Section 8.1

1 FOCUS

Objectives

8.1.1 **Describe** how a substance can dissolve in water by dissociation, dispersion, or ionization.

8.1.2 **Describe** how the physical properties of a solution can differ from those of its solute and solvent.

8.1.3 **Identify** energy changes that occur during the formation of a solution.

8.1.4 **Describe** factors affecting the rate at which a solute dissolves in a solvent.

Reading Focus

Build Vocabulary L2

Word Forms Ask students to name the verb forms for the three types of dissolving: *dissociation, dispersion,* and *ionization. (Dissociate, disperse, and ionize)* Give a definition of each term and have students discuss how these words give clues as to what type of particle is involved in each type of dissolving.

Reading Strategy L2

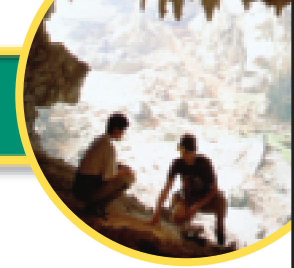
a. Physical change
b. Ions are present before and after.
c. Chemical change
d. Ions are present after, but not before.

2 INSTRUCT

Integrate Biology L2

To avoid decompression sickness, or "the bends," scuba divers make "decompression stops" as they return to the surface. They rise from deeper waters very slowly and pause periodically to allow the dissolved gases to come out of solution. Scuba divers are at risk for the bends even in water as shallow as 10 m. However, the bends is not a problem for diving animals or people who dive without scuba tanks. Ask, **Why do you think decompression sickness is not a risk when diving without scuba tanks?** *(People who dive without scuba tanks take one breath at the surface and hold it while diving underwater. They have the same amount of gas in their body at the surface as they have throughout the dive, so they do not get a dangerous level of dissolved gases in their blood and tissues.)* **Logical**

8.1 Formation of Solutions



Reading Focus

Key Concepts

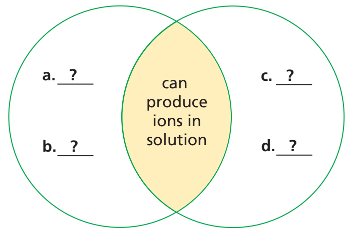
- What are three processes that can occur when substances dissolve?
- What are some properties of a solution that differ from those of its solvent and solutes?
- What happens to energy when a solution forms?
- What factors affect the rate of dissolving?

Vocabulary

- solute
- solvent
- dissociation
- dispersion
- ionization

Reading Strategy

Comparing and Contrasting Copy the Venn diagram below. Contrast dissociation and ionization by listing the ways they differ.



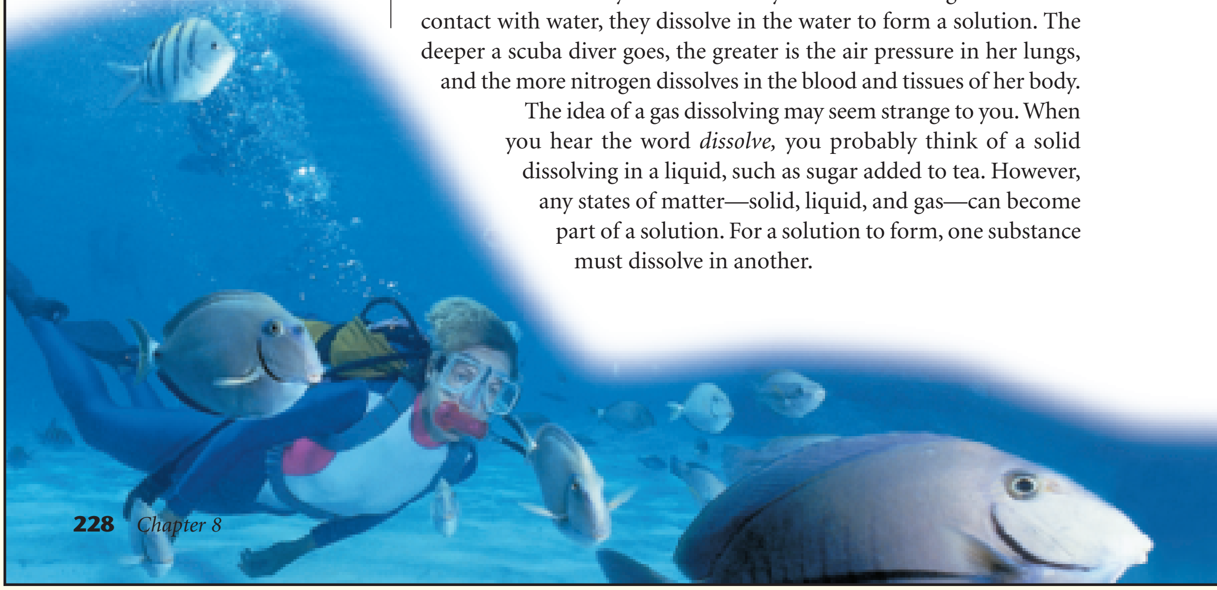


Figure 1 If divers surface too quickly from great depths, the nitrogen that has dissolved in their blood and other tissues bubbles out of solution. These bubbles can become trapped in joints and cause great pain, a condition called "the bends."

Scuba divers, like the one in Figure 1, are able to breathe underwater with the aid of a tank containing compressed air. Like the air you breathe at sea level, the air inside the tank contains about 78 percent nitrogen. As a scuba diver descends to greater depths, the pressure of the air in the diver's lungs increases. At a depth of 10 meters, the air in the diver's lungs is already twice the pressure of the air at sea level.

The human body consists mainly of water. When gases come in contact with water, they dissolve in the water to form a solution. The deeper a scuba diver goes, the greater is the air pressure in her lungs, and the more nitrogen dissolves in the blood and tissues of her body.

The idea of a gas dissolving may seem strange to you. When you hear the word *dissolve,* you probably think of a solid dissolving in a liquid, such as sugar added to tea. However, any states of matter—solid, liquid, and gas—can become part of a solution. For a solution to form, one substance must dissolve in another.

Section Resources

Print
- ***Reading and Study Workbook With Math Support,*** Section 8.1
- ***Transparencies,*** Chapter Pretest and Section 8.1

Technology
- ***Interactive Textbook,*** Section 8.1
- ***Presentation Pro CD-ROM,*** Chapter Pretest and Section 8.1
- ***Go Online,*** NSTA SciLinks, Solutions

Types of Solutions		
Solute	**Solvent**	**Example**
Gas	Gas	Air (oxygen, carbon dioxide in nitrogen)
Liquid	Gas	Water in air
Gas	Liquid	Carbonated beverage (carbon dioxide in water)
Liquid	Liquid	Vinegar (acetic acid in water)
Solid	Liquid	Sugar water (sugar in water)
Solid	Solid	Stainless steel (Chromium and nickel in iron)

Figure 2 A stainless steel pot or pan is a solution of chromium and nickel in iron. In a solution, the solvent is the substance in the greatest quantity.

Dissolving

Recall that a solution is a homogeneous mixture of two or more substances. Every solution has two types of components. A **solute** is a substance whose particles are dissolved in a solution. The substance in which the solute dissolves is called the **solvent.** For example, seawater is a solution in which salt is the solute and water is the solvent.

Solutes and solvents can take the form of a solid, liquid, or gas. The solution takes the state of the solvent. Figure 2 lists some common solutions and the states of their respective solutes and solvents. Air, for instance, is a solution of several gases dissolved in another gas. Nitrogen, making up about 78 percent of air, is the solvent. Oxygen, carbon dioxide, argon, and other gases are solutes.

You are probably most familiar with solutions in which water is the solvent. Carbonated drinks, hot tea, and seawater are just a few examples of the many water-based solutions you might have encountered. **Substances can dissolve in water in three ways—by dissociation, dispersion, and ionization.**

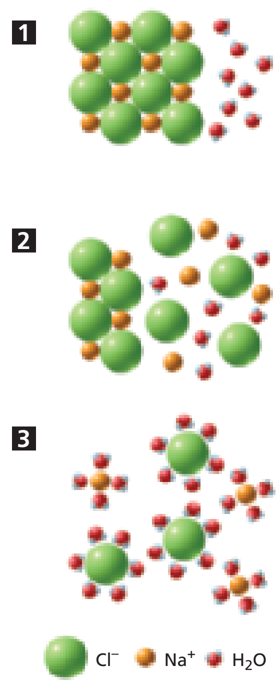
Dissociation of Ionic Compounds

For a solute to dissolve in water, the solute and solvent particles must attract one another. However, the particles within the solute are attracted to one another, and the particles within the solvent are attracted to one another. So before a solution can form, the attractions that hold the solute together and the solvent together must be overcome.

Figure 3 illustrates how a sodium chloride crystal dissolves in water. Sodium chloride is an ionic compound. Water is a polar molecule, and is attracted to the ions in the solute. The crystal dissolves as the sodium and chlorine ions are pulled into solution, one by one, by the surrounding water molecules. The process in which an ionic compound separates into ions as it dissolves is called **dissociation.**

Reading Checkpoint *How does sodium chloride dissolve in water?*

Figure 3 When an ionic compound dissolves in water, the charged ends of water molecules surround the oppositely charged ions.



Dissolving

Build Reading Literacy L1

Relate Text and Visuals Refer to page **190D** in **Chapter 7**, which provides the guidelines for relating text and visuals.

Have students read the text on pp. 229–230 describing different ways in which a substance can dissolve in water. Then, have students form groups of three. Each student will choose a type of dissolving. Encourage students to use Figure 3, Figure 4, or the diagram in the passage to explain to their group what happens on the particle level when substances dissolve by dissociation, dispersion, or ionization.
Visual, Logical

Address Misconceptions L2

Many students do not differentiate between solvent and solute particles when learning about solutions. Challenge this misconception by having students examine the keys at the bottom of Figure 3 and Figure 4. Have them note the different colors and sizes used to differentiate between solvent and solute particles. Point out that these figures show models of particles in order to represent the movement and relationship of solvent and solute particles. The figures do not show what the atoms, molecules, and ions actually look like. For example, the colors, shapes, and relative sizes of the particles are symbolic and do not represent the actual characteristics of the particles.
Visual

Customize for Inclusion Students

Hearing Impaired
If you have students with hearing impairments, have students draw what happens to solvent and solute particles during dissociation, dispersion, and ionization. Encourage them to label their illustrations and provide brief written descriptions.

Answer to . . .

Reading Checkpoint *Sodium chloride dissolves by dissociating into ions.*

Section 8.1 (continued)

Use Visuals L1

Figure 4 Have students examine Figure 4. Ask, **What symbol is used to represent water molecules?** *(A larger red sphere with two smaller blue spheres attached)* **How are the sugar molecules arranged in the beginning?** *(The sugar molecules are arranged in a packed crystal.)* **What symbol is used to represent sugar molecules?** *(A purple, two-ringed structure, with the rings joined at one point)* **How are the sugar molecules arranged in the end?** *(The sugar molecules are spread out and mixed in uniformly with the water molecules.)*
Visual

Build Science Skills L2

Predicting Have students look at the figure in the text on ionization of molecular compounds. Ask, **What ions would be produced as molecules of hydrogen bromide, HBr, dissolved in water?** *(Hydronium ions [H_3O^+] and bromide ions [Br^-])*
Logical, Visual

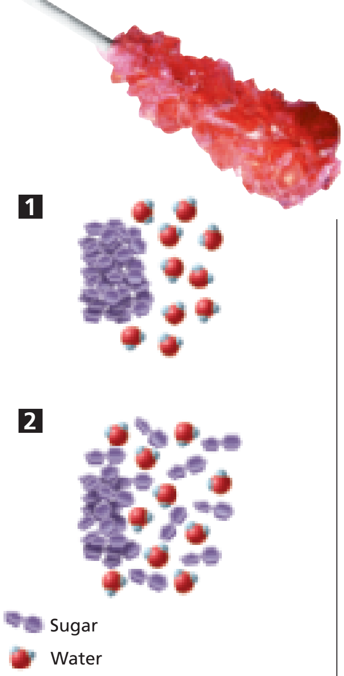


Figure 4 Saliva dissolves the sugar in hard candy by dispersion. As water molecules collide with sugar crystals, attractions develop between the water molecules and sugar molecules at the surface of the solid.

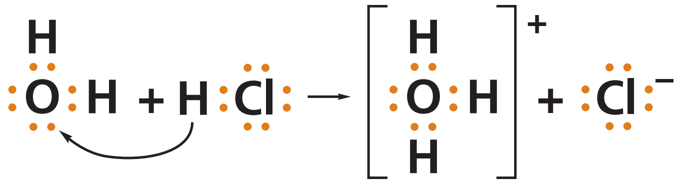
Dispersion of Molecular Compounds When you place a piece of hard candy on your tongue, the sweet taste spreads, or disperses, throughout your mouth. The water in your saliva dissolves the sugar and flavoring in the candy. Sugar dissolves in water by **dispersion,** or breaking into small pieces that spread throughout the water.

Both sugar and water are polar molecules, so they attract one another. Because the water molecules are constantly moving, they collide frequently with the surface of the sugar crystals, as shown in Figure 4. Attractions form between the water molecules and the exposed sugar molecules. When enough water molecules have surrounded a sugar molecule, the attractions between them are great enough to overcome the attractions holding the sugar molecule to the surface of the crystal. The sugar molecule breaks free, and is pulled into solution by the water molecules.

As more sugar molecules break free of the crystal, another layer of sugar molecules is exposed to the water, and the process repeats. The solute particles become evenly spread throughout the solvent.

Reading Checkpoint ***How does sugar dissolve in water?***

Ionization of Molecular Compounds Hydrogen chloride, HCl, is a molecular compound in which a hydrogen atom and a chlorine atom share a pair of electrons. Recall that a hydrogen atom has only one proton and one electron. When HCl gas dissolves in water, the hydrogen proton from each HCl molecule is transferred to a water molecule. For each HCl molecule that reacts, a hydronium ion, H_3O^+, and a chloride ion, Cl^-, are produced.



Notice that when hydrogen chloride and water form a solution, two molecular compounds react to form two ions. The process in which neutral molecules gain or lose electrons is known as **ionization.** Unlike dissociation and dispersion, which are physical changes, dissolving by ionization is a chemical change. The solution that results contains new substances. When a solute dissolves by dissociation, the ions pulled into solution are the same ions present in the solute. When a solute dissolves by ionization, the ions in solution are formed by the reaction of solute and solvent particles.

Properties of Liquid Solutions

The physical properties of salt are clearly different from the physical properties of water. But how do the properties of a saltwater solution compare to those of its solute and solvent? **Three physical properties of a solution that can differ from those of its solute and solvent are conductivity, freezing point, and boiling point.**

Conductivity Solid sodium chloride is a poor conductor of electric current. But when sodium chloride dissociates in water, the sodium and chloride ions are able to move freely. The ions in solution will then conduct an electric current. Hydrogen chloride gas is also a poor conductor of electric current. However, when hydrogen chloride ionizes in water, the resulting solution conducts an electric current.

Freezing Point and Boiling Point If you live in a cold climate, you are probably familiar with icy roads like the one in Figure 5. You may have seen snowplows or salt trucks spreading magnesium chloride, $MgCl_2$, or a similar ionic compound on these icy roads. When magnesium chloride dissolves in melting ice and snow, it dissociates into magnesium (Mg^{2+}) ions and chloride (Cl^-) ions. As Figure 6A shows, ice forms when water molecules are able to arrange themselves in a rigid, honeycomb-like structure. In Figure 6B, the presence of magnesium and chloride ions, which are attracted to the water molecules, interferes with the freezing process. The freezing point of water at sea level is 0°C. When icy roads are salted with magnesium chloride, the resulting solution can have a freezing point as low as −15°C.

A solute can also raise the boiling point of the solvent. For example, the coolant used in most car radiators is a solution containing water and ethylene glycol, $C_2H_6O_2$. Water at sea level boils at 100°C. Adding ethylene glycol to water raises the boiling point. The resulting solution helps prevent the engine from overheating. Because ethylene glycol also lowers the freezing point of water, the coolant does not freeze during spells of cold weather.

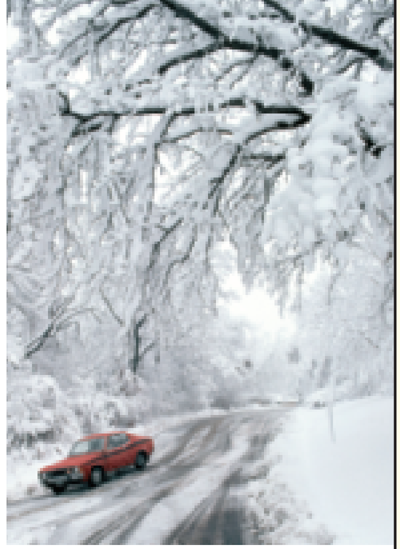


Figure 5 Salt spread on icy roads lowers the freezing point of water.

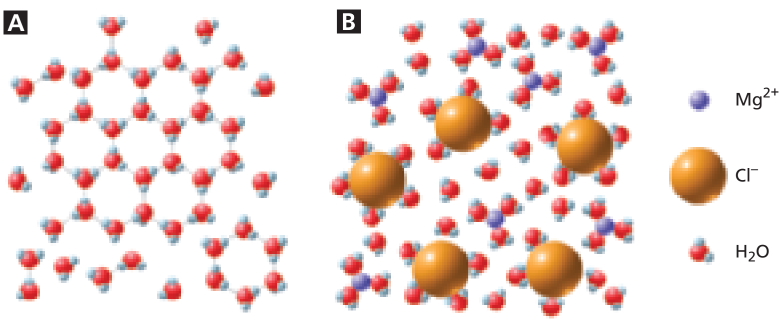


Figure 6 The presence of solute particles affects how a solvent freezes. **A** Pure water freezes in a hexagonal pattern. **B** In water "salted" with $MgCl_2$, the dissociated Mg^{2+} and Cl^- ions disrupt the formation of ice crystals. Using Models ***How do the interactions between Mg^{2+} and H_2O differ from the interactions between Cl^- and H_2O?***

Properties of Liquid Solutions

Teacher Demo

Freezing Points of Solutions

L2

Purpose Students observe the lower freezing point of a saltwater solution.

Materials 2 trays with sides at least 2 in deep, ice, rock salt, water, 2 small plastic containers (clear), thermometer

Procedure Explain to students that the water in an ice bath will remain at 0°C as long as some of the ice still remains. However, a saltwater solution in an ice bath will remain at an even lower temperature, depending on the concentration of the solution and the original temperature of the solid ice. Fill both trays with ice to a depth of 2 inches. Cover the ice of one of the trays with a generous amount of rock salt. Add water to both trays to a depth of 1 inch. Add one or two inches of water to each plastic container and place one of the containers in each ice water bath. Set the baths aside for the remainder of the class, checking them on occasion to see that they still contain unmelted ice. Add more ice if necessary. Have volunteers periodically check the temperatures of the two ice water baths. Check the contents of the plastic containers at the end of class.

Expected Outcome The water in the container placed in the ice water bath will remain liquid. The water in the container placed in the salt and ice water bath will freeze.
Visual

Facts and Figures

Structure of Ice The unusual structure of ice is due to the formation of hydrogen bonds between molecules and the angle between water's two O–H bonds. Because the formation of hydrogen bonds in place of weaker intermolecular forces releases energy, hydrogen bonding is energetically favorable. Thus, the open structure of ice maximizes the number of hydrogen bonds that can form among water molecules. Adding a solute prevents the water molecules from achieving this low energy structure.

Answer to . . .

Figure 6 *The Mg^{2+} ions are attracted to the oxygen atoms in the water molecules. The Cl^- ions are attracted to the hydrogen atoms in the water molecules.*

Reading Checkpoint *Sugar is a molecular compound that dissolves in water through dispersion.*

Section 8.1 (continued)

Heat of Solution

Quick Lab

Comparing Heats of Solution

L2

Objective

After completing this activity, students will be able to
- determine whether a solution process is exothermic or endothermic.

Skills Focus Observing, Measuring, Classifying, Inferring

Prep Time 15 minutes

Class Time 15 minutes

Safety Caution students to use the stirring rod, not the thermometer, to stir the solutions. Do not use mercury thermometers. Have students observe safety symbols and wear safety goggles, plastic gloves, and lab aprons.

Teaching Tips
- Dispose of all waste solutions in the sink with excess water.

Expected Outcome The potassium chloride solution process is endothermic, and the temperature should fall. The alcohol solution process is exothermic, and the temperature should rise.

Analyze and Conclude

1. The temperature of the potassium chloride solution fell. The temperature of the alcohol solution rose.
2. The alcohol solution process is exothermic. The potassium chloride solution process is endothermic.
3. Assuming that the solute dissolved, students should infer that the amount of energy absorbed as the particles separated would be equal (or very similar) to the amount of energy released when the solution formed.
Visual, Logical

Go Online NSTA SciLinks

Download a worksheet on solutions for students to complete, and find additional teacher support from NSTA SciLinks.

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For: Links on solutions
Visit: www.SciLinks.org
Web Code: ccn-1081

Heat of Solution

When sodium hydroxide, NaOH, dissolves in water, the solution becomes warmer. The solution releases energy to the surroundings. In contrast, when ammonium nitrate, NH_4NO_3, dissolves in water, the solution becomes colder. The solution absorbs energy from the surroundings. **During the formation of a solution, energy is either released or absorbed.**

Like chemical reactions, the solution process can be described as exothermic or endothermic. Dissolving sodium hydroxide in water is exothermic, as it releases heat. Dissolving ammonium nitrate in water is endothermic, as it absorbs heat. The How It Works box on page 233 describes how dissolving ammonium nitrate is used in cold packs.

In order for a solution to form, both the attractions among solute particles and the attractions among solvent particles must be broken. Breaking attractions requires energy. As the solute dissolves, new attractions form between solute and solvent particles. The formation of attractions releases energy. The difference between these energies is known as the heat of solution. For example, dissolving one mole of sodium hydroxide in water releases 44.5 kilojoules of heat. In this exothermic change, energy is released as NaOH and H_2O form new attractions. It is 44.5 kilojoules greater than the energy required to break the attractions among NaOH crystals and among H_2O molecules.

Reading Checkpoint ***Does the breaking of attractions among solvent particles release energy or absorb energy?***

Quick Lab

Comparing Heats of Solution

Materials

2 large test tubes, 10-mL graduated cylinder, distilled water, thermometer, 1 g potassium chloride, 5 mL 95% isopropyl alcohol solution, stirring rod

Procedure

1. Add 5 mL of distilled water to each test tube. Measure and record the temperature of the water in each test tube to the nearest 0.2°C.
2. Remove the thermometer. Add the potassium chloride to one of the test tubes. Stir until the potassium chloride dissolves. **CAUTION:** *Use the stirring rod, not the thermometer, to stir the solution.*
3. Measure and record the final temperature of the solution. Rinse the thermometer.
4. Add 5 mL of the alcohol solution to the second test tube. Stir the mixture. Measure and record the final temperature.

Analyze and Conclude

1. **Observing** What happened to the temperature of each solution?
2. **Classifying** Which process was exothermic? Which was endothermic?
3. **Inferring** If there were no change in temperature during the formation of a solution, how would you explain this observation?

HOW It Works

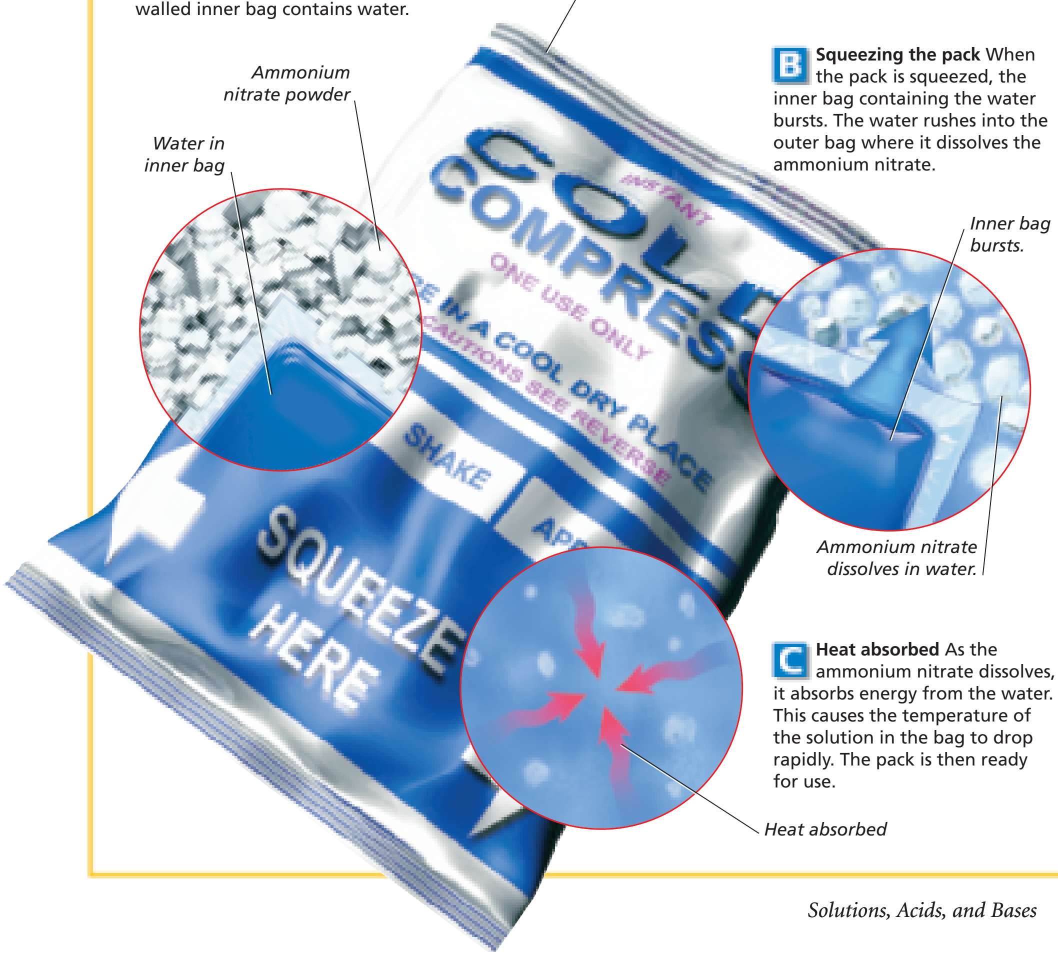
Cold Packs

Instant hot and cold packs are often used by athletes to treat injuries. Hot packs are also used in cold weather to warm hands and feet. Both types of pack work through the action of chemicals that either release or absorb heat when they dissolve in water. One type of cold pack is shown below. **Inferring** ***How does shaking the pack after squeezing it affect the rate of dissolving?***

Using a cold pack
A cold pack removes heat from the inflammation around an injury. It also decreases the size of capillaries (small blood vessels) in the injured area, which reduces swelling and bruising.

A **Inside the pack** A cold pack consists of two sealed bags, one inside the other. The strong outer bag contains solid ammonium nitrate powder. The thin-walled inner bag contains water.

B **Squeezing the pack** When the pack is squeezed, the inner bag containing the water bursts. The water rushes into the outer bag where it dissolves the ammonium nitrate.



C **Heat absorbed** As the ammonium nitrate dissolves, it absorbs energy from the water. This causes the temperature of the solution in the bag to drop rapidly. The pack is then ready for use.

Build Science Skills L2

Inferring Have students examine the description of what happens when NaOH dissolves in water. Tell them that the solute-solute attractions that are broken when NaOH dissociates are the ionic bonds between Na^+ and OH^- ions. Ask, **What solute-solute attractions are broken when molecular compounds dissolve through dispersion?** *(The intermolecular attractions between the solute molecules)*
Logical

HOW It Works

Cold Packs L2

The heat of solution for ammonium nitrate, NH_4NO_3, is 25.7 kJ/mol. This means that 25.7 kJ are absorbed when one mole, or about 80 g, of ammonium nitrate is dissolved in water. The amount of cooling that occurs depends on the amount of solid ammonium nitrate present in the cold pack.

Interpreting Diagrams Like stirring a mixture, shaking the bag moves more dissolved ions away from the surface of the solid ammonium nitrate and allows for more collisions between solute and solvent particles.
Visual

For Enrichment L3

Interested students can design a method for testing the effectiveness of different brands of hot or cold packs. They might compare how hot or cold each brand makes a sample of water. Alternatively, they might determine how long a desired temperature range is maintained by each brand.
Kinesthetic

Facts and Figures

Instant Hot Packs Many hot packs use a mechanism similar to that of cold packs in order to produce the opposite effect. Hot packs can use calcium chloride, $CaCl_2$, or magnesium sulfate, $MgSO_4$, which have negative heats of solution. Both substances have other home uses. Calcium chloride is used to keep pickles crisp and magnesium sulfate is used as bath salts.

Another type of hot pack uses a supersaturated solution of sodium acetate, $NaC_2H_3O_2$. Clicking a disk in the pack causes the solute to crystallize, which is an exothermic process. These hot packs are reusable because placing the pack in boiling water causes the solute crystals to go back into solution.

Answer to . . .

Reading Checkpoint *Breaking attractions among solvent particles absorbs energy.*

Section 8.1 (continued)

Factors Affecting Rates of Dissolving

Address Misconceptions L2

The text states that increasing temperature speeds up the rate of dissolving. There are some exceptions to this rule. In the next section, students will read about the relationship between temperature and the solubility of gases. Gases (and some solids) are more soluble as the temperature of the solution decreases. Have students speculate as to how increasing the temperature of a solution affects the solubility of a gas. **Logical**

3 ASSESS

Evaluate Understanding L2

Have students draw illustrations that represent the terms *solvent, solute, dissociation, dispersion,* and *ionization* on index cards. Then, have students shuffle the cards and exchange them with a partner. The partner then tries to identify what each illustration represents.

Reteach L1

Use Figures 3, 4, and 6 to summarize key concepts about solutions, including dissociation, dispersion, and freezing point depression.

Connecting Concepts

Factors that affect chemical reaction rates include temperature, surface area, concentration, stirring, and catalysts. Rates of dissolving are affected by temperature, surface area, and stirring.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 8.1.

Answer to . . .

Figure 7 *Increasing the temperature setting causes the detergent to dissolve at a faster rate.*

Figure 7 The rate of dissolving can be increased by reducing the particle size of the solute, by stirring, and by heating the solvent. **Predicting** ***How does changing the temperature setting on a washing machine affect how fast the detergent will dissolve?***

Factors Affecting Rates of Dissolving

You already know that sugar dissolves in water. But what do you know about the rate at which it dissolves? Like rates of chemical reactions, rates of dissolving depend on the frequency and energy of collisions that occur between very small particles. During a chemical reaction, collisions occur between particles of the reactants. During the formation of a solution, collisions occur between particles of the solute and solvent. **Factors that affect the rate of dissolving include surface area, stirring, and temperature.**

When a sugar cube dissolves in water, the dissolving takes place at the surfaces of the cube. The greater the surface area of a solid solute, the more frequent the collisions are between solute and solvent particles. More collisions result in a faster rate of dissolving. You can increase the surface area of a solid by dividing it into smaller particles. The more finely divided a solid solute, the faster it dissolves. For example, one gram of granulated sugar dissolves faster in water than a 1-gram sugar cube.

You can also make sugar dissolve faster by stirring the mixture. Stirring moves dissolved particles away from the surface of the solid, and allows for more collisions between solute and solvent particles.

Another way to speed up the rate of dissolving is to increase the temperature of the solvent. For example, sugar dissolves faster in warm water than it does in cold water. Increasing the temperature of a solvent causes its particles to move faster, on average. As a result, both the number of collisions and the energy of these collisions with solute particles increase. The solute goes into solution more quickly.

Section 8.1 Assessment

Reviewing Concepts

1. What are three ways that substances can dissolve in water?
2. What physical properties of a solution differ from those of its solutes and solvent?
3. How does the formation of a solution involve energy?
4. What factors affect dissolving rates?

Critical Thinking

5. **Comparing and Contrasting** Compare the processes by which sugar crystals and hydrogen chloride gas dissolve in water.
6. **Predicting** Suppose you put equal amounts of pure water and salt water into separate ice cube trays of the same size and shape. When you put both trays in the freezer, what would you expect to happen?

Connecting Concepts

Reaction Rates In Section 7.3, factors affecting chemical reaction rates are discussed. Find out which of these factors also affect rates of dissolving.

Section 8.1 Assessment

1. Dispersion, dissociation, and ionization
2. Conductivity, boiling point, and melting point
3. Breaking the attractions among solute particles and the attractions among solvent particles absorbs energy. Energy is released as new attractions form between solute and solvent particles.
4. Rates of dissolving are affected by temperature, surface area, and stirring.
5. Sugar crystals dissolve by dispersion, which means that the sugar molecules break away from the surface of the crystals as water molecules surround them. Hydrogen chloride gas dissolves in water by ionization, which means that a hydrogen proton is transferred from the hydrogen chloride molecule to a water molecule, forming a hydronium ion and a chloride ion.
6. The pure water would freeze before the saltwater because the salt would lower the freezing point of the water.