LAB: Properties of Water

OBJECTIVES: Upon completion of this lab, you will:

- Explain that organisms must exchange matter with the environment to grow, reproduce and maintain organization.
- Describe how water contributes to the fitness of the environment to support life.
- Describe the structure and geometry of a water molecule, and explain what properties emerge as a result of this structure.
- Explain the relationship between the polar nature of water and its ability to form hydrogen bonds.
- List four characteristics of water that are emergent properties resulting from hydrogen bonding.
- Describe the biological significance of the cohesiveness of water.
- Explain how water molecules dissociate and re-form, and the significance of this dissociation and re-formation to the pH scale.

There is no doubt that water is vital to living organisms. Besides being the most plentiful chemical compound on the Earth’s surface, water makes up roughly 50-95% of the composition of living cells, depending on their function and nutrient content. As a chemical compound, water possesses some unique physical and chemical properties that make it an ideal compound for life. In this lab activity, you will explore a few of water’s properties by performing some short experiments that illustrate water’s importance to life.

MATERIALS:
Water
Ethanol
Salt
Beral pipets
Mineral oil
Molecular models of water
Various solutions with differing pH levels

Glass microscope slide
Sponge piece
Granulated sugar
Paper towels
400 mL beaker
pH paper

Dixie cups
Test tubes
400 mL beaker

Fan
Balloon
Penny

SAFETY: Alcohol is flammable and toxic. Keep away from sources of heat. Do not ingest! Also, dispose of alcohol as your teacher directs.

WATER FORMS HYDROGEN BONDS

These weak bonds that collectively are very strong make possible most of water’s unique properties, such as cohesive and adhesive properties, high specific heat, high heat of vaporization and polarity. Hydrogen bonds are what are known as intermolecular forces—attractive forces that act between particles that are next to one another. Specifically, hydrogen bonds are weak bonds that form between hydrogen atoms of one molecule and the lone pair(s) of neighboring electronegative atoms. This hydrogen bonding allows for water molecules to be both adhesive (sticking to other surfaces) and cohesive (sticking to each other). Both the adhesive and cohesive properties of water are critical to living organisms, as water is able to reach the tops of the tallest trees due to adhesion and cohesion. When water adheres to the xylem tissues of plants and “crawls” to the tops of these plants, this is known as capillary action. Capillary action also occurs in non-living objects, such as drinking straws and graduated cylinders.
Activity 1A: Water’s Molecular Structure and Hydrogen Bonding

1. Using the molecular models provided for you by your instructor, sketch, color, and label a space-filling model of water in the space provided. Be sure it is an accurate representation of the actual model! Give a description of the shape of the water molecule.

2. Now, using your model, demonstrate for your instructor what hydrogen bonding of multiple water molecules to each other looks like. Get your instructor’s approval of your model by having him/her stamp in the space at right.

3. When you have received approval from your instructor as to the correctness of your model, label the diagram shown at right. Identify the hydrogen bonds, the covalent bonds, and the individual atoms and charges on at least one individual water molecule.

Activity 1B: Capillary Action, Adhesion and Cohesion

1. Cut a strip of paper towel about 2 cm wide x 15 cm in length.
2. Tape the strip of paper towel to a pencil.
3. Fill a 400 mL beaker with about 10 mL of water.
4. Now place the pencil with the paper towel strip over the opening of the beaker so that the end of the paper towel strip touches the surface of the water. Wait for 5 minutes.
5. When you are done making observations, answer the questions at right and clean your workstation.

What happens to the paper?

How could this be applicable to living things?
Activity 1B Continued

1. At this station you will see two graduated cylinders—one plastic and one glass. Both hold the same quantity of liquid.
2. Fill each graduated cylinder to the same volume: 25mL.
3. Observe how the meniscus reading differs in each cylinder. Sketch what you see at right and make qualitative observations about the water in each cylinder.
4. Clean up your work area.

<table>
<thead>
<tr>
<th>Plastic Cylinder</th>
<th>Glass Cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative Observations</td>
<td>Qualitative Observations</td>
</tr>
</tbody>
</table>

**QUESTION:** Which cylinder demonstrates greater adhesive forces between it and the water inside? Justify your answer.

**WATER IS POLAR**

Water has both a positive and a negative charge on its molecular structure. This is due to the unpaired electrons of the oxygen atom hanging out in its outer valence shell. There is a slightly positive charge on the ends where the hydrogen atoms are. This unequal sharing of electrons causes the water molecule to be polar. This enables it to dissolve almost anything. Contrary to popular belief, water is not a universal solvent, as it is unable to dissolve nonpolar molecules such as lipids and some proteins. This property of water is critical to the formation of cell membranes, which are composed of phospholipids and proteins.

Activity 2A: Polarity

1. Fill one test tube with 5 ml of water from the sink. Fill a second tube with 5 mL of ethanol.
2. Using a balance, mass out 0.5 grams of salt and place this into the test tube of water and swirl it around. Record your results in the data table at right.
3. Repeat step 2, except place the salt into the test tube containing ethanol.
4. Repeat this experiment with 0.5 grams of sugar. Record your results in the data table at right.
5. Clean up your work area.

<table>
<thead>
<tr>
<th>Water</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt</td>
<td>Sugar</td>
</tr>
<tr>
<td>Salt</td>
<td>Sugar</td>
</tr>
</tbody>
</table>
**QUESTION:** In what liquids do the salt and sugar dissolve, and why? Justify your answer.

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**Activity 2B: Polarity**

1. Using the Beral pipet, form a small puddle (about the size of a dime) on a piece of wax paper.
2. Place the tip of the pipet in the center of the puddle and slowly drag the tip of the dropper around the wax paper.
3. Repeat this procedure for the glass microscope slide and make note of your observations in the table at right.
4. Clean up your work area.

<table>
<thead>
<tr>
<th>Behavior of water on wax paper</th>
<th>Behavior of water on glass slide</th>
</tr>
</thead>
</table>

**QUESTION:** Explain the behavior of the water as it is dragged across the wax paper and across the glass slide. Which surface does the water cling to? Which surface is the water repelled by?

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**QUESTION:** Objects that are attracted to water are said to be hydrophilic (“water loving”), while objects that are repelled by water are said to be hydrophobic (“water hating”). Identify the hydrophilic and hydrophobic surfaces in this activity.

<table>
<thead>
<tr>
<th>Hydrophilic</th>
<th>Hydrophobic</th>
</tr>
</thead>
</table>

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**Activity 2C: Polarity**

1. Obtain 2 sauce cups. Place 2mL of water in one of the cups. In the other cup, place 2 mL of alcohol.
2. Use the Beral pipet provided to put a small drop of mineral oil in each cup. Stir the mixture with a toothpick and observe what happens to the drop. Record your observations in the data table at right.
3. Dispose of your cups and liquids as your teacher directs.

<table>
<thead>
<tr>
<th>Behavior of oil droplet in water</th>
<th>Behavior of oil droplet in alcohol</th>
</tr>
</thead>
</table>

**QUESTION:** In what liquids does the oil dissolve, and why? Justify your answer.
Activity 2D: Polarity

1. Inflate a balloon. Gently rub the balloon against your clothing.
2. Using the faucet at a sink (be sure to remove the hose first!), turn on the water so that a slowly running stream of water exits the faucet.
3. Bring the balloon close to the stream of water but do not allow the balloon to touch the water.
4. Sketch what you see occurring in the space at right and write a description of what you see happening.

QUESTION: How does water’s polarity explain why the water behaves as it does in this activity?

WATER HAS A HIGH SURFACE TENSION
Because of the hydrogen bonds that hold water molecules to each other, this creates a ‘net’ of water molecules that allows some organisms to walk on water, such as water striders. The surface tension of water is also what allows water to bead up on waxy surfaces of leaves and organisms with waterproof coatings. In order to clean clothes or wash dirty dishes/ hands, surface tension must be reduced so water can spread and wet surfaces. Chemicals that are able to do this effectively are called surface-active agents, or surfactants. They are said to make water “wetter.” Surfactants perform other important functions in cleaning, such as loosening, emulsifying (dispersing in water) and holding soil in suspension until it can be rinsed away. Surfactants can also provide alkalinity, which is useful in removing acidic soils.

Activity 3A: Surface Tension

1. At this station, there are two pennies and two beakers of water: one with soap and one without.
2. See how many drops of each solution you can fit on the head of each coin. Repeat each of these 3 times and record your data in the table at right.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Water Droplets on Penny</th>
<th>Soapy Water Droplets on Penny</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

QUESTION: Which coin held more water droplets, and why? How does adding soap affect the number of drops of liquid you can add to the penny in this experiment?
Activity 3B: Surface Tension

1. At this station, there are two pennies and two beakers: one with water, and the other with alcohol.
2. See how many drops of each solution you can fit on the head of each coin. Repeat each of these 3 times and record your data in the table at right.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Water Droplets on Penny</th>
<th>Alcohol Droplets on Penny</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

QUESTION: Using the data you collected above, explain which liquid has the higher surface tension.

QUESTION: What is the relationship between surface tension and cohesion?

WATER HAS A HIGH HEAT OF VAPORIZATION

The heat of vaporization of water is 2260 J/g. This means that to change water from a liquid into a gas, the water itself must absorb 2260 J of energy. As a comparison, the alcohol we have been using in this lab has a heat of vaporization of 124 J/g. This property of water is important because many organisms use evaporative cooling; or the evaporation of water, in order to cool themselves off when they are hot. This is why sweating is a great way to cool down on a hot day.

Activity 4: High Heat of Vaporization

1. Get a piece of sponge and rub some water on the inside of your forearm.
2. Place your moistened arm in front of a fan, and time how long it takes for the water to completely evaporate so that your arm is dry.
3. Repeat this activity with an alcohol swab. Record your data in the data chart at right.

<table>
<thead>
<tr>
<th>Water</th>
<th>Alcohol swab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to dry</td>
<td>Time to dry</td>
</tr>
</tbody>
</table>

QUESTION: Which liquid appears to dry faster, and why? Justify your answer.
WATER IS LESS DENSE AS A SOLID THAN IT IS AS A LIQUID

When frozen, water molecules spread themselves apart in a latticework (see picture at left). This creates air spaces in the resulting solid that cause the ice that forms to be less dense than the liquid water it originated from. This is essential to organisms that live where it is always cold. The ice floating on top of bodies of water provides insulation for the life below and prevents organisms’ bodies from freezing solid in the winter.

Activity 5: Density

1. You will see two water-filled tubs, each with an “ice balloon” inside.
2. In the space at right, describe the behavior of the ice balloon in each tub.

<table>
<thead>
<tr>
<th>Tub #1</th>
<th>Tub #2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

QUESTION: Explain the behavior of the ice balloons in each of the tubs of water. Which tub contained salt water? How do you know?
WATER DISSOCIATES INTO HYDROXIDE AND HYDROGEN IONS

Most chemical reactions in organisms involve solutes dissolved in water. So that we better understand chemical reactions, we need to know how many atoms and molecules are involved in those reactions. To do this, we must work in units that make working with molecules easier to quantify. In chemistry, the unit of measure when dealing with quantities of molecules is the mole. Recall that one mole represents Avogadro’s number of molecules: 1 mole = 6.02 x 10^{23} molecules of a substance.

Water molecules exist in equilibrium between hydrogen ions and hydroxide ions:

\[
\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-
\]

What this ultimately means is that the concentration of both of these ions is equal to one another, at \(1 \times 10^{-7}\) M. In any aqueous solution at 25° C, the product of the H^+ and OH^- concentrations is constant at \(10^{-14}\) M. To find this, simply add the [H^+] value and the [OH^-] value together. It will always be equal to \(10^{-14}\) M, regardless of what the individual concentrations are.

When acids or bases are added to a solution of pure water, the equilibrium of H^+ ions and OH^- ions is disturbed and will shift. If acids are added to water, then the [H^+] will increase and the [OH^-] will decrease. If bases are added to water, then the [OH^-] will increase, and the [H^+] will decrease.

The concentrations of hydrogen and hydroxide ions are the basis for the pH scale, which is used to describe how acidic or basic a solution is. If a solution has a [H^+] of less than \(10^{-7}\) M, then it is considered to be basic. If a solution has a [OH^-] of greater than \(10^{-7}\) M, then it is considered to be basic. If a solution has a [H^+] = [OH^-], where both have concentrations of \(10^{-7}\) M, then the solution is considered to be neutral.

Because the pH scale is a logarithmic scale, each pH unit represents a 10-fold difference in ion concentration. Thus, a solution of pH 3 is not 3 times more acidic than a solution of pH 6; it is 1,000 times more acidic.

Water molecules also dissociate into hydroxide and hydronium (H_3O^+) ions, but its existence as these two ions is very short-lived.

Activity 6: Measurement of pH

1. You will see several different solutions at this station.
2. To measure the pH of each solution, do the following:
   a. Use the pipet in each solution to place a drop of the solution on the pH paper provided.
   b. Wait for 1 minute, then compare the paper strip to the color scale provided.

<table>
<thead>
<tr>
<th>Solution</th>
<th>pH</th>
<th>Acid, base, neutral?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vinegar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemon juice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicarbonate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tap water</td>
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