

Nanomagnetism: A Threshold of Interaction

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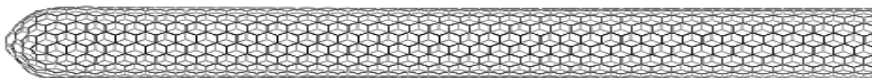
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July 2009

Please cite as:

Sederberg, D., & Bryan. (2009). *Nanomagnetism: A threshold of interaction*. Retrieved on [insert date] from <http://www.physics.purdue.edu/psas>

This work was funded by NSF Award #ESI-0426328: NCLT: A Center to Develop Nanoscale Science and Engineering Educators with Leadership Capabilities



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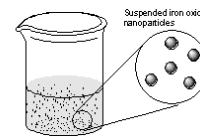
Part I: Shrinking Magnets Down to Size

Supplies you will need (per group):

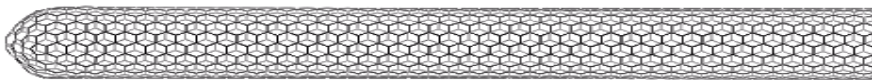
Apparatus		Chemicals	
Small beakers (150 mL)	2	FeCl ₃ solution	4.0 mL
Large waste beaker (250 mL)	share	FeCl ₂ solution	1.0mL
1 mL graduated pipets	2	NH ₄ OH solution	50mL
Distilled water (wash bottle)	share	Surfactant solution	1.0mL
Plastic weighing boat	1		
Stirring rod	1		
Bar magnet	1		

Part 1: Making nanomagnetic particles and the ferrofluid

1. Wear goggles and protective gloves.
2. Using a 1 mL plastic disposable pipet, add **4.0 mL** of FeCl₃ solution (yellow) to a clean dry 150 mL beaker. *Do not use this same pipet with any other solution.*
3. With a second pipet, add **1.0 mL** of the FeCl₂ solution (green) to the same 150 mL beaker. Swirl the solutions in the beaker to mix them thoroughly. *Discard the two pipets.*
4. Obtain 50 mL of NH₄OH (ammonium hydroxide) solution in a small beaker and a clean pipet. Using the pipet, add the NH₄OH solution to the beaker containing the mixture of iron solutions. Add the NH₄OH solution, **one drop at a time**, over period of about 5 minutes (2 to 3 drops per second) swirling constantly. The mixture in the beaker must be swirled **briskly and continuously** throughout this process. **Do not add more NH₄OH solution** until the solid formed with the addition of each drop disappears. Placing the beaker on a piece of white paper or paper towel will help you see the reaction.
5. A rust-colored precipitate will form during the addition of the ammonium solution. This precipitate is *magnetite*, an oxide of iron, Fe₃O₄. The particles of magnetite may be invisible at first, but will begin to be apparent as the color of the solution begins to change.
6. After *all 50 mL* of the NH₄OH solution has been added, continue stirring or swirling the contents of the beaker for a minute or two to keep the particles suspended and to make sure the reaction is complete.
7. Cease stirring and let the mixture rest a minute or two until the solid particles begin to settle.



Pictures taken from Chun, 2006



8. Hold a bar magnet under the beaker to help pull the solid magnetite particles out of the solution until the aqueous layer is clear.
9. Keep the magnet *in contact with the underside of the beaker* to hold the magnetic particles in place and decant the water layer into a waste beaker.
10. Remove the magnet and using a rinse bottle, squirt about 5 mL of distilled water into the beaker to wash the solid product. You may need to use a glass stirring rod to help dislodge the particles from the bottom of the beaker. Swirl the mixture to rinse the particles.
11. Again, holding the magnet under the bottom of the beaker to hold the particles in place, decant the excess water into the same waste beaker
12. Remove the magnet again and rinse the product one more time with distilled water. This time, *without using the magnet*, swiftly pour the entire contents of the beaker into a plastic weighing boat.
Rinse the beaker with several mL of water using the squirt bottle to remove any remaining particles and add the rinse to the plastic boat.
13. Holding the magnet under the weighing boat to keep the magnetite particles in place, pour off all of the water from the boat into the waste beaker. You may have to move the magnet back and forth slightly to “coax” the last drop of water out of the mixture.
The mixture in the weighing boat will have the correct consistency when the magnet is removed and the mixture just oozes along the bottom of the dish when tilted.
14. Examine the appearance of the fluid mixture in the dish when it is approached by the magnet from underneath. Draw a “side view” diagram using the outlines below to show what the fluid looks like both with and without a magnet underneath the dish.

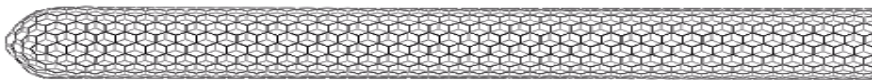


Fluid without magnet underneath



Fluid with magnet underneath

Describe what you think is happening when the magnet is placed under the bottom of the dish and taken away.



- Using a clean pipet, add 1 mL of surfactant (tetramethylammonium hydroxide solution) to the mixture in the weighing boat and, by moving a magnet in circular motion against the underside of the dish, mix the contents thoroughly to ensure that the solid particles are thoroughly mixed with the surfactant.

Please be careful to keep the magnet away from the top edges of the dish and away from the contact with the fluid.

Be careful with this liquid; it is toxic. If you get the liquid on your hands wash it off with soap and water and notify your instructor.

- Once the mixture reaches a uniform consistency, hold a bar magnet in to the underside of the weighing boat to hold the particles in place and pour off the excess black liquid into a clean empty beaker, as you did before during the rinsing. Once again, coax off as much liquid as possible from the mixture.

What remains in your weighing boat should be your final product.

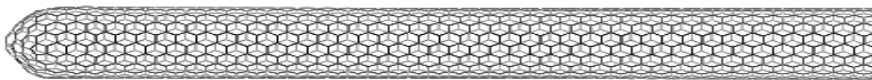
Part 2: Behavior of the ferrofluid

- Hold the bar magnet with one pole pointing upward from underneath the dish and observe what happens when you move it around. ***Remember, do not touch the fluid with the magnet from above.***

Describe what you observe when you move the magnet around under the dish.

- What happens when you take the magnet away?
- When you take the magnet away, does the fluid show any magnetic behavior? Does it stay magnetized? Describe what you would do to find out. Try it. What do you find?
- Draw another side view diagram in the outline below to show the appearance of the ferrofluid in the dish with a magnet underneath.





5. Experiment with holding the magnet in different positions (different ends, sides, flat, different distances from the dish) and describe what you find.

6. Explain what you think might be causing the ferrofluid in the dish to appear the way it does when a magnet is placed underneath.

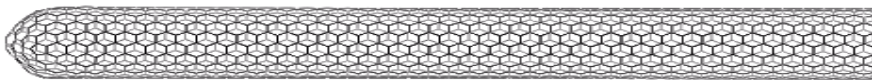
Wrap-up questions:

1. In the first part of the synthesis of the magnetic particles, the particles tend to settle to the bottom of the beaker.
 - a. What do you think causes the solid particles to settle to the bottom?

 - b. The solid magnetic particles in the final product (the ferrofluid) do not settle out, but stay suspended in the liquid. What do you think might be happening to cause these particles to remain suspended in the liquid without settling?

 - c. The solid particles in both the beginning and the end product consist of magnetite, or iron oxide. If the particles are identical in chemical composition, what do you think is the difference between them?

2. Think back. You can magnetize a paperclip or nail by rubbing it with a magnet. Think about these questions: What did have to do to unmagnetized the piece? What did this provide to the particles in the material? How did this demagnetize the object? Based on what you think happened in your previous investigations, write a few sentences to propose a theory to explain why you *think* the ferrofluid particles do not stay magnetized.



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Part II: Funny Things Happen on the Way Down to Nano

This activity will help you make connections between the way magnetic things behave at the nanoscale compared to larger scales and some of the factors that account for the differences. As you conduct the investigation try to keep in mind differences in size, the surroundings of the things you are investigating and the forces acting on those things.

Materials you will need:

Square dish containing iron filings in oil Compass
Bar magnet

Before we get started:

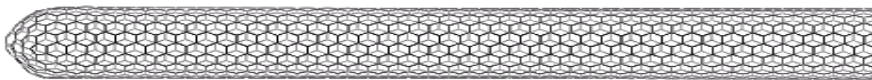
1. What evidence have you seen so far that would convince you that magnetic forces act as a field in space, rather than by two or more objects touching?

2. In terms of a specific cause to produce an effect, explain what you think causes more sugar to dissolve in hot tea than in iced tea.

Procedure

1. Obtain a square dish. Inside is a mixture of mineral oil and iron filings. What metric prefix do you think would best be used to describe the size of the iron filings?

2. Hold a bar magnet flat underneath the dish. Move the magnet around. Describe what you observe (a picture could serve as your description).



3. We previously examined the influence of the magnet's field on the compass needle to see the nature of the space surrounding a magnet. What do the iron filings in the dish show you?

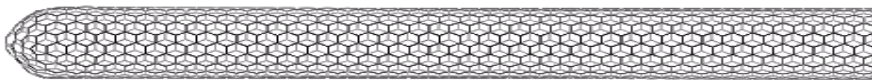
4. Pull the magnet slowly across the underside of the dish to form several parallel lines of filings. Remove the magnet.
 - a. Do the filings stay in place after the magnet is removed?
 - b. Do the iron filings exhibit a magnetic field even after the magnet is removed?
 - c. Does the pattern change by tilting the dish from side to side?

5. The ferrofluid consists of nanoscale particles of iron oxide in an oily surfactant. Describe two ways in which the iron filings in the dish with oil are *different* from the iron particles in the ferrofluid.

6. Think back magnetizing a nail. It is easy to magnetize something like a paperclip or a nail by simply rubbing it with a bar magnet.
 - a. What did you have to do to take away the paperclip's magnetic field?

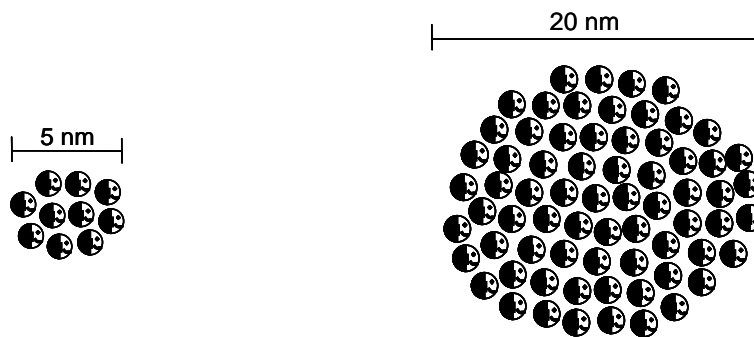
 - b. How were the particles making up the material affected by what you did?

 - c. What did this do to unmagnetize the object?

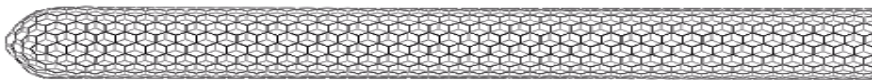


Let's explore where the energy comes from to keep a ferrofluid from retaining its magnetic field:

7. The models below represent two magnetic clusters of atoms, a 5 nm cluster and a 20 nm cluster. The pictures represent a cross section of each cluster. As you can tell from the orientation of the faces, the magnetic fields of the atoms are all pointing the same direction.



- a. Based on these two models, describe how the ratio of the number of atoms on the surface to the number of atoms inside *change* with the size of the cluster?
- b. Describe what would happen to the magnetic orientation of the atoms if you heated the clusters (increased the thermal energy of the particles they contain)?
- c. Which of the magnetized clusters do you think would be more affected by heating? Why do you think so?
8. Why would a paper clip, iron filings, and the particles in a ferrofluid, which are all made of similar magnetic solids, require different amounts of energy to affect their magnetic fields?



9. Think back to the ferrofluid. Where do you think the energy comes from to prevent the solid particles in the ferrofluid from retaining a magnetic field?

10. Think back to the graphic description of the types of magnetic behavior you drew in Investigation 1. Now for the big question:

Is ferrofluid a ferromagnetic or a paramagnetic material? Justify your answer.