9 Solutions

OUR KIDNEYS PRODUCE URINE, WHICH CARRIES WASTE products and excess fluid from the body. They also reabsorb electrolytes such as potassium and produce hormones that regulate blood pressure and calcium blood levels. Diseases such as diabetes and high blood pressure can cause a decrease in kidney function. Symptoms of kidney malfunction include protein in the urine, an abnormal level of urea nitrogen in the blood, frequent urination, and swollen feet. If kidney failure occurs, it may be treated with dialysis or transplantation.

Michelle has been suffering from kidney disease because of severe strep throat as a child. When her kidneys stopped functioning, Michelle was placed on dialysis three times a week. As she enters the dialysis unit, her dialysis nurse, Amanda, asks Michelle how she is feeling. Michelle indicates that she feels tired today and has considerable swelling around her ankles. The dialysis nurse informs her that these side effects occur because of her body's inability to regulate the amount of water in her cells. Amanda explains that the amount of water is regulated by the concentration of electrolytes in her body fluids and the rate at which waste products are removed from her body. Amanda explains that although water is essential for the many chemical reactions that occur in the body, the amount of water can become too high or too low because of various diseases and conditions. Because Michelle's kidneys no longer perform dialysis, she cannot regulate the amount of electrolytes or waste in her body fluids. As a result, she has an electrolyte imbalance and a buildup of waste products, so her body is retaining water. Amanda then explains that the dialysis machine does the work of her kidneys to reduce the high levels of electrolytes and waste products.

CAREER Dialysis Nurse

A dialysis nurse specializes in assisting patients with kidney disease undergoing dialysis. This requires monitoring the patient before, during, and after dialysis for any complications such as a drop in blood pressure or cramping. The dialysis nurse connects the patient to the dialysis unit via a dialysis catheter that is inserted into the neck or chest, which must be kept clean to prevent infection. A dialysis nurse must have considerable knowledge about how the dialysis machine functions to ensure that it is operating correctly at all times.

Solutions are everywhere around us. Most of the gases, liquids, and solids we see are mixtures of at least one substance dissolved in another. There are different types of solutions. The air we breathe is a solution that is primarily oxygen and nitrogen gases. Carbon dioxide gas dissolved in water makes carbonated drinks. When we make solutions of coffee or tea, we use hot water to dissolve substances from coffee beans or tea leaves. The ocean is also a solution, consisting of many ionic compounds such as sodium chloride dissolved in water. In your medicine cabinet, the antiseptic tincture of iodine is a solution of iodine dissolved in ethanol.

Our body fluids contain water and dissolved substances such as glucose and urea and electrolytes such as K^+, Na^+, Cl^-, Mg^{2+}, HCO_3^-, and HPO_4^{2-}. Proper amounts of each of these dissolved substances and water must be maintained in the body fluids. Small changes in electrolyte levels can seriously disrupt cellular processes and endanger our health. Solutions can be described by their concentration, which is the amount of solute in a specific amount of that solution. These relationships, which include mass % (m/m), volume % (v/v), mass /volume % (m/v), and molarity (M), can be used to convert between the amount of a solute and the quantity of its solution. Solutions are also diluted by adding a specific amount of solvent to a solution.

In the processes of osmosis and dialysis, water, essential nutrients, and waste products enter and leave the cells of the body. The kidneys utilize osmosis and dialysis to regulate the amount of water and electrolytes that are excreted.

LOOKING AHEAD

CHAPTER READINESS*

KEY MATH SKILLS

- Calculating a Percentage (1.4C)
- Solving Equations (1.4D)
- Interpreting a Graph (1.4E)

CORE CHEMISTRY SKILLS

- Writing Conversion Factors from Equalities (2.5)
- Using Conversion Factors (2.6)
- Identifying Attractive Forces (6.9)
- Using Mole–Mole Factors (7.6)

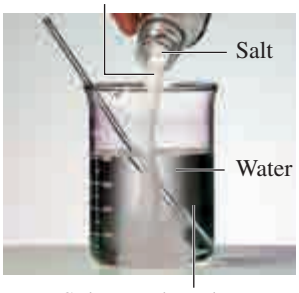
*These Key Math Skills and Core Chemistry Skills from previous chapters are listed here for your review as you proceed to the new material in this chapter.

9.1 Solutions

LEARNING GOAL

Identify the solute and solvent in a solution; describe the formation of a solution.

A **solution** is a homogeneous mixture in which one substance, called the **solute**, is uniformly dispersed in another substance called the **solvent**. Because the solute and the solvent do not react with each other, they can be mixed in varying proportions. A solution of a little salt dissolved in water tastes slightly salty. When a large amount of salt is dissolved in water, the solution tastes very salty. Usually, the solute (in this case, salt) is the substance present in the lesser amount, whereas the solvent (in this case, water) is present in the greater amount. For example, in a solution composed of 5.0 g of salt and 50. g of water, salt is the solute and water is the solvent. In a solution, the particles of the solute are evenly dispersed among the molecules within the solvent (see Figure 9.1).



A solution has at least one solute dispersed in a solvent.

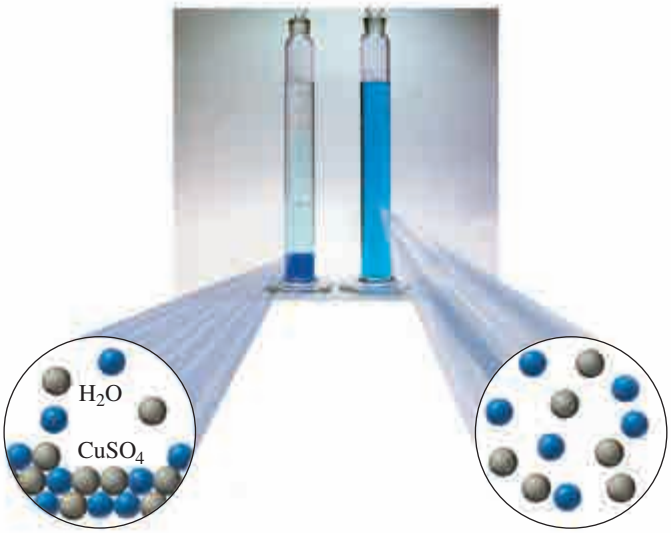


FIGURE 9.1 ▶ A solution of copper(II) sulfate ($CuSO_4$) forms as particles of solute dissolve, move away from the crystal, and become evenly dispersed among the solvent (water) molecules.

What does the uniform blue color in the graduated cylinder on the right indicate?

Types of Solutes and Solvents

Solutes and solvents may be solids, liquids, or gases. The solution that forms has the same physical state as the solvent. When sugar crystals are dissolved in water, the resulting sugar solution is liquid. Sugar is the solute, and water is the solvent. Soda water and soft drinks are prepared by dissolving carbon dioxide gas in water. The carbon dioxide gas is the solute, and water is the solvent. Table 9.1 lists some solutes and solvents and their solutions.

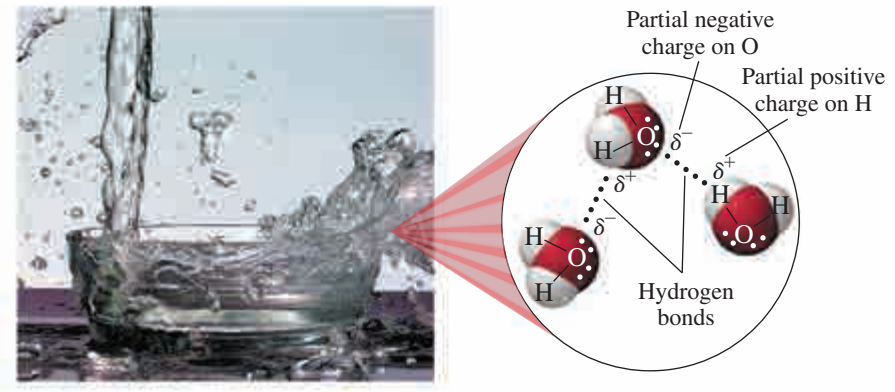
TABLE 9.1 Some Examples of Solutions

Type	Example	Primary Solute	Solvent
Gas Solutions			
Gas in a gas	Air	$O_2(g)$	$N_2(g)$
Liquid Solutions			
Gas in a liquid	Soda water	$CO_2(g)$	$H_2O(l)$
	Household ammonia	$NH_3(g)$	$H_2O(l)$
Liquid in a liquid	Vinegar	$HC_2H_3O_2(l)$	$H_2O(l)$
Solid in a liquid	Seawater	$NaCl(s)$	$H_2O(l)$
	Tincture of iodine	$I_2(s)$	$C_2H_5OH(l)$
Solid Solutions			
Solid in a solid	Brass	$Zn(s)$	$Cu(s)$
	Steel	$C(s)$	$Fe(s)$

Water as a Solvent

Water is one of the most common solvents in nature. In the H_2O molecule, an oxygen atom shares electrons with two hydrogen atoms. Because oxygen is much more electronegative than hydrogen, the O—H bonds are polar. In each polar bond, the oxygen atom has a partial negative (δ^-) charge and the hydrogen atom has a partial positive (δ^+) charge. Because the shape of a water molecule is bent, not linear, its dipoles do not cancel out. Thus, water is polar, and is a *polar solvent*.

Attractive forces known as *hydrogen bonds* occur between molecules where partially positive hydrogen atoms are attracted to the partially negative atoms F, O, or N. As seen in the diagram, the hydrogen bonds are shown as a series of dots. Although hydrogen bonds are much weaker than covalent or ionic bonds, there are many of them linking water molecules together. Hydrogen bonds are important in the properties of biological compounds such as proteins, carbohydrates, and DNA.



In water, hydrogen bonds form between an oxygen atom in one water molecule and the hydrogen atom in another.

Chemistry Link to **Health**

Water in the Body

The average adult is about 60% water by mass, and the average infant about 75%. About 60% of the body's water is contained within the cells as intracellular fluids; the other 40% makes up extracellular fluids, which include the interstitial fluid in tissue and the plasma in the blood. These external fluids carry nutrients and waste materials between the cells and the circulatory system.

Typical water gain and loss during 24 hours

Water Gain	
Liquid	1000 mL
Food	1200 mL
Metabolism	300 mL
Total	2500 mL

Water Loss	
Urine	1500 mL
Perspiration	300 mL
Breath	600 mL
Feces	100 mL
Total	2500 mL

The water lost from the body is replaced by the intake of fluids.

Every day you lose between 1500 and 3000 mL of water from the kidneys as urine, from the skin as perspiration, from the lungs as you exhale, and from the gastrointestinal tract. Serious dehydration can occur in an adult if there is a 10% net loss in total body fluid; a 20% loss of fluid can be fatal. An infant suffers severe dehydration with only a 5 to 10% loss in body fluid.

Water loss is continually replaced by the liquids and foods in the diet and from metabolic processes that produce water in the cells of the body. Table 9.2 lists the percentage by mass of water contained in some foods.

TABLE 9.2 Percentage of Water in Some Foods

Food	Water (% by mass)	Food	Water (% by mass)
Vegetables		**Meats/Fish**	
Carrot	88	Chicken, cooked	71
Celery	94	Hamburger, broiled	60
Cucumber	96	Salmon	71
Tomato	94		
Fruits		**Milk Products**	
Apple	85	Cottage cheese	78
Cantaloupe	91	Milk, whole	87
Orange	86	Yogurt	88
Strawberry	90		
Watermelon	93		

Formation of Solutions

The interactions between solute and solvent will determine whether a solution will form. Initially, energy is needed to separate the particles in the solute and the solvent particles. Then energy is released as solute particles move between the solvent particles to form a solution. However, there must be attractions between the solute and the solvent particles to provide the energy for the initial separation. These attractions occur when the solute and the solvent have similar polarities. The expression "like dissolves like" is a way of saying that the polarities of a solute and a solvent must be similar in order for a solution to form (see Figure 9.2). In the absence of attractions between a solute and a solvent, there is insufficient energy to form a solution (see Table 9.3).

Explore Your World

Like Dissolves Like

Obtain small samples of vegetable oil, water, vinegar, salt, and sugar. Then combine and mix the substances as listed in **a** through **e**.

a. oil and water
b. water and vinegar
c. salt and water
d. sugar and water
e. salt and oil

Questions

1. Which of the mixtures formed a solution?
2. Which of the mixtures did not form a solution?
3. Why do some mixtures form solutions, but others do not?

(a) (b) (c)

FIGURE 9.2 ▶ Like dissolves like. In each test tube, the lower layer is CH_2Cl_2 (more dense), and the upper layer is water (less dense).
(a) CH_2Cl_2 is nonpolar and water is polar; the two layers do not mix. **(b)** The nonpolar solute I_2 (purple) is soluble in the nonpolar solvent CH_2Cl_2. **(c)** The ionic solute $Ni(NO_3)_2$ (green) is soluble in the polar solvent water.

In which layer would polar molecules of sucrose ($C_{12}H_{22}O_{11}$) be soluble?

TABLE 9.3 Possible Combinations of Solutes and Solvents

Solutions Will Form		Solutions Will Not Form	
Solute	Solvent	Solute	Solvent
Polar	Polar	Polar	Nonpolar
Nonpolar	Nonpolar	Nonpolar	Polar

Solutions with Ionic and Polar Solutes

In ionic solutes such as sodium chloride, NaCl, there are strong ionic bonds between positively charged Na^+ ions and negatively charged Cl^- ions. In water, a polar solvent, the hydrogen bonds provide strong solvent–solvent attractions. When NaCl crystals are placed in water, partially negative oxygen atoms in water molecules attract positive Na^+ ions, and the partially positive hydrogen atoms in other water molecules attract negative Cl^- ions (see Figure 9.3). As soon as the Na^+ ions and the Cl^- ions form a solution, they undergo **hydration** as water molecules surround each ion. Hydration of the ions diminishes their attraction to other ions and keeps them in solution.

In the equation for the formation of the NaCl solution, the solid and aqueous NaCl are shown with the formula H_2O over the arrow, which indicates that water is needed for the dissociation process but is not a reactant.

$$NaCl(s) \xrightarrow[\text{Dissociation}]{H_2O} Na^+(aq) + Cl^-(aq)$$

In another example, we find that a polar molecular compound such as methanol, $CH_3—OH$, is soluble in water because methanol has a polar —OH group that forms hydrogen bonds with water (see Figure 9.4). Polar solutes require polar solvents for a solution to form.

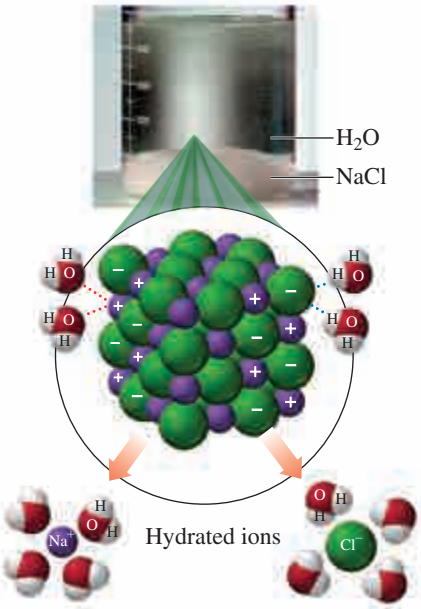


FIGURE 9.3 ▶ Ions on the surface of a crystal of NaCl dissolve in water as they are attracted to the polar water molecules that pull the ions into solution and surround them.

What helps keep Na^+ and Cl^- ions in solution?

Solutions with Nonpolar Solutes

Compounds containing nonpolar molecules, such as iodine (I_2), oil, or grease, do not dissolve in water because there are essentially no attractions between the particles of a nonpolar solute and the polar solvent. Nonpolar solutes require nonpolar solvents for a solution to form.

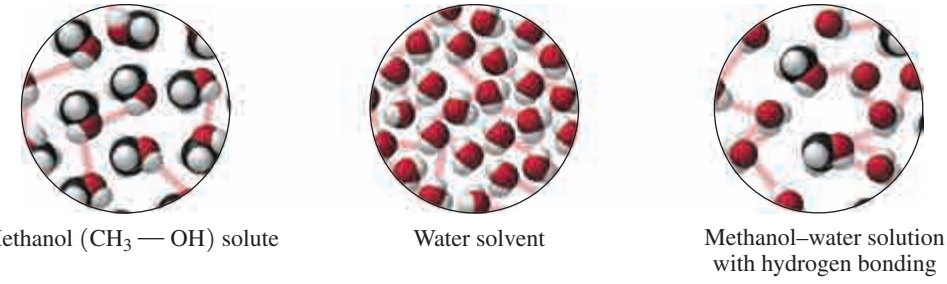


FIGURE 9.4 ▶ Molecules of methanol, CH_3—OH, form hydrogen bonds with polar water molecules to form a methanol–water solution.

Why are there attractions between the solute methanol and the solvent water?

QUESTIONS AND PROBLEMS

9.1 Solutions

LEARNING GOAL Identify the solute and solvent in a solution; describe the formation of a solution.

9.1 Identify the solute and the solvent in each solution composed of the following:
- **a.** 10.0 g of NaCl and 100.0 g of H_2O
- **b.** 50.0 mL of ethanol, C_2H_5OH, and 10.0 mL of H_2O
- **c.** 0.20 L of O_2 and 0.80 L of N_2

9.2 Identify the solute and the solvent in each solution composed of the following:
- **a.** 10.0 mL of acetic acid and 200. mL of water
- **b.** 100.0 mL of water and 5.0 g of sugar
- **c.** 1.0 g of Br_2 and 50.0 mL of methylene chloride(l)

9.3 Describe the formation of an aqueous KI solution, when solid KI dissolves in water.

9.4 Describe the formation of an aqueous LiBr solution, when solid LiBr dissolves in water.

Clinical Applications

9.5 Water is a polar solvent and carbon tetrachloride (CCl_4) is a nonpolar solvent. In which solvent is each of the following, which is found or used in the body, more likely to be soluble?
- **a.** $CaCO_3$ (calcium supplement), ionic
- **b.** retinol (vitamin A), nonpolar
- **c.** sucrose (table sugar), polar
- **d.** cholesterol (lipid), nonpolar

9.6 Water is a polar solvent and hexane is a nonpolar solvent. In which solvent is each of the following, which is found or used in the body, more likely to be soluble?
- **a.** vegetable oil, nonpolar
- **b.** oleic acid (lipid), nonpolar
- **c.** niacin (vitamin B_3), polar
- **d.** $FeSO_4$ (iron supplement), ionic

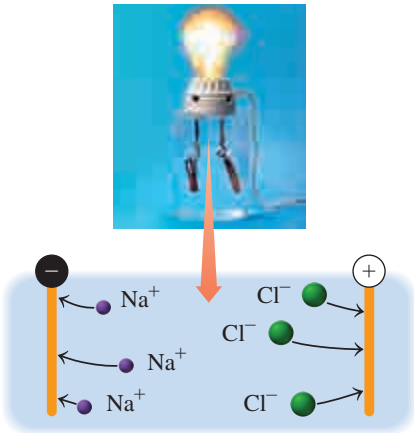
9.2 Electrolytes and Nonelectrolytes

LEARNING GOAL

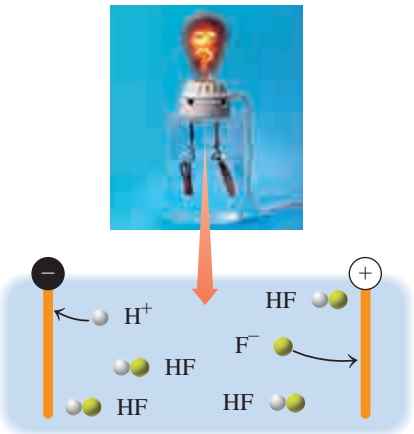
Identify solutes as electrolytes or nonelectrolytes.

Solutes can be classified by their ability to conduct an electrical current. When **electrolytes** dissolve in water, the process of *dissociation* separates them into ions forming solutions that conduct electricity. When **nonelectrolytes** dissolve in water, they do not separate into ions and their solutions do not conduct electricity.

To test solutions for the presence of ions, we can use an apparatus that consists of a battery and a pair of electrodes connected by wires to a light bulb. The light bulb glows when electricity can flow, which can only happen when electrolytes provide ions that move between the electrodes to complete the circuit.



(a) Strong electrolyte



(b) Weak electrolyte

Types of Electrolytes

Electrolytes can be further classified as *strong electrolytes* or *weak electrolytes*. For a **strong electrolyte**, such as sodium chloride (NaCl), there is 100% dissociation of the solute into ions. When the electrodes from the light bulb apparatus are placed in the NaCl solution, the light bulb glows very brightly.

In an equation for dissociation of a compound in water, the charges must balance. For example, magnesium nitrate dissociates to give one magnesium ion for every two nitrate ions. However, only the ionic bonds between Mg^{2+} and NO_3^- are broken, not the covalent bonds within the polyatomic ion. The equation for the dissociation of $Mg(NO_3)_2$ is written as follows:

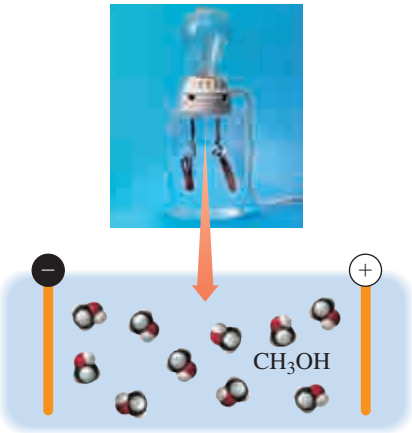
$$Mg(NO_3)_2(s) \xrightarrow[\text{Dissociation}]{H_2O} Mg^{2+}(aq) + 2NO_3^-(aq)$$

A **weak electrolyte** is a compound that dissolves in water mostly as molecules. Only a few of the dissolved solute molecules undergo *dissociation*, producing a small number of ions in solution. Thus solutions of weak electrolytes do not conduct electrical current as well as solutions of strong electrolytes. When the electrodes are placed in a solution of a weak electrolyte, the glow of the light bulb is very dim. In an aqueous solution of the weak electrolyte HF, a few HF molecules dissociate to produce H^+ and F^- ions. As more H^+ and F^- ions form, some recombine to give HF molecules. These forward and reverse reactions of molecules to ions and back again are indicated by two arrows between reactant and products that point in opposite directions:

$$HF(aq) \underset{\text{Recombination}}{\overset{\text{Dissociation}}{\rightleftharpoons}} H^+(aq) + F^-(aq)$$

TABLE 9.4 Classification of Solutes in Aqueous Solutions

Type of Solute	In Solution	Type(s) of Particles in Solution	Conducts Electricity?	Examples
Strong electrolyte	Dissociates completely	Ions only	Yes	Ionic compounds such as NaCl, KBr, $MgCl_2$, $NaNO_3$; bases such as NaOH, KOH; acids such as HCl, HBr, HI, HNO_3, $HClO_4$, H_2SO_4
Weak electrolyte	Ionizes partially	Mostly molecules and a few ions	Weakly	HF, H_2O, NH_3, $HC_2H_3O_2$ (acetic acid)
Nonelectrolyte	No ionization	Molecules only	No	Carbon compounds such as CH_3OH (methanol), C_2H_5OH (ethanol), $C_{12}H_{22}O_{11}$ (sucrose), CH_4N_2O (urea)



(c) Nonelectrolyte

A nonelectrolyte such as methanol (CH_3OH) dissolves in water only as molecules, which do not ionize. When electrodes of the light bulb apparatus are placed in a solution of a nonelectrolyte, the light bulb does not glow, because the solution does not contain ions and cannot conduct electricity.

$$CH_3OH(l) \xrightarrow{H_2O} CH_3OH(aq)$$

Table 9.4 summarizes the classification of solutes in aqueous solutions.

SAMPLE PROBLEM 9.1 Solutions of Electrolytes and Nonelectrolytes

Indicate whether solutions of each of the following contain only ions, only molecules, or mostly molecules and a few ions. Write the equation for the formation of a solution for each of the following:

a. $Na_2SO_4(s)$, a strong electrolyte
b. sucrose, $C_{12}H_{22}O_{11}(s)$, a nonelectrolyte
c. acetic acid, $HC_2H_3O_2(l)$, a weak electrolyte

SOLUTION

a. An aqueous solution of $Na_2SO_4(s)$ contains only the ions Na^+ and SO_4^{2-}.

$$Na_2SO_4(s) \xrightarrow{H_2O} 2Na^+(aq) + SO_4^{2-}(aq)$$

b. A nonelectrolyte such as sucrose, $C_{12}H_{22}O_{11}(s)$, produces only molecules when it dissolves in water.

$$C_{12}H_{22}O_{11}(s) \xrightarrow{H_2O} C_{12}H_{22}O_{11}(aq)$$

c. A weak electrolyte such as $HC_2H_3O_2(l)$ produces mostly molecules and a few ions when it dissolves in water.

$$HC_2H_3O_2(l) \underset{}{\overset{H_2O}{\rightleftharpoons}} H^+(aq) + C_2H_3O_2^-(aq)$$

STUDY CHECK 9.1

Boric acid, $H_3BO_3(s)$, is a weak electrolyte. Would you expect a boric acid solution to contain only ions, only molecules, or mostly molecules and a few ions?

ANSWER

A solution of a weak electrolyte would contain mostly molecules and a few ions.

Equivalents

Body fluids and intravenous (IV) solutions contain a mixture of electrolytes, such as Na^+, Cl^-, K^+, and Ca^{2+}. We measure each individual ion in terms of an **equivalent (Eq)**, which is the amount of that ion equal to 1 mole of positive or negative electrical charge. For example, 1 mole of Na^+ ions and 1 mole of Cl^- ions are each 1 equivalent because they each contain 1 mole of charge. For an ion with a charge of 2+ or 2−, there are 2 equivalents for each mole. Some examples of ions and equivalents are shown in Table 9.5.

TABLE 9.5 Equivalents of Electrolytes in Clinical Intravenous (IV) Solutions

Ion	Ionic Charge	Number of Equivalents in 1 Mole
Na^+, K^+, Li^+, NH_4^+	1+	1 Eq
Ca^{2+}, Mg^{2+}	2+	2 Eq
Fe^{3+}	3+	3 Eq
Cl^-, $C_2H_3O_2^-$ (acetate), $H_2PO_4^-$, $C_3H_5O_3^-$ (lactate)	1−	1 Eq
CO_3^{2-}, HPO_4^{2-}	2−	2 Eq
PO_4^{3-}, $C_6H_5O_7^{3-}$ (citrate)	3−	3 Eq

In any solution, the charge of the positive ions is always balanced by the charge of the negative ions. The concentrations of electrolytes in intravenous fluids are expressed in milliequivalents per liter (mEq/L); 1 Eq = 1000 mEq. For example, a solution containing 25 mEq/L of Na^+ and 4 mEq/L of K^+ has a total positive charge of 29 mEq/L. If Cl^- is the only anion, its concentration must be 29 mEq/L.

SAMPLE PROBLEM 9.2 Electrolyte Concentration

The laboratory tests for a patient indicate a blood calcium level of 8.8 mEq/L.

a. How many moles of calcium ion are in 0.50 L of blood?
b. If chloride ion is the only other ion present, what is its concentration in mEq/L?

SOLUTION

a. Using the volume and the electrolyte concentration in mEq/L, we can find the number of equivalents in 0.50 L of blood.

$$0.50\ \cancel{L} \times \frac{8.8\ \cancel{mEq\ Ca^{2+}}}{1\ \cancel{L}} \times \frac{1\ Eq\ Ca^{2+}}{1000\ \cancel{mEq\ Ca^{2+}}} = 0.0044\ Eq\ of\ Ca^{2+}$$

We can then convert equivalents to moles (for Ca^{2+} there are 2 Eq per mole).

$$0.0044\ \cancel{Eq\ Ca^{2+}} \times \frac{1\ mole\ Ca^{2+}}{2\ \cancel{Eq\ Ca^{2+}}} = 0.0022\ mole\ of\ Ca^{2+}$$

b. If the concentration of Ca^{2+} is 8.8 mEq/L, then the concentration of Cl^- must be 8.8 mEq/L to balance the charge.

STUDY CHECK 9.2

A lactated Ringer's solution for intravenous fluid replacement contains 109 mEq of Cl^- per liter of solution. If a patient received 1250 mL of Ringer's solution, how many moles of chloride ion were given?

ANSWER

0.136 mole of Cl^-

Chemistry Link to Health

Electrolytes in Body Fluids

Electrolytes in the body play an important role in maintaining the proper function of the cells and organs in the body. Typically, the electrolytes sodium, potassium, chloride, and bicarbonate are measured in a blood test. Sodium ions regulate the water content in the body and are important in carrying electrical impulses through the nervous system. Potassium ions are also involved in the transmission of electrical impulses and play a role in the maintenance of a regular heartbeat. Chloride ions balance the charges of the positive ions and also control the balance of fluids in the body. Bicarbonate is important in maintaining the proper pH of the blood. Sometimes when vomiting, diarrhea, or sweating is excessive, the concentrations of certain electrolytes may decrease. Then fluids such as Pedialyte may be given to return electrolyte levels to normal.

An intravenous solution is used to replace electrolytes in the body.

The concentrations of electrolytes present in body fluids and in intravenous fluids given to a patient are often expressed in milliequivalents per liter (mEq/L) of solution. For example, one liter of Pedialyte contains the following electrolytes: Na^+ 45 mEq, Cl^- 35 mEq, K^+ 20 mEq, and citrate^{3-} 30 mEq.

Table 9.6 gives the concentrations of some typical electrolytes in blood plasma and various types of solutions. There is a charge balance because the total number of positive charges is equal to the total number of negative charges. The use of a specific intravenous solution depends on the nutritional, electrolyte, and fluid needs of the individual patient.

TABLE 9.6 Electrolytes in Blood Plasma and Selected Intravenous Solutions

	Normal Concentrations of Ions (mEq/L)				
	Blood Plasma	Normal Saline 0.9% NaCl	Lactated Ringer's Solution	Maintenance Solution	Replacement Solution (extracellular)
Purpose		Replaces fluid loss	Hydration	Maintains electrolytes and fluids	Replaces electrolytes
Cations					
Na^+	135–145	154	130	40	140
K^+	3.5–5.5		4	35	10
Ca^{2+}	4.5–5.5		3		5
Mg^{2+}	1.5–3.0				3
Total		154	137	75	158
Anions					
Acetate$^-$					47
Cl^-	95–105	154	109	40	103
HCO_3^-	22–28				
Lactate$^-$			28	20	
HPO_4^{2-}	1.8–2.3			15	
Citrate^{3-}					8
Total		154	137	75	158

QUESTIONS AND PROBLEMS

9.2 Electrolytes and Nonelectrolytes

LEARNING GOAL Identify solutes as electrolytes or nonelectrolytes.

9.7 KF is a strong electrolyte, and HF is a weak electrolyte. How is the solution of KF different from that of HF?

9.8 NaOH is a strong electrolyte, and CH_3OH is a nonelectrolyte. How is the solution of NaOH different from that of CH_3OH?

9.9 Write a balanced equation for the dissociation of each of the following strong electrolytes in water:

a. KCl **b.** $CaCl_2$
c. K_3PO_4 **d.** $Fe(NO_3)_3$

9.10 Write a balanced equation for the dissociation of each of the following strong electrolytes in water:

a. LiBr **b.** $NaNO_3$
c. $CuCl_2$ **d.** K_2CO_3

9.11 Indicate whether aqueous solutions of each of the following solutes contain only ions, only molecules, or mostly molecules and a few ions:

a. acetic acid, $HC_2H_3O_2$, a weak electrolyte
b. NaBr, a strong electrolyte
c. fructose, $C_6H_{12}O_6$, a nonelectrolyte

9.12 Indicate whether aqueous solutions of each of the following solutes contain only ions, only molecules, or mostly molecules and a few ions:

a. NH_4Cl, a strong electrolyte
b. ethanol, C_2H_5OH, a nonelectrolyte
c. HCN, hydrocyanic acid, a weak electrolyte

9.13 Classify the solute represented in each of the following equations as a strong, weak, or nonelectrolyte:

a. $K_2SO_4(s) \xrightarrow{H_2O} 2K^+(aq) + SO_4^{2-}(aq)$

b. $NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

c. $C_6H_{12}O_6(s) \xrightarrow{H_2O} C_6H_{12}O_6(aq)$

9.14 Classify the solute represented in each of the following equations as a strong, weak, or nonelectrolyte:

a. $CH_3OH(l) \xrightarrow{H_2O} CH_3OH(aq)$

b. $MgCl_2(s) \xrightarrow{H_2O} Mg^{2+}(aq) + 2Cl^-(aq)$

c. $HClO(aq) \xrightarrow{H_2O} H^+(aq) + ClO^-(aq)$

9.15 Calculate the number of equivalents in each of the following:

a. 1 mole of K^+ **b.** 2 moles of OH^-
c. 1 mole of Ca^{2+} **d.** 3 moles of CO_3^{2-}

9.16 Calculate the number of equivalents in each of the following:

a. 1 mole of Mg^{2+} **b.** 0.5 mole of H^+
c. 4 moles of Cl^- **d.** 2 moles of Fe^{3+}

Clinical Applications

9.17 An intravenous saline solution contains 154 mEq/L each of Na^+ and Cl^-. How many moles each of Na^+ and Cl^- are in 1.00 L of the saline solution?

9.18 An intravenous solution to replace potassium loss contains 40. mEq/L each of K^+ and Cl^-. How many moles each of K^+ and Cl^- are in 1.5 L of the solution?

9.19 An intravenous solution contains 40. mEq/L of Cl^- and 15 mEq/L of HPO_4^{2-}. If Na^+ is the only cation in the solution, what is the Na^+ concentration, in milliequivalents per liter?

9.20 A Ringer's solution contains the following concentrations (mEq/L) of cations: Na^+ 147, K^+ 4, and Ca^{2+} 4. If Cl^- is the only anion in the solution, what is the Cl^- concentration, in milliequivalents per liter?

9.21 When Amanda's blood was tested, the chloride level was 0.45 g/dL.

a. What is this value in milliequivalents per liter?
b. According to Table 9.6, is this value above, below, or within the normal range?

9.22 After dialysis, the level of magnesium in Amanda's blood was 0.0026 g/dL.

a. What is this value in milliequivalents per liter?
b. According to Table 9.6, is this value above, below, or within the normal range?

9.3 Solubility

LEARNING GOAL

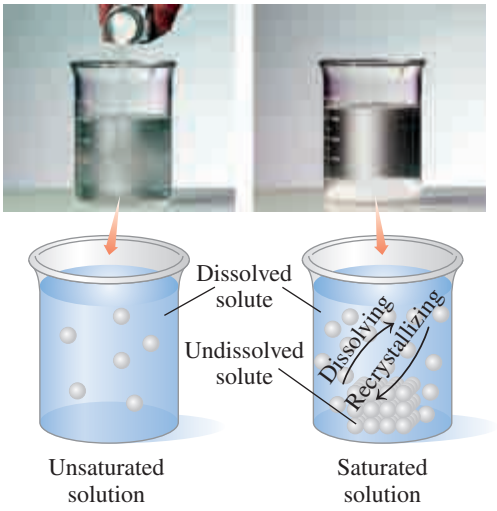
Define solubility; distinguish between an unsaturated and a saturated solution. Identify an ionic compound as soluble or insoluble.

The term *solubility* is used to describe the amount of a solute that can dissolve in a given amount of solvent. Many factors, such as the type of solute, the type of solvent, and the temperature, affect the solubility of a solute. **Solubility**, usually expressed in grams of solute in 100 g of solvent, is the maximum amount of solute that can be dissolved at a certain temperature. If a solute readily dissolves when added to the solvent, the solution does not contain the maximum amount of solute. We call this solution an **unsaturated solution**.

A solution that contains all the solute that can dissolve is a **saturated solution**. When a solution is saturated, the rate at which the solute dissolves becomes equal to the rate at which solid forms, a process known as *recrystallization*. Then there is no further change in the amount of dissolved solute in solution.

$$\text{Solute} + \text{solvent} \underset{\text{Solute recrystallizes}}{\overset{\text{Solute dissolves}}{\rightleftharpoons}} \text{saturated solution}$$

We can prepare a saturated solution by adding an amount of solute greater than that needed to reach solubility. Stirring the solution will dissolve the maximum amount of solute and leave the excess on the bottom of the container. Once we have a saturated solution, the addition of more solute will only increase the amount of undissolved solute.



Additional solute can dissolve in an unsaturated solution, but not in a saturated solution.

SAMPLE PROBLEM 9.3 Saturated Solutions

At 20 °C, the solubility of KCl is 34 g/100 g of H_2O. In the laboratory, a student mixes 75 g of KCl with 200. g of H_2O at a temperature of 20 °C.

a. How much of the KCl will dissolve?
b. Is the solution saturated or unsaturated?
c. What is the mass, in grams, of any solid KCl left undissolved on the bottom of the container?

SOLUTION

a. At 20 °C, KCl has a solubility of 34 g of KCl in 100 g of water. Using the solubility as a conversion factor, we can calculate the maximum amount of KCl that can dissolve in 200. g of water as follows:

$$200.\ \cancel{\text{g H}_2\text{O}} \times \frac{34\ \text{g KCl}}{100\ \cancel{\text{g H}_2\text{O}}} = 68\ \text{g of KCl}$$

b. Because 75 g of KCl exceeds the maximum amount (68 g) that can dissolve in 200. g of water, the KCl solution is saturated.

c. If we add 75 g of KCl to 200. g of water and only 68 g of KCl can dissolve, there is 7 g (75 g − 68 g) of solid (undissolved) KCl on the bottom of the container.

STUDY CHECK 9.3

At 40 °C, the solubility of KNO_3 is 65 g/100 g of H_2O. How many grams of KNO_3 will dissolve in 120 g of H_2O at 40 °C?

ANSWER

78 g of KNO_3

Chemistry Link to **Health**

Gout and Kidney Stones: A Problem of Saturation in Body Fluids

The conditions of gout and kidney stones involve compounds in the body that exceed their solubility levels and form solid products. Gout affects adults, primarily men, over the age of 40. Attacks of gout may occur when the concentration of uric acid in blood plasma exceeds its solubility, which is 7 mg/100 mL of plasma at 37 °C. Insoluble deposits of needle-like crystals of uric acid can form in the cartilage, tendons, and soft tissues where they cause painful gout attacks. They may also form in the tissues of the kidneys, where they can cause renal damage. High levels of uric acid in the body can be caused by an increase in uric acid production, failure of the kidneys to remove uric acid, or a diet with an overabundance of foods containing purines, which are metabolized to uric acid in the body. Foods in the diet that contribute to high levels of uric acid include certain meats, sardines, mushrooms, asparagus, and beans. Drinking alcoholic beverages may also significantly increase uric acid levels and bring about gout attacks.

Treatment for gout involves diet changes and drugs. Medications, such as probenecid, which helps the kidneys eliminate uric acid, or allopurinol, which blocks the production of uric acid by the body may be useful.

Kidney stones are solid materials that form in the urinary tract. Most kidney stones are composed of calcium phosphate and calcium oxalate, although they can be solid uric acid. Insufficient water intake and high levels of calcium, oxalate, and phosphate in the urine can lead to the formation of kidney stones. When a kidney stone passes through the urinary tract, it causes considerable pain and discomfort, necessitating the use of painkillers and surgery. Sometimes ultrasound is used to break up kidney stones. Persons prone to kidney stones are advised to drink six to eight glasses of water every day to prevent saturation levels of minerals in the urine.

Gout occurs when uric acid exceeds its solubility.

Kidney stones form when calcium phosphate exceeds its solubility.

Effect of Temperature on Solubility

The solubility of most solids is greater as temperature increases, which means that solutions usually contain more dissolved solute at higher temperature. A few substances show little change in solubility at higher temperatures, and a few are less soluble (see Figure 9.5). For example, when you add sugar to iced tea, some undissolved sugar may form on the bottom of the glass. But if you add sugar to hot tea, many teaspoons of sugar are needed before solid sugar appears. Hot tea dissolves more sugar than does cold tea because the solubility of sugar is much greater at a higher temperature.

When a saturated solution is carefully cooled, it becomes a *supersaturated solution* because it contains more solute than the solubility allows. Such a solution is unstable, and if the solution is agitated or if a solute crystal is added, the excess solute will recrystallize to give a saturated solution again.

Conversely, the solubility of a gas in water decreases as the temperature increases. At higher temperatures, more gas molecules have the energy to escape from the solution. Perhaps you have observed the bubbles escaping from a cold carbonated soft drink as it warms. At high temperatures, bottles containing carbonated solutions may burst as more gas molecules leave the solution and increase the gas pressure inside the bottle. Biologists have found that increased temperatures in rivers and lakes cause the amount of dissolved oxygen to decrease until the warm water can no longer support a biological community. Electricity-generating plants are required to have their own ponds to use with their cooling towers to lessen the threat of thermal pollution in surrounding waterways.

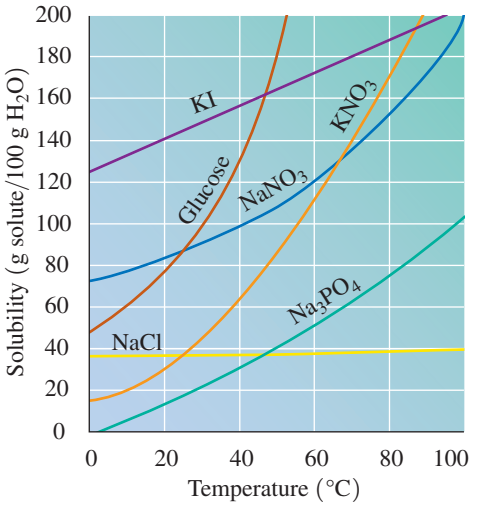
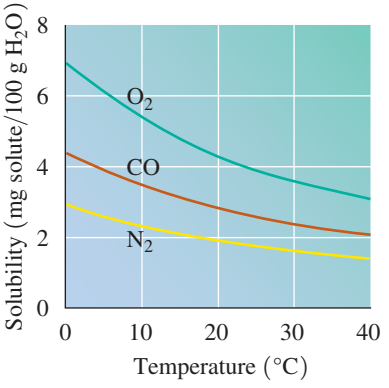


FIGURE 9.5 ▶ In water, most common solids are more soluble as the temperature increases.

Compare the solubility of $NaNO_3$ at 20 °C and 60 °C.



In water, gases are less soluble as the temperature increases.

Explore Your World

Preparing Rock Candy

Need: one cup of water, three cups of granulated sugar, clean narrow glass or jar, wooden stick (skewer) or thick string that is the height of the glass, pencil, and food coloring (optional)

Process:

1. Place the water and two cups of sugar in a pan and begin heating and stirring. The sugar should all dissolve. Continue heating, but not boiling, adding small amounts of the remaining sugar and stirring thoroughly each time, until some of the sugar no longer dissolves. There may be some sugar crystals on the bottom of the pan. Carefully pour the sugar solution into the glass or jar. Add two to three drops of food coloring, if desired.
2. Wet the wooden stick and roll it in granulated sugar to provide crystals for the sugar solution to attach to. Place the stick in the sugar solution. If using string, tape the string to a pencil so it will hang slightly above the bottom of the glass. Wet the lower half of the string, roll it in the granulated sugar, and place the pencil across the top of the glass with the string in the sugar solution. Place the glass and wooden stick or string in a place where it will not be disturbed. You should see sugar crystals grow over the next several days.

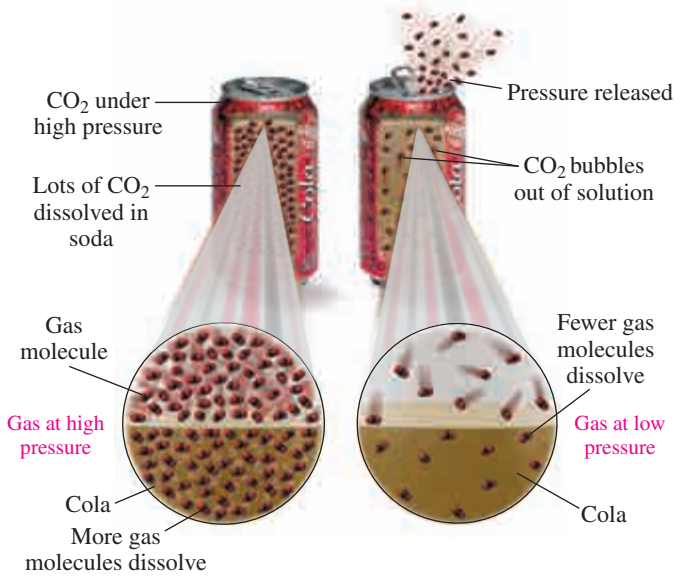
Rock candy can be made from a saturated solution of sugar (sucrose).

Questions

1. Why did more sugar dissolve as the solution was heated?
2. How did you know when you obtained a saturated solution?
3. Why did you see crystals forming on the stick or string over time?

Henry's Law

Henry's law states that the solubility of gas in a liquid is directly related to the pressure of that gas above the liquid. At higher pressures, there are more gas molecules available to enter and dissolve in the liquid. A can of soda is carbonated by using CO_2 gas at high pressure to increase the solubility of the CO_2 in the beverage. When you open the can at atmospheric pressure, the pressure on the CO_2 drops, which decreases the solubility of CO_2. As a result, bubbles of CO_2 rapidly escape from the solution. The burst of bubbles is even more noticeable when you open a warm can of soda.



When the pressure of a gas above a solution decreases, the solubility of that gas in the solution also decreases.

Explore Your World

Preparing Solutions

Obtain a drinking glass and water and place one-fourth or half cup of cold water in a glass. Begin adding one tablespoon of sugar at a time and stir thoroughly. Take a sip of the liquid in the glass as you proceed. As the sugar solution becomes more concentrated, you may need to stir for a few minutes until all the sugar dissolves. Each time, observe the solution after several minutes to determine when it is saturated.

Repeat the above activity with one-fourth or half cup of warm water. Count the number of tablespoons of sugar you need to form a saturated solution.

Questions

1. What do you notice about how sweet each sugar solution tastes?
2. How did you know when you obtained a saturated solution?
3. How much sugar dissolved in the warm water compared to the cold water?

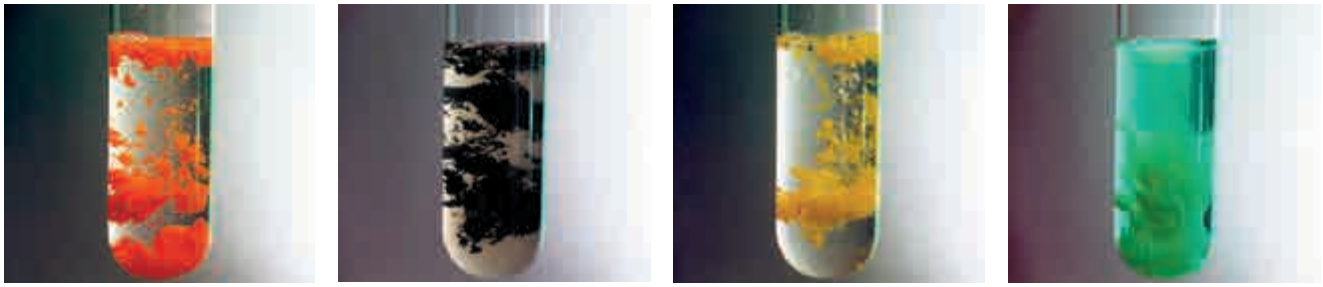
Soluble and Insoluble Ionic Compounds

In our discussion up to now, we have considered ionic compounds that dissolve in water. However, some ionic compounds do not dissociate into ions and remain as solids even in contact with water. The **solubility rules** give some guidelines about the solubility of ionic compounds in water.

Ionic compounds that are soluble in water typically contain at least one of the ions in Table 9.7. *Only an ionic compound containing a soluble cation or anion will dissolve in water.* Most ionic compounds containing Cl^- are soluble, but AgCl, $PbCl_2$, and Hg_2Cl_2 are insoluble. Similarly, most ionic compounds containing SO_4^{2-} are soluble, but a few are insoluble. Most other ionic compounds are insoluble (see Figure 9.6). In an insoluble ionic compound, the ionic bonds between its positive and negative ions are too strong for the polar water molecules to break. We can use the solubility rules to predict whether a solid ionic compound would be soluble or not. Table 9.8 illustrates the use of these rules.

TABLE 9.7 Solubility Rules for Ionic Compounds in Water

An ionic compound is soluble in water if it contains one of the following:	
Positive Ions:	Li^+, Na^+, K^+, Rb^+, Cs^+, NH_4^+
Negative Ions:	NO_3^-, $C_2H_3O_2^-$
	Cl^-, Br^-, I^- except when combined with Ag^+, Pb^{2+}, or Hg_2^{2+}
	SO_4^{2-} except when combined with Ba^{2+}, Pb^{2+}, Ca^{2+}, Sr^{2+}, or Hg_2^{2+}
Ionic compounds that do not contain at least one of these ions are usually insoluble.	



CdS FeS PbI_2 $Ni(OH)_2$

FIGURE 9.6 ▶ If an ionic compound contains a combination of a cation and an anion that are not soluble, that ionic compound is insoluble. For example, combinations of cadmium and sulfide, iron and sulfide, lead and iodide, and nickel and hydroxide do not contain any soluble ions. Thus, they form insoluble ionic compounds.

Why are each of these ionic compounds insoluble in water?

TABLE 9.8 Using Solubility Rules

Ionic Compound	Solubility in Water	Reasoning
K_2S	Soluble	Contains K^+
$Ca(NO_3)_2$	Soluble	Contains NO_3^-
$PbCl_2$	Insoluble	Is an insoluble chloride
NaOH	Soluble	Contains Na^+
$AlPO_4$	Insoluble	Contains no soluble ions

CORE CHEMISTRY SKILL

Using Solubility Rules

In medicine, insoluble $BaSO_4$ is used as an opaque substance to enhance X-rays of the gastrointestinal tract. $BaSO_4$ is so insoluble that it does not dissolve in gastric fluids (see Figure 9.7). Other ionic barium compounds cannot be used because they would dissolve in water, releasing Ba^{2+} which is poisonous.

FIGURE 9.7 ▶ A barium sulfate-enhanced X-ray of the abdomen shows the lower gastrointestinal (GI) tract.

Is $BaSO_4$ a soluble or an insoluble substance?

SAMPLE PROBLEM 9.4 Soluble and Insoluble Ionic Compounds

Predict whether each of the following ionic compounds is soluble in water and explain why:

a. Na_3PO_4 **b.** $CaCO_3$

SOLUTION

a. The ionic compound Na_3PO_4 is soluble in water because any compound that contains Na^+ is soluble.

b. The ionic compound $CaCO_3$ is not soluble. The compound does not contain a soluble positive ion, which means that ionic compound containing Ca^{2+} and CO_3^{2-} is not soluble.

STUDY CHECK 9.4

In some electrolyte drinks, $MgCl_2$ is added to provide magnesium. Why would you expect $MgCl_2$ to be soluble in water?

ANSWER

$MgCl_2$ is soluble in water because ionic compounds that contain chloride are soluble unless they contain Ag^+, Pb^{2+}, or Hg_2^{2+}.

Formation of a Solid

We can use solubility rules to predict whether a solid, called a *precipitate*, forms when two solutions containing soluble reactants are mixed as shown in Sample Problem 9.5.

Guide to Writing an Equation for the Formation of an Insoluble Ionic Compound

STEP 1 Write the ions of the reactants.

STEP 2 Write the combinations of ions and determine if any are insoluble.

STEP 3 Write the ionic equation including any solid.

STEP 4 Write the net ionic equation.

SAMPLE PROBLEM 9.5 Writing Equations for the Formation of an Insoluble Ionic Compound

When solutions of NaCl and $AgNO_3$ are mixed, a white solid forms. Write the ionic and net ionic equations for the reaction.

SOLUTION

STEP 1 Write the ions of the reactants.

Reactants (initial combinations)

$Ag^+(aq) + NO_3^-(aq)$

$Na^+(aq) + Cl^-(aq)$

STEP 2 Write the combinations of ions and determine if any are insoluble. When we look at the ions of each solution, we see that the combination of Ag^+ and Cl^- forms an insoluble ionic compound.

Mixture (new combinations)	Product	Soluble
$Ag^+(aq) + Cl^-(aq)$	AgCl	No
$Na^+(aq) + NO_3^-(aq)$	$NaNO_3$	Yes

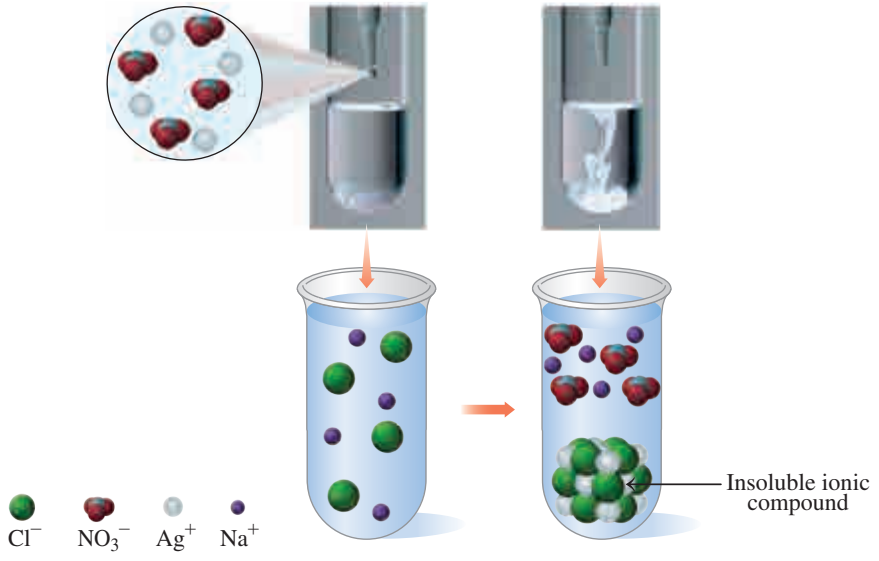
STEP 3 Write the ionic equation including any solid. In the *ionic equation*, we show all the ions of the reactants. The products include the solid AgCl that forms along with the remaining ions Na^+ and NO_3^-.

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \longrightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$$

STEP 4 Write the net ionic equation. To write a *net ionic equation*, we remove the Na^+ and NO_3^- ions, known as *spectator ions*, which are unchanged. This leaves only the ions and solid of the chemical reaction.

$$Ag^+(aq) + \underbrace{\cancel{NO_3^-(aq)} + \cancel{Na^+(aq)}}_{\text{Spectator ions}} + Cl^-(aq) \longrightarrow AgCl(s) + \underbrace{\cancel{Na^+(aq)} + \cancel{NO_3^-(aq)}}_{\text{Spectator ions}}$$

$$Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s) \quad \text{Net ionic equation}$$



Type of Equation				
Chemical	$AgNO_3(aq)$	$+ NaCl(aq)$	$\longrightarrow AgCl(s)$	$+ NaNO_3(aq)$
Ionic	$Ag^+(aq) + NO_3^-(aq)$	$+ Na^+(aq) + Cl^-(aq)$	$\longrightarrow AgCl(s)$	$+ Na^+(aq) + NO_3^-(aq)$
Net Ionic	$Ag^+(aq)$	$+ Cl^-(aq)$	$\longrightarrow AgCl(s)$	

STUDY CHECK 9.5

Predict whether a solid might form in each of the following mixtures of solutions. If so, write the net ionic equation for the reaction.

a. $NH_4Cl(aq) + Ca(NO_3)_2(aq)$ **b.** $Pb(NO_3)_2(aq) + KCl(aq)$

ANSWER

a. No solid forms because the products, $NH_4NO_3(aq)$ and $CaCl_2(aq)$, are soluble.
b. $Pb^{2+}(aq) + 2Cl^-(aq) \longrightarrow PbCl_2(s)$

QUESTIONS AND PROBLEMS

9.3 Solubility

LEARNING GOAL Define solubility; distinguish between an unsaturated and a saturated solution. Identify an ionic compound as soluble or insoluble.

Use the following table for problems 9.23 to 9.26:

	Solubility (g/100 g H_2O)	
Substance	20 °C	50 °C
KCl	34	43
$NaNO_3$	88	110
$C_{12}H_{22}O_{11}$ (sugar)	204	260

9.23 Determine whether each of the following solutions will be saturated or unsaturated at 20 °C:
a. adding 25 g of KCl to 100. g of H_2O
b. adding 11 g of $NaNO_3$ to 25 g of H_2O
c. adding 400. g of sugar to 125 g of H_2O

9.24 Determine whether each of the following solutions will be saturated or unsaturated at 50 °C:
a. adding 25 g of KCl to 50. g of H_2O
b. adding 150. g of $NaNO_3$ to 75 g of H_2O
c. adding 80. g of sugar to 25 g of H_2O

9.25 A solution containing 80. g of KCl in 200. g of H_2O at 50 °C is cooled to 20 °C.
a. How many grams of KCl remain in solution at 20 °C?
b. How many grams of solid KCl crystallized after cooling?

9.26 A solution containing 80. g of $NaNO_3$ in 75 g of H_2O at 50 °C is cooled to 20 °C.
a. How many grams of $NaNO_3$ remain in solution at 20 °C?
b. How many grams of solid $NaNO_3$ crystallized after cooling?

9.27 Explain the following observations:
a. More sugar dissolves in hot tea than in iced tea.
b. Champagne in a warm room goes flat.
c. A warm can of soda has more spray when opened than a cold one.

9.28 Explain the following observations:
a. An open can of soda loses its "fizz" faster at room temperature than in the refrigerator.
b. Chlorine gas in tap water escapes as the sample warms to room temperature.
c. Less sugar dissolves in iced coffee than in hot coffee.

9.29 Predict whether each of the following ionic compounds is soluble in water:
a. LiCl **b.** AgCl **c.** $BaCO_3$ **d.** K_2O **e.** $Fe(NO_3)_3$

9.30 Predict whether each of the following ionic compounds is soluble in water:
a. PbS **b.** KI **c.** Na_2S **d.** Ag_2O **e.** $CaSO_4$

9.31 Determine whether a solid forms when solutions containing the following ionic compounds are mixed. If so, write the ionic equation and the net ionic equation.
a. $KCl(aq)$ and $Na_2S(aq)$ **b.** $AgNO_3(aq)$ and $K_2S(aq)$
c. $CaCl_2(aq)$ and $Na_2SO_4(aq)$ **d.** $CuCl_2(aq)$ and $Li_3PO_4(aq)$

9.32 Determine whether a solid forms when solutions containing the following ionic compounds are mixed. If so, write the ionic equation and the net ionic equation.
a. $Na_3PO_4(aq)$ and $AgNO_3(aq)$
b. $K_2SO_4(aq)$ and $Na_2CO_3(aq)$
c. $Pb(NO_3)_2(aq)$ and $Na_2CO_3(aq)$
d. $BaCl_2(aq)$ and $KOH(aq)$

9.4 Solution Concentrations and Reactions

LEARNING GOAL

Calculate the concentration of a solute in a solution; use concentration units to calculate the amount of solute or solution. Given the volume and concentration of a solution, calculate the amount of another reactant or product in a reaction.

The amount of solute dissolved in a certain amount of solution is called the **concentration** of the solution. We will look at ways to express a concentration as a ratio of a certain amount of solute in a given amount of solution. The amount of a solute may be expressed in units of grams, milliliters, or moles. The amount of a solution may be expressed in units of grams, milliliters, or liters.

$$\text{Concentration of a solution} = \frac{\text{amount of solute}}{\text{amount of solution}}$$

Add 8.00 g of KCl

Add water until the solution has a mass of 50.00 g

When water is added to 8.00 g of KCl to form 50.00 g of a KCl solution, the mass percent concentration is 16.0% (m/m).

Mass Percent (m/m) Concentration

Mass percent (m/m) describes the mass of the solute in grams for exactly 100 g of solution. In the calculation of mass percent (m/m), the units of mass of the solute and solution must be the same. If the mass of the solute is given as grams, then the mass of the solution must also be grams. The mass of the solution is the sum of the mass of the solute and the mass of the solvent.

$$\text{Mass percent (m/m)} = \frac{\text{mass of solute (g)}}{\text{mass of solute (g)} + \text{mass of solvent (g)}} \times 100\%$$

$$= \frac{\text{mass of solute (g)}}{\text{mass of solution (g)}} \times 100\%$$

Suppose we prepared a solution by mixing 8.00 g of KCl (solute) with 42.00 g of water (solvent). Together, the mass of the solute and mass of solvent give the mass of the solution (8.00 g + 42.00 g = 50.00 g). Mass percent is calculated by substituting the mass of the solute and the mass of the solution into the mass percent expression.

$$\frac{8.00 \text{ g KCl}}{\underbrace{8.00 \text{ g KCl} + 42.00 \text{ g } H_2O}_{\text{Solute} \quad + \quad \text{Solvent}}} \times 100\% = 16.0\% \text{ (m/m) KCl solution}$$

Guide to Calculating Solution Concentration

STEP 1 State the given and needed quantities.

STEP 2 Write the concentration expression.

STEP 3 Substitute solute and solution quantities into the expression and calculate.

SAMPLE PROBLEM 9.6 Calculating Mass Percent (m/m) Concentration

What is the mass percent of NaOH in a solution prepared by dissolving 30.0 g of NaOH in 120.0 g of H_2O?

SOLUTION

STEP 1 State the given and needed quantities.

	Given	Need
ANALYZE THE PROBLEM	30.0 g of NaOH solute, 30.0 g NaOH + 120.0 g H_2O = 150.0 g of NaOH solution	mass percent (m/m)

STEP 2 Write the concentration expression.

$$\text{Mass percent (m/m)} = \frac{\text{grams of solute}}{\text{grams of solution}} \times 100\%$$

STEP 3 Substitute solute and solution quantities into the expression and calculate.

$$\text{Mass percent (m/m)} = \frac{30.0 \text{ g NaOH}}{150.0 \text{ g solution}} \times 100\%$$

$$= 20.0\% \text{ (m/m) NaOH solution}$$

STUDY CHECK 9.6

What is the mass percent (m/m) of NaCl in a solution made by dissolving 2.0 g of NaCl in 56.0 g of H_2O?

ANSWER

3.4% (m/m) NaCl solution

Volume Percent (v/v) Concentration

Because the volumes of liquids or gases are easily measured, the concentrations of their solutions are often expressed as **volume percent (v/v)**. The units of volume used in the ratio must be the same, for example, both in milliliters or both in liters.

$$\text{Volume percent (v/v)} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$$

We interpret a volume percent as the volume of solute in exactly 100 mL of solution. On a bottle of extract of vanilla, a label that reads alcohol 35% (v/v) means 35 mL of ethanol solute in exactly 100 mL of vanilla solution.

The label indicates that vanilla extract contains 35% (v/v) alcohol.

SAMPLE PROBLEM 9.7 Calculating Volume Percent (v/v) Concentration

A bottle contains 59 mL of lemon extract solution. If the extract contains 49 mL of alcohol, what is the volume percent (v/v) of the alcohol in the solution?

SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	49 mL of alcohol, 59 mL of solution	volume percent (v/v)

STEP 2 Write the concentration expression.

$$\text{Volume percent (v/v)} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$$

STEP 3 Substitute solute and solution quantities into the expression and calculate.

$$\text{Volume percent (v/v)} = \frac{49 \text{ mL alcohol}}{59 \text{ mL solution}} \times 100\% = 83\% \text{ (v/v) alcohol solution}$$

Lemon extract is a solution of lemon flavor and alcohol.

CORE CHEMISTRY SKILL

Calculating Concentration

STUDY CHECK 9.7

What is the volume percent (v/v) of Br_2 in a solution prepared by dissolving 12 mL of liquid bromine (Br_2) in the solvent carbon tetrachloride (CCl_4) to make 250 mL of solution?

ANSWER

4.8% (v/v) Br_2 in CCl_4

Mass/Volume Percent (m/v) Concentration

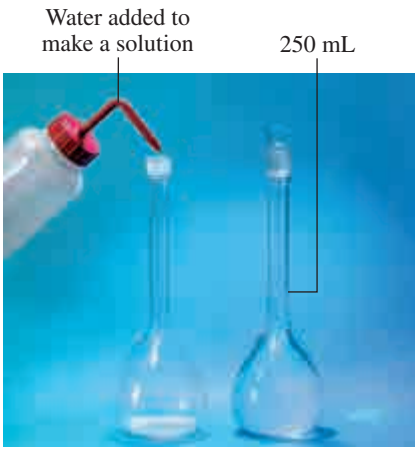
Mass/volume percent (m/v) describes the mass of the solute in grams for exactly 100 mL of solution. In the calculation of mass/volume percent, the unit of mass of the solute is grams and the unit of the solution volume is milliliters.

$$\text{Mass/volume percent (m/v)} = \frac{\text{grams of solute}}{\text{milliliters of solution}} \times 100\%$$

The mass/volume percent is widely used in hospitals and pharmacies for the preparation of intravenous solutions and medicines. For example, a 5% (m/v) glucose solution contains 5 g of glucose in 100 mL of solution. The volume of solution represents the combined volumes of the glucose and H_2O.

SAMPLE PROBLEM 9.8 Calculating Mass/Volume Percent (m/v) Concentration

A potassium iodide solution may be used in a diet that is low in iodine. A KI solution is prepared by dissolving 5.0 g of KI in enough water to give a final volume of 250 mL. What is the mass/volume percent (m/v) of the KI solution?



SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	5.0 g of KI solute, 250 mL of KI solution	mass/volume percent (m/v)

STEP 2 Write the concentration expression.

$$\text{Mass/volume percent (m/v)} = \frac{\text{mass of solute}}{\text{volume of solution}} \times 100\%$$

STEP 3 Substitute solute and solution quantities into the expression and calculate.

$$\text{Mass/volume percent (m/v)} = \frac{5.0\text{ g KI}}{250\text{ mL solution}} \times 100\%$$
$$= 2.0\%\text{ (m/v) KI solution}$$

STUDY CHECK 9.8

What is the mass/volume percent (m/v) of NaOH in a solution prepared by dissolving 12 g of NaOH in enough water to make 220 mL of solution?

ANSWER

5.5% (m/v) NaOH solution

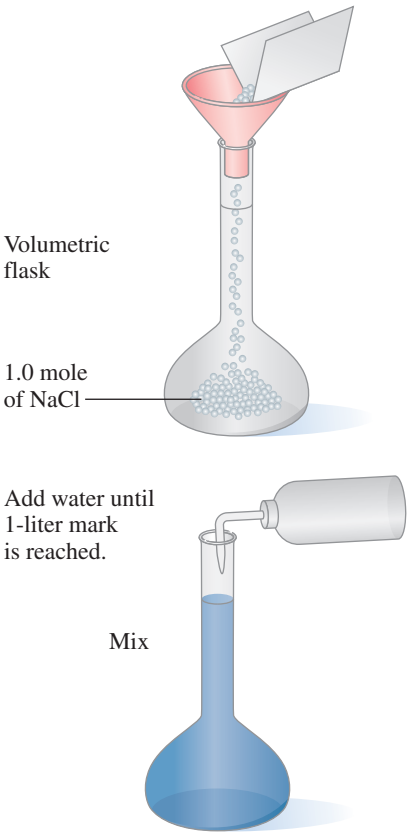
Molarity (M) Concentration

When chemists work with solutions, they often use **molarity (M)**, a concentration that states the number of moles of solute in exactly 1 L of solution.

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

The molarity of a solution can be calculated knowing the moles of solute and the volume of solution in liters. For example, if 1.0 mole of NaCl were dissolved in enough water to prepare 1.0 L of solution, the resulting NaCl solution has a molarity of 1.0 M. The abbreviation M indicates the units of mole per liter (mole/L).

$$\text{M} = \frac{\text{moles of solute}}{\text{liters of solution}} = \frac{1.0\text{ mole NaCl}}{1\text{ L solution}} = 1.0\text{ M NaCl solution}$$



A 1.0 molar (M) NaCl solution

SAMPLE PROBLEM 9.9 Calculating Molarity

What is the molarity (M) of 60.0 g of NaOH in 0.250 L of NaOH solution?

SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	60.0 g of NaOH, 0.250 L of NaOH solution	molarity (mole/L)

To calculate the moles of NaOH, we need to write the equality and conversion factors for the molar mass of NaOH. Then the moles in 60.0 g of NaOH can be determined.

$$1 \text{ mole of NaOH} = 40.00 \text{ g of NaOH}$$

$$\frac{1 \text{ mole NaOH}}{40.00 \text{ g NaOH}} \quad \text{and} \quad \frac{40.00 \text{ g NaOH}}{1 \text{ mole NaOH}}$$

$$\text{moles of NaOH} = 60.0 \text{ g NaOH} \times \frac{1 \text{ mole NaOH}}{40.00 \text{ g NaOH}}$$

$$= 1.50 \text{ moles of NaOH}$$

$$\text{volume of solution} = 0.250 \text{ L of NaOH solution}$$

STEP 2 Write the concentration expression.

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

STEP 3 Substitute solute and solution quantities into the expression and calculate.

$$\text{M} = \frac{1.50 \text{ moles NaOH}}{0.250 \text{ L solution}} = \frac{6.00 \text{ moles NaOH}}{1 \text{ L solution}} = 6.00 \text{ M NaOH solution}$$

STUDY CHECK 9.9

What is the molarity of a solution that contains 75.0 g of KNO_3 dissolved in 0.350 L of solution?

ANSWER

2.12 M KNO_3 solution

Table 9.9 summarizes the types of units used in the various types of concentration expressions for solutions.

TABLE 9.9 Summary of Types of Concentration Expressions and Their Units

Concentration Units	Mass Percent (m/m)	Volume Percent (v/v)	Mass/Volume Percent (m/v)	Molarity (M)
Solute	g	mL	g	mole
Solution	g	mL	mL	L

Using Concentration as a Conversion Factor

CORE CHEMISTRY SKILL

Using Concentration as a Conversion Factor

In the preparation of solutions, we often need to calculate the amount of solute or solution. Then the concentration is useful as a conversion factor. Some examples of percent concentrations and molarity, their meanings, and conversion factors are given in Table 9.10. Some examples of using percent concentration or molarity as conversion factors are given in Sample Problems 9.10 and 9.11.

TABLE 9.10 Conversion Factors from Concentrations

Percent Concentration	Meaning	Conversion Factors		
10% (m/m) KCl solution	10 g of KCl in 100 g of KCl solution	$\frac{10 \text{ g KCl}}{100 \text{ g solution}}$	and	$\frac{100 \text{ g solution}}{10 \text{ g KCl}}$
12% (v/v) ethanol solution	12 mL of ethanol in 100 mL of ethanol solution	$\frac{12 \text{ mL ethanol}}{100 \text{ mL solution}}$	and	$\frac{100 \text{ mL solution}}{12 \text{ mL ethanol}}$
5% (m/v) glucose solution	5 g of glucose in 100 mL of glucose solution	$\frac{5 \text{ g glucose}}{100 \text{ mL solution}}$	and	$\frac{100 \text{ mL solution}}{5 \text{ g glucose}}$
Molarity				
6.0 M HCl solution	6.0 moles of HCl in 1 liter of HCl solution	$\frac{6.0 \text{ moles HCl}}{1 \text{ L solution}}$	and	$\frac{1 \text{ L solution}}{6.0 \text{ moles HCl}}$

Guide to Using Concentration to Calculate Mass or Volume

STEP 1 State the given and needed quantities.

STEP 2 Write a plan to calculate the mass or volume.

STEP 3 Write equalities and conversion factors.

STEP 4 Set up the problem to calculate the mass or volume.

SAMPLE PROBLEM 9.10 Using Mass/Volume Percent to Find Mass of Solute

A topical antibiotic is 1.0% (m/v) clindamycin. How many grams of clindamycin are in 60. mL of the 1.0% (m/v) solution?

SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	60. mL of 1.0% (m/v) clindamycin solution	grams of clindamycin

STEP 2 Write a plan to calculate the mass.

milliliters of solution → % (m/v) factor → grams of clindamycin

STEP 3 Write equalities and conversion factors. The percent (m/v) indicates the grams of a solute in every 100 mL of a solution. The 1.0% (m/v) can be written as two conversion factors.

$$100 \text{ mL of solution} = 1.0 \text{ g of clindamycin}$$

$$\frac{1.0 \text{ g clindamycin}}{100 \text{ mL solution}} \quad \text{and} \quad \frac{100 \text{ mL solution}}{1.0 \text{ g clindamycin}}$$

STEP 4 Set up the problem to calculate the mass. The volume of the solution is converted to mass of solute using the conversion factor that cancels mL.

$$60.\ \cancel{\text{mL solution}} \times \frac{1.0 \text{ g clindamycin}}{100\ \cancel{\text{mL solution}}} = 0.60 \text{ g of clindamycin}$$

STUDY CHECK 9.10

In 2010, the FDA approved a 2.0% (m/v) morphine oral solution to treat severe or chronic pain. How many grams of morphine does a patient receive if 0.60 mL of 2.0% (m/v) morphine solution was ordered?

ANSWER

0.012 g of morphine

SAMPLE PROBLEM 9.11 Using Molarity to Calculate Volume of Solution

How many liters of a 2.00 M NaCl solution are needed to provide 67.3 g of NaCl?

SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	67.3 g of NaCl, 2.00 M NaCl solution	liters of NaCl solution

STEP 2 Write a plan to calculate the volume.

grams of NaCl → Molar mass → moles of NaCl → Molarity → liters of NaCl solution

STEP 3 Write equalities and conversion factors.

1 mole of NaCl = 58.44 g of NaCl

$$\frac{1 \text{ mole NaCl}}{58.44 \text{ g NaCl}} \quad \text{and} \quad \frac{58.44 \text{ g NaCl}}{1 \text{ mole NaCl}}$$

1 L of NaCl solution = 2.00 moles of NaCl

$$\frac{1 \text{ L NaCl solution}}{2.00 \text{ moles NaCl}} \quad \text{and} \quad \frac{2.00 \text{ moles NaCl}}{1 \text{ L NaCl solution}}$$

STEP 4 Set up the problem to calculate the volume.

$$\text{liters of NaCl solution} = 67.3 \text{ g NaCl} \times \frac{1 \text{ mole NaCl}}{58.44 \text{ g NaCl}} \times \frac{1 \text{ L NaCl solution}}{2.00 \text{ moles NaCl}}$$

$$= 0.576 \text{ L of NaCl solution}$$

STUDY CHECK 9.11

How many milliliters of a 6.0 M HCl solution will provide 164 g of HCl?

ANSWER

750 mL of HCl solution

CORE CHEMISTRY SKILL

Calculating the Quantity of a Reactant or Product for a Chemical Reaction in Solution

Chemical Reactions in Solution

When chemical reactions involve aqueous solutions, we use the balanced chemical equation, the molarity, and the volume to determine the moles or grams of the reactants or products. For example, we can determine the volume of a solution from the molarity and the grams of reactant as seen in Sample Problem 9.12.

Guide to Calculations Involving Solutions in Chemical Reactions

STEP 1 State the given and needed quantities.

STEP 2 Write a plan to calculate the needed quantity or concentration.

STEP 3 Write equalities and conversion factors including mole–mole and concentration factors.

STEP 4 Set up the problem to calculate the needed quantity or concentration.

SAMPLE PROBLEM 9.12 Volume of a Solution in a Reaction

Zinc reacts with HCl to produce hydrogen gas, H_2, and $ZnCl_2$.

$$Zn(s) + 2HCl(aq) \longrightarrow H_2(g) + ZnCl_2(aq)$$

How many liters of a 1.50 M HCl solution completely react with 5.32 g of zinc?

SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	5.32 g of Zn, 1.50 M HCl solution	liters of HCl solution
	Equation	
	$Zn(s) + 2HCl(aq) \longrightarrow H_2(g) + ZnCl_2(aq)$	

STEP 2 Write a plan to calculate the needed quantity.

grams of Zn → Molar mass → moles of Zn → Mole–mole factor → moles of HCl → Molarity → liters of HCl solution

STEP 3 Write equalities and conversion factors including mole–mole and concentration factors.

1 mole of Zn = 65.41 g of Zn

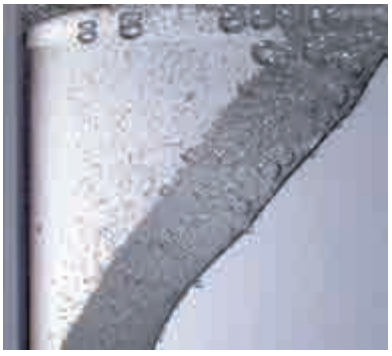
$$\frac{1 \text{ mole Zn}}{65.41 \text{ g Zn}} \quad \text{and} \quad \frac{65.41 \text{ g Zn}}{1 \text{ mole Zn}}$$

1 mole of Zn = 2 moles of HCl

$$\frac{1 \text{ mole Zn}}{2 \text{ moles HCl}} \quad \text{and} \quad \frac{2 \text{ moles HCl}}{1 \text{ mole Zn}}$$

1 L of solution = 1.50 moles of HCl

$$\frac{1 \text{ L solution}}{1.50 \text{ moles HCl}} \quad \text{and} \quad \frac{1.50 \text{ moles HCl}}{1 \text{ L solution}}$$



Zinc reacts when placed in a solution of HCl.

STEP 4 Set up the problem to calculate the needed quantity.

$$5.32\ \cancel{\text{g Zn}} \times \frac{1\ \cancel{\text{mole Zn}}}{65.41\ \cancel{\text{g Zn}}} \times \frac{2\ \cancel{\text{moles HCl}}}{1\ \cancel{\text{mole Zn}}} \times \frac{1\ \text{L solution}}{1.50\ \cancel{\text{moles HCl}}} = 0.108\ \text{L of HCl solution}$$

STUDY CHECK 9.12

Using the reaction in Sample Problem 9.12, how many grams of zinc can react with 225 mL of a 0.200 M HCl solution?

ANSWER

1.47 g of Zn

SAMPLE PROBLEM 9.13 Volume of a Reactant in a Solution

How many milliliters of a 0.250 M $BaCl_2$ solution are needed to react with 0.0325 L of a 0.160 M Na_2SO_4 solution?

$$Na_2SO_4(aq) + BaCl_2(aq) \longrightarrow BaSO_4(s) + 2NaCl(aq)$$

When a $BaCl_2$ solution is added to a Na_2SO_4 solution, $BaSO_4$, a white solid, forms.

SOLUTION

STEP 1 State the given and needed quantities.

	Given	Need
ANALYZE THE PROBLEM	0.0325 L of 0.160 M Na_2SO_4 solution 0.250 M $BaCl_2$ solution	milliliters of $BaCl_2$ solution
	Equation	
	$Na_2SO_4(aq) + BaCl_2(aq) \longrightarrow BaSO_4(s) + 2NaCl(aq)$	

STEP 2 Write a plan to calculate the needed quantity.

liters of Na_2SO_4 solution → Molarity → moles of Na_2SO_4 → Mole–mole factor → moles of $BaCl_2$

→ Molarity → liters of $BaCl_2$ solution → Metric factor → milliliters of $BaCl_2$ solution

STEP 3 Write equalities and conversion factors including mole–mole and concentration factors.

1 L of solution = 0.160 mole of Na_2SO_4

$$\frac{1\ \text{L solution}}{0.160\ \text{mole } Na_2SO_4} \quad \text{and} \quad \frac{0.160\ \text{mole } Na_2SO_4}{1\ \text{L solution}}$$

1 mole of Na_2SO_4 = 1 mole of $BaCl_2$

$$\frac{1\ \text{mole } Na_2SO_4}{1\ \text{mole } BaCl_2} \quad \text{and} \quad \frac{1\ \text{mole } BaCl_2}{1\ \text{mole } Na_2SO_4}$$

1 L of solution = 0.250 mole of $BaCl_2$

$$\frac{1\ \text{L solution}}{0.250\ \text{mole } BaCl_2} \quad \text{and} \quad \frac{0.250\ \text{mole } BaCl_2}{1\ \text{L solution}}$$

1 L = 1000 mL

$$\frac{1\ \text{L}}{1000\ \text{mL}} \quad \text{and} \quad \frac{1000\ \text{mL}}{1\ \text{L}}$$

STEP 4 Set up the problem to calculate the needed quantity.

$$0.0325\ \cancel{\text{L solution}} \times \frac{0.160\ \cancel{\text{mole } Na_2SO_4}}{1\ \cancel{\text{L solution}}} \times \frac{1\ \cancel{\text{mole } BaCl_2}}{1\ \cancel{\text{mole } Na_2SO_4}} \times \frac{1\ \cancel{\text{L solution}}}{0.250\ \cancel{\text{mole } BaCl_2}} \times \frac{1000\ \text{mL } BaCl_2\ \text{solution}}{1\ \cancel{\text{L solution}}}$$

$$= 20.8\ \text{mL of } BaCl_2 \text{ solution}$$

STUDY CHECK 9.13

For the reaction in Sample Problem 9.13, how many milliliters of a 0.330 M Na_2SO_4 solution are needed to react with 26.8 mL of a 0.216 M $BaCl_2$ solution?

ANSWER

17.5 mL of Na_2SO_4 solution

Figure 9.8 gives a summary of the pathways and conversion factors needed for substances including solutions involved in chemical reactions.

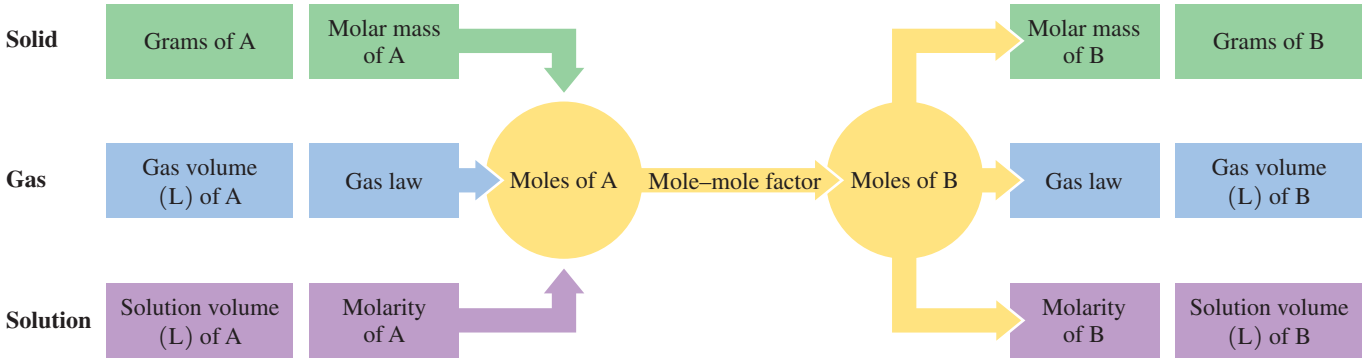


FIGURE 9.8 ▶ In calculations involving chemical reactions, substance A is converted to moles of A using molar mass (if solid), gas laws (if gas), or molarity (if solution). Then moles of A are converted to moles of substance B, which are converted to grams of solid, liters of gas, or liters of solution, as needed.

What sequence of conversion factors would you use to calculate the number of grams of $CaCO_3$ needed to react with 1.50 L of a 2.00 M HCl solution in the reaction $CaCO_3(s) + 2HCl(aq) \longrightarrow CO_2(g) + H_2O(l) + CaCl_2(aq)$?

QUESTIONS AND PROBLEMS

9.4 Solution Concentrations and Reactions

LEARNING GOAL Calculate the concentration of a solute in a solution; use concentration units to calculate the amount of solute or solution. Given the volume and concentration of a solution, calculate the amount of another reactant or product in a reaction.

Interactive Video

Solutions

9.33 Calculate the mass percent (m/m) for the solute in each of the following:
- **a.** 25 g of KCl and 125 g of H_2O
- **b.** 12 g of sucrose in 225 g of tea solution
- **c.** 8.0 g of $CaCl_2$ in 80.0 g of $CaCl_2$ solution

9.34 Calculate the mass percent (m/m) for the solute in each of the following:
- **a.** 75 g of NaOH in 325 g of NaOH solution
- **b.** 2.0 g of KOH and 20.0 g of H_2O
- **c.** 48.5 g of Na_2CO_3 in 250.0 g of Na_2CO_3 solution

9.35 Calculate the mass/volume percent (m/v) for the solute in each of the following:
- **a.** 75 g of Na_2SO_4 in 250 mL of Na_2SO_4 solution
- **b.** 39 g of sucrose in 355 mL of a carbonated drink

9.36 Calculate the mass/volume percent (m/v) for the solute in each of the following:
- **a.** 2.50 g of LiCl in 40.0 mL of LiCl solution
- **b.** 7.5 g of casein in 120 mL of low-fat milk

9.37 Calculate the grams or milliliters of solute needed to prepare the following:
- **a.** 50. g of a 5.0% (m/m) KCl solution
- **b.** 1250 mL of a 4.0% (m/v) NH_4Cl solution
- **c.** 250. mL of a 10.0% (v/v) acetic acid solution

9.38 Calculate the grams or milliliters of solute needed to prepare the following:
- **a.** 150. g of a 40.0% (m/m) $LiNO_3$ solution
- **b.** 450 mL of a 2.0% (m/v) KOH solution
- **c.** 225 mL of a 15% (v/v) isopropyl alcohol solution

9.39 A mouthwash contains 22.5% (v/v) alcohol. If the bottle of mouthwash contains 355 mL, what is the volume, in milliliters, of alcohol?

9.40 A bottle of champagne is 11% (v/v) alcohol. If there are 750 mL of champagne in the bottle, what is the volume, in milliliters, of alcohol?

9.41 For each of the following solutions, calculate the:
- **a.** grams of 25% (m/m) $LiNO_3$ solution that contains 5.0 g of $LiNO_3$
- **b.** milliliters of 10.0% (m/v) KOH solution that contains 40.0 g of KOH
- **c.** milliliters of 10.0% (v/v) formic acid solution that contains 2.0 mL of formic acid

9.42 For each of the following solutions, calculate the:
a. grams of 2.0% (m/m) NaCl solution that contains 7.50 g of NaCl
b. milliliters of 25% (m/v) NaF solution that contains 4.0 g of NaF
c. milliliters of 8.0% (v/v) ethanol solution that contains 20.0 mL of ethanol

9.43 Calculate the molarity of each of the following:
a. 2.00 moles of glucose in 4.00 L of a glucose solution
b. 4.00 g of KOH in 2.00 L of a KOH solution
c. 5.85 g of NaCl in 400. mL of a NaCl solution

9.44 Calculate the molarity of each of the following:
a. 0.500 mole of glucose in 0.200 L of a glucose solution
b. 73.0 g of HCl in 2.00 L of a HCl solution
c. 30.0 g of NaOH in 350. mL of a NaOH solution

9.45 Calculate the grams of solute needed to prepare each of the following:
a. 2.00 L of a 1.50 M NaOH solution
b. 4.00 L of a 0.200 M KCl solution
c. 25.0 mL of a 6.00 M HCl solution

9.46 Calculate the grams of solute needed to prepare each of the following:
a. 2.00 L of a 6.00 M NaOH solution
b. 5.00 L of a 0.100 M $CaCl_2$ solution
c. 175 mL of a 3.00 M $NaNO_3$ solution

9.47 For each of the following solutions, calculate the:
a. liters of a 2.00 M KBr solution to obtain 3.00 moles of KBr
b. liters of a 1.50 M NaCl solution to obtain 15.0 moles of NaCl
c. milliliters of a 0.800 M $Ca(NO_3)_2$ solution to obtain 0.0500 mole of $Ca(NO_3)_2$

9.48 For each of the following solutions, calculate the:
a. liters of a 4.00 M KCl solution to obtain 0.100 mole of KCl
b. liters of a 6.00 M HCl solution to obtain 5.00 moles of HCl
c. milliliters of a 2.50 M K_2SO_4 solution to obtain 1.20 moles of K_2SO_4

9.49 Answer the following for the reaction:

$$Pb(NO_3)_2(aq) + 2KCl(aq) \longrightarrow PbCl_2(s) + 2KNO_3(aq)$$

a. How many grams of $PbCl_2$ will be formed from 50.0 mL of a 1.50 M KCl solution?
b. How many milliliters of a 2.00 M $Pb(NO_3)_2$ solution will react with 50.0 mL of a 1.50 M KCl solution?
c. What is the molarity of 20.0 mL of a KCl solution that reacts completely with 30.0 mL of a 0.400 M $Pb(NO_3)_2$ solution?

9.50 Answer the following for the reaction:

$$NiCl_2(aq) + 2NaOH(aq) \longrightarrow Ni(OH)_2(s) + 2NaCl(aq)$$

a. How many milliliters of a 0.200 M NaOH solution are needed to react with 18.0 mL of a 0.500 M $NiCl_2$ solution?
b. How many grams of $Ni(OH)_2$ are produced from the reaction of 35.0 mL of a 1.75 M NaOH solution and excess $NiCl_2$?
c. What is the molarity of 30.0 mL of a $NiCl_2$ solution that reacts completely with 10.0 mL of a 0.250 M NaOH solution?

9.51 Answer the following for the reaction:

$$Mg(s) + 2HCl(aq) \longrightarrow H_2(g) + MgCl_2(aq)$$

a. How many milliliters of a 6.00 M HCl solution are required to react with 15.0 g of magnesium?
b. How many liters of hydrogen gas can form at STP when 0.500 L of a 2.00 M HCl solution reacts with excess magnesium?
c. What is the molarity of a HCl solution if the reaction of 45.2 mL of the HCl solution with excess magnesium produces 5.20 L of H_2 gas at 735 mmHg and 25 °C?

9.52 Answer the following for the reaction:

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CO_2(g) + H_2O(l) + CaCl_2(aq)$$

a. How many milliliters of a 0.200 M HCl solution can react with 8.25 g of $CaCO_3$?
b. How many liters of CO_2 gas can form at STP when 15.5 mL of a 3.00 M HCl solution reacts with excess $CaCO_3$?
c. What is the molarity of a HCl solution if the reaction of 200. mL of the HCl solution with excess $CaCO_3$ produces 12.0 L of CO_2 gas at 725 mmHg and 18 °C?

Clinical Applications

9.53 A patient receives 100. mL of 20.% (m/v) mannitol solution every hour.
a. How many grams of mannitol are given in 1 h?
b. How many grams of mannitol does the patient receive in 12 h?

9.54 A patient receives 250 mL of a 4.0% (m/v) amino acid solution twice a day.
a. How many grams of amino acids are in 250 mL of solution?
b. How many grams of amino acids does the patient receive in 1 day?

9.55 A patient needs 100. g of glucose in the next 12 h. How many liters of a 5% (m/v) glucose solution must be given?

9.56 A patient received 2.0 g of NaCl in 8 h. How many milliliters of a 0.90% (m/v) NaCl (saline) solution were delivered?

9.57 A doctor orders 0.075 g of chlorpromazine, which is used to treat schizophrenia. If the stock solution is 2.5% (m/v), how many milliliters are administered to the patient?

9.58 A doctor orders 5 mg of compazine, which is used to treat nausea, vertigo, and migraine headaches. If the stock solution is 2.5% (m/v), how many milliliters are administered to the patient?

9.59 A $CaCl_2$ solution is given to increase blood levels of calcium. If a patient receives 5.0 mL of a 10.% (m/v) $CaCl_2$ solution, how many grams of $CaCl_2$ were given?

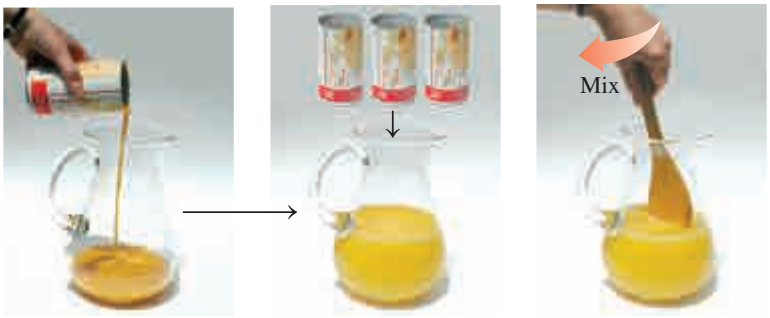
9.60 An intravenous solution of mannitol is used as a diuretic to increase the loss of sodium and chloride by a patient. If a patient receives 30.0 mL of a 25% (m/v) mannitol solution, how many grams of mannitol were given?

9.5 Dilution of Solutions

LEARNING GOAL

Describe the dilution of a solution; calculate the unknown concentration or volume when a solution is diluted.

In chemistry and biology, we often prepare diluted solutions from more concentrated solutions. In a process called **dilution**, a solvent, usually water, is added to a solution, which increases the volume. As a result, the concentration of the solution decreases. In an everyday example, you are making a dilution when you add three cans of water to a can of concentrated orange juice.



1 can of orange juice concentrate + 3 cans of water = 4 cans of orange juice

Although the addition of solvent increases the volume, the amount of solute does not change; it is the same in the concentrated solution and the diluted solution (see Figure 9.9).

Grams or moles of solute = grams or moles of solute

Concentrated solution — Diluted solution

We can write this equality in terms of the concentration, C, and the volume, V. The concentration, C, may be percent concentration or molarity.

$$C_1V_1 = C_2V_2$$

Concentrated solution — Diluted solution

If we are given any three of the four variables (C_1, C_2, V_1, or V_2), we can rearrange the dilution expression to solve for the unknown quantity as seen in Sample Problem 9.14.

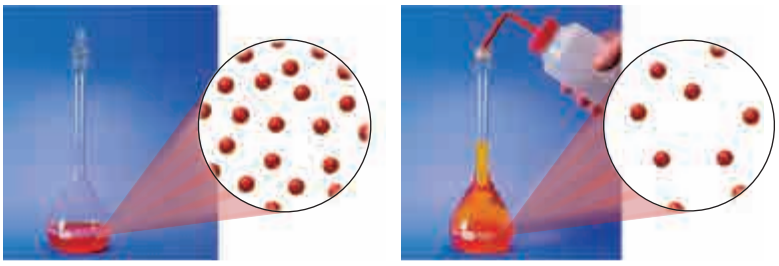


FIGURE 9.9 ▶ When water is added to a concentrated solution, there is no change in the number of particles. However, the solute particles spread out as the volume of the diluted solution increases.

What is the concentration of the diluted solution after an equal volume of water is added to a sample of a 6 M HCl solution?

SAMPLE PROBLEM 9.14 Dilution of a Solution

A doctor orders 1000. mL of a 35.0% (m/v) dextrose solution. If you have a 50.0% (m/v) dextrose solution, how many milliliters would you use to prepare 1000. mL of 35.0% (m/v) dextrose solution?

SOLUTION

STEP 1 **Prepare a table of the concentrations and volumes of the solutions.** For our problem analysis, we organize the solution data in a table, making sure that the units of concentration and volume are the same.

Guide to Calculating Dilution Quantities

STEP 1 Prepare a table of the concentrations and volumes of the solutions.

STEP 2 Rearrange the dilution expression to solve for the unknown quantity.

STEP 3 Substitute the known quantities into the dilution expression and calculate.

	Concentrated Solution	Diluted Solution	Know	Predict
ANALYZE THE PROBLEM	$C_1 = 50.0\%$ (m/v) dextrose	$C_2 = 35.0\%$ (m/v) dextrose	C_1 increases	
	$V_1 = ?$ mL	$V_2 = 1000.$ mL		V_1 decreases

STEP 2 Rearrange the dilution expression to solve for the unknown quantity.

$$C_1V_1 = C_2V_2$$

$$\frac{\cancel{C_1}V_1}{\cancel{C_1}} = \frac{C_2V_2}{C_1} \quad \text{Divide both sides by } C_1$$

$$V_1 = V_2 \times \frac{C_2}{C_1}$$

STEP 3 Substitute the known quantities into the dilution expression and calculate.

$$V_1 = 1000.\text{ mL} \times \underbrace{\frac{35.0\%}{50.0\%}}_{\text{Concentration factor decreases volume}} = 700.\text{ mL of dextrose solution}$$

When the final volume (V_2) is multiplied by a ratio of the percent concentrations (concentration factor) that is less than 1, the initial volume (V_1) is less than the final volume (V_2) as predicted in Step 1.

STUDY CHECK 9.14

What initial volume of a 15% (m/v) mannose solution is needed to prepare 125 mL of a 3.0% (m/v) mannose solution?

ANSWER

25 mL of a 15% (m/v) mannose solution

SAMPLE PROBLEM 9.15 Molarity of a Diluted Solution

What is the molarity of a solution when 75.0 mL of a 4.00 M KCl solution is diluted to a volume of 500. mL?

SOLUTION

STEP 1 Prepare a table of the concentrations and volumes of the solutions.

	Concentrated Solution	Diluted Solution	Know	Predict
ANALYZE THE PROBLEM	$C_1 = 4.00$ M KCl	$C_2 = ?$ M KCl		C (molarity) decreases
	$V_1 = 75.0$ mL $= 0.0750$ L	$V_2 = 500.$ mL $= 0.500$ L	V increases	

STEP 2 Rearrange the dilution expression to solve for the unknown quantity.

$$C_1V_1 = C_2V_2$$

$$\frac{C_1V_1}{V_2} = \frac{C_2\cancel{V_2}}{\cancel{V_2}} \quad \text{Divide both sides by } V_2$$

$$C_2 = C_1 \times \frac{V_1}{V_2}$$

STEP 3 Substitute the known quantities into the dilution expression and calculate.

$$C_2 = 4.00\ \text{M} \times \underbrace{\frac{75.0\ \cancel{\text{mL}}}{500.\ \cancel{\text{mL}}}}_{\text{Volume factor decreases concentration}} = 0.600\ \text{M (diluted KCl solution)}$$

When the initial molarity (C_1) is multiplied by a ratio of the volumes (volume factor) that is less than 1, the molarity of the diluted solution decreases as predicted in Step 1.

STUDY CHECK 9.15

What is the molarity of a solution when 50.0 mL of a 4.00 M KOH solution is diluted to 200. mL?

ANSWER

1.00 M KOH solution

QUESTIONS AND PROBLEMS

9.5 Dilution of Solutions

LEARNING GOAL Describe the dilution of a solution; calculate the unknown concentration or volume when a solution is diluted.

9.61 To make tomato soup, you add one can of water to the condensed soup. Why is this a dilution?

9.62 A can of frozen lemonade calls for the addition of three cans of water to make a pitcher of the beverage. Why is this a dilution?

9.63 Calculate the final concentration of each of the following:
- **a.** 2.0 L of a 6.0 M HCl solution is added to water so that the final volume is 6.0 L.
- **b.** Water is added to 0.50 L of a 12 M NaOH solution to make 3.0 L of a diluted NaOH solution.
- **c.** A 10.0-mL sample of a 25% (m/v) KOH solution is diluted with water so that the final volume is 100.0 mL.
- **d.** A 50.0-mL sample of a 15% (m/v) H_2SO_4 solution is added to water to give a final volume of 250 mL.

9.64 Calculate the final concentration of each of the following:
- **a.** 1.0 L of a 4.0 M HNO_3 solution is added to water so that the final volume is 8.0 L.
- **b.** Water is added to 0.25 L of a 6.0 M NaF solution to make 2.0 L of a diluted NaF solution.
- **c.** A 50.0-mL sample of an 8.0% (m/v) KBr solution is diluted with water so that the final volume is 200.0 mL.
- **d.** A 5.0-mL sample of a 50.0% (m/v) acetic acid ($HC_2H_3O_2$) solution is added to water to give a final volume of 25 mL.

9.65 Determine the final volume, in milliliters, of each of the following:
- **a.** a 1.5 M HCl solution prepared from 20.0 mL of a 6.0 M HCl solution
- **b.** a 2.0% (m/v) LiCl solution prepared from 50.0 mL of a 10.0% (m/v) LiCl solution
- **c.** a 0.500 M H_3PO_4 solution prepared from 50.0 mL of a 6.00 M H_3PO_4 solution
- **d.** a 5.0% (m/v) glucose solution prepared from 75 mL of a 12% (m/v) glucose solution

9.66 Determine the final volume, in milliliters, of each of the following:
- **a.** a 1.00% (m/v) H_2SO_4 solution prepared from 10.0 mL of a 20.0% H_2SO_4 solution
- **b.** a 0.10 M HCl solution prepared from 25 mL of a 6.0 M HCl solution
- **c.** a 1.0 M NaOH solution prepared from 50.0 mL of a 12 M NaOH solution
- **d.** a 1.0% (m/v) $CaCl_2$ solution prepared from 18 mL of a 4.0% (m/v) $CaCl_2$ solution

9.67 Determine the initial volume, in milliliters, required to prepare each of the following:
- **a.** 255 mL of a 0.200 M HNO_3 solution using a 4.00 M HNO_3 solution
- **b.** 715 mL of a 0.100 M $MgCl_2$ solution using a 6.00 M $MgCl_2$ solution
- **c.** 0.100 L of a 0.150 M KCl solution using an 8.00 M KCl solution

9.68 Determine the initial volume, in milliliters, required to prepare each of the following:
- **a.** 20.0 mL of a 0.250 M KNO_3 solution using a 6.00 M KNO_3 solution
- **b.** 25.0 mL of a 2.50 M H_2SO_4 solution using a 12.0 M H_2SO_4 solution
- **c.** 0.500 L of a 1.50 M NH_4Cl solution using a 10.0 M NH_4Cl solution

Clinical Applications

9.69 You need 500. mL of a 5.0% (m/v) glucose solution. If you have a 25% (m/v) glucose solution on hand, how many milliliters do you need?

9.70 A doctor orders 100. mL of 2.0% (m/v) ibuprofen. If you have 8.0% (m/v) ibuprofen on hand, how many milliliters do you need?

LEARNING GOAL

Identify a mixture as a solution, a colloid, or a suspension. Describe how the number of particles in a solution affects the freezing point, the boiling point, and the osmotic pressure of a solution.

9.6 Properties of Solutions

The size and number of solute particles in different types of mixtures play an important role in determining the properties of that mixture.

Solutions

In the solutions discussed up to now, the solute was dissolved as small particles that are uniformly dispersed throughout the solvent to give a homogeneous solution. When you observe a solution, such as salt water, you cannot visually distinguish the solute from the solvent. The solution appears transparent, although it may have a color. The particles are so small that they go through filters and through *semipermeable membranes*. A semipermeable membrane allows solvent molecules such as water and very small solute particles to pass through, but does allow the passage of large solute molecules.

Colloids

The particles in a **colloid** are much larger than solute particles in a solution. Colloidal particles are large molecules, such as proteins, or groups of molecules or ions. Colloids, similar to solutions, are homogeneous mixtures that do not separate or settle out. Colloidal particles are small enough to pass through filters, but too large to pass through semipermeable membranes. Table 9.11 lists several examples of colloids.

TABLE 9.11 Examples of Colloids

Colloid	Substance Dispersed	Dispersing Medium
Fog, clouds, hair sprays	Liquid	Gas
Dust, smoke	Solid	Gas
Shaving cream, whipped cream, soapsuds	Gas	Liquid
Styrofoam, marshmallows	Gas	Solid
Mayonnaise, homogenized milk	Liquid	Liquid
Cheese, butter	Liquid	Solid
Blood plasma, paints (latex), gelatin	Solid	Liquid

Suspensions

Suspensions are heterogeneous, nonuniform mixtures that are very different from solutions or colloids. The particles of a suspension are so large that they can often be seen with the naked eye. They are trapped by filters and semipermeable membranes.

The weight of the suspended solute particles causes them to settle out soon after mixing. If you stir muddy water, it mixes but then quickly separates as the suspended particles settle to the bottom and leave clear liquid at the top. You can find suspensions among the medications in a hospital or in your medicine cabinet. These include Kaopectate, calamine lotion, antacid mixtures, and liquid penicillin. It is important to follow the instructions on the label that states "shake well before using" so that the particles form a suspension.

Water-treatment plants make use of the properties of suspensions to purify water. When chemicals such as aluminum sulfate or iron(III) sulfate are added to untreated water, they react with impurities to form large suspended particles called *floc*. In the water-treatment plant, a system of filters traps the suspended particles, but clean water passes through.

Table 9.12 compares the different types of mixtures and Figure 9.10 illustrates some properties of solutions, colloids, and suspensions.

TABLE 9.12 Comparison of Solutions, Colloids, and Suspensions

Type of Mixture	Type of Particle	Settling	Separation
Solution	Small particles such as atoms, ions, or small molecules	Particles do not settle	Particles cannot be separated by filters or semipermeable membranes
Colloid	Larger molecules or groups of molecules or ions	Particles do not settle	Particles can be separated by semipermeable membranes but not by filters
Suspension	Very large particles that may be visible	Particles settle rapidly	Particles can be separated by filters

Chemistry Link to **Health**

Colloids and Solutions in the Body

In the body, colloids are retained by semipermeable membranes. For example, the intestinal lining allows solution particles to pass into the blood and lymph circulatory systems. However, the colloids from foods are too large to pass through the membrane, and they remain in the intestinal tract. Digestion breaks down large colloidal particles, such as starch and protein, into smaller particles, such as glucose and amino acids that can pass through the intestinal membrane and enter the circulatory system. Certain foods, such as bran, a fiber, cannot be broken down by human digestive processes, and they move through the intestine intact.

Because large proteins, such as enzymes, are colloids, they remain inside cells. However, many of the substances that must be obtained by cells, such as oxygen, amino acids, electrolytes, glucose, and minerals, can pass through cellular membranes. Waste products, such as urea and carbon dioxide, pass out of the cell to be excreted.

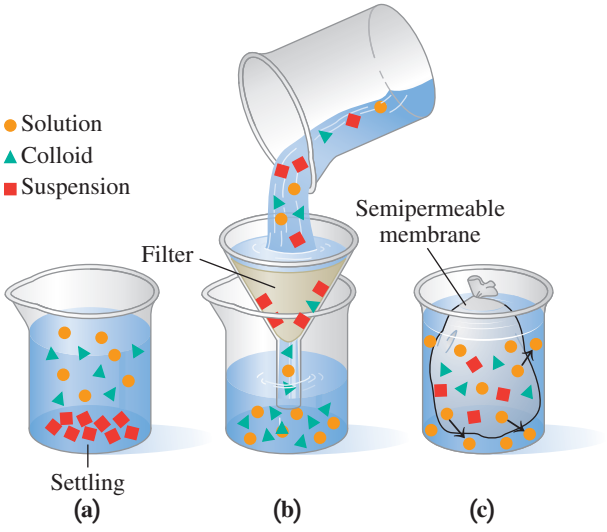


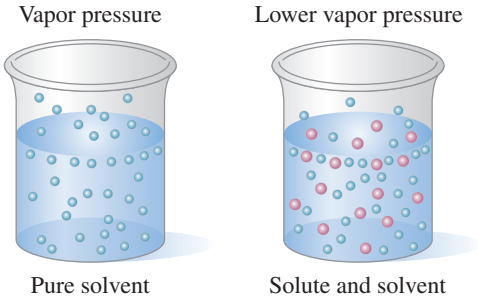
FIGURE 9.10 ▶ Properties of different types of mixtures: **(a)** suspensions settle out; **(b)** suspensions are separated by a filter; **(c)** solution particles go through a semipermeable membrane, but colloids and suspensions do not.

A filter can be used to separate suspension particles from a solution, but a semipermeable membrane is needed to separate colloids from a solution. Explain.

Boiling Point Elevation and Freezing Point Lowering

When we add a solute to water, it changes the vapor pressure, boiling point, and freezing point of pure water. Therefore, an aqueous solution will have a higher boiling point and a lower freezing point than that of pure water. These types of changes in physical properties, known as *colligative properties*, depend only on the concentration of solute particles in the solution.

We can illustrate how these changes in physical properties occur by comparing the number of evaporating solvent molecules in pure solvent with those in a solution with a nonvolatile solute in the solvent. In the solution, there are fewer solvent molecules at the surface because the solute that has been added takes up some of the space at the surface. As a result, fewer solvent molecules can evaporate compared to the pure solvent. Vapor pressure is lowered for the solution. If we add more solute molecules, the vapor pressure will be lowered even more.



Ethylene glycol is added to a radiator to form an aqueous solution that has a lower freezing point than water.

The boiling point of a solvent is raised when a nonvolatile solute is added. The vapor pressure of a solvent must reach atmospheric pressure before it begins boiling. However, because the solute lowers the vapor pressure of the solvent, a temperature higher than the normal boiling point of the pure solvent is needed to cause the solution to boil.

The freezing point of a solvent is lowered when a nonvolatile solute is added. In this case, the solute particles prevent the organization of solvent molecules needed to form the solid state. Thus, a lower temperature is required before the molecules of the solvent can become organized enough to freeze.

The Alaska Upis beetle produces biological antifreeze to survive subfreezing temperatures.

Thus, when you spread salt on an icy sidewalk when temperatures drop below freezing, the particles from the salt combine with water to lower the freezing point, which causes the ice to melt. Another example is the addition of antifreeze, such as ethylene glycol HO—CH_2—CH_2—OH, to the water in a car radiator. Ethylene glycol forms many hydrogen bonds, which makes it very soluble in water. If an ethylene glycol and water mixture is about 50–50% by mass, it does not freeze until the temperature drops to about −30 °F, and does not boil unless the temperature reaches about 225 °F. The solution in the radiator prevents the water in the radiator from forming ice in cold weather or boiling over on a hot desert highway.

Insects and fish in climates with subfreezing temperatures control ice formation by producing biological antifreezes made of glycerol, proteins, and sugars, such as glucose, within their bodies. Some insects can survive temperatures below −60 °C. These forms of biological antifreezes may one day be applied to the long-term preservation of human organs.

Particles in Solution

A solute that is a nonelectrolyte dissolves as molecules, whereas a solute that is a strong electrolyte dissolves entirely as ions. The solute in antifreeze, ethylene glycol, $C_2H_6O_2$—a nonelectrolyte—dissolves as molecules.

$$\text{Nonelectrolyte: 1 mole of } C_2H_6O_2(l) = \text{1 mole of } C_2H_6O_2(aq)$$

However, when 1 mole of a strong electrolyte, such as NaCl or $CaCl_2$, dissolves in water, the NaCl solution will contain 2 moles of particles and the $CaCl_2$ solution will contain 3 moles of particles.

Strong electrolytes:

$$\text{1 mole of NaCl}(s) = \underbrace{\text{1 mole of } Na^+(aq) + \text{1 mole of } Cl^-(aq)}_{\text{2 moles of particles } (aq)}$$

$$\text{1 mole of } CaCl_2(s) = \underbrace{\text{1 mole of } Ca^{2+}(aq) + \text{2 moles of } Cl^-(aq)}_{\text{3 moles of particles } (aq)}$$

CORE CHEMISTRY SKILL

Calculating the Boiling Point/Freezing Point of a Solution

Change in Boiling Point and Freezing Point

The change in boiling point or freezing point depends on the number of particles in the solution. One mole of an electrolyte such as glucose raises the boiling point of one kilogram of pure water (100.00 °C) by 0.51 °C, which gives a boiling point of 100.51 °C. If the solute is a strong electrolyte such as NaCl, one mole produces two moles of particles

(ions). Then the boiling point of one kilogram of water is raised by 1.02 °C (2 × 0.51 °C), to give a boiling point of 101.02 °C.

The presence of solute particles also changes the freezing point. One mole of a nonelectrolyte such as glucose lowers the freezing point (0.00 °C) of one kilogram of pure water by 1.86 °C, to give a freezing point of −1.86 °C. For NaCl, one mole dissociates to form two moles of particles (ions). Then the freezing point of one kilogram of water is lowered by 3.72 °C (2 × 1.86 °C), which gives a freezing point of −3.72 °C.

The effect of some solutes on freezing and boiling point is summarized in Table 9.13.

A truck spreads calcium chloride on the road to melt ice and snow.

TABLE 9.13 Effect of Solute Concentration on Freezing and Boiling Points of 1 kg of Water

Substance in One Kilogram of Water	Type of Solute	Moles of Solute Particles in One Kilogram of Water	Freezing Point	Boiling Point
Pure water	None	0	0.00 °C	100.00 °C
1 mole of $C_2H_6O_2$	Nonelectrolyte	1	−1.86 °C	100.51 °C
1 mole of NaCl	Strong electrolyte	2	−3.72 °C	101.02 °C
1 mole of $CaCl_2$	Strong electrolyte	3	−5.58 °C	101.53 °C

SAMPLE PROBLEM 9.16 Calculating the Freezing Point of a Solution

In the northern United States during freezing temperatures, $CaCl_2$ is spread on icy highways to melt the ice. Calculate the freezing point of a solution containing 0.50 mole of $CaCl_2$ in 1 kg of water.

SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	0.50 mole of $CaCl_2$, 1 kg of water	freezing point of solution

STEP 2 Determine the number of moles of solute particles.

$$CaCl_2(s) \longrightarrow Ca^{2+}(aq) + 2Cl^-(aq) = 3 \text{ moles of solute particles}$$

$$1 \text{ mole of } CaCl_2 = 3 \text{ moles of solute particles}$$

$$\frac{1 \text{ mole } CaCl_2}{3 \text{ moles solute particles}} \quad \text{and} \quad \frac{3 \text{ moles solute particles}}{1 \text{ mole } CaCl_2}$$

STEP 3 Determine the temperature change using the moles of solute particles and the degrees Celsius change per mole of particles.

$$1 \text{ mole of solute particles} = 1.86\ °C$$

$$\frac{1.86\ °C}{1 \text{ mole solute particles}} \quad \text{and} \quad \frac{1 \text{ mole solute particles}}{1.86\ °C}$$

$$\text{Temperature change} = 0.50\ \cancel{\text{mole } CaCl_2} \times \frac{3\ \cancel{\text{moles solute particles}}}{1\ \cancel{\text{mole } CaCl_2}} \times \frac{1.86\ °C}{1\ \cancel{\text{mole solute particles}}}$$

$$= 2.8\ °C$$

STEP 4 Subtract the temperature change from the freezing point. Finally, the freezing point lowering, ΔT_f, is subtracted from 0.0 °C to obtain the new freezing point of the $CaCl_2$ solution.

$$T_{solution} = T_{water} - \Delta T_f$$
$$= 0.0\ °C - 2.8\ °C$$
$$= -2.8\ °C$$

Calculating Freezing Point Lowering/Boiling Point Elevation

STEP 1 State the given and needed quantities.

STEP 2 Determine the number of moles of solute particles.

STEP 3 Determine the temperature change using the moles of solute particles and the degrees Celsius change per mole of particles.

STEP 4 Subtract the temperature change from the freezing point or add the temperature change to the boiling point.

STUDY CHECK 9.16

Ethylene glycol, $C_2H_6O_2$, a nonelectrolyte, is added to the water in a radiator to give a solution containing 0.75 mole of ethylene glycol in 1 kg of water (solvent). What is the boiling point of the solution?

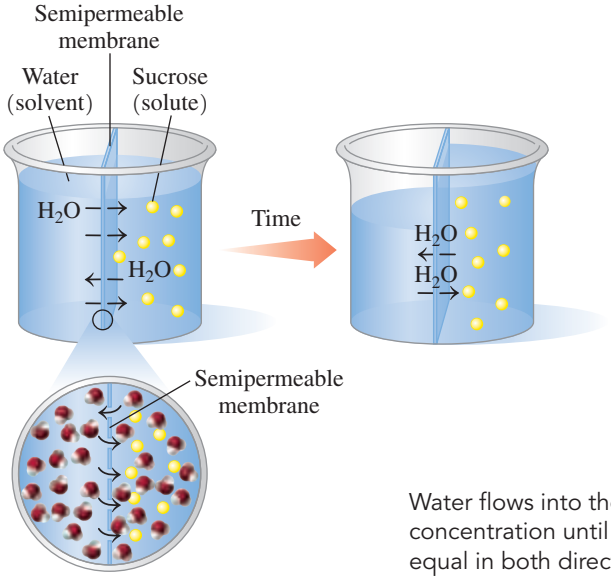
ANSWER

100.38 °C

Osmosis and Osmotic Pressure

The movement of water into and out of the cells of plants as well as the cells of our bodies is an important biological process that also depends on the solute concentration. In a process called **osmosis**, water molecules move through a semipermeable membrane from the solution with the lower concentration of solute into a solution with the higher solute concentration. In an osmosis apparatus, water is placed on one side of a semipermeable membrane and a sucrose (sugar) solution on the other side. The semipermeable membrane allows water molecules to flow back and forth but blocks the sucrose molecules because they cannot pass through the membrane. Because the sucrose solution has a higher solute concentration, more water molecules flow into the sucrose solution than out of the sucrose solution. The volume level of the sucrose solution rises as the volume level on the water side falls. The increase of water dilutes the sucrose solution to equalize (or attempt to equalize) the concentrations on both sides of the membrane.

Eventually the height of the sucrose solution creates sufficient pressure to equalize the flow of water between the two compartments. This pressure, called **osmotic pressure**, prevents the flow of additional water into the more concentrated solution. Then there is no further change in the volumes of the two solutions. The osmotic pressure depends on the concentration of solute particles in the solution. The greater the number of particles dissolved, the higher its osmotic pressure. In this example, the sucrose solution has a higher osmotic pressure than pure water, which has an osmotic pressure of zero.



Water flows into the solution with a higher solute concentration until the flow of water becomes equal in both directions.

In a process called *reverse osmosis*, a pressure greater than the osmotic pressure is applied to a solution so that it is forced through a purification membrane. The flow of water is reversed because water flows from an area of lower water concentration to an area of higher water concentration. The molecules and ions in solution stay behind, trapped by the membrane, while water passes through the membrane. This process of reverse osmosis is used in a few desalination plants to obtain pure water from sea (salt) water. However, the pressure that must be applied requires so much energy that reverse osmosis is not yet an economical method for obtaining pure water in most parts of the world.

Explore Your World
Everyday Osmosis

1. Place a few pieces of dried fruit such as raisins, prunes, or banana chips in water. Observe them after 1 hour or more. Look at them again the next day.
2. Place some grapes in a concentrated salt-water solution. Observe them after 1 hour or more. Look at them again the next day.
3. Place one potato slice in water and another slice in a concentrated salt-water solution. After 1 to 2 hours, observe the shapes and size of the slices. Look at them again the next day.

Questions

1. How did the shape of the dried fruit change after being in water? Explain.
2. How did the appearance of the grapes change after being in a concentrated salt solution? Explain.
3. How does the appearance of the potato slice that was placed in water compare to the appearance of the potato slice placed in salt water? Explain.
4. At the grocery store, why are sprinklers used to spray water on fresh produce such as lettuce, carrots, and cucumbers?

Osmolarity

Every molecule and every ion that dissolves in a solution contributes to its osmotic pressure. A solution with a higher concentration of dissolved particles has a higher osmotic pressure than a solution with fewer dissolved particles. Because the osmotic pressure depends on the number of particles in solution, which is equal to the number of osmoles. We use a concentration term *osmolarity* to indicate the number of osmoles dissolved in each liter of solution.

$$\text{Osmolarity (Osm)} = \frac{\text{number of osmoles}}{\text{1 L of solution}}$$

When one mole of NaCl dissolves in one liter of solution, it produces one mole of Na^+ ions and one mole of Cl^- ions, or two osmoles. This would be a 1 M NaCl or a 2 Osm solution.

$$\underset{\text{1 mole}}{NaCl(s)} \xrightarrow{H_2O} \underset{\text{1 mole}}{Na^+(aq)} + \underset{\text{1 mole}}{Cl^-(aq)} \quad = \text{2 osmoles}$$

When one mole of K_2SO_4 dissolves, two moles of K^+ ions and one mole of SO_4^{2-} ions or three osmoles are produced from each one mole of $K_2SO_4(s)$.

$$\underset{\text{1 mole}}{K_2SO_4(s)} \xrightarrow{H_2O} \underset{\text{2 moles}}{2K^+(aq)} + \underset{\text{1 mole}}{SO_4^{2-}(aq)} \quad = \text{3 osmoles}$$

Using the number of moles of ions as a conversion factor, we can convert the molarity of the solution to the osmolarity. For example, a 0.10 M K_2SO_4 solution would be a 0.30 Osm K_2SO_4 solution.

$$\frac{0.10\ \cancel{\text{mole } K_2SO_4}}{\text{1 L solution}} \times \frac{\text{3 osmoles}}{1\ \cancel{\text{mole } K_2SO_4}} = \text{0.30 Osm } K_2SO_4 \text{ solution}$$

The physiological solutions 0.9% (m/v) NaCl and 5% (m/v) glucose are isotonic solutions because they have the same concentration of particles and the same osmolarities as body fluids.

SAMPLE PROBLEM 9.17 Calculating the Osmolarity of a Solution

The osmolarity of normal blood serum is 0.30 Osm. Show that the osmolarity of 0.90% (m/v) NaCl solution is the same as that of normal serum.

SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	0.90% (m/v) NaCl	osmolarity (Osm) of NaCl solution

STEP 2 Determine the number of osmoles in one mole of solute.

$$\text{1 mole } NaCl(s) \longrightarrow \text{1 mole } Na^+(aq) + \text{1 mole } Cl^-(aq) = \text{2 moles of particles} = \text{2 osmoles}$$

STEP 3 Calculate the osmolarity (Osm).

$$\frac{0.90\ \cancel{\text{g NaCl}}}{100\ \cancel{\text{mL}} \text{ solution}} \times \frac{1\ \cancel{\text{mole NaCl}}}{58.44\ \cancel{\text{g NaCl}}} \times \frac{\text{2 osmoles}}{1\ \cancel{\text{mole NaCl}}} \times \frac{1000\ \cancel{\text{mL}}}{\text{1 L}} = \text{0.30 Osm NaCl solution}$$

The osmolarity of 0.90% (m/v) NaCl solution is 0.30 Osm, which is the same as that of normal blood serum.

STUDY CHECK 9.17

Calculate the osmolarity of 5% (m/v) glucose solution. (The molar mass of the nonelectrolyte glucose is 180 g/mole.)

ANSWER

0.3 Osm

Guide to Calculating Osmolarity

STEP 1 State the given and needed quantities.

STEP 2 Determine the number of osmoles in one mole of solute.

STEP 3 Calculate the osmolarity (Osm).

A 0.9% NaCl solution is isotonic with the solute concentration of the blood cells of the body.

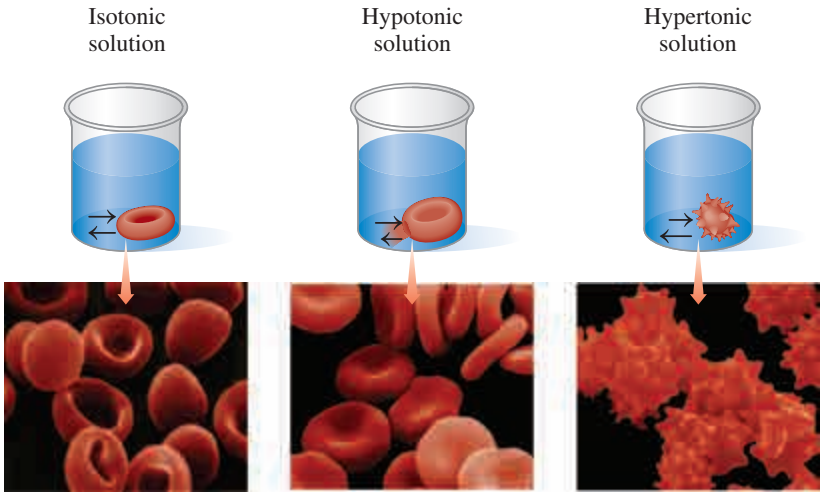
Isotonic Solutions

Because the cell membranes in biological systems are semipermeable, osmosis is an ongoing process. The solutes in body solutions such as blood, tissue fluids, lymph, and plasma all exert osmotic pressure. Most intravenous (IV) solutions used in a hospital are **isotonic solutions**, which exert the same osmotic pressure as body fluids such as blood. The percent concentration typically used in IV solutions is mass/volume percent (m/v), which is a type of percent concentration we have already discussed. The most typical isotonic solutions are 0.9% (m/v) NaCl solution, or 0.9 g of NaCl/100 mL of solution, and 5% (m/v) glucose, or 5 g of glucose/100 mL of solution. Although they do not contain the same kinds of particles, a 0.9% (m/v) NaCl solution as well as a 5% (m/v) glucose solution both have the same osmolarity, 0.3 Osm. A red blood cell placed in an isotonic solution retains its volume because there is an equal flow of water into and out of the cell (see Figure 9.11a).

Hypotonic and Hypertonic Solutions

If a red blood cell is placed in a solution that is not isotonic, the differences in osmotic pressure inside and outside the cell can drastically alter the volume of the cell. When a red blood cell is placed in a **hypotonic solution**, which has a lower solute concentration (*hypo* means "lower than"), water flows into the cell by osmosis. The increase in fluid causes the cell to swell, and possibly burst—a process called **hemolysis** (see Figure 9.11b). A similar process occurs when you place dehydrated food, such as raisins or dried fruit, in water. The water enters the cells, and the food becomes plump and smooth.

If a red blood cell is placed in a **hypertonic solution**, which has a higher solute concentration (*hyper* means "greater than"), water flows out of the cell into the hypertonic solution by osmosis. Suppose a red blood cell is placed in a 10% (m/v) NaCl solution. Because the osmotic pressure in the red blood cell is the same as a 0.9% (m/v) NaCl solution, the 10% (m/v) NaCl solution has a much greater osmotic pressure. As water leaves the cell, it shrinks, a process called **crenation** (see Figure 9.11c). A similar process occurs when making pickles, which uses a hypertonic salt solution that causes the cucumbers to shrivel as they lose water.



(a) Normal (b) Hemolysis (c) Crenation

FIGURE 9.11 ▶ **(a)** In an isotonic solution, a red blood cell retains its normal volume. **(b)** Hemolysis: In a hypotonic solution, water flows into a red blood cell, causing it to swell and burst. **(c)** Crenation: In a hypertonic solution, water leaves the red blood cell, causing it to shrink.

What happens to a red blood cell placed in a 4% NaCl solution?

SAMPLE PROBLEM 9.18 Isotonic, Hypotonic, and Hypertonic Solutions

Describe each of the following solutions as isotonic, hypotonic, or hypertonic. Indicate whether a red blood cell placed in each solution will undergo hemolysis, crenation, or no change.

a. a 5% (m/v) glucose solution
b. a 0.2% (m/v) NaCl solution

SOLUTION

a. A 5% (m/v) glucose solution is isotonic. A red blood cell will not undergo any change.
b. A 0.2% (m/v) NaCl solution is hypotonic. A red blood cell will undergo hemolysis.

STUDY CHECK 9.18

What will happen to a red blood cell placed in a 10% (m/v) glucose solution?

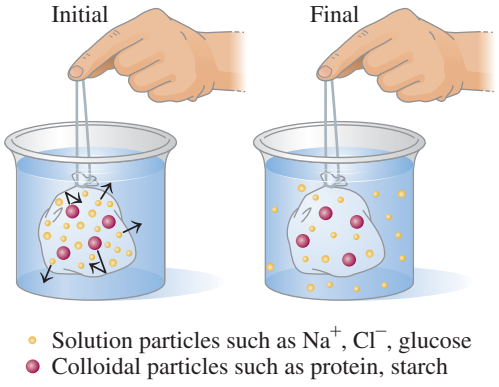
ANSWER

The red blood cell will shrink (crenate).

Dialysis

Dialysis is a process that is similar to osmosis. In dialysis, a semipermeable membrane, called a dialyzing membrane, permits small solute molecules and ions as well as solvent water molecules to pass through, but it retains large particles, such as colloids. Dialysis is a way to separate solution particles from colloids.

Suppose we fill a cellophane bag with a solution containing NaCl, glucose, starch, and protein and place it in pure water. Cellophane is a dialyzing membrane, and the sodium ions, chloride ions, and glucose molecules will pass through it into the surrounding water. However, large colloidal particles, like starch and protein, remain inside. Water molecules will flow into the cellophane bag. Eventually the concentrations of sodium ions, chloride ions, and glucose molecules inside and outside the dialysis bag become equal. To remove more NaCl or glucose, the cellophane bag must be placed in a fresh sample of pure water.



Solution particles pass through a dialyzing membrane, but colloidal particles are retained.

Chemistry Link to **Health**

Dialysis by the Kidneys and the Artificial Kidney

The fluids of the body undergo dialysis by the membranes of the kidneys, which remove waste materials, excess salts, and water. In an adult, each kidney contains about 2 million nephrons. At the top of each nephron, there is a network of arterial capillaries called the *glomerulus*.

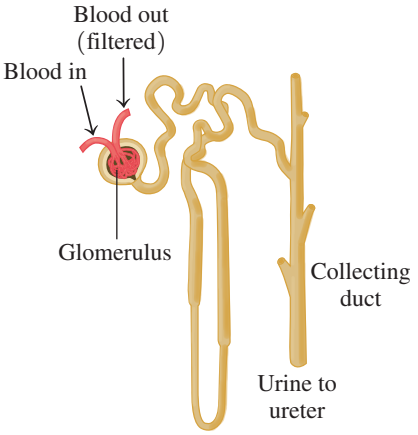
As blood flows into the glomerulus, small particles, such as amino acids, glucose, urea, water, and certain ions, will move through the capillary membranes into the nephron. As this solution moves through the nephron, substances still of value to the body (such as amino acids, glucose, certain ions, and 99% of the water) are reabsorbed. The major waste product, urea, is excreted in the urine.

Hemodialysis

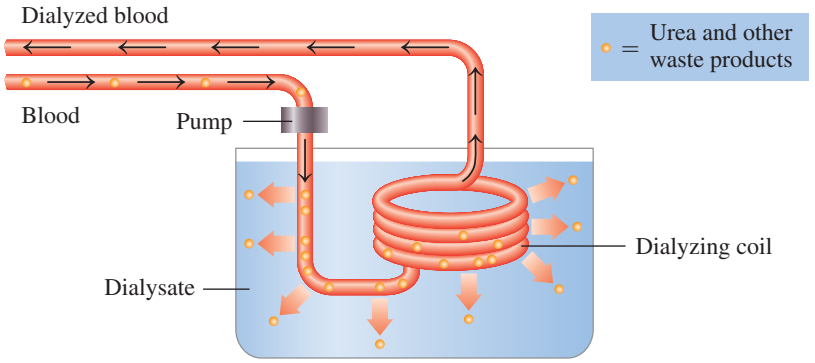
If the kidneys fail to dialyze waste products, increased levels of urea can become life-threatening in a relatively short time. A person with kidney failure must use an artificial kidney, which cleanses the blood by **hemodialysis**.

A typical artificial kidney machine contains a large tank filled with water containing selected electrolytes. In the center of this dialyzing bath (dialysate), there is a dialyzing coil or membrane made of cellulose tubing. As the patient's blood flows through the dialyzing coil, the highly concentrated waste products dialyze out of the blood. No blood is lost because the membrane is not permeable to large particles such as red blood cells.

Dialysis patients do not produce much urine. As a result, they retain large amounts of water between dialysis treatments, which produces a strain on the heart. The intake of fluids for a dialysis patient may be restricted to as little as a few teaspoons of water a day. In the dialysis procedure, the pressure of the blood is increased as it circulates through the dialyzing coil so water can be squeezed out of the blood. For some dialysis patients, 2 to 10 L of water may be removed during one treatment. Dialysis patients have from two to three treatments a week, each treatment requiring about 5 to 7 h. Some of the newer treatments require less time. For many patients, dialysis is done at home with a home dialysis unit.



In the kidneys, each nephron contains a glomerulus where urea and waste products are removed to form urine.



During dialysis, waste products and excess water are removed from the blood.

QUESTIONS AND PROBLEMS

9.6 Properties of Solutions

LEARNING GOAL Identify a mixture as a solution, a colloid, or a suspension. Describe how the number of particles in a solution affects the freezing point, the boiling point, and the osmotic pressure of a solution.

9.71 Identify the following as characteristic of a solution, a colloid, or a suspension:
- **a.** a mixture that cannot be separated by a semipermeable membrane
- **b.** a mixture that settles out upon standing

9.72 Identify the following as characteristic of a solution, a colloid, or a suspension:
- **a.** Particles of this mixture remain inside a semipermeable membrane but pass through filters.
- **b.** The particles of solute in this solution are very large and visible.

9.73 In each pair, identify the solution that will have a lower freezing point. Explain.
- **a.** 1.0 mole of glycerol (nonelectrolyte) and 2.0 moles of ethylene glycol (nonelectrolyte) each in 1.0 kg of water
- **b.** 0.50 mole of KCl (strong electrolyte) and 0.50 mole of $MgCl_2$ (strong electrolyte) each in 1.0 kg of water

9.74 In each pair, identify the solution that will have a higher boiling point. Explain.
- **a.** 1.50 moles of LiOH (strong electrolyte) and 3.00 moles of KOH (strong electrolyte) each in 1.0 kg of water
- **b.** 0.40 mole of $Al(NO_3)_3$ (strong electrolyte) and 0.40 mole of CsCl (strong electrolyte) each in 1.0 kg of water

9.75 Calculate the freezing point of each of the following solutions:
- **a.** 1.36 moles of methanol, CH_3OH, a nonelectrolyte, added to 1.00 kg of water
- **b.** 640. g of the antifreeze propylene glycol, $C_3H_8O_2$, a nonelectrolyte, dissolved in 1.00 kg of water
- **c.** 111 g of KCl, a strong electrolyte, dissolved in 1.00 kg of water

9.76 Calculate the boiling point of each of the following solutions:
- **a.** 2.12 moles of glucose, $C_6H_{12}O_6$, a nonelectrolyte, added to 1.00 kg of water
- **b.** 110. g of sucrose, $C_{12}H_{22}O_{11}$, a nonelectrolyte, dissolved in 1.00 kg of water
- **c.** 146 g of $NaNO_3$, a strong electrolyte, dissolved in 1.00 kg of water

9.77 A 10% (m/v) starch solution is separated from a 1% (m/v) starch solution by a semipermeable membrane. (Starch is a colloid.)
- **a.** Which compartment has the higher osmotic pressure?
- **b.** In which direction will water flow initially?
- **c.** In which compartment will the volume level rise?

9.78 A 0.1% (m/v) albumin solution is separated from a 2% (m/v) albumin solution by a semipermeable membrane. (Albumin is a colloid.)

a. Which compartment has the higher osmotic pressure?
b. In which direction will water flow initially?
c. In which compartment will the volume level rise?

9.79 Indicate the compartment (**A** or **B**) that will increase in volume for each of the following pairs of solutions separated by a semipermeable membrane:

A	B
a. 5% (m/v) sucrose	10% (m/v) sucrose
b. 8% (m/v) albumin	4% (m/v) albumin
c. 0.1% (m/v) starch	10% (m/v) starch

9.80 Indicate the compartment (**A** or **B**) that will increase in volume for each of the following pairs of solutions separated by a semipermeable membrane:

A	B
a. 20% (m/v) starch	10% (m/v) starch
b. 10% (m/v) albumin	2% (m/v) albumin
c. 0.5% (m/v) sucrose	5% (m/v) sucrose

Clinical Applications

9.81 What is the osmolarity of each of the following solutions?
a. hypertonic saline, NaCl, 3.0% (m/v) (strong electrolyte)
b. 50.% (m/v) dextrose ($C_6H_{12}O_6$), used to treat severe hypoglycemia

9.82 What is the osmolarity of each of the following solutions?
a. 3% (m/v) NaCl (strong electrolyte), used to treat hyponatremia
b. 2.5% (m/v) dextrose ($C_6H_{12}O_6$), used to hydrate cells

9.83 Are the following solutions isotonic, hypotonic, or hypertonic compared with a red blood cell?
a. distilled H_2O
b. 1% (m/v) glucose
c. 0.9% (m/v) NaCl
d. 15% (m/v) glucose

9.84 Will a red blood cell undergo crenation, hemolysis, or no change in each of the following solutions?
a. 1% (m/v) glucose
b. 2% (m/v) NaCl
c. 5% (m/v) glucose
d. 0.1% (m/v) NaCl

9.85 Each of the following mixtures is placed in a dialyzing bag and immersed in distilled water. Which substances will be found outside the bag in the distilled water?
a. NaCl solution
b. starch solution (colloid) and alanine (an amino acid) solution
c. NaCl solution and starch solution (colloid)
d. urea solution

9.86 Each of the following mixtures is placed in a dialyzing bag and immersed in distilled water. Which substances will be found outside the bag in the distilled water?
a. KCl solution and glucose solution
b. albumin solution (colloid)
c. an albumin solution (colloid), KCl solution, and glucose solution
d. urea solution and NaCl solution

Clinical Update

Using Dialysis for Renal Failure

As a dialysis patient, Michelle has a 4-h dialysis treatment three times a week. When she arrives at the dialysis clinic, her weight, temperature, and blood pressure are taken and blood tests are done to determine the level of electrolytes and urea in her blood. In the dialysis center, tubes to the dialyzer are connected to the catheter she has had implanted. Blood is then pumped out of her body, through the dialyzer where it is filtered, and returned to her body. As Michelle's blood flows through the dialyzer, electrolytes from the dialysate move into her blood, and waste products in her blood move into the dialysate, which is continually renewed. To achieve normal serum electrolyte levels, dialysate fluid contains sodium, chloride, and magnesium levels that are equal to serum concentrations. These electrolytes are removed from the blood only if their concentrations are higher than normal. Typically, in dialysis patients, the potassium ion level is higher than normal. Therefore, initial dialysis may start with a low concentration of potassium ion in the dialysate. During dialysis excess fluid is removed by osmosis. A 4-h dialysis session requires at least 120 L of dialysis fluid. During dialysis, the electrolytes in the dialysate are adjusted until the electrolytes have the same levels as normal serum. Initially the dialysate solution prepared for Michelle's pre-dialysis blood tests shows that the electrolyte levels in her blood are HCO_3^- 24 mEq/L, K^+ 6.0 mEq/L, Na^+ 148 mEq/L, Ca^{2+} 3.0 mEq/L, Mg^{2+} 1.0 mEq/L, Cl^- 111.0 mEq/L.

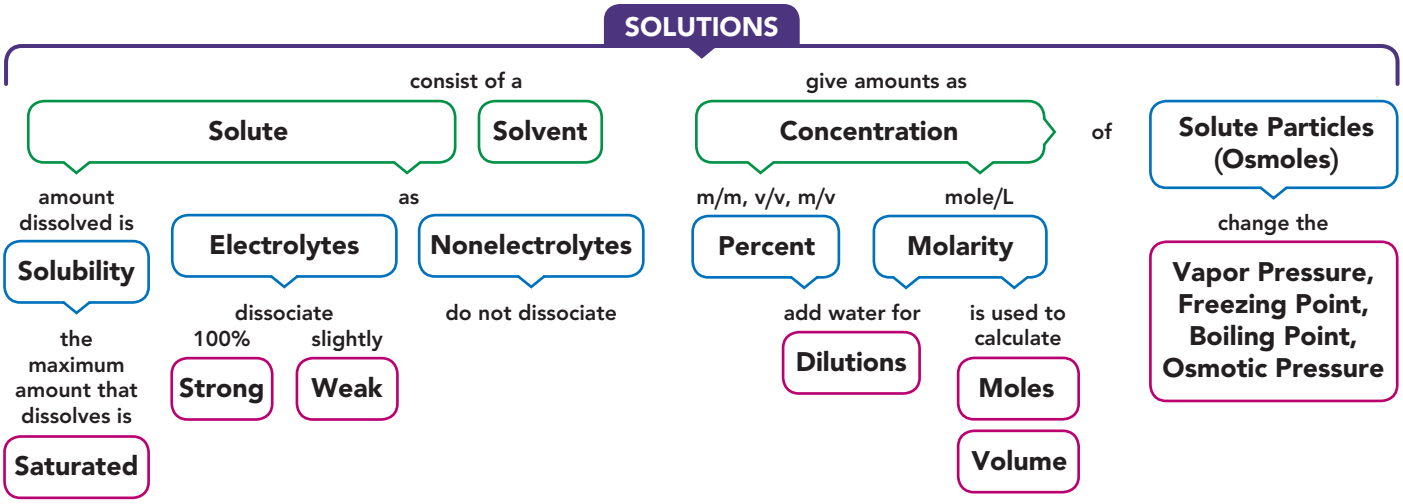
A dialysis solution is prepared for Michelle that contains the following: HCO_3^- 35.0 mEq/L, K^+ 2.0 mEq/L, Na^+ 130 mEq/L, Ca^{2+} 5.0 mEq/L, Mg^{2+} 3.0 mEq/L, Cl^- 105.0 mEq/L, glucose 5.0%(m/v).

Clinical Applications

9.87 **a.** Which electrolyte concentrations are higher than normal serum values in Michelle's pre-dialysis blood test (see Table 9.6)?
b. Which electrolyte concentrations are lower than normal serum values in Michelle's pre-dialysis blood test (see Table 9.6)?
c. Which electrolytes need to be increased by dialysis for Michelle's blood serum?
d. Which electrolytes are decreased by dialysis for Michelle's blood serum?

9.88 **a.** What is the total positive charge, in milliequivalents/L, of the electrolytes in the dialysate fluid?
b. What is the total negative charge, in milliequivalents/L, of the electrolytes in the dialysate fluid?
c. What is the net total charge, in milliequivalents/L, of the electrolytes in the dialysate fluid?
d. What is the osmolarity of the dialysate fluid?

CONCEPT MAP



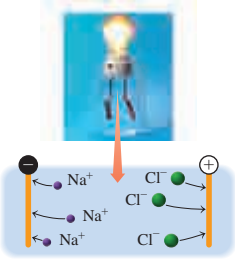
CHAPTER REVIEW

9.1 Solutions

LEARNING GOAL Identify the solute and solvent in a solution; describe the formation of a solution.

- A solution forms when a solute dissolves in a solvent.
- In a solution, the particles of solute are evenly dispersed in the solvent.
- The solute and solvent may be solid, liquid, or gas.
- The polar O—H bond leads to hydrogen bonding between water molecules.
- An ionic solute dissolves in water, a polar solvent, because the polar water molecules attract and pull the ions into solution, where they become hydrated.
- The expression *like dissolves like* means that a polar or an ionic solute dissolves in a polar solvent while a nonpolar solute dissolves in a nonpolar solvent.

9.2 Electrolytes and Nonelectrolytes

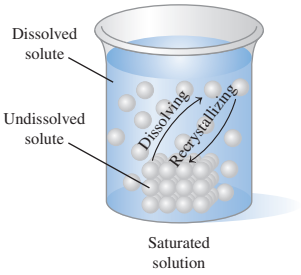


Strong electrolyte

LEARNING GOAL Identify solutes as electrolytes or nonelectrolytes.

- Substances that produce ions in water are called electrolytes because their solutions will conduct an electrical current.
- Strong electrolytes are completely dissociated, whereas weak electrolytes are only partially ionized.
- Nonelectrolytes are substances that dissolve in water to produce only molecules and cannot conduct electrical currents.
- An equivalent (Eq) is the amount of an electrolyte that carries one mole of positive or negative charge.
- One mole of Na^+ is 1 Eq. One mole of Ca^{2+} has 2 Eq.

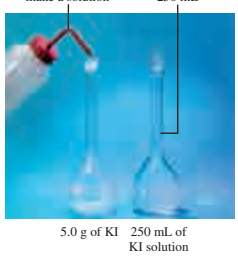
9.3 Solubility



LEARNING GOAL Define solubility; distinguish between an unsaturated and a saturated solution. Identify an ionic compound as soluble or insoluble.

- The solubility of a solute is the maximum amount of a solute that can dissolve in 100 g of solvent.
- A solution that contains the maximum amount of dissolved solute is a saturated solution.
- A solution containing less than the maximum amount of dissolved solute is unsaturated.
- An increase in temperature increases the solubility of most solids in water, but decreases the solubility of gases in water.
- Ionic compounds that are soluble in water usually contain Li^+, Na^+, K^+, NH_4^+, NO_3^-, or acetate, $C_2H_3O_2^-$.

9.4 Solution Concentrations and Reactions



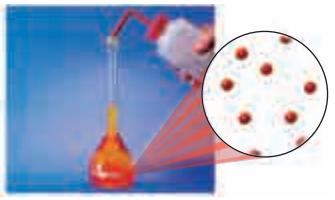
LEARNING GOAL Calculate the concentration of a solute in a solution; use concentration units to calculate the amount of solute or solution. Given the volume and concentration of a solution, calculate the amount of another reactant or product in a reaction.

- Mass percent expresses the mass/mass (m/m) ratio of the mass of solute to the mass of solution multiplied by 100%.
- Percent concentration can also be expressed as volume/volume (v/v) and mass/volume (m/v) ratios.
- Molarity is the moles of solute per liter of solution.
- In calculations of grams or milliliters of solute or solution, the concentration is used as a conversion factor.
- Molarity (mole/L) is written as conversion factors to solve for moles of solute or volume of solution.

- When solutions are involved in chemical reactions, the moles of a substance in solution can be determined from the volume and molarity of the solution.
- When mass, volume, and molarities of substances in a reaction are given, the balanced equation is used to determine the quantities or concentrations of other substances in the reaction.

9.5 Dilution of Solutions

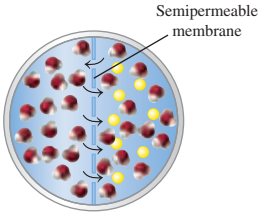
LEARNING GOAL Describe the dilution of a solution; calculate the unknown concentration or volume when a solution is diluted.



- In dilution, a solvent such as water is added to a solution, which increases its volume and decreases its concentration.

9.6 Properties of Solutions

LEARNING GOAL Identify a mixture as a solution, a colloid, or a suspension. Describe how the number of particles in a solution affects the freezing point, the boiling point, and the osmotic pressure of a solution.



- Colloids contain particles that pass through most filters but do not settle out or pass through permeable membranes.
- Suspensions have very large particles that settle out of solution.
- The particles in a solution lower the vapor pressure, raise the boiling point, lower the freezing point, and increase the osmotic pressure.
- In osmosis, solvent (water) passes through a semipermeable membrane from a solution with a lower osmotic pressure (lower solute concentration) to a solution with a higher osmotic pressure (higher solute concentration).
- Isotonic solutions have osmotic pressures equal to that of body fluids.
- In osmosis, solvent (water) passes through a selectively permeable membrane from a solution with a lower solute concentration to a solution with a higher concentration.
- Isotonic solutions have osmotic pressures equal to that of body fluids.
- A red blood cell maintains its volume in an isotonic solution but swells in a hypotonic solution, and shrinks in a hypertonic solution.
- In dialysis, water and small solute particles pass through a dialyzing membrane, while larger particles are retained.

KEY TERMS

colloid A mixture having particles that are moderately large. Colloids pass through filters but cannot pass through semipermeable membranes.

concentration A measure of the amount of solute that is dissolved in a specified amount of solution.

crenation The shriveling of a cell because water leaves the cell when the cell is placed in a hypertonic solution.

dialysis A process in which water and small solute particles pass through a semipermeable membrane.

dilution A process by which water (solvent) is added to a solution to increase the volume and decrease (dilute) the concentration of the solute.

electrolyte A substance that produces ions when dissolved in water; its solution conducts electricity.

equivalent (Eq) The amount of a positive or negative ion that supplies 1 mole of electrical charge.

hemodialysis A mechanical cleansing of the blood by an artificial kidney using the principle of dialysis.

hemolysis A swelling and bursting of red blood cells in a hypotonic solution because of an increase in fluid volume.

Henry's law The solubility of a gas in a liquid is directly related to the pressure of that gas above the liquid.

hydration The process of surrounding dissolved ions by water molecules.

hypertonic solution A solution that has a higher particle concentration and higher osmotic pressure than the cells of the body.

hypotonic solution A solution that has a lower particle concentration and lower osmotic pressure than the cells of the body.

isotonic solution A solution that has the same particle concentration and osmotic pressure as that of the cells of the body.

mass percent (m/m) The grams of solute in exactly 100 g of solution.

mass/volume percent (m/v) The grams of solute in exactly 100 mL of solution.

molarity (M) The number of moles of solute in exactly 1 L of solution.

nonelectrolyte A substance that dissolves in water as molecules; its solution does not conduct an electrical current.

osmosis The flow of a solvent, usually water, through a semipermeable membrane into a solution of higher solute concentration.

osmotic pressure The pressure that prevents the flow of water into the more concentrated solution.

saturated solution A solution containing the maximum amount of solute that can dissolve at a given temperature. Any additional solute will remain undissolved in the container.

solubility The maximum amount of solute that can dissolve in exactly 100 g of solvent, usually water, at a given temperature.

solubility rules A set of guidelines that states whether an ionic compound is soluble or insoluble in water.

solute The component in a solution that is present in the lesser amount.

solution A homogeneous mixture in which the solute is made up of small particles (ions or molecules) that can pass through filters and semipermeable membranes.

solvent The substance in which the solute dissolves; usually the component present in greater amount.

strong electrolyte A compound that ionizes completely when it dissolves in water. Its solution is a good conductor of electricity.

suspension A mixture in which the solute particles are large enough and heavy enough to settle out and be retained by both filters and semipermeable membranes.

unsaturated solution A solution that contains less solute than can be dissolved.

volume percent (v/v) A percent concentration that relates the volume of the solute in exactly 100 mL of solution.

weak electrolyte A substance that produces only a few ions along with many molecules when it dissolves in water. Its solution is a weak conductor of electricity.

CORE CHEMISTRY SKILLS

The chapter section containing each Core Chemistry Skill is shown in parentheses at the end of each heading.

Using Solubility Rules (9.3)

- Soluble ionic compounds contain Li^+, Na^+, K^+, NH_4^+, NO_3^-, or $C_2H_3O_2^-$ (acetate).
- Ionic compounds containing Cl^-, Br^-, or I^- are soluble, but if they are combined with Ag^+, Pb^{2+}, or Hg_2^{2+}, the ionic compounds are insoluble.
- Most ionic compounds containing SO_4^{2-} are soluble, but if SO_4^{2-} is combined with Ba^{2+}, Pb^{2+}, Ca^{2+}, Sr^{2+}, or Hg_2^{2+}, the ionic compounds are insoluble.
- Ionic compounds that do not contain at least one of these ions are usually insoluble.

Example: Is K_2SO_4 soluble or insoluble in water?
Answer: K_2SO_4 is soluble in water because it contains K^+.

Calculating Concentration (9.4)

The amount of solute dissolved in a certain amount of solution is called the concentration of the solution.

- $\text{Mass percent (m/m)} = \dfrac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$
- $\text{Volume percent (v/v)} = \dfrac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$
- $\text{Mass/volume percent (m/v)} = \dfrac{\text{grams of solute}}{\text{milliliters of solution}} \times 100\%$
- $\text{Molarity (M)} = \dfrac{\text{moles of solute}}{\text{liters of solution}}$

Example: What is the mass/volume percent (m/v) and the molarity (M) of 225 mL (0.225 L) of a LiCl solution that contains 17.1 g of LiCl?

Answer:

$$\text{Mass/volume percent (m/v)} = \frac{\text{grams of solute}}{\text{milliliters of solution}} \times 100\%$$

$$= \frac{17.1 \text{ g LiCl}}{225 \text{ mL solution}} \times 100\%$$

$$= 7.60\% \text{ (m/v) LiCl solution}$$

$$\text{moles of LiCl} = 17.1 \text{ g } \cancel{\text{LiCl}} \times \frac{1 \text{ mole LiCl}}{42.39 \text{ g } \cancel{\text{LiCl}}}$$

$$= 0.403 \text{ mole of LiCl}$$

$$\text{Molarity (M)} = \frac{\text{moles of solute}}{\text{liters of solution}} = \frac{0.403 \text{ mole LiCl}}{0.225 \text{ L solution}}$$

$$= 1.79 \text{ M LiCl solution}$$

Using Concentration as a Conversion Factor (9.4)

- When we need to calculate the amount of solute or solution, we use the mass/volume percent (m/v) or the molarity (M) as a conversion factor.
- For example, the concentration of a 4.50 M HCl solution means there are 4.50 moles of HCl in 1 L of HCl solution, which gives two conversion factors written as

$$\frac{4.50 \text{ moles HCl}}{1 \text{ L solution}} \quad \text{and} \quad \frac{1 \text{ L solution}}{4.50 \text{ moles HCl}}$$

Example: How many milliliters of a 4.50 M HCl solution will provide 1.13 moles of HCl?

Answer:

$$1.13 \text{ moles HCl} \times \frac{1 \text{ L solution}}{4.50 \text{ moles HCl}} \times \frac{1000 \text{ mL solution}}{1 \text{ L solution}}$$

$$= 251 \text{ mL of HCl solution}$$

Calculating the Quantity of a Reactant or Product for a Chemical Reaction in Solution (9.4)

- When chemical reactions involve aqueous solutions of reactants or products, we use the balanced chemical equation, the molarity, and the volume to determine the moles or grams of the reactants or products.

Example: How many grams of zinc metal will react with 0.315 L of a 1.20 M HCl solution?

$$Zn(s) + 2HCl(aq) \longrightarrow H_2(g) + ZnCl_2(aq)$$

Answer:

$$0.315 \text{ L solution} \times \frac{1.20 \text{ moles HCl}}{1 \text{ L solution}} \times \frac{1 \text{ mole Zn}}{2 \text{ moles HCl}} \times \frac{65.41 \text{ g Zn}}{1 \text{ mole Zn}}$$

$$= 12.4 \text{ g of Zn}$$

Calculating the Boiling Point/Freezing Point of a Solution (9.6)

- The particles in a solution raise the boiling point, lower the freezing point, and increase the osmotic pressure.
- The boiling point elevation is determined from the moles of particles in one kilogram of water.
- The freezing point lowering is determined from the moles of particles in one kilogram of water.

Example: What is the boiling point of a solution that contains 1.5 moles of the strong electrolyte KCl in 1.0 kg of water?

Answer: A solution of 1.5 moles of KCl in 1.0 kg of water contains 3.0 moles of particles (1.5 moles of K^+ and 1.5 moles of Cl^-) in 1.0 kg of water and has a boiling point change of

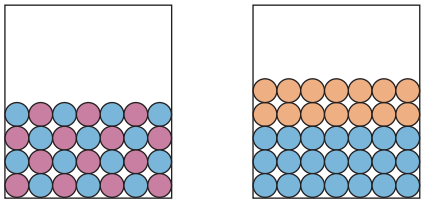
$$3.0 \text{ moles particles} \times \frac{0.51\ ^\circ\text{C}}{1 \text{ mole particles}} = 1.53\ ^\circ\text{C}$$

The boiling point would be 100.00 °C + 1.53 °C = 101.53 °C.

UNDERSTANDING THE CONCEPTS

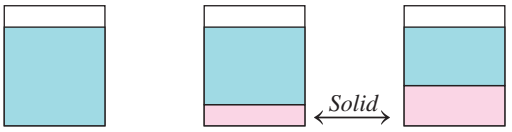
The chapter sections to review are shown in parentheses at the end of each question.

9.89 Match the diagrams with the following: (9.1)
a. a polar solute and a polar solvent
b. a nonpolar solute and a polar solvent
c. a nonpolar solute and a nonpolar solvent



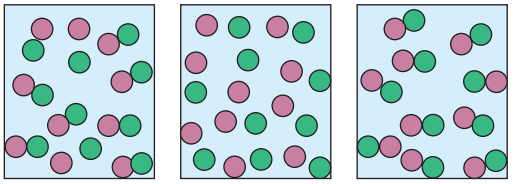
1 **2**

9.90 If all the solute is dissolved in diagram **1**, how would heating or cooling the solution cause each of the following changes? (9.3)
a. **2** to **3** **b.** **2** to **1**



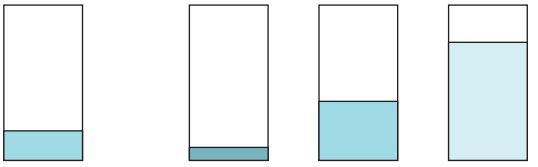
1 **2** **3**

9.91 Select the diagram that represents the solution formed by a solute that is a (9.2)
a. nonelectrolyte
b. weak electrolyte
c. strong electrolyte



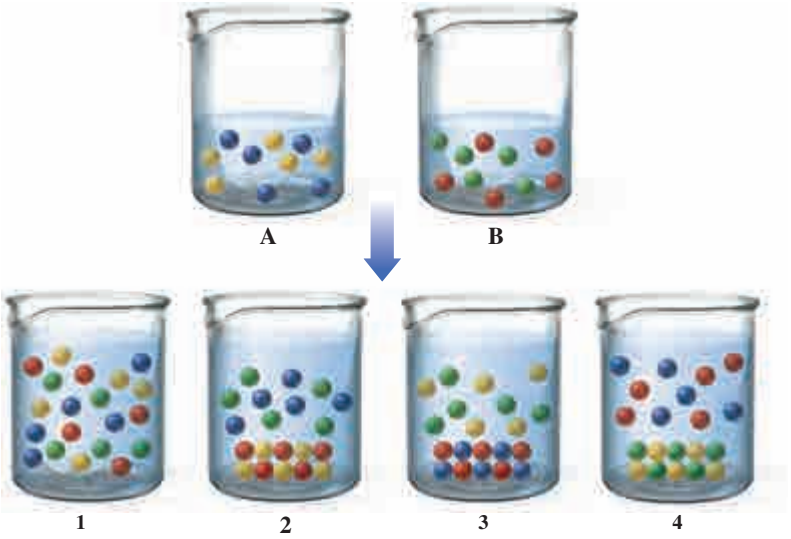
1 **2** **3**

9.92 Select the container that represents the dilution of a 4% (m/v) KCl solution to give each of the following: (9.5)
a. a 2% (m/v) KCl solution
b. a 1% (m/v) KCl solution



4% (m/v) KCl **1** **2** **3**

Use the following illustration of beakers and solutions for problems 9.93 and 9.94:



A **B**

1 **2** **3** **4**

9.93 Use the following types of ions: (9.3)

Na^+ Cl^- Ag^+ NO_3^-

a. Select the beaker (**1**, **2**, **3**, or **4**) that contains the products after the solutions in beakers **A** and **B** are mixed.
b. If an insoluble ionic compound forms, write the ionic equation.
c. If a reaction occurs, write the net ionic equation.

9.94 Use the following types of ions: (9.3)

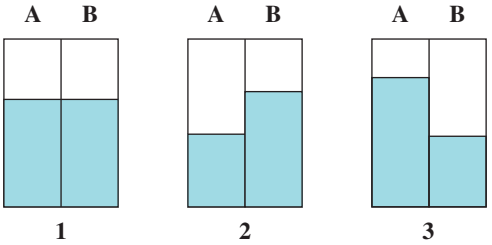
K^+ NO_3^- NH_4^+ Br^-

a. Select the beaker (**1**, **2**, **3**, or **4**) that contains the products after the solutions in beakers **A** and **B** are mixed.
b. If an insoluble ionic compound forms, write the ionic equation.
c. If a reaction occurs, write the net ionic equation.

9.95 A pickle is made by soaking a cucumber in brine, a salt-water solution. What makes the smooth cucumber become wrinkled like a prune? (9.6)

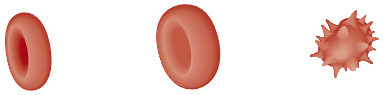
9.96 Why do lettuce leaves in a salad wilt after a vinaigrette dressing containing salt is added? (9.6)

9.97 A semipermeable membrane separates two compartments, **A** and **B**. If the levels in **A** and **B** are equal initially, select the diagram that illustrates the final levels in **a** to **d**: (9.6)



Solution in A	Solution in B
a. 2% (m/v) starch	8% (m/v) starch
b. 1% (m/v) starch	1% (m/v) starch
c. 5% (m/v) sucrose	1% (m/v) sucrose
d. 0.1% (m/v) sucrose	1% (m/v) sucrose

9.98 Select the diagram that represents the shape of a red blood cell when placed in each of the following **a** to **e**: (9.6)



1 **2** **3**

Normal red blood cell

a. 0.9% (m/v) NaCl solution
b. 10% (m/v) glucose solution
c. 0.01% (m/v) NaCl solution
d. 5% (m/v) glucose solution
e. 1% (m/v) glucose solution

ADDITIONAL QUESTIONS AND PROBLEMS

9.99 Why does iodine dissolve in hexane, but not in water? (9.1)

9.100 How do temperature and pressure affect the solubility of solids and gases in water? (9.3)

9.101 Potassium nitrate has a solubility of 32 g of KNO_3 in 100 g of H_2O at 20 °C. Determine if each of the following forms an unsaturated or saturated solution at 20 °C: (9.3)
a. adding 32 g of KNO_3 to 200. g of H_2O
b. adding 19 g of KNO_3 to 50. g of H_2O
c. adding 68 g of KNO_3 to 150. g of H_2O

9.102 Potassium chloride has a solubility of 43 g of KCl in 100 g of H_2O at 50 °C. Determine if each of the following forms an unsaturated or saturated solution at 50 °C: (9.3)
a. adding 25 g of KCl to 100. g of H_2O
b. adding 15 g of KCl to 25 g of H_2O
c. adding 86 g of KCl to 150. g of H_2O

9.103 Indicate whether each of the following ionic compounds is soluble or insoluble in water: (9.3)
a. KCl **b.** $MgSO_4$ **c.** CuS
d. $AgNO_3$ **e.** $Ca(OH)_2$

9.104 Indicate whether each of the following ionic compounds is soluble or insoluble in water: (9.3)
a. $CuCO_3$ **b.** FeO **c.** $Mg_3(PO_4)_2$
d. $(NH_4)_2SO_4$ **e.** $NaHCO_3$

9.105 Write the net ionic equation to show the formation of a solid (insoluble ionic compound) when the following solutions are mixed. Write *none* if no solid forms. (9.3)
a. $AgNO_3(aq)$ and $LiCl(aq)$
b. $NaCl(aq)$ and $KNO_3(aq)$
c. $Na_2SO_4(aq)$ and $BaCl_2(aq)$

9.106 Write the net ionic equation to show the formation of a solid (insoluble ionic compound) when the following solutions are mixed. Write *none* if no solid forms. (9.3)
a. $Ca(NO_3)_2(aq)$ and $Na_2S(aq)$
b. $Na_3PO_4(aq)$ and $Pb(NO_3)_2(aq)$
c. $FeCl_3(aq)$ and $NH_4NO_3(aq)$

9.107 Calculate the mass percent (m/m) of a solution containing 15.5 g of Na_2SO_4 and 75.5 g of H_2O. (9.4)

9.108 Calculate the mass percent (m/m) of a solution containing 26 g of K_2CO_3 and 724 g of H_2O. (9.4)

9.109 How many milliliters of a 12% (v/v) propyl alcohol solution would you need to obtain 4.5 mL of propyl alcohol? (9.4)

9.110 An 80-proof brandy is a 40.% (v/v) ethanol solution. The "proof" is twice the percent concentration of alcohol in the beverage. How many milliliters of alcohol are present in 750 mL of brandy? (9.4)

9.111 How many liters of a 12% (m/v) KOH solution would you need to obtain 86.0 g of KOH? (9.4)

9.112 How many liters of a 5.0% (m/v) glucose solution would you need to obtain 75 g of glucose? (9.4)

9.113 What is the molarity of a solution containing 8.0 g of NaOH in 400. mL of NaOH solution? (9.4)

9.114 What is the molarity of a solution containing 15.6 g of KCl in 274 mL of KCl solution? (9.4)

9.115 How many grams of solute are in each of the following solutions? (9.4)
a. 2.5 L of a 3.0 M $Al(NO_3)_3$ solution
b. 75 mL of a 0.50 M $C_6H_{12}O_6$ solution
c. 235 mL of a 1.80 M LiCl solution

9.116 How many grams of solute are in each of the following solutions? (9.4)
a. 0.428 L of a 0.450 M K_2CO_3 solution
b. 10.5 mL of a 2.50 M $AgNO_3$ solution
c. 28.4 mL of a 6.00 M H_3PO_4 solution

9.117 Calculate the final concentration of the solution when water is added to prepare each of the following: (9.5)
a. 25.0 mL of a 0.200 M NaBr solution is diluted to 50.0 mL
b. 15.0 mL of a 12.0% (m/v) K_2SO_4 solution is diluted to 40.0 mL
c. 75.0 mL of a 6.00 M NaOH solution is diluted to 255 mL

9.118 Calculate the final concentration of the solution when water is added to prepare each of the following: (9.5)
- **a.** 25.0 mL of a 18.0 M HCl solution is diluted to 500. mL
- **b.** 50.0 mL of a 15.0% (m/v) NH_4Cl solution is diluted to 125 mL
- **c.** 4.50 mL of a 8.50 M KOH solution is diluted to 75.0 mL

9.119 What is the initial volume, in milliliters, needed to prepare each of the following diluted solutions? (9.5)
- **a.** 250 mL of 3.0% (m/v) HCl from 10.0% (m/v) HCl
- **b.** 500. mL of 0.90% (m/v) NaCl from 5.0% (m/v) NaCl
- **c.** 350. mL of 2.00 M NaOH from 6.00 M NaOH

9.120 What is the initial volume, in milliliters, needed to prepare each of the following diluted solutions? (9.5)
- **a.** 250 mL of 5.0% (m/v) glucose from 20.% (m/v) glucose
- **b.** 45.0 mL of 1.0% (m/v) $CaCl_2$ from 5.0% (m/v) $CaCl_2$
- **c.** 100. mL of 6.00 M H_2SO_4 from 18.0 M H_2SO_4

9.121 Calculate the freezing point of each of the following solutions: (9.6)
- **a.** 0.580 mole of lactose, a nonelectrolyte, added to 1.00 kg of water
- **b.** 45.0 g of KCl, a strong electrolyte, dissolved in 1.00 kg of water
- **c.** 1.5 moles of K_3PO_4, a strong electrolyte, dissolved in 1.00 kg of water

9.122 Calculate the boiling point of each of the following solutions: (9.6)
- **a.** 175 g of glucose, $C_6H_{12}O_6$, a nonelectrolyte, added to 1.00 kg of water
- **b.** 1.8 moles of $CaCl_2$, a strong electrolyte, dissolved in 1.00 kg of water
- **c.** 50.0 g of $LiNO_3$, a strong electrolyte, dissolved in 1.00 kg of water

Clinical Applications

9.123 An antacid tablet, such as Amphojel, may be taken to reduce excess stomach acid, which is 0.20 M HCl. If one dose of Amphojel contains 450 mg of $Al(OH)_3$, what volume, in milliliters, of stomach acid will be neutralized? (9.4)

$$Al(OH)_3(s) + 3HCl(aq) \longrightarrow 3H_2O(l) + AlCl_3(aq)$$

9.124 Calcium carbonate, $CaCO_3$, reacts with stomach acid, (HCl, hydrochloric acid) according to the following equation: (9.4)

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CO_2(g) + H_2O(l) + CaCl_2(aq)$$

Tums, an antacid, contains $CaCO_3$. If Tums is added to 20.0 mL of a 0.400 M HCl solution, how many grams of CO_2 gas are produced?

9.125 What is the osmolarity (Osm) of a half-normal 0.45% (m/v) NaCl solution? (9.6)

9.126 A Ringer's Injection solution contains Na^+ 147 mEq/L, K^+ 4 mEq/L, Ca^{2+} 4 mEq/L, and Cl^- 155 mEq/L. What is the osmolarity (Osm) of the solution? (9.6)

9.127 A patient on dialysis has a high level of urea, a high level of sodium, and a low level of potassium in the blood. Why is the dialyzing solution prepared with a high level of potassium but no sodium or urea? (9.6)

9.128 Why would a dialysis unit (artificial kidney) use isotonic concentrations of NaCl, KCl, $NaHCO_3$, and glucose in the dialysate? (9.6)

CHALLENGE QUESTIONS

The following groups of questions are related to the topics in this chapter. However, they do not all follow the chapter order, and they require you to combine concepts and skills from several sections. These questions will help you increase your critical thinking skills and prepare for your next exam.

9.129 In a laboratory experiment, a 10.0-mL sample of NaCl solution is poured into an evaporating dish with a mass of 24.10 g. The combined mass of the evaporating dish and NaCl solution is 36.15 g. After heating, the evaporating dish and dry NaCl have a combined mass of 25.50 g. (9.4)
- **a.** What is the mass percent (m/m) of the NaCl solution?
- **b.** What is the molarity (M) of the NaCl solution?
- **c.** If water is added to 10.0 mL of the initial NaCl solution to give a final volume of 60.0 mL, what is the molarity of the diluted NaCl solution?

9.130 In a laboratory experiment, a 15.0-mL sample of KCl solution is poured into an evaporating dish with a mass of 24.10 g. The combined mass of the evaporating dish and KCl solution is 41.50 g. After heating, the evaporating dish and dry KCl have a combined mass of 28.28 g. (9.4)
- **a.** What is the mass percent (m/m) of the KCl solution?
- **b.** What is the molarity (M) of the KCl solution?
- **c.** If water is added to 10.0 mL of the initial KCl solution to give a final volume of 60.0 mL, what is the molarity of the diluted KCl solution?

9.131 Potassium fluoride has a solubility of 92 g of KF in 100 g of H_2O at 18 °C. Determine if each of the following mixtures forms an unsaturated or saturated solution at 18 °C: (9.3)
- **a.** adding 35 g of KF to 25 g of H_2O
- **b.** adding 42 g of KF to 50. g of H_2O
- **c.** adding 145 g of KF to 150. g of H_2O

9.132 Lithium chloride has a solubility of 55 g of LiCl in 100 g of H_2O at 25 °C. Determine if each of the following mixtures forms an unsaturated or saturated solution at 25 °C: (9.3)
- **a.** adding 10 g of LiCl to 15 g of H_2O
- **b.** adding 25 g of LiCl to 50. g of H_2O
- **c.** adding 75 g of LiCl to 150. g of H_2O

9.133 A solution is prepared with 70.0 g of HNO_3 and 130.0 g of H_2O. The HNO_3 solution has a density of 1.21 g/mL. (9.4)
- **a.** What is the mass percent (m/m) of the HNO_3 solution?
- **b.** What is the total volume, in milliliters, of the solution?
- **c.** What is the mass/volume percent (m/v) of the solution?
- **d.** What is the molarity (M) of the solution?

9.134 A solution is prepared by dissolving 22.0 g of NaOH in 118.0 g of water. The NaOH solution has a density of 1.15 g/mL. (9.4)
- **a.** What is the mass percent (m/m) of the NaOH solution?
- **b.** What is the total volume, in milliliters, of the solution?
- **c.** What is the mass/volume percent (m/v) of the solution?
- **d.** What is the molarity (M) of the solution?

Clinical Applications

9.135 A Pedialyte solution contains Na^+ 45 mEq/L, K^+ 20. mEq/L, Cl^- 35 mEq/L, citrate^{3-} 30. mEq/L, and glucose ($C_6H_{12}O_6$) 25 g/L. (9.6)
a. What is the total positive charge of the electrolytes?
b. What is the total negative charge of the electrolytes?
c. What is the osmolarity (Osm) of the solution?

9.136 A lactated Ringer's solution with 5% glucose contains Na^+ 130. mEq/L, K^+ 4 mEq/L, Ca^{2+} 3 mEq/L, Cl^- 109 mEq/L, lactate$^-$ 28 mEq/L, and glucose ($C_6H_{12}O_6$) 50. g/L. (9.6)
a. What is the total positive charge of the electrolytes?
b. What is the total negative charge of the electrolytes?
c. What is the osmolarity (Osm) of the solution?

ANSWERS

Answers to Selected Questions and Problems

9.1 **a.** NaCl, solute; water, solvent
b. water, solute; ethanol, solvent
c. oxygen, solute; nitrogen, solvent

9.3 The polar water molecules pull the K^+ and I^- ions away from the solid and into solution, where they are hydrated.

9.5 **a.** water **b.** CCl_4
c. water **d.** CCl_4

9.7 In a solution of KF, only the ions of K^+ and F^- are present in the solvent. In an HF solution, there are a few ions of H^+ and F^- present but mostly dissolved HF molecules.

9.9 **a.** $KCl(s) \xrightarrow{H_2O} K^+(aq) + Cl^-(aq)$
b. $CaCl_2(s) \xrightarrow{H_2O} Ca^{2+}(aq) + 2Cl^-(aq)$
c. $K_3PO_4(s) \xrightarrow{H_2O} 3K^+(aq) + PO_4^{3-}(aq)$
d. $Fe(NO_3)_3(s) \xrightarrow{H_2O} Fe^{3+}(aq) + 3NO_3^-(aq)$

9.11 **a.** mostly molecules and a few ions
b. ions only
c. molecules only

9.13 **a.** strong electrolyte
b. weak electrolyte
c. nonelectrolyte

9.15 **a.** 1 Eq **b.** 2 Eq
c. 2 Eq **d.** 6 Eq

9.17 0.154 mole of Na^+, 0.154 mole of Cl^-

9.19 55 mEq/L

9.21 **a.** 130 mEq/L **b.** above the normal range

9.23 **a.** unsaturated **b.** unsaturated
c. saturated

9.25 **a.** 68 g of KCl **b.** 12 g of KCl

9.27 **a.** The solubility of solid solutes typically increases as temperature increases.
b. The solubility of a gas is less at a higher temperature.
c. Gas solubility is less at a higher temperature and the CO_2 pressure in the can is increased.

9.29 **a.** soluble **b.** insoluble **c.** insoluble
d. soluble **e.** soluble

9.31 **a.** No solid forms.
b. $2Ag^+(aq) + 2NO_3^-(aq) + 2K^+(aq) + S^{2-}(aq) \longrightarrow Ag_2S(s) + 2K^+(aq) + 2NO_3^-(aq)$
$2Ag^+(aq) + S^{2-}(aq) \longrightarrow Ag_2S(s)$
c. $Ca^{2+}(aq) + 2Cl^-(aq) + 2Na^+(aq) + SO_4^{2-}(aq) \longrightarrow CaSO_4(s) + 2Na^+(aq) + 2Cl^-(aq)$
$Ca^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow CaSO_4(s)$
d. $3Cu^{2+}(aq) + 6Cl^-(aq) + 6Li^+(aq) + 2PO_4^{3-}(aq) \longrightarrow Cu_3(PO_4)_2(s) + 6Li^+(aq) + 6Cl^-(aq)$
$3Cu^{2+}(aq) + 2PO_4^{3-}(aq) \longrightarrow Cu_3(PO_4)_2(s)$

9.33 **a.** 17% (m/m) KCl solution
b. 5.3% (m/m) sucrose solution
c. 10.% (m/m) $CaCl_2$ solution

9.35 **a.** 30.% (m/v) Na_2SO_4 solution
b. 11% (m/v) sucrose solution

9.37 **a.** 2.5 g of KCl **b.** 50. g of NH_4Cl
c. 25.0 mL of acetic acid

9.39 79.9 mL of alcohol

9.41 **a.** 20. g of $LiNO_3$ solution
b. 400. mL of KOH solution
c. 20. mL of formic acid solution

9.43 **a.** 0.500 M glucose solution
b. 0.0356 M KOH solution
c. 0.250 M NaCl solution

9.45 **a.** 120. g of NaOH **b.** 59.6 g of KCl
c. 5.47 g of HCl

9.47 **a.** 1.50 L of KBr solution
b. 10.0 L of NaCl solution
c. 62.5 mL of $Ca(NO_3)_2$ solution

9.49 **a.** 10.4 g of $PbCl_2$
b. 18.8 mL of $Pb(NO_3)_2$ solution
c. 1.20 M KCl solution

9.51 **a.** 206 mL of HCl solution
b. 11.2 L of H_2 gas
c. 9.09 M HCl solution

9.53 **a.** 20. g of mannitol **b.** 240 g of mannitol

9.55 2 L of glucose solution

9.57 3.0 mL of chlorpromazine solution

9.59 0.50 g of $CaCl_2$

9.61 Adding water (solvent) to the soup increases the volume and dilutes the tomato soup concentration.

9.63 **a.** 2.0 M HCl solution
b. 2.0 M NaOH solution
c. 2.5% (m/v) KOH solution
d. 3.0% (m/v) H_2SO_4 solution

9.65 **a.** 80. mL of HCl solution
b. 250 mL of LiCl solution
c. 600. mL of H_3PO_4 solution
d. 180 mL of glucose solution

9.67 **a.** 12.8 mL of the HNO_3 solution
b. 11.9 mL of the $MgCl_2$ solution
c. 1.88 mL of the KCl solution

9.69 1.0×10^2 mL

9.71 **a.** solution **b.** suspension

9.73 **a.** 2.0 moles of ethylene glycol in 1.0 kg of water will have a lower freezing point because it has more particles in solution.
b. 0.50 mole of $MgCl_2$ in 1.0 kg of water has a lower freezing point because each $MgCl_2$ dissociates in water to give three particles, whereas each KCl dissociates to give only two particles.

9.75 **a.** −2.53 °C **b.** −15.6 °C **c.** −5.54 °C

9.77 **a.** 10% (m/v) starch solution
b. from the 1% (m/v) starch solution into the 10% (m/v) starch solution
c. 10% (m/v) starch solution

9.79 **a.** B 10% (m/v) sucrose solution
b. A 8% (m/v) albumin solution
c. B 10% (m/v) starch solution

9.81 **a.** 1.0 Osm **b.** 2.8 Osm

9.83 **a.** hypotonic **b.** hypotonic
c. isotonic **d.** hypertonic

9.85 **a.** NaCl **b.** alanine
c. NaCl **d.** urea

9.87 **a.** K^+, Na^+, Cl^- **b.** Ca^{2+}, Mg^{2+}
c. Ca^{2+}, Mg^{2+} **d.** K^+, Na^+, Cl^-

9.89 **a.** 1 **b.** 2 **c.** 1

9.91 **a.** 3 **b.** 1 **c.** 2

9.93 **a.** beaker 3
b. $Na^+(aq) + Cl^-(aq) + Ag^+(aq) + NO_3^-(aq) \longrightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$
c. $Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$

9.95 The skin of the cucumber acts like a semipermeable membrane, and the more dilute solution inside flows into the brine solution.

9.97 **a.** 2 **b.** 1 **c.** 3 **d.** 2

9.99 Because iodine is a nonpolar molecule, it will dissolve in hexane, a nonpolar solvent. Iodine does not dissolve in water because water is a polar solvent.

9.101 **a.** unsaturated solution **b.** saturated solution
c. saturated solution

9.103 **a.** soluble **b.** soluble
c. insoluble **d.** soluble
e. insoluble

9.105 **a.** $Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$
b. none
c. $Ba^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow BaSO_4(s)$

9.107 17.0% (m/m) Na_2SO_4 solution

9.109 38 mL of propyl alcohol solution

9.111 0.72 L of KOH solution

9.113 0.500 M NaOH solution

9.115 **a.** 1600 g of $Al(NO_3)_3$ **b.** 6.8 g of $C_6H_{12}O_6$
c. 17.9 g of LiCl

9.117 **a.** 0.100 M NaBr solution
b. 4.50% (m/v) K_2SO_4 solution
c. 1.76 M NaOH solution

9.119 **a.** 75 mL of 10.0% (m/v) HCl solution
b. 90. mL of 5.0% (m/v) NaCl solution
c. 117 mL of 6.00 M NaOH solution

9.121 **a.** −1.08 °C **b.** −2.25 °C **c.** −11 °C

9.123 87 mL of HCl solution

9.125 0.15 Osm

9.127 A dialysis solution contains no sodium or urea so that these substances will flow out of the blood into the solution. High levels of potassium are maintained in the dialyzing solution so that the potassium will dialyze into the blood.

9.129 **a.** 11.6% (m/m) NaCl solution
b. 2.40 M NaCl solution
c. 0.400 M NaCl solution

9.131 **a.** saturated **b.** unsaturated
c. saturated

9.133 **a.** 35.0% (m/m) HNO_3 solution
b. 165 mL
c. 42.4% (m/v) HNO_3 solution
d. 6.73 M HNO_3 solution

9.135 **a.** 65 mEq/L
b. 65 mEq/L
c. 0.25 Osm