15.2

1 FOCUS

Objectives

15.2.1 Distinguish between a solvent and a solute.

15.2.2 Describe what happens in the solution process.

15.2.3 Explain why all ionic compounds are electrolytes.

15.2.4 Demonstrate how the formula for a hydrate is written.

Guide for Reading

Build Vocabulary L2

Concept Map Have students make a concept map using the following terms: *solvation, solute, aqueous solution, solvent.*

Reading Strategy L2

Outline Before students read this section, encourage them to make an outline using the red and blue headings as divisions and subdivisions. As they read, have them write a short summary under each heading.

2 INSTRUCT

Connecting to Your World

Have students study the photograph and read the text. Ask, **What is it about the pickle that allows it to produce light?** *(It conducts electricity.)* Ask students if they know of other materials that conduct electricity. *(Students will probably answer that metals conduct electricity. They may also know that ionic solutions conduct.)*

Solvents and Solutes

Discuss L2

Remind students that an anion is any negatively charged atom or group of atoms. A cation is any positively charged atom or group of atoms. Have students suggest a memory aid to help them remember. *(For example, the first two letters of anion, a and n, relate anion to negative.)*

15.2 Homogeneous Aqueous Systems

Guide for Reading

Key Concepts

- What is the difference between a solvent and a solute?
- What happens in the solution process?
- Why are all ionic compounds electrolytes?
- How do you write the formula for a hydrate?

Vocabulary

aqueous solution
solvent
solute
solvation
electrolyte
nonelectrolyte
strong electrolyte
weak electrolyte
hydrate

Reading Strategy

Relating Text and Visuals As you read, look carefully at Figure 15.7. In your notebook, explain in your own words how this illustration helps clarify the process of solvation.

Connecting to Your World

Is it possible to read by the light of a glowing pickle? Although it sounds absurd, an ordinary dill pickle from the deli can be a source of light! Iron or copper electrodes are inserted into the ends of the pickle and connected to a source of alternating electric current. After a time, during which the pickle becomes hot and produces water vapor, the pickle begins to glow. The mechanism by which the light is generated is not fully understood, but it is clear that conduction of electricity by the pickle is an important factor. In this section you will learn what kind of solution conducts electricity.

Solvents and Solutes

Water dissolves so many of the substances that it comes in contact with that you won't find chemically pure water in nature. Even the tap water you drink is a solution that contains varying amounts of dissolved minerals and gases. An **aqueous solution** is water that contains dissolved substances. In a solution, the dissolving medium is the **solvent,** and the dissolved particles are the **solute.** **A solvent dissolves the solute. The solute becomes dispersed in the solvent.** Solvents and solutes may be gases, liquids, or solids.

Recall that solutions are homogeneous mixtures. They are also stable mixtures. For example, sodium chloride does not settle out when its solutions are allowed to stand, provided other conditions, such as temperature, remain constant. Solute particles can be atoms, ions, or molecules, and their average diameters are usually less than 1 nm (10^{-9} m). Therefore, if you filter a solution through filter paper, both the solute and the solvent pass through the filter, as Figure 15.6 shows.

Substances that dissolve most readily in water include ionic compounds and polar covalent molecules. Nonpolar covalent molecules, such as methane, and compounds found in oil, grease, and gasoline, do not dissolve in water. However, oil and grease will dissolve in gasoline. To understand this difference, you must know more about the structures of the solvent and the solute and what attractions exist between them.

Figure 15.6 A solution cannot be separated by filtration. The small size of the solute particles allows them to pass through filter paper.

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 15.2
- **Core Teaching Resources,** Section 15.2 Review
- **Laboratory Manual,** Lab 26, 27, 28, 29
- **Small-Scale Chemistry Laboratory Manual,** Labs 22, 23, 24
- **Laboratory Practicals,** 15.1
- **Probeware Lab Manual,** Section 15.2
- **Transparencies,** T162–T165

Technology

- **Virtual Chemistry Labs,** Lab 21
- **Interactive Textbook with ChemASAP,** Simulation 18, 19, Problem-Solving 15.6, Assessment 15.2
- **Go Online,** Section 15.2

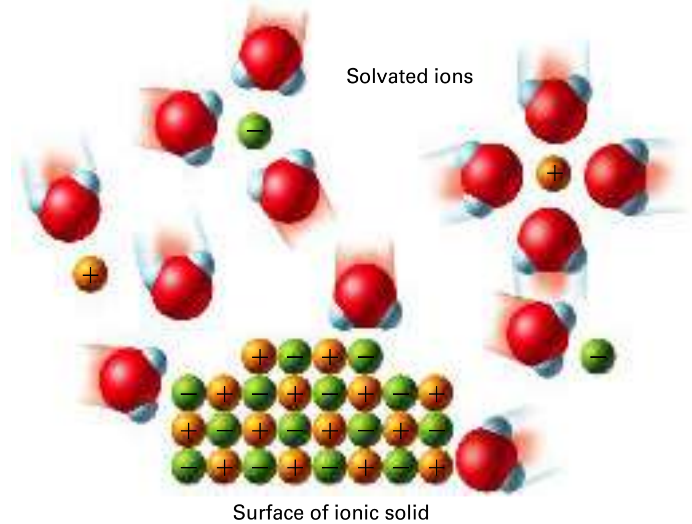

Figure 15.7 When an ionic solid dissolves, the ions become solvated or surrounded by solvent molecules. **Inferring** ***Why do the water molecules orient themselves differently around the anions and the cations?***

The Solution Process

Water molecules are in continuous motion because of their kinetic energy. When a crystal of sodium chloride is placed in water, the water molecules collide with it. Remember that a water molecule is polar, with a partial negative charge on the oxygen atom and partial positive charges on the hydrogen atoms. The polar solvent molecules (H_2O) attract the solute ions (Na^+, Cl^-). **As individual solute ions break away from the crystal, the negatively and positively charged ions become surrounded by solvent molecules and the ionic crystal dissolves.** The process by which the positive and negative ions of an ionic solid become surrounded by solvent molecules is called **solvation.** Figure 15.7 shows a model of the solvation of an ionic solid such as sodium chloride.

In some ionic compounds, the attractions among the ions in the crystals are stronger than the attractions exerted by water. These compounds cannot be solvated to any significant extent and are therefore nearly insoluble. Barium sulfate ($BaSO_4$) and calcium carbonate ($CaCO_3$) are examples of nearly insoluble ionic compounds.

Figure 15.8 shows that oil and water do not mix. But what about oil in gasoline? Both oil and gasoline are composed of nonpolar molecules. The attractive forces that hold two oil molecules together are similar in magnitude to the forces that hold two gasoline molecules together. Oil molecules can easily separate and replace gasoline molecules to form a solution. As a rule, polar solvents such as water dissolve ionic compounds and polar compounds; nonpolar solvents such as gasoline dissolve nonpolar compounds. This relationship can be summed up in the expression "like dissolves like."

Checkpoint ***What is meant by solvation?***

Interactive Textbook

Simulation 18 Explore the nature of solute-solvent interactions.

with ChemASAP

Figure 15.8 Oil and water do not mix. Oil is less dense than water, so it floats on top. The colors result from the bending of light rays by the thin film of oil.

The Solution Process

Use Visuals L1

Figure 15.7 Have students study the figure. Stress the idea that when a solid dissolves in water, it breaks into small pieces. Ask, **What must happen for an ionic solid to dissolve?** *(The molecules of the solvent must be able to overcome the attractive forces between ions that hold the solid together.)* **What part of a water molecule is attracted to a negatively charged solute ion?** *(the hydrogen atoms)*

Discuss L2

Remind students that solutions are homogeneous mixtures containing a solvent and one or more solutes. Usually the solvent is defined as the component in the system that is present in the greatest amount. Point out that a water-soluble solute can be a solid, liquid, or gas. Ask students to name some of the solutes in blood. *(Solutes in blood are typically ions such as sodium, potassium, calcium, chloride, hydrogen carbonate, and phosphate. Glucose, a covalent compound, also is dissolved in blood. Dissolved gases such as oxygen and carbon dioxide are also present.)*

Differentiated Instruction

Less Proficient Readers L1

Have students preview the section by looking for vocabulary and other unfamiliar terms. Encourage students to write the terms, their phonetic respellings, and their definitions in their notebooks.

Answers to...

Figure 15.7 The positive hydrogen end of the water molecule orients itself toward the anion. The negative-oxygen end of the water molecule orients itself toward the cation.

Checkpoint the process by which the ions of an ionic solid become surrounded by solvent molecules

Careers *in* Chemistry

Wastewater Engineer

Disinfection is the last step in the process of making wastewater safe for drinking or for release back into the environment. Chlorine is a safe, inexpensive, and effective disinfectant against waterborne bacteria and viruses. Chlorine remains in the water and continues to provide protection against these organisms. Other disinfectants include ozone and ultraviolet light. Although ozone and UV are both powerful disinfectants, they do not remain in the water to provide residual protection. Chloramines, compounds formed by the reaction of chlorine and ammonia or other nitrogen compounds, provide residual protection, but they do not have the disinfecting power of chlorine. Chlorine dioxide is a powerful disinfectant and offers residual protection; however, the technology is relatively new and complex.

Go Online PHSchool.com

Have students research chemistry-related careers in the library or on the Internet. Students can then construct a table that describes the nature of the work, educational and training requirements, employment outlook, working conditions, and other necessary information.

Wastewater Engineer

Wastewater must be physically and chemically treated before it is returned to the environment or recycled for human use. A wastewater engineer is responsible for monitoring this process. These engineers control the amount of water treated, the level of treatment, and the quality of water produced. When water is received at a treatment plant, a wastewater engineer oversees primary treatment that involves filtering the water for solids and debris. The engineer then adds microorganisms to the water that convert the remaining dissolved organic matter into solids that can be removed as sludge. If this water is to be released into a river or stream, the engineer then tests the water for levels of remaining organic compounds. If amounts of these compounds fall below recommended levels, the water is safe to be released.

Production of drinking water often requires additional steps. The engineer must test the water for nitrogen and phosphorus compounds that would need to be removed. The engineer then disinfects the water using chlorine, ozone, or other disinfectants, and might add fluoride to strengthen consumers' teeth.

Interpreting the results of tests requires experience and an understanding of the entire chemical, and often biological, environment. Wastewater engineers usually have a degree in engineering. They must take courses in water toxicology, organic chemistry, and environmental biology.

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For: Careers in Chemistry
Visit: PHSchool.com
Web Code: cdb-1152

Electrolytes and Nonelectrolytes

Remember the glowing pickle that you read about in *Connecting to Your World?* The pickle contained an electrolyte. An **electrolyte** is a compound that conducts an electric current when it is in an aqueous solution or in the molten state. Conduction of electricity requires ions that are mobile and thus able to carry an electrical current. **All ionic compounds are electrolytes because they dissociate into ions.** Sodium chloride, copper(II) sulfate, and sodium hydroxide are typical water-soluble electrolytes. Barium sulfate is an ionic compound that cannot conduct electricity in aqueous solution because it is insoluble, but it can conduct in the molten state.

A compound that does not conduct an electric current in either aqueous solution or the molten state is called a **nonelectrolyte.** Many molecular compounds are nonelectrolytes because they are not composed of ions. Most compounds of carbon, such as table sugar (sucrose) and the alcohol in rubbing alcohol (2-propanol), are nonelectrolytes.

Checkpoint ***How do electrolytes and nonelectrolytes differ?***

Facts and Figures

Wastewater Treatment

Cleaning wastewater protects the environment from the harmful substances it carries. Wastewater treatment also helps recycle water, a resource that is in increasingly short supply. Wastewater treatment begins with the used water from your home, your school, or industry. The water collects in underground pipes called sewers. Gravity moves the water through the sewers to the treatment plant. Once at the plant, the wastewater undergoes a number of purification stages. The primary treatment stage is mostly a physical process involving filtration and sedimentation. In secondary treatment, large populations of microorganisms convert the remaining dissolved organic matter into solids that separate as a sludge. Sometimes tertiary treatment is needed as well. At this level of treatment, nutrients such as nitrogen or phosphorus compounds that produce unwanted growth of algae are removed.

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Some polar molecular compounds are nonelectrolytes in the pure state, but become electrolytes when they dissolve in water. This occurs because such compounds ionize in solution. For example, neither ammonia ($NH_3(g)$) nor hydrogen chloride ($HCl(g)$) is an electrolyte in the pure state. Yet an aqueous solution of ammonia conducts electricity because ammonium ions (NH_4^+) and hydroxide ions (OH^-) form when ammonia dissolves in water.

$$NH_3(g) + H_2O(l) \longrightarrow NH_4^+(aq) + OH^-(aq)$$

Similarly, in aqueous solution, hydrogen chloride produces hydronium ions (H_3O^+) and chloride ions (Cl^-). An aqueous solution of hydrogen chloride conducts electricity and is therefore an electrolyte.

$$HCl(g) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$

Not all electrolytes conduct an electric current to the same degree. In the simple conductivity test shown in Figure 15.9, a bulb glows brightly when electrodes attached to it are immersed in a sodium chloride solution. The bright glow shows that sodium chloride is a **strong electrolyte** because nearly all the dissolved sodium chloride exists as separate Na^+ and Cl^- ions. The ions move in solution and conduct an electric current. Most soluble salts, inorganic acids, and inorganic bases are strong electrolytes.

The bulb glows dimly when the electrodes are immersed in a mercury(II) chloride solution because mercury(II) chloride is a weak electrolyte. A **weak electrolyte** conducts electricity poorly because only a fraction of the solute in the solution exists as ions. Other weak electrolytes are ammonia (NH_3) and organic acids and bases. In a solution of glucose, the bulb does not glow. Glucose ($C_6H_{12}O_6$) is a molecular compound. It does not form ions, so it is a nonelectrolyte.

Checkpoint ***Name an electrolyte and a nonelectrolyte.***

Interactive Textbook

Simulation 19 Simulate the behavior of electrolytes and nonelectrolytes in a circuit and at the atomic level.

with ChemASAP

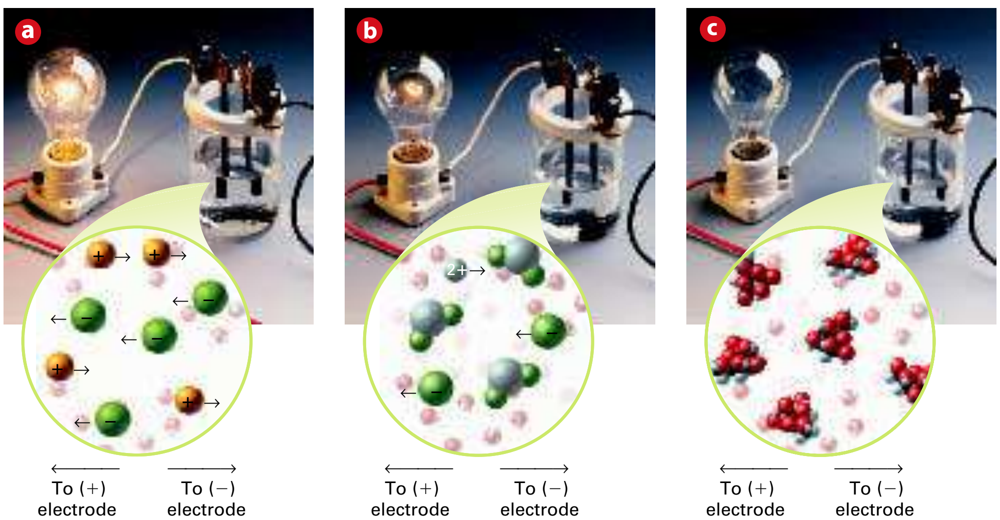

Figure 15.9 A solution conducts electricity if it contains ions. **a** Sodium chloride, a strong electrolyte, is nearly 100% dissociated into ions in water. **b** Mercury(II) chloride, a weak electrolyte, is only partially dissociated in water. **c** Glucose, a nonelectrolyte, does not dissociate in water.

Electrolytes and Nonelectrolytes

TEACHER Demo

Electrolytes L2

Purpose Students compare electrolytes using a conductivity tester

Materials light bulb in a porcelain socket; 9V or lantern battery; 2 copper metal strips; lamp cord; alligator clips; 0.1*M* solutions of glucose ($C_6H_{12}O_6$), alanine ($HC_3H_6O_2N$), glycine ($HC_2H_4O_2N$), ascorbic acid ($HC_6H_7O_6$), malonic acid ($H_2C_3H_2O_4$), citric acid ($H_3C_6H_5O_7$), acetic acid ($HC_2H_3O_2$), and hydrochloric acid (HCl); 8 beakers labeled 1–8; marking pen

The complete circuit consists of a light bulb (in a porcelain socket), a 9V or lantern battery, and two copper metal strips to be immersed in the test solution. Connect the leads of the battery and lightbulb sockets using lamp cord and alligator clips. If possible, prepare 8 such testers so that students can directly compare the brightness of the lightbulbs.

Procedure Write the names and numbers of the beakers on the board. Pour an equal volume of each solution into a labeled beaker. Remind students that all the solutions have the same concentration (0.1*M*). Immerse a set of electrodes in each solution and have students compare the brightness of the light bulbs. Ask students to list the substances in order from strongest to weakest electrolyte. Remind them that a strong electrolyte is a substance that exists in solution almost entirely as ions. A weak electrolyte is a substance that only partly dissociates into ions in solution.

Expected Outcomes Students infer that the different substances are dissociated, or ionized, to different extents.

Answers to...

Checkpoint An electrolyte conducts electricity; a nonelectrolyte does not.

Checkpoint electrolyte: sodium chloride; nonelectrolyte: glucose

Facts and Figures

Electrolytes

Electrolytes are essential to all metabolic processes. Sodium and potassium ions control nerve impulse transmission and muscle contraction. If renal function is impaired or malabsorption from the gut disturbs optimum sodium and potassium levels, then serious nervous-system problems arise. Loss of consciousness or difficulty in maintaining muscle coordination could result. Any condition that causes prolonged bouts of diarrhea can be life threatening because of the dramatic loss of electrolytes. Electrolytes are excreted through the skin via sweat, and they must be replenished or cramps and heat stroke may occur. Sports drinks are a good source of electrolytes; they contain Na^+, K^+, and Ca^{2+}.

Hydrates

Use Visuals

L1

Figure 15.10 Have students study the photographs. Ask, **What is a hydrate?** *(a compound that contains weakly bound water molecules as part of its crystal structure)* **What does the dot between the $CuSO_4$ and the $5H_2O$ in the compound formula mean?** *(It indicates that water is an integral part of the representative unit of the compound.)* **How can the presence of water in the structure of the crystal lattice be inferred?** *(by the change in the appearance of the hydrated substance when the water is driven off)*

TEACHER Demo

Magic Writing

L1

Purpose Students observe the color change when a hydrate gains and loses water.

Materials $CoCl_2 \cdot 6H_2O$ solution, cotton swab, white paper, hot plate, misting bottle, water

Procedure Use a cotton swab to draw a picture or write a message on a piece of white paper using a solution of hydrated cobalt(II) chloride. Place the paper on a warm (not hot) hot plate until the writing dries. Use a misting bottle to mist water on the paper. The paper can be used as a weather predictor.

Safety and Disposal Wear gloves. Cobalt chloride is toxic if ingested. Collect cobalt chloride solution, evaporate to dryness, place cooled residue in bag, and label for disposal.

Expected Outcomes The picture or message will appear blue when the paper dries and pink when the paper is misted with water.

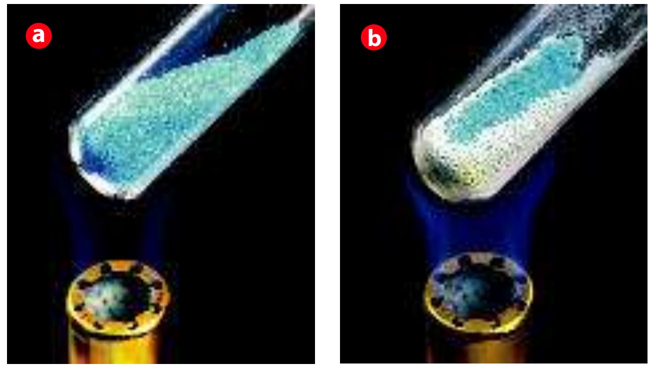

Figure 15.10 Water can be driven from a hydrate by heating. (a) Heating of a sample of blue $CuSO_4 \cdot 5H_2O$ begins. (b) After a time, much of the blue hydrate has been converted to white anhydrous $CuSO_4$.

Hydrates

When an aqueous solution of copper(II) sulfate is allowed to evaporate, deep-blue crystals of copper(II) sulfate pentahydrate are deposited. The chemical formula for this compound is $CuSO_4 \cdot 5H_2O$. Water molecules are an integral part of the crystal structure of copper(II) sulfate pentahydrate and many other substances. The water contained in a crystal is called the water of hydration or water of crystallization. A compound that contains water of hydration is called a **hydrate.** **In writing the formula of a hydrate, use a dot to connect the formula of the compound and the number of water molecules per formula unit.** Crystals of copper(II) sulfate pentahydrate always contain five molecules of water for each copper and sulfate ion pair. The deep-blue crystals are dry to the touch. They are unchanged in composition or appearance in normally moist air. But when heated above 100°C, the crystals lose their water of hydration. Figure 15.10 shows how the blue crystals of $CuSO_4 \cdot 5H_2O$ crumble to a white anhydrous powder that has the formula $CuSO_4$. If anhydrous copper(II) sulfate is treated with water, the blue pentahydrate is regenerated.

$$CuSO_4 \cdot 5H_2O(s) \underset{-\text{heat}}{\overset{+\text{heat}}{\rightleftharpoons}} CuSO_4(s) + 5H_2O(g)$$

Another compound that changes color in the presence of moisture is cobalt(II) chloride. A piece of filter paper that has been dipped in an aqueous solution of cobalt(II) chloride and then dried is blue in color (anhydrous $CoCl_2$). But as you can see in Figure 15.11, when the paper is exposed to moist air, it turns pink because of the formation of the hydrate cobalt(II) chloride hexahydrate ($CoCl_2 \cdot 6H_2O$). The blue paper could be used to test for the presence of water.

Some familiar hydrates are listed in Table 15.2 and shown in Figure 15.12. Each one contains a fixed quantity of water and has a definite composition.

Figure 15.11 Paper treated with anhydrous cobalt(II) chloride is blue. In the presence of moisture the paper turns pink. **Inferring** ***How could you change the pink paper back to blue?***

Table 15.2

Some Common Hydrates		
Formula	**Chemical name**	**Common name**
$MgSO_4 \cdot 7H_2O$	magnesium sulfate heptahydrate	Epsom salt
$Ba(OH)_2 \cdot 8H_2O$	barium hydroxide octahydrate	
$CaCl_2 \cdot 2H_2O$	calcium chloride dihydrate	
$CuSO_4 \cdot 5H_2O$	copper(II) sulfate pentahydrate	blue vitriol
$Na_2SO_4 \cdot 10H_2O$	sodium sulfate decahydrate	Glauber's salt
$KAl(SO_4)_2 \cdot 12H_2O$	potassium aluminum sulfate dodecahydrate	alum
$Na_2B_4O_7 \cdot 10H_2O$	sodium tetraborate decahydrate	borax
$FeSO_4 \cdot 7H_2O$	iron(II) sulfate heptahydrate	green vitriol
$H_2SO_4 \cdot H_2O$	sulfuric acid hydrate (mp 8.6°C)	

Figure 15.12 Epsom salts can be used as a mild laxative. Borax is a strong cleaner, water softener, and fireproofing agent.

Efflorescent Hydrates The forces holding the water molecules in hydrates are not very strong, so the water is easily lost and regained. Because the water molecules are held by weak forces, hydrates often have an appreciable vapor pressure. If a hydrate has a vapor pressure higher than the pressure of water vapor in the air, the hydrate will lose its water of hydration or effloresce. For example, $CuSO_4 \cdot 5H_2O$ has a vapor pressure of about 1.0 kPa at room temperature. The average pressure of water vapor at room temperature is about 1.3 kPa. Copper(II) sulfate pentahydrate is stable until the humidity decreases. When the vapor pressure drops below 1.0 kPa, the hydrate effloresces. Washing soda, or sodium carbonate decahydrate ($Na_2CO_3 \cdot 10H_2O$), is efflorescent. As the crystals lose water of hydration, they effloresce and become coated with a white powder of anhydrous sodium carbonate (Na_2CO_3).

Hygroscopic Hydrates Hydrated salts that have a low vapor pressure remove water from moist air to form higher hydrates. These hydrates and other compounds that remove moisture from air are called hygroscopic. For example, calcium chloride monohydrate spontaneously absorbs a second molecule of water when exposed to moist air.

$$CaCl_2 \cdot H_2O(s) \xrightarrow{\text{moist air}} CaCl_2 \cdot 2H_2O(s)$$

Calcium chloride is used as a desiccant in the laboratory. A desiccant is a substance used to absorb moisture from the air and create a dry atmosphere. For example, anhydrous $CaCl_2$ can be placed in the bottom of a tightly sealed container called a desiccator. Substances that must be kept dry are stored inside. A solid desiccant such as calcium sulfate ($CaSO_4$) can also be added to a liquid solvent to keep it dry. A bottle labeled "dry ethanol" may have solid calcium sulfate at the bottom. The calcium sulfate does not dissolve appreciably in the solvent but absorbs water from the ethanol and keeps it dry. When a desiccant has absorbed all the water it can hold, the salt can be returned to its anhydrous state by heating.

Checkpoint ***What is a hygroscopic hydrate?***

Discuss L2

Many of the terms used to describe the properties of hydrates may be unfamiliar to students. Review the definition and pronunciation of the terms *effloresce, hygroscopic, desiccant,* and *deliquescent*. Have students write the definition for each term in their notebooks. Demonstrate some of these phenomena by setting out watch glasses containing fresh NaOH pellets, anhydrous calcium chloride, and anhydrous copper sulfate. Advise students not to touch the compounds. Point out the compounds that are hygroscopic and those that are deliquescent. Many students may have seen rice in salt shakers at restaurants. Ask them what purpose the rice serves. (*Rice acts as a desiccant.*) Explain why hygroscopic agents are preferred over deliquescent agents for use as desiccants or drying agents. Emphasize the reversible properties of hydration. Desiccants can be recycled by heating to drive off absorbed water. If possible, show students a desiccator and explain why desiccators are used in the laboratory to store hygroscopic chemicals.

Use Visuals L1

Table 15.2 Display the table on an overhead projector. Review the nomenclature used to name salts and the use of prefixes to indicate the number of water molecules in the crystalline hydrate. Ask, **Do you know the uses for any of the compounds in the table?** *(Epsom salt is used as a cathartic; Glauber's salt is used as a cathartic or diuretic; alum is used as an astringent, as an emetic, and in the manufacture of baking powder, dyes, and paper; borax is used in the manufacture of glass, enamel, artificial gems, soaps, and antiseptics.)*

Facts and Figures

Desiccants

Cameras and electronic equipment made in Japan and other Asian countries are usually shipped to the United States in the holds of ships. Because ocean air contains so much moisture, the packaging for this equipment usually contains small packets of a desiccant. The desiccant absorbs the water vapor from the air, preventing it from condensing on the delicate wiring and circuit boards of the equipment, which could cause corrosion and short circuits.

Answers to...

Figure 15.11 Heat it gently to drive off the water.

Checkpoint a hydrate that removes water from moist air to form a higher hydrate

Sample Problem 15.1

Answers

6. 36.1%
7. 49.3%

Practice Problems Plus L2

Magnesium sulfate forms a heptahydrate.

a. Write the equation for the formation of this hydrate from the anhydrous salt. *($MgSO_4 + 7H_2O \rightarrow MgSO_4 \cdot 7H_2O$)*

b. Calculate the percent by mass of water. (51.2%)

Relate L2

After students have studied Sample Problem 15.1, have them work in groups to find the percent by mass of water in the compounds in Table 15.2.

Math Handbook

For a math refresher and practice, direct students to percents, page R72.

Go Online NSTA SciLinks

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

Suppose you are measuring a mass of Na_2CO_3 for a chemical reaction. You want to use the hydrate of the compound because it is less expensive than the anhydrous compound. To determine what percent of the hydrate is water, first determine the mass of the number of moles of water in one mole of hydrate. Then determine the total mass of the hydrate. The percent by mass of water can be calculated using this equation.

$$\text{percent } H_2O = \frac{\text{mass of water}}{\text{mass of hydrate}} \times 100\%$$

Math Handbook

For help with percents go to page R72.

Interactive Textbook

Problem-Solving 15.6
Solve Problem 6 with the help of an interactive guided tutorial.

with ChemASAP

SAMPLE PROBLEM 15.1

Finding the Percent of Water in a Hydrate

Calculate the percent by mass of water in washing soda, sodium carbonate decahydrate ($Na_2CO_3 \cdot 10H_2O$).

1 Analyze ***List the known and the unknown.***

Known	Unknown
• Formula of hydrate = $Na_2CO_3 \cdot 10H_2O$	• percent H_2O = ? %

To determine the percent by mass, determine the mass of 10 moles of water and the mass of one mole of the hydrated compound. Substitute these values into the following equation and solve.

$$\text{Percent } H_2O = \frac{\text{mass of water}}{\text{mass of hydrate}} \times 100\%$$

2 Calculate ***Solve for the unknown.***

mass of 10 moles H_2O = 180 g

molar mass of $Na_2CO_3 \cdot 10H_2O$ = 286.0 g

$$\text{percent } H_2O = \frac{1.80 \times 10^2\ \text{g}}{286.0\ \text{g}} \times 100\% = 62.9\%$$

3 Evaluate ***Does the result make sense?***

Because the mass of the water accounts for more than half the molar mass of the compound, a percentage greater than 50% should be expected. The answer should have three significant figures.

Practice Problems

6. What is the percent by mass of water in $CuSO_4 \cdot 5H_2O$?

7. Calculate the percent by mass of water in calcium chloride hexahydrate ($CaCl_2 \cdot 6H_2O$).

If you need 5.00 g of anyhydrous Na_2CO_3 for your reaction, how many grams of $Na_2CO_3 \cdot 10H_2O$ could you use instead? You know now that 62.9% of the hydrate is water, so 37.1 g out of every 100 g is Na_2CO_3 (100.0 g − 62.9 g = 37.1 g). Calculate how much hydrate you need as follows.

$$5.00\ \cancel{\text{g } Na_2CO_3} \times \frac{(100\ \text{g } Na_2CO_3 \cdot 10H_2O)}{37.1\ \cancel{\text{g } Na_2CO_3}} = 13.5\ \text{g } Na_2CO_3 \cdot 10H_2O$$

456 Chapter 15

Figure 15.13 Deliquescent substances can remove water from the air. **a** Sodium hydroxide pellets absorb moisture from the air. **b** Eventually a solution is formed. **Applying Concepts** ***Identify the solvent and the solute.***

Deliquescent Compounds Have you ever noticed the small packets of silica gel that are often packaged with electronic equipment and leather goods? Although the structure of silica gel is not the same as a hydrated salt, it is a hygroscopic substance used to absorb moisture from the air to prevent damage to sensitive equipment and materials. Some compounds are so hygroscopic that they become wet when exposed to normally moist air. These compounds are deliquescent, which means that they remove sufficient water from the air to dissolve completely and form solutions. Figure 15.13 shows that pellets of sodium hydroxide are deliquescent. For this reason, containers of NaOH and other chemicals should always be tightly stoppered and the chemicals should never be touched by fingers. The solution formed by a deliquescent substance has a lower vapor pressure than that of the water in the air.

Go Online NSTA SCILINKS
For: Links on Deliquescent Compounds
Visit: www.SciLinks.org
Web Code: cdn-1152

15.2 Section Assessment

8. **Key Concept** In the formation of a solution, how does the solvent differ from the solute?
9. **Key Concept** Describe what happens to the solute and the solvent when an ionic compound dissolves in water.
10. **Key Concept** Why are all ionic compounds electrolytes?
11. **Key Concept** How do you write the formula for a hydrate?
12. Which of the following substances dissolve to a significant extent in water? Explain your answer in terms of polarity.
    a. CH_4 **b.** KCl **c.** He
    d. $MgSO_4$ **e.** Sucrose **f.** $NaHCO_3$
13. Identify the solvent and the solute in vinegar, a dilute aqueous solution of acetic acid.
14. Distinguish between efflorescent and hygroscopic substances.
15. Calculate the percent by mass of water in magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$).

Connecting Concepts

Percent Composition Review Sample Problem 10.10 in Chapter 10 and compare it with Sample Problem 15.1. How are the procedures the same? Is the percent of copper in $CuSO_4 \cdot 5H_2O$ the same as in $CuSO_4$? Explain.

Interactive Textbook
Assessment 15.2 Test yourself on the concepts in Section 15.2.
with ChemASAP

Section 15.2 Assessment

8. The dissolving medium is the solvent, and the dissolved particles are the solute.
9. As individual solute ions break away from the crystal, the negatively and positively charged ions become surrounded by solvent molecules and the ionic crystal dissolves.
10. Because they dissociate into ions.
11. In writing the formula of a hydrate, a dot is used to connect the formula of the compound with the number of water molecules per formula unit.
12. **a.** insoluble, nonpolar **b.** soluble, ionic **c.** insoluble, nonpolar **d.** soluble, ionic **e.** soluble, polar **f.** soluble, ionic
13. Water is the solvent; acetic acid is the solute.
14. Efflorescent compounds such as certain hydrates lose water to the air. Hygroscopic compounds remove moisture from air, sometimes forming hydrates.
15. 51.2% water

3 ASSESS

Evaluate Understanding L2

To assess students' understanding of the properties of aqueous solutions, ask, **What types of substances will dissolve in water to form aqueous solutions?** *(ionic compounds and polar covalent molecules)* Dissolve a small amount of nickel(II) chloride in 500 mL of distilled water and ask, **In this solution, what is the solute and what is the solvent?** *(Water is the solvent and nickel(II) chloride is the solute.)* **What type of electrolyte is nickel(II) chloride? Explain.** *(Nickel(II) chloride is an ionic compound and is soluble in water; therefore, it is a strong electrolyte.)*

Reteach L1

Project models of water molecules, cations, and anions on an overhead projector to show how water molecules orient their dipoles to solvate ions. Point out that cations and anions are attracted to different ends of the water molecule. Stress that the classification of water-soluble substances as strong electrolytes, weak electrolytes, or nonelectrolytes is determined by the relative number of ions in solution. Nonelectrolytes do not produce ions.

Connecting Concepts

In both procedures, the mass of a component of a compound is compared to the mass of the compound. The percent of copper in copper sulfate and copper sulfate pentahydrate is different because the formula masses of the two compounds are different.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 15.2.
with ChemASAP

Answers to...

Figure 15.13 The solute is sodium hydroxide and the solvent is water.

Small-Scale LAB

Electrolytes

L2

Objectives After completing this activity, students will be able to:

- classify compounds as electrolytes or nonelectrolytes by testing them for conductivity.

Address Misconceptions

Students often think that a substance will conduct electricity if it dissolves in water. Tell students that some covalent compounds dissolve in water but do not conduct electricity.

Prep Time 45 minutes

Advance Prep

- Make up reagents as follows:

Solution	Preparation
1.0*M* HCl	82 mL of 12*M* in 1.0 L
1.0*M* HNO_3	63 mL of 15.8*M* in 1.0 L
1.0*M* H_2SO_4	56 mL of 18*M* in 1.0 L

CAUTION: *Always add acid to water.*

1.0*M* NH_3	67 mL of 15*M* in 1.0 L

CAUTION: *Using proper ventilation, add ammonia to water.*

CH_3COOH	Use white vinegar.
0.5*M* NaOH	20.0 g in 1.0 L

- Obtain various liquids such as rubbing alcohol, distilled water, soft drinks, orange juice, pickle juice, and coffee.

Class Time 20 minutes

Safety Be sure students wear goggles and aprons.

Teaching Tips

- Ask students to bring in small samples of orange juice and other liquid foods.

Expected Outcome None of the compounds conduct electricity when in the solid state. Aqueous solutions of NaCl, $MgSO_4$, Na_2CO_3, $NaHCO_3$, KCl, and KI conduct electricity and are thus electrolytes. Cornstarch and table sugar do not conduct electricity and are nonelectrolytes.

Analyze

1. Electrolytes: NaCl, $MgSO_4$, Na_2CO_3, $NaHCO_3$, KCl, KI; nonelectrolytes: sugar, cornstarch

Small-Scale LAB

Electrolytes

Purpose

To classify compounds as electrolytes by testing their conductivity in aqueous solution.

Materials

- pencil
- paper
- ruler
- reaction surface
- chemicals shown in the grid below
- conductivity tester
- water
- micropipet or dropper
- conductivity probe (optional)

Procedure

Probeware version available in the Probeware Lab Manual.

On separate sheets of paper, draw two grids similar to the one below. Make each square 2 cm on each side. Place a reaction surface over one of the grids and place a few grains of each solid in the indicated places. Test each solid for conductivity. Then add 1 drop of water to each solid and test the wet mixture for conductivity. Be sure to clean and dry the conductivity leads between each test.

NaCl(*s*)	$MgSO_4$(*s*)
Na_2CO_3(*s*)	Table Sugar $C_{12}H_{22}O_{11}$
$NaHCO_3$(*s*)	Cornstarch $(C_6H_{12}O_6)n$
KCl(*s*)	KI(*s*)

Analyze

Using your experimental data, record the answers to the following questions in the space below your data table.

1. Electrolytes are compounds that conduct electric current in aqueous solution. Which compounds in your table are electrolytes? Which are not electrolytes?
2. Do any of these electrolytes conduct electric current in the solid form? Explain.
3. Are these ionic or covalent compounds? Classify each compound in the grid as ionic or covalent. For a compound to be an electrolyte, what must happen when it dissolves in water?

You're The Chemist

The following small-scale activities allow you to develop your own procedures and analyze the results.

1. **Analyze It!** When an ionic solid dissolves in water, water molecules attract the ions, causing them to come apart, or dissociate. The resulting dissolved ions are electrically charged particles that allow the solution to conduct electric current. The following chemical equations represent this phenomenon.

$$NaCl(s) \longrightarrow Na^+(aq) + Cl^-(aq)$$

$$Na_2CO_3(s) \longrightarrow 2Na^+(aq) + CO_3^{2-}(aq)$$

   Write a similar chemical equation for each electrolyte you tested. Draw diagrams to explain how the ions conduct electric current.
2. **Design It!** Obtain the following aqueous solutions: HCl, H_2SO_4, HNO_3, CH_3COOH, NH_3, NaOH, rubbing alcohol, and distilled water. Design and carry out an experiment to test their conductivity. Use your data to classify each substance as a strong electrolyte, weak electrolyte, or nonelectrolyte.
3. **Design It!** Test various liquids for conductivity. Try soft drinks, orange juice, pickle juice, and coffee. Which liquids are electrolytes?

2. No, because the ions are locked in a crystal lattice and cannot move.
3. Table sugar and cornstarch are covalent compounds. NaCl, $MgSO_4$, Na_2CO_3, $NaHCO_3$, KCl, and KI are ionic compounds. An electrolyte is a compound that dissociates into ions in solution.

You're The Chemist

1. $NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$
   $KCl(s) \rightarrow K^+(aq) + Cl^-(aq)$
   $MgSO_4(s) \rightarrow Mg^{2+}(aq) + SO_4^{2-}(aq)$
   $KI(s) \rightarrow K^+(aq) + I^-(aq)$
   Diagrams should be similar to Figure 15.9.
2. Test each solution. Strong electrolytes: HCl, H_2SO_4, HNO_3, NaOH; Weak electrolytes: CH_3COOH, NH_3; Nonelectrolytes: rubbing alcohol, distilled water
3. Strong electrolytes: soft drinks, pickle juice Weak electrolytes: orange juice, coffee

For Enrichment

L3

Have students design and carry out an experiment to determine whether the conductivity of an electrolyte depends on its concentration.