MRSEC Education and Outreach Education and Outreach

Ferrofluid Activity Guide

Quick Reference Activity Guide

Activity Materials

Ferrofluid demonstration cells
Ferrofluid fish tank
Cow magnets

Starting Points

Do you think that this is a solid or a liquid? [Ask this while pouring the ferrofluid; i.e., without a magnet near the ferrofluid.]

Can liquids be magnetic? Have you ever seen a liquid that is magnetic?

How could you keep a liquid in place in outerspace (where there is no gravity)?

Can you make a penny float?

Demonstration Procedures

Use starting points to introduce the idea that this is a unique material that has both magnetic and liquid properties. In fact, there is no such thing as a liquid magnet (because magnetism is a cooperative property of electrons in a solid) but ferrofluid is the closest material to that. It contains nano-sized particles of magnetite, a magnetic compound found as black sand on some beaches, suspended in a liquid.

Participants should carefully look at the ferrofluid that is in the demonstration cell. Let them investigate the vial and its contents with and without a magnet. Most observers would say that the material in the vial is a liquid but in fact it is a mixture of nanoscale solid particles within a liquid. Ask them if they can describe the differences between solids and liquids. Most people are familiar with the states of matter of water if you need to give them an example. Observers should think about what the atoms are doing in each material and how closely they are spaced from one another. In a liquid the atoms or molecules are free to move around as opposed to a solid in which they are more tightly bound in one spot.

Participants should note the effects of the magnet on the ferrofluid. By bringing the magnet close to the ferrofluid they should see spikes appear that follow the lines of the magnetic field that is emitted by the magnet. This experiment is similar to a magnet and iron filings, except that the small particles make everything look smoother.

Participants can use the cow magnets to drag the ferrofluid up the sides of the ferrofluid tank. They should notice that when the magnet is removed the ferrofluid will flow down the sides of the tank like a liquid. The magnet should not be placed over the tank.

Participants can float a penny on top of the ferrofluid spikes by using a strong magnet. The density of the ferrofluid over the magnet is increased because of the large number of nanoparticles attracted. When the density is high enough, the penny floats. Note: It’s not a good idea to pick up the penny since it will stain your hands.

Fact Sheet

Ferrofluids have the fluid properties of a liquid and the magnetic properties of a solid. The commercial ferrofluids contain tiny particles (~10 nm diameter) of a magnetic solid suspended in a liquid medium.

Ferrofluids were originally discovered in the 1960s by researchers at NASA, where scientists were investigating different methods of controlling liquids in space. The benefits of a magnetic fluid were immediately obvious: location of the fluid could be precisely controlled through the application of a magnetic field, and, by varying the strength of the field, the fluids could be forced to flow.

Ferrofluids containing magnetite can be prepared by combining the appropriate amounts of an Fe(II) salt and an Fe(III) salt in basic solution, a combination that results in magnetite solid, Fe_3O_4, precipitating from solution. This lab is can be done in high school and college chemistry courses. See http://www.mrsec.wisc.edu/edetc/cineplex/ffexp/index.html.

Ferrofluids can either be water-based (particles suspended in water) or organic-based (particles suspended in oil, fluorocarbons, etc.) depending on their intended use. The ferrofluid used in the demonstrations is an organic-based ferrofluid. The ferrofluids made in chemistry courses is water-based for easier clean up.

Applications

LOW FRICTION SEALS

Ferrofluids have been used to create low friction seals for rotating shaft motors. A ferrofluid can behave as a liquid O-ring for a rotating shaft. The ferrofluid is held in place by permanent magnets and forms a tight seal, eliminating most of the friction produced in a traditional mechanical seal. These rotating shaft seals are found in rotating anode X-ray generators and in vacuum chambers used in the semiconductor industry.

COMPUTER DISK DRIVES SEALS

Ferrofluid seals are also used in high-speed computer disk drives to eliminate harmful dust particles or other impurities that can cause the data-reading heads to crash into the disks.

LOUDSPEAKERS

Ferrofluids are being used to improve the performance of loudspeakers. In a loudspeaker, electric current is sent through a coil located in the center of a circular permanent magnet. The magnetic field induced by the electric current causes the coil to vibrate, which produces sound but also unwanted heat. Bathing the electric coil in a ferrofluid held in place by circular permanent magnets dampens unwanted resonance and also provides a mechanism to dissipate excess heat energy. Both of these factors improve sound quality.

BIOMEDICAL APPLICATIONS

There is much hope for future biomedical applications of ferrofluids. For example, researchers are attempting to design ferrofluids that can carry medications to specific locations in the body through the use of applied magnetic fields. Other ongoing work is investigating the use of ferrofluids to increase contrast in magnetic resonance imaging (MRI).

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Background and Supporting Information

Many students are aware that certain materials can be magnetic or can respond to a magnet but most do not understand the underlying concepts of magnetism. Our goal is to introduce the idea that magnetism occurs due to things happening at the atomic and electronic level. Ferrofluids display the novel combination of properties of both a magnet and liquid when, in fact, there is no such thing as a liquid magnet.

How to Talk To the Public About Magnetism

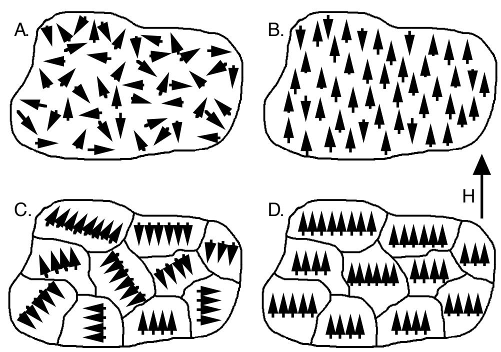
Magnetism was originally discovered in ancient Greece and China. *Magnetism* is derived from the term *Magnesia*, the name of a region in Asia Minor where lodestone, a naturally occurring magnetic mineral, was the found. Due to lodestone's ability to respond to the magnetic poles of the Earth, it was found useful in early navigational systems on ships.

Every magnet has a North Pole and a South Pole. Like poles repel and unlike poles attract. Whenever a magnet is broken, a north pole will appear at one of the broken faces and a south pole at the other, such that each piece has its own north and south poles.

The basis for magnetism has been verified down to the atomic level. Electrons have both an electrical charge and a spin. (Electron spin is a quantum mechanical property unlike the spin we experience in everyday life.) This spin gives rise to a magnetic field and can be oriented in one of two directions. When electrons pair up in orbit around the nucleus they have opposite spins and their magnetic fields cancel.

In some atoms there can be more electrons with spins in one direction than the other because they are not all paired up. The result is that there is a net magnetic field for the atom. Materials made up of atoms with a net magnetization are called *paramagnetic*. When placed in an external magnetic field, the atoms in a paramagnetic material will tend to align their fields with the external one, i.e., the North Pole of each atom will align with the North Pole of the applied magnetic field. Paramagnetic substances are only weakly attracted by a magnet.

A diagram showing the orientation of atomic magnetic fields in (A) a paramagnetic solid in the absence of a magnetic field, H; (B) a paramagnetic solid in the presence of a magnetic field; (C) a ferromagnetic solid in the absence of a magnetic field; and (D) a ferromagnetic solid in the presence of a magnetic field.



By comparison, some substances contain regions in which the atoms tend to line up in the same direction spontaneously so that they reinforce one another. Such a region is called a domain. A material containing these domains is called a ferromagnetic material. When placed in a magnetic field the domains will tend to align their fields with the external one. This alignment remains after the external field is removed, resulting in a permanent magnet. The magnetite nanoparticles in ferrofluid are ferromagnetic. Liquids cannot be ferromagnetic because their atoms are moving around too much align in domains.

IF THESE RELATE TO MODEL ACADEMIC STANDARDS, WE SHOULD LIST WHAT THEY ARE

By the end of the 2nd grade, students should know that*

- Magnets can be used to make some things move without being touched.

By the end of the 5th grade, students should know that

- Without touching them, a magnet pulls on all things made of iron and either pushes or pulls on other magnets.

By the end of the 8th grade, students should know that

- Electric currents and magnets can exert a force on each other.

By the end of the 12th grade, students should know that

- Magnetic forces are very closely related to electric forces and can be thought of as different aspects of a single electromagnetic force. Moving electric charges produce magnetic forces and moving magnets produce electric forces. The interplay of electric and magnetic forces is the basis for electric motors, generators, and many other modern technologies, including the production of electromagnetic waves.

Sources of Ferrofluid

Ferrofluidics	http://ferrofluidics.com/
Educational Innovations	http://www.teachersource.com

References

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* (Taken from "Benchmarks for Science Literacy," Project 2061, American Association for the Advancement of Science, 1993.)

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