Chemistry of Life:
Bonding and Properties of Water

Investigation Manual

CAROLINA DISTANCE LEARNING

CHEMISTRY OF LIFE: Bonding and Properties of Water

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Overview

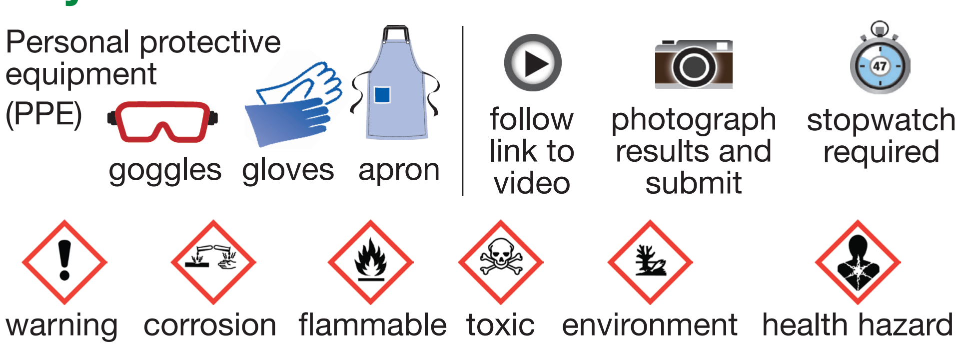
To understand how cells and organisms are assembled, we must first understand the fundamentals of atomic structure. We must understand how atoms are linked together, what type of chemical bonds are used, and how these bonds, as well as other chemical interactions, can form larger molecules. These chemical interactions are responsible for the unique properties or characteristics of certain molecules.

In this investigation, three types of chemical bonds will be investigated: ionic, covalent, and hydrogen. In a series of activities, some of the properties of water will be tested and the molecular interactions at play will be examined. In the first activity, the solubility of covalent and ionic substances in polar solvents is investigated. The physical properties of adhesion and cohesion of water due to hydrogen bonding is examined in the second activity. In the third activity, we investigate density and miscibility, and in the final activity, we observe the high heat capacity of water.

Outcomes

- Perform basic experiments to investigate the properties of chemical bonds.
- Demonstrate and explain the physical aspects of water, such as surface tension, adhesion, cohesion, polarity, density, and heat capacity.
- Discuss the intermolecular forces between polar substances and nonpolar substances.
- Explain hydrogen bond formation and relate how hydrogen bonds are involved in the structure of water.

Key



Time Requirements

Preparation	5 minutes
Activity 1: Solubility	10 minutes
Activity 2: Adhesion and Cohesion	10 minutes
Activity 3: Density and Miscibility	5 minutes
Activity 4: Heat Capacity	10 minutes

Background

Ionic Bonding

Ionic bonds are typically formed when a metal atom loses one or more electrons to become a positively charged **cation**, and when a nonmetal atom gains one or more electrons to become a negatively charged **anion**. These opposite charges cause the cation and anion to be attracted to each other, forming an ionic bond. Because ionic bonds form crystalline structures, ionic compounds are often very hard. Table salt (sodium chloride) is a good example of an ionic compound that exists in crystalline form. Ionic bonds are broken when ionic substances are dissolved. For example, when table salt is dissolved in water its crystalline form is broken down. Ions in solution are important for conducting the electrical charges that play a critical role in proton pumps, heart rhythms, and nerve impulses in the body.

Covalent Bonding

Covalent bonds are typically formed when two nonmetal atoms share one or more pairs of electrons. There are two different types of covalent bonds: **nonpolar** and **polar**. A nonpolar covalent bond forms when two atoms share electrons equally. A polar covalent bond forms when two atoms share electrons unequally. Unequal sharing is a direct consequence of **electronegativity**, which is the relative ability of an atom to attract electrons. If one atom is slightly more electronegative than the other in a covalent bond, the shared electrons will be pulled slightly closer to that atom, giving it a partial charge. The existence of partial charges on each of the atoms results in polarity of the molecule.

In covalent molecules, the atoms are held together by strong covalent bonds. When covalent bonds are broken, stored chemical energy is released. For instance, the covalent bonds of glucose, a simple sugar, can be broken to provide the energy used to generate adenosine triphosphate (ATP).

Solubility

Liquid mixtures of substances can be categorized into three main groups: **suspensions**, **colloids**, and **solutions**. Suspensions are heterogeneous mixtures that spontaneously separate into their individual components. A common example is a suspension of fine clay particles, which will eventually settle to the bottom if the mixture is left standing. Colloids are stable heterogeneous mixtures in which the particles do not separate into their individual component molecules (as in a suspension) but also will not spontaneously separate into layers. Some common examples of colloids include smoke and gelatin. Solutions are homogeneous mixtures in which the solute separates into individual molecules or ions that are evenly distributed throughout the solvent.

Solubility is the ability of a substance to dissolve. More precisely, solubility is the maximum amount of solute that can be dissolved in a given amount of solvent at a specific temperature and pressure. If a substance dissolves in a solvent, it is **soluble**. If it does not dissolve, it is **insoluble**. **Miscible**

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Background continued

substances are liquids that are completely soluble with each other, whereas **immiscible** substances are insoluble with each other.

The substance that comprises the larger portion of a solution is the **solvent**, and the substance that makes up the smaller portion is the **solute**. When water is used as a solvent, the resulting solution is said to be **aqueous**. For example, if you stir a spoonful of sodium chloride into a glass of water, sodium chloride is considered the solute and water is the solvent. The mixture is an aqueous sodium chloride solution.

In a **saturated** solution, the amount of solute dissolved cannot be increased for that volume of solvent under those conditions. You can keep adding more and more sodium chloride to a glass of water until eventually the solution becomes saturated, and any more added sodium chloride will settle to the bottom of the glass regardless of how much you stir.

The solubility of one substance with another is often challenging to predict. Despite the numerous exceptions that exist, there are general rules that can be applied. Polar substances are more soluble in polar solvents, whereas nonpolar substances are more soluble in nonpolar solvents. This is known as the "like dissolves like" rule.

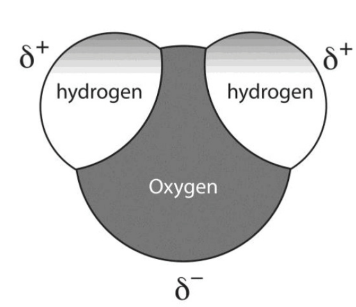
Water is often called the "universal solvent" because, as a highly polar substance, it is able to dissolve many solutes, especially ionic compounds and polar molecules. Substances that are easily dissolved in water are often described as **hydrophilic** ("water-loving"). It is important to remember that not all substances can be dissolved in water. Think of a salad dressing containing water, vinegar (acetic acid), and vegetable oil. You need to shake this kind of dressing before pouring it onto your salad because the water and vinegar solution will not dissolve the nonpolar vegetable oil. In fact, the water and vinegar solution forms one layer and the vegetable oil separates into another. Therefore, the vegetable oil would be described as **hydrophobic** ("water-fearing").

Another commonly used solvent is isopropanol (rubbing alcohol), which is a polar molecule that exhibits less polarity than water. Isopropanol can dissolve some nonpolar substances, but it can also mix with water and other polar solvents. This allows for the creation of solutions that might otherwise be immiscible.

Adhesion and Cohesion of Water

The water molecule has a simple structure: one oxygen atom is covalently bonded to two hydrogen atoms. In addition to the two pairs of electrons it shares with the hydrogen atoms, the highly electronegative oxygen atom has a pair of unshared electrons. Due to this uneven sharing of electrons, a water molecule has a partial negative charge (δ–) near the oxygen atom and partial positive charges (δ+) near the hydrogen atoms (Figure 1). **Hydrogen bonds** between adjacent water molecules result from an electrostatic attraction between the partial negative charge of the oxygen atom

Figure 1.



Water Molecule

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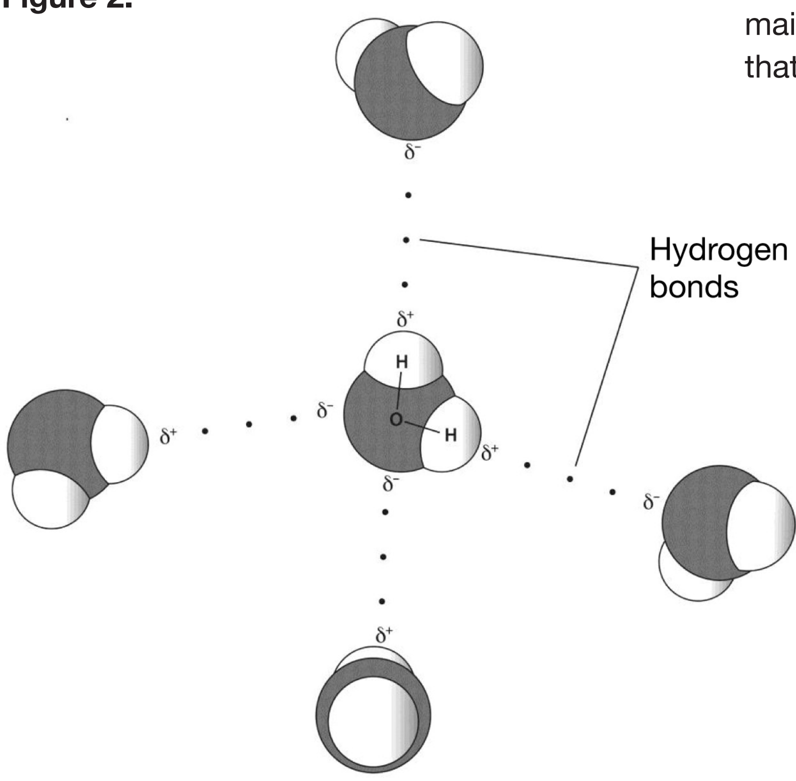
and the partial positive charge of the hydrogen atom. Hydrogen bonds are relatively weak; thus, they are constantly breaking and reforming as water molecules move around one another.

The attraction between water molecules due to hydrogen bonding is known as **cohesion** (Figure 2). Water forms droplets due to cohesion. For the same reason, water is resistant to objects passing through its surface, and thus is said to have a high **surface tension**. Some organisms, like the water strider (a type of insect) and the common basilisk (a type of lizard), exploit this property when walking or running across the surface of water.

The attraction of water molecules with other different molecules is termed **adhesion**. Water clinging to a dog's fur is an example of adhesion. Think of how hard a dog has to shake in order to dry its fur. This illustrates the power of adhesion.

Figure 2.



Hydrogen Bonds

Heat Capacity

Specific heat capacity denotes the amount of energy required to raise the temperature of 1 g of a substance 1 °C. Water's specific heat capacity is high, so it requires a relatively large amount of energy to change the temperature of water. A substance with a low specific heat capacity requires much less energy to change its temperature. This property of water is extremely important for life on Earth. A body of water, such as a lake, maintains a relatively constant temperature throughout a 24-hour period even though the ambient temperature may rise and fall drastically between day and night. This helps maintain a constant environment for organisms that live in the water.

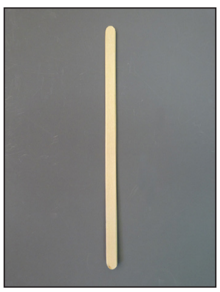
Materials

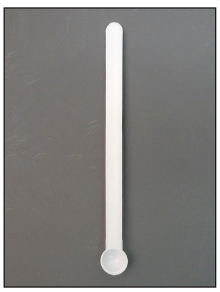
Included in the materials kit:

Isopropanol, 10 mL

Benzoic acid, 2 g


Well plate


15 Wooden splints


3 Scoops


2 Paper cups (waxless)

Needed from the equipment kit:

Graduated cylinder, 25 mL


Beaker, 250 mL


2 Transfer pipets

Needed but not supplied:

- Permanent marker
- Table sugar (about 1 g of sucrose)*
- Table salt (about 1 g of sodium chloride)*
- Finely ground pepper (about 1 g)*
- Match or lighter
- Tap water (about 100 mL)
- Timer or timing device
- Drop of dish soap
- Access to running water at a sink
- Access to a fire extinguisher
- Timer or stopwatch

*One condiment packet each of sugar, salt, and pepper will be sufficient to conduct the activity.

Reorder Information: Replacement supplies for the Chemistry of Life: Bonding and Properties of Water investigation (item number 580104) can be ordered from Carolina Biological Supply Company.

Call: 800.334.5551 to order.

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Safety

Wear your goggles, gloves, and lab apron at all times while conducting this investigation.

Read all the instructions for this laboratory activity before beginning. Follow the instructions closely, and observe established laboratory safety practices, including the use of appropriate personal protective equipment.

Use isopropanol (rubbing alcohol) with caution. Avoid contact with skin and eyes, and use in a ventilated room. Keep isopropanol away from heat, sparks, and flames.

Keep combustible materials, including hair and clothing, away from flames. Do not leave open flames unattended. Know the location of your nearest accessible fire extinguisher and how to use it.

Benzoic acid is harmful when swallowed and can cause serious eye damage. It may cause respiratory irritation, drowsiness, or dizziness. Benzoic acid is toxic to aquatic life.

Do not eat, drink, or chew gum while performing this activity. Wash your hands with soap and water before and after performing the activity. Clean the work area with soap and water after completing the investigation. Keep pets and children away from lab materials and equipment.

Preparation

1. Read through the procedure.
2. Obtain all materials.
3. Clean the work area.
4. Collect about 100 mL of tap water in the 250 mL beaker.
5. Use a permanent marker to label one dropper pipet as “water” and the other as “isopropanol.” These pipets should be used only with their designated liquids.

ACTIVITY

ACTIVITY 1

A Solubility

1. Orient the well plate such that A1 is in the top left corner. This table summarizes the contents of each well as described in Steps 2–12.

	Sucrose	Sodium Chloride	Benzoic Acid
Isopropanol	A1	A2	A3
Water	B1	B2	B3

2. Use the “isopropanol” pipet to transfer 2 mL of isopropanol into wells A1, A2, and A3.
3. Use the “water” pipet to transfer 2 mL of water into wells B1, B2, and B3.
4. Add one leveled scoop of table sugar (sucrose) to wells A1 and B1.

Be sure to use a clean scoop for each chemical.

5. Use clean wooden splints to stir each well for 30 seconds as you attempt to dissolve the solute.
6. Record your observations about the solubility of table sugar (sucrose) in each solvent in the “Observations” section.
7. With a clean scoop, add one leveled scoop of table salt (sodium chloride) to wells A2 and B2.
8. Use clean wooden splints to stir each well for 30 seconds as you attempt to dissolve the solute.
9. Record your observations about the solubility of table salt (sodium chloride) in each solvent in the “Observations” section.
10. With a clean scoop, add one leveled scoop of benzoic acid to wells A3 and B3.
11. Use clean wooden splints to stir each well for 30 seconds as you attempt to dissolve the solute.
12. Record your observations about the solubility of benzoic acid in each solvent in the “Observations” section.

ACTIVITY 2

A Adhesion and Cohesion

1. Orient the well plate such that A1 is in the top left corner. This table summarizes the contents of each well as described in Steps 2–10 below.

	Pepper	Pepper + Splint	Pepper + Soapy Splint
Isopropanol	C1	C2	C3
Water	D1	D2	D3

2. Use the pipet labeled “isopropanol” to transfer 1 mL of isopropanol into wells C1, C2, and C3.
3. Use the pipet labeled “water” to transfer 1 mL of water into wells D1, D2, and D3.
4. Add a pinch of pepper to each well, allowing it to float or sink as it may.
5. Record your observations in the “Observations” section.
6. Dip a wooden splint very slowly into well C2 so that it does not disturb the pepper layer, and then lift it back up out of the well. Record your observations.

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7. Dip a wooden splint very slowly into well C2 again until it touches the bottom of the well, and then slowly lift it back out. Record your observations.
8. Coat the end (about 1 cm) of a clean wooden splint with a thin layer of soap and dip it into well C3.
9. Record your observations in the "Observations" section.
10. Repeat Steps 7–9 with the water in wells D2 and D3.

ACTIVITY 3

A Density and Miscibility

1. Use the pipet labeled "water" to transfer 1 mL of water into well D6.
2. Gently pipet an additional 1 mL of isopropanol on top of the water.

> Dispense the isopropanol so that it runs down the side of the well to meet the water.

3. Record your observations in the "Observations" section.
4. Add a pinch of pepper to each well, allowing it to float or sink as it may.
5. Record your observations in the "Observations" section.
6. Use a wooden splint to stir the water and isopropanol, and record your observations in the "Observations" section.

ACTIVITY 4

A Heat Capacity

> **Caution:** Before starting Activity 4, make sure all flammables, including the isopropanol used in Activities 1–3, are put away. Monitor all burning items closely and continuously during this activity.

1. Add about 50 mL of water to a paper cup and place it in an empty sink.
2. Use a match or lighter to ignite a clean wooden splint. If you are using a match to light the splint, douse the match with water once the splint is lit.
3. While holding the water-filled cup, touch the flame to the bottom of the cup. Note that the cup does not burn.
4. Set the cup down in the sink and light the rim of the cup above the water line.
5. Allow the cup to burn just until the flames die down.
6. When burning is complete, douse the entire cup and splint with water.
7. Record your observations in the "Observations" section. If you want to conduct a second trial, use the second cup.

Disposal and Cleanup

1. Dispose of the paper cup and wooden splints in the trash.
2. Dispose of the solutions and suspensions down the drain. Allow the faucet to run a few minutes to dilute the solutions.
3. Rinse the lab equipment, and return the materials to the equipment kit.
4. Clean your work space.

ACTIVITY

OBSERVATIONS

Activity 1: Solubility

Activity 2: Adhesion and Cohesion

Activity 3: Density and Miscibility

Activity 4: Heat Capacity

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