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IV 2
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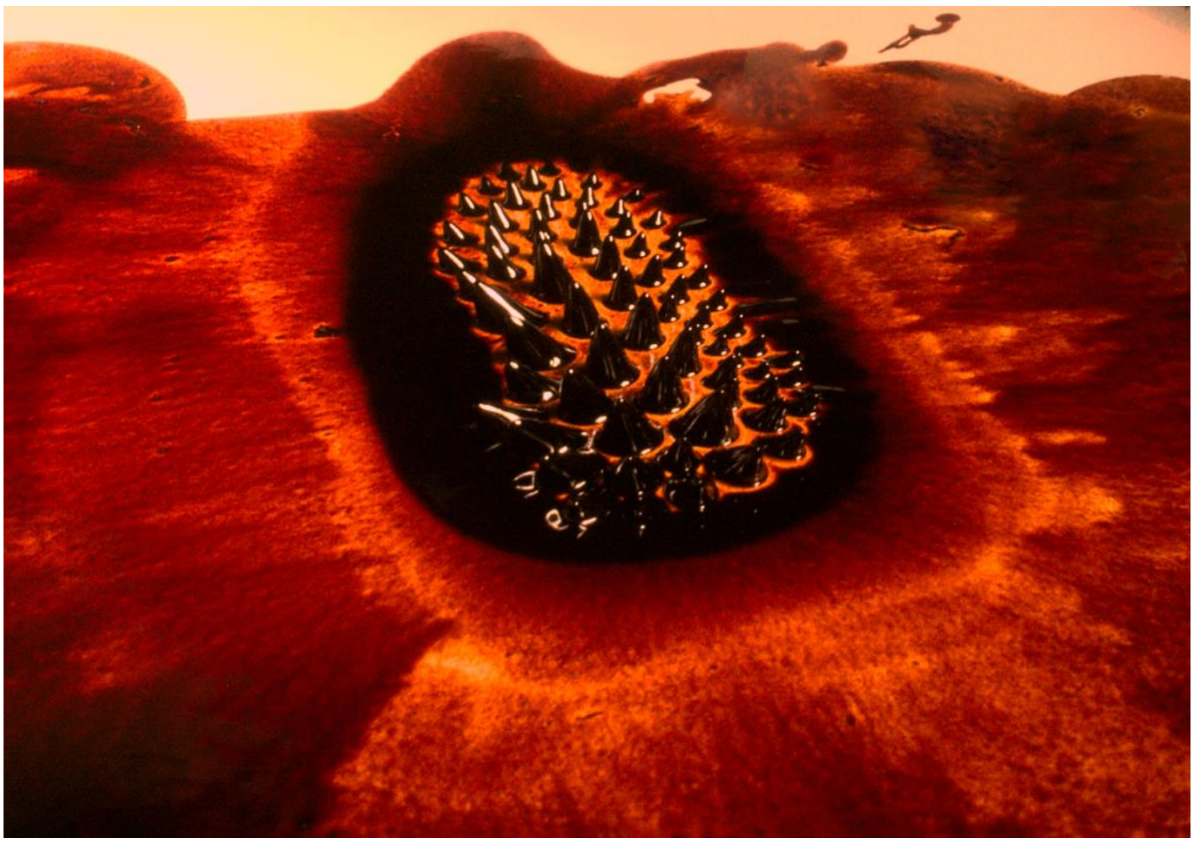
Ferrofluid



Introduction

The objective of this image is to capture the interesting pattern ferrofluid makes when a magnet is passed close to it. I would like to thank Anders, Sander, and Abdullah for assisting with lighting and maneuvering the magnet.

Apparatus

The apparatus for this image was quite simple in practice. A sketch of the setup is provided below.

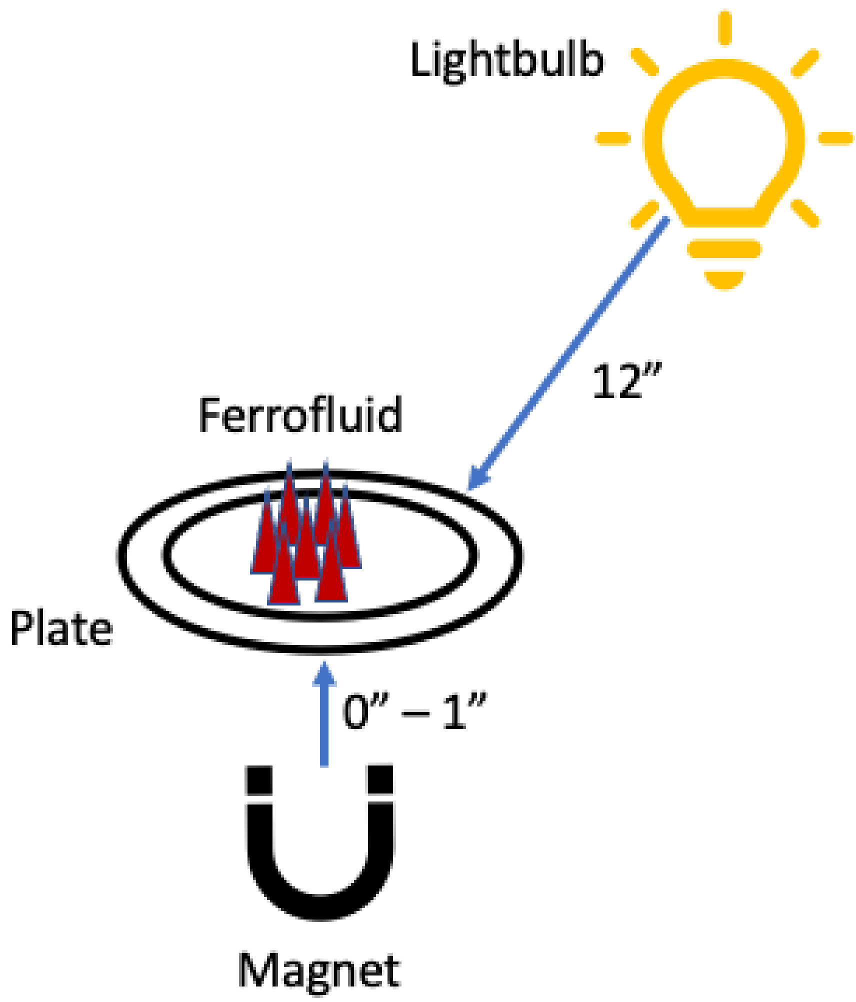


Figure 1: Apparatus

Ferrofluid was poured onto an opaque white plate and subsequently maneuvered by a magnet positioned below the plate. There was some variability in the magnet's position due to human error, as it is impossible to hold the magnet in the exact same spot indefinitely. In order to capture as much detail as possible, the plate was held 12 inches from the light source. This allowed the ferrofluid to reflect as much light as possible, improving the image from previous trials where the light was positioned farther away. Additionally, the light was positioned roughly 70 degrees above the horizontal relative to the ferrofluid. After some experimentation this was determined to be the best lighting for the image. Not pictured above is the camera position, which was approximately 3-5 inches from the ferrofluid.

Flow Physics

The primary fluid phenomena seen in this image is called Rosensweig instability, or normal field instability. This is characterized by the peaks and valleys as seen in the ferrofluid when it is exposed to a magnetic field. The fluid aligns itself along the magnetic field lines in order to transition to a lower energy state. This instability is seen only when the magnetic field reaches a critical value, H_{crit}, given by (Li and Huang)

$$H_{crit} = \left(\frac{2}{\mu_0} \frac{\left(\frac{\mu_0}{\mu} + 1\right)}{\left(\frac{\mu_0}{\mu} + 1\right)^2} \right)^{0.5} (\rho g \gamma)^{0.25}$$

Or, in nondimensional form

$$\frac{\mu_0 M_c^2}{\sqrt{g \Delta \rho_m \sigma}} = 2(1 + \frac{1}{r_p})$$

Where

$$r_p = \left(\frac{\mu_c \mu_t}{\mu_0^2} \right)^{0.5}$$

μ_0 is the vacuum permeability, μ is the magnetic permeability of the fluid, ρ is the density of the fluid, g is the acceleration due to gravity, γ is the surface tension, M_c is the critical magnetization, $\Delta\rho_m$ is the difference in mass densities across the fluid interface, σ is the interfacial tension, r_p is the dimensionless permeability ratio, μ_c is chord permeability, and μ_t is the tangent permeability. This magnetic field must overcome the forces of surface tension and gravity in order to produce this normal field instability. The spacing between the peaks seen in the fluid are given by

$$\lambda = 2\pi \left(\frac{\sigma}{g\Delta\rho_m}\right)^{0.5}$$

Interestingly, this is the same wavelength as occurs at the onset of Rayleigh-Taylor instability (Yoav Tsori).

Visualization Technique

The technique for this image is very simplistic and easily repeatable. As described previously, the ferrofluid (courtesy of Professor Hertzberg) was poured onto a plate and manipulated using a magnet.

The lighting of this shot was also very straightforward. This experiment was done with a single lamp as the light source in an otherwise dark room. The lamp, with a metal lampshade, was directed so that the 60-Watt bulb would impinge more powerfully on the ferrofluid. The lightbulb itself was positioned 12 inches from the subject of the image and roughly 70 degrees from the horizontal above the subject. Additionally, as mentioned before, the light source was placed roughly 120 degrees counterclockwise from the position of the camera. Camera flash was not used when taking this photograph.

Photographic Technique

This image was taken using a Canon EOS DIGITAL REBEL XS with an 18-55mm lens. The properties for my final image are tabulated below.

Image Property	Value
Shutter Speed	1/25 sec
Focal Length	32 mm
ISO	800
Aperture	f/29
Pixels	3888 x 2592

Table 1: Photograph Specifications

The lens itself was 4 inches from the ferrofluid structure. The fluid phenomenon was contained to a few square inches which is why the camera was positioned so close. The field of view of the camera at the distance I photographed was 6.75 inches in width and 4.5 inches in height.

The ISO setting was set to auto so the selection of 800 is the optimal setting for the light in the image. An aperture of f/29 was chosen so the entire structure of the ferrofluid was in focus, and due to aperture priority mode being used for this photo, the shutter speed was automatically selected.

Finally, Dark Table was used to make a few adjustments to the original image. First, the image was cropped to feature the actual ferrofluid over the distracting parts of the image. Second, the RGB curve was adjusted to increase contrast within the mid tones. Additionally, I used the heal tool to remove a glare in the upper right of the ferrofluid. The final adjustment was a color correction to make the image a brighter red, closer to what it looked like in person.

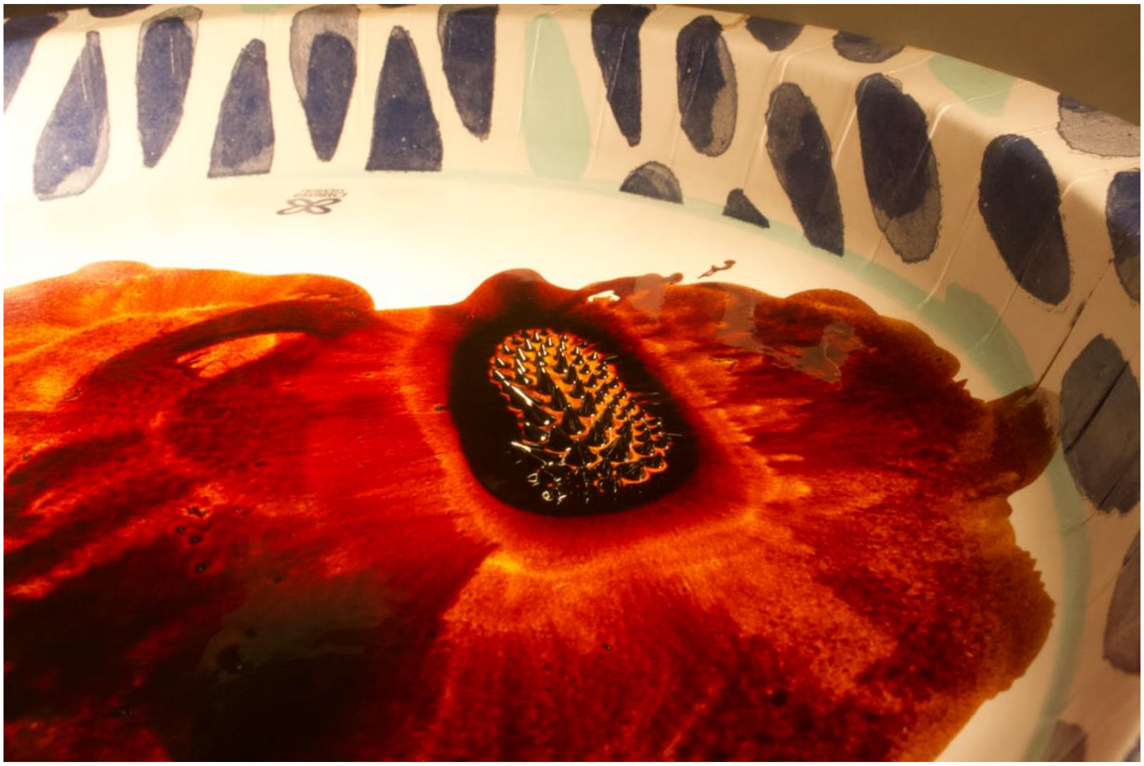


Figure 2: Original Image

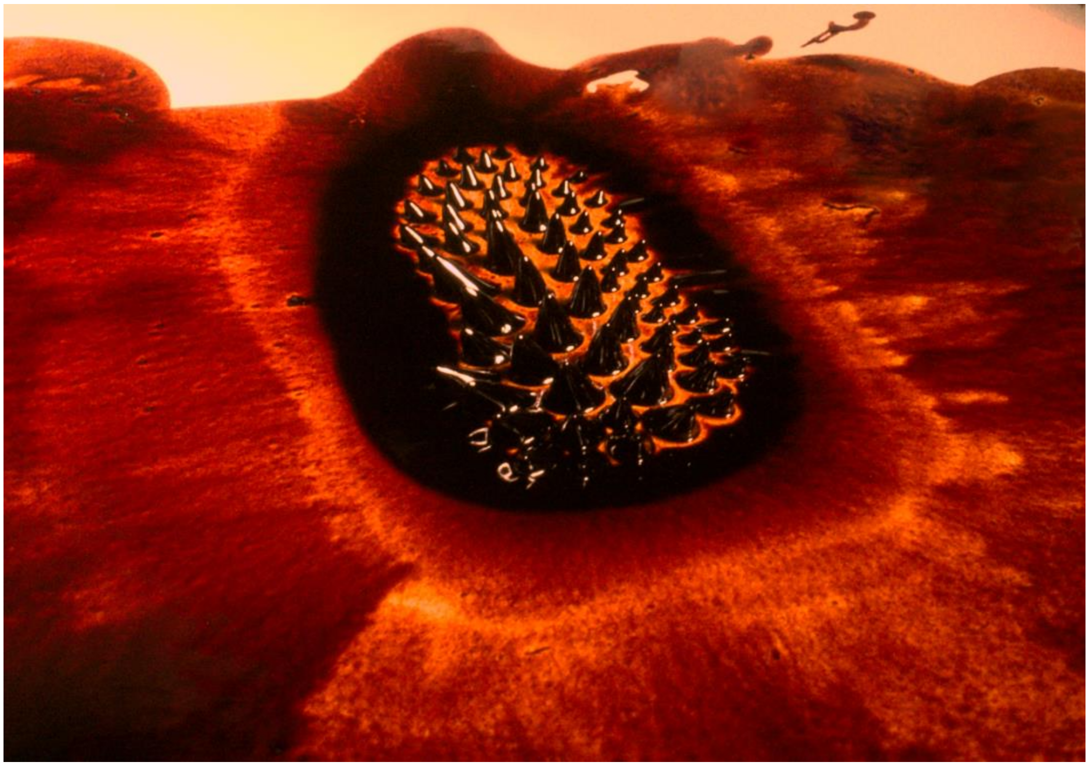


Figure 3: Final, edited image

Conclusion

This image shows how ferrofluid reacts to a magnetic field in its vicinity. The ferrofluid aligns itself with the magnetic field and ultimately allows us to visualize what we cannot typically see. I love the individual tendrils appearing out of seemingly nothing, and I enjoy the variability in the size of the tendrils as well. The one thing I would improve on a second attempt is my management of reflections. In post processing I had to remove a glare from the photo, which I would like to avoid in the future. Ultimately this image was able to capture the fluid phenomenon that I wanted to see.

References

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