Teacher Introduction for Nanotechnology Activities

Experiments in Nanotechnology: Ferrofluids is a lab activity created by William S. Vitori as part of a National Science Foundation Grant.

This particular activity was used in an Advanced Placement Chemistry class. It is recommended that this lab only be attempted by an advanced class or a group with good laboratory experience. The chemicals used are caustic and the ferrofluid easily stains skin and clothing. Proper safety equipment and gloves are essential.

The ferrofluids were produced in a single laboratory period of 90 minutes long. The time could have been reduced if the solutions had been prepared in advance. Students enjoyed "playing" with the ferrofluids they produced. The product showed excellent spiking while subjected to a magnetic field, comparable to that shown by commercially-produced ferrofluids.

This lab was used strictly to demonstrate a chemical reaction, laboratory techniques, and the properties of substances in the AP class. When they evaluated the activity, they stated that they would have liked to have spent more time learning about nanotechnology prior to the activity.

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Experiments in Nanotechnology: Ferrofluids

William S. Vitori
Chemistry Teacher
Elizabeth Forward High School

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Ferrofluids were originally developed and classified in the 1960s by Stephen Pappell at NASA as a method for controlling fluids in space. NASA initially used them as rotating shaft seals in satellites and are now being used to serve the same purpose in a variety of machines. The ferrofluid is held in place by permanent magnets and forms a tight seal, eliminating most of the friction produced in a traditional seal. These rotating shaft seals are found in rotating anode x-ray generators and in vacuum chambers used in the semiconductor industry. Ferrofluids are used in high-speed computer disk devices to eliminate harmful dust particles or other impurities that can cause the data-reading heads to crash into the disks. Ferrofluids are also used to improve the performance of loudspeakers. In a loudspeaker, electric energy is sent through a coil located in the center of a circular permanent magnet. The magnetic field induced by the electric energy causes the coil to vibrate and this produces heat and sound. Bathing the electric coil in a ferrofluid, which is held in place by circular permanent magnets, dampens unwanted resonances and also provides a mechanism to dissipate heat from excess energy supplied to the coil. This leads to an overall improved sound quality. Xerox has developed a new series of water-based ferrofluids based on hydrogel technology that gives ferrofluids high stability and optical transparency. The fluids have led to a unique solution to the generation of highly colored magnetic inks. The mean particle diameter, magnetization, and viscosity of the fluids can be tailored to meet unique solution requirements. Finally, there is much hope for future biomedical applications of ferrofluids. For example, researchers are attempting to design ferrofluids that can carry medication to specific locations in the body through use of applied magnetic fields. Other ongoing work is investigating the use of ferrofluids as contrast agents for magnetic resonance imaging (MRI).

What Will You Need?

<u>Synthesizing Ferrofluids:</u>

1. 2.0 M HCl solution
2. 2.0 M iron(II) chloride tetrahydrate in 2.0 M HCl
3. 1.0 M iron(III) chloride hexahydrate in 2.0 M HCl
4. 1.0 M ammonium hydroxide
5. 25% tetramethylammonium hydroxide in water (commercially available from Sigma-Aldrich, Inc.)
6. Plastic weighing boats
7. Disposable Gloves
8. Stir plate with Teflon coated stir bar
9. 100-mL beaker
10. Strong magnets
11. Cow magnets
12. Wash bottle with distilled water
13. Fountain pen

Procedures:

<u>Ferrofluids</u>:

<u>Safety Precautions</u>:
Gloves and goggles must be worn at all times. Hydrochloric acid and aqueous ammonia are corrosive and should be handled with care. Iron(II) Chloride is toxic, corrosive, and a mutagen. Iron(III) Chloride is corrosive. Tetramethylammonium hydroxide is a strong base and flammable. Caution must be exercised when handling any of these materials. Ferrofluids can be messy. This particular ferrofluid will permanently stain almost any fabric and it has a high pH. It is also difficult to remove from magnets.

<u>Procedure:</u>

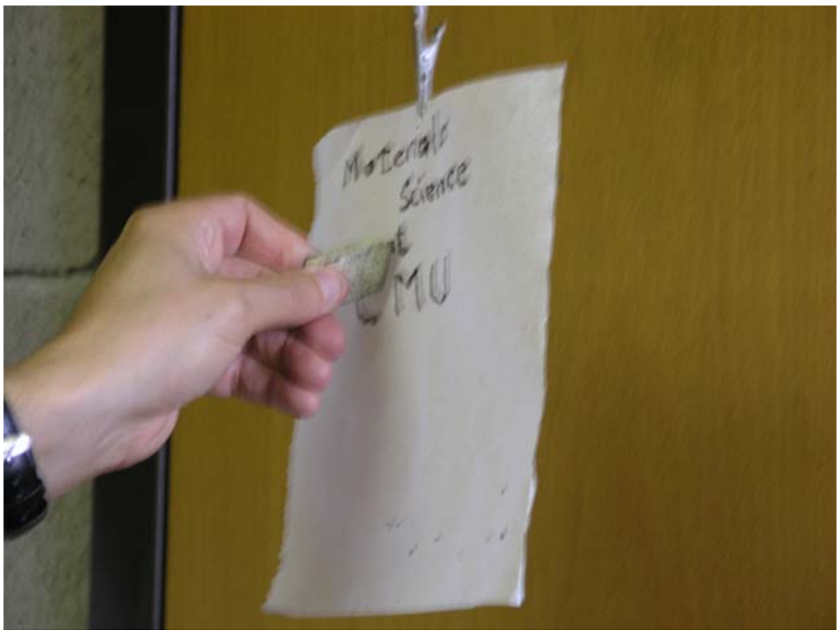
1. First you make a 2 M solution of HCl. (42 mL of concentrated HCl and 208 mL of distilled water. Then make a 2.0 M solution of iron(II) chloride in 2 M HCl. (19.9 grams of iron(II) chloride tetrahydrate in 50 mL of 2 M HCl). Make a 1.0 M solution of iron(III) chloride in 2 M HCL. (54.1 grams of iron(III) chloride hexahydrate in 200 mL of 2 M HCl.). Make a 1 M solution of aqueous ammonia. (50 mL of concentrated aqueous ammonia and 700 mL of water.) (**Note**: The solids used in making the solutions are hygroscopic and previously unopened reagents will work better. It is absolutely essential that there is no undissolved material in the solutions. Prepare the iron chloride solutions by adding the solid iron chlorides to the 2 M HCl solution. The acidic conditions prevent the formation of iron hydroxides. The iron(II) solution is susceptible to air oxidation and should be used within a week of preparation.)

2. Add 4.0 mL of 1 M iron(III) chloride solution and 1.0 mL of the 2.0 M iron(II) solution to a 100 mL beaker and add a stir bar. Place on a stir plate and begin stirring.
3. Continue stirring throughout the slow addition of 50 mL of 1.0 M aqueous ammonia solution over a period of 5 minutes. (This can be done by setting up a buret with a slow drip.) Magnetite, a black precipitate, will form immediately. After all of the aqueous ammonia has been added, turn off the stirrer and immediately use a strong magnet to work the stir magnet up the sides of the wall of the beaker. Remove the stir bar carefully with tongs or a gloved hand before it touches the magnet. Let the magnetite settle, then decant and discard the clear liquid without losing a substantial amount of solid. You can speed up the process by putting a magnet under the container. Transfer the solid to a weighing boat with the aid of a few squirts from a wash bottle.
4. Use a strong magnet to attract the ferrofluid to the bottom of the weighing boat. Pour off and discard as much clear liquid as possible. Rinse again with water from a wash bottle and discard the rinse as before. Repeat the rinsing a third time.
5. Add 1-2 mL of 24% tetramethylammonium hydroxide. Gently stir with a glass stir rod for at least a minute to suspend the solid in the liquid. Use a strong magnet to attract the ferrofluid to the bottom of the weighing boat. Pour off and discard the dark liquid. Move the strong magnet around and again pour off any liquid.
6. Hold a cow magnet up to the bottom of the weighing boat to check whether the ferrofluid forms spikes in the presence of a moderate magnetic field. If the fluid does not spike, or the spikes are small, remove the cow magnet and add one drop of distilled water, stir well with the glass rod and then check again for spiking with the cow magnet. If there still are no spikes, try adding one or two more drops of water. It should only take a few drops of water to obtain a good spiking effect. If the ferrofluid is too dilute, spiking will not occur either. If it is too dilute, hold the strong magnet under the weighing boat, then tilt the weighing boat to remove the excess liquid.

Results and Analysis

<u>Ferrofluids</u>

The ferrofluids made on July 8, 2005 and July 14, 2005 showed the characteristic spiking when a cow magnet was brought nearby. (When a high quality ferrofluid is brought into contact with a moderate magnetic field, such as that from a cow magnet, it develops spikes on its surface. These spikes, which may adapt a close-packed hexagonal pattern, are due to surface instability of the suspended particles. The surface instability associated with the ferrofluids causes small waves to be constantly present on the surface of the liquid. When a magnetic field is applied, the amplitude of the waves increases until they begin to form peaks. If the magnetic force is large enough to dominate the forces of surface tension and gravity, the spikes appear. The spikes increase in size as the magnetic field is increased. This is the easiest and most fascinating test for a high-quality ferrofluid. However, if the magnetic field becomes too great, the magnetic particles will reversibly precipitate from the solution.) These ferrofluids were transferred to a vial so that I could see if it could be used as a magnetic ink as found in the United States Currency. Using a "calligraphy" pen, I was able to write "Materials Science at CMU" on a sheet of lightweight paper. When a neodymium magnet was brought neat the paper, the paper was attracted toward the magnet!



Ferrofluids:

Many science students are aware of the fact that the ink used in US currency can be attracted by a strong magnet. Many of us have either shown a video on this or illustrated this phenomenon using a neodymium magnet. This activity allows students to synthesize a "ferrofluid", which can be used as an ink, similar to the one used by the US Department of Bureau and Engraving. This activity allows teachers to have their students do some research ahead of time on ferrofluids; how they were developed, and their many uses now and possibly in the future. Since writing skills are an integral part of the Pennsylvania State Standards Assessment Exam, instructors may have each student write a report on their research findings. The spiking of the "ferrofluid" is just another way to spark the students' excitement in science and the "nano-world".

References

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