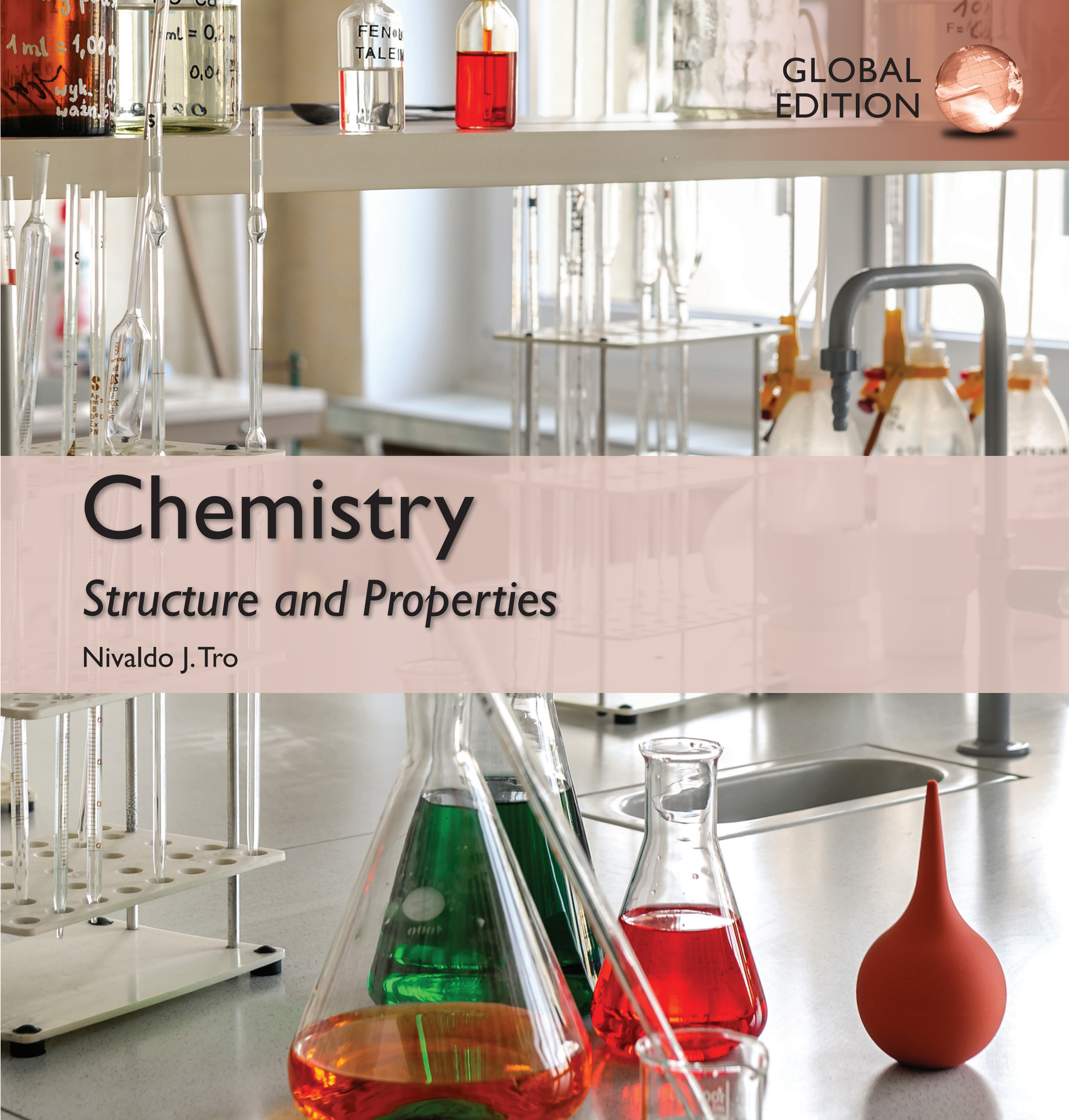


GLOBAL EDITION

Chemistry

Structure and Properties

Nivaldo J. Tro

ALWAYS LEARNING

PEARSON

Main groups | Transition metals | Main groups

Metals | Metalloids | Nonmetals

Period	1A[a] 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.94	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** [98]	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** [208.98]	85 **At** [209.99]	86 **Rn** [222.02]
7	87 **Fr** [223.02]	88 **Ra** [226.03]	89 **Ac** [227.03]	104 **Rf** [261.11]	105 **Db** [262.11]	106 **Sg** [266.12]	107 **Bh** [264.12]	108 **Hs** [269.13]	109 **Mt** [268.14]	110 **Ds** [271]	111 **Rg** [272]	112 **Cn** [285]	113	114 **Fl** [289]	115	116 **Lv** [292]	117*	118

Lanthanide series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** [145]	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
Actinide series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** [237.05]	94 **Pu** [244.06]	95 **Am** [243.06]	96 **Cm** [247.07]	97 **Bk** [247.07]	98 **Cf** [251.08]	99 **Es** [252.08]	100 **Fm** [257.10]	101 **Md** [258.10]	102 **No** [259.10]	103 **Lr** [262.11]

[a]The labels on top (1A, 2A, etc.) are common American usage. The labels below these (1, 2, etc.) are those recommended by the International Union of Pure and Applied Chemistry.

Atomic masses in brackets are the masses of the longest-lived or most important isotope of radioactive elements.

*Element 117 is currently under review by IUPAC.

EXAMPLE 9.3
Solution Dilution

To what volume should you dilute 0.200 L of a 15.0 M NaOH solution to obtain a 3.00 M NaOH solution?

SORT You are given the initial volume, initial concentration, and final concentration of a solution, and you need to determine the final volume.

GIVEN: $V_1 = 0.200$ L
$M_1 = 15.0$ M
$M_2 = 3.00$ M
FIND: V_2

STRATEGIZE Equation 9.1 relates the initial and final volumes and concentrations for solution dilution problems. You are asked to find V_2. The other quantities (V_1, M_1, and M_2) are all given in the problem.

CONCEPTUAL PLAN

V_1, M_1, M_2 → V_2

$M_1V_1 = M_2V_2$

RELATIONSHIPS USED
$M_1V_1 = M_2V_2$

SOLVE Begin with the solution dilution equation and solve it for V_2.

Substitute in the required quantities and calculate V_2.

Make the solution by diluting 0.200 L of the stock solution to a total volume of 1.00 L (V_2). The resulting solution has a concentration of 3.00 M.

SOLUTION

$$M_1V_1 = M_2V_2$$

$$V_2 = \frac{M_1V_1}{M_2} = \frac{15.0\ \cancel{\text{mol/L}} \times 0.200\ \text{L}}{3.00\ \cancel{\text{mol/L}}} = 1.00\ \text{L}$$

CHECK The final units (L) are correct. The magnitude of the answer is reasonable because the solution is diluted from 15.0 M to 3.00 M, a factor of five. Therefore the volume should increase by a factor of five.

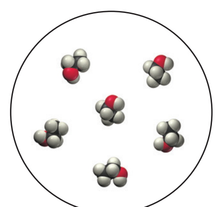
FOR PRACTICE 9.3
To what volume (in mL) should you dilute 100.0 mL of a 5.00 M $CaCl_2$ solution to obtain a 0.750 M $CaCl_2$ solution?

FOR MORE PRACTICE 9.3
What volume of a 6.00 M $NaNO_3$ solution should you use to make 0.525 L of a 1.20 M $NaNO_3$ solution?

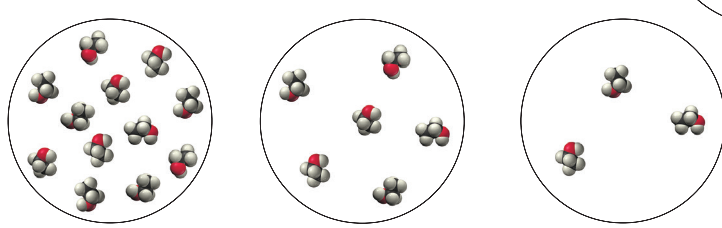
9.2 Cc Conceptual Connection

Solution Dilution

The image at right represents a small volume within 500 mL of aqueous ethanol (CH_3CH_2OH) solution. (The water molecules have been omitted for clarity.)



Which image best represents the same volume of the solution after we add an additional 500 mL of water?



(a) **(b)** **(c)**

9.3 Solution Stoichiometry

In Section 8.4 we discussed how to use the coefficients in chemical equations as conversion factors between the amounts of reactants (in moles) and the amounts of products (in moles). In aqueous reactions, quantities of reactants and products are often specified in terms of volumes and concentrations. We can use the volume and concentration of a reactant or product to calculate its amount in moles. We can then use the stoichiometric coefficients in the chemical equation to convert to the amount in moles of another reactant or product. The general conceptual plan for these kinds of calculations begins with the volume of a reactant or product:

Volume A → Amount A (in moles) → Amount B (in moles) → Volume B

We make the conversions between solution volumes and amounts in moles of solute using the molarities of the solutions. We make the conversions between amounts in moles of A and B using the stoichiometric coefficients from the balanced chemical equation. Example 9.4 demonstrates solution stoichiometry.

EXAMPLE 9.4 Solution Stoichiometry

What volume (in L) of 0.150 M KCl solution will completely react with 0.150 L of a 0.175 M $Pb(NO_3)_2$ solution according to this balanced chemical equation?

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

SORT You are given the volume and concentration of a $Pb(NO_3)_2$ solution. You are asked to find the volume of KCl solution (of a given concentration) required to react with it.

GIVEN: 0.150 L of $Pb(NO_3)_2$ solution, 0.175 M $Pb(NO_3)_2$ solution, 0.150 M KCl solution

FIND: volume KCl solution (in L)

STRATEGIZE The conceptual plan has the form: volume A ⟶ amount A (in moles) ⟶ amount B (in moles) ⟶ volume B. Use the molar concentrations of the KCl and $Pb(NO_3)_2$ solutions as conversion factors between the number of moles of reactants in these solutions and their volumes. Use the stoichiometric coefficients from the balanced equation to convert between number of moles of $Pb(NO_3)_2$ and number of moles of KCl.

CONCEPTUAL PLAN

L $Pb(NO_3)_2$ solution → mol $Pb(NO_3)_2$ → mol KCl → L KCl solution

$$\frac{0.175\ \text{mol}\ Pb(NO_3)_2}{1\ \text{L}\ Pb(NO_3)_2\ \text{solution}} \qquad \frac{2\ \text{mol KCl}}{1\ \text{mol}\ Pb(NO_3)_2} \qquad \frac{1\ \text{L KCl solution}}{0.150\ \text{mol KCl}}$$

RELATIONSHIPS USED

$$M\ [Pb(NO_3)_2] = \frac{0.175\ \text{mol}\ Pb(NO_3)_2}{1\ \text{L}\ Pb(NO_3)_2\ \text{solution}}$$

2 mol KCl : 1 mol $Pb(NO_3)_2$ (from chemical equation)

$$M\ [KCl] = \frac{0.150\ \text{mol KCl}}{1\ \text{L KCl solution}}$$

SOLVE Begin with L $Pb(NO_3)_2$ solution and follow the conceptual plan to arrive at L KCl solution.

SOLUTION

$$0.150\ \text{L}\ Pb(NO_3)_2\ \text{solution} \times \frac{0.175\ \text{mol}\ Pb(NO_3)_2}{1\ \text{L}\ Pb(NO_3)_2\ \text{solution}} \times \frac{2\ \text{mol KCl}}{1\ \text{mol}\ Pb(NO_3)_2} \times \frac{1\ \text{L KCl solution}}{0.150\ \text{mol KCl}} = 0.350\ \text{L KCl solution}$$

—Continued on the next page

Continued from the previous page—

CHECK The final units (L KCl solution) are correct. The magnitude (0.350 L) is reasonable because the reaction stoichiometry requires 2 mol of KCl per mole of $Pb(NO_3)_2$. Since the concentrations of the two solutions are not very different (0.150 M compared to 0.175 M), the volume of KCl required is roughly two times the 0.150 L of $Pb(NO_3)_2$ given in the problem.

FOR PRACTICE 9.4

What volume (in mL) of a 0.150 M HNO_3 solution will completely react with 35.7 mL of a 0.108 M Na_2CO_3 solution according to this balanced chemical equation?

$$Na_2CO_3(aq) + 2\,HNO_3(aq) \longrightarrow 2\,NaNO_3(aq) + CO_2(g) + H_2O(l)$$

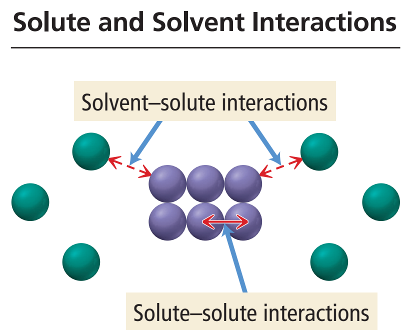
FOR MORE PRACTICE 9.4

In the reaction in For Practice 9.4, what mass (in grams) of carbon dioxide forms?

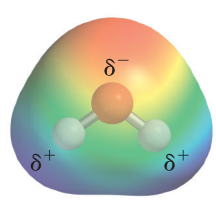
9.4 Types of Aqueous Solutions and Solubility

Consider two familiar aqueous solutions: salt water and sugar water. Salt water is a homogeneous mixture of NaCl and H_2O, and sugar water is a homogeneous mixture of $C_{12}H_{22}O_{11}$ and H_2O. You may have made these solutions yourself by adding table salt or sugar to water. As you stir either of these two substances into the water, the substance seems to disappear. However, you know that the original substance is still present because you can taste saltiness or sweetness in the water. How do solids such as salt and sugar dissolve in water?

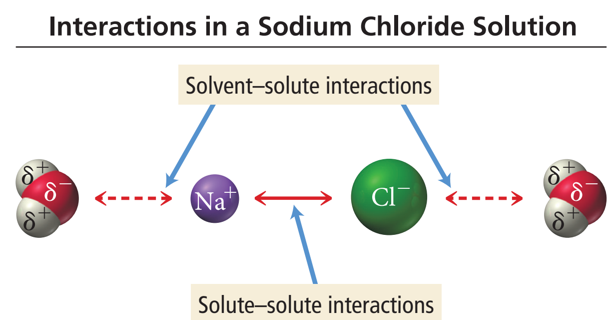
When a solid is put into a liquid solvent, the attractive forces that hold the solid together (the solute–solute interactions) compete with the attractive forces between the solvent molecules and the particles that compose the solid (the solvent–solute interactions), as shown in Figure 9.5 ◀. For example, when we add sodium chloride to water, there is a competition between the attraction of Na^+ cations and Cl^- anions to each other (due to their opposite charges) and the attraction of Na^+ and Cl^- to water molecules. The attraction of Na^+ and Cl^- to water is based on the *polar nature* of the water molecule (see Section 6.10). The oxygen atom in water is electron-rich, giving it a partial negative charge (δ^-), as shown in Figure 9.6 ▼. The hydrogen atoms, in contrast, are electron-poor, giving them a partial positive charge (δ^+). As a result, the positively charged sodium ions are strongly attracted to the oxygen side of the water molecule, and the negatively charged chloride ions are attracted to the hydrogen side of the water molecule, as shown in Figure 9.7 ▼. In the case of NaCl, the attraction between the separated ions and the water molecules overcomes the attraction of sodium and chloride ions to each other, and the sodium chloride dissolves in the water (Figure 9.8 ▶).



▲ **FIGURE 9.5 Solute and Solvent Interactions** When a solid is put into a solvent, the interactions among solvent and solute particles compete with the interactions among the solute particles themselves.



▲ **FIGURE 9.6 Electrostatic Potential Map of a Water Molecule** An uneven distribution of electrons within the water molecule causes the oxygen side of the water molecule to have a partial negative charge and the hydrogen side to have a partial positive charge.



▲ **FIGURE 9.7 Solute and Solvent Interactions in a Sodium Chloride Solution** When sodium chloride is put into water, the attraction of Na^+ and Cl^- ions to water molecules competes with the attraction among the oppositely charged ions themselves.

Dissolution of an Ionic Compound

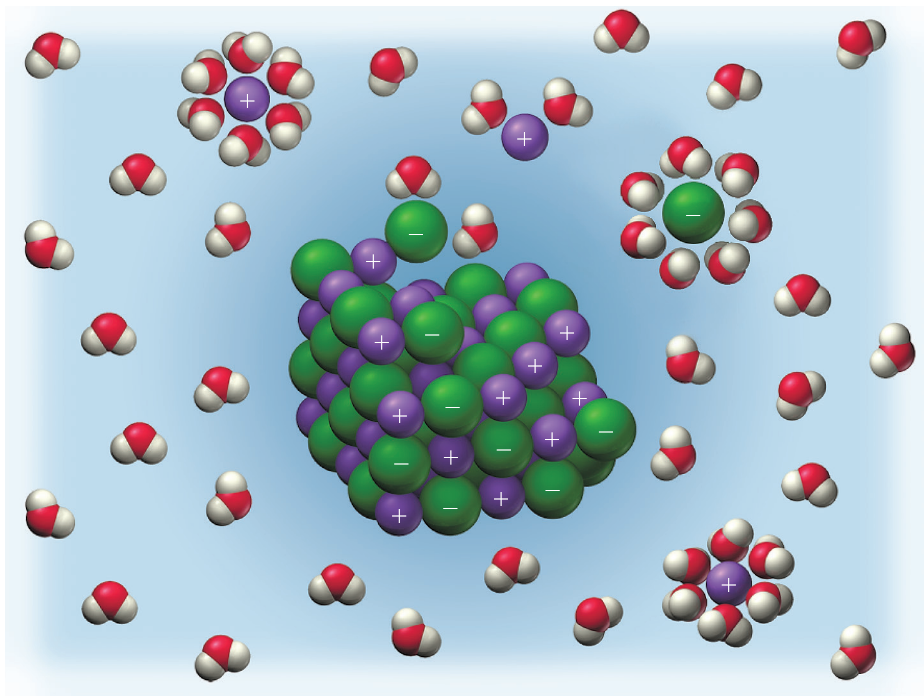
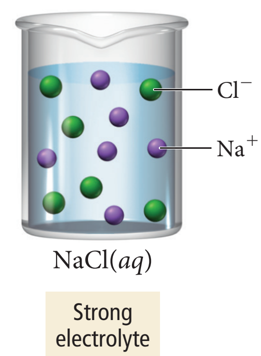


FIGURE 9.8 Sodium Chloride Dissolving in Water The attraction between water molecules and the ions of sodium chloride causes NaCl to dissolve in the water.

Electrolyte and Nonelectrolyte Solutions

As Figure 9.9 ▼ illustrates, a salt solution conducts electricity while a sugar solution does not. The difference between the way that salt (an ionic compound) and sugar (a molecular compound) dissolve in water illustrates a fundamental difference between types of solutions. Ionic compounds such as the sodium chloride in the previous example (or the calcium chloride used for spherification in molecular gastronomy discussed in Section 9.1), dissociate into their component ions when they dissolve in water. An NaCl solution, represented as NaCl(*aq*), does not contain any NaCl units, but rather dissolved Na^+ ions and Cl^- ions.



Electrolyte and Nonelectrolyte Solutions

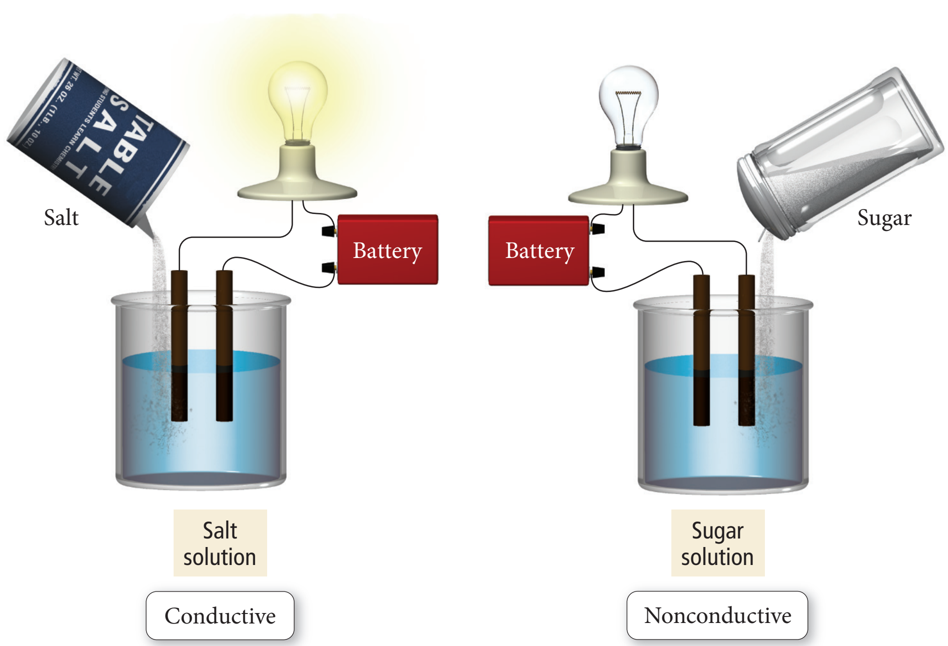
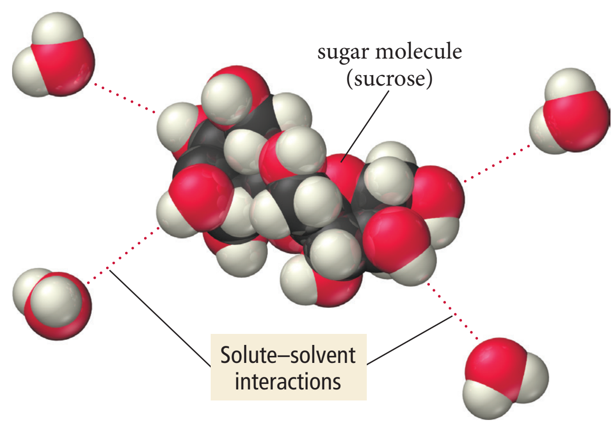


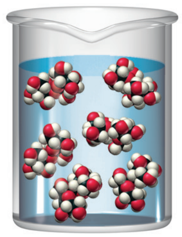
FIGURE 9.9 Electrolyte and Nonelectrolyte Solutions A solution of salt (an electrolyte) conducts electrical current. A solution of sugar (a nonelectrolyte) does not.

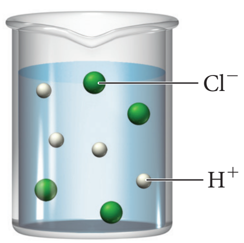
The dissolved ions act as charge carriers, allowing the solution to conduct electricity. Substances that dissolve in water to form solutions that conduct electricity are **electrolytes**. Substances such as sodium chloride that completely dissociate into ions when they dissolve in water are **strong electrolytes**, and the resulting solutions are strong electrolyte solutions.

Interactions between Sugar and Water Molecules



▶ **FIGURE 9.10 Sugar and Water Interactions** Partial charges on sugar molecules and water molecules (discussed more fully in Chapter 14) result in attractions between the sugar molecules and water molecules.



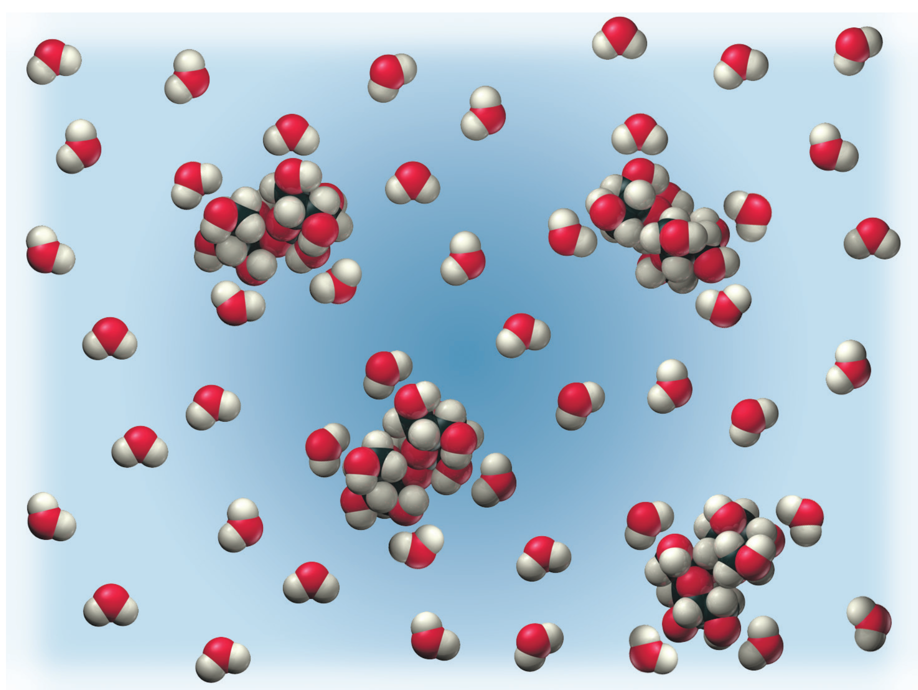


In contrast to sodium chloride, sugar is a molecular compound. Most molecular compounds—with the important exception of acids, which we discuss shortly—dissolve in water as intact molecules. Sugar dissolves because the attraction between sugar molecules and water molecules, shown in Figure 9.10 ▲, overcomes the attraction of sugar molecules to each other (Figure 9.11 ▼). So unlike a sodium chloride solution (which is composed of dissociated ions), a sugar solution is composed of intact $C_{12}H_{22}O_{11}$ molecules homogeneously mixed with the water molecules.

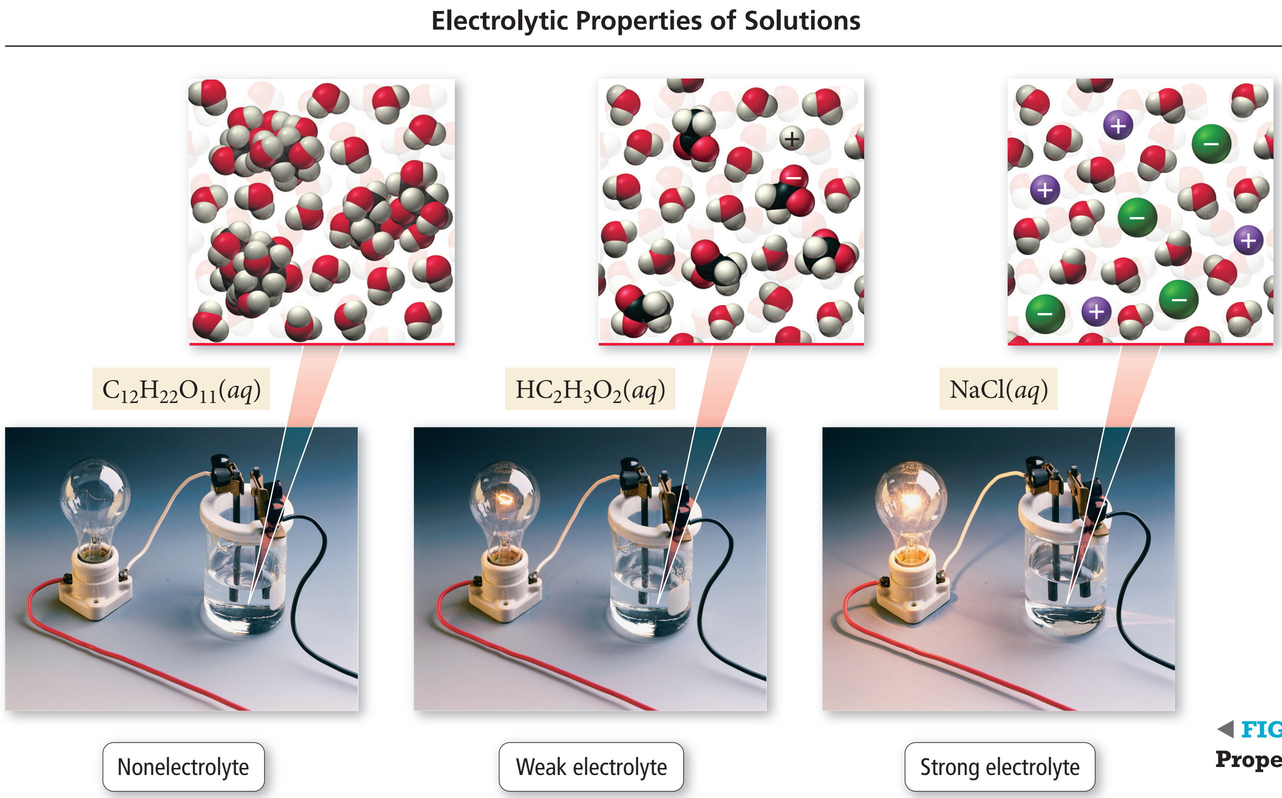
Compounds such as sugar that do not dissociate into ions when dissolved in water are **nonelectrolytes**, and the resulting solutions—called *nonelectrolyte solutions*—do not conduct electricity.

Acids are molecular compounds that ionize to form H^+ ions when they dissolve in water. Hydrochloric acid (HCl), for example, ionizes into H^+ and Cl^- when it dissolves in water. HCl is an example of a **strong acid**, one that completely ionizes in solution. Since strong acids completely ionize in

Sugar Solution



▶ **FIGURE 9.11 A Sugar Solution** Sugar dissolves because the attractions between sugar molecules and water molecules, which both contain a distribution of electrons that results in partial positive and partial negative charges, overcome the attractions among sugar molecules to each other.



◀ **FIGURE 9.12 Electrolytic Properties of Solutions**

solution, they are also strong electrolytes. We represent the complete ionization of a strong acid with a single reaction arrow between the acid and its ionized form:

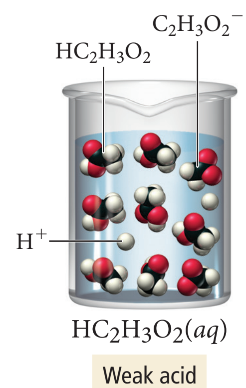
$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

Many acids are **weak acids**; they do not completely ionize in water. For example, acetic acid ($HC_2H_3O_2$), the acid in vinegar, is a weak acid. A solution of a weak acid is composed mostly of the nonionized acid—only a small percentage of the acid molecules ionize. We represent the partial ionization of a weak acid with opposing half arrows between the reactants and products:

$$HC_2H_3O_2(aq) \rightleftharpoons H^+(aq) + C_2H_3O_2^-(aq)$$

Weak acids are classified as **weak electrolytes**, and the resulting solutions—called *weak electrolyte solutions*—conduct electricity only weakly. Figure 9.12 ▲ summarizes the electrolytic properties of solutions.

Unlike soluble ionic compounds, which contain ions and therefore *dissociate* in water, acids are molecular compounds that *ionize* in water.



The Solubility of Ionic Compounds

As we have just discussed, when an ionic compound dissolves in water, the resulting solution contains, not the intact ionic compound itself, but its component ions dissolved in water. However, not all ionic compounds dissolve in water. If we add AgCl to water, for example, it remains solid and appears as a white powder at the bottom of the water.

In general, a compound is termed **soluble** if it dissolves in water and **insoluble** if it does not. However, these classifications are a bit of an oversimplification. In reality, solubility is a continuum and even "insoluble" compounds dissolve to some extent, though usually orders of magnitude less than soluble compounds. However, this oversimplification is useful in allowing us to systematically categorize a large number of compounds. (See Karl Popper's quote at the beginning of this chapter.)

As an example, consider silver nitrate, which is soluble. If we mix solid $AgNO_3$ with water, it dissolves and forms a strong electrolyte solution. Silver chloride, on the other hand, is almost