# 2.2 Properties of Water

## Key Questions

*How does the structure of water contribute to its unique properties?*

*How does water's polarity influence its properties as a solvent?*

*Why is it important for cells to buffer solutions against rapid changes in pH?*

## Vocabulary

hydrogen bond • cohesion • adhesion • mixture • solution • solute • solvent • suspension • pH scale • acid • base • buffer

## Taking Notes

**Venn Diagram** As you read, draw a Venn diagram showing the differences between solutions and suspensions and the properties that they share.

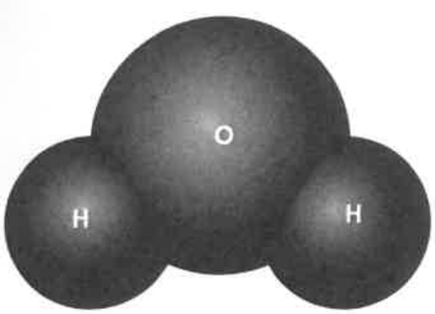



**FIGURE 2–6 A Water Molecule** A water molecule is polar because there is an uneven distribution of electrons between the oxygen and hydrogen atoms. The negative pole is near the oxygen atom and the positive pole is between the hydrogen atoms.

**THINK ABOUT IT** Looking back at our beautiful planet, an astronaut in space said that if other beings have seen the Earth, they must surely call it "the blue planet." He referred, of course, to the oceans of water that cover nearly three fourths of Earth's surface. The very presence of liquid water tells a scientist that life may also be present on such a planet. Why should this be so? Why should life itself be connected so strongly to something so ordinary that we often take it for granted? The answers to those questions suggest that there is something very special about water and the role it plays in living things.

## The Water Molecule

*How does the structure of water contribute to its unique properties?*

Water is one of the few compounds found in a liquid state over most of the Earth's surface. Like other molecules, water ($H_2O$) is neutral. The positive charges on its 10 protons balance out the negative charges on its 10 electrons. However, there is more to the story.

**Polarity** With 8 protons, water's oxygen nucleus attracts electrons more strongly than the single protons of water's two hydrogen nuclei. As a result, water's shared electrons are more likely to be found near the oxygen nucleus. Because the oxygen nucleus is at one end of the molecule, as shown in **Figure 2–6**, water has a partial negative charge on one end, and a partial positive charge on the other.

A molecule in which the charges are unevenly distributed is said to be "polar," because the molecule is a bit like a magnet with two poles. The partial charges on a polar molecule are written in parentheses, (–) or (+), to show that they are weaker than the charges on ions such as $Na^+$ and $Cl^-$.

**Hydrogen Bonding** Because of their partial positive and negative charges, polar molecules such as water can attract each other. The attraction between a hydrogen atom with a partial positive charge and another atom with a partial negative charge is known as a **hydrogen bond.** The most common partially negative atoms involved in hydrogen bonding are oxygen, nitrogen, and fluorine.

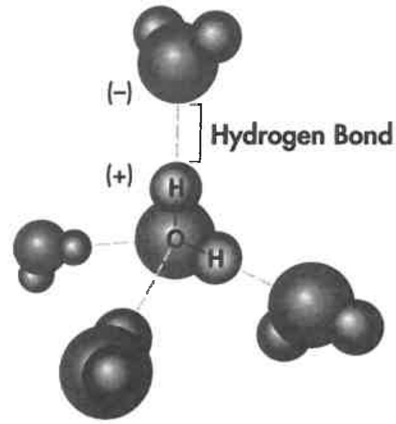
Hydrogen bonds are not as strong as covalent or ionic bonds, but they give one of life's most important molecules many of its unique characteristics. **Because water is a polar molecule, it is able to form multiple hydrogen bonds, which account for many of water's special properties.** These include the fact that water expands slightly upon freezing, making ice less dense than liquid water. Hydrogen bonding also explains water's ability to dissolve so many other substances, a property essential in living cells.

▶***Cohesion*** **Cohesion** is an attraction between molecules of the same substance. Because a single water molecule may be involved in as many as four hydrogen bonds at the same time, water is extremely cohesive. Cohesion causes water molecules to be drawn together, which is why drops of water form beads on a smooth surface. Cohesion also produces surface tension, explaining why some insects and spiders can walk on a pond's surface, as shown in **Figure 2–7.**

▶***Adhesion*** On the other hand, **adhesion** is an attraction between molecules of different substances. Have you ever been told to read the volume in a graduated cylinder at eye level? As shown in **Figure 2–8,** the surface of the water in the graduated cylinder dips slightly in the center because the adhesion between water molecules and glass molecules is stronger than the cohesion between water molecules. Adhesion between water and glass also causes water to rise in a narrow tube against the force of gravity. This effect is called capillary action. Capillary action is one of the forces that draws water out of the roots of a plant and up into its stems and leaves. Cohesion holds the column of water together as it rises.

▶***Heat Capacity*** Another result of the multiple hydrogen bonds between water molecules is that it takes a large amount of heat energy to cause those molecules to move faster, which raises the temperature of the water. Therefore, water's heat capacity, the amount of heat energy required to increase its temperature, is relatively high. This allows large bodies of water, such as oceans and lakes, to absorb large amounts of heat with only small changes in temperature. The organisms living within are thus protected from drastic changes in temperature. At the cellular level, water absorbs the heat produced by cell processes, regulating the temperature of the cell.

**In Your Notebook** *Draw a diagram of a meniscus. Label where cohesion and adhesion occur.*



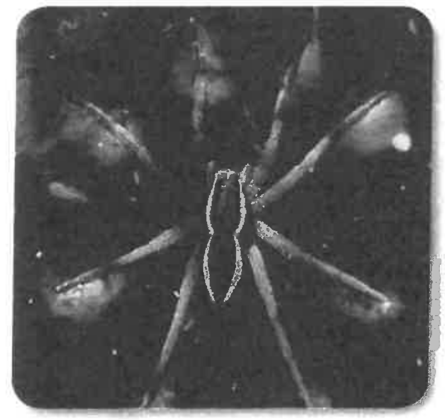



**FIGURE 2–7 Hydrogen Bonding and Cohesion** Each molecule of water can form multiple hydrogen bonds with other water molecules. The strong attraction between water molecules produces a force sometimes called "surface tension," which can support very lightweight objects, such as this raft spider. **Apply Concepts** ***Why are water molecules attracted to one another?***

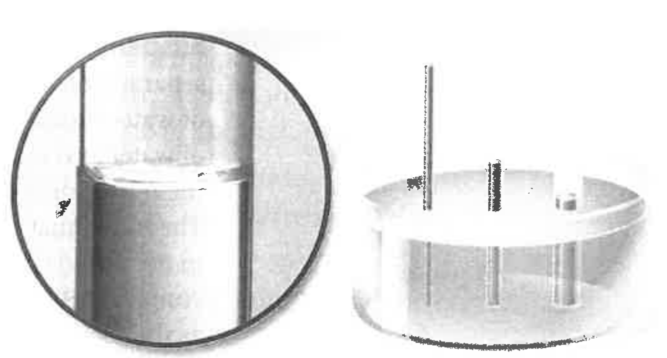


**FIGURE 2–8 Adhesion** Adhesion between water and glass molecules is responsible for causing the water in these columns to rise. The surface of the water in the glass column dips slightly in the center, forming a curve called a meniscus.

MYSTERY
CLUE

**The solubility of gases increases as temperature decreases. Think about what would happen if you opened two cans of soda—one ice cold, and the other very warm. Which would give the bigger "pop"? The warm can, of course! That's because the gas in the soda is much less soluble at warm temperatures. How might the temperature of Antarctic waters affect the amount of dissolved oxygen available for ice fish?**

## Solutions and Suspensions

***How does water's polarity influence its properties as a solvent?***

Water is not always pure; it is often found as part of a mixture. A **mixture** is a material composed of two or more elements or compounds that are physically mixed together but not chemically combined. Salt and pepper stirred together constitute a mixture. So do sugar and sand. Earth's atmosphere is a mixture of nitrogen, oxygen, carbon dioxide, and other gases. Living things are in part composed of mixtures involving water. Two types of mixtures that can be made with water are solutions and suspensions.

**Solutions** If a crystal of table salt is placed in a glass of warm water, sodium and chloride ions on the surface of the crystal are attracted to the polar water molecules. Ions break away from the crystal and are surrounded by water molecules, as illustrated in **Figure 2–9.** The ions gradually become dispersed in the water, forming a type of mixture called a solution. All the components of a **solution** are evenly distributed throughout the solution. In a saltwater solution, table salt is the **solute**—the substance that is dissolved. Water is the **solvent**—the substance in which the solute dissolves. **Water's polarity gives it the ability to dissolve both ionic compounds and other polar molecules.**

Water easily dissolves salts, sugars, minerals, gases, and even other solvents such as alcohol. Without exaggeration, water is the greatest solvent on Earth. But even water has limits. When a given amount of water has dissolved all of the solute it can, the solution is said to be saturated.

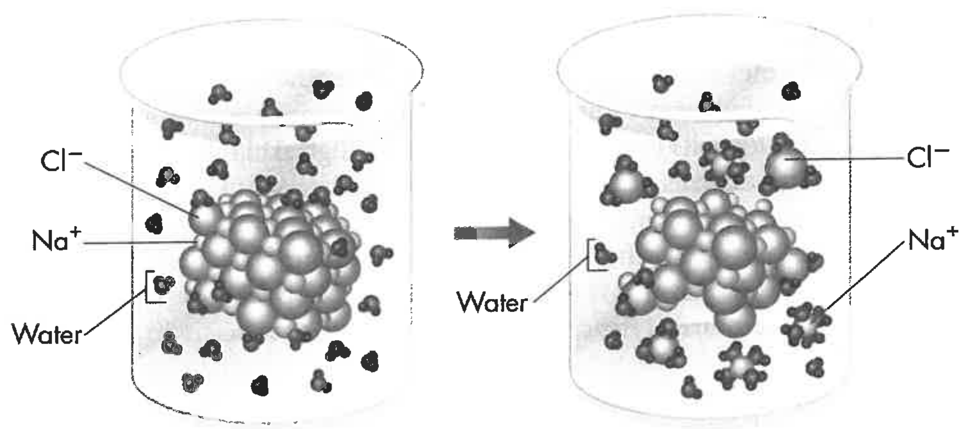



**FIGURE 2–9 A Salt Solution** When an ionic compound such as sodium chloride is placed in water, water molecules surround and separate the positive and negative ions.
**Interpret Visuals** ***What happens to the sodium ions and chloride ions in the solution?***

**Suspensions** Some materials do not dissolve when placed in water, but separate into pieces so small that they do not settle out. The movement of water molecules keeps the small particles suspended. Such mixtures of water and nondissolved material are known as **suspensions.** Some of the most important biological fluids are both solutions and suspensions. The blood that circulates through your body is mostly water. The water in the blood contains many dissolved compounds. However, blood also contains cells and other undissolved particles that remain in suspension as the blood moves through the body.

# Acids, Bases, and pH

***Why is it important for cells to buffer solutions against rapid changes in pH?***

Water molecules sometimes split apart to form ions. This reaction can be summarized by a chemical equation in which double arrows are used to show that the reaction can occur in either direction.

$$H_2O \rightleftharpoons H^+ + OH^-$$

**water** ⇌ **hydrogen ion** + **hydroxide ion**

How often does this happen? In pure water, about 1 water molecule in 550 million splits to form ions in this way. Because the number of positive hydrogen ions produced is equal to the number of negative hydroxide ions produced, pure water is neutral.

**The pH Scale** Chemists devised a measurement system called the **pH scale** to indicate the concentration of $H^+$ ions in solution. As **Figure 2–10** shows, the pH scale ranges from 0 to 14. At a pH of 7, the concentration of $H^+$ ions and $OH^-$ ions is equal. Pure water has a pH of 7. Solutions with a pH below 7 are called acidic because they have more $H^+$ ions than $OH^-$ ions. The lower the pH, the greater the acidity. Solutions with a pH above 7 are called basic because they have more $OH^-$ ions than $H^+$ ions. The higher the pH, the more basic the solution. Each step on the pH scale represents a factor of 10. For example, a liter of a solution with a pH of 4 has 10 times as many $H^+$ ions as a liter of a solution with a pH of 5.

**In Your Notebook** *Order these items in order of increasing acidity: soap, lemon juice, milk, acid rain.*

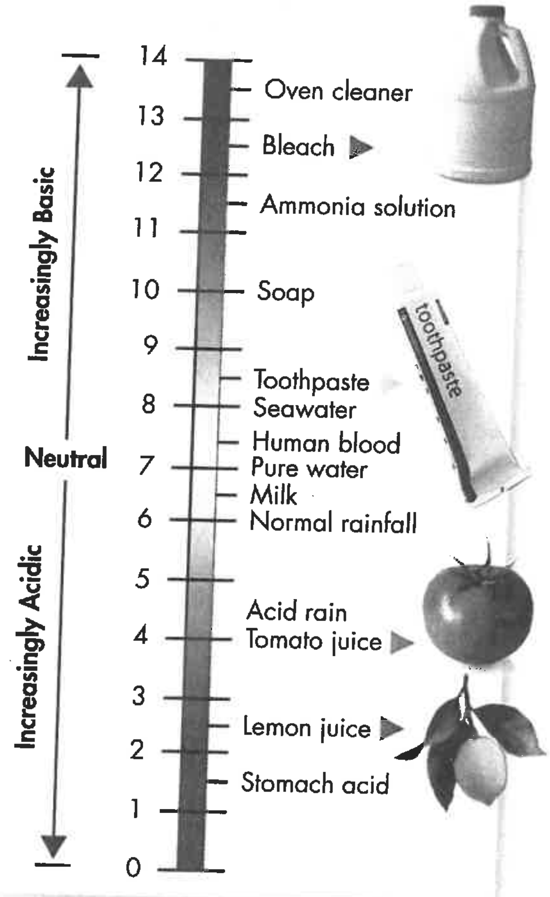



**FIGURE 2–10 The pH Scale** The concentration of $H^+$ ions determines whether solutions are acidic or basic. The most acidic material on this pH scale is stomach acid. The most basic material on this scale is oven cleaner.

## Quick Lab
GUIDED INQUIRY

### Acidic and Basic Foods

❶ Predict whether the food samples provided are acidic or basic.

❷ Tear off a 2-inch piece of pH paper for each sample you will test. Place these pieces on a paper towel.

❸ Construct a data table in which you will record the name and pH of each food sample.

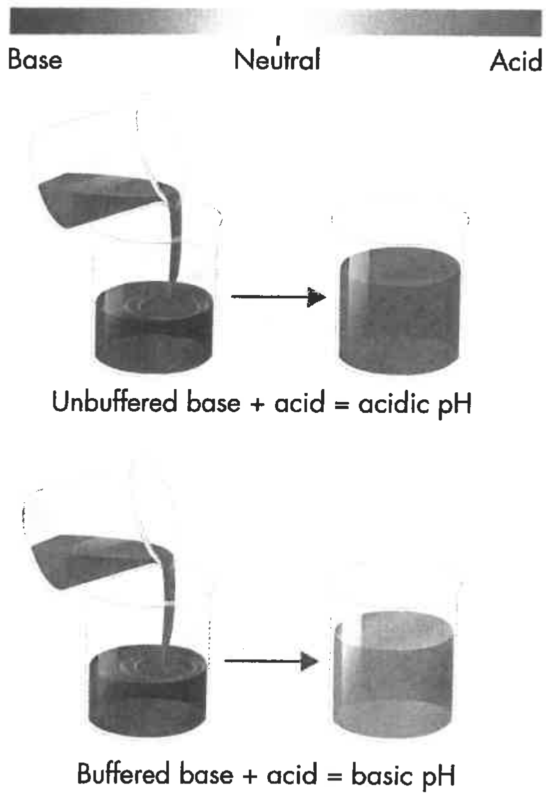
❹ Use a scalpel to cut a piece off each solid. **CAUTION:** *Be careful not to cut yourself. Do not eat the food.* Touch the cut surface of each sample to a square of pH paper. Use a dropper pipette to place a drop of any liquid sample on a square of pH paper. Record the pH of each sample in your data table.

#### Analyze and Conclude

**1. Analyze Data** Were most of the samples acidic or basic?

**2. Evaluate** Was your prediction correct?

FIGURE 2–11 **Buffers** Buffers help prevent drastic changes in pH. Adding acid to an unbuffered solution causes the pH of the unbuffered solution to drop. If the solution contains a buffer, however, adding the acid will cause only a slight change in pH.




**Acids** Where do all those extra $H^+$ ions in a low-pH solution come from? They come from acids. An **acid** is any compound that forms $H^+$ ions in solution. Acidic solutions contain higher concentrations of $H^+$ ions than pure water and have pH values below 7. Strong acids tend to have pH values that range from 1 to 3. The hydrochloric acid (HCl) produced by the stomach to help digest food is a strong acid

**Bases** A **base** is a compound that produces hydroxide ($OH^-$) ions in solution. Basic, or alkaline, solutions contain lower concentrations of $H^+$ ions than pure water and have pH values above 7. Strong bases, such as the lye (commonly NaOH) used in soapmaking, tend to have pH values ranging from 11 to 14.

**Buffers** The pH of the fluids within most cells in the human body must generally be kept between 6.5 and 7.5. If the pH is lower or higher, it will affect the chemical reactions that take place within the cells. Thus, controlling pH is important for maintaining homeostasis. One of the ways that organisms control pH is through dissolved compounds called buffers. **Buffers** are weak acids or bases that can react with strong acids or bases to prevent sharp, sudden changes in pH. Blood, for example, has a normal pH of 7.4. Sudden changes in blood pH are usually prevented by a number of chemical buffers, such as bicarbonate and phosphate ions. **Buffers dissolved in life's fluids play an important role in maintaining homeostasis in organisms.**

## 2.2 Assessment

### Review Key Concepts

1. a. **Review** What does it mean when a molecule is said to be "polar"?
   b. **Explain** How do hydrogen bonds between water molecules occur?
   c. **Use Models** Use the structure of a water molecule to explain why it is polar.
2. a. **Review** Why is water such a good solvent?
   b. **Compare and Contrast** What is the difference between a solution and a suspension?
3. a. **Review** What is an acid? What is a base?
   b. **Explain** The acid hydrogen fluoride (HF) can be dissolved in pure water. Will the pH of the solution be greater or less than 7?
   c. **Infer** During exercise, many chemical changes occur in the body, including a drop in blood pH, which can be very serious. How is the body able to cope with such changes?

**WRITE ABOUT SCIENCE**

### Creative Writing

4. Suppose you are a writer for a natural history magazine for children. This month's issue will feature insects. Write a paragraph explaining why some bugs, such as the water strider, can walk on water.