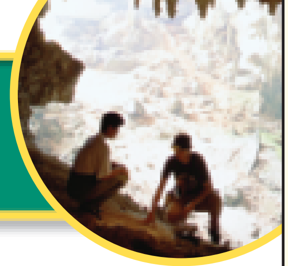
8.2 Solubility and Concentration



Reading Focus

Key Concepts
- How are solutions with different amounts of solute described?
- What factors determine the solubility of a solute?
- What are three ways to measure the concentration of a solution?

Vocabulary
- solubility
- saturated solution
- unsaturated solution
- supersaturated solution
- concentration
- molarity

Reading Strategy
Previewing Copy the table below. Before you read the section, rewrite the green topic headings as *how, why,* and *what* questions. As you read, write an answer to each question.

Question	Answer
What is solubility?	a.____?______
b.____?______	Solvent, temperature, and pressure
c.____?______	d.____?______

Have you ever prepared a pitcher of lemonade or iced tea? Fresh lemonade is a solution of water, lemon juice, and sugar. Water is the solvent. Lemon juice and sugar are the solutes.

You might be surprised at how much sugar can dissolve in water. However, there is a limit to the amount of sugar that can dissolve in a given amount of water. Once that limit is reached, no more sugar will dissolve, and you cannot make the solution taste any sweeter.

Solubility

The maximum amount of a solute that dissolves in a given amount of solvent at a constant temperature is called **solubility.** Solubilities are usually expressed in grams of solute per 100 grams of solvent at a specified temperature. Figure 8 lists the solubilities of some common substances in water at 20°C. Notice that table sugar is more soluble in water than table salt, which is more soluble than baking soda.

Solubility in 100 g of Water at 20°C

Compound	Solubility (g)
Table salt ($NaCl$)	36.0
Baking soda ($NaHCO_3$)	9.6
Table sugar ($C_{12}H_{22}O_{11}$)	203.9

Figure 8 At a given temperature, different solutes have different solubilities in water. **Calculating** *At 20°C, how much baking soda can dissolve in 200 grams of water?*

Knowing the solubility of a substance can help you classify solutions based on how much solute they contain. **Solutions are described as saturated, unsaturated, or supersaturated, depending on the amount of solute in solution.**

Section Resources

Print
- ***Laboratory Manual,*** Investigation 8B
- ***Reading and Study Workbook With Math Support,*** Section 8.2 and **Math Skill:** Calculating the Molarity of a Solution
- ***Math Skills and Problem Solving Workbook,*** Section 8.2
- ***Transparencies,*** Section 8.2

Technology
- ***Interactive Textbook,*** Section 8.2
- ***Presentation Pro CD-ROM,*** Section 8.2

Section 8.2

1 FOCUS

Objectives
8.2.1 **Define** solubility and **describe** factors affecting solubility.
8.2.2 **Classify** solutions as unsaturated, saturated, or supersaturated.
8.2.3 **Calculate** and **compare** and **contrast** solution concentrations expressed as percent by volume, percent by mass, and molarity.

Reading Focus

Build Vocabulary L2
Word-Part Analysis Ask students what words they know that have the prefix *super-*. *(Superhero, supersonic, supervise)* Give a definition of the word part. (*Super-* means "above.") Have students predict the meaning of *supersaturated,* given that *saturated* means "unable to hold more." (*Supersaturated* means "holding an amount over the normal level.")

Reading Strategy L2
a. The maximum amount of solute that dissolves in a given amount of solvent at a given temperature
b. What factors affect solubility?
c. How is the concentration of a solution expressed?
d. Percent by volume, percent by mass, molarity

2 INSTRUCT

Solubility

Build Science Skills L1
Calculating Have students answer the following questions: Suppose you add 60 g of lead nitrate, $Pb(NO_3)_2$, to 100 g of water at 20°C. After you stir it, 8 g of lead nitrate remains undissolved. **What is the solubility of lead nitrate at 20°C?** *(52 g per 100 g of water)* **If you add 44 g of table salt to 100 g of water at 20°C, how many grams will remain undissolved?** *(8 g)*
Logical

Answer to . . .

Figure 8 *19.2 g*

Solutions, Acids, and Bases 235

Build Reading Literacy

L1

Outline Refer to page **156D** in **Chapter 6**, which provides the guidelines for outlining.

Have students read the section. Then, have them use the headings as major divisions in an outline. Have students refer to their outlines when answering the questions in the Section 8.2 Assessment. **Verbal**

Address Misconceptions

L2

Some students think that when things dissolve they "disappear" and are no longer there. Challenge this misconception by reviewing the law of conservation of mass. Explain that mass is conserved in all ordinary chemical and physical processes, including solutes dissolving and coming out of solution. Have students examine the beakers on this page. Explain that even though you cannot see the solute in the first beaker, it is still there. Adding a crystal causes the solute to come out of solution and become visible again. **Visual**

Teacher Demo

Crystallization

L2

Purpose Students observe crystallization of a solute from a supersaturated solution.

Materials beakers, 200 g sodium acetate trihydrate, distilled water, spatula, hot plate (An alternative to sodium acetate trihydrate is sodium thiosulfate hydrate.)

Procedure The day before, prepare a supersaturated solution consisting of 200 g sodium acetate trihydrate dissolved in 20 mL distilled water. Heat the solution until all of the solute has dissolved. Allow to cool overnight. (Consider preparing multiple solutions in case one crystallizes while it is cooling.) Tell the class that you have prepared a supersaturated solution. Add a crystal of sodium acetate to the cooled solution.

Expected Outcome Upon adding the crystal, the solute will crystallize out of solution and form a solid mass. Be prepared in case the beaker breaks due to expansion of the contents. Have students stand a safe distance away, and do not let students pick up broken glass if the beaker does break. **Visual**

Figure 9 A supersaturated solution is analogous to the overloaded man shown above. One wrong step, and he might drop all the boxes. In the photo sequence below, a single crystal of sodium acetate, $NaC_2H_3O_2$, is added to a supersaturated solution of sodium acetate in water. The excess solute rapidly crystallizes out of the solution.

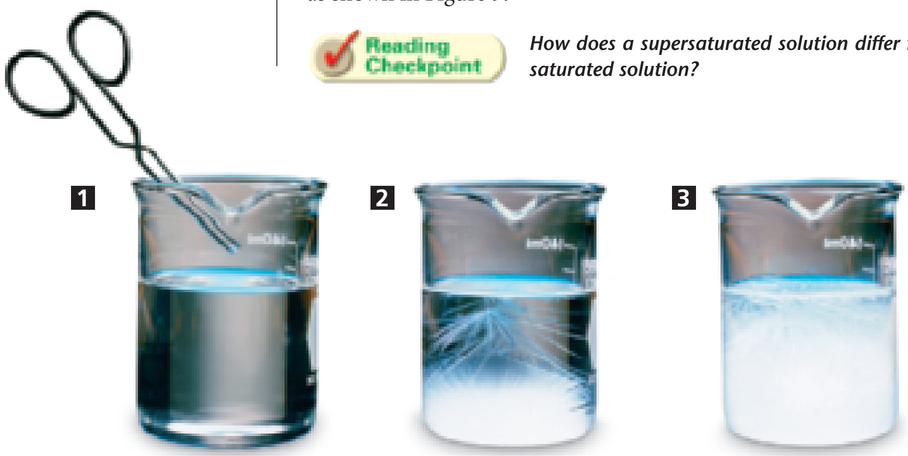
Saturated Solutions Table sugar is very soluble in water. At 20°C, 203.9 grams of table sugar will dissolve in 100 grams of water. What will happen if you try to dissolve more than 203.9 grams of table sugar in the same amount of water? The extra sugar will not go into solution. The solution is already saturated. A **saturated solution** is one that contains as much solute as the solvent can hold at a given temperature. When a solution is saturated, the solvent is "filled" with solute. If you add more solute, it will not dissolve.

Unsaturated Solutions A solution that has less than the maximum amount of solute that can be dissolved is called an **unsaturated solution.** For example, many of the beverages you drink are unsaturated solutions of sugar in water. If you sweeten your lemonade with a spoonful of sugar, and the sugar dissolves, you know that the solution is unsaturated. As long as the amount of solute is less than the solubility at that temperature, the solution is unsaturated.

Supersaturated Solutions Have you ever tried to carry more books than you can easily manage? If you're not careful, you'll drop them all because the load is so unstable. Similarly, a solvent can sometimes dissolve more solute than you might expect, based on its solubility. Solubility is given at a specific temperature, such as 20°C. If you heat a solvent above that temperature, more solute may dissolve. If you then carefully cool the solvent back to 20°C without jarring it, you may be able to keep the extra solute in solution.

A **supersaturated solution** is one that contains *more* solute than it can normally hold at a given temperature. Supersaturated solutions are very unstable. If even a tiny crystal of the solute falls into a supersaturated solution, the extra solute can rapidly deposit out of solution, as shown in Figure 9.

Reading Checkpoint *How does a supersaturated solution differ from a saturated solution?*



Customize for English Language Learners

Discussion
Students who are learning English can benefit from real-life examples that relate to science content. Encourage students to think of observations they may have made about factors that affect solubility. For example, perhaps they have seen that vinegar and oil salad dressing separates into layers. Also, they may have noticed that carbonated beverages taste "flat" when they are warm. Encourage students to share their observations with the class.

Factors Affecting Solubility

Have you ever had to clean oil or grease from your hands? If you rinse your hands in water alone, the oil remains on your hands. But if you use soapy water, you can easily rinse the oil off your hands. Oil is soluble in soapy water, but not in pure water. Solubility varies not only with the solvent used, but also with the conditions of the solution process. **Three factors that affect the solubility of a solute are the polarity of the solvent, temperature, and pressure.**

Figure 10 Generally, a solute is more likely to dissolve in a "like" solvent than an "unlike" solvent. **Classifying** ***How is saltwater an example of "like dissolving in like"?***

Solvent-Solute Combinations

Solvent Type	Solute Type	Will Solution Form?
Polar	Polar (or ionic)	More likely
Polar	Nonpolar	Not likely
Nonpolar	Polar (or ionic)	Not likely
Nonpolar	Nonpolar	More likely

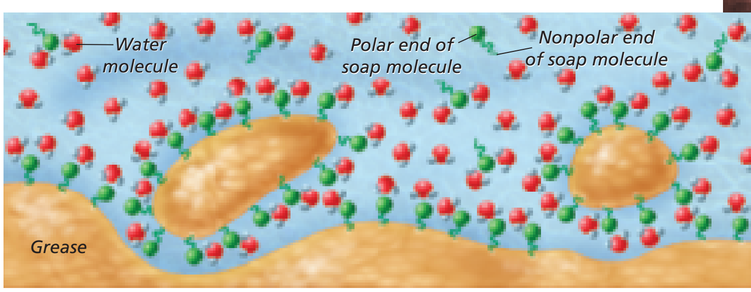
Polar and Nonpolar Solvents Oil does not dissolve in water because oil molecules are nonpolar and water molecules are polar. A common guideline for predicting solubility is "like dissolves like." Solution formation is more likely to happen when the solute and solvent are either both polar or both nonpolar. Figure 11 illustrates how soapy water dissolves oil. A soap molecule has a polar end, which attracts water molecules, and a nonpolar end, which attracts oil. The soap molecules break up the oil into small droplets that are soluble in water.

Temperature When you add a large amount of sugar to cold tea, only a small amount dissolves. If you add the same amount of sugar to the same amount of hot tea, more sugar will dissolve. In general, the solubility of solids increases as the solvent temperature increases.

When a glass of cold water warms up to room temperature, bubbles form on the inside of the glass. These bubbles are gases that were dissolved in the water. They come out of the solution as the water temperature rises. Unlike most solids, gases usually become less soluble as the temperature of the solvent increases.

Pressure How do manufacturers produce a carbonated beverage? They use pressure to force carbon dioxide (CO_2) to dissolve in the liquid. Increasing the pressure on a gas increases its solubility in a liquid. The pressure of CO_2 in a sealed 12-ounce can of soda at room temperature can be two to three times atmospheric pressure.

Figure 11 Soaps and detergents are used to remove grease and oil stains. Soap molecules form attractions to both polar water molecules and nonpolar oil molecules. As the water flows away, it carries the oil with it.



Factors Affecting Solubility

Build Science Skills L2

Measuring

ACTIVITY

Purpose Students approximate the solubility of sodium chloride at two different temperatures.

Materials For each group of students: 2 400-mL beakers, water, ice, hot plate, 2 70-mL test tubes, salt, scoop, 2 stirring rods, thermometer, weigh paper, balance, test tube tongs

Class Time 15–30 minutes

Procedure Have students make a 0°C ice water bath in one beaker. Then, have students heat water in the other beaker to 100°C. Have students measure 50 mL of room-temperature water into each test tube. Have them place one test tube in each bath. When the water in each test tube reaches 0°C and 100°C, respectively, have students add 10 g of salt to each test tube. They should then add salt in 1 g increments, stirring until all the salt is dissolved. Have them add salt until it no longer dissolves in the water. Have students record the total mass of salt added to each sample.

Safety Remind students to use caution when handling glassware and hot objects. Do not allow students to stir the solutions with the thermometers.

Expected Outcome Solubility of NaCl is 36 g in 100 mL at 0°C and 40 g in 100 mL at 100°C. **Kinesthetic, Logical**

Use Visuals L1

Figure 11 Have students examine Figure 11. Ask, **Which part of the soap molecule is polar?** *(The part represented by a sphere)* **Which substance is the polar end of the soap molecule attracted to?** *(Water)* **Visual**

Facts and Figures

Micelles and Soap When the nonpolar ends of soap molecules clump together in water in such a way that their polar ends radiate outward, they make a ball-shaped formation called a *micelle.* When a mixture of water and soap is mixed, the small micelles become suspended in the water. Because the micelles scatter light, soapy water is cloudy. The process for making soap is discussed in Section 8.3.

Answer to . . .

Figure 10 *NaCl contains positive and negative ions. Water contains atoms that have partial positive and negative charges.*

Reading Checkpoint *A supersaturated solution contains more solute than it can normally hold at a given temperature, while a saturated solution contains as much solute as the solvent can hold at a given temperature.*

Section 8.2 (continued)

Concentration of Solutions

Build Science Skills

L2

Interpreting Diagrams Have students examine the label in Figure 12. Then, have students calculate the volume of real cranberry juice in 300 mL of Smith's Cranberry Juice. *(81 mL)*
Logical

Problem-Solving Activity

Putting the Fizz Into Carbonated Beverages

L2

Defining the Problem The problem is how to find a supplier of carbon dioxide for adding carbonation to beverages and how to keep the levels of carbon dioxide in the beverages constant.

Organizing Information Examples of reactions that create carbon dioxide include reacting vinegar and baking soda, fermentation in yeast, cellular respiration in plants and animals, and combustion of carbon compounds. Students will need to find out what kinds of manufacturers produce large amounts of carbon dioxide gas. They will also need to find out how temperature, pressure, and type of solvent affect the solubility of gases.

Creating a Solution Students may choose a gas or petroleum company as a supplier. (CO_2 is also a by-product in fertilizer and fermentation processes.) Two factors that affect solubility of a gas in a liquid are temperature and pressure.

Presenting Your Plan Acceptable proposals should include reasons for choosing the supplier, such as low cost, facility of distribution, or quality of product. To regulate carbonation levels, the factory can manipulate the temperature and pressure at which CO_2 dissolves. The solubility of a gas increases as pressure increases and temperature decreases.
Logical

For Extra Help

L1

Encourage students to be creative in their research. They do not have to limit their research to the library or Internet. Students may want to call a local restaurant that serves carbonated fountain drinks to find out where they get their carbon dioxide. They could also call or visit a local bottling company.
Interpersonal

Figure 12 The juice squeezed from fruit is already a solution. Most bottled or canned juices are less-concentrated solutions of fruit juices, made by adding water. Percent by volume is a way to measure the concentration of one liquid dissolved in another.

Concentration of Solutions

How do you take your tea? Some people prefer their tea very concentrated, so they leave the tea bag in hot water for several minutes. Other people immerse the tea bag for only a minute or two, because they prefer their tea much less concentrated, or dilute. The resulting solutions differ in how much solute is present. The **concentration** of a solution is the amount of solute dissolved in a specified amount of solution. **Concentration can be expressed as percent by volume, percent by mass, and molarity.**

Percent by Volume Fruit juice bottles often have labels, such as the one in Figure 12, that state the percentage of "real juice" in the bottle. For example, if 27 percent of the total volume of liquid is fruit juice, the concentration of fruit juice is 27 percent by volume. Use the following equation to calculate concentration as a percent by volume.

$$\text{Percent by volume} = \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100\%$$

Percent by Mass Concentration expressed as a percent by mass is more useful when the solute is a solid. Percent by mass is the percent of a solution's total mass that is accounted for by a solute.

$$\text{Percent by mass} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100\%$$

Suppose you have 100 grams of a solution of sugar in water. After allowing the water to evaporate, 15 grams of sugar remain. So, the concentration of sugar in the solution was 15 percent by mass.

Problem-Solving Activity

Putting the Fizz Into Carbonated Beverages

You have been asked to find a supplier of carbon dioxide for a factory that produces carbonated beverages. You also must find out how to regulate the carbonation levels of the beverages produced.

Defining the Problem Describe your task in your own words.

Organizing Information Find examples of chemical reactions that produce carbon dioxide. What industries use such reactions? In addition, list and review the general factors affecting solubility.

Creating a Solution Choose a business or industry to supply your factory with carbon dioxide. Figure out how the solubility of a gas in a liquid varies under different conditions.

Presenting Your Plan Write a proposal to the manager of your factory. Explain your choice of a carbon dioxide supplier, and describe how to regulate carbonation levels of the beverages produced.

Facts and Figures

Molality Another way of describing solution concentration is called *molality*. Molality is defined as the number of moles of solute per kilogram of solvent, and is represented by a lower case *m*. The advantage of using molality over molarity to describe concentrations is that molality does not involve volume and thus does not change with changes in temperature. For this reason, molality is often used in calculations involving colligative properties (such as freezing point depression and boiling point elevation) that are observed over a range of temperatures.

Molarity Suppose you add 10 grams of sodium chloride to 100 milliliters of water. Then, in a different container, you add 10 grams of table sugar to 100 milliliters of water. Do the two solutions contain the same number of solute particles? No, they do not, because the two different solutes have different molar masses.

To compare the number of solute particles in solutions, chemists often use moles to measure concentration. Recall that a mole is the amount of a substance that contains approximately 6.02×10^{23} particles of that substance. **Molarity** is the number of moles of a solute dissolved per liter of solution. Use the following equation to calculate molarity.

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Liters of solution}}$$

Figure 13 A 1M NaCl solution contains 58.5 grams of NaCl per liter of solution. **Calculating** ***How much solute would you need to make to make one liter of a 0.2-molar solution of sodium chloride in water?***

To make a 1-molar (1M) solution of sodium chloride in water, first calculate the molar mass of the solute. Sodium chloride, NaCl, has a molar mass of 58.5 grams. If 58.5 grams of sodium chloride is mixed with enough water to make one liter of solution, the resulting solution is 1-molar.

Table sugar, $C_{12}H_{22}O_{11}$, has a molar mass of 342 grams. To make a 1-molar solution of table sugar in water, 342 grams of table sugar must be added to enough water to make one liter of solution.

Section 8.2 Assessment

Reviewing Concepts

1. What terms are used to describe solutions with different amounts of solute?
2. List three factors that affect solubility.
3. What are three ways to measure the concentration of a solution?
4. What is the effect of pressure on the solubility of a gas?
5. Compare a 2-molar solution of salt water with a 2-molar solution of sugar water. How are they similar? How are they different?

Critical Thinking

6. **Problem Solving** How would you figure out the solubility of an unknown solid in water?
7. **Inferring** Despite the name, dry cleaning does involve the use of liquid solvents. Why would a dry cleaner use both polar and nonpolar cleaning solvents?
8. **Calculating** Use the periodic table to find the mass of potassium nitrate (KNO_3) needed to make 1 liter of 1-molar solution.

Writing in Science

Compare and Contrast Paragraph Write a paragraph comparing the different ways that concentration can be expressed. (*Hint*: Describe what quantities must be measured for each type of concentration calculation.)

Section 8.2 Assessment

1. Unsaturated, saturated, and supersaturated
2. Polarity of the solute and solvent, temperature, and pressure
3. Percent by volume, percent by mass, and molarity
4. It increases the solubility of a gas.
5. The molar concentrations of the solutions are identical; each contains the same number of moles of solute per liter of solution. The solutions differ in percent by mass concentration; the sugar water solution contains more grams of solute per gram of solution than the saltwater solution.
6. Measure the mass of a beaker containing 100 g of water. Add the unknown solid, while stirring, until no more dissolves. Measure the mass of the beaker and its contents again. Measure the temperature of the solution. The difference in mass is the solubility of the unknown solid in grams per 100 g of water.
7. To remove both polar and nonpolar stains
8. 101.1 g

Build Math Skills L1

Calculating With Significant Figures Have students solve the following problems and express their answers using the correct significant figures. **What is the molarity of a solution consisting of 111 g of $CaCl_2$ dissolved in enough water to make 2.0 L of solution?** *(0.50 M)* **What volume of a 2.00-M solution KI in water contains 5.96 moles of solute?** *(2.98 L)*
Logical

Direct students to the **Math Skills** in the **Skills and Reference Handbook** at the end of the student text for additional help.

3 ASSESS

Evaluate Understanding L2

Have students write three math problems (with solutions) based on the equations given for percent by volume, percent by mass, and molarity. Have students take turns analyzing and solving the problems in class. Note that even incorrectly worded problems are useful because students can be asked to identify and correct the errors.

Reteach L1

Use the table on p. 235 to review solubility. Have students describe how much solute would be in an unsaturated, saturated, and supersaturated solution of each type of solute given in the table. For example, any amount less than 36.0 g of sodium chloride in 100 g of water would be an unsaturated solution.

Writing in Science

Concentration can be expressed in at least three different ways—percent by volume, percent by mass, and molarity. To determine percent by volume, you need to find the volume of solute and the volume of solution. To determine percent by mass, you need to find the mass of solute and the mass of solution. To determine molarity, you need to find the moles of solute and the volume of solution (in liters).

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 8.2.

Answer to . . .

Figure 13 *11.7 g*