

# Solubility and Concentration

## KEY IDEAS

As you read this section, keep these questions in mind:

- What is solubility?
- What happens when you add more solute to a saturated solution?
- How do you describe how much solute is in a solution?

## What Is Solubility?

Have you ever mixed a large amount of sugar in a glass of tea? You may have found that only some of the sugar dissolved. Some of the sugar may not have dissolved, no matter how much you stirred the water. Sugar is *soluble* in water, which means that it can dissolve. However, once a certain amount of sugar has been added to water, no more sugar will dissolve.

The **solubility** of a substance is the maximum amount that can dissolve in 100 g of solvent at a certain temperature. For example, 36 g of salt is the maximum amount that can dissolve in 100 g of water at 20 °C. Some substances, such as acetic acid and ethanol, are completely soluble in water in any amount. Other substances, such as AgCl, are almost completely insoluble in water.



No matter how much you heat, shake, or stir a mixture of oil and water, the oil will not dissolve.

## READING TOOLBOX

**Outline** As you read, make an outline of this section. Use the headers to help you organize the main points.

## LOOKING CLOSER

**1. Describe** Describe the solubility of oil in water.

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## DIFFERENT SUBSTANCES, DIFFERENT SOLUBILITIES

You may think that compounds with some of the same elements have similar solubilities. However, the solubilities of related compounds can vary greatly. Use the table on the next page to compare the solubilities of compounds that contain sodium. Why are their solubilities so different?

**SECTION 3** Solubility and Concentration *continued*

Solubilities of Some Ionic Compounds in Water		
Compound	Formula	Solubility in grams per 100 g of H <sub>2</sub> O at 20 °C
Calcium chloride	CaCl <sub>2</sub>	75
Calcium fluoride	CaF <sub>2</sub>	0.0015
Calcium sulfate	CaSO <sub>4</sub>	0.32
Iron (II) sulfide	FeS	0.0006
Silver chloride	AgCl	0.00019
Silver nitrate	AgNO <sub>3</sub>	216
Sodium chloride	NaCl	35.9
Sodium fluoride	NaF	4.06
Sodium iodide	NaI	178
Sodium sulfide	Na <sub>2</sub> S	26.3

**LOOKING CLOSER**

**2. Compare** Which compound is more soluble in water—sodium fluoride or sodium iodide?

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**Critical Thinking**

**3. Infer** How does the strength of attraction between Na<sup>+</sup> and F<sup>-</sup> compare to the attraction between Na<sup>+</sup> and I<sup>-</sup>? Explain your answer.

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The solubility of a substance depends on the strength of attractions between particles of the solvent and solute. In a highly soluble substance, attractions between solute particles are weak compared to attractions between solvent and solute particles.

**What Is Concentration?**

How could you compare a solution with one teaspoon of salt to a solution with one tablespoon of salt? You would need to indicate that the solutions have different amounts of solute. The amount of a solute dissolved in a particular amount of solution is known as **concentration**. A *concentrated* solution has a large amount of solute. A *dilute* solution has a small amount of solute.

**How Is Concentration of a Solution Expressed?**

The terms *concentrated* and *dilute* can help you compare two solutions. However, they do not tell you how much solute is in the solution. Scientists express the amount of solute in a solution, or concentration, in several ways. One common expression of concentration is molarity. **Molarity** is the number of moles of solute per liter of solution. ✓

**READING CHECK**

**4. Identify** What does molarity express?

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$$\text{Molarity (M)} = \frac{\text{moles of solute}}{\text{liters of solution}} = \frac{\text{mol}}{\text{L}}$$

A 1.0 M solution is read as “one molar solution.”

**SECTION 3** Solubility and Concentration *continued***CALCULATING MOLARITY**

What is the molarity of a 0.500 L sucrose ( $C_{12}H_{22}O_{11}$ ) solution that contains 124 g of solute?

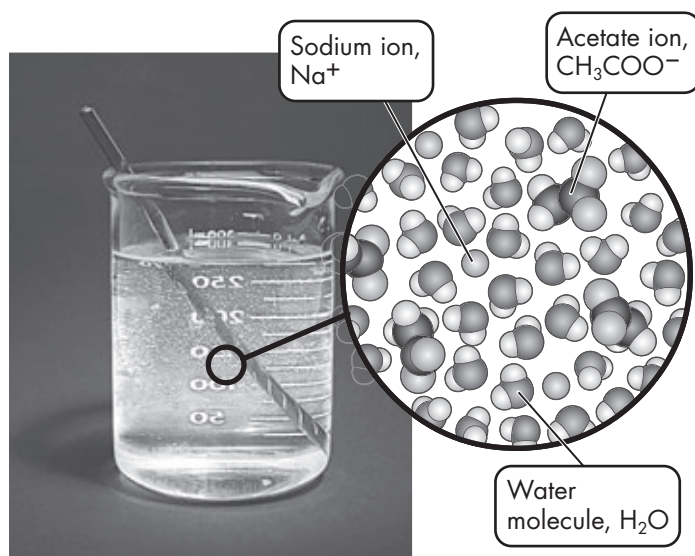
<b>Step 1:</b> List the given and unknown values.	<b>Given:</b> mass of sucrose, $m = 124 \text{ g}$  volume of solution, $V = 0.500 \text{ L}$	<b>Unknown:</b> molarity, $M$
<b>Step 2:</b> Write the equations.	$\text{moles } C_{12}H_{22}O_{11} = \frac{\text{mass of } C_{12}H_{22}O_{11}}{\text{molar mass of } C_{12}H_{22}O_{11}}$ $\text{molarity} = \frac{\text{moles of } C_{12}H_{22}O_{11}}{\text{liters of solution}}$	
<b>Step 3:</b> Insert the known values and solve for the unknown value.	$\text{molar mass } C_{12}H_{22}O_{11} = 342 \text{ g/mol}$ $\text{moles } C_{12}H_{22}O_{11} = \frac{124 \text{ g}}{342 \text{ g/mol}} = 0.362 \text{ mol}$ $\text{molarity} = \frac{0.362 \text{ mol } C_{12}H_{22}O_{11}}{0.500 \text{ L solution}} = 0.724 \text{ M}$	

**Math Skills**

**5. Calculate** What is the molarity of 525 g of lead(II) nitrate,  $Pb(NO_3)_2$ , dissolved in 1,250 mL of solution?  
Tip: When volume is given in mL, you must change milliliters to liters. To do this, multiply by 1 L/1,000 mL.

**What Is an Unsaturated Solution?**

If you add a small amount of sugar to water and stir, the sugar will probably dissolve. If you add another small amount, it will probably dissolve as well. The solution is unsaturated. An **unsaturated solution** contains less solute than the maximum amount that could dissolve in the solvent.



This sodium acetate solution is unsaturated. A solution is unsaturated as long as more solute can dissolve in it.

**LOOKING CLOSER**

**6. Infer** How will the concentration of  $Na^+$  change if you add more sodium acetate?

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**SECTION 3** Solubility and Concentration *continued*

### What Is a Saturated Solution?

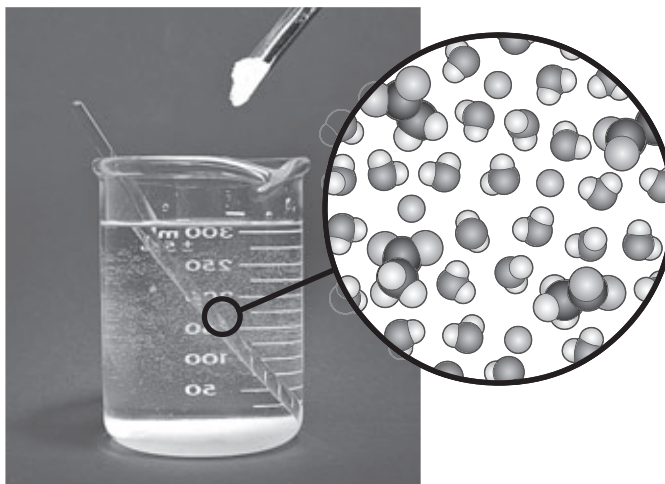
When you add the maximum amount of solute that will dissolve in a solvent, you have a **saturated solution**. In a saturated solution, the dissolved solute is in *equilibrium* with undissolved solute. If you add more solute, some of it will dissolve, but other solute particles will settle out of the solution. Thus, the total amount of dissolved solute stays the same. ✓

**READING CHECK**

**7. Describe** If you add more solute to a saturated solution, what will happen to the total amount of dissolved solute?

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This sodium acetate solution is saturated. No more sodium acetate will dissolve in the solution.

### What Is a Supersaturated Solution?

Recall that solubility of a substance refers to how much of it will dissolve in a solvent at a certain temperature. If the temperature of the solvent changes, the solubility of a solute can change. The solubility of most solid solutes increases as the temperature of the solution increases. ✓

**READING CHECK**

**8. Describe** How does the solubility of solid solutes change as temperature of the solution increases?

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If you heat a saturated solution of sodium acetate, more sodium acetate will dissolve. If you let the solution cool, the extra solute you added may stay dissolved. Then the solution is supersaturated. A **supersaturated solution** holds more solute than it normally would at a lower temperature.

**LOOKING CLOSER**

**9. Describe** Complete the table to describe three types of solutions.

Type of solution	Description
Unsaturated	
Saturated	Contains the maximum amount of solute that will dissolve in the solvent
Supersaturated	

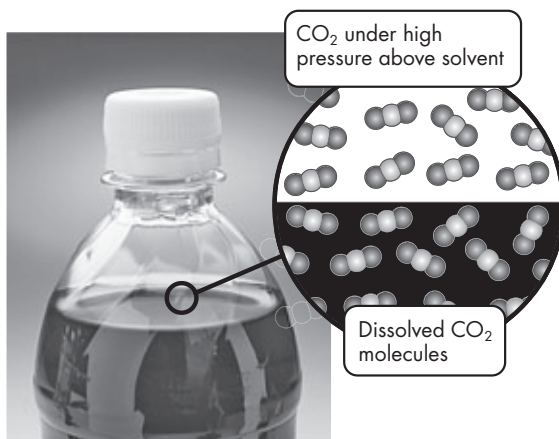
**SECTION 3** Solubility and Concentration *continued*

## How Do Temperature and Pressure Affect Solubility of Gases?

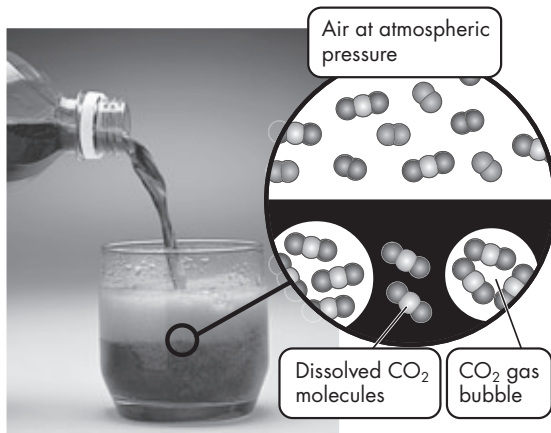
The solubility of a solid generally increases as the temperature of the solvent increases. However, the solubility of gases generally decreases as the temperature of the solvent increases. Carbonated beverages contain carbon dioxide, CO<sub>2</sub>, gas dissolved in water. Because gases are less soluble in warmer solvents, less CO<sub>2</sub> stays dissolved in warm soda than in cold soda. You may have noticed this if you've ever sipped a warm, flat soda. ✓

Solubility of gases also depends on pressure. Carbon dioxide is dissolved in soda under high pressure. When you open the bottle, gas pressure decreases. Soda fizzes as the carbon dioxide comes out of solution.

The pressure inside the bottle is higher than the pressure outside the bottle. At this high pressure, carbon dioxide gas is dissolved in water.



When you open the bottle, the pressure inside the bottle decreases. Bubbles form as carbon dioxide comes out of solution.



The solubility of gases is important to scuba divers. Increased pressure underwater causes more nitrogen gas to dissolve in their blood. If divers returns to the surface too quickly, nitrogen comes out of solution and forms bubbles in their blood vessels. This condition is known as the bends. It is very painful and can be dangerous.

**READING CHECK**

**10. Describe** How does an increase in the temperature of a solution affect the solubility of a gas?

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**LOOKING CLOSER**

**11. Explain** How does pressure affect the solubility of a gas?

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**12. Infer** Will more bubbles come out of a warm soda or a cold one? Explain your answer.

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# Section 3 Review

## SECTION VOCABULARY

**concentration** the amount of a particular substance in a given quantity of a mixture, solution, or ore

**molarity** a concentration unit of a solution expressed as moles of solute dissolved per liter of solution

**saturated solution** a solution that cannot dissolve any more solute under the given conditions

**solubility** the ability of one substance to dissolve in another at a given temperature and pressure; expressed in terms of the amount of solute that will dissolve in a given amount of solvent to produce a saturated solution

**supersaturated solution** a solution that holds more dissolved solute than is required to reach equilibrium at a given temperature

**unsaturated solution** a solution that contains less solute than a saturated solution does and that is able to dissolve additional solute

**1. Explain** If you add salt continuously to a glass of water, eventually some salt will remain at the bottom. Why?

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**2. Compare** Use the chart below to compare the solubilities of silver nitrate and silver chloride in water. Explain why their solubilities are different.

Compound	Formula	Solubility in grams per 100 g of H <sub>2</sub> O at 20 °C
Silver nitrate	AgNO <sub>3</sub>	216
Silver chloride	AgCl	0.00019

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**3. Calculate** What is the molarity of 2 mol of calcium carbonate, CaCl<sub>2</sub>, dissolved in 1 L of solution?

**4. Explain** Why do scientists typically use molarity to express the concentration of a solution rather than the words *dilute* and *concentrated*?

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