Topic 1.1

Structure of Water and Hydrogen Bonding

Learning Objectives

- Learn the structure of a water molecule
- Understand how covalent bond polarity determines the properties of water
- Know the concepts of cohesion, adhesion, and surface tension as related to the structure of water

Topic Questions

- What atoms make up a molecule of water?
- Why are water molecules described as being polar?
- How does the structure of water molecules cause water to have the properties of cohesion, adhesion, and surface tension?

1.1.01 Polarity and Hydrogen Bonding in Water

[SYI-1.A.1 SYI-1.A.2]

A water molecule contains one oxygen atom covalently bonded to two hydrogen atoms. The bonds within a water molecule are **polar** because oxygen is more electronegative than hydrogen and pulls harder on the shared electrons. The increased electron density (ie, presence of electrons in a given space) around the oxygen atom gives oxygen a partial negative charge, and the decreased electron density around the hydrogen atoms gives each hydrogen a partial positive charge (see Figure 1.1).

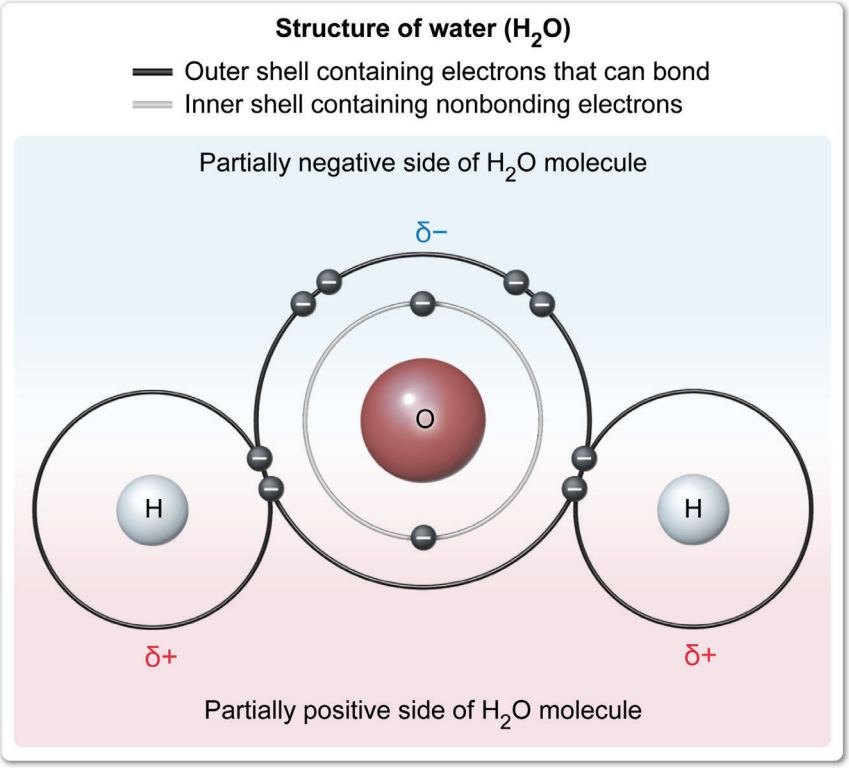

Figure 1.1 Structure of a water molecule.

The attraction between these partial positive and partial negative charges lets hydrogen bonds form between oxygen and hydrogen atoms that belong to *different* water molecules. Hydrogen bonding can also occur between water and other polar molecules (eg, carbohydrates) that, like water, contain covalent bonds in which hydrogen atoms are bound to highly electronegative atoms such as oxygen or nitrogen.

The polarity of water makes it a good **solvent** for a variety of compounds, such as salts. Salts are made of cations (ie, positively charged ions) and anions (ie, negatively charged ions). Water dissolves salts by forming **hydration shells** (ie, spheres of water molecules) around individual ions, separating them from each other. The partial negative charges of the water molecules' oxygen atoms are attracted to the cations, and the partial positive charges of the water molecules' hydrogen atoms are attracted to the anions. Therefore, the hydration shells form so that the hydrogen atoms face anions and the oxygen atoms face cations (Figure 1.2).

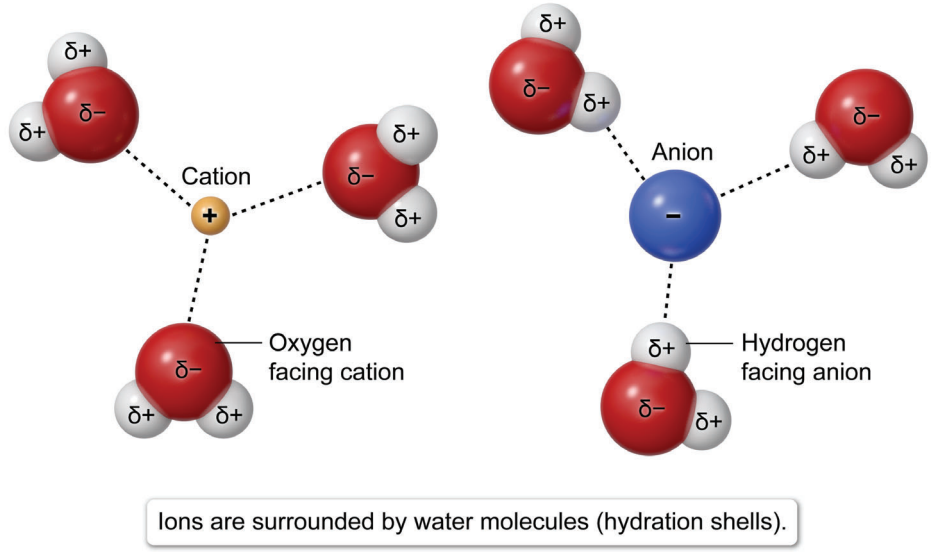

Figure 1.2 Formation of hydration shells around dissolved ions.

Water's **high heat of vaporization** (Figure 1.3) is another important property resulting from hydrogen bonding among water molecules. A substance's heat of vaporization refers to the amount of heat 1 mole of a substance must absorb to transition from the liquid phase to the gas phase with no temperature change. Because water molecules in the liquid phase are attracted to one another and form hydrogen bonds, a large amount of energy (ie, heat) must be absorbed by liquid water for molecules to break free from the surrounding liquid and enter the gas phase.

The **heat of vaporization** is the amount of heat 1 mole of a substance must absorb to transition from the liquid phase to the gas phase with no temperature change

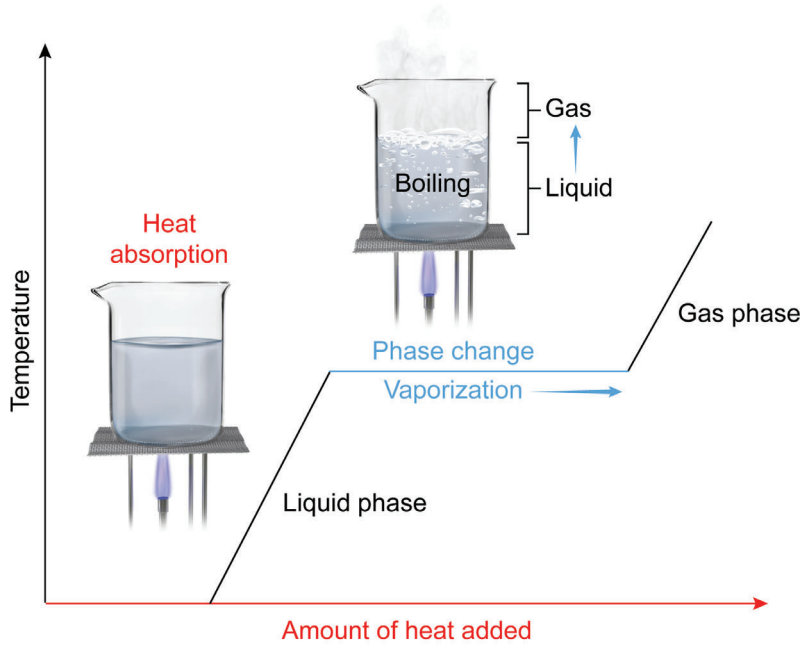

Figure 1.3 Heat of vaporization.

1.1.02 Cohesion, Adhesion, and Surface Tension in Water

[SYI-1.A.3]

Living organisms contain large amounts of water (H_2O). Biologically important properties of water (Figure 1.4) result from unequal sharing of electrons (ie, **covalent bond polarity**) between the oxygen (O) atom and the hydrogen (H) atoms of a water molecule.

Important properties of water include the following:

- **Adhesion** is the attraction between water molecules and *other* polar molecules (eg, cellulose). Adhesion results from the formation of hydrogen bonds between water and other substances made up of polar molecules.
- **Cohesion** refers to the ability of water molecules to stick to each other. Cohesion results from hydrogen bonding between individual water molecules.

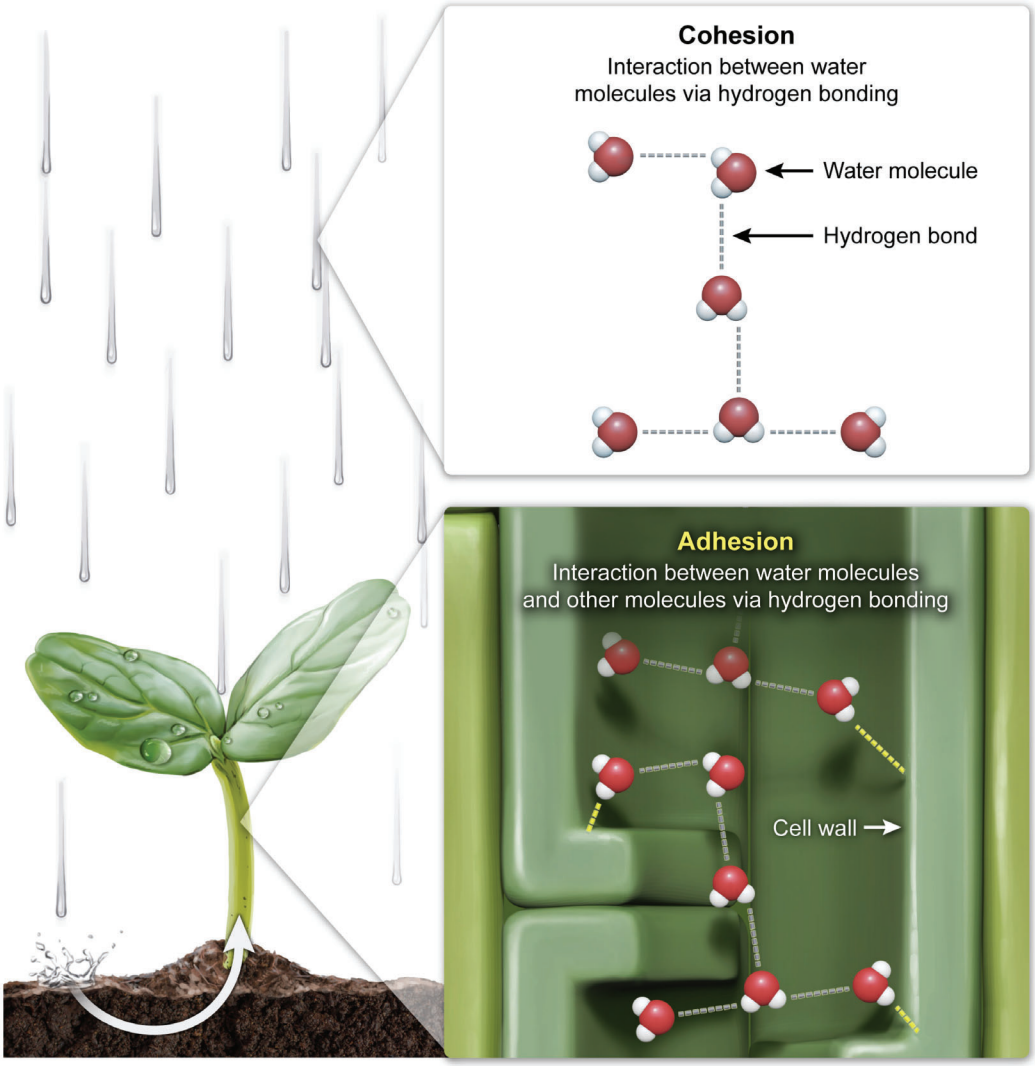

Figure 1.4 Adhesion and cohesion of water.

Cohesion causes the surface of liquid water to resist being broken; a property known as **surface tension** (see Figure 1.5).

Unlike water molecules *below* the surface of liquid water, water molecules *at* the surface do not experience attractive forces from all sides equally. This imbalance of forces occurs because water molecules at the surface of the liquid are exposed on one side to air molecules, which, unlike water molecules within the liquid, do *not* form hydrogen bonds with the surface water molecules. The unbalanced forces acting on surface water molecules cause these molecules to form a more organized arrangement than water molecules below the surface. This organization is maintained through hydrogen bonding (ie, cohesion) between the surface water molecules.

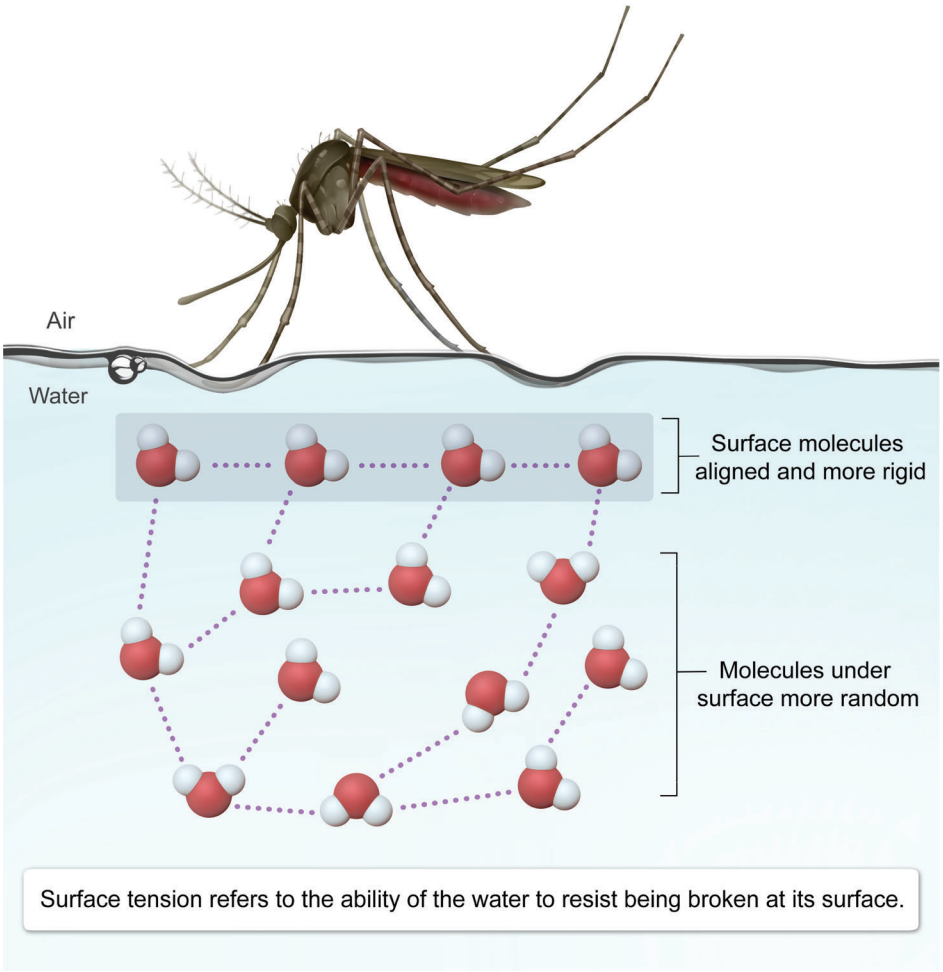

Figure 1.5 Surface tension of water.

Although surface tension allows the surface of liquid water to resist breaking, this property can be decreased by some environmental factors. For example, surface tension of water is decreased at higher temperatures and when water contains high concentrations of salt.

When liquid water is heated, kinetic energy is transferred to the water molecules, causing them to move with increased speed. At high temperatures, this molecular movement lowers the surface tension of water by breaking and preventing the formation of cohesive hydrogen bonds. Likewise, because surface tension depends on hydrogen bonding among *water* molecules (*not* between water molecules and dissolved ions), salts decrease surface tension by interfering with the formation of cohesive hydrogen bonds between water molecules.

Topic 1.1 Structure of Water and Hydrogen Bonding
Check for Understanding Quiz

1. The bonds within a single water molecule can be described as:
    I. Polar bonds
    II. Hydrogen bonds
    III. Covalent bonds

    A. I only
    B. II only
    C. I and III only
    D. I, II, and III

2. Which of the following terms refers to the attraction between water molecules and other (ie, not water) polar molecules?

    A. Adhesion
    B. Cohesion
    C. Surface tension
    D. Kinetic energy

Note: Answers to this quiz are in the back of the book (appendix).