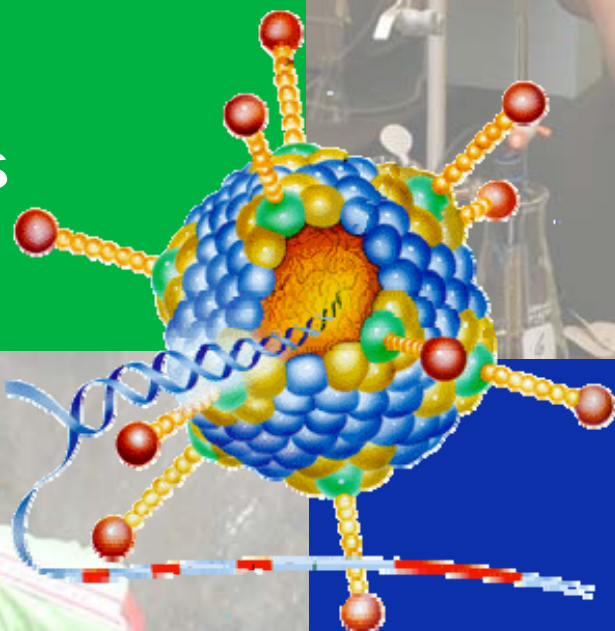


Magic Sand and the Hydrophobic Effect

Teacher's Guide



*The water*CAMPWS
Center for Advanced Materials
for Purification of Water with Systems



Curriculum Connection: Biology, Chemistry, or Physics

Bloom's Taxonomy:

Grade Level: 9-12

Topic: Properties of Water, Polarity,

Lesson Duration: Approximately 2.5-3 hours

Purpose

Water is often described as the universal solvent because it has the ability to dissolve most materials. Of all the substances on earth, only liquid ammonia is capable of dissolving more substances than water. This presents an interesting challenge for researchers and engineers concerned about water quality because water can dissolve and retain traces, often microscopic, of almost any substance.

In this lesson, students will examine how the polarity of a solvent (such as water) can affect the behavior of the solute.

Learning Goals and Objectives

1. Students will learn key vocabulary associated with physical and chemical properties of water, including polar, non-polar, hydrophobic, thermodynamics, methane.
2. Have a basic understanding of entropy and its significance as a thermodynamic force
3. Be able to explain why the polarity of a solvent can affect the behavior of the solute
4. Be aware of the importance of the hydrophobic affect in biological systems.

Benchmarks and Standards

Illinois State Learning Standards:

- *11.A.3b* Conduct controlled experiments or simulations to test hypotheses.
- *11.A.4c* Collect, organize and analyze data accurately and precisely.
- *12.C.4a* Use kinetic theory, wave theory, quantum theory and the laws of thermodynamics to explain energy transformations.
- *12.C.4b* Analyze and explain the atomic and nuclear structure of matter.
- *12.D.4a* Explain and predict motions in inertial and accelerated frames of reference.
- *12.D.4b* Describe the effects of electromagnetic and nuclear forces including atomic and molecular bonding, capacitance and nuclear reactions.
- *13.A.4a* Estimate and suggest ways to reduce the degree of risk involved in science activities.
- *13.A.4b* Assess the validity of scientific data by analyzing the results, sample set, sample size, similar previous experimentation, possible misrepresentation of data.
- *13.A.4c* Describe how scientific knowledge, explanations and technological designs may change with new information over time.

NSES Standards: In grades 9-12, students will learn:

- *Content A* Abilities necessary to do scientific inquiry & understandings about scientific inquiry.
- *Content B* Structure and properties of matter, motions and forces, and interactions of energy and matter
- *Content E* Abilities of technical design and understandings about science and technology
- *Content F* Personal and Community health, population growth, natural resources, environmental quality, natural and human induced hazards, and science and technology in local, national and global challenges
- *Teaching A* Plan an inquiry-based science program for their students
- *Teaching B* Guide and facilitate learning
- *Teaching D* Design and manage learning environments that provide students with the time, space and resources need for learning science.
- *Teaching E* Develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.

Materials and Equipment

Materials required for this lesson are (for each group of students):

- 6 400mL beakers, each containing
- 500 mL of H₂O
 - 500 mL of mineral or vegetable oil
 - Balance
 - 15 grams of beach sand
 - 15 grams of magic sand
 - Mixing rod



Introduction

Water is often described as the universal solvent because it has the ability to dissolve most materials. Of all the substances on earth, only liquid ammonia is capable of dissolving more substances than water. Most of the functions of water as well as the behavior of many substances in its presence can be attributed to its physical or non-solvent properties. Polarity, one of the most important physical properties of water is due to the size, structure and covalent bonding of oxygen and hydrogen. In Figure 1 to the right, magnetic models depict the shape and polar attraction of water.

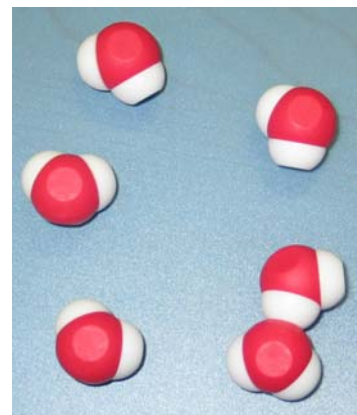


Figure 1

The symmetrical polarity of water and its affinity for other water molecules are significant for its activity as a biological solvent. For example, water is responsible for the structure and stability of proteins, as their behavior and arrangement would not be the same if they were isolated and placed in a less polar solvent. In addition, the polarity of the molecules approaching cell membranes determines whether or not they are able to pass through the outer membrane. Non-polar molecules pass through the cell's bi-layer membrane freely, while polar molecules need to be bound to carrier proteins to penetrate the cell membrane.

The Hydrophobic Effect:

The hydrophobic effect describes the weak interactions between non-polar substances in aqueous solutions. These weak forces do not arise from interactions between the atoms of chemical groups of the substance, but instead are attributed to changes in entropy when polar and non-polar molecules are mixed together.

Hydrophobic =
water repelling

Hydrophilic =
water attracting

Common table salt is an example of a simple ionic bond. Sodium, a metal, gives an electron to Chlorine, a non-metal. Thus, Sodium takes on a positive charge while Chlorine, with an extra electron takes on a negative charge.

Water also exhibits similar positive and negative charges, but does so through covalent bonds or sharing of the covalent electrons. Covalent bonds are less rigid than ionic bonds and tend to bend rather than break.

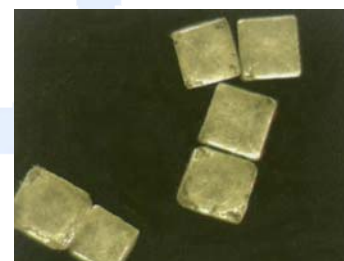


Figure 2. Salt Cubes
one side of cube = 600um

One atom has a greater attraction to the electrons and carries a partial negative charge, while the other has a partial positive charge. In the case of water, oxygen is the bigger of the atoms and has more attraction for the electrons supplied by the hydrogen atoms. As a result, the hydrogen end of the molecule is positive due to the loss of electrons and the oxygen end of the molecule is negative due to the gain of electrons. (See the water molecule Figure 4.)

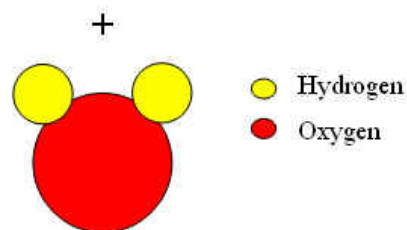


Figure 4

Thus, polar molecules such as salt dissolve in water because of positive to negative attractions. In nature, the dissolving of a substance or the completion of exothermic reactions occurs using the least amount of energy expenditure possible. This is explained by the Second law of Thermodynamics.

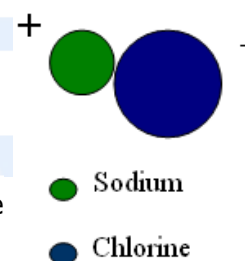


Figure 3

The Second law of Thermodynamics:

The second law of thermodynamics mandates that a system will always move towards greater entropy producing favorable change. In other words, "energy spontaneously tends to flow only from being concentrated in one place to becoming diffused or dispersed and spread out." www.secondlaw.com.

The equation shown at the right (Gibbs free energy equation) is an expression used to obtain a quantitative measurement of the energy change in a system and is useful in determining whether a reaction favors the products or reactants. G is the term for free energy. H symbolizes enthalpy (heat). T is representative of temperature and S is the symbol for entropy.

A negative G means that the reaction is spontaneous and will proceed in the forward direction ($\Delta G < \Delta H - T\Delta S$). While this equation explains entropy mathematically, we might look at nature to understand how we can logically apply entropy to everyday life. Entropy is a measure of the disorder or randomness in any given system and its surroundings.

We know that water molecules move little in the form of ice. We also know that when ice melts, the water molecules separate and become more chaotic in their movements as temperature increases. Water will not take on the form of ice without the removal of heat and will not melt without the addition of heat. As water loses heat and becomes colder, the water molecules slow down, form crystals, and the amount of free energy is diminished. Conversely, as water melts, changing from a crystalline to a liquid state, the water molecules speed up and move in a random fashion causing an increase in the amount of free energy. Potential energy held in the ice is transformed to kinetic energy within water, upholding the second law of thermodynamics.

Another interesting example of the second law of thermodynamics is the mixture of polar and non polar materials. When a non-polar substance such as methane is mixed with water under conditions of high pressure and low temperatures, ice structures form surrounding the methane. These structures are generally referred to as clathrates. Scientists, studying clathrates formed with methane gas in the cold depths just past the continental shelf, are concerned with the effects of global warming and the release of methane stored in these "ice cages" formed under these unique oceanic conditions.

An estimated 400 gigatons of methane encased clathrates is stored in the arctic. A temperature increase of only a few degrees could cause these clathrates to "burp" into the atmosphere greatly increasing the amount of methane and effecting global warming. It is believed that two huge burps, one 55 million years ago and the "mother" of all burps 251 million years ago have greatly impacted the temperature increase on earth. The potential to kinetic energy release from these clathrate burps quickly dissipates the methane throughout our atmosphere. It has been suggested that huge burps in the Bermuda triangle have caused the disappearance of ships. While these disappearances are probably not due to clathrates, an oil rig in 1981 did drill into a large methane clathrate bed and caused an explosion, sinking the rig. This unfortunate accident supports the second law of thermo dynamics!

The second law of thermodynamics
 $\Delta G = \Delta H - T\Delta S$

Did you know that snow flakes are always six-pointed? All of us are aware that when water freezes, heat is removed and the water molecules slow down. At about 30⁰ C, the water molecules compress and become the densest form of water. As the temperature decreases, the water molecules begin to rearrange themselves forming a six sided figure, each water molecule forming one side. This explains why snow flakes are always six-pointed!

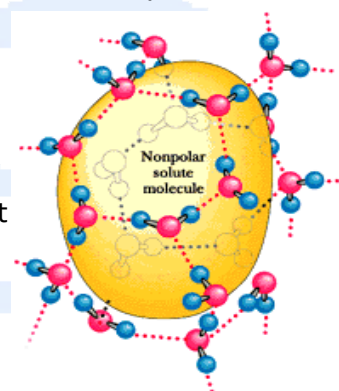


Figure 5. Water molecules forming a clathrate around a non-polar molecule.¹

For more clathrate information see:

<http://ethomas.web.wesleyan.edu/ees123/clathrate.htm>, <http://ethomas.web.wesleyan.edu/ees123/clathrate.htm>, .

For burp information see:

http://www.bermuda-triangle.org/html/methane_hydrates.html

Why does heat radiate out in a campfire?

Energy is held chemically in the wood until the heat applied, by a match, reaches the kindling temperature and the wood burns, breaking bonds and releasing energy in the form of heat and light. The energy of the fire disperses or spreads out from its source and warms the surrounding area. This is why the surrounding area is cooler, when we back away from the fire. Thus, for a spontaneous reaction or change, the entropy increases. The ordered bonds of the wood are broken to give off heat and light that is released into the atmosphere.



Activities

1. Present the introduction to this lab, or some other materials appropriate to properties of water, specifically polarity and the 2nd law of thermodynamics.
2. Break the students into groups of 2-4 and distribute the materials for the lab.
3. Give students approximately 30-50 minutes to follow the procedures listed in their lab books.
4. Have students complete the comprehension and analysis questions in their lab books.
5. Conclude the lab with a discussion of their results.
 - a. **Adaptation:** Play a trivia game with the vocabulary associated with this lab.

Conclusion

Have the students clean up the lab. With remaining time, have some of the groups share their results. Collect the lab books at the end.

Assessment

The lab book should provide an assessment tool for this lesson.