Ferrofluid
Student Materials

Ferrofluids

Ferrofluid -

________________ - a dispersion of particles from ~1 nm to 1000 nm in size and suspended in a fluid

Magnetite - the name of the compound, __________

<u>Properties of ferrofluids</u>

1. _________________ - a force that can act at a distance between two materials due to properties of their electrons' spin and orbital motions

   _______________ - a phenomenon in which the internal magnetic moments of multiple spin sets of unpaired electrons within the domain of the solid do not completely cancel and therefore leave a net spin

   _______________ - a phenomenon in which the internal magnetic moments of unpaired electrons within a domain of the solid are aligned and act cooperatively

2. ___________ - a pattern of uplifted particles that results from placing a magnet near the ferrofluid

3. they don't stick together
   Why?
   A ______________ has been added
   Surfactant –

4. Why aren't the spikes permanent?
   Individual particles of magnetite behave as ______________________. Therefore, in the absence of a magnetic field and as a result of thermal agitation, the particles' magnetic domains become ______________________ relative to one another.

   ________________ - regions where unpaired electrons strongly interact with one another and align even in the absence of a magnetic field

<u>Unit Cells</u>

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______________: a 3-D parallelepiped that, when shifted along each edge by the length of the edge, creates the entire structure of atoms in a crystal

Holes-

For example, in magnetite there are holes formed by oxide ions - these holes provide various environments for the iron ions

What constitutes unit cells:

Parts of a unit cell

Corner atoms = _____ atom per unit cell

Edges atoms = _____ atom per unit cell

Face atoms = _____ atom per unit cell

Inside atoms = _____ atom per unit cell

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Atoms in the unit cell -

Empirical formula -

INVESTIGATION 1

PURPOSE

In this investigation you will experiment further with the magnetic properties of ferrofluids. More specifically, you will determine if any relationship exists between the "spiking phenomena" and the strength of the magnet used and the distance between the magnet and the fluid. In addition, you will observe the behavior of non-magnetic materials in contact with the fluid and in the field of a strong magnet.

PROCEDURE

a. Pour enough ferrofluid into a Petri dish to just cover the bottom of the dish. **CAUTION! Ferrofluids cause stains that are difficult to remove from skin and fabrics.**

b. Slowly bring one end of a strong magnet up to the fluid from **below** the dish. Note the distance from the dish to the magnet when the first spike appears. Repeat using the other end of the magnet. **It is practically impossible to remove the ferrofluid from a strong magnet so avoid direct contact of the ferrofluid with the magnet.**

c. Continue to move the magnet closer to the bottom of the dish, until it touches the dish, and note the pattern of spikes produced.

d. Hold the magnet horizontally and slowly bring it up **underneath** the dish. Note the pattern of spikes.

e. Place a penny in a Petri dish containing water. What happened to the penny?

f. Bring the magnet up **underneath** the dish. What happened to the penny?

g. Repeat (e) and (f) above using the ferrofluid instead of water.

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FOLLOW-UP QUESTIONS

1. What factors would affect the distance observed in (b)?

2. For any given spike in the final pattern observed in (c), how many nearest neighbors does it have? Why do you think this particular pattern forms?

3. How do you explain the behavior of the penny in (f)? How would this behavior be different if the penny were magnetic?

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INVESTIGATION 2

PURPOSE

To construct a unit cell of the extended three-dimensional crystalline structure of magnetite (Fe_3O_4) and to verify this empirical formula based on this structure.

INTRODUCTION

The crystalline structure of magnetite consists of a repeating arrangement of oxide ions in what is referred to as cubic close-packed (recall the pattern of spikes that you observed in Investigation 1). Fe(II) and Fe(III) ions are distributed into some of the spaces (holes) that are created between the oxide ions. These holes do not provide the same chemical environment for all the iron ions and it is this difference in environment that results in the magnetic properties of the compound.

PROCEDURE

Following the directions as provided by your instructor, use the Solid State Model Kit to construct the layer sequences for:

Team A: the conventional cubic unit cell.

Team B: the tetragonal unit cell.

Alternatively your instructor may provide you with a completed model of one or both of these unit cells.

FOLLOW-UP QUESTIONS

1. For each of the structures complete the table below, indicating HOW MANY COLORLESS SPHERES LIE WITH THEIR CENTERS AT THE ____________OF THE UNIT CELL.

STRUCTURE	CORNERS	EDGES	FACES	INSIDE
CUBIC UNIT CELL (A)				
TETRAGONAL UNIT CELL (B)				

2. For each of the structures complete the table below, indicating HOW MANY PINK SPHERES LIE WITH THEIR CENTERS AT THE _______________ OF THE UNIT CELL.

STRUCTURE	CORNERS	EDGES	FACES	INSIDE
CUBIC UNIT CELL (A)				
TETRAGONAL UNIT CELL (B)				

3. For each of the structures complete the table below, indicating HOW MANY BLUE AND RED SPHERES LIE WITH THEIR CENTERS AT THE _______________ OF THE UNIT CELL.

STRUCTURE	CORNERS	EDGES	FACES	INSIDE
CUBIC UNIT CELL (A)				
TETRAGONAL UNIT CELL (B)				

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Note that the colorless spheres are oxides, small pink spheres are ferric ions in tetrahedral holes, and blue and red are ferrous and ferric ions in octahedral holes.

4. Convince yourself that each of the corner atoms is shared with seven <u>other</u> unit cells; that the edge atoms are shared with three <u>other</u> unit cells; and that the face atoms are shared with one other unit cell. Remember that these structures extend in all three dimensions indefinitely. It may be helpful to stack books or CD cases together to help to visualize the relationships stated above. Given that the stated information is correct, then only part of the spheres occupying each site belong to the unit cell under consideration, i.e., only 1/8 of the corner spheres, 1/4 of the edge spheres, and 1/2 of the face spheres belong to a given unit cell. Those spheres lying totally inside the cell of course belong only to that cell. Using the information above, complete the tables below.

COLORLESS	CUBIC UNIT CELL (A)	TETRAGONAL UNIT CELL (B)
__CORNERS X 1/8 =		
__EDGES X 1/4 =		
__FACES X 1/2 =		
__INSIDE X 1 =		
__ TOTAL IN CELL =		

PINK	CUBIC UNIT CELL (A)	TETRAGONAL UNIT CELL (B)
__CORNERS X 1/8 =		
__EDGES X 1/4 =		
__FACES X 1/2 =		
__INSIDE X 1 =		
__ TOTAL IN CELL =		

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RED AND BLUE	CUBIC UNIT CELL (A)	TETRAGONAL UNIT CELL (B)
__CORNERS X 1/8 =		
__EDGES X 1/4 =		
__FACES X 1/2 =		
__INSIDE X 1 =		
__ TOTAL IN CELL =		

5. The ratio between the sum of the Fe (II) and Fe (III) relative to the O^{-2} from the tables above is then:

   a. For the cubic unit cell Fe__O__. And the simplest ratio is Fe__O__.

   b. For the tetragonal cell Fe__O__. And the simplest ratio is Fe__O__.

EXPERIMENT 1

PURPOSE

To determine experimentally the optimum mole ratio between $FeCl_2$ and $FeCl_3$ reactants used in the synthesis of a so-called "ferrofluid" whose appearance is altered by the presence of a magnet.

INTRODUCTION

The successful synthesis of a ferrofluid begins with the formation of a *colloidal suspension* of magnetic nanoparticles in a liquid medium. These colloids are suspensions of very small particles on the order of 100 nanometers (10nm) in size. By synthesizing the nanoparticles in the presence of molecules called surfactants, the particles can be suspended in solution rather than clumped together.

These ferrofluids possess the interesting property of "spiking" that you observed in Investigation 1. This spiking will be used to determine whether a high-quality ferrofluid has been produced , conversely, the formation of a high-quality ferrofluid will be used to optimize the synthesis and to estimate the stoichiometric ratio needed for complete reaction of the two iron solutions used in the synthesis.

You and your partner will make an aqueous-based ferrofluid following the procedure below. Your instructor will assign to you a specific combination of the $FeCl_2$ and $FeCl_3$ solutions and your results will be pooled with those from your classmates.

SAFETY PRECAUTIONS

All of the chemicals used in this synthesis are to be handled with extreme caution. Remember that ferrofluids can be messy and this particular one will permanently stain almost any fabric. Do not let the fluid come into contact with any magnet. Keep the magnet and the ferrofluid well separated at all times.

PROCEDURE

1. To a 100 mL beaker add the amounts of the stock 2M $FeCl_2$ and stock 1M $FeCl_3$ solutions assigned to you by your instructor. Add a magnetic stirring bar and begin stirring. Use a buret to add 50 mL of 0.7M aqueous ammonia (NH_3) drop by drop to the solution. A black precipitate of magnetite should form as you slowly add the ammonia solution over a period of about 5 minutes.

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2. Turn off the stirrer and quickly use a strong magnet to slide the stir bar up the walls of the beaker. Remove the stir bar with gloved hands **before** it touches the magnet.

3. Let the magnetite settle for a few minutes, then decant and discard the clear liquid, making sure to save as much of the solid as possible. Transfer the solid to a plastic weighing boat. It may be necessary to rinse the beaker with water from a wash bottle.

4. Use a strong magnet to hold the magnetite to the bottom of the weighing boat and once again decant as much of the clear liquid as possible. Repeat this step two more times.

5. Add 2.0 mL of 25% tetramethylammonium hydroxide and stir with a glass stir rod to suspend the solid in the liquid. Using the strong magnet to hold the ferrofluid to the bottom of the weighing boat, pour off and discard the liquid. Move the magnet around and pour off the remaining liquid.

6. Place a cow magnet or other very strong magnet under the remaining fluid and record your observations relative to its spiking behavior. If the fluid does not spike readily, then add **one drop** of water and try again. Share your ferrofluid results with the rest of the class and be sure to observe the spiking behavior of the ferrofluids produced by your classmates.

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DATA TABLE I

Group	1	2	3	4	5	6	7
mL 1 M $FeCl_3$	1	2	3	4	5	6	7
mL 2M $FeCl_2$	1	1	1	1	1	1	1
"spiking" (Y or N)							

ANALYZING THE DATA

1. Determine the mole ratio of $FeCl_3$ to $FeCl_2$ and enter in the table below. Show your work!

GROUP	1	2	3	4	5	6	7
RATIO							

2. Which of the ratios from the table above corresponds to the ferrofluids that produced the best spiking behavior?

3. Use your answer to question (2) above to balance the equation for the synthesic reaction below.

$$\_\_\_ FeCl_3 + \_\_\_ FeCl_2 + \_\_\_ NH_3 + \_\_\_ H_2O \rightarrow \_\_\_ Fe_3O_4 + \_\_\_ NH_4Cl$$

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Ferrofluid Review Questions

Name ___________________
Date _________ Hour _____

1. Elemental iron is ferromagnetic, yet an iron nail does not attract iron fillings.
   a. Explain.

   b. If, however, a magnet is rubbed over the surface of a nail, the nail will attract iron fillings. Why?

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2. Analysis of a compound shows it to be potassium, 49.4%; sulfur, 20.2%; and oxygen, 30.4%. What is its empirical formula?

3. Consider the layered structures below and determine the total number of each type of atom belonging to the unit cell and empirical formulas for the compound.

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Layer 5

Potassium Atoms	Sites in the Cell	Atoms in the Unit Cell From that Site
	Corners	
	Edges	
	Faces	
	Inside	
----------	Total in Cell	

Platinum Atoms	Sites in the Unit Cell	Atoms in the Unit Cell From that Site
	Corners	
	Edges	
	Faces	
	Inside	
----------	Total in Cell	

Chloride Atoms	Sites in the Unit Cell	Atoms in the Unit Cell From that Site
	Corners	
	Edges	
	Faces	
	Inside	
----------	Total in Cell	

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Use the data from the tables above.

a. What is the total number of each type of atom in the unit cell? K ____; Pt ____: Cl ____.

b. What is the empirical formula for this compound? ________________

4. Determine the mole ratios from the balanced equation below.

$$3\,CuO + 2\,NH_3 \rightarrow 3\,Cu + N_2 + 3\,H_2O$$

$CuO : Cu$ $NH_3 : CuO$ $N_2 : NH_3$ $Cu : H_2O$

5. Compare the solids VO and V_2O_5 in their attraction to a magnetic field.

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Ferrofluid Assessment

Name ____________________

Date __________ Hour _____

Matching

Match the word with the best definition.

_____ 1. stoichiometry

_____ 2. spikes

_____ 3. ferromagnetism

_____ 4. colloid

_____ 5. hole

_____ 6. ferrimagnetism

_____ 7. magnetic domain

_____ 8. Unit cell

_____ 9. Nanoparticle

_____ 10. empirical formula

_____ 11. surfactant

_____ 12. ferrofluid

_____ 13. magnetite

_____ 14. Van der Waals forces

a. weak forces of attraction between molecules

b. a 3-D parallelpiped that, when shifted along each edge by the length of the edge creates the entire structure of atoms in a crystal

c. regions where unpaired electrons strongly interact with one another and align, even in the absence of a magnetic field

d. a pattern of uplifted suspended particles that results from placing a magnet near a ferrofluid

e. a word describing that part of chemistry that deals with the relative amounts of substances involved in chemical reactions

f. a dispersion of particles from ~ 1 nm to 1000 nm

g. a phenomenon in which the internal magnetic moments of multiple spin sets of unpaired electrons within the magnetite domain of a solid partially cancel and thus leave a net spin

h. a phenomenon in which the internal magnetic moments of unpaired electrons within a domain of the solid are aligned and act cooperatively

i. an empty site in a crystalline solid

j. a very small particle on a scale of nanometers (10^{-9}m)

k. the name for Fe_3O_4

l. information that gives the simplest ratio between the atoms of the elements present in a compound

m. a molecule that surrounds particles and isolates them from the attractive forces of their neighbors

n. a suspension of a magnetic solid in a liquid that responds to an external magnetic field

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Multiple Choice

Choose the best answer.

_____ 15. Ferrofluids exhibit magnetic properties because
- a. they consist of a magnetic solid suspended in a liquid medium.
- b. they become magnetic under the influence of the earth's magnetic field.
- c. they consist of positively and negatively charged ions.
- d. none of the above.

_____ 16. The potential advantage of using a ferrofluid to administer medication is
- a. that it is cheaper.
- b. that it also acts as an iron supplement.
- c. that it tastes better.
- d. that it can be directed to specific sites in the body.

_____ 17. In the production of a ferrofluid, the van der Waals attractions can be overcome by
- a. shielding the reaction vessel from the earth's magnetic field.
- b. adding a substance called a surfactant.
- c. adding a substance called a catalyst.
- d. adding a coagulating agent.

Problems

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18. a. Not all of the atoms occupying each site in a unit cell belong to that unit cell. What fraction of each of the following belong to a given unit cell?

Edge ________ Face ________

Corner ________ Inside ________

b. Based on your answers in part *a*, sodium thallide was constructed and contained the following

Sodium Atoms	Sites in the Unit Cell	Atoms in the Unit Cell From that Site
8	Corners	
0	Edges	
4	Faces	
4	Inside	
	Total in Cell	

Thallium Atoms	Sites in the Unit Cell	Atoms in the Unit Cell From that Site
0	Corners	
12	Edges	
0	Faces	
4	Inside	
	Total in Cell	

c. What is the total number of each type of atom in this compound? _______________

d. What is the emipirical formula for this compound? ______________

19. Determine the percent composition of each element in magnitite.

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20. The mole ratio of NH_4OH to NH_4Cl was experimentally determined to be 4 : 2; balance the equation below.

____ $MnCl_2$ + ____ Br_2 + ____ NH_4OH → ____ MnO_2 + ____ NH_4Cl + ____ NH_4Br + ____ H_2O