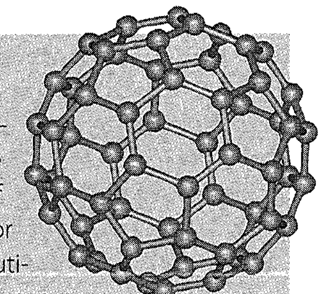
II .... CHAPTER 7

NANOMAGNETS: FUN WITH FERROFLUID

OVERVIEW



Ferrofluid provides an easy opportunity to introduce students to the fascinating properties of the nanoscale. It is essentially a liquid magnet made of nanosized magnetic particles suspended in water or oil. Not only does it demonstrate the strange and beautiful properties of the nanoscale, but is also illustrates a case where nanoparticles and their associated properties provide interesting opportunities for technological applications.

OBJECTIVES

- To investigate the properties of ferrofluid

Process Skills

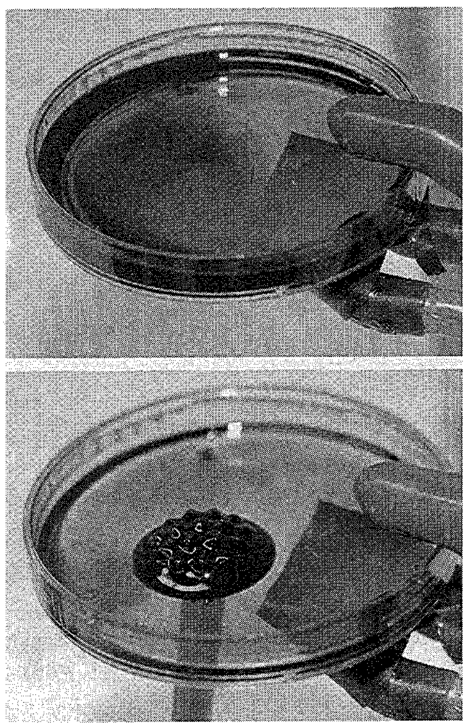
- Observing
- Predicting
- Modeling

Activity Duration

30 minutes

BACKGROUND

Did you know that the dollar bill in your pocket is magnetic? The United States Treasury uses magnetic ink in the one-dollar bill! Magnetic fluids have a variety of interesting technological uses. One particularly fascinating type of magnetic liquid is called *ferrofluid*. Ferrofluid can be purchased relatively cheaply and with the aid of a strong permanent magnet and close supervision, students can experience a truly amazing example of the beautiful phenomena that can occur using magnetic fields and nanomaterials.



Ferrofluid in a small petri dish. Top: Ferrofluid with no applied magnetic field. Bottom, Ferrofluid "spiking" in the presence of a strong permanent magnet on the underside of the dish.

WHAT IS FERROFLUID?

Ferrofluid is a colloidal suspension of small magnetic particles, usually made of iron oxide (magnetite). These particles are extremely small: about 10 nanometers in diameter. A coating, called a "surfactant" surrounds each particle and keeps them from sticking together and falling out of solution. Though the name suggests ferrofluids are made up of ferromagnetic particles (permanently magnetized like a refrigerator magnet), the particles are in fact "superparamagnetic." Superparamagnetism is a special property of the nanoscale. When a normally ferromagnetic material like magnetite is shrunk down to the size of a nanoparticle (<20nm or so), it loses its permanent magnetic capability. Ferromagnetism depends on many (thousands) of neighboring ferromagnetic atoms reinforcing each other to sustain a collective magnetic moment. When the particle gets too small, the reinforcing effect becomes too weak to achieve this phenomena. The particle instead is "paramagnetic," which means it becomes magnetic when in the presence of a magnetic field. The particles in the ferrofluid are just normal metal particles when there is no magnetic field near them, and the fluid as a whole acts like a normal fluid. However, when a strong magnet is brought close to the fluid, something very unusual and amazing happens. The fluid becomes more solidlike as the magnetic particles are magnetized by the applied field. The particles attract each other and form structures within the fluid. At the human scale, we see "spikes" and other strange shapes forming. The petri dish figure (p. 49) shows a case of some subtle "spiking" behavior. A small, strong magnet usually produces the best results.

Uses of Ferrofluids

Ferrofluids were originally developed at NASA for use as a liquid seal between moving parts. Because the fluid is magnetic, it can be held in place without leaking out of designated areas such as bearing surfaces. Ferrofluids are also regularly used in high performance speakers. All speakers use magnetic fields to produce the movement that ultimately produces the sound. Ferrofluids are incorporated into the speakers to damp out vibrations that create unwanted overtones. Ferrofluids are also being studied for use as inks in encryption or tagging technologies. In this case, very small patterns of magnetic material could be printed on important documents or objects that could be read later by magnetic sensors. In this way, these items could be identified uniquely using invisible and microscopic "bar codes."

Materials

Each group will need:

- Ferrofluid kits or vials
- Magnets (different shapes and sizes)
- Paper and pencil to draw resulting shapes

Note: Ferrofluid can be obtained from a variety of scientific supply companies. Ferrotec Corporation makes a demonstration kit that may be useful (see *www.ferrotec.com* for further information).

Procedures

ENGAGE Ask students to share different uses for magnets in and out of school. Challenge them to see if any of their coins or folding money is magnetic. Provide strong magnets and invite them to explore their money. Warn students to keep strong magnets away from their watches and electronic equipment.

Amazingly, American paper money has magnetic ink on it. See if your students can attract the bill with the magnet. Explain that ferrofluid is a colloidal suspension made up of many nano-sized particles. These particles (usually made of iron oxide) show interesting behaviors when brought into close contact with a strong magnet.

EXPLORE Distribute a small glass vial of ferrofluid and a magnet to each group and ask students to make predictions and observations about what will happen when the magnet is brought near the vial. **Note:** Ferrofluid is a very messy substance that needs to be handled with care. To keep the mess to a minimum, you may want to use it in small vials rather than allowing students to explore it in an open container. Gloves and goggles are needed if the ferrofluid is investigated outside of a vial.

Have students draw what they observe when the magnet is placed in different locations near the vial. Encourage them not to shake the vial of ferrofluid. Shaking it causes the ferrofluid to separate into droplets and reduces the spiking.

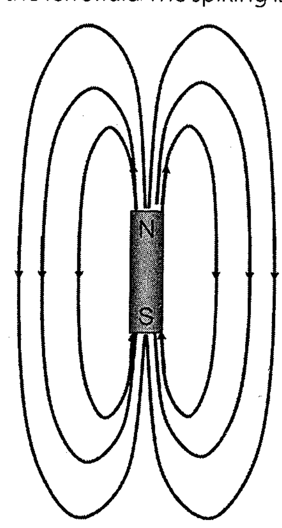
Ask the students to think about their observations and propose an explanation to describe the strange behavior of the fluid.

Challenge them to make as many different shapes with the magnet as possible.

EXPLAIN Demonstrate the spiking that occurs when the magnet is brought close to the ferrofluid. The spiking is a result of the ferrofluid aligning to the invisible magnetic lines of force. The spikes occur when the lines of force are perpendicular to the ferrofluid.

Turn the magnet and show students using an overhead projector what happens when the magnets are not perpendicular but are parallel to the ferrofluid.

Discuss the colloidal properties of ferrofluid and explain that the particles are about 10nm in diameter. Note that ferrofluids are made up of ferromagnetic particles that are superparamagnetic, a property that is found at the nanoscale. When a normally ferromagnetic material like magnetite is shrunk down to the size of a nanoparticle (<20nm or so), it loses its permanent magnetic capability. Ferromagnetism depends on many (thousands) of neighboring ferromagnetic atoms reinforcing each other to sustain a collective magnetic moment. When the particle gets too small, the reinforcing effect becomes too weak to achieve this. The particle instead is paramagnetic, which means it becomes magnetic when in the presence of a magnetic field. So the particles in the ferrofluid are just normal metal particles when there is no magnetic field near them. So the fluid as a whole acts like a normal fluid would act. However, when a strong magnet is brought close to the fluid, the fluid becomes more solid as particles are magnetized by the applied field. The particles attract each other and form structures within the fluid.



Magnetic Lines of Force

EXTEND Ferrofluid can be used to create wonderful designs. Take several small magnets and glue them into an interesting shape (a star, flower, or symbol). Place the magnet in the bottom of an aluminum pie pan and slowly add ferrofluid to the pan using a syringe. Watch as the ferrofluid takes on the shape of the magnet creating a three-dimensional design.

Ask students to think of new products that could be made or enhanced with ferrofluid. Explain that ferrofluids are often used in high performance speakers to dampen unwanted vibrations. What new applications could be made that use the unusual properties of ferrofluid? How would the ferrofluid enhance the product?

Homemade ferrofluid can be simulated with corn syrup, iron filings, and magnets. Stir the iron filings into the corn syrup and pour the mixture into a shallow dish. Use the magnet to manipulate the fluid into odd forms.

EVALUATE Check for understanding:

1. What makes ferrofluid behave the way it does?
2. Why is the behavior of ferrofluid considered to be a nanoscale phenomena?
3. Where might you encounter ferrofluid in your home?
4. Imagine you had a spill of ferrofluid in a creek or waterway. How could you clean it up efficiently?