Example Exercise 14.1 Henry's Law

Calculate the solubility of carbon dioxide in water at 0 °C and a pressure of 3.00 atm. The solubility of carbon dioxide is 0.348 g/100 mL water at 0 °C and 1.00 atm.

Solution

The solubility of carbon dioxide gas is proportional to the pressure of the gas above the liquid.

$$\text{Solubility} \times \text{pressure factor} = \text{solubility}$$

Since pressure increases, solubility increases, and the pressure factor is greater than one.

$$0.348 \text{ g}/100 \text{ mL} \times \frac{3.00 \cancel{\text{atm}}}{1.00 \cancel{\text{atm}}} = 1.044 \text{ g}/100 \text{ mL}$$

Practice Exercise

Oxygen is much less soluble in water than carbon dioxide, 0.00412 g/100 mL at 20 °C and 760 mm Hg. Calculate the solubility of oxygen gas in water at 20 °C and a pressure of 1150 mm Hg.

Answers: 0.00623 g/100 mL

Concept Exercise

The elevation of Lake Havasu is 400 feet, and Lake Tahoe is 6200 feet. If the water temperatures are the same, which lake has a lower concentration of oxygen gas?

Answer: See Appendix G.

Example Exercise 14.2 Miscibility Predictions

Predict whether each of the following solvents is miscible or immiscible with water:

(a) methanol, CH_3OH (b) toluene, C_7H_8

Solution

Let's use the simplifying assumption that most solvents containing oxygen are polar. Thus, methanol is polar and toluene is nonpolar. Applying the *like dissolves like* rule gives the following:

(a) CH_3OH is polar and therefore is *miscible* with H_2O.

(b) C_7H_8 is nonpolar and therefore is *immiscible* with H_2O.

Practice Exercise

Predict whether each of the following solvents is miscible or immiscible with water:

(a) methylene chloride, CH_2Cl_2 (b) glycerin, $C_3H_5(OH)_3$

Answers: (a) immiscible with H_2O; (b) miscible with H_2O

Concept Exercise

The *like dissolves like* rule states that two liquids are miscible if what property of the two liquids is alike?

Answer: See Appendix G.

Example Exercise 14.3 Solubility Predictions

Predict whether each of the following solid compounds is soluble or insoluble in water:

(a) fructose, $C_6H_{12}O_6$ (b) lithium carbonate, Li_2CO_3 (c) naphthalene, $C_{10}H_8$

Solution

Generally, we can apply the *like dissolves like* rule to determine if a compound is soluble. Since water is a polar solvent, we can predict that water dissolves polar compounds and many ionic compounds.

(a) Fructose has six oxygen atoms and is a polar compound. We can predict that $C_6H_{12}O_6$ is *soluble* in water.

(b) Lithium carbonate contains lithium and carbonate ions; it is therefore an ionic compound. We can predict that Li_2CO_3 is *soluble* in water.

(c) Naphthalene does not contain an oxygen atom and is a nonpolar compound. Thus, $C_{10}H_8$ is *insoluble* in water.

Practice Exercise

Predict whether each of the following solid compounds is soluble or insoluble in water:

(a) anthracene, $C_{14}H_{10}$ (b) cupric sulfate, $CuSO_4$ (c) lactic acid, $HC_3H_5O_3$

Answers: (a) insoluble; (b) soluble; (c) soluble

Concept Exercise

The *like dissolves like* rule states that a solid is soluble in a liquid if what property is alike?

Answer: See Appendix G.

Example Exercise 14.4 The Dissolving Process

When potassium iodide, KI, dissolves in water, why does the oxygen atom of the water molecule attack the potassium ion, K^+?

Solution

Refer to Figure 14.1 and notice the oxygen atom bears a partial negative charge. Thus, the oxygen atom in a water molecule is attracted to the positive potassium ion.

Practice Exercise

When potassium iodide, KI, dissolves in water, why do the hydrogen atoms of the water molecule attack the iodide ion, I^-?

Answers: Refer to Figure 14.1 and notice the hydrogen atoms bear a partial positive charge. Thus, the hydrogen atoms in a water molecule are attracted to the negative iodide ion.

Concept Exercise

When an ionic compound dissolves in water, is the oxygen atom in a water molecule attracted to the cation or anion in the compound?

Answer: See Appendix G.

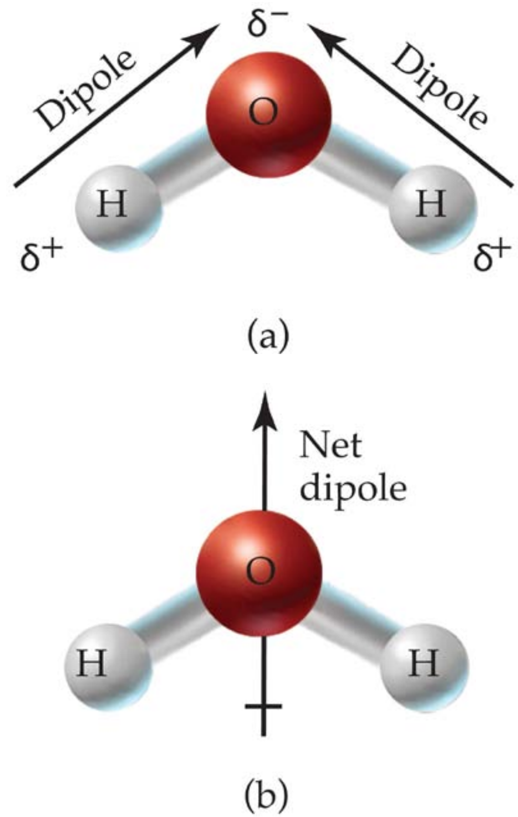


Figure 14.1 The Polar Water Molecule The more electronegative oxygen atom polarizes the O—H bond, which in turn creates two dipoles in a water molecule. The two dipoles produce a net dipole for the entire water molecule.

Example Exercise 14.5 Rate of Dissolving

Why does heating a solution increase the rate of dissolving of a solid solute in water?

Solution

Heating increases the motion and energy of solvent molecules; thus, water molecules attack solid solute at a faster rate.

Practice Exercise

Why does stirring a solution increase the rate of dissolving of a solid solute in water?

Answers: Stirring increases the rate that solvent molecules come in contact with solute, and the rate that solvent cages are pulled from the solid solute.

Concept Exercise

Why does grinding solid crystals increase the rate of dissolving of a solid solute in water?

Answer: See Appendix G.

Example Exercise 14.6 Determining Solubility from a Graph

Determine the solubility of each of the following solid compounds at 50 °C as shown in Figure 14.5:

(a) NaCl (b) KCl

(c) LiCl (d) $C_{12}H_{22}O_{11}$

Solution

From Figure 14.5, let's find the point at which the solubility of the compound intersects 50 °C.

(a) The solubility of NaCl at 50 °C is about 38 g/100 g water.

(b) The solubility of KCl at 50 °C is about 45 g/100 g water.

(c) The solubility of LiCl at 50 °C is about 98 g/100 g water.

(d) The solubility of $C_{12}H_{22}O_{11}$ at 50 °C is about 130 g/100 g water.

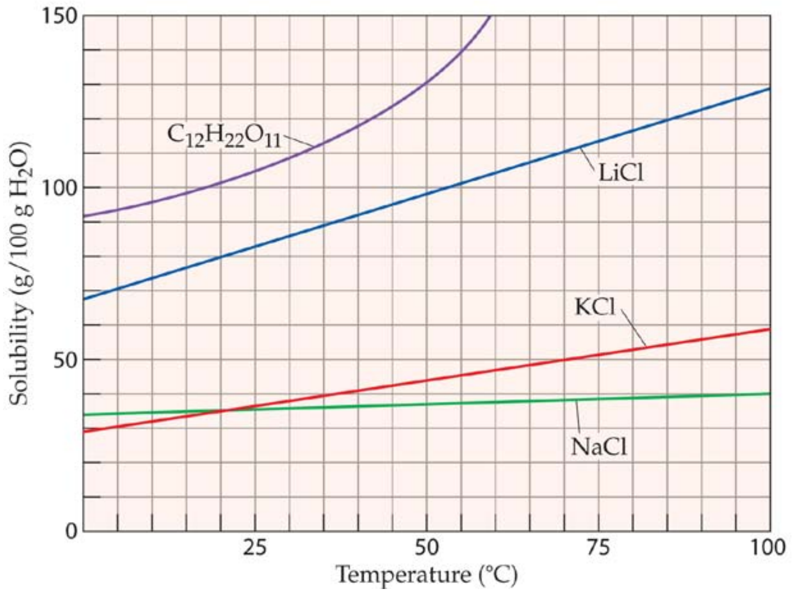


Figure 14.5 Solubility of Solid Compounds in Water Although there are a few exceptions, solid compounds usually become more soluble as the temperature increases.

Practice Exercise

Refer to the solubility behavior shown in Figure 14.5 and determine the minimum temperature required to obtain the following solutions:

(a) 35 g NaCl per 100 g of water

(b) 45 g KCl per 100 g of water

(c) 120 g LiCl per 100 g of water

(d) 109 g $C_{12}H_{22}O_{11}$ per 100 g of water

Answers: (a) 20 °C; (b) 55 °C; (c) 85 °C; (d) 30 °C

Example Exercise 14.6 Determining Solubility from a Graph

Continued

Concept Exercise

Given two cups of coffee, which can dissolve more sugar: hot coffee or coffee at room temperature?

Answer: See Appendix G.

Example Exercise 14.7 Determining Saturation from a Graph

A sodium acetate solution contains 110 g of $NaC_2H_3O_2$ per 100 g of water. Refer to Figure 14.6 and determine whether the solution is unsaturated, saturated, or supersaturated at each of the following temperatures:

(a) 50 °C (b) 70 °C (c) 90 °C

Solution

(a) At 50 °C the solubility of $NaC_2H_3O_2$ is about 97 g/100 g water. Since the solution contains more solute, 110 g/100 g water, the solution is *supersaturated*.

(b) At 70 °C the solubility is about 110 g/100 g water. Since the solution contains the same amount of solute, 110 g/100 g water, the solution is *saturated*.

(c) At 90 °C the solubility is about 130 g/100 g water. Since the solution has only 110 g/100 g water, the solution is *unsaturated*.

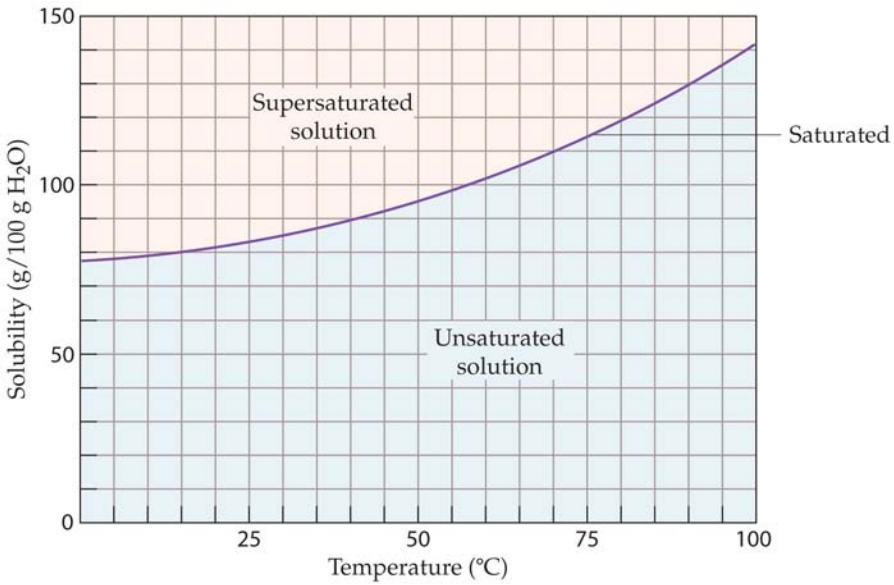


Figure 14.6 Solubility of Sodium Acetate in Water The curve represents a saturated solution of sodium acetate, $NaC_2H_3O_2$, at various temperatures. The region below the curve represents unsaturated solutions, whereas that above represents supersaturated solutions.

Example Exercise 14.7 Determining Saturation from a Graph

Continued

Practice Exercise

A sodium acetate solution contains 80 g of $NaC_2H_3O_2$ per 100 g water. Refer to Figure 14.6 and determine whether the solution is unsaturated, saturated, or supersaturated at each of the following temperatures:

(a) 0 °C (b) 15 °C (c) 45 °C

Answers: (a) supersaturated; (b) saturated; (c) unsaturated

Concept Exercise

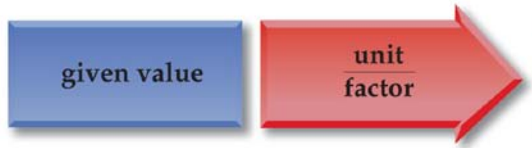
How is it possible to exceed the saturation of a solution and produce a supersaturated solution?

Answer: See Appendix G.

Example Exercise 14.8 Mass/Mass Percent Concentration

Intravenous saline injections are given to restore the mineral balance in trauma patients. What is the mass of water required to dissolve 1.50 g of NaCl for a 0.90% normal IV saline solution?

Let's recall the unit analysis format of problem solving; that is,



Solution

Step 1: The unit asked for in the answer is g water.
Step 2: The given value is 1.50 g NaCl.
Step 3: We apply a conversion factor to cancel units. Since the solution concentration is 0.90%, there is 0.90 g of solute in 100 g of solution. Therefore, there is 0.90 g NaCl for every 99.10 g water. We can write the unit factors

$$\frac{0.90 \text{ g NaCl}}{99.10 \text{ g water}} \quad \text{and} \quad \frac{99.10 \text{ g water}}{0.90 \text{ g NaCl}}$$

In this example, we select the second unit factor to cancel the given units.

$$1.50 \cancel{\text{g NaCl}} \times \frac{99.10 \text{ g water}}{0.90 \cancel{\text{g NaCl}}} = 170 \text{ g water}$$

We can summarize the conversion as follows:

Example Exercise 14.8 Mass/Mass Percent Concentration

Continued

Practice Exercise

A 7.50% potassium chloride solution is prepared by dissolving enough of the salt to give 100.0 g of solution. What is the mass of water required?

Answer: 92.5 g water

Concept Exercise

Given the mass percent concentration of a solution, how many unit factors can we write?

Answer: See Appendix G.

Example Exercise 14.9 Molar Concentration

How many milliliters of 12.0 *M* hydrochloric acid contain 7.30 g of HCl solute (36.46 g/mol)?

In molarity calculations, we relate the given value to moles and then convert to the unit asked for in the answer.

Solution

Step 1: The unit asked for in the answer is mL acid.
Step 2: The relevant given value is 7.30 g HCl.
Step 3: The molar mass of HCl (36.46 g/mol) and the molarity of the solution (12.0 mol/1000 mL) provide the unit factors. We select unit factors so as to cancel units.

$$7.30\ \cancel{\text{g HCl}} \times \frac{1\ \cancel{\text{mol HCl}}}{36.46\ \cancel{\text{g HCl}}} \times \frac{1000\ \text{mL acid}}{12.0\ \cancel{\text{mol HCl}}} = 16.7\ \text{mL acid}$$

We can summarize the two conversions as follows:

Practice Exercise

What volume of 6.00 *M* hydrochloric acid contains 10.0 g of HCl solute (36.46 g/mol)?

Answer: 45.7 mL acid

Example Exercise 14.9 Molar Concentration

Continued

Concept Exercise

Given the molar concentration of a solution, how many unit factors can we write?

Answer: See Appendix G.

Example Exercise 14.10 Dilution of a Solution

Concentrated hydrochloric acid is available commercially as a 12 *M* solution. What is the molarity of an HCl solution prepared by diluting 50.0 mL of concentrated acid with distilled water to give a total volume of 2.50 L?

Conceptual Solution

Let's find the moles of concentrated HCl before dilution.

$$50.0\ \cancel{\text{mL solution}} \times \frac{12\ \text{mol HCl}}{1000\ \cancel{\text{mL solution}}} = 0.60\ \text{mol HCl}$$

We know that the moles of HCl do not change during dilution; the moles of diluted HCl solution must be the same as the moles of concentrated HCl. Since the volume of diluted HCl is 2.50 L, we can calculate the diluted concentration.

$$\frac{0.60\ \text{mol HCl}}{2.50\ \text{L solution}} = \frac{0.24\ \text{mol HCl}}{1\ \text{L solution}} = 0.24\ M\ \text{HCl}$$

Algebraic Solution

Alternatively, we can solve this problem using the equation

$$M_1 \times V_1 = M_2 \times V_2$$

Substituting, we have 12 $M \times 50.0$ mL = $M_2 \times 2.50$ L

We must use the same units for volume; for example, we can convert 2.50 L to mL, which equals 2500 mL. Solving for M_2, we have

$$\frac{12\ M \times 50.0\ \cancel{\text{mL}}}{2500\ \cancel{\text{mL}}} = 0.24\ M\ \text{HCl}$$

Example Exercise 14.10 Dilution of a Solution

Continued

Practice Exercise

Battery acid is 18 *M* sulfuric acid. What volume of battery acid must be diluted with distilled water to prepare 1.00 L of 0.50 *M* H_2SO_4?

Answer: 28 mL H_2SO_4 (diluted to 1.00 L with distilled H_2O)

Concept Exercise

If equal volumes of 6 *M* sulfuric acid and distilled water are added together, what is the concentration of the diluted acid?

Answer: See Appendix G.

Example Exercise 14.11 Solution Stoichiometry Problem

Given that 37.5 mL of 0.100 *M* aluminum bromide solution reacts with a silver nitrate solution, what is the mass of AgBr (187.77 g/mol) produced? The balanced equation is

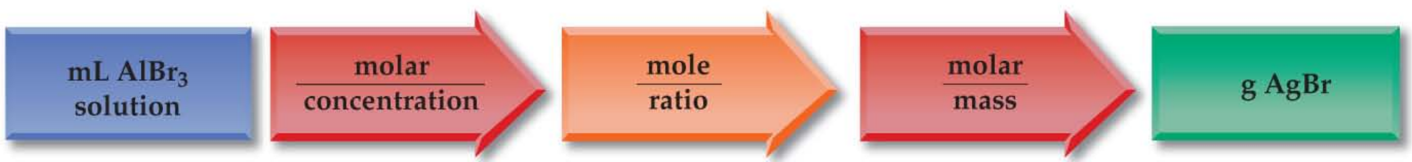
$$AlBr_3(aq) + 3\ AgNO_3(aq) \rightarrow 3\ AgBr(s) + Al(NO_3)_3(aq)$$

Solution

Step 1: The unit asked for in the answer is g AgBr.
Step 2: The given value is 37.5 mL solution.
Step 3: We apply unit conversion factors to cancel units. In this example, we can use molar concentration (0.100 mol $AlBr_3$/1000 mL solution) and molar mass (187.77 g/mol) as unit factors. From the balanced equation, we see that 1 mol $AlBr_3$ = 3 mol AgBr; therefore,

$$37.5\ \cancel{\text{mL solution}} \times \frac{0.100\ \cancel{\text{mol } AlBr_3}}{1000\ \cancel{\text{mL solution}}} \times \frac{3\ \cancel{\text{mol AgBr}}}{1\ \cancel{\text{mol } AlBr_3}} \times \frac{187.77\ \text{g AgBr}}{1\ \cancel{\text{mol AgBr}}} = 2.11\ \text{g AgBr}$$

We can summarize the three conversions as follows:



Practice Exercise

Given that 27.5 mL of 0.210 *M* lithium iodide solution reacts with 0.133 *M* lead(II) nitrate solution, what volume of $Pb(NO_3)_2$ solution is required for complete precipitation?

Answers: 21.7 mL $Pb(NO_3)_2$

Example Exercise 14.11 Solution Stoichiometry Problem

Continued

Concept Exercise

Before applying unit analysis and solving a solution stoichiometry problem, what must always be done first?

Answer: See Appendix G.