Liquid Magnets (Activity)

Subject Area(s) **Material Science, Physics, Chemistry**

Associated Unit **NanoTech Unit or Magnetism**

Associated Lesson **N/A: Associated with Magnetism**

Activity Title **Liquid Magnets**

Image 1

ADA Description: Magnetic fluid (Ferrofluid) under an induced magnetic field

Caption:

Image file: NTUnit_Activity2_Heading.jpg

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http://actualityscience.blogspot.com/2010/07/liquid-metal-moving-art.html

Grade Level 11-12 (7-12)

Activity Dependency

Time Required 45-60 minutes (1 full period)

Group Size 3-4 students

Expendable Cost per Group US$ Variable

Summary
This activity is designed to introduce to students a unique fluid which its shape can be influenced by magnetic fields. Students will be introduced to concepts of magnetism, surfactants and nanotechnology by relating movie magic (popular culture reference: FRINGE) to practical science. Additionally, students will participate in a fun, engaging activity working with ferrofluids and nanotechnology. This activity serves best to supplement traditional magnetism activities and offer comparisons between large scale materials and nanomaterials. As a fun exercise students will be expected to observe the fluid properties as a stand-alone-fluid and under an imposed magnetic field. Students will understand the components of ferrofluids and there functionality. Also, students will be able to create drawings using magnetically controlled ink out of ferrofluids and create their masterpiece.

Engineering Connection
Ferrofluids have been around since the 60's for uses as audio speaker coolants and high end engineering seals. Recently, this technology has been a topic of research involving nano particle suspensions and engineering such materials to have greater magnetic properties under moderate magnetic fields. New applications have come into play with notable reference to targeted transport of drugs by an induced magnetic field. Material Scientists and Engineers are using basic fundamentals and newly acquired nanoscience to introduce particles small enough to transport through capillary systems and organs, have sufficient magnetization, and be biodegradable and nontoxic. Most importantly the fluid must behave like a fluid until a magnetic is present.

Engineering Category = #1,2

Choose the category that best describes this activity’s amount/depth of engineering content:

1. Relating science and/or math concept(s) to engineering
2. Engineering analysis or partial design
3. Engineering design process

Keywords

Ferrofluids, magnetic fluids, magnetic, fields, magnetize, nanotechnology, nanoparticles,

Educational Standards

Choose from http://www.jesandco.org/asn/viewer/default.aspx.

ITEEA (provide standard number, grade band, benchmark letter and text):

State/national science/math/technology (provide source, year, number[s] and text):

Texas Physics, 2009, grades 9-12, 112.47

1. **C.112.47 (1) Scientific processes. The student conducts investigations, for at least 40% of instructional time, using safe, environmentally appropriate, and ethical practices. These investigations must involve actively obtaining and analyzing data with physical equipment, but may also involve experimentation in a simulated environment as well as field observations that extend beyond the classroom.**
2. **C.112.47 (2) Scientific processes. The student uses a systematic approach to answer scientific laboratory and field investigative questions. The student is expected to:**
    a. (E) design and implement investigative procedures, including making observations, asking well-defined questions, formulating testable hypotheses, identifying variables, selecting appropriate equipment and technology, and evaluating numerical answers for reasonableness
    b. (G) use a wide variety of additional course apparatus, equipment, techniques, materials, and procedures as appropriate such as ripple tank with wave generator, wave motion rope, micrometer, caliper, radiation monitor, computer, ballistic pendulum, electroscope, inclined plane, optics bench, optics kit, pulley with table clamp, resonance tube, ring stand screen, four inch ring, stroboscope, graduated cylinders, and ticker timer;
    c. (J) organize and evaluate data and make inferences from data, including the use of tables, charts, and graphs
    d. (K) communicate valid conclusions supported by the data through various methods such as lab reports, labeled drawings, graphic organizers, journals, summaries, oral reports, and technology-based reports;
3. **C.112.47 (3) Scientific processes. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions within and outside the classroom.**
4. **C.112.47 (5) Science concepts. The student knows the nature of forces in the physical world. The student is expected to:**
    a. (D) identify examples of electric and magnetic forces in everyday life;
5. **5D TSW identify examples of electric and magnetic forces in everyday life. Students are able to distinguish between electric and magnetic forces.**
    a. • Examines Coulomb’s law and calculations of net electric forces using the superposition principle.
    b. • Define magnets, magnetic fields, magnetic forces and magnetization.
    c. • Explain the right hand rule for magnetism.
    d. • Describe how moving charges in a magnetic field experience a force.
6. **5G TSW investigate and describe the relationship between electric and magnetic fields in applications such as generators, motors, and transformers. Explain how electromagnets are use in generators, motors and transformers. Give examples of application of electromagnetism use in everyday life.**

Pre-Requisite Knowledge

Students are required to have been introduced to basic magnetism principles. Basic principles include but are not limited to: theory of magnetic domains, Curie temperature, magnetic poles, ferromagnetism, paramagnetism and diamagnetic materials. Basic chemistry principles such as: colloids or suspensions, surface tension, and surfactants.

Learning Objectives

After this activity, students should be able to:

- **Understand magnetism theory**
- **Relate differneces in large scale magnetic materials and nano-magnetic materials**
- **Be able to describe the role of each ferrofluid ingredient**
- **Be able to describe the unique behavior of ferrofluids under magnetic field**
- **Understand applications and uses for ferrofluids**

Materials List

Each group needs:

- 1 25 ml test tube with threaded lid option
- 1 appropriate lid
- 1 rare earth magnet
- 1 250 ml Beaker
- Glass stir rod or popsickle stick
- 1 4"x6" clear plastic dish
- 1 latex glove

To share with the entire class:

- 1 bottle MCRI toner powder refill (Must be magnetic ink toner)
- 1 bottle vegetable oil

Introduction / Motivation

Introduce popular culture TV show FRINGE to students. Ask students if they have heard of the television series and explain relevance to science. Prepare a short segment from Episode #317: "The Day We Died" where the Fringe team uncovers murder victim's blood is magnetic.   NOTE: show up to 10 minutes worth of episode.

Upon completion of video, engage students with a series of questions involving their knowledge of magnetism and how a liquid can be magnetic. Below are example questions.

1) **Is magnetic blood or fluid science fiction or science fact?** ***Allow students to answer question and tally number of answers for science fiction or fact. Do not give any particular answer but proceed to the next question.***
2) **How can a liquid be magnetic?** ***Allow student participation and critical thinking. Direct students with supplementary thoughts such as: Curie point, traditional magnetic materials and melting points etc…***
3) **Have you heard of Ferrofluids?** ***Allow students to participate briefly and then go into a brief explanation of ferrofluid ingredients and function. Visual aids might be useful. NOTE: applications are listed in 'Background' section.***

Conclude introduction with general instructions for conducting the activity. Reference Procedure for pre-lab instructions.

Vocabulary / Definitions

Word	Definition
Ferrofluid	Ferromagnetic particles suspended in a carrier fluid with the aid of a surfactant
Ferromagnetic	Long-range ordering phenomenon at the atomic level which causes unpaired electron spins to line up parallel with each other in a domain.
Curie Point	Temperature at which ferromagnetism is lost due to excessive thermal agitation
Domain	Region where unpaired electrons are aligned parallel creating a magnetic field
Surfactant	Chemical that acts as a wetting agent to lower the surface tension of a liquid and allow for spreadability
Colloidal	Chemical system which a continuous liquid phase exists with a solid phase suspended in the liquid.
Surface Tension	An increased attraction of molecules at the surface of a liquid resulting from forces of attraction on fewer sides of the molecules.

Procedure

Background

Most materials fall into three categories of magnetic materials: Paramagnetic, diamagnetic and ferromagnetic. Amongst these categories ferromagnetic materials exhibit the largest magnetic permeability. As the name suggests ferrofluids are composed of ferromagnetic particles, surfactant, and carrier fluid. Ferromagnetic particles are used because of its large magnetic permeability as compared to other classifications of magnets. Essentially, the resultant magnetic field is orders of magnitude larger than the induced magnetic field. This becomes important when manipulating ferrofluids under moderate and controlled magnetic fields.

Typical ferromagnetic materials consist of Iron, Nickel and Cobalt based metals and occasional rare earth materials. Ferromagnetism is caused by a long-range atomic scale ordering which causes unpaired electrons to align parallel with each other in a domain. These domains or regions of magnetic alignment are randomly oriented and confined within the bulk material leading to a net magnetic field of zero. However, under an external magnetic field, these domains align causing an amplification of the applied magnetic field. These domains created under atomic scale long-range ordering may span over large numbers of atoms. However, to make a ferromagnetic material fluid, for our purposes, would require melting the metal. Under such conditions, typical ferromagnetic alloys have melting points in excess of the point when ferromagnetic properties transition to paramagnetic. This transition is denoted as the Curie temperature.

As a material scientist these principles become important when developing a magnetic fluid. The challenge is making a fluid magnetic without exceeding the materials' Curie point. Scientists have developed paramagnetic salt solutions for magnetic fluids. These fluids exhibited less than adequate magnetic permeability. This would be expected considering paramagnetic materials have a magnetic permeability far less than a ferromagnetic material. This is where nanomaterials become increasingly important.

To meet such a challenge scientists have developed ferromagnetic nanoparticles. These particles are approximately 10 nm in diameter but small enough to be suspended in various carrier fluids. Such suspension could be considered colloidal. Additionally, the size of each nanoparticle is on the order of a few atoms in diameter. This creates a single magnetic domain particle. Meaning, each nanoparticle is its own permanent magnet suspended in the carrier fluid. With a suitable surfactant to prevent particle agglomeration, the suspension can then be manipulated under a controlled moderate magnetic field.

These magnetic fluids have received considerable attention over the last few decades with applications geared towards rotary shaft sealing and audible speaker cooling systems. However, recent interest has cropped up to apply ferrofluids to cancer treatment and drug delivery systems. Cancer treatment has been proposed through methods utilizing the heating effect of alternating magnetic fields and the energy lost from such cycling. For drug delivery systems, magnetic drugs with a suitable surfactant be injected into the blood stream and manipulated with external magnetic fields to localize treatment to a particular human system. For the case of medical treatments, these advancements are only limited by the ability to create nontoxic, biologically compatible, magnetic particles.

As students you are the material scientist creating your own ferrofluid. I challenge you to make a magnetic fluid that you can manipulate. Using your observation skills and newly found knowledge of ferrofluids to complete the handout. Good luck!!

Before the Activity

- All lab supplies are placed out and available to students
- Pre-make ferrofluid and distribute equal portions to each group. Provide a glass mixing rod or popsickle stick for mixing if ingredients begin to separate. NOTE: you can have students measure and mix their own ferrofluid, but this will add activity time.
- Handouts printed for students

With the Students

1. Instruct students to get into groups of 3-4 students.
2. Instruct students to review activity supplies.

Ferrofluid fabrication

1. Pour 50 ml of MICR toner into 250 ml beaker
2. Pour 30 ml of vegetable oil in 250 ml beaker.
3. With a glass rod or wooden stick, stir the mixture until has a light smooth texture.
4. Carefully, pour ~ 10-15 ml of fluid in 25 ml test tube and secure the lid.

Magnetic Fluid Manipulation

1. Place permanent magnet under clear plastic dish and pour a small amount of fluid over the plastic area that the magnet occupies.
2. Using your hands manipulate the magnet and fluid making symbols, pictures etc.
3. Release magnetic from under plastic dish and observe how fluid behaves. Place magnet back under fluid and observe how fluid behaves.
4. Place magnet under fluid and begin touching fluid with a latex glove. Can you spin your fluid?
5. Complete worksheet.
6. Cleanup plastic dish by wiping magnetic fluid up with paper towels. Make sure no fluid residue is present on dish.
7. Cleanup laboratory area.

Attachments

- Insert Worksheets for Activity

Safety Issues

- Ingredients used in this activity are harmless when exposed to skin in standard form. However, with all laboratory practices, make sure instructor reads the appropriate MSDS prior to conducting activity.
- All students are to wear goggles and aprons when conducting this activity. Caution, toner may stain skin and clothes, latex gloves may be used to prevent this but is not necessary.

Troubleshooting Tips

If magnets are not strong enough than fluid will not show individual magnetic “spikes”, but will still control the fluid. In the event this occurs, have students use gravity to move fluid around and direct fluid flow with magnet. This will achieve the same educational objectives without the flare.

Investigating Questions

1) Is magnetic blood or fluid science fiction or science fact?
2) How can a liquid be magnetic?
3) Have you heard of Ferrofluids?

Assessment

Pre-Activity Assessment
Opening Discussion: Reference "Introduction and Motivation".

Activity Embedded Assessment
Activity Handout: This handout serves as teaching aid for students to record all observations during the activity. Additionally, questions have been provided within the handout to stimulate students' critical thinking of this topic. Students will be asked to answer questions related to magnetism with a main focus on importance of scientific observations. Students are also required to finish the entire handout in the time allotted.

Post-Activity Assessment

- *Students will submit handouts for grading.*
- *A post activity discussion can be implemented.*
- *Take home assessment is detailed below:*

Research Paper:
Scope: Students are required to research the fundamental differences between magnetic fluids and traditional bulk magnetic solids. Furthermore, students should review a minimum of two applications where ferrofluids may be useful. Students are to use the three web-based resources below and any additional physics text or prior knowledge of magnetism to identify fundamental differences and applications. Paper should include a concise introduction (problem statement), fundamental content review, explanation of differences and technology application review. Research paper should not exceed two pages of double spaced text including figures and tables.

Rubric:
Introduction:

- Did student introduce research objectives in a concise manner. – 10pts
- Are objective clear to reader. – 10pts

Content Review:

- Did student provide a comprehensive overview of magnetism content. – 15pts
  - Include key terms such as: Curie point, domains, poles, electrons, spins etc…-5pts
  - Provide explanation of key terms where necessary. -10pts
- Did student list which concepts apply to each type of magnetic solid or liquid material.-5pts

Magnetic Differences:

- Did student identify fundamental differences between liquid and bulk solid magnets.-10pts
- Did student use content from resources or class to support claims for differences.-10pts

Technology Applications:

- Did student select two applications to discuss. – 5pts
- Did student introduce and explain technology applications.-10pts
- Did student use reference material and prior knowledge to support explanation.-5pts

Additional Criteria:

- Did student use proper grammer and sentence structure throughout paper. 15pts
- Did student utilize online or word processing tools and/or techniques to spell check and format paper. – 5pts

References:

1) http://mrsec.wisc.edu/Edetc/background/ferrofluid/index.html
2) http://en.wikipedia.org/wiki/Ferrofluid
3) http://en.wikipedia.org/wiki/Ferromagnetism

Activity Extensions

None

Activity Scaling

- For lower grades, None
- For upper grades, None

Additional Multimedia Support

- FOX-Fringe Episode #317, “The Day We Died”, http://www.fox.com/fringe/full-episodes/

References

1. S. Odenbach, “*Ferrofluids: magnetically controllable liquids*,” PAMM, Proc. Appl. Math. Mech. 1 (2002)
2. E.K. Ruuge and A.N. Rusetski, “*Magnetic fluids as drug carriers: Targeted transport of drugs by a magnetic field,”* Journal of Magnetism and Magnetic Materials, 121, (1993) 335-339
3. Benson, Harris. University Physics Revised Edition. New York: John Wiley & Sons, Inc., 1995. 662-667

Other

None

Redirect URL

None

Contributors

Marc Bird, Sara Castillo

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None

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Liquid Magnets

Background

Most materials fall into three categories of magnetic materials: Paramagnetic, diamagnetic and ferromagnetic. Amongst these categories ferromagnetic materials exhibit the largest magnetic permeability. As the name suggests ferrofluids are composed of ferromagnetic particles, surfactant, and carrier fluid. Ferromagnetic particles are used because of its large magnetic permeability as compared to other classifications of magnets. Essentially, the resultant magnetic field is orders of magnitude larger than the induced magnetic field. This becomes important when manipulating ferrofluids under moderate and controlled magnetic fields.

As students you are the material scientist manipulating your own ferrofluid. I want you to be exceptional observers and document everything you see. Using your observation skills and newly found knowledge of ferrofluids to complete the handout. Good luck!!

Materials

- 10-15 ml of ferrofluid in 25 ml threaded cap container.
- 4"x6" plastic dish
- Latex gloves
- 1 rare earth magnet
- 1 sheet of blank paper
- Glass stir rod

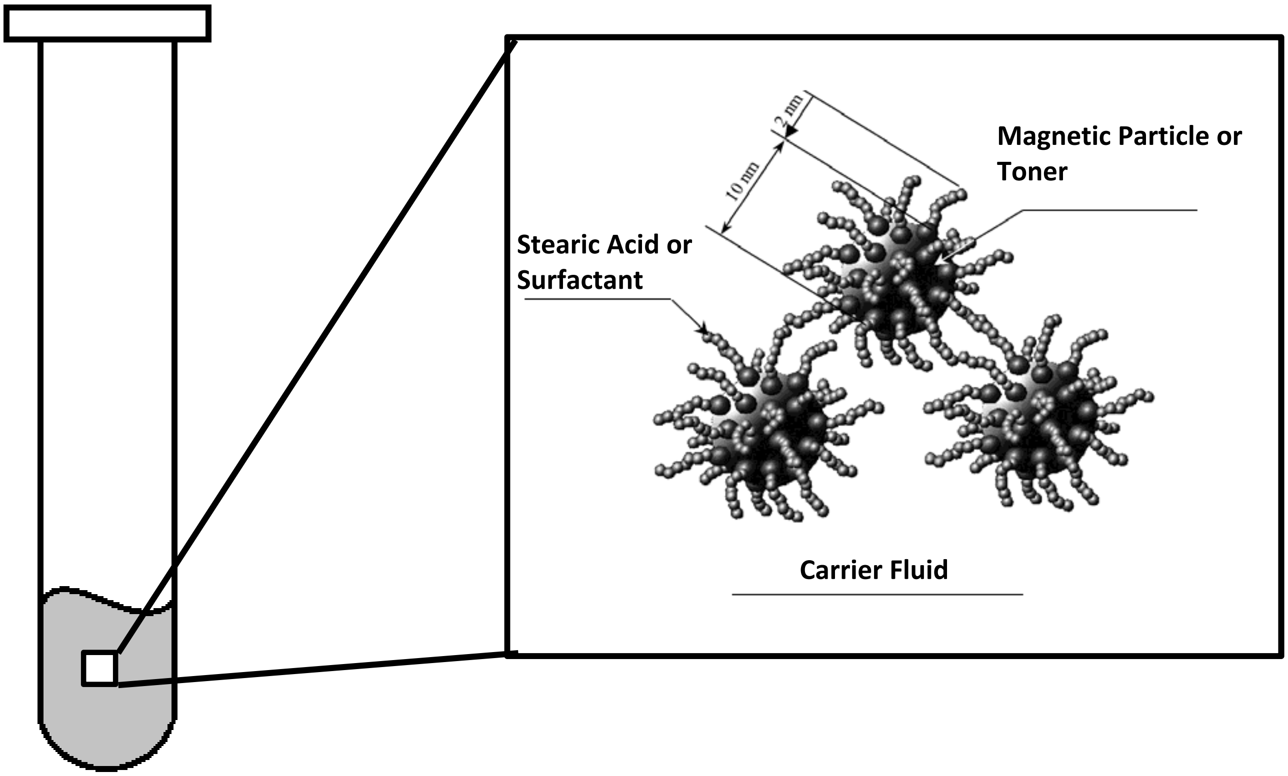
Part 1-Concepts

How can a Liquid be magnetic?

What type of magnetic material (paramagnetic, diamagnetic, or ferromagnetic) would be best for making a liquid magnet? Explain the fundamental differences between the three classifications of magnets and why you would use one over the other.

The picture below depicts what is going on in your test tube. Although you cannot see the particles they are there. Fill in the three spaces in the magnified picture. Below the picture write the purpose of each labeled component.

Magnetic Fluids Name:



Component 1:

____

Component 2:

____

Component 3:

____

Part 2:

Procedure

Fun with ferrofluids

1. Place magnet under plastic dish.
2. Pour a small drop of ferrofluid on the plastic dish over the magnetic region.
3. Answer appropriate questions and record observations.
4. Move magnet slowly and then remove the magnet and manipulate the fluid.
5. Answer appropriate questions and record observations.
6. Touch the ink; try spinning the ink.
7. Answer appropriate questions and record observations.

Questions

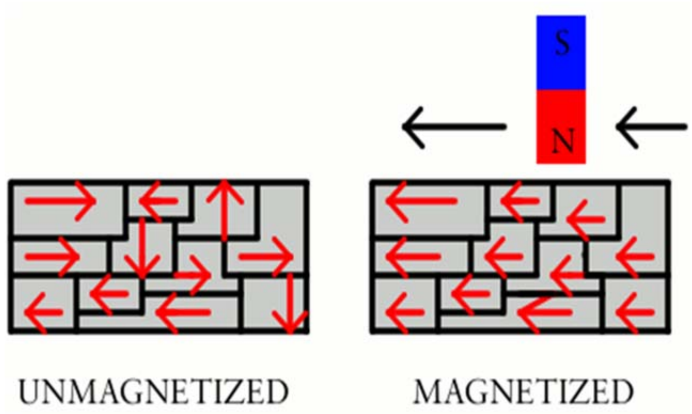
(1) In the boxes below, draw your observations of the ferrofluid when exposed to the external magnet and when not exposed.

Without Magnetic Field	**With Magnetic Field**

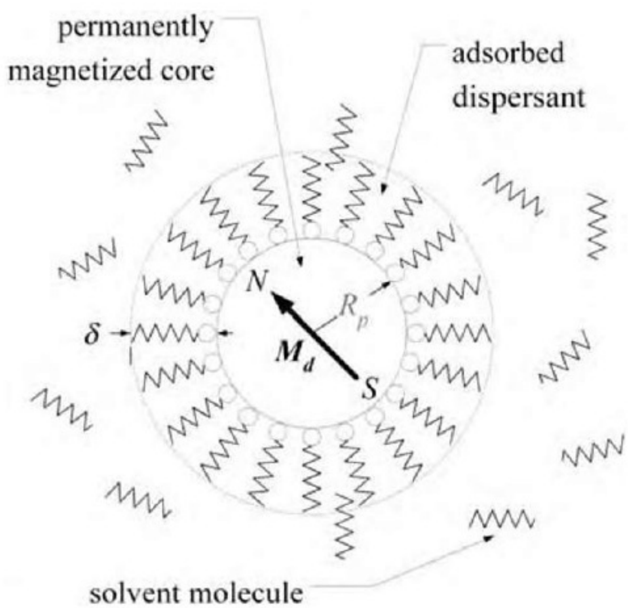
(2) How would you describe the ferrofluid when it is NOT exposed to an external magnet?

(3) How would you describe the ferrofluid when it is exposed to an external magnet? Explain how the physical properties of the fluid changed.

(4) In the space provided below draw the magnetic domains associated with nanoparticles. Compare this behavior to traditional magnetic materials.



http://www.explainthatstuff.com/magnetism.html



http://what-when-how.com/nanoscience-and-nanotechnology/magnetic-nanoparticles-in-fluid-suspension-ferrofluid-applications-part-1-nanotechnology/

(5) Why do ferrofluid materials behave differently than bulk magnetic materials?

(6) Where might you use this type of technology or property manipulation? Name 3 applications with a 1-2 sentence explanation.

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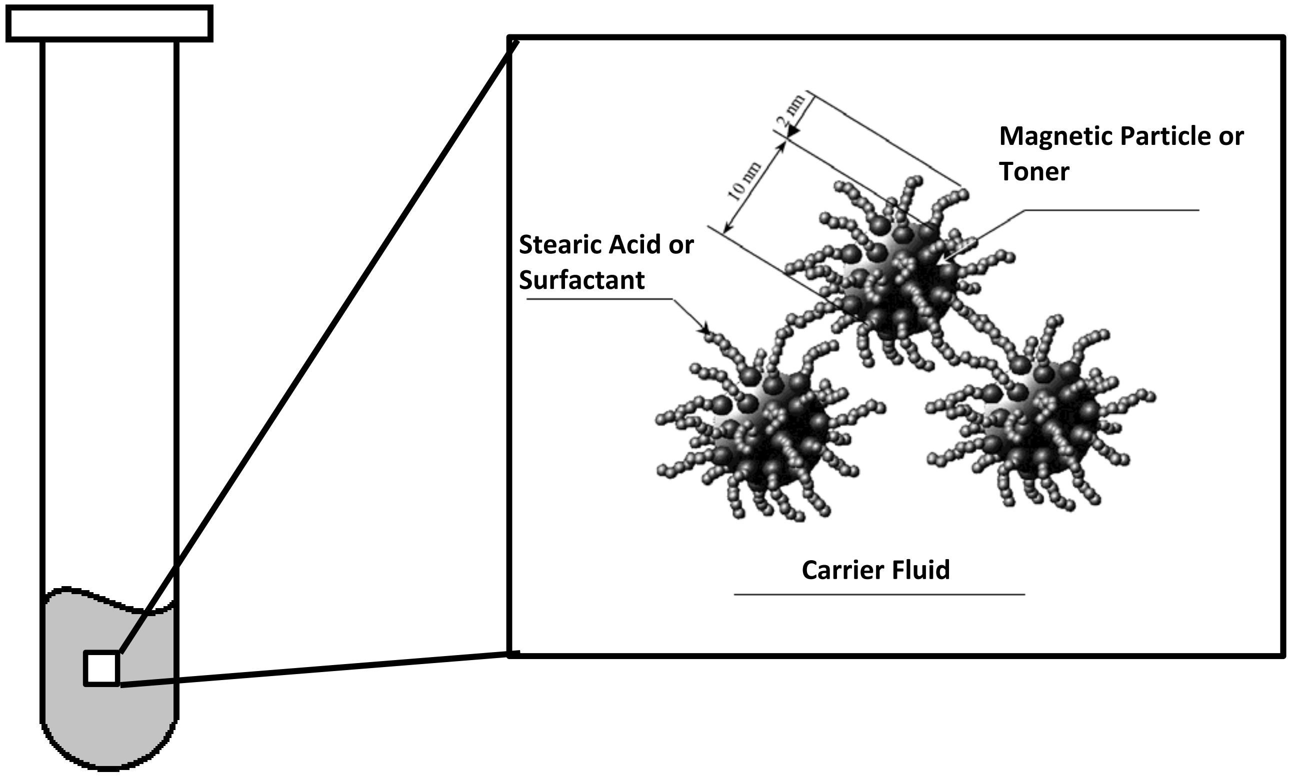

Component 1:

Carrier Fluid: is what transports magnetic nanoparticles when not induced by a magnetic field

Component 2:

Magnetic Particle: is what provides the magnetic attraction when exposed to an external magnetic field

Component 3:

Stearic Acid: chemical that helps spread magnetic particles apart and attach to carrier liquid

Part 2:

Procedure

Fun with ferrofluids

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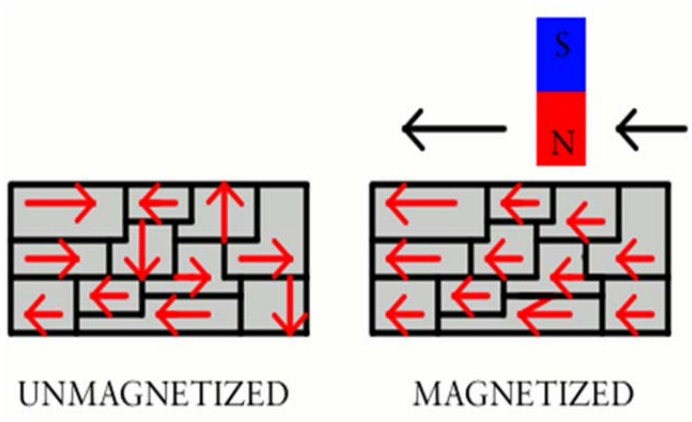
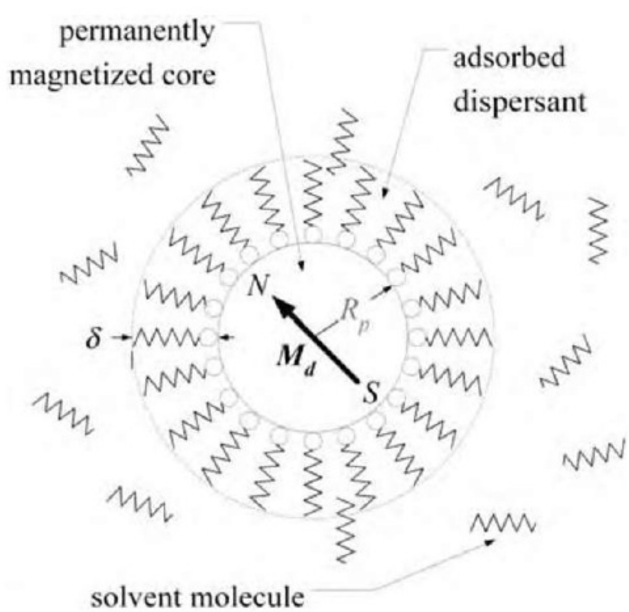


http://www.explainthatstuff.com/magnetism.html

Traditional Bulk Magnetic Material. Figure shows a gradual alignment of domains with direction of magnet as a magnetic field is applied. A three dimensional magnetic field exists but is not shown because of the rigid magnetic object.



http://what-when-how.com/nanoscience-and-nanotechnology/magnetic-nanoparticles-in-fluid-suspension-ferrofluid-applications-part-1-nanotechnology/

Individual nanoparticles align with magnetic field. Result is a three dimensional depiction of magnetic field directions and varying strengths.

(5) Why do ferrofluid materials behave differently than bulk magnetic materials?

(6) Where might you use this type of technology or property manipulation? Name 3 applications with a 1-2 sentence explanation.

1. **Drug Delivery systems: Targeted delivery by developing magnetic drug compatible with human systems where delivery path is guided by a controlled magnetic field**

2. **Magnetic tracking beacon: Inject fluids where a magnetic signature could be detected under an applied magnetic field.**

3. **Cooling systems: utilize convection cooling from liquid to achieve higher heat transfer in electronic systems.**

This question is intended to stimulate out-of-box thinking.