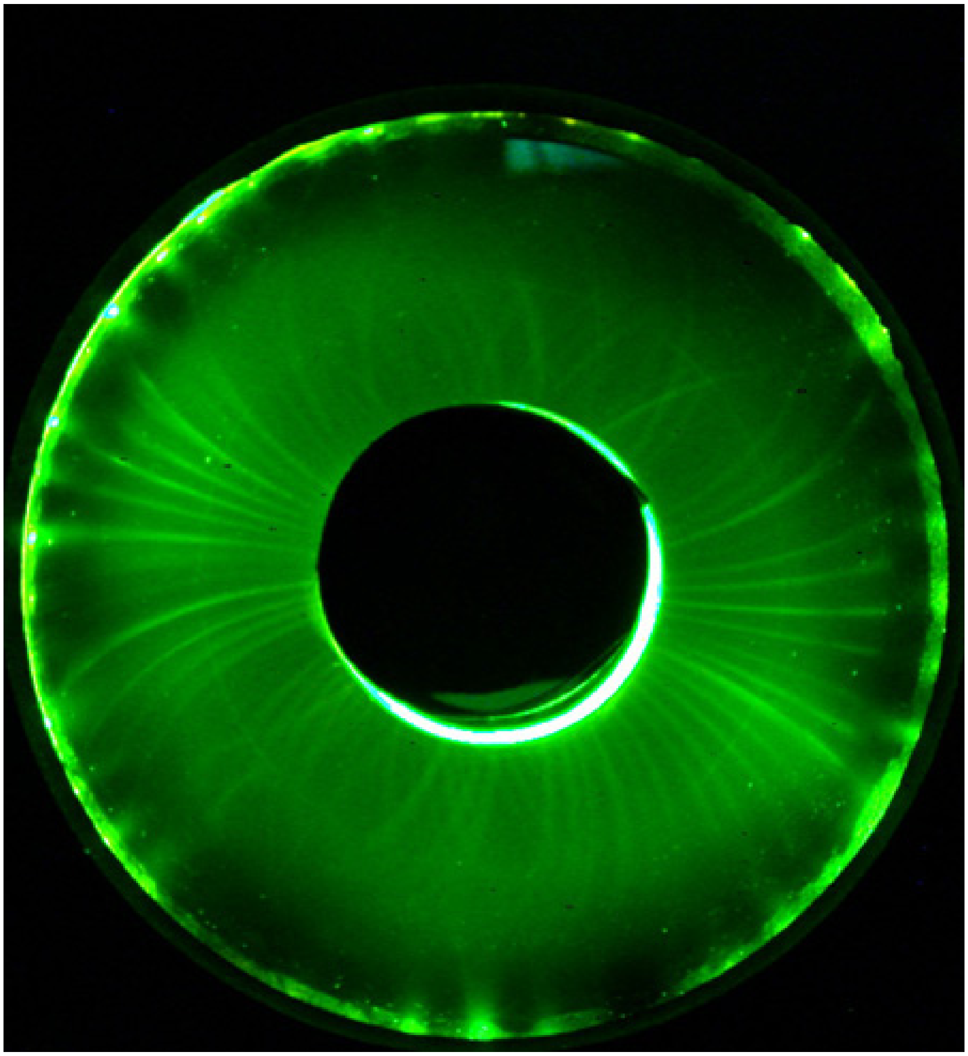
# Photographing Magnetic Lines of Constant Scalar Potential



This post is intended as an introduction to my paper, Photonic Dipole Contours. I have been asked to address some deficiencies in my paper such as background information and prior work. Please excuse my informal first person writing style; it is my most practiced form of writing.

In a nutshell, my work can be easily characterized as we took a bunch of lab photographs and found a pattern in every picture, and then found equations that produce the same pattern. I think this is the most pure form of physics; find something in nature, find the mathematics for it, and report it.

Let's start with the visualization instrument. All of our photographs use a Ferrofluid Hele-Shaw as the main subject. I think the first use of such an instrument was by D. E. Rosensweig in Ferrohydrodynamics (ISBN 0486678342). It is my understanding that Dr. Rosensweig used a Hele-Shaw cell to investigate the microscopic physical proprieties of ferrofluids.

Hele-Shaw cells themselves are mostly used in chemistry and fluid dynamics. Most readers probably don't know much about them. My understanding is that their main use is to study fluid viscosity and density gradients. A Hele-Shaw cell consists of two flat plates that are parallel to each other and separated by a small distance. At least one of the plates is transparent.

The instrument I used was built by Timm Vanderelli of Ligonier, Pennsylvania. He has a commercial business building these cells. Timm has a website at http://nanomagnetics.us and would glad to answer questions about his cells.

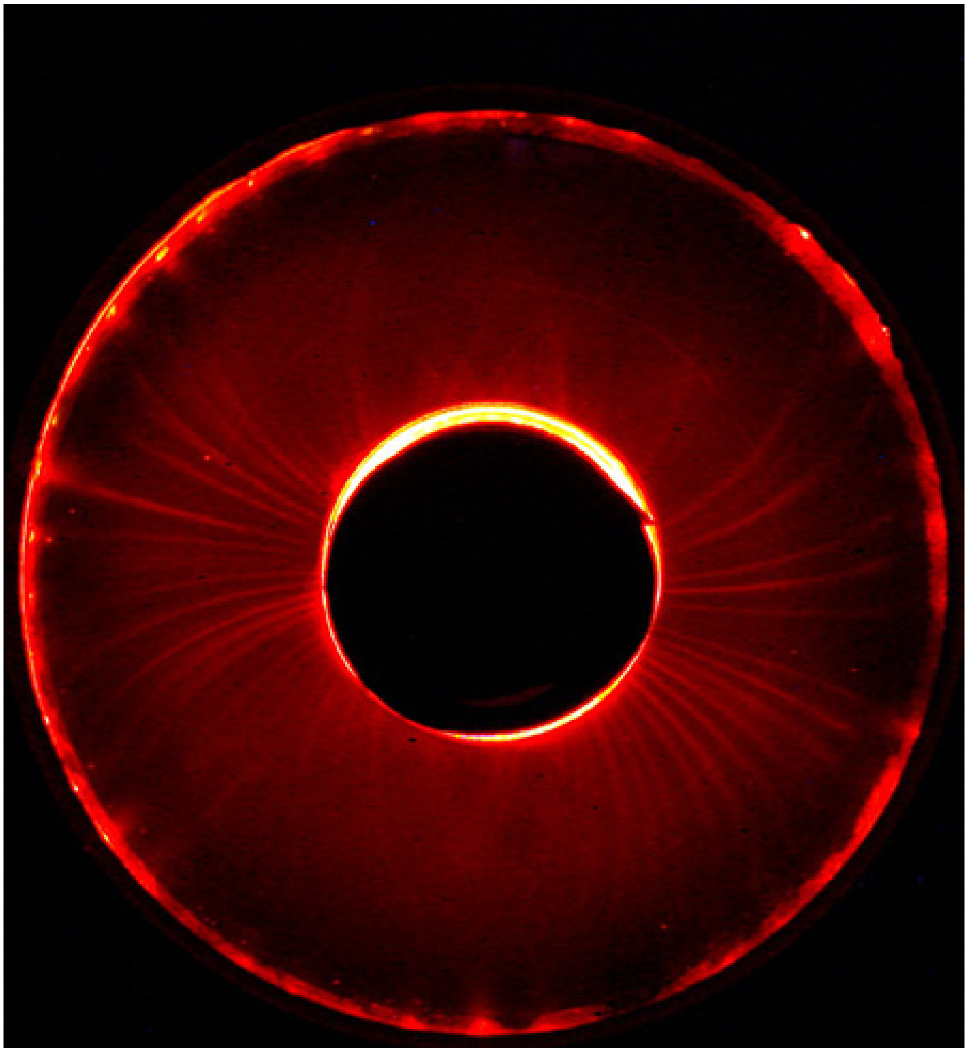
I would point out that my photographs use a completely different mindset than Dr. Rosensweig. The Hele-Shaw cell and external magnetic fields were well known tools he used to study unknown ferrofluid properties. Years later, my approach is the reverse. The ferrofluid is a well-known subject, but the light paths seen in cell have not been studied. My work brings the instrument and the external magnetic fields into question.

**Why does light curve when passing orthogonally through the cell? What mathematical pattern does it take? These two questions are the basis of my paper**.

Here is a picture of the cells used in the paper. These were made by hand and are quite large. The one on the left is 150mm diameter and the one on the right is 114mm diameter. The one on the right has a 38mm hole missing in the center. Notice the frames have radial holes for orthogonal light injection. In practice the magnets are placed right next to the glass for the large cell, and with the smaller cell, right in the middle of the donut. In the photos, there is a piece of black paper around the magnet in the center of the cell. The poles and light injection are in the xy plane, and the camera in the z plane.

Below is a picture showing the lines pattern we solved. The magnetic poles are located at where the lines cross in the photographs, and we believe related to Rosensweig peaks seen in many ferrofluid experiments.

In both the green photo above and the red photo below, the non-crossing lines are what we have studied. Notice each line starts at an edge radial light source and curves into the center of the cell where the magnet is located. The poles in this case are roughly at the 1'oclock and 7'oclock locations, nearly vertical. The lines we solved for are the curving horizontal ones.

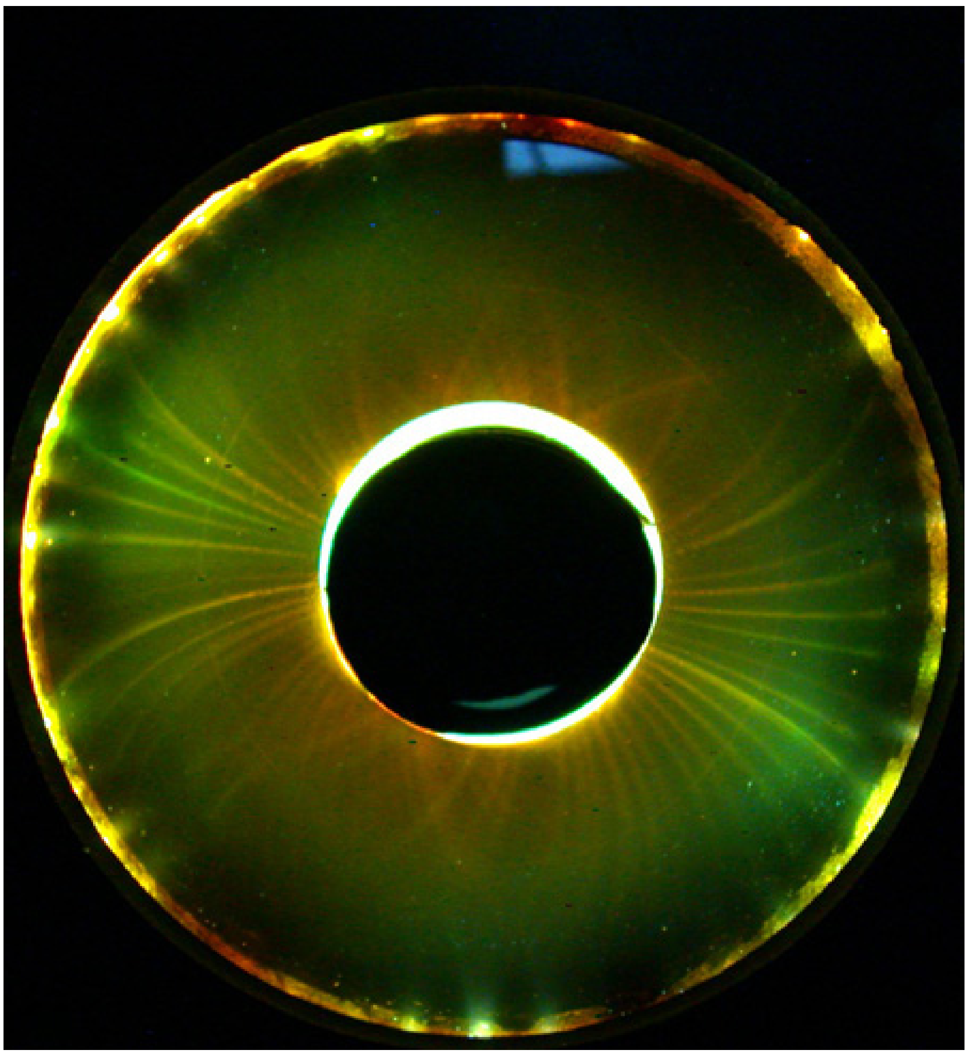


The curving lines are a bit problematic. Based on Snell's law the speed of light must be changing in the medium related to the location of the external field. In other words the complex impedance of the ferrofluid medium must be changing proportional to the locations of the magnetic poles. This line of thinking is not that strange, because we know that Helmholtz's equations do have a magnetic component for plane wave propagation in a dielectric. In this case, the ferrofluid medium is a light mineral oil.

But what are we seeing? It is clear that xy plane's orthogonal light must be scattering off the particles in order to reach the camera on the z-axis. Maybe there are long chains of particles and the light is just showing us chains of particles.

Well, in the photograph below, we have yellow and green light injection side by side. We were using fiber optics and our light source was misaligned. This gave us random red/yellow/green light sources at the edges. Notice in the photo below, around the 10 o'clock location there is a green line parallel to yellow line.

I believe having two different color lines parallel to each other proves the light is curving in the medium based on dipole field vectors and not just scattering off particle chains.



And finally, what pattern are the curve lines following? We found three different sets of equations that will plot the same lines within the margin of error of our experiments. The field dipole equation was chosen because we were dealing with magnetism. Where $V_M$ is a constant solved for each of the contour lines.

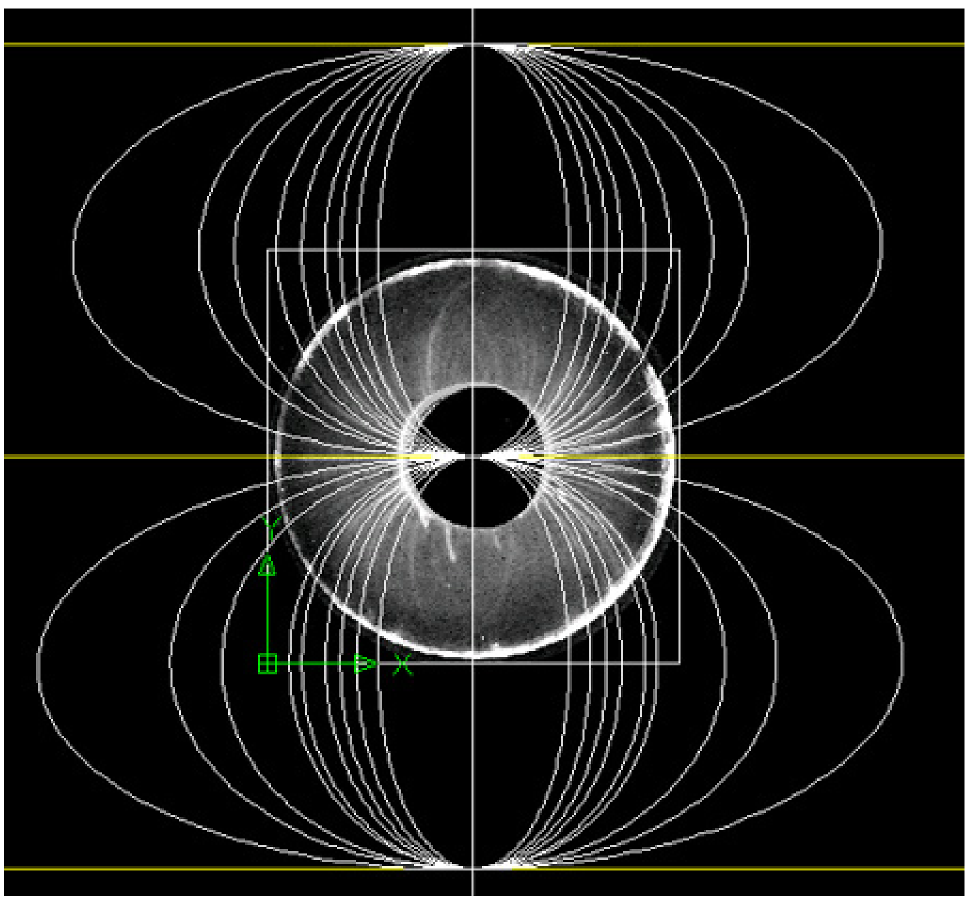
**I should stress the lines that we have photographed are not B- field flux lines, but instead a form of magnetic ‘voltage’ equipotential lines.**

$$V_M = \frac{1}{\sqrt{(x-x_{p1})^2+(y-y_{p1})^2+(z-z_{p1})^2}} - \frac{1}{\sqrt{(x-x_{p2})^2+(y-y_{p2})^2+(z-z_{p2})^2}}$$

We also found the well known fluid dynamics doublet equation would give very similar contour lines.

The first solution we found is not directly mentioned in the paper. If you connect the non-crossing curved lines into sets of elongated circles, you will find the same four foci points can be used to express all the lines into families of ellipses. This is where the paper’s working name came from, the round donut shape of the cell and field contour lines made the instrument look like an eye, and the lines can be completed into ellipses.

**Hence for two years, the paper’s working name was “Eye of Ellipses”.**

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