



Activity Two

Getting to Know the Water Molecule

Activity Overview:

Key concepts:

Water molecules are small and highly polar. Their polar nature gives water its unusual, macroscopic properties. On a microscopic level, water is a network of these polar molecules linked together by hydrogen bonds.

Students discover that water molecules are polar, and that the polarity makes water a liquid under normal (room temperature and average atmospheric pressure) conditions. In the previous activity, students built their model of a simplified cell, with solutions on both sides of a membrane. In this activity students "turn up the magnification" to look at water molecules and their interrelations in a network of other water molecules, thus expanding their understanding of the properties of water and aquatic solutions.

Learning Objectives:

Students will:

- be able to represent, in drawing or text, that on an atomic level, water is a network of polar molecules linked together by hydrogen bonds.
- be able to revise their model of an erythrocyte in solution to incorporate their molecular view on water.

Macro to Micro Connection:

Macroscopic properties of water, such as its liquid state under normal conditions, its ability to dissolve many other polar substances, its high boiling point, and its unique role in living organisms, all depends on the physical characteristics of the individual water molecule and the interactions among-them.

Conceptual Prologue:

Our bodies are largely water. The liquid portion of the blood, the plasma, is a very complex solution of many organic and inorganic chemicals containing more than 90 percent water. Red blood cells are designed to move about in this watery solution, using its hemoglobin to carry oxygen, and delivering it for burning organic food by the different cells. Without water, nothing would work or move around our bodies! So what is special about the water molecule? How does it behave?

In order to understand water properties, students will build a model that takes an account the structure of a water molecule and the character of water-to-water interactions. In this activity, students will work in a way similar to the way a scientist works; in fact, scientists have developed a large number of "hypothetical" models for water. They know from experience that the right model should explain and successfully predict the physical properties of a system, in our case - an erythrocyte immersed in the aquatic solution of changing salinity. Here we invite students to develop a model of such a system based on their knowledge of water molecules and how the molecules interact with each other.

We know that the chemical formula of a water molecule is simple (H_2O), yet the physical and chemical properties of this chemical compound are very unusual, and in many instances unique. Every water molecule is composed of two hydrogen and one oxygen atom; these atoms are not arranged in a line, but bent in a special way. As a result, part of the molecule is negatively charged and part positively charged. It makes the water molecules highly polar. One region of the water molecule, its oxygen, is negative, while another region, its two hydrogen atoms, is positive.

Polar molecules tend to line up with each other, the positive pole of one molecule closely aligned to the negative pole of another molecule, as do magnets. Therefore, polar water molecules create a network that is held together by special weak bonds, called hydrogen bonds. In a hydrogen bond, the slightly positive hydrogen

atom of a water molecule is attracted to a slightly negative area around an oxygen atom of another water molecule.

The reason a hydrogen atom is somewhat positive within a water molecule is because the pair of electrons that hydrogen and oxygen are sharing in their covalent bond is shifted toward the oxygen atom. As a result, the overall charge on the water molecule gets out of balance: the area around hydrogen becomes slightly positive (we call it a positive pole); the area around oxygen becomes slightly negative (we call it a negative pole). With those two poles, therefore, we call water a polar molecule. Any two polar molecules bond to each other with a hydrogen bond (H-bond). Each water molecule several H-bonds makes with its neighbors, making as a result water a structured network of H-bonded molecules.

Hydrogen bonds between water molecules give water its special properties. For example, the presence of hydrogen bonds is responsible for water being a liquid at normal room temperature, and its ability to dissolve ionic and organic compounds effectively.

Hydrogen bonds are very weak (See Bond Table below), and can be easily broken, giving water its flexible, fluid nature.

Water molecules tend to make as many hydrogen bonds as possible; polar particles of dissolved materials can become part of the network, while neutral particles of dissolved materials will "clump" to each other, pushed off the "tight". This ability to "pull" and "push" is useful in shaping proteins.

Activity Design and Execution:

STEPS



1: Derive a model of what holds water together. Students open Molecular Workbench Solutions. They will first be shown a dynamic model of water (a slight oblong shape) in the liquid state, with some guided discussion about how all the molecules stick together. After an introduction, students will be challenged to create a bunch of (similar) water molecules that will behave in the same way as the model they have observed. They will have the

options of making all molecules (1) neutral, (2) positive, (3) negative, or (4) one end positive and one end negative. Working with the model, students compare these four options and come up with a conclusion about the polar nature of water. This conclusion will be reinforced with reading, pictures of water molecules and kinesthetic movement.

See screenshots of working model.



2. (Optional) Look at the shape and behavior of a single water molecule. Let's see what science knows about the water molecule that supports this model:

Water rotations and vibrations (view with CHIME)

<http://www4.ncsu.edu:8030/~ajschult/pchem/water/water.html>

Ask your students; How do you think water rotations and vibrations will change as you increase or decrease the temperature?



3. Investigate the proposition: **Water tries to make as many hydrogen bonds as possible, forming a network.** Students use choreographed science to do this section of the activity.

- Select some students to be observers/experimenters.
- Explain to students that in this movement exercise their bodies represent the negative Oxygen, and their hands represent the two positive hydrogen atoms. The colored portion of the sash represents the attachment possibilities for positive hydrogen atoms in the area (represented by other students' arms.)
- Have them start in a straight line and then try to make as many hydrogen bonds as possible. They will pull together in a way that represents surface tension.
- Each student attaches the colored sash loosely around his/her waist. The colored portion should be in the back. Holding arms about 104° apart, each student tries to grab lightly the sash belonging to another student in each hand. Holding onto a sash represents forming a hydrogen bond.
- The students should shake, bounce, and spin, representing thermal energy. [Remember States of Matter] After a while, s/he lets his/her grip slip away when it is pulled hard. When this happens, the one with a free hand tries to grab another

sash, always keeping the arms straight and about 104° apart. Keeping arms straight is needed because the water molecules cannot get too close.

•Students can then relate what they see, starting with the Observers.

This basic water simulation illustrates many key points about water. Hopefully, they will notice that:

- The water molecules remain about the same distance apart, but can slide around.
- The individuals end up facing every which way (instead of the rigid ordering of crystals).
- If every kid grabs a sash they will make a compact group. No matter what the starting shape, the liquid will become roughly circular, because students acting as water will want to form the largest number of hydrogen bonds and will pull together. They can relate this to the formation of water drops.
- If a student on the periphery finds no one holding on to his/her sash, s/he becomes a gas molecule and starts walking in a straight line and bouncing off the container. Eventually s/he will be able to grab a sash and join the liquid again. (evaporation and condensation) [...Water molecules leave water as steam, lose energy and fall back into the liquid.]

4. Ask students: How were hydrogen bonds indicated in both the "dance" model and the computer laboratory model? (Possibly homework, if there is not enough time) Ask students to add these to their Erythrocyte in Solution model.

Extensions and Connections [below]

BOND TABLE

BOND TYPE	BOND STRENGTH	MECHANISM
Hydrogen	~ 5-10 kcal/mol	Formed by a hydrogen atom belonging to one polar molecule and a negatively charged atom of another polar molecule
Covalent single	~ 80 (50-100) kcal/mol in strength C-C is 83; S-S is 51; O-H is 110	One electron pair is shared between 2 atoms. Bond is made with electrostatic attraction between positive nuclei and electron cloud.
Covalent double	~150 (120-170) kcal/mol in strength C=C is 146; C=C is 146	Two electron pairs are shared between 2 atoms. Bond is made with electrostatic attraction between positive nuclei and electron cloud.
Covalent triple	~200 kcal/mol in strength (e.g. C - triple-C)	Three electron pairs are shared between 2 atoms. Bond is made with electrostatic attraction between positive nuclei and electron cloud.
Ionic	150-370 kcal/mol	Such a bond forms when the valence (outermost) electrons of one atom are transferred permanently to another atom. Bond is made with electrostatic attraction between cation and anion.

Extensions:

Take a Science Challenge

Science Challenge 1: Compare Water with Methane: Students can compare water with other light atoms and molecules such as methane that are very similar in size. Why do you suppose that in order to get it to boil, you have to heat up water to 100 degrees C, while you only have to heat methane to -40-50? The answer is that you need to provide more energy for the atoms to break the hydrogen bonds that hold water together. As tiny as water is, and having energy that room temperature provides, water remains a liquid. We would predict that it would be a gas, but it doesn't have enough energy to fly around. Students should discover that the greater force between water molecules gives rise to water's unusually high temperature liquid-to-gas transition.

A molecule of methane is neutral, non polar; water is highly polar. Students can consider how polarity can have such dramatic effect on the boiling - transition from liquid to gas In methane this occurs under -162.0 degrees C (-259.6 degrees F).

Science Challenge 2: Compare Attractive Forces and Boiling and Melting Temperatures. Play around with the attractive forces in MW2D (Change the depth of the attractive force, eliminate it, and change its diameter. For each setting, note the apparent boiling and melting temperatures. (@Note, these are very high now, but Qian can easily adjust the values.) Students should find that deep wells result in high melting and boiling temperatures. They may need some coaching to realize that a deep well results from a strong attractive force.

•**Add to This History Note:** Learning That Water is made of Hydrogen and Oxygen. Scientists didn't always know what atoms made up water. (You might ask students, "Do you?") In 1781, Cavendish, an English physicist, prepared water by exploding a mixture of oxygen (O₂) and hydrogen (H₂). Cavendish: $O_2 + H_2 \nrightarrow H_2O$ A year later, Lavoisier, a French chemist who was executed in the French Revolution, decomposed steam by passing it over iron. He showed that water can be decomposed to hydrogen and oxygen. Lavoisier: $H_2O \nrightarrow O_2 + H_2$ Read more about Cavendish, the man of few words but many experiments.

http://mattson.creighton.edu/History_Gas_Chemistry/Cavendish.html Read more

about Lavoisier, the French martyr to the revolution.

<http://scienceworld.wolfram.com/biography/Lavoisier.html>

- Find out more about States of Matter.
- Do more Choreographed Science: density and freezing

1. Measuring density: Freeze the simulation and count how many hydrogen bonds are formed and measure the density of the liquid. There should be almost two bonds per molecule and the density should remain constant wherever there is water, independent of the container, providing the container is large enough.

What happens when the temperature drops? It should be clear that polar molecules make harder crystals. One of the ice rules: Each water molecule is oriented so that its two hydrogen atoms are directed approximately toward two of the four oxygen atoms which surround it tetrahedrally, forming hydrogen bonds.

2. Theme: Evolution: Research the history of water on earth.

What are the signs of the presence of water in the Universe

<http://witcombe.sbc.edu/water/physicsuniverse.html> [replace with search words]

- Read about Hydrogen Bonds

<http://www.aip.org/physnews/preview/1999/h-bond/h-bond.htm>

<http://mccoy.lib.siu.edu/projects/chem140a/CH06ED/sld024.htm> (plus next two slides) <http://mdp2.phys.ucl.ac.uk/Talks/Ice/Ice.html#4>

<http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html>

<http://www.sbu.ac.uk/water/hbond.html>

<http://www.aip.org/physnews/preview/1999/h-bond/h-bond.htm>

<http://www.sbu.ac.uk/water/anmlies.html>

Additional Resources: Water: its structure and importance - Martin Chaplin

<http://www.sbu.ac.uk/water/>

<http://www.sbu.ac.uk/water/molecule.html>