CHAPTER 7 SOLUBILITY AND REACTIONS

Reflect on your Learning

(Page 312)

1. Most of the liquids that we encounter in the home are solutions. This could be tested by cooling, evaporating, or smelling — anything that would encourage the components of a solution to separate.
2. Dissolving rate is usually speeded up by stirring, warming the solution, or finely dividing (grinding) the solute. If excess solid remains after prolonged stirring, probably no more solute will dissolve.
3. Evidence for a reaction might be colour change, formation of a precipitate, formation of a gas, or a noticeable temperature change. The dissolving of both salt and sugar involves the solid separating into particles too small to see. This is a physical change. Like most physical changes, it is reversible: the water can be removed, leaving the solute in its original state.

Try This Activity: Measuring the Dissolving Process

(Page 313)

(a) The slightly cloudy mixture of table salt in water indicates that some substance(s) did not dissolve. Because we know that sodium chloride is soluble, table salt must be a mixture containing at least one low-solubility solid. The solution of pickling salt was completely clear.
(b) The ingredients are salt, calcium silicate, potassium iodide, sodium thiosulfate (for Sifto brand). Calcium silicate is likely the cause of the cloudiness because silicates (such as sand) are not soluble in water.
(c) About 5 to 6 teaspoons of pickling salt appeared to dissolve.
(d) The final volume is a little more than 100 mL, based on the approximate markings on the side of the Erlenmeyer flask.
(e) The volume would likely be around 100 mL but not 120 mL, because solids generally dissolve in water without increasing the volume. This can be tested by measuring 20.0 mL of sodium chloride in a graduated cylinder and adding this to 100.0 mL of water measured in another graduated cylinder.
Note: The answer is about 106 mL.

7.1 SOLUBILITY

PRACTICE

(Page 316)

Understanding Concepts

1. (a) About 20 g of $K_2SO_{4(s)}$ will dissolve in 100 mL of water at 70°C.
   (b) $KNO_{3(s)}$ and $KCl_{(s)}$ have equal solubilities at about 22°C.
   (c) To calculate molar concentration we would need to know the volume of the solution. The graph only gives the volume of water used.
   (d) The only substance shown for which 100 g will dissolve in 100 mL of water is $KNO_{3(s)}$, at about 56°C.
2. (a) NaCl would precipitate first at temperatures above 31°C.
   (b) KCl would precipitate first at temperatures below 31°C.

Applying Inquiry Skills

3. The graph created from Investigation 7.1.1 will normally differ somewhat from the one in Figure 2. The difference is primarily experimental error, due to a less than precise design for the Investigation.

Try This Activity: Gas Solubility

(Page 317)

Some suggested answers are given.
(a) The lit match is extinguished. This suggests the presence of carbon dioxide, which does not support combustion.
(b) (Observations will vary depending on the relative humidity.) The air near the outside of the cold glass cools. As the temperature of the air decreases, so does the solubility of water vapour in the air. Some water vapour condenses to liquid water. A qualitative test for water is to use cobalt(II) chloride paper.

(c) The small gas bubbles on the inside wall of the glass are likely due to air coming out of solution as the temperature of the water increases to room temperature. As the temperature increases in the cold water glass, the volume of gas also increases. In the hot water, the temperature is decreasing so the bubbles would stay small or decrease in volume.

PRACTICE

(Page 318)

Understanding Concepts

4. A room temperature can of pop is more likely to spray: as gases are less soluble in warm liquids than in cold, the gases will tend to come out of solution, so the pressure in the can is higher.

Reflecting

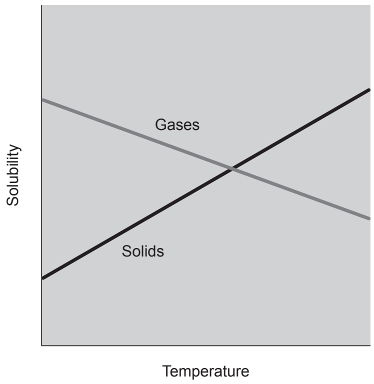
5. (a) Red blood cells contain hemoglobin molecules, that bind chemically to oxygen molecules, making the oxygen appear more soluble.
   (b) If blood held the same amount of oxygen as water, there would be only enough oxygen in our blood to keep our cells alive for a few seconds, i.e., our lives would be different in the event of such a change by becoming dramatically shorter. To compensate, we would require completely different circulatory systems, for example, one that supplied a much greater volume of blood to our organs.

PRACTICE

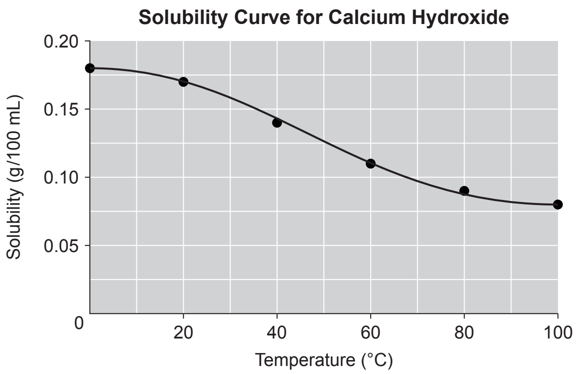
(Page 319)

Understanding Concepts

6. Temperature must always be stated when reporting a solubility.
7.



8. (a) $CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$
   (b) $H_2CO_{3(aq)} + Ca(OH)_{2(aq)} \rightarrow CaCO_{3(s)} + 2\ H_2O_{(l)}$
   (c) The second reaction can only occur if carbon dioxide is present for the first reaction, so the test is diagnostic.
   (d) If the calcium hydroxide solution were too dilute, the calcium carbonate that forms might be below its solubility, and stay in solution rather than forming a precipitate. Thus, the test would not work.
   (e)



(f) From the solubility curve drawn in (e), the solubility of $Ca(OH)_{2(s)}$ at 22°C is 0.17 g/100 mL, or 0.17 g/0.100 L.

$$v_{Ca(OH)_2} = 1.0 \text{ L}$$

$$c_{Ca(OH)_2} = 0.17 \text{ g/100 mL} = 0.17 \text{ g/0.100 L}$$

$$m_{Ca(OH)_2} = 1.0 \cancel{\text{L}} \times \frac{0.17 \text{ g}}{0.100 \cancel{\text{L}}}$$

$$m_{Ca(OH)_2} = 1.7 \text{ g}$$

The minimum mass of calcium hydroxide required to make up 1 L of saturated solution will be about 1.7 g. The actual mass one would use should be much more than this — say, 15 to 20 g, to ensure a large excess of solute, which in turn ensures saturation.

Note: In this particular instance the volume of the solute added is very small compared to the volume of the solvent; so the difference between solvent volume and solution volume may be considered negligible.

(g) The solubility of calcium hydroxide is anomalous — unlike most solids it decreases in solubility with increasing temperature. The generalization we use is still valid and useful for most soluble solids. It just needs to be understood that generalizations are exactly that — statements that generally (not invariably) describe events correctly.

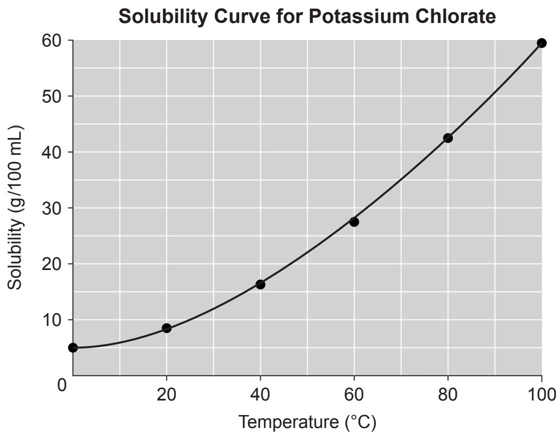
Applying Inquiry Skills

9. **Prediction**

(a) The solubility of potassium chlorate should increase with an increase in temperature, according to the generalization for the solubility of solids, and also according to Figure 2 on page 316 of the text.

Analysis

(b)



(c) According to the Evidence, the solubility of potassium chlorate increases with increasing temperature, for solution temperatures from 0°C to 100°C.

Making Connections

10. Gases such as oxygen are less soluble in warm water, so active fish that require high oxygen levels may not thrive in water that is warmed by an outside source, such as a power plant. In addition, power plants may alter the ecology of a body of water by preventing it from freezing over in the winter. This would attract waterfowl that would feed on aquatic organisms normally under the ice at this time.

PRACTICE

(Page 325)

Understanding Concepts

11. (a) The high/low solubility cutoff point is 0.10 mol/L at SATP.

(b) The 0.10 mol/L cutoff is useful because most laboratory solutions are within an order of magnitude of this concentration, and because most ionic solids are either markedly more or less soluble than this value.

(c) The table need only be used to determine the solubility of an ionic solid if the solid does *not* contain a group I ion, an ammonium ion, or a nitrate ion — because such compounds are *always* highly soluble. To determine the solubility of any other ionic solid, find the anion in its column heading, and look down the column to find the row containing the cation. The row where the cation is found will identify the compound as having low or high solubility.

(d) In chemistry class, the word soluble usually refers to compounds that the table classes as "high solubility." The word insoluble usually refers to the compounds that the table classes as "low solubility," provided their solubility is so low that no effect is noticed from dissolving.

12. (a) $NaOH_{(s)}$ high solubility
(b) $MnCl_{2(s)}$ high solubility
(c) $Al(OH)_{3(s)}$ low solubility
(d) $Ca_3(PO_4)_{2(s)}$ low solubility
(e) $CuSO_4 \cdot 5H_2O_{(s)}$ high solubility

13. (a) Large crystals take more time to "grow," so the sugar probably crystallized slowly from a saturated solution.
(b) Solubility is not affected by crystal size, so the specialty sugar would have the same solubility as regular white sugar.
(c) The dissolving rate is slower for large crystals.

Applying Inquiry Skills

14. **Experimental Design**
Small quantities of a solid may be dissolved sequentially in a measured sample of a solute until no more will dissolve, to determine the solubility; or a saturated solution of known volume can be evaporated to dryness, and the solubility calculated from the measured mass of solid solute remaining.

Making Connections

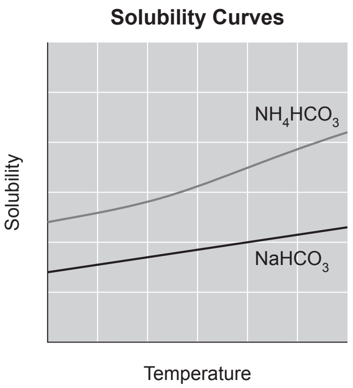
15. Pollutants in natural water can enter the water cycle through runoff from agricultural areas or landfills, or industrial tailings ponds. Some pollutants are toxic and/or noxious at extremely low concentrations, so they may be dangerous even if they have very low solubility.

PRACTICE

(Page 326)

Understanding Concepts

16.



Making Connections

17. In the Solvay process, the scientific knowledge of solubility effects made possible a new technique for producing a commercial chemical much more efficiently — a classic example of science leading technology.

SECTION 7.1 QUESTIONS

(Page 326)

Understanding Concepts

1. (a) The presence of the solid is evidence that sodium bromide is precipitating, probably because the solvent is evaporating (or maybe because of a drop in temperature). The solution is therefore at the limit of its concentration for this temperature.
(b) The concentration of sodium bromide in the remaining solution is at the maximum possible value. Such a solution is said to be saturated.

(c) The mixture could be converted to a single phase solution by adding more solvent, or by warming. Either process would dissolve the solid present.

2. Solids generally become more soluble as temperature increases, while gases generally become less soluble as temperature increases.

Applying Inquiry Skills

3. **Prediction**

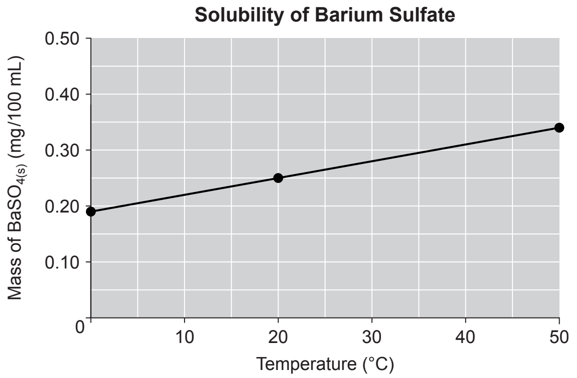
(a) Barium sulfate should become more soluble as temperature increases, according to the generalization about the solubility of ionic solids.

Experimental Design

(b) The independent variable is the solution temperature. The dependent variable is the mass of barium sulfate. The most important controlled variable is the volume of saturated solution taken each time.

Analysis

(c)



(d) According to the evidence from this investigation, barium sulfate does become more soluble as temperature increases.

Evaluation

(e) The experiment could be improved by just making and using a single saturated solution, and taking samples from it at different temperatures.

(f) The prediction was verified, according to the evidence gathered.

(g) The solubility generalization is supported by the results of this experiment. One test of one compound is certainly not enough evidence to justify stating such a generalization. Many repeated tests of many compounds would be required for scientific acceptance and confidence.

Making Connections

4. If a non-aqueous solvent is used, it is probably because the dirt and grease on clothing dissolves better in such solvents. Also, some clothing fabrics are damaged by water, but are not affected by non-aqueous solvents.

5. (a) Cold, fast-flowing streams will have a higher concentration of dissolved oxygen, because more air will be mixed with turbulent water, and because gases dissolve better in colder water.

(b) Trout probably require more oxygen than carp.

(c) Thermal pollution would probably affect trout seriously, because warming their water will reduce its oxygen concentration.

7.2 HARD WATER TREATMENT

PRACTICE

(Page 329)

Understanding Concepts

1. (a) Scale in kettles and soap scum are both evidence of hard water.

(b) Ground water is hard in areas where soluble calcium and magnesium minerals exist in the ground.