SECTION 8.1

Classifying Solutions

Key Terms

solution
solvent
solute
aqueous solution
solubility
saturated solution
unsaturated solution
supersaturated solution

You encounter a great variety of solutions in your daily life. For example, you likely know that the tea in **Figure 8.1** is a solution. However, are you aware that the stainless steel in the spoon is also a solution? A **solution** is a homogeneous mixture of two or more substances. *Homogeneous* means that the mixture has a uniform composition throughout. Once a solution has been fully mixed, the substances in it remain evenly distributed throughout the solution. Solutions are homogeneous even at the microscopic scale. All samples of a given solution, no matter how small, contain the same substances in the same proportions.

For example, each drop in a cup of tea contains the same proportions of water and dissolved substances that give the coffee its colour and flavour. In another pot of tea, however, the proportions will likely be somewhat different. If the tea is stronger, the proportions of the substances from the tea leaves will be greater. But, again, each drop in a cup of the stronger tea will have the same proportions of water and other substances as any other drop of tea in that cup. Similarly, the proportions of metals in solution in a stainless steel spoon may vary from one manufacturer to another. However, these proportions are consistent throughout any particular stainless steel spoon.

Figure 8.1 This cup contains two solutions. The coffee is an aqueous solution, and the stainless steel spoon is a solution of metals.

solution a homogeneous mixture of two or more substances

solvent the component of a solution that is present in the greatest amount

solute a substance that is dissolved in a solvent

aqueous solution a solution that contains water

The substance that is present in the greatest amount in a solution is called the **solvent**. Any other substance in the solution is a **solute**. In a cup of coffee, water is the solvent and all the different substances from the coffee beans are solutes. Solutions that contain water, such as coffee and tea, are called **aqueous solutions**. This term comes from the Latin word *aqua*, meaning water. Aqueous solutions may be coloured or colourless, but they are always clear. Not all solutions have water as a solvent. In a stainless steel spoon, for example, the solvent and the solutes are metals.

Types of Solutions

A solution can be formed from a solvent and a solute in any state: solid, liquid, or gas. Thus, nine different types of solutions are possible. These different types of solutions are shown in **Table 8.1**.

Table 8.1 Examples of Solutions in Different States of Matter

Solid Dissolved in Solid	Solid Dissolved in Liquid	Solid Dissolved in Gas
The structural steel that is used to construct buildings usually contains from 0.2 to 1.5% carbon dissolved in iron.	On average, 1 L of seawater contains about 19 g of chloride ions, 11 g of sodium ions, and 5 g of other solutes, including magnesium, sulfate, calcium, and potassium ions.	Molecules of naphthalene or paradichlorobenzene separate from the surface of a mothball to form a solution with air. The vapour from a mothball is toxic to moths and many other organisms.
		
Liquid Dissolved in Solid	**Liquid Dissolved in Liquid**	**Liquid Dissolved in Gas**
Liquid mineral spirits or liquid toluene are dissolved in solid wax to make the wax easier to apply.	Antifreeze liquids are mixed with water in car radiators to form solutions with low freezing points.	Humidity results from water dissolving in the air. A hygrometer is a tool that measures humidity.
		
Gas Dissolved in Solid	**Gas Dissolved in Liquid**	**Gas Dissolved in Gas**
Most ice contains a small amount of dissolved air.	When a bottle of a carbonated beverage is opened, some of the dissolved carbon dioxide bubbles out of the solution.	Natural gas is a solution of methane gas with ethane, nitrogen, carbon dioxide, and other gases dissolved in it.
		

Solubility and Saturation

solubility the maximum amount of solute that will dissolve in a given quantity of solvent at a specific temperature

Substances vary in how readily they will dissolve in a solvent. The **solubility** of a substance is defined in terms of the maximum amount of solute that will dissolve in a given quantity of solvent at a specific temperature. Solubility in water is often stated in terms of the mass, in grams, of solute that will dissolve in a decilitre (100 mL) of water at 20°C. For example, the solubility of table salt, NaCl(s), in water is 35.9 g/100 mL at 20°C, whereas the solubility of oxygen, $O_2(g)$, is only 0.0009 g/100 mL at 20°C.

Qualitatively, solubility can be described using the terms described in the bulletted points below. **Figure 8.2** applies these terms to the solubilities of three ionic compounds:

- A solute is described as *soluble* if more than 1 g will dissolve in 100 mL of solvent. Thus, table salt is soluble in water.
- A solute is described as *sparingly* (or *slightly*) *soluble* if it has a solubility between 0.1 g and 1 g per 100 mL of solvent.
- A solute is described as *insoluble* if less than 0.1 g of a solute will dissolve in 100 mL of solvent. In chemistry, the term "insoluble" should not be taken literally. It does not necessarily mean that no solute at all will dissolve. For example, oxygen is described as being insoluble in water, but the small amount that does dissolve is tremendously important to life in oceans, lakes, and rivers.

Figure 8.2 At 20°C, sodium chloride is soluble in water (35.9 g/100 mL), calcium hydroxide is sparingly soluble in water (0.183 g/100 mL), and calcium carbonate is insoluble (about 0.005 g/100 mL).

Saturated, Unsaturated, and Supersaturated Solutions

saturated solution a solution that cannot dissolve more solute

unsaturated solution a solution that could dissolve more solute

supersaturated solution a solution that contains more dissolved solute than a saturated solution at the same temperature

A **saturated solution** cannot dissolve any more solute. To determine whether a solution is saturated, you can compare the amount of dissolved solute per unit volume of the solution with the solubility of the solute. Therefore, the presence of solute that will not dissolve in a solution indicates that the solution is saturated. For example, dissolving 36 g of table salt in 100 mL of water at 25°C forms a saturated solution. If 40 g of table salt is added to 100 mL of water at 25°C, then 4 g of the salt will remain undissolved. In contrast, an **unsaturated solution** of any solute will dissolve more of the same solute if it is added to the solution. A **supersaturated solution** contains more dissolved solute than a saturated solution at the same temperature. A change in temperature can cause a saturated solution to become supersaturated. For example, many saturated solutions of a solid dissolved in water become supersaturated when cooled. Conversely, most saturated solutions of a gas in a liquid become supersaturated when heated.

Supersaturated solutions are unstable. If a crystal of solute is added to a supersaturated liquid solution of the solute, the excess solute will precipitate, leaving the solution saturated. Similarly, a disturbance in a supersaturated solution of a vapour in air can cause the vapour to condense into droplets.

Learning Check

1. Some sunscreens contain finely powdered zinc oxide, suspended in a lotion or ointment. Explain why these sunscreens are not solutions of zinc oxide.
2. Dry air contains about 78 percent nitrogen, 21 percent oxygen, and 0.9 percent argon, plus much smaller percentages of several other gases. Which gas is the solvent in air? Explain why.
3. Give three examples of aqueous solutions: one with a solid solute, one with a liquid solute, and one with a gas solute.
4. Water that condenses from air in the gas tank of a car tends to collect at the bottom of the tank or at the lowest point in the fuel line. What does this information indicate about the solubility of water in gasoline?
5. Can an insoluble compound form a saturated solution? Explain your reasoning.
6. When you open a can of soft drink, is the soft drink a supersaturated solution? Explain your reasoning.

Activity 8.1 Unsaturated, Saturated, and Supersaturated Solutions

In this activity, you will make qualitative observations of the properties of unsaturated, saturated, and supersaturated solutions of sodium thiosulfate pentahydrate, $Na_2S_2O_3 \cdot 5H_2O(s)$.

Safety Precautions

- Wear safety eyewear throughout this activity.
- When you are heating a test tube, keep the mouth of the test tube pointed away from you and other students.
- Tie back loose hair and clothing.
- Wash your hands after completing this activity.
- Use EXTREME CAUTION when you are near an open flame.

Materials

- 2 mL of distilled water
- 15 g of sodium thiosulfate pentahydrate, $Na_2S_2O_3 \cdot 5H_2O(s)$
- 10 mL graduated cylinder
- test tube
- scoopula
- test-tube rack
- stirring rod
- wooden test-tube holder
- Bunsen burner secured to a retort stand
- beaker of cold water
- watch or timer

Procedure

1. Use the 10 mL graduated cylinder to pour 2 mL of distilled water into the test tube. Add about a quarter of a scoopula of sodium thiosulfate pentahydrate crystals. Place the test tube in a test-tube rack. Stir to dissolve the crystals.
2. Gradually add more sodium thiosulfate pentahydrate crystals to the solution, stirring as you add them, until no more dissolve. Feel the side of the test tube as you stir.
3. Add the rest of the sodium thiosulfate pentahydrate, except for a few crystals. Using the test-tube holder, gently heat the solution over the Bunsen burner. Do not boil the solution. Move the test tube from side to side in the flame so that the heat is not concentrated on the bottom of the test tube. Note how many of the added crystals dissolve.
4. Place the warm test tube into a beaker of cold water, and allow it to cool for about 3 min. Record the appearance of the cooled solution.
5. Add one or two crystals of sodium thiosulfate to the cooled solution. Feel the side of the test tube again. Record your observations.
6. Dispose of the solution and clean the equipment as directed by your teacher.

Questions

1. At what step in the Procedure did the solution become saturated? Explain your reasoning.
2. Explain the high solubility of sodium thiosulfate pentahydrate in water. (**Hint:** Think about the formula of this compound.)
3. Explain what happened in step 5.
4. Suppose that you are given a clear solution in a test tube along with a small sample of the solid solute. How could you determine whether the solution is unsaturated, saturated, or supersaturated?

Section 8.1 REVIEW

Section Summary

- A solution is a completely homogeneous mixture. It can be formed from a solute and a solvent in any initial state: solid, liquid, or gas.
- The solvent in a solution is the substance present in the greatest amount. Solutes are anything dissolved in a solvent.
- The solubility of a substance is stated in terms of the maximum amount of solute that dissolves in a given quantity of solvent at a specific temperature.
- A solution can be classified as unsaturated, saturated, or supersaturated, depending on the amount of dissolved solute per unit volume of solution.

Review Questions

1. K/U A solution can have more than one solute.
   a. Give an example of a solution that has more than one solute.
   b. Explain why a solution can have many solutes, but only one solvent.

2. K/U Explain why stainless steel, seawater, and air are all considered solutions.

3. A Some processes for making coffee leave tiny particles of ground coffee beans suspended in the coffee when it is served. Can these particles be considered a solute if they are evenly distributed throughout the cup of coffee? Explain.

4. K/U Explain the difference between a solvent and a solute.

5. K/U Distinguish between the terms "insoluble" and "unsaturated." Give an example to illustrate each term.

6. A In a decorative lava lamp, a clear glass jar contains coloured water and a mixture of wax and carbon tetrachloride. Heat from a light bulb in the base of the lamp melts and expands the wax mixture, causing it to form blobs that change shape as they slowly float to the top of the lamp. The wax blobs then cool and sink back down again.
   a. Identify the two solutions in a lava lamp.
   b. Explain why a lava lamp would not work if the solutions dissolved in each other.

7. K/U A liquid can be a pure substance, a solution of two liquids, a solution of a gas in a liquid solvent, or a solution of a solid in a liquid solvent. Give one example of each type of liquid.

8. T/I Suppose that you are given two unlabelled beakers. One beaker contains water, and the other beaker contains a solution of ethanol and water. How could you safely determine which beaker contains just water?

9. T/I If a jar of honey sits for a long time, sugar may crystallize in the jar. Describe two possible causes for this crystallization.

10. A Describe two processes that could cause water vapour in the atmosphere to condense and form clouds.

11. C Draw a flowchart that shows a procedure for determining whether an aqueous solution is unsaturated, saturated, or supersaturated.

12. A About half of all the sodium chloride that is processed worldwide is used to melt snow and ice on roads. Explain how the solubility of sodium chloride is related to environmental concerns about this use.

13. C Two beakers in a laboratory are full of white crystals. One beaker contains sodium chloride, and the other beaker contains sucrose. The labels have come off the beakers, however, so you are not sure which is which. A chemistry handbook lists the solubility of sodium chloride in water as 36 g/100 mL at 25°C and the solubility of sucrose in water as 200 g/100 mL at 25°C. Write a procedure that describes how to safely identify the two chemicals.

14. K/U Explain why all supersaturated solutions are unstable.

15. T/I At 25°C, 35 g of solute A makes a saturated solution when dissolved in 100 mL of water, and 26 g of solute B makes a saturated solution when dissolved in 80 mL of water. Which solute is more soluble? Explain your reasoning.