Teacher's Preparatory Guide

Discovering the Properties of Magic Sand

Purpose
- Explore the properties of molecular bonding
- Introduce students to the engineering of hydrophobic surface.
- Demonstrate the concepts of hydrophobic and hydrophilic behavior.

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Time required
Time: 30-50 minutes
Level: High School

Teacher Background

1. **What is nanotechnology?** Nanotechnology is the science and technology of very small things. It is an exciting area of science and engineering that occurs at the atomic and molecular level. This interdisciplinary field occurs at the 1-100 nanometer range. One nanometer is 10^{-9} meters or about 3 atoms long. For comparison, a human hair is about 60-80,000 nanometers wide.

There are many different views of precisely what is included in nanotechnology. In general, however, most researchers agree that three things are important:

1. Small size, measured in 100s of nanometers or less
2. Unique properties because of the small size
3. Control the structure and composition on the nanometer scale in order to control the properties.

Scientists have discovered that materials at small dimensions, i.e., at the nanoscale, can have significantly different properties than the same materials at larger scale. Researchers are developing and engineering devices so small they are measured on a molecular scale. Nanotechnology has great potential for improving devices, structures, and materials if we can understand these nanoscale differences and learn how to control the assembly of small structures.

This emerging field is truly interdisciplinary and involves scientists from many different disciplines, including physics, chemistry, biology, engineering, material science, and information technology. Nanotechnology is being applied to a wide variety of fields, including electronics, optics, information technology, materials, homeland security, and medicine.

2. **The Molecular World – polar and non polar molecules** It is recommended that the teacher will have covered molecular bonding and polarity prior to this activity. However, the unit can be used as a way to explore polarity and intermolecular forces.

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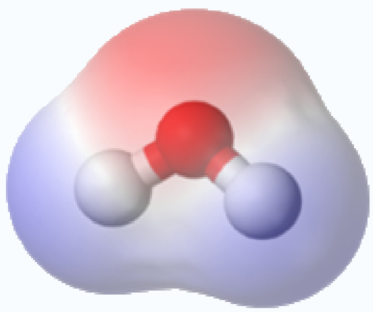
Development and distribution partially funded by the National Science Foundation

NNIN Document: NNIN-1038
Rev: 06/07

In the molecular world, the forces that exist between molecules (intermolecular) are electrostatic in nature, i.e., they arise from attractions between oppositely charged parts of molecules. Chemical polarity describes how electrons are shared between the atoms and this distribution can affect intermolecular forces so that some molecules are considered polar and others non-polar. Molecules that are polar avoid molecules that are nonpolar. Of the polar molecules, like charges repel and unlike charges attract.

"A compound is comprised of one or more chemical bonds between atoms. The polarity of each bond within the compound determines the *overall polarity* of the compound: how polar or non-polar it is. A polar molecule usually contains polar bonds - bonds which have unequal sharing of electrons between the two atoms involved in bonding. A non-polar compound usually contains non-polar bonds - bonds which have identical or similar sharing of electrons."



A commonly-used example of a polar compound is water (H_2O). The electrons of water's hydrogen atoms are strongly attracted to the oxygen atom, and are actually closer to oxygen's nucleus than to the hydrogen nuclei; thus, water has a relatively strong negative charge in the middle (red shade), and a positive charge at the ends (blue shade).

From: http://en.wikipedia.org/wiki/Polar_molecules

For this activity, it is important that the students understand that polar molecules are generally able to dissolve in water and are considered hydrophilic (likes water). This is the case where "like dissolves like." Non-polar molecules do not dissolve in water and area considered hydrophobic (fears water). These molecules will be repelled from water molecules and prefer other non-polar molecules.

3. **Magic Sand –** Magic Sand is ordinary sand that has been treated by dyeing it and adding a hydrophobic silicon coating. The sand was developed by reserachers at Cabot Corporation in Massachussets. They developed a method to react the compound trimethylchlorosilane [$(CH_3)_3SiCl$] with the surface of silicate-based materials like sand and glass. Sand is a silicate mineral with the formula SiO_2. Sand grain surfaces are convalently bonded to hydrogen atoms which are polar bonds. Thus both water and sand contain polar molecules allowing water to be attracted to sand (remember "like with like"). If you drop water on a sand grain, the water will spread out rather than forming a bead on top of the grain. Sand is considered to be hydrophilic (water "liking").

Magic Sand does not behave like ordinary sand because of the thin coating of the organohalosilane which forms a silicone film (monolayer) on the grain. When magic sand is poured into water, the grains of sand come together to minimize the amount of surface area exposed and water is unable to bond to the hydrophobic end groups. This leaves an air gap between the sand and water allowing you to mold structures that maintain their shape. Typcially, the process uses sand grains that have rounded features rather than those with high angles and

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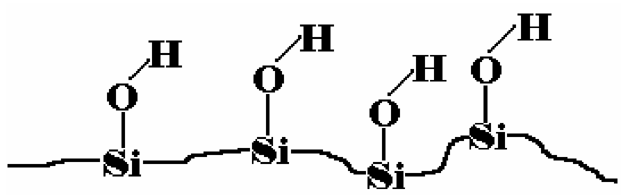
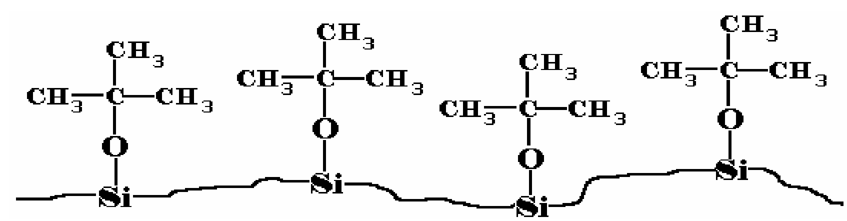
sharp points. The more smooth surface allows the monolayer to better adhere to the grain's surface. The monolayer on the sand grain contains CH_3 groups (non-polar) making the surface hydrophobic or insoluble in water.

A *molecular representation* of the surface of sand would look like the following:

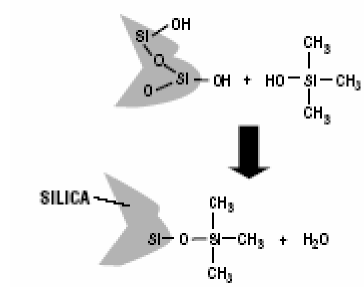


What that representation of sand's surface is showing is that there are *hydroxyl* (**--OH**) groups connected to *silicon* (**Si**) atoms sticking out of the surface of the grains of sand (the Si atoms are actually bonded to other oxygen atoms in a *tetrahedral* arrangement within the sand grains). It is this structure that will help students understand the way that *regular* sand interacts with water.

In Magic Sand, the *trimethylchlorosilane* [**$(CH_3)_3SiCl$**] interacts with the surface of the sand to replace the **H** atoms that are part of the *hydroxyl groups* on such surfaces with [**$(CH_3)_3Si$--**] groups.



Below is a pictoria … trimethylhydroxysi … ie silica, water is produced a … cles are what make the "magic sand" hydrophobic.



The bottom line is that as water molecules approach the grains of sand, they 'see' a different surface environment. This affects the way that water will interact with the *modified* – or *Magic* sand – and the students will investigate how the interaction is affected.

A surfactant, such as soap, is usually an organic compound with a hydrophilic head and a hydrophobic tail. The hydrophobic end aligns near the hydrophobic methyl groups on the sand and the hydrophilic end is free to bond and interact with the water. This reverses the hydrophobicity of the "magic sand" and it should interact with water as normal sand does.

Oil, which is naturally hydrophobic, sticks to the hydrophobic surface of magic sand. Hydrophobic is sometimes also referred to as lipophilic, which means having an affinity for

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things like oil and other lipids. A lipid is something that cannot dissolve in water but can dissolve in nonpolar solvents. Magic sand will aggregate with oil and eventually make the oil heavy enough to sink in water.

Magic Sand was originally developed to clean up oil contaminantion especially that caused by oil spills. The idea was to spread the sand on top of the oil on the water's surface and the sand would mix with the oil and not the water. This would cause the oil to become heavy and sink to the bottom of the ocean where it could be dredged and removed. However, Magic Sand is too costly to manufacture for such purposes and it is not used for oil spills.

Another use for the sand involves pipes in cold northern environments like the Arctic. In these climates it is difficult to dig into the soil in winter (it is frozen) to reach damaged underground utility lines. The idea is to cover the junction boxes with Magic Sand and then cap these with regular sand. Any rainwater will flow around the Magic Sand and the junction box will not freeze. The upper sand layer can be considered a frozen cap that can be broken away to reveal the unfrozen Magic Sand layer.

Materials

This list is per group of students. It is recommended that no more than three students be assigned per group:

- One copy *Nano Science Surface Properties Lab* sheet (below)
- Three 60 ml Petri dishes per lab sheet or any other shallow clear dish
- Small bottles (30-60ml) of regular sand and magic sand
- One 250 ml beaker with water.
- One 30-60 ml dropper bottle with cooking oil (corn, etc)
- One stirring rod
- Filter paper, funnel, and residue beaker

Advance Preparation

- Print and laminate the lab work sheet. Make one work sheet per group of students.
- Prepare bottles with the two types of sand. Label regular sand and Magic Sand
- Prepare one drop bottle with cooking oil and label it surfactant.
- Assemble enough beakers and Petri dishes for each group of students.
- Set up materials on a counter and have students gather the necessary materials to complete the activity.
- Set up a filtration stand where students can pour off the water and save the regular sand and the Magic Sand. The regular sand can be air dried on the filter paper and then reused. The Magic Sand can be poured back into the bottle from the filter paper without additional drying.
- **Discard** the Magic Sand that was used with the **surfactant**. It is not re-useable. Designate a waste area for the students to pour this dish into.

Safety Information

There are no safety hazards in working with Magic Sand.

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Directions for the Activity

- Distribute to the students the Student Activity Guide for *Discovering the Properties of Magic Sand*
- Provide an introduction to nanotechnology
- Review molecular bonding and polarity
- Have students complete the activity following the steps outlined in the procedures section
- Have the students record results on their worksheet
- Have students write a paragraph to describe the results of the experiment and their reflections on their experiences during this activity

Procedure (from Student Activity Guide)

- Place each of the Petri dishes on the circles of the lab sheet.
- Fill your beaker with water and pour some water in each of the Petri dishes.
- Open your bottle of regular sand and sprinkle a small amount into the first dish labeled regular sand and water. Observe what happens and note this on your worksheet. Add additional regular sand if you want. Did the results change?
- Open your bottle of Magic Sand and sprinkle a small amount into the second dish labeled Magic Sand and water. Observe what happens and note this on your worksheet.
- Add some additional Magic Sand into the second dish and using a stirring rod press down on the surface of the sand. You may also mix the sand and water with the rod. Observe what happens and note this on your worksheet.
- Take the bottle labeled "surfactant" and add several drops to the third dish labeled Magic Sand, water, and surfactant. Now, sprinkle a small amount of Magic Sand over the dish. Observe what happens and note this on your worksheet.

Cleanup:

- Decant the first Petri dish (regular sand) into the filtration set up in your classroom. Remove the filter paper with the sand and let it dry before returning it to the bottle. Your teacher will direct you to where these will be placed for drying.
- Decant the second Petri dish (Magic Sand) into the filtration set up in your classroom. Remove the filter paper and pour the Magic Sand back into its bottle.
- Pour the third Petri dish (with surfactant) into the classroom's waste container as indicated by your teacher. **Do not** mix the Magic Sand from this dish with the bottle of Magic Sand.

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Discovering the Properties of Magic Sand Worksheet

1. What do you know about regular sand such as beach sand? Its usually light in color, grain size varies, it does not float in water, when mixed with a lot of water it doesn't hold shape (it slumps or slides when you make a sand castle)

2. What is hydrophilic? Can you provide an example?
A substance that likes water. Water will mix with the hydrophilic substance. Examples: sugar and water, lemon juice and water.

3. What is hydrophobic? Can you provide an example?
A substance that does not like water. The two substances will not mix well or at all. Examples: oil and water, raindrops on water-proof material.

4. What causes a substance to be either hydrophilic or hydrophobic?
The polarity of the molecules cause a substance to be one or the other. Polar molecules are hydrophilic and non- polar molecules are hydrophobic

5. What occurred when you sprinkled regular sand into the first dish of water? Why do you think this occurred?
The sand sank to the bottom of the dish. The sand is hydrophilic and water lows freely between the grains of sand allowing the two to mix. Continued addition of the sand creates a larger pile of sand at the bottom of the dish.

6. What occurred when you sprinkled Magic Sand into the second dish of water? Why do you think this occurred?
The Magic Sand floated on the top of the water. When pressing the sand with the stirring rod it formed indentations but did not sink or mix with the water. With additions of Magic Sand the material will clump and it has a silvery look to it. If you lift the sand out of the dish it will be dry. The Magic Sand is hydrophobic and has a non-polar coating on it. Hydrophobic molecules in water often cluster together

7. What occurred when you sprinkled Magic Sand into the third dish of water with the surfactant? Why do you think this occurred?
The Magic Sand clumps together with the surfactant and can sink. Remember how like materials will cluster together. The surfactant is oil and it is also non-polar.

8. Can the properties of a surface be changed? What is your evidence?
Yes the surface properties can be changed. The evidence is that two forms of sand have two different types of properties in relation to water. The Magic Sand must have something on its surface to make it non-polar or hydrophobic.

9. Can you predict what Magic Sand was originally developed for? What was its possible commercial use besides being a fun "toy-like" substance? Can you think of other uses for this sand?
See aboceaa description in Teacher Background of Magic Sand for uses.

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NNIN Document: NNIN-1038

Rev: 06/07

10. What is the relationship of Magic Sand to nanotechnology?
    Nanotechnology is working at the very small scale of atoms and molecules. The Magic Sand was created by using the properties intermolecular bonds to create a different surface effect on the sand. Researchers worked at the atomic level to create a new product that has unique properties.

Assessment

- Work sheet answers should be correct and complete.

To learn more about Magic Sand visit these web sites:

http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=vc2%5C1rp%5Crp1_sand.html

http://jchemed.chem.wisc.edu/Journal/Issues/2000/Jan/abs40A.html

http://www.stevespanglerscience.com/product/1331 (also info on purchasing)

http://video.google.com/videoplay?docid=-4846085155561290961 (video of magic sand with water)

http://en.wikipedia.org/wiki/Magic_sand

http://www.chymist.com/Magic%20sand.pdf

To learn more about nanotechnology, here are some web sites with educational resources:
http://www.nano.gov
http://www.howstuffworks.com.nanotechnology.htm
http://www.sciencentral.com
http://mrsec.wisc.edu/edetc/
http://www.education.nnin.org
http://www.mos.org/doc/1137?words+nanotechnology
http://www.nclt.us
http://www.lawrencehallofscience.org/exhibits/nanotechnology.html
http://nanozone.org
http://www.ieee-virtual-museum.org
http://www.nbtc.cornell.edu/mainstreetscience/index2.html

Magic Sand can be purchased at:
http://www.teachersource.com/
http://www.stevespanglerscience.com/product/1331
http://www.reade.com/Products/Sand/Hydrophobic-%10-Magic-Sand.html
Toys R US and other craft and educational resource outlets

1. Robson, D. "Magic Sand", *Chem Matters*, April 1994, p.8-9.

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National Science Education Standards

Middle School Content Standard

- Standard A
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- Standard B
  - Properties and changes of properties in matter
- Standard E
  - Abilities of technological design
  - Understanding about science and technology
- Standard F
  - Science and technology in society
- Standard G
  - Science as a human endeavor
  - Nature of science

High School Content Standards

- Standard A
  - Identify questions and concepts that guide scientific investigations
  - Understanding about scientific inquiry
- Standard B
  - Structure and properties of matter
  - Chemical reactions
- Standard E
  - Abilities about technological design
  - Understanding about science and technology
- Standard G
  - Science as a human endeavor
  - Nature of scientific inquiry

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