Measuring Magnetic Field Strengths Using Ferrofluids

Background:
A ferrofluid is properly classified as a stable colloidal suspension, composed of very small particles of magnetite suspended in a liquid medium. Each particle is coated with a stabilizing agent, usually a synthetic hydrocarbon, to prevent them from clumping together when they are exposed to a magnetic field. In spite of the name, ferrofluids are not themselves magnetic, but only display magnetic properties when they are in the presence of a strong magnetic field.

Ferrofluids are one of the many applications of nanotechnology – a branch of science that deals with particles the size of atoms and molecules. The average size of a ferrofluid particle is about 100 Angstroms, or 10 nanometers. This is smaller than a magnetic domain. Ferrofluids are a spin-off of the US Space Program from the late 1960's. They were developed as a way to control the flow of liquid fuels in space.

Ferrofluids have many uses industrially and medically. They are used in audio speakers to improve transmission, and also to detect domain structures in magnetic tapes, CD's and floppy disks, as well as metal alloys, garnets, steel alloys and geological rocks. They can detect defects in magnetic recording media as well as very tiny flaws in steel. Ferrofluids can be combined with a liquid polymer to create magnetic plastic. They can be easily reclaimed and recycled in the environment due to their high density and magnetic properties.

Purpose:
There are two purposes to this lab. The first is to examine the relationship between magnetic field strength and distance to see the inverse square properties of magnetic fields. These will be used for the second purpose, which is to develop a way to use the ferrofluid display cell to indicate relative magnetic field strength, and to detect magnetic domains.

Materials: (* optional)
Ferrofluid contained in a protective vial
A very strong, neodymium magnet and 1 ceramic cowmagnet with 5 ceramic sections.
*Pasco® Data Studio Science Workshop software with a magnetic probe attachment
Computer with Windows 98 or higher or Macintosh System 7.5 or higher to run the Pasco program
2 Centimeter rulers
Tape

Procedure A: Describing Magnetic Field Lines
1. Arrange the ceramic sections of the cow magnet so that the poles of each section are lined up N-S-N-S, etc. with each section separated by two washers. Hold it so that it is horizontal and parallel to the floor.
2. Orient the ferrofluid vial so that it also is horizontal, and place it on top of and centered on the magnet.

3. Sketch or describe the appearance of the ferrofluid on this magnet. Record your observations in Table I of the data page.
4. Rearrange the sections N-S-S-N, washers in between each section, so that they repel each other. Be careful as they want to fly off the center pole. Screw the end cap on tightly.
5. Repeat steps 1-4 for this magnet.
6. Disassemble the cow magnet and reassemble the ceramic sections N-S-N-S as in step #1, but without the steel washers. Repeat steps 1-4 for this magnet.
7. Repeat steps 1-4 for a strong neodymium magnet.

Procedure B: Measuring Magnetic Field Strength (*optional)

*1. Tape a strong magnet to a horizontal surface so that it is in line with and touches the 0 cm end of a centimeter ruler.

*2. Place the Pasco® probe at the 0 mark on the meter stick, and record the strength of the magnetic field using the accompanying the computer program.

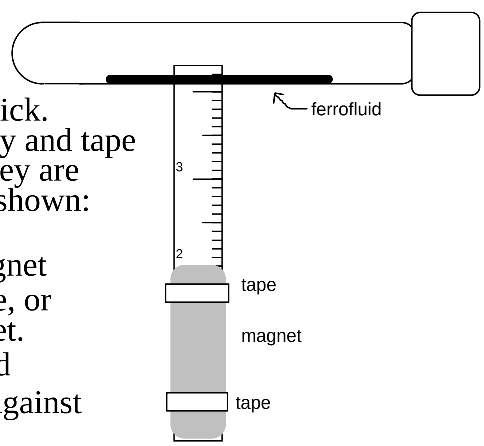
*3. Move the probe back ½ cm from the end and record the strength of the magnetic field again. Continue moving the probe back in ½ cm increments until fields for distances up to 5 cm have been recorded. Record all data in Table II.

*4. Make a graph of magnetic field strength vs. distance, placing field strength on the y-axis and distance on the x-axis.

(steps 1 – 4 can be omitted if the Pasco probe is not available. Use the data provided in Appendix Table IA pg. 7 instead).

5. Untape the magnet and meter stick. Hold a centimeter ruler vertically and tape the magnet to one end so that they are both held vertically together as shown:

   It will help to tape the ruler/magnet combination to a vertical surface, or stick it up against a metal cabinet. That will free your hands to hold the ferrofluid vial horizontally against the ruler as shown:



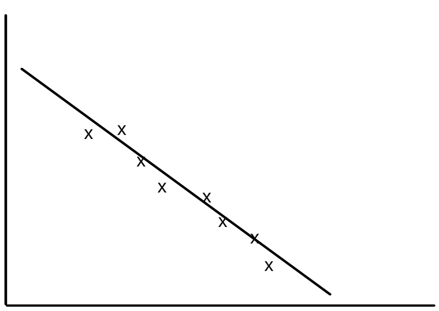
6. Hold the ferrofluid vial horizontally so that the edge of the vial touches the top of the magnet. Measure the width of the ferrofluid and record this value in Table II. Sketch or describe the appearance of the fluid in the space provided.
7. Move the vial up so that it is ½ cm from the magnet and again measure the width of the fluid and describe or sketch the appearance of the ferrofluid in the vial.
8. Continue moving the vial away from the magnet in ½ centimeter intervals. Measure the width of the fluid at each interval, and either sketch or record the appearance of the ferrofluid at each interval.
9. Repeat steps 1-3 and steps 5-6 with another magnet and see if the ferrofluid behaves similarly when exposed to the same magnetic field strength.

A Word on Graphing

A graph is a picture of the data. It is a way to represent data so that trends and changes can be visualized. Line graphs are a way to visualize many data points individually and as a group. Since raw data points are rarely accurate on their own, the line representing the trend shown among all the data points **should not** be drawn “dot- to-dot” to include each point. Instead, a “best fit” line is drawn in such a way that most of the raw data points are scattered equally around the line, but not necessarily resting on it. **When you graph your data**, draw one “best fit” straight or curved line through the data points, and not a jagged point-to-point line that connects each dot.

The slope of a best fit line is equal to the derivative of the two values being graphed.

Examples of “best fit” lines through individual data points:



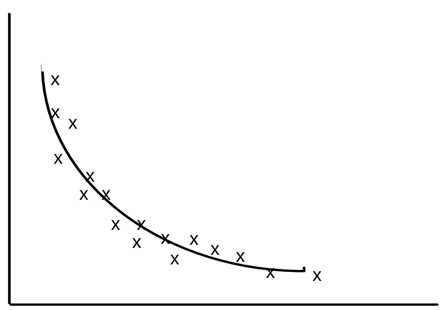


Table I

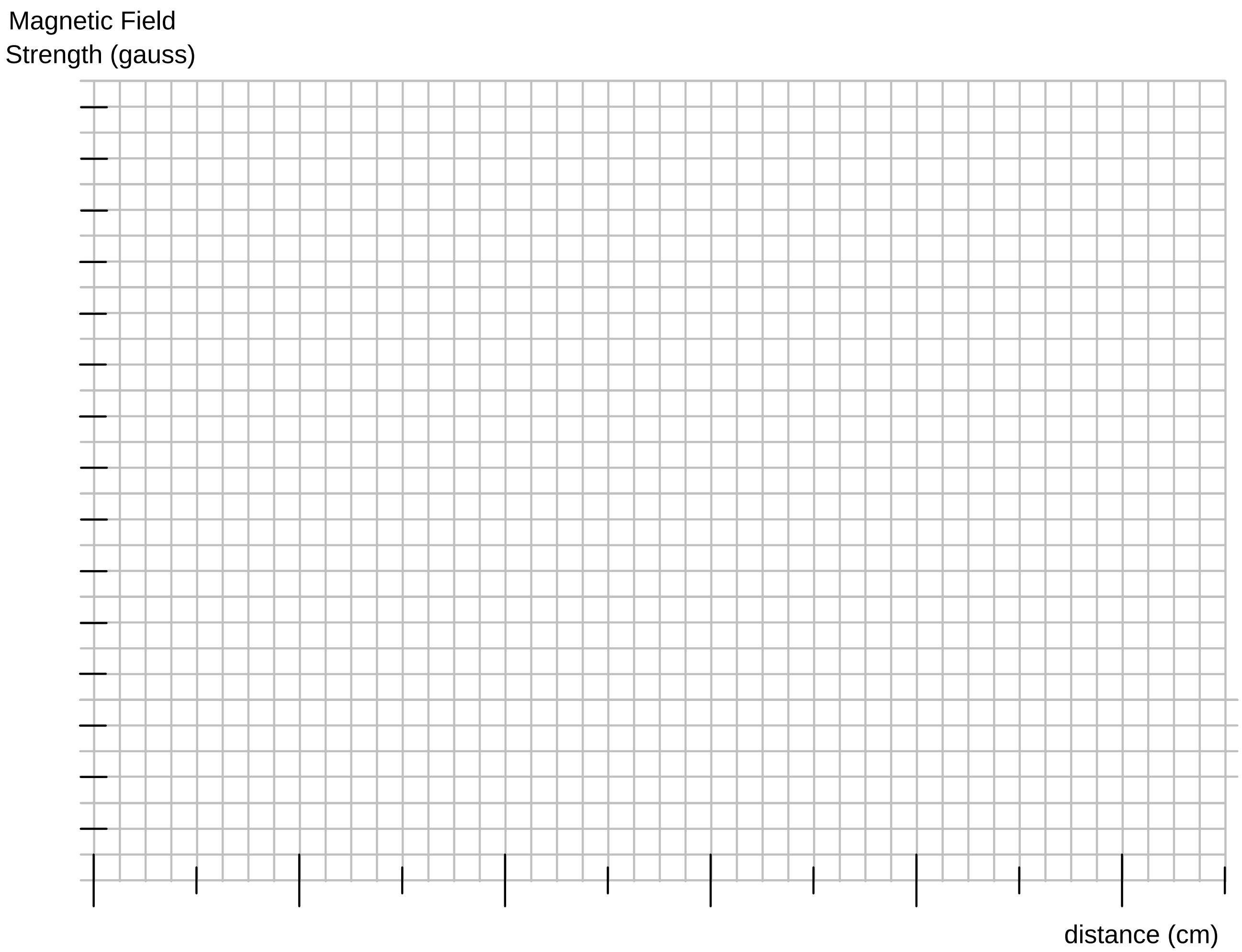
Detection of Magnetic Field Lines

	Appearance of Ferrofluid
Cow Magnet with N-S oriented sections	
Cow Magnet with N-N and S-S oriented sections	
Cow Magnet without Washers	
Neodynium Magnet	

Table II
Magnetic Field Strength

	Magnetic Field Strength (gauss)	Width of ferrofluid (cm)	Description or sketch of spikes	Height of tallest spikes (cm)
Distance (cm)				
0.50				
1.00				
1.50				
2.00				
2.50				
3.00				
3.50				
4.00				
4.50				
5.00				

Graph of Magnetic Field Strength vs. Distance



Questions:

1. What is the shape of your magnetic strength vs. distance graph? _______________

2. How does magnetic field strength change with distance? ____

3. Is the relationship between magnetic field strength linear or exponential? _______________________________________

4. Name 2 other forces that exhibit the same type of relationship between field strength and distance as that between magnetic field strength and distance.

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5. How does the shape of the ferrofluid change as magnetic field strength increases?

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6. What happens to the width of the ferrofluid in the vial, as the magnetic field strength increases?

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7. How does the appearance of the ferrofluid next to the cow magnet with disks arranged N-S compare to the appearance of the ferrofluid next to the cow magnet arranged N-N-S-S

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8. How could you use ferrofluids to determine the strength of a magnetic field?

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Insight: ____

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Appendix

Magnetic Field Strength Data:

Table IA

	Magnetic Field Strength (gauss)	Width of ferrofluid (cm)	Description or sketch of spikes	Height of tallest spikes (cm)
Distance (cm)				
0.50	530	2.0	About 20	1.1
1.00	340	2.3	About 15	1.0
1.50	210	2.7	About 9	0.9
2.00	140	3.5	About 9	0.8
2.50	100	4.0	5	0.4
3.00	75	5.0	None	Flat
3.50	53	6.5	None	Flat
4.00	43	7.0	None	Flat
4.50	33	7.0	None	Flat
5.00	25	7.0	None	Flat

