Student Activity

Ferrofluids

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Overview
Nanotechnology is a cutting-edge field with potential applications that scientists and engineers are still discovering. But the study of nanoparticles is not new. In the 1960s for example, scientists at NASA were trying to figure out a way to control liquids in space. They discovered that nanoparticles of metal could be dispersed in oil or water. The liquid could then be controlled by a magnet. These new liquids were called ferrofluids.

The nanoparticles in ferrofluids are typically about 100 angstroms, or 10 nanometers (nm) in size, making them small enough to remain suspended in a liquid medium.

In this activity, you will be making your own ferrofluids using three different methods.

Collect your Materials (per group of two students)

4 mL of $FeCl_3$
1.0 mL of 2 M $FeCl_2$
50 mL of ammonia solution
3 mL of tetramethylammonium hydroxide
2 g iron fillings
Karo corn syrup
10 mL of hydrogen peroxide
magnetic stirrer and magnetic bar
2 beakers
gloves
goggles
Petri dishes
50 mL and 10 mL graduated cylinders
stirring rod
paper towels
1 wash bottle with distilled water
(always keep vials containing solutions closed)

Procedure – Solution #1

1. Add 4.0 mL of 1 M $FeCl_3$ and 1.0 mL of 2 M $FeCl_2$ to a 100 mL beaker.
1. Stir with magnetic stirring bar.
2. Add 50 mL of aqueous ammonia drop-by-drop while stirring (should take about 5 min).
3. The color will darken as you add the ammonia and will form a black precipitate. Remove the stir bar and transfer to a Petri dish.
4. Decant and rinse three times with water.
5. Use a strong magnet to attract the magnetic nanoparticles to the bottom of the dish.
6. Add 1.5 mL of 25% tetramethylammonium hydroxide and discard any excess liquid.
7. Hold a strong magnet under the dish and move slowly.
8. Record your observations.

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Procedure – Solution #2

1. In a separate beaker, add 2 g of iron oxide.
2. Add 10 mL of 10% hydrogen peroxide drop-by-drop.
3. Swirl the beaker.
4. Leave undisturbed for 30 minutes.
5. Hold a strong magnet under the beaker and move it slowly.
6. Record your observations.

Procedure – Solution #3

1. Pour corn syrup (Karo) into a Petri dish, just enough to cover the bottom.
2. Add 2 g of iron fillings and stir until evenly distributed.
3. Hold a strong magnet under the dish and move it slowly.
4. Record your observations.

QUESTIONS

1. What observations did you make when you placed the magnet under each ferrofluid sample container? Was the reaction the same for all three samples? What could be the reason for the discrepancies?

2. What are spikes? Were the ones you observed permanent?

3. Is the magnetic effect of ferrofluid a physical change or a chemical change? Explain your answer.

4. From the balanced chemical equation in this method, calculate the number of moles of ferrofliuid (Fe_3O_4) that will be formed from 0.5 moles of $FeCl_3$.

5. Why was a surfactant added during the synthesis?

HOMEWORK

1. Do some research on your own to find four current and/or potential uses for ferrofluids?

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Summary
This activity introduces students to ferrofluids and their magnetic properties. Students work in groups of two to prepare: (1) a ferrofluid sample using ferrous and ferric chlorides,[1] (2) a ferrofluid sample using iron oxide and hydrogen peroxide,[2] and (3) a ferrofluid like substance from Karo (corn) syrup[3]. The materials and processes used are relatively safe and economical.

The activity culminates with comparing the spiking abilities of the three synthesized ferrofluids with a commercial grade one, varying the reactants to determine which produces best results, and developing possible explanations for the differences.

Background
Particles less than 100 nm are considered nanoparticles. With the aid of a suitable carrier liquid, metal oxide nanoparticles can form a stable suspension of colloids. There must be a surfactant in order for this synthesized ferrofluid to remain suspended in aqueous or other medium. One of the ionic surfactants used is tetramethylammoniun hydroxide (TMAH) because it produces an electrostatic repulsion in an aqueous medium. The hydroxide anions bind to the iron atoms at the surface of the magnetic nanoparticles, and the tetramethylammonium cations form a sheath around the negatively–charged particles through electrostatic attraction (see figure A). These sheaths of positive charges, thus, prevent the particles from agglomerating, which makes it easier to investigate its magnetic ability. Other surfactants like *cis* oleic acid can be used for oil-based ferrofluids.[1-2]

Integration
This project articulates the periodic table, oxidation/reduction, and stoichiometric concepts and provides a connection between them. It also produces a nanoparticle system that can be visualized by using a magnet. Students will complete an *anticipation guide* as a pre-activity to connect them to the lesson. They will then read about ferrofluids from a literature article and discuss their nature using a magnet summary reading strategy to target vocabularies. Students will compare their observations of the ferrofluid samples to a commercial sample and make comparisons. They will then calculate a given number of moles from the stoichiometric ratio of the balanced chemical equation and answer analysis questions.

In an oxidation lesson, the reactants ($FeCl_2$ and $FeCl_3$) are either oxidized or reduced to a divalent state respectively. The students will write balanced half equations for the reactions.

Materials Needed

1. Iron (II) chloride tetrahydrate, iron (III) chloride hexahydrate, can be purchased from Fisher Scientific or Edmund Optics.

2. **>**25% tetramethylammonium hydroxide is commercially available from Fisher Scientific, Edmund Optics, or Aldrich.

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3. Plastic weigh boats or Petri dishes, disposable gloves, magnetic stirrers and stir bars, strong craft magnets, cow magnets, 3% hydrogen peroxide can be purchased directly from Fisher Scientific, Edmund Scientific, or neighborhood science stores.

4. Iron oxide nanoparticles can be purchased from Nanophase Technologies Corporation, Romeoville, IL.

5. Commercial ferrofluid can be purchased from Ferrotec Educational Materials, Nashua, NH.

First step: *Prepare stock solutions in advance.* (yields 50 samples)

1. Prepare 2 M $FeCl_2$ by dissolving 19.9 g of the salt in 50 mL of 2 M HCl.. It should be prepared fresh as it reacts with oxygen. Each group will need 1 mL.

2. Prepare 1.0 M $FeCl_3 \bullet 4H_2O$ by slowly dissolving 54.1 g of $FeCl_3 \bullet 4H_20$ in 200 mL of 2 M HCl. This quantity will serve 50 students group. Each group will need 4 mL.

3. Prepare 1.0 M NH_4OH by dissolving 200 mL of concentrated ammonia solution in 3.0 L of water. Each group will need 50 mL.

4. The 25% TMAH is ready to use as purchased. Each group will need 2 mL.

Answers to questions

1. The ferrofluids show **spiked structures** in the presence of a magnetic field. The two laboratory-prepared fluids show smaller spikes than the commercially available fluid.

    a. This could be due to **the larger particle size** of the magnetite in the laboratory made ones (30 to 50 nm) which is larger than those in the commercial one (5 to 10 nm).

    b. Another reason is that the **surfactant attachments** may also have been **less efficient** and the particles may have agglomerated.

2. Spikes are a **pattern of uplifted particles** that result from placing a magnet near the ferrofluid.

3. The spikes are not permanent. They last only as long as there is a magnetic field in the proximity of the ferrofluid. They disappear when the magnet is removed.

4. The magnetic effect on the ferrofluid samples is a **physical change** because no new substance is produced (i.e. the particles are still made of magnetite).

5. **0.25 moles** of the ferrofluid containing magnetite (Fe_3O_4) will be formed from 2 moles of $FeCl_3$. The balanced equation for the reaction is $2FeCl_3 + FeCl_2 + 8NH_3 + 4H_20 \rightarrow Fe_3O_4 + 8NH_4Cl$.

6. A surfactant is added during the synthesis of the ferrofluid to surround the small particles and overcome their attractive tendencies and prevent them from agglomerating as shown below.

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7. (a) In targeted drug delivery, diagnosis of diseases like Alzheimer's disease, as carrier fluids; (b) for magnetically powered pumps, for maintaining vacuum seals; (c) as imaging agents, synthesis of copolymers and magnetic dispersion stabilizers; and (d) for laboratory experiments in schools.

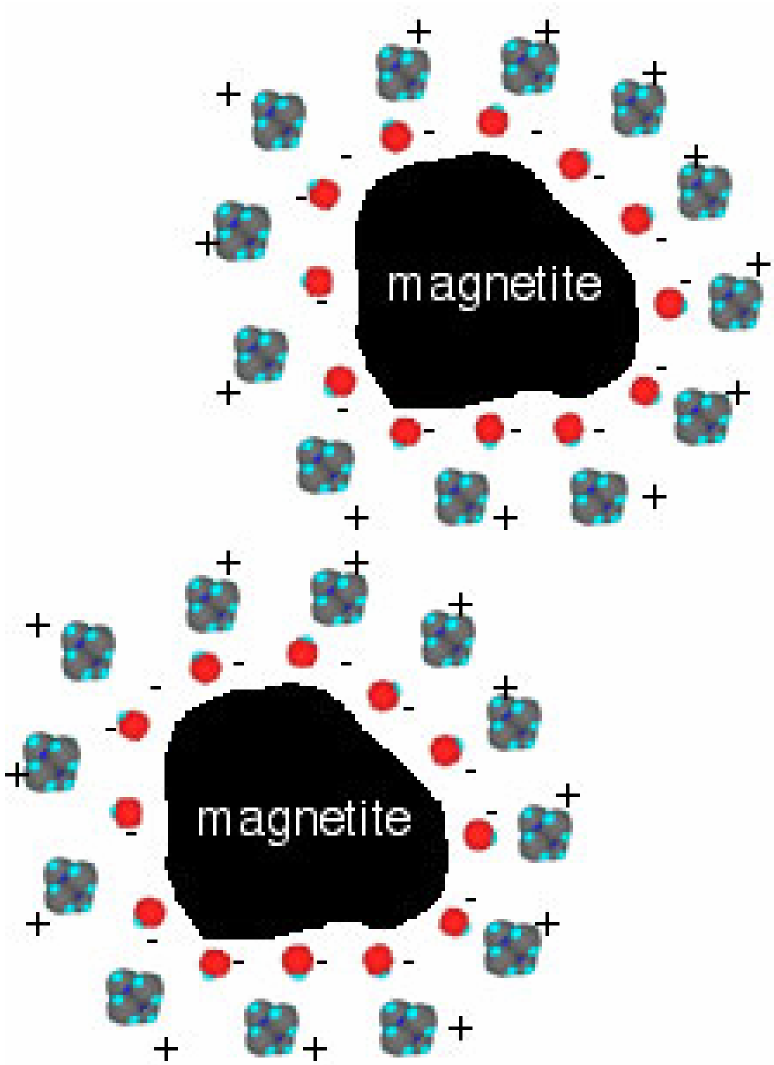

Figure A. How surfactants prevent agglomeration. Interaction of the hydroxide ions (red) with the magnetite and the interactions of the tetramethylammonium cations (blue and grey) with the water serving as the medium prevent the magnetite nanoparticles (black) from interacting with each other through electrostatic repulsion.

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