Section 2–2

1 FOCUS

Objectives

2.2.1 ***Explain*** why water molecules are polar.

2.2.2 ***Differentiate*** between solutions and suspensions.

2.2.3 ***Explain*** what acidic solutions and basic solutions are.

Guide for Reading

Vocabulary Preview

Challenge students to divide the Vocabulary terms into three groups of related words. *(Cohesion, adhesion; mixture, solution, solute, solvent, suspension; pH scale, acid, base, buffer)*

Reading Strategy

Figure 2–7 shows that hydrogen bonds form between polar water molecules. Figure 2–9 shows that an ionic compound can dissolve in water because its ions are attracted to the polar water molecules, which surround and separate the ions.

2 INSTRUCT

The Water Molecule

Use Visuals

Figure 2–7 Point out that water is the most abundant compound in most living things, making an understanding of the chemical makeup of water extremely important for understanding how living things function. Then, ask: **What kind of bonds join the atoms in a water molecule?** *(Covalent bonds)* **Are the hydrogen atoms bonded to each other?** *(No, each is bonded to the oxygen atom.)* **Why is the hydrogen end of the molecule positive and the oxygen end negative?** *(In a water molecule, the electrons are shared unequally. At any moment, there is a greater probability of finding the shared electrons near the oxygen atom than near the hydrogen atoms.)* L1 L2

2–2 Properties of Water

Guide for Reading

Key Concepts
- Why are water molecules polar?
- What are acidic solutions? What are basic solutions?

Vocabulary
cohesion
adhesion
mixture
solution
solute
solvent
suspension
pH scale
acid
base
buffer

Reading Strategy: Using Visuals Before you read, preview **Figure 2–7** and **Figure 2–9.** As you read, note how these two figures are related.

After several days in space, one of the first astronauts to travel to the moon looked back longingly at Earth and marveled at its distant beauty. If there are other beings who have seen Earth, he said, they must surely call it "the blue planet." The astronaut was referring to the blue appearance of the water in the oceans, which cover three fourths of Earth's surface. Water is also the single most abundant compound in most living things.

Water is one of the few compounds that is a liquid at the temperatures found over much of Earth's surface. Unlike most substances, water expands as it freezes. Thus, ice is less dense than liquid water, which explains why ice floats on the surface of lakes and rivers. If the ice sank to the bottom, the situation would be disastrous for fish and plant life in regions with cold winters, to say nothing of the sport of ice skating!

The Water Molecule

Like all molecules, a water molecule (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 in its nucleus, an oxygen atom has a much stronger attraction for electrons than does the hydrogen atom with a single proton in its nucleus. Thus, at any moment, there is a greater probability of finding the shared electrons near the oxygen atom than near the hydrogen atom. Because the water molecule has a bent shape, as shown in **Figure 2–6**, the oxygen atom is on one end of the molecule and the hydrogen atoms are on the other. As a result, the oxygen end of the molecule has a slight negative charge and the hydrogen end of the molecule has a slight positive charge.

A molecule in which the charges are unevenly distributed is called a polar molecule because the molecule is like a magnet with poles. **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.

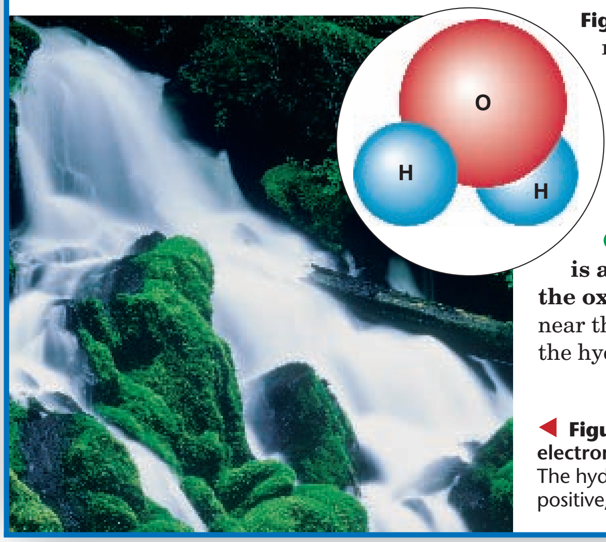


Figure 2–6 **The unequal sharing of electrons causes the water molecule to be polar.** The hydrogen end of the molecule is slightly positive, and the oxygen end is slightly negative.

TIME SAVER

SECTION RESOURCES

Print:
- ***Teaching Resources,*** Lesson Plan 2–2, Adapted Section Summary 2–2, Section Summary 2–2, Worksheets 2–2, Section Review 2–2, Enrichment
- ***Reading and Study Workbook A,*** Section 2–2
- ***Probeware Lab Manual,*** Are foods acidic or basic?

Technology:
- ***iText,*** Section 2–2
- ***Transparencies Plus,*** Section 2–2

Hydrogen Bonds Because of their partial positive and negative charges, polar molecules such as water can attract each other, as shown in **Figure 2–7.** The 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^-. The attraction between the hydrogen atom on one water molecule and the oxygen atom on another water molecule is an example of a hydrogen bond. Hydrogen bonds are not as strong as covalent or ionic bonds, but water's ability to form multiple hydrogen bonds is responsible for many of its special properties.

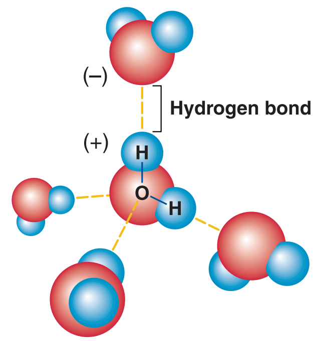
A single water molecule may be involved in as many as four hydrogen bonds at the same time. The ability of water to form multiple hydrogen bonds is responsible for many of water's properties. **Cohesion** is an attraction between molecules of the same substance. Because of hydrogen bonding, water is extremely cohesive. Water's cohesion causes molecules on the surface of water to be drawn inward, which is why drops of water form beads on a smooth surface. Cohesion also explains why some insects and spiders can walk on a pond's surface, as shown in **Figure 2–8.**

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? 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 draw 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.

CHECKPOINT *How are cohesion and adhesion similar? Different?*

Solutions and Suspensions

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 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.



▲ **Figure 2–7** The illustration shows the hydrogen bonds that form between water molecules. **Applying Concepts** *Why are water molecules attracted to one another?*

Go Online
NSTA SCILINKS
For: Links on properties of water
Visit: www.SciLinks.org
Web Code: cbn-1022

▶ **Figure 2–8** Cohesion is responsible for enabling this tarantula to rest on the water's surface. The strong attraction between water molecules produces a force sometimes called "surface tension," which can support very light objects, including this spider. **Observing** *How does the tarantula's physical structure help it to stay afloat?*

Go Online
NSTA SCILINKS
Download a worksheet on properties of water for students to complete, and find additional teacher support from NSTA SciLinks.

Solutions and Suspensions

Demonstration

Show students that when a solution is formed, the solute seems to disappear and yet takes up space. First, pour 225 mL of water into a 250-mL flask. Mark the level of the water with masking tape, and make sure students note this level. Then, stir in 25 g of sugar, which will dissolve almost immediately. Ask: **Is there any evidence that the sugar dissolved into the water?** *(Most students will note that the solution is transparent.)* Have students check to see if the level of the liquid is at the same height as before, as marked by the tape. Use a metric ruler to show that the liquid's level is about 1 cm higher than before, indicating that the sugar is present in the solution. L1 L2

UNIVERSAL ACCESS

Inclusion/Special Needs

Direct students' attention to the summary chemical equation on page 42, and call on volunteers to explain what it means that the reaction can occur in either direction. Make sure students understand what a hydrogen ion and a hydroxide ion are. Review the definition of *ion* in Section 2–1. Once students fully understand the definition of H^+ ions and OH^- ions, draw their attention to the definitions of *acid* and *base* on page 43. L1

English Language Learners

Explain that *cohesion* and *adhesion* are both derived from Latin verbs meaning "to stick." A subtle difference between the terms can be found in their prefixes. The prefix *co-* means "common," and the prefix *ad-* means "toward." Point out that *cohesion* means "an attraction," or "sticking," between molecules that have properties "in common." *Adhesion* means "attraction," or "sticking," from one substance "toward" another. L1 L2

Answers to . . .

CHECKPOINT *Cohesion and adhesion are similar because they are attractions between molecules, but cohesion occurs between molecules of the same substance and adhesion occurs between molecules of different substances.*

Figure 2–7 *Water molecules are polar, meaning they have regions with partial positive and negative charges. This polarity causes the attraction between water molecules.*

Figure 2–8 *Because of its multiple legs, a tarantula's mass is distributed over a large area on the surface of the water, which means that the pull of gravity is limited at any one location on the surface.*

2–2 (continued)

Acids, Bases, and pH

Quick Lab

Objective Students will be able to conclude whether foods are acidic or basic. L2

Skill Focus **Analyzing Data, Evaluating**

Materials pH paper, solid foods and fruit juices, paper towel, scalpel, dropper pipette, plastic gloves

Time 15 minutes

Advance Prep Obtain a variety of foods for students to test, including orange juice, lemon juice, tomato juice, egg white, meat, fish, fruits, and vegetables. For the test to work, the samples must be moist. If you are using probeware in this activity, use the instructions in the *Probeware Lab Manual.*

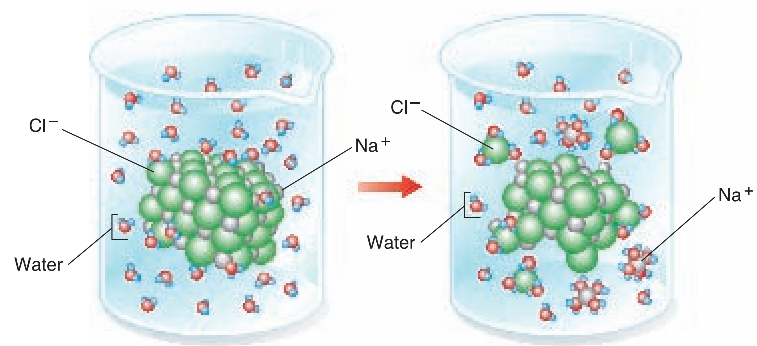
Safety Demonstrate safe cutting techniques, such as holding the sample behind the cutting edge when using the scalpel. Make sure students wash their hands with soap and warm water before leaving the lab.

Strategies
- Ask students to write down their predictions.
- Make sure each student constructs a data table to record the pH of each sample. This simple table needs only two columns, headed Sample and pH.
- Review how pH paper acts as an indicator: a base turns red litmus paper blue; an acid turns blue litmus paper red.
- Either supply a pipette for each liquid or have students use one pipette and clean it between samples.

Expected Outcomes Students should discover that most foods are acidic.

Analyze and Conclude
1. Most of the samples were acidic.
2. Students were correct if they predicted that most foods are acidic.

Figure 2–9 When an ionic compound such as sodium chloride is placed in water, water molecules surround and separate the positive and negative ions. **Interpreting Graphics** *What happens to the sodium ions and chloride ions in the solution?*



Quick Lab

Are foods acidic or basic?

Materials pH paper, samples of food, paper towel, scalpel, dropper pipette

Procedure

1. **Predicting** Predict whether most foods are acidic or basic.
2. If using a pH probe, see your teacher for instructions.
3. Tear off a 2-inch piece of pH paper for each sample you will test. Place these pieces on a paper towel.
4. Construct a data table in which you will record the name and pH of each food sample.
5. 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. **Analyzing Data** Were most of the samples acidic or basic?
2. **Evaluating** Was your prediction correct?

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, such as sugar. Without exaggeration, water is the greatest solvent on Earth.

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, which 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

A water molecule can react 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.

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

$$\text{water} \rightleftharpoons \text{hydrogen ion} + \text{hydroxide ion}$$

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

BIO INSIGHTS — HISTORY OF SCIENCE

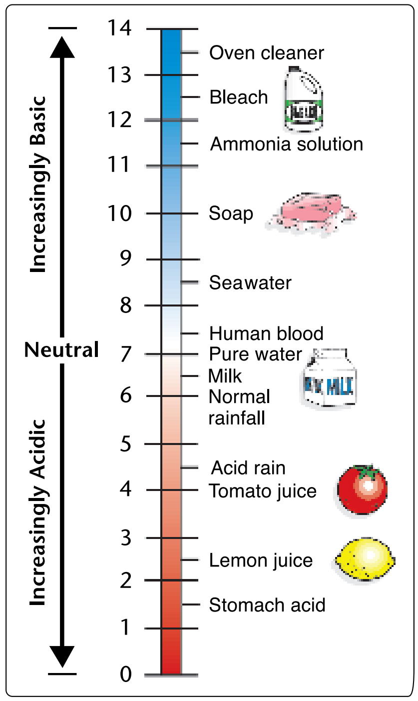
pH—a simpler way of expression
In 1909, the Danish chemist Søren Sørensen introduced the expression *pH*, or *p*otential of *H*ydrogen. A pH value represents the concentration of hydrogen ions in solution, an important factor in many chemical reactions. Before Sørensen's suggestion, chemists had to deal with negative logarithms of the concentration of the ions, such as a concentration of 1.0×10^{-4} moles/liter. Today, that would be expressed as a pH of 4, which is about the pH of wine. Pure water has a pH of 7, which means that the concentration of H^+ ions equals the concentration of OH^- ions. That is, there is about one ten-millionth of a mole of H^+ ions per liter of water and the same number of OH^- ions. If an acid is added to the water, the H^+ ions outnumber the OH^- ions, and the pH of the solution decreases. The opposite occurs if a base is added to the water.

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.

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 produced by the stomach to help digest food is a strong acid.

Bases A **base** is a compound that produces hydroxide ions (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 lye, 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 the body controls 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.



▲ **Figure 2–10** **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.

2–2 Section Assessment

1. **Key Concept** Use the structure of a water molecule to explain why it is polar.
2. **Key Concept** Compare acidic and basic solutions in terms of their H^+ ion and OH^- ion concentrations.
3. What is the difference between a solution and a suspension?
4. What does pH measure?
5. **Critical Thinking** **Predicting** The strong acid hydrogen fluoride (HF) can be dissolved in pure water. Will the pH of the solution be greater or less than 7?

Thinking Visually

Creating a Concept Map
Draw a concept map on the properties of water. Include the following terms in your concept map: hydrogen bonds, polarity, cohesion, adhesion, capillary action, and solvent.

Address Misconceptions

Students might mistakenly conclude that all water has a pH of 7. Explain that only pure water has a neutral pH. Normal rainwater, for example, can have a pH as low as 5.6, making it slightly acidic. As rain falls, it reacts with CO_2 in the atmosphere and forms carbonic acid, which lowers the pH of the rain. Acid rain has an even lower pH due to reactions between water and oxides of nitrogen and sulfur, which are pollutants found in air. Ask volunteers to collect rain or melt snow and use pH paper to check on the acidity of local precipitation. L2 L3

3 ASSESS

Evaluate Understanding

Ask students to write a paragraph that explains how the concentration of hydrogen ions determines the acid-base properties of a solution. Students should discuss how water reacts and forms ions, the difference between acids and bases, and the significance of the pH scale.

Reteach

Use Figure 2–9 to review the section's Key Concepts, including the polarity of water molecules, how this polarity gives water the ability to interact with other particles, how sodium and chloride ions become evenly dispersed in water to form a solution, and why some solutions are neutral, some are acidic, and others are basic.

Thinking Visually

Students' concept maps may vary. All should mention that water is polar, that because of hydrogen bonding water is extremely cohesive, that adhesion causes the capillary action of water in a narrow tube, and that water is the greatest solvent on Earth.

2–2 Section Assessment

1. The hydrogen atoms form covalent bonds with the oxygen atom. Because of oxygen's greater attraction for electrons, there is an unequal distribution of electrons. The oxygen end of the bent water molecule is negative; the hydrogen end is positive.
2. Per volume, there are more H^+ ions than OH^- ions in an acidic solution and more OH^- ions than H^+ ions in a basic solution.
3. In a solution, all components are evenly distributed. In a suspension, undissolved particles are suspended in the mixture and can settle out over time.
4. The pH scale measures the concentration of H^+ ions in a solution.
5. The pH will be less than 7.0.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 2–2.

Answer to . . .

Figure 2–9 *They become evenly dispersed in the water.*