Physical and Chemical Properties of Water

Strand Life at the Molecular and Cellular Level

Topic Understanding physical and chemical properties of water

Primary SOL BIO.2 The student will investigate and understand the chemical and biochemical principles essential for life. Key concepts include
- a) water chemistry and its impact on life processes.

Related SOL BIO.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which
- a) observations of living organisms are recorded in the lab and in the field;
- i) appropriate technology, including computers, graphing calculators, and probeware, is used for gathering and analyzing data, communicating results, modeling concepts, and simulating experimental conditions;
- l) alternative scientific explanations and models are recognized and analyzed.

Background Information

On this planet, water is the only substance that occurs abundantly in all three physical states. It is our only common liquid and is our most widely distributed pure solid, ever present somewhere in the atmosphere as suspended ice particles or on Earth's surface as various types of snow and ice. It is essential to life as a stabilizer of body temperature, as a carrier of nutrients and waste products, as a reactant and reaction medium, as a stabilizer of biopolymer conformation, as a likely facilitator of the dynamic behavior of macromolecules, including their catalytic (enzymic) properties, and, perhaps, in other ways yet unknown.

Water is so essential for life that when we look for indications of life extraterrestrially, we typically look first for water or signs of water. The suitability of a habitat for life here on Earth, or extraterrestrially, depends in large part on the chemical and physical properties of water. These unique properties are due to the nature of the polar and hydrogen bonding between and within the water molecules.

Materials
- Construction paper
- Hole-punches
- Drinking glasses
- Deionized water
- Pennies or nails
- Shallow bowls
- Pepper
- Sugar cubes
- Dish detergent
- Pipettes
- Capillary tubes or straws of different sizes

- Metric rulers
- Sand
- Scales
- Beakers of the same size
- Thermometers
- Hot water
- Ice water
- Beakers or test tubes
- Vinegar
- Ammonia
- Freshly squeezed lemon juice (citric acid)
- Milk
- pH meter/probe or pH paper
- Stir rods
- Water samples taken from various sources (e.g., tap, well, pond, stream, lake)
- Calorimeters (optional)
- Physical and Chemical Properties of Water handout (attached)

Vocabulary

adhesion, capillary action, cohesion, conductivity, electron, hydrogen bond, pH, polar bond, specific heat, surface tension

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

There are several activities in this lesson. If there is not enough time for every lab group to do every activity, you may wish to have groups do different activities and then share data.

1. As an introductory stimulus, read aloud the following selection, "Prologue — Water: The Deceptive Matter of Life and Death"[1]:

   > Unnoticed in the darkness of a subterranean cavern, a water droplet trickles slowly down a stalactite, following a path left by countless predecessors, imparting as did they, a small but almost magical touch of mineral beauty. Pausing at the tip, the droplet grows slowly to full size, then plunges quickly to the cavern floor, as if anxious to perform other tasks or to assume different forms. For water, the possibilities are countless. Some droplets assume roles of quiet beauty—on a child's coat sleeve, where a snowflake of unique design and exquisite perfection lies unnoticed, on a spider's web, where dew drops burst into sudden brilliance at the first touch of the morning sun, in the countryside, where a summer shower brings refreshment, or in the city, where fog gently permeates the night air, subduing harsh sounds with a glaze of tranquility. Others lend themselves to the noise and vigor of a waterfall, to the overwhelming immensity of a glacier, to the ominous nature of an impending storm, or to the persuasiveness of a tear on a woman's cheek. For others the role is less obvious but far more critical. There is life—initiated and sustained by water in a myriad subtle and poorly understood way—or death inevitable, catalyzed under special circumstances by a few hostile crystals of ice, or decay at the forest's floor, where water works relentlessly to disassemble the past so life can begin anew. But the form of water most familiar is none of these; rather it is simple, ordinary, and uninspiring, unworthy of special notice as it flows forth in cool abundance from a household tap.

[1] Owen R. Fennema, "Prologue — Water: The Deceptive Matter of Life and Death, Water and Ice," *Food Chemistry* (1985): 24.

> "Humdrum," galunks a frog in concurrence, or so it seems, as it views with stony indifference the water milieu on which its very life depends. Surely, then, water's most remarkable feature is deception, for it is in reality a substance of infinite complexity, of great and unassessable importance, and one endowed with a strangeness and beauty sufficient to excite and challenge anyone making its acquaintance.

2. Discuss the many forms of water mentioned in the selection or that students have encountered in their lives.
3. Have students create models of a water molecule, using simple cutouts from construction paper, as follows: Cut out one large circle for the oxygen atom, two smaller circles for the hydrogen atoms, and several hole-punch dots for electrons. Guide students in arranging their cutouts to illustrate that in a polar bond, the negatively charged electrons shared between oxygen and hydrogen are closer to the oxygen atom, making the oxygen atom slightly negative and the hydrogen atom slightly positive. Show students how a hydrogen bond could form between the oxygen atom of one water molecule and a hydrogen atom of another.
4. Ask students to consider why water is different from other liquids, and what it is about hydrogen bonding that makes water behave the way it does. Also ask why, when we explore other planets, one of the first substances we look for is water. Introduce the properties of water that make it unique as a result of its polarity.
5. Have students complete the differentiated activities found on the attached Physical and Chemical Properties of Water handout. Alternatively, assign each group one of the five activities to complete, and have groups share their experiments, observations, and explanations of results with the class.

Assessment

- **Questions**
  - How are ionic and covalent bonds relevant to the suitability of water as a medium for living systems? Explain.
- **Journal/Writing Prompts**
  - Given three specific heat values, discuss the relevancy of the values and their relationship to those of others liquids to the suitability of water as a medium for living systems.
  - Three living arrangements are described below. For each one, state which bond—hydrogen, polar covalent, or nonpolar covalent—it illustrates, and explain why.
    - Ms. Scarlett and Mr. Green purchase a home together. They split the cost 50-50. (nonpolar covalent)
    - Professor Plum and Colonel Mustard buy a condo. Plum lives in the condo for eight months of the year, and then Mustard lives there for the other four months. (polar covalent)
    - Ms. White and Ms. Peacock live next door to each other and are always visiting each other's apartments. (hydrogen)
- **Other**
  - Have students write thank-you notes to water, specifically addressing its four properties. Notes should include writing (prose, poem, or song lyrics) as well as graphics.

- Tug of War: Create a game board by drawing a pond/river in the middle of a sheet of paper. Make one copy for each group. Create tug of war "ropes" by tying ten equidistant knots in a piece of string. Divide students into groups, and give each group a piece of knotted string. Have the groups subdivide into two teams and place their string on the game board so that it is evenly spread across the water. One team poses a review question. If the other team answers correctly, the string moves one knot in their direction, thus moving their opponent closer to the water. If they are incorrect, the string moves in the other direction. Game ends when one team gets pulled into the water.
- Word Puzzles: Display the following on the board:
  - p b = s p and s n
  - n p b = e s of e
  - h b = w a b p m

  Challenge students to hypothesize the meaning behind the letters:
  - p b = s p and s n (polar bond = slightly positive and slightly negative)
  - n p b = e s of e (non polar bond = equal sharing of electrons)
  - h b = w a b p m (hydrogen bond = weak attraction between polar molecules)

  (Word Puzzles like this can be used as a pre- or post-activity for any vocabulary in any lesson.)

Extensions and Connections (for all students)

- Discuss the role of cohesion and adhesion in transpiration. Have students design an experiment to test the effect of an environmental factor on the rate of transpiration.
- Have students write a paragraph about the ways they use water in their lives, relating water's physical and chemical characteristics to its suitability for living systems.
- Have students extend understanding to areas such as
  - water as a cooling agent in perspiration
  - water as a wetting agent in membrane function (lungs of premature children)
  - water's influence on global climate patterns and local microhabitats
  - the global requirement for clean and sustainable water
  - the presence or absence of water on other planets and/or moons.
- Have students investigate the insulating properties of water by using reference materials to research the conditions of the subnivean zone and its importance to survival in cold temperatures. If a snowy field is available, they may directly observe a microhabitat and its various temperatures that depend in part on the insulating properties of water. From this, they may infer water's function in insulating aquatic ecosystems.
- Divide students into groups, and provide each group with a molecular model kit and a list of simple molecular formulas. Have groups build the molecules to represent the proper atomic arrangements.
- Just for fun, have students research dihydrogen monoxide, or DHMO (actually water, or H_2O) and visit some Web sites that have been created to ban it.

Strategies for Differentiation

- (Strategies for differentiation are embedded in the activities listed under "Other" and "Extensions" above.)

- Assign tasks within laboratory groups/pairings to suit individual strengths or needs.
- Have students enter data into a prepared computer spreadsheet and use the program to prepare and present the graphs.
- Create a large pH scale to hang on the wall or chalkboard. After students have measured the pH of the substances in the lab, have them place cards naming the substances they have tested on the chart in the appropriate locations. You might also provide students with a list of other common substances and their pHs and have them make and place name cards on the chart for these substances.
- Have students create a graphic organizer that relates and/or classifies the key concepts of water chemistry.

Physical and Chemical Properties of Water

Part 1: Surface Tension

Materials

Drinking glass, water, pennies or nails

Procedure

1. Put the glass on a counter or in the sink. Add water until the glass is full to the brim.
2. Hypothesize the number of pennies or nails you can add to the glass before it overflows.
3. Carefully hold a penny or nail over the glass so its edge or point just touches the surface of the water. Let go of the penny or nail so it slides into the water.
4. Record the actual number of pennies or nails you could add before the water overflowed.
5. Write a sentence to summarize and explain your observations.

Part 2: Surface Tension

Materials

Shallow bowl, tap water, pepper, sugar cube, dish detergent, pipette

Procedure

1. Fill the bowl almost full with water. Gently sprinkle pepper across the surface of the water.
2. Slowly place the sugar cube in the center of the water's surface. Record observations.
3. Change the water, and sprinkle pepper again.
4. Use the pipette to add one drop of dish detergent in the center of the water's surface. Record observations.
5. Write a sentence to summarize and explain your observations.

Part 3: Capillary Action

Materials

Deionized water, capillary tubes or straws of different sizes, metric ruler, dish detergent

Procedure

1. Using the deionized water, the capillary tubes or straws of different sizes, and the metric ruler, determine the height to which pure water will rise in the tubes. Record and graph the data, using height in mm × inside diameter in mm.
2. Repeat the experiment with another set of tubes and a diluted soap solution.
3. Write a sentence to summarize and explain your observations. How do the graphs compare? Explain the differences in terms of surface tension, adhesion, cohesion, and the impact that soap has on these properties. Explain the relevancy of water's capillarity to its suitability as a medium for living systems.

Part 4: Heating and Cooling Rates

Materials

- Deionized water, sand, scales, identical beakers, thermometers, hot water, ice water

Procedure

1. Place equal masses of sand and deionized water in each of two identical beakers.
2. Insert identical thermometers into the materials.
3. Put one beaker in a hot water bath and the other in an ice water bath.
4. Observe and record the temperature of each materials every 5 minutes.
5. Graph and compare the rates of heating or cooling over time. Write a sentence to summarize and explain your observations.
6. Relate these results to the subnivean ("situated under the snow") conditions that make life in cold environments more tolerable.

Part 5: pH

Materials

Beakers or test tubes, deionized water, vinegar, ammonia, freshly squeezed lemon juice, and milk, pH meter/probe or pH paper, stir rods, water samples taken from various sources (e.g., tap, well, pond, stream, lake)

Procedure

1. Set up five identical beakers or test tubes, each containing 10mL of one of five liquids: deionized water, vinegar, ammonia, lemon juice, and milk.
2. Test the pH of each liquid, using the pH meter/probe or pH paper. Record observations.
3. Create your own solutions using provided materials, for example:
   - 10mL solution with a pH of 4, using water and one other ingredient
   - 10mL solution with a pH of 4, using three ingredients