing down the frames per second to 45 fps, cropping different parts of the video, and rearranging the order of the frames. This was done to create a more dynamic video, with cuts showing clips where different light was used, as well as different angles capturing the fluid physics. The postprocessing and editing of the film was done using iMovie. To select some frames to be used as snapshots, the video was paused and several key frames were used to showcase important aspects of the video. Figures 2, 3, and 4 show these highlighted frames.

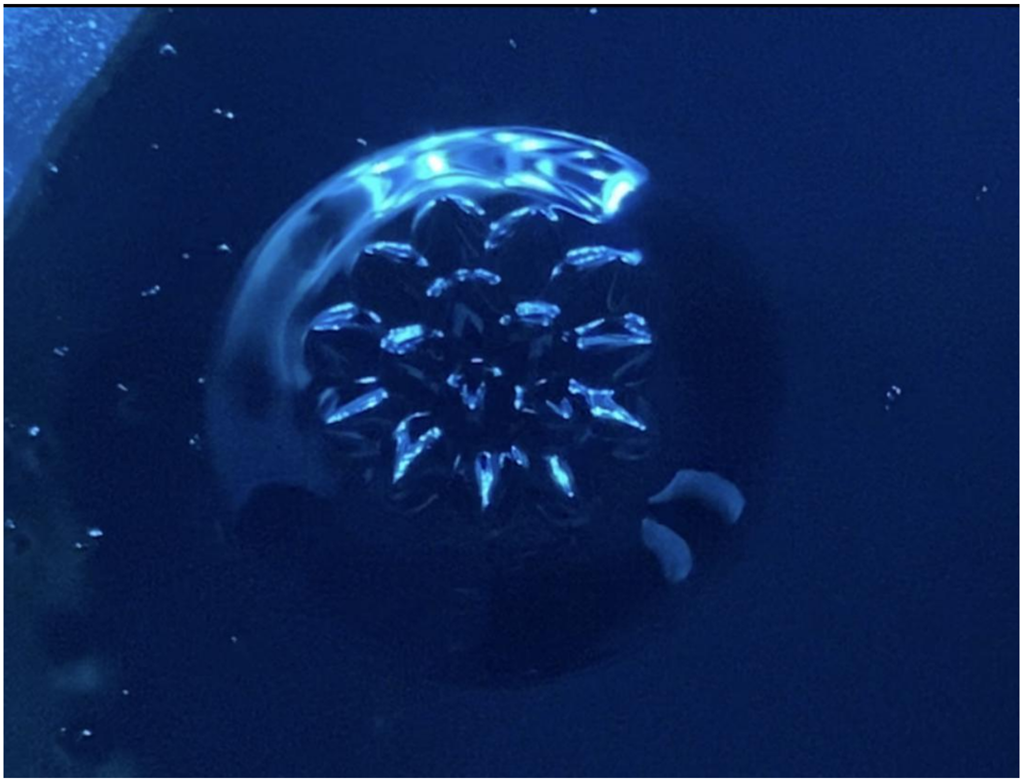

Figure 2: Main Snapshot of a ferrofluid's Normal Field instability, unedited

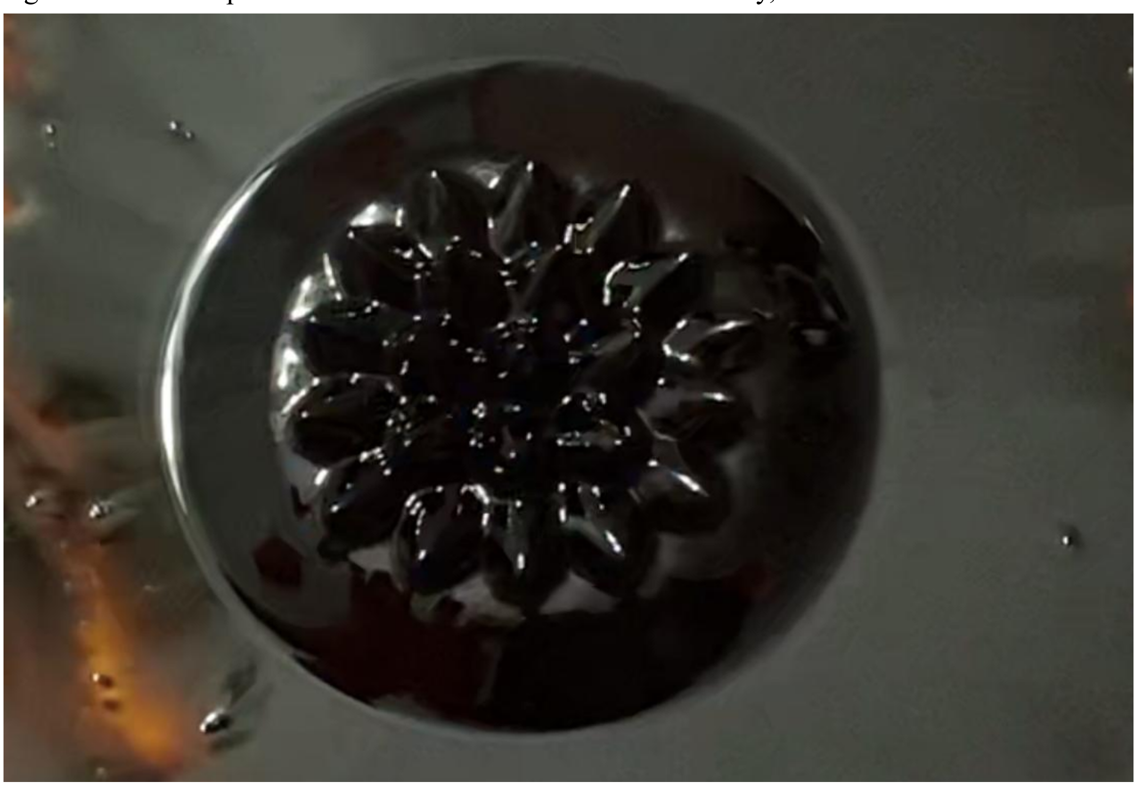

Figure 3: Snapshot of a ferrofluid's Normal Field instability with white lighting

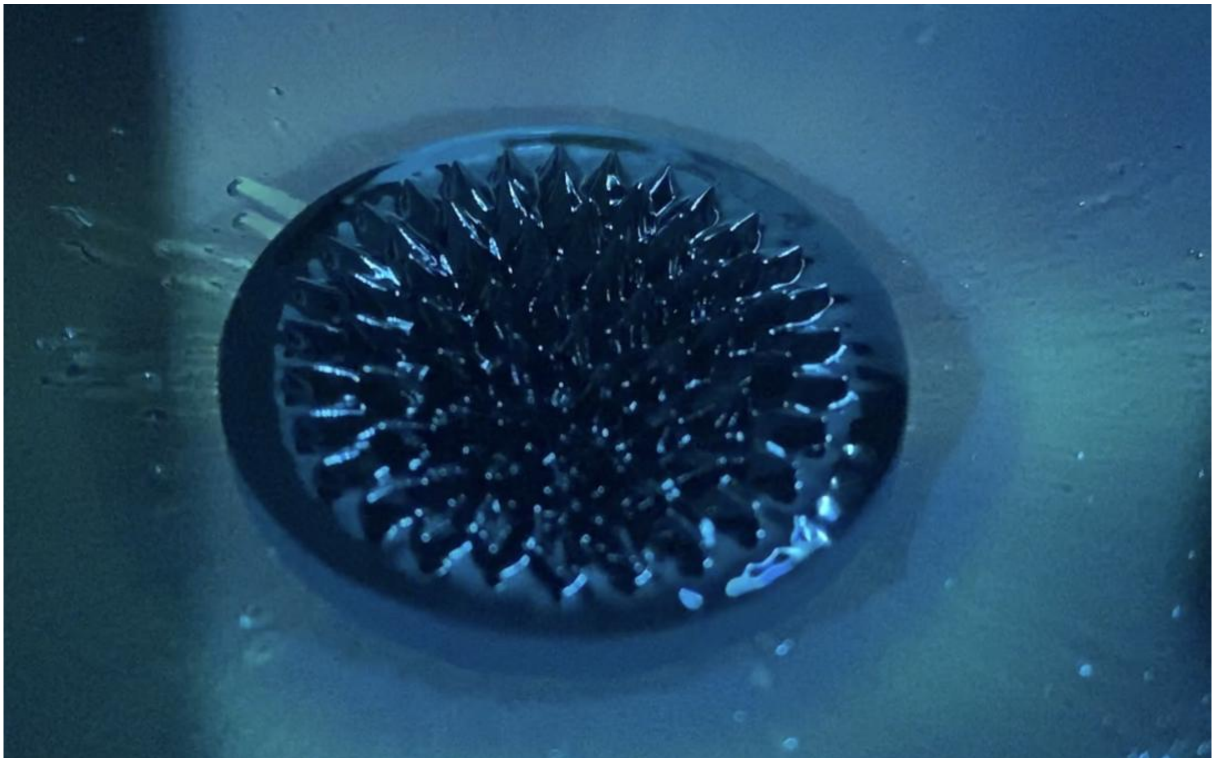

Figure 4: Snapshot of a ferrofluid's Normal Field instability with blue background lighting

Conclusion

The video recorded shows the interesting effects of a normal field instability on a ferrofluid, displaying both the physics behind this phenomenon and its aesthetic elements. Coupled with the changing lighting, it looks like a futuristic technology or scfi-fi being, which I think looks very cool. The setup was straightforward and easy to follow and reproduce. However, this experiment could be improved by using a better camera to capture higher quality footage. Another great addition to the setup would be to use a tripod to stabilize the camera and reduce shakiness in the film. Overall, I think the experiment was successful, the final video has a very unique aesthetic and feel, and the physics behind a ferrofluid's movement can be seen and appreciated.

References

[1] Andelman, David; Rosensweig, Ronald E. (2009). "The Phenomenology of Modulated Phases: From Magnetic Solids and Fluids to Organic Films and Polymers". In Tsori, Yoav; Steiner, Ullrich (eds.). Polymers, liquids and colloids in electric fields: interfacial instabilities, orientation and phase transitions. pp. 1–56.

[2] Berger, Patricia; Adelman, Nicholas B.; Beckman, Katie J.; Campbell, Dean J.; Ellis, Arthur B.; Lisensky, George C. (1999). "Preparation and Properties of an Aqueous Ferrofluid". Journal of Chemical Education. American Chemical Society (ACS). 76 (7): 943.

[3] Wang, J., Li, J., Kou, H. et al. Instability Pattern Formation in a Liquid Metal under High Magnetic Fields. Sci Rep 7, 2248 (2017). https://doi.org/10.1038/s41598-017-02610-6