Dancing Magnets (Ferrofluids) Lab
Instructor Guide

Objective

Investigate the properties of a material that acts differently when it is nanometer sized to create a model to explain the forces between objects.

Alignment to NGSS Standards

HSPS35 ENERGY: Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to interaction.

Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.

[*Assessment Boundary: Assessment is limited to systems containing two objects.*]

Evidence of 3-D learning:

- Science and Engineering Practices – *Developing and Using Models*
    - Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.
- Disciplinary Core Ideas – *PS3.C Relationships Between Energy and Forces*
    - When two objects interacting through a field change position, the energy stored in the field is changed.
- Crosscutting Concepts – *Cause and Effect*
    - Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

Materials

- 2.0 M Ferrous Chloride Hexahydrate Solution ($FeCl_2\ 6H_2O$). **Each student needs 1 mL.** Dissolve 19.9 g in 50 mL of 2 M HCl. Verify color as you mass the solid. This material dissolves readily but the solution reacts with oxygen and should be freshly prepared.

- 1 M NH_4OH. **Each student needs 50 mL.** Keep solution in dropper bottles on ice to slightly reduce vaporization, open containers of ammonia will smell unpleasant and their concentration will decrease leading to poor results. It may be possible to use household ammonia; its concentration varies and an initial estimate would be to dilute 1.0 L household ammonia to 3.0 L using DI water.
- 25% Tetramethylammonium Hydroxide Solution ($C_4H_{12}N{\cdot}OH$). A strong, fishy, amine odor indicates hydrolysis products which may interfere with the synthesis of ferrofluid. In this case adding an additional 1-2 mL may help. This is a caustic chemical so exercise caution!
- 2 M Hydrochloric Acid. Dilute 21.0 mL of 12M HCl in 250 mL of H_2O. This is used for making the iron solutions.
- Citric Acid: Use for neutralization of waste products, you will generate A LOT of waste.
- Steel Wool
- 150 mL glass beaker
- Glass dropper
- Glass Stir Rod
- Wash Bottle with Deionized H_2O
- Plastic Weighing Boat
- Rare Earth Magnets (a set of two with an index card between them works well)

Instructor Procedures

1. Verify iron solution color is lime green to ensure that the solution is optimal. Fe(II) reacts slowly with atmospheric oxygen to become oxidized Fe(III).
   - 1 M $FeCl_3$ in 2 M HCl
   - 2 M $FeCl_2$ in 2 M HCl
2. Add 4.0mL of 1 M Ferric Chloride solution to a 150 mL beaker.
3. Add steel wool in small clumps and stir with a glass stirring rod to reduce the Fe(II) to Fe(III).
4. Continue stirring to dissolve the steel wool and adding more clumps until the solution color is green, not yellow green, more lime green.
5. Continue stirring throughout the drop-wise application of 50 mL of 1.0 M NH_3 solution over a period of about 5-10 minutes, adding approximately 1 mL every 10 seconds. Avoid addition that is faster than the solution can be mixed, but also avoid addition that is so slow that the particles grow large. CAUTION Although 1 M NH_3 is fairly dilute, NH_3 is a strong base with corrosive properties.
6. Let the magnetite settle. You can speed the settling process by putting a magnet under the glass beaker.
7. Decant and discard the clear liquid without losing a substantial amount of the solid. This works best if you keep a magnet under the container.
   a. Transfer the solid to a weighting boat with the aid of a few squirts from a wash bottle.
   b. Use a strong magnet to attract the ferrofluid to the bottom of the weighing boat.
   c. Pour off and discard as much clear liquid as possible, again keeping the magnet under the weight boat.
   d. Rise with water from a wash bottle and decant the rinse as before.
   e. Remove the magnet. Add 1-2 mL of 25% Tetramethylammonium Hydroxide solution. Again, use caution as this is a caustic and toxic chemical.
   f. Gently stir with a glass stirring 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 weighting boat. Pour off and discard the dark liquid. Move the strong magnet around and again pour off any liquid. If the ferrofluid does not spike, continue to move the strong magnet around, pouring off any liquid.

Calculation Notes

1.0M Ferric Chloride ($FeCl_3 \cdot 6H_2O$) Stock Solution:

$$\left(\frac{1.0\,\text{mol}}{1\text{L}}\right)\times\left(\frac{270.3\text{g}}{1\text{mol}}\right)\times\left(\frac{0.1\text{L}}{1}\right)=27.0\,\text{g of } FeCl_3\cdot 6H_2O \text{ in } 100\,\text{mL of 2M HCl}$$

2.0M Ferric Chloride ($FeCl_2 \cdot 3H_2O$) Stock Solution:

$$\left(\frac{2.0\,\text{mol}}{1\text{L}}\right)\times\left(\frac{198.8\text{g}}{1\text{mol}}\right)\times\left(\frac{0.1\text{L}}{1}\right)=39.8\,\text{g of } FeCl_2\cdot 3H_2O \text{ in } 100\,\text{mL of 2M HCl}$$

Verifying the Ferric Chloride stock solution

1. Pour 10 ml of 1.0M Ferric Chloride solution and 10 ml of 2.0M HCl into a 150 beaker.
2. Add a piece of steel wool to the solution. Mix the liquid with a stirring rod until a color change occurs – usually bright green – which indicates $FeCl_2$ (ferrous chloride).

Instructor Notes: *In precipitating magnetite, $FeCl_3$ and $FeCl_2$ react in a 2:1 ratio. The ammonia interaction causes magnetite (Fe_3O_4) precipitate. The next step is to suspend the magnetite in a carrier solution, which in this case will be the surfactant so the particles won't stick together when magnetized. Be sure to do the next procedure in a well-ventilated area (fume hood).*

Day 2

Instructor Notes: *The magnetite coated with oleic acid is insoluble in water, but not in kerosene. The coated particles will leave the watery solution in favor of the more soluble kerosene. Ferrofluid is highly attracted to magnets, so maintain a barrier between the magnet and liquid (a clean glass slide would work). Also avoid contact with skin and clothing!*

Experiments on Ferrofluid

Instructor Notes: *Other experiments can be done. For example, float a penny on top of the ferrofluid, then move the fluid up the side of a container with a magnet, or use an electromagnet to explore the lines of force as they get turned on or turned off.*

Using the **ferrofluid,** place 10 mL into a falcon tube. Fill it to the brim with kerosene then screw the lid on tightly. Use a magnet at various distances; start farther away and progressively get closer to the fluid. Record your observations on the data table.