Topic 4.1-4.4

Introduction to Reactions

Learning Objectives

- Use experimental evidence to determine whether a change is physical or chemical.
- Define physical and chemical changes in terms of the types of interactions broken and formed.
- Understand how to balance a chemical equation.
- Write balanced molecular, ionic, and net ionic equations.
- Represent chemical equations using particle diagrams.

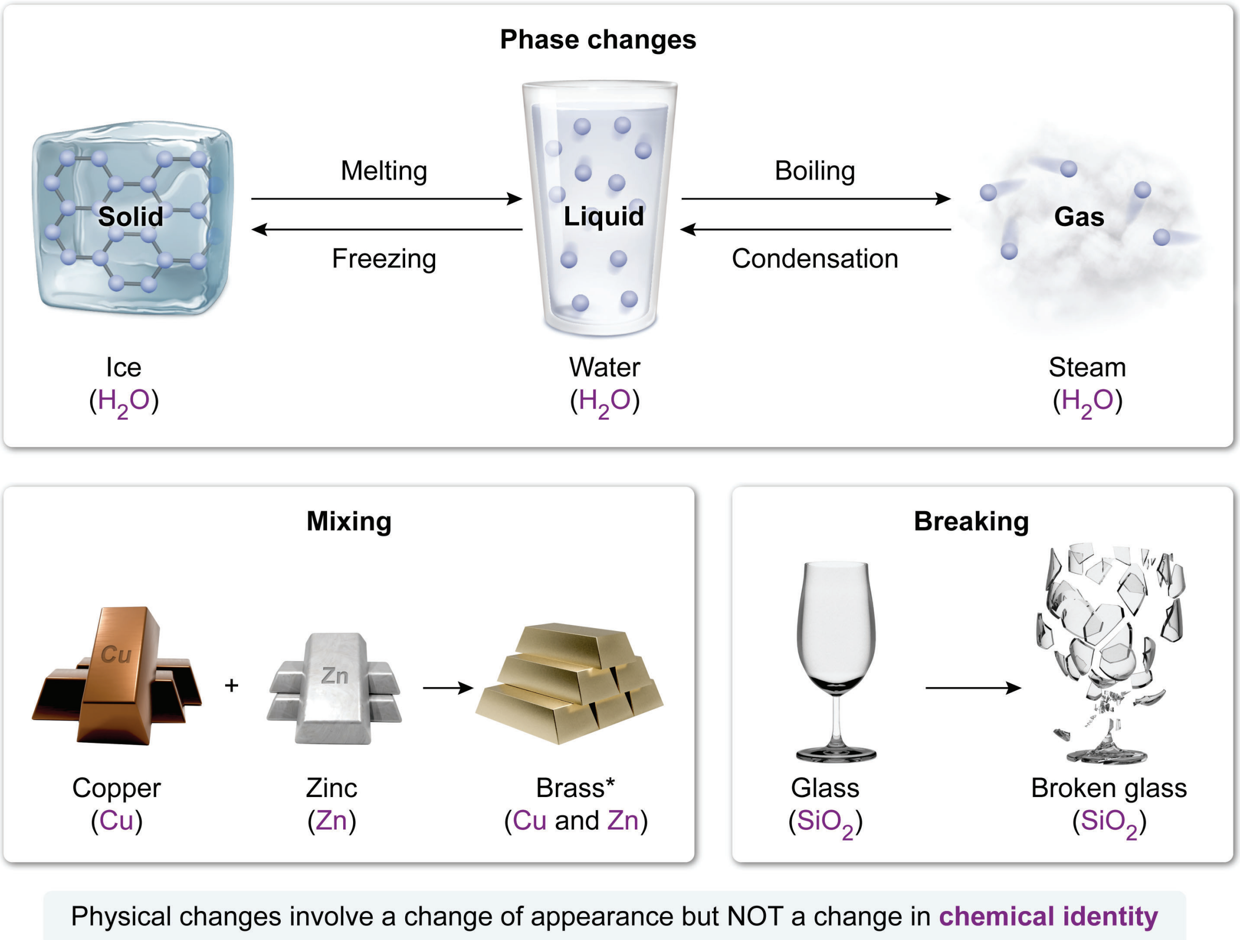
Topic Questions

- What is a physical change? What is a chemical change?
- What experimental evidence indicates a chemical change?
- What happens to particle interactions when physical or chemical changes occur?
- What are the steps for balancing an unbalanced chemical equation?
- How are chemical equations represented by balanced molecular, ionic, and net ionic equations?
- How are chemical equations shown using particle diagrams?

4.1.01 Physical and Chemical Changes

[TRA-1.A.1 TRA-1.A.2 TRA-1.D.1 TRA-1.D.2]

Molecules can undergo two types of changes: **physical** or **chemical**. A physical change occurs when properties such as the state, shape, size, or appearance of a substance change, but the composition of the molecules in that substance does not change. For example, when water freezes, it changes from a liquid to a solid (ie, a **phase change**), but it is still water. When a substance undergoes a physical change, its **chemical identity** stays the same, as Figure 4.1 illustrates.



*Brass is a homogeneous mixture of copper and zinc.

Figure 4.1 Examples of physical changes.

Chemical changes occur when the chemical identity of a substance changes. In other words, one or more new substances form that have chemical and physical properties that differ from those of the original substance. During an experiment, evidence that a chemical change has occurred may include observations such as:

- The production of heat or light
- The formation of a gas
- The formation of a **precipitate** (ie, an insoluble solid formed through the mixing of two aqueous solutions)
- A permanent color change

Examples of these four experimental observations are shown in Figure 4.2.

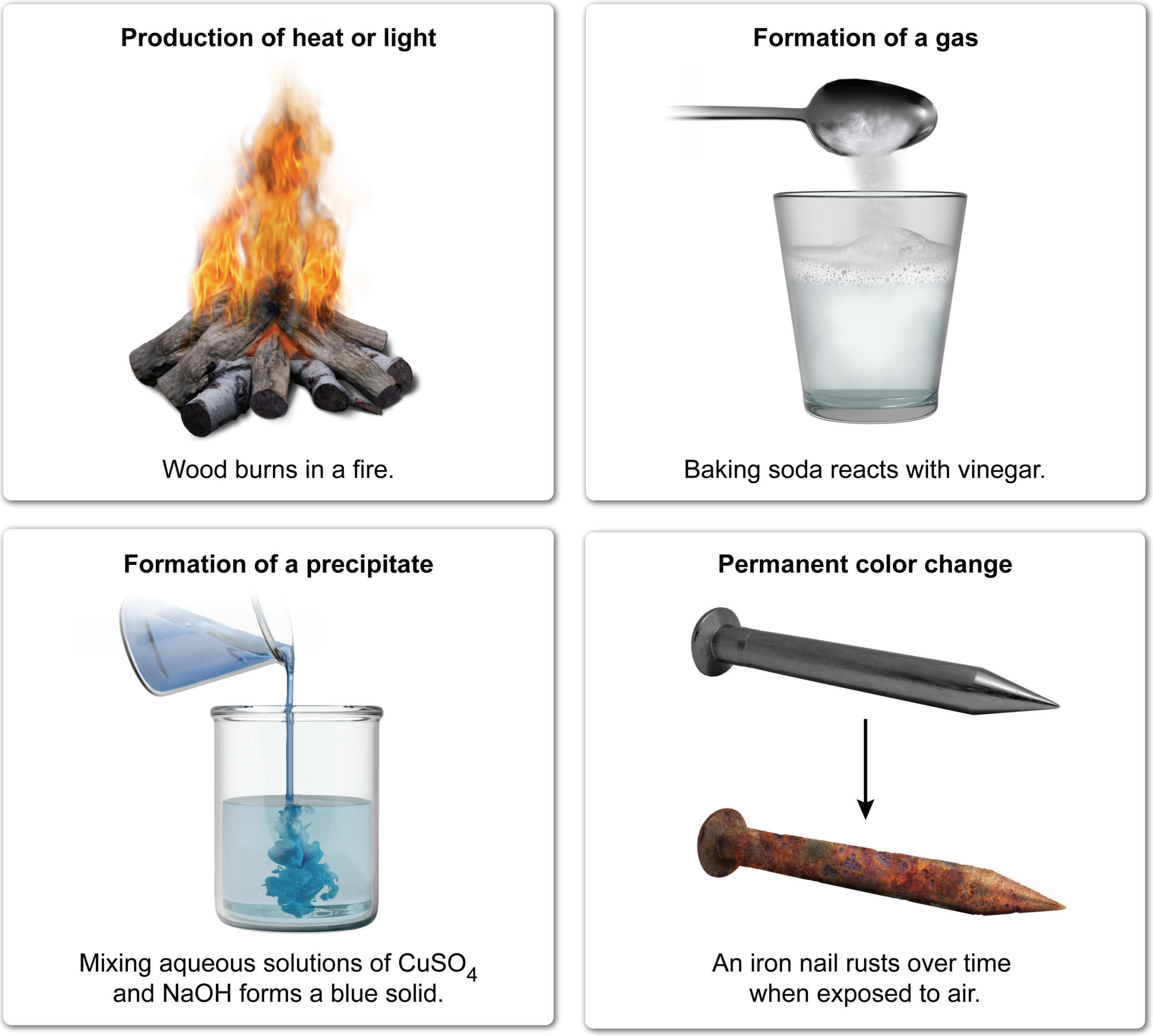


Figure 4.2 Examples of experimental observations that suggest a chemical change has occurred.

At the molecular level, the key difference between physical and chemical changes is the type of interactions that are broken and formed. A physical change occurs when intermolecular forces (ie, interactions between molecules) are broken, causing a substance's physical properties (eg, state, shape, appearance) to change while the composition and chemical identity of the substance remain the same. A chemical change occurs when bonds within a molecule are broken or formed, resulting in the formation of one or more new molecules with a new identity and composition.

The **dissolution** of an ionic substance in water, shown in Figure 4.3, is an ambiguous change.

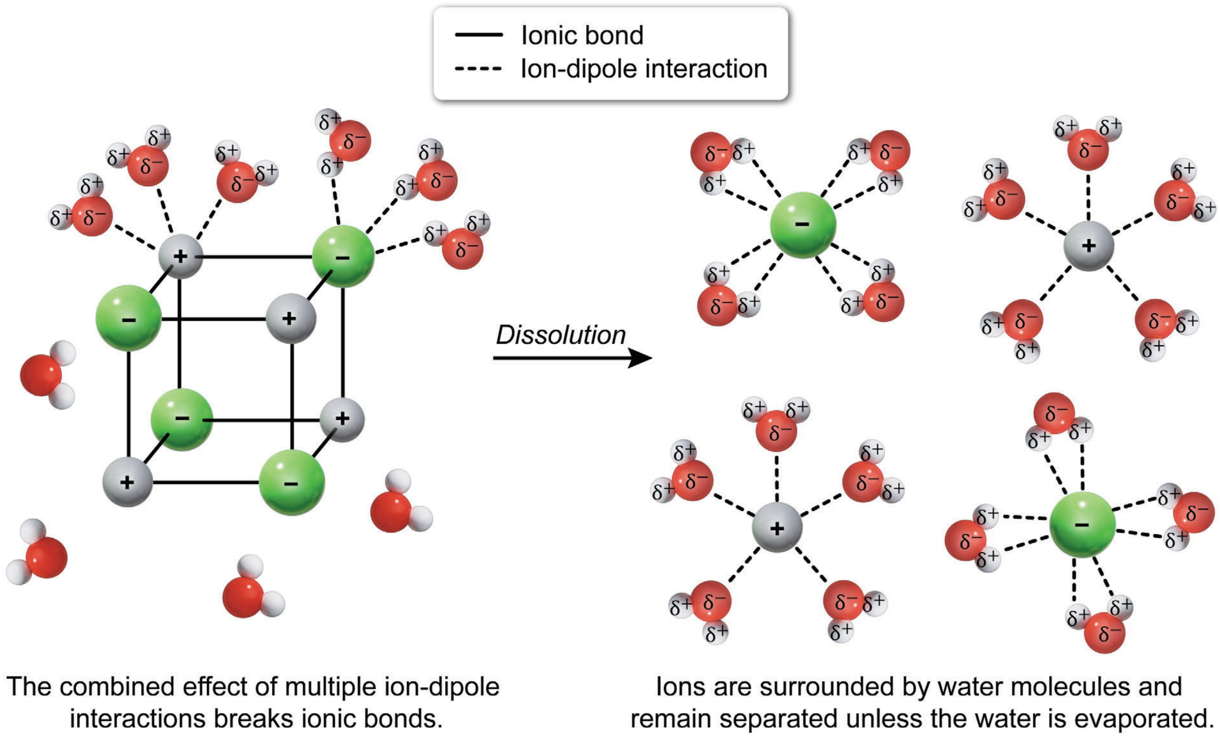


Figure 4.3 The dissolution of an ionic solid in water.

It can be argued that dissolving an ionic compound is a chemical change because ionic bonds are broken in this process and new ion-dipole interactions are formed. However, the ionic bonds can be reformed by evaporating the solvent. Because a physical change (ie, evaporation of the solvent) is all that is necessary to reform the ionic solid, dissolution is generally considered a physical change.

4.2.01 Balanced Reactions

[TRA-1.B.1 TRA-1.B.2]

For any chemical reaction, the law of conservation of mass states that atoms are neither created nor destroyed; they are only rearranged. Therefore, the same number of each type of atom must be present on the left and right sides of a reaction arrow (ie, the reaction must be balanced), as shown in Figure 4.4.

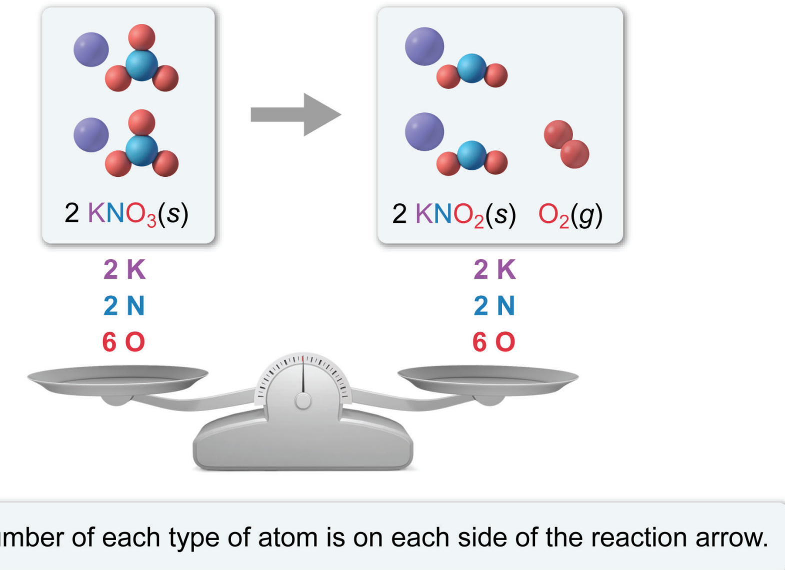


Figure 4.4 The balanced chemical reaction for the decomposition of $KNO_3(s)$.

Because positively charged protons and negatively charged electrons within the atoms are conserved, the sum of the charges must also be the same on both sides of the equation, as Figure 4.5 illustrates.

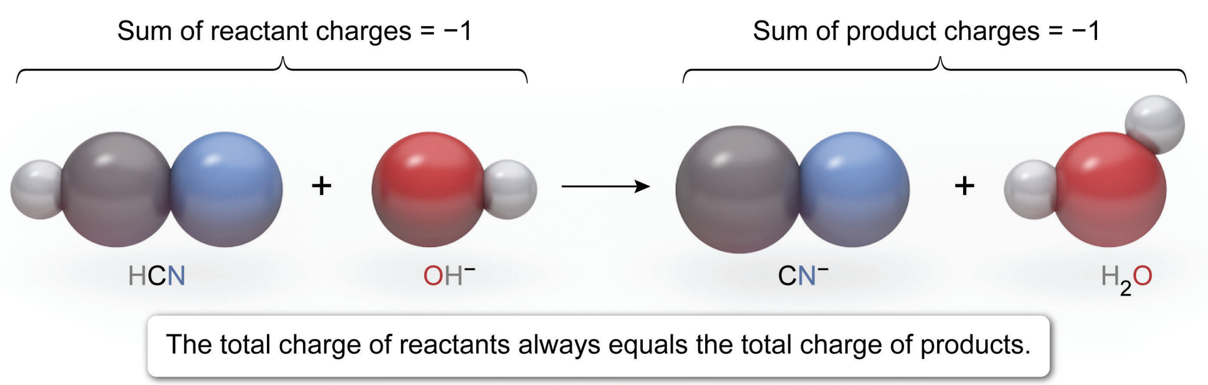


Figure 4.5 Conservation of charge in the reaction of HCN with OH^-.

The coefficients and chemical formulas of a balanced chemical equation show the lowest whole-number ratio of the substances (and their charges) present in the reaction. Because of this, the reaction can only occur in multiples of these ratios.

Consider the reaction between copper metal (Cu) and nitric acid (HNO_3), which produces copper (**II**) nitrate ($Cu(NO_3)_2$), nitrogen dioxide (NO_2), and water (H_2O). One useful method of balancing the equation is as follows:

Step 1: Given the unbalanced reaction equation, list out the elements present on both sides of the equation. Then, count how many of each atom are present initially and determine which elements need to be balanced. This is illustrated in Figure 4.6.

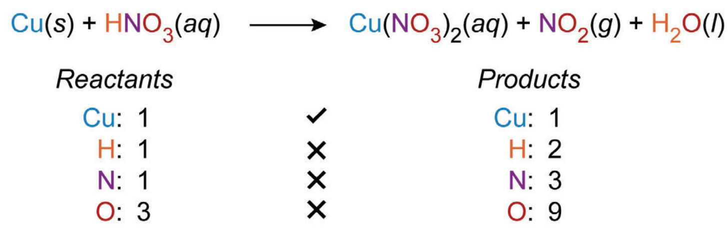


Figure 4.6 The number of each type of element present in the unbalanced reaction between Cu(*s*) and HNO_3(*aq*).

Step 2: Next, count how many substances each element appears in. The elements that appear in the *fewest* substances should be balanced first (Figure 4.7).

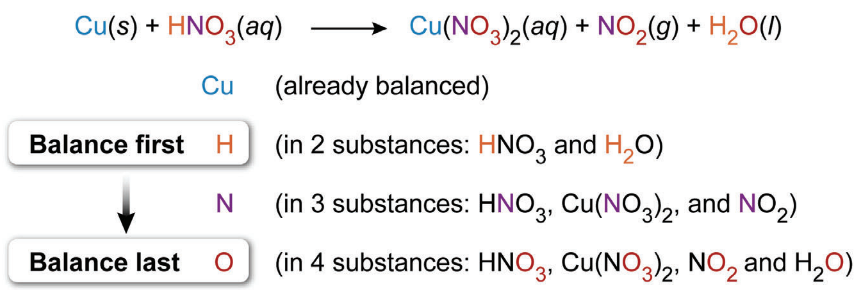


Figure 4.7 The order in which to balance elements is determined by how many substances they appear in.

Step 3: When balancing an element, *only* the coefficients (ie, the numbers to the left of each substance) can be changed. Changing the coefficient *multiplies* the number of each element in the substance by that coefficient. In the example reaction, H is the first element that needs to be balanced (note that Cu is already balanced). To balance H, the number of hydrogens (and therefore HNO_3 molecules) is doubled (Figure 4.8).

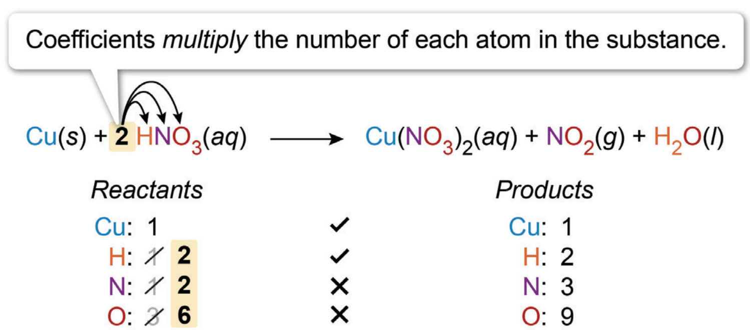


Figure 4.8 Hydrogen is balanced by a coefficient of 2 on the reactant side.

Step 4: If an element has an odd number of atoms on one side of the equation and an even number of atoms on the other side, double the coefficient of the substance with the odd number of atoms of that element. Then, rebalance the reaction. At this point in the balancing process, there are an odd number of N atoms on the product side and an even number on the reactant side. Because NO_2 on the product side has an odd number of N atoms, its coefficient is doubled (Figure 4.9).

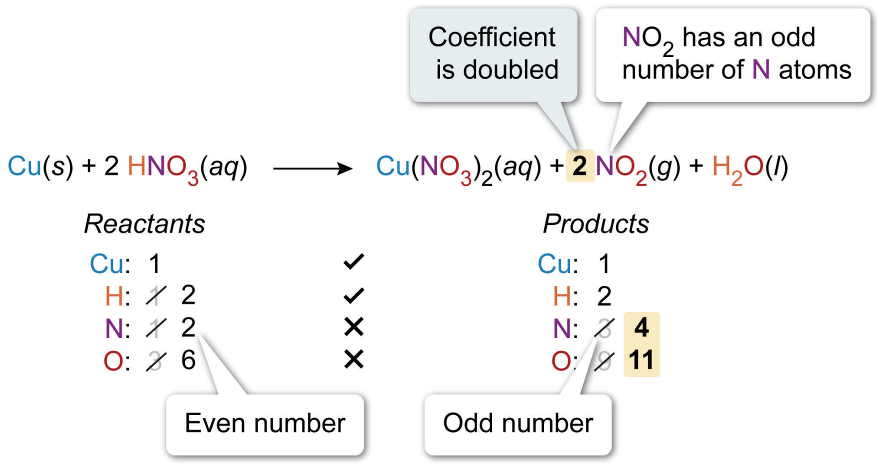


Figure 4.9 Doubling the coefficient of NO_2.

To finish balancing N, the coefficient of HNO_3 is changed to 4 (Figure 4.10).

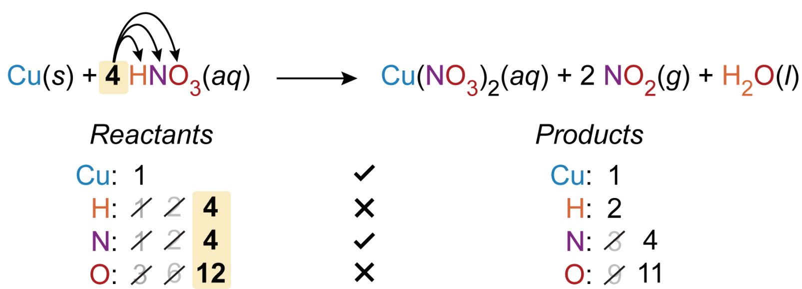


Figure 4.10 Balancing N atoms after doubling the coefficient of NO_2.

Step 5: Continue to balance the elements (in order) by changing coefficients until each element is balanced, always returning to rebalance elements earlier in the balancing order if they become unbalanced. In this case, balancing N caused H to become unbalanced. Doubling the coefficient of water fixes this, balancing H and O and producing the final balanced equation shown in Figure 4.11.

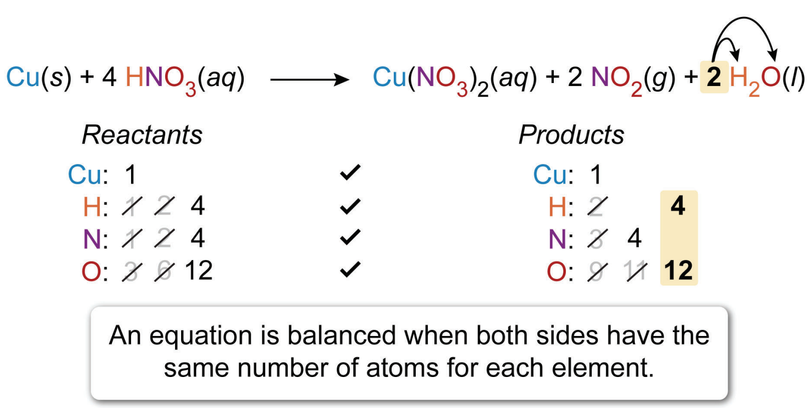


Figure 4.11 Balanced equation for the reaction between Cu(*s*) and HNO_3(*aq*).

4.2.02 Net Ionic Equations

[TRA-1.B.3]

As illustrated in Figure 4.12, a soluble ionic compound dissociates (ie, breaks apart) and forms free ions when dissolved in an **aqueous solution** (ie, a solution in which water is the solvent). Note that an aqueous solution is indicated by adding "(*aq*)" at the end of each ion's chemical formula.

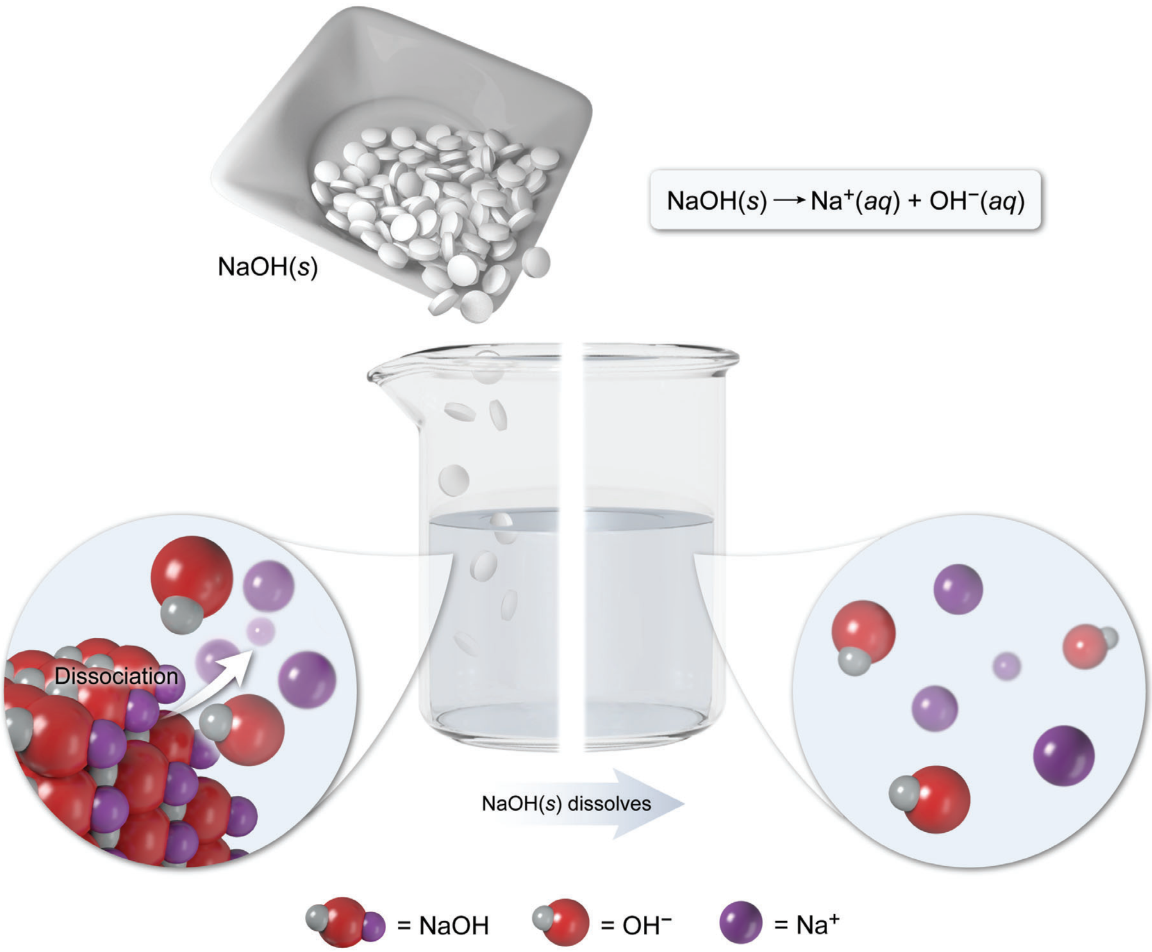


Figure 4.12 Dissociation of a soluble ionic compound.

Chemical reactions in aqueous solutions can be expressed in three ways:

- **Molecular equations** represent compounds as molecules rather than as separated ions. This equation does not show aqueous species as they exist in solution.
- **Complete ionic equations** represent soluble ionic compounds (and strong acids) as separated ions.
- **Net ionic equations** show only the ions that participate in a reaction and the products they form while leaving out the ions that do not react (ie, ions that remain aqueous). These nonreacting ions are called spectator ions.

Consider the reaction between the soluble ionic compounds $Mg(NO_3)_2(aq)$ and $NaF(aq)$, which results in the formation of a **precipitate** and a water-soluble salt. This reaction is represented by the following balanced molecular equation:

$$\mathrm{Mg(NO_3)_2}(aq) + 2\ \mathrm{NaF}(aq) \longrightarrow \mathrm{MgF_2}(s) + 2\ \mathrm{NaNO_3}(aq)$$

However, the molecular equation does not show the aqueous substances as they really are. In water, $Mg(NO_3)_2$(*aq*) dissociates into Mg^{2+} and NO_3^- ions and NaF(*aq*) dissociates into Na^+ and F^- ions. Therefore, the interaction of Mg^{2+} ions with F^- ions to form the precipitate MgF_2(*s*) is more accurately expressed by the complete ionic equation:

$$\mathrm{Mg^{2+}}(aq) + 2\ \mathrm{NO_3}^-(aq) + 2\ \mathrm{Na^+}(aq) + 2\ \mathrm{F^-}(aq) \longrightarrow \mathrm{MgF_2}(s) + \ 2\ \mathrm{Na^+}(aq) + 2\ \mathrm{NO_3}^-(aq)$$

The complete ionic equation can be simplified by removing the nonreacting (ie, spectator) ions Na^+ and NO_3^-:

$$\mathrm{Mg^{2+}}(aq) + \cancel{2\ \mathrm{NO_3}^-(aq)} + \cancel{2\ \mathrm{Na^+}(aq)} + 2\ \mathrm{F^-}(aq) \longrightarrow \mathrm{MgF_2}(s) + \cancel{2\ \mathrm{Na^+}(aq)} + \cancel{2\ \mathrm{NO_3}^-(aq)}$$

This results in the net ionic equation shown in Figure 4.13. Net ionic equations are useful for focusing *exclusively* on the reacting species in an aqueous environment.

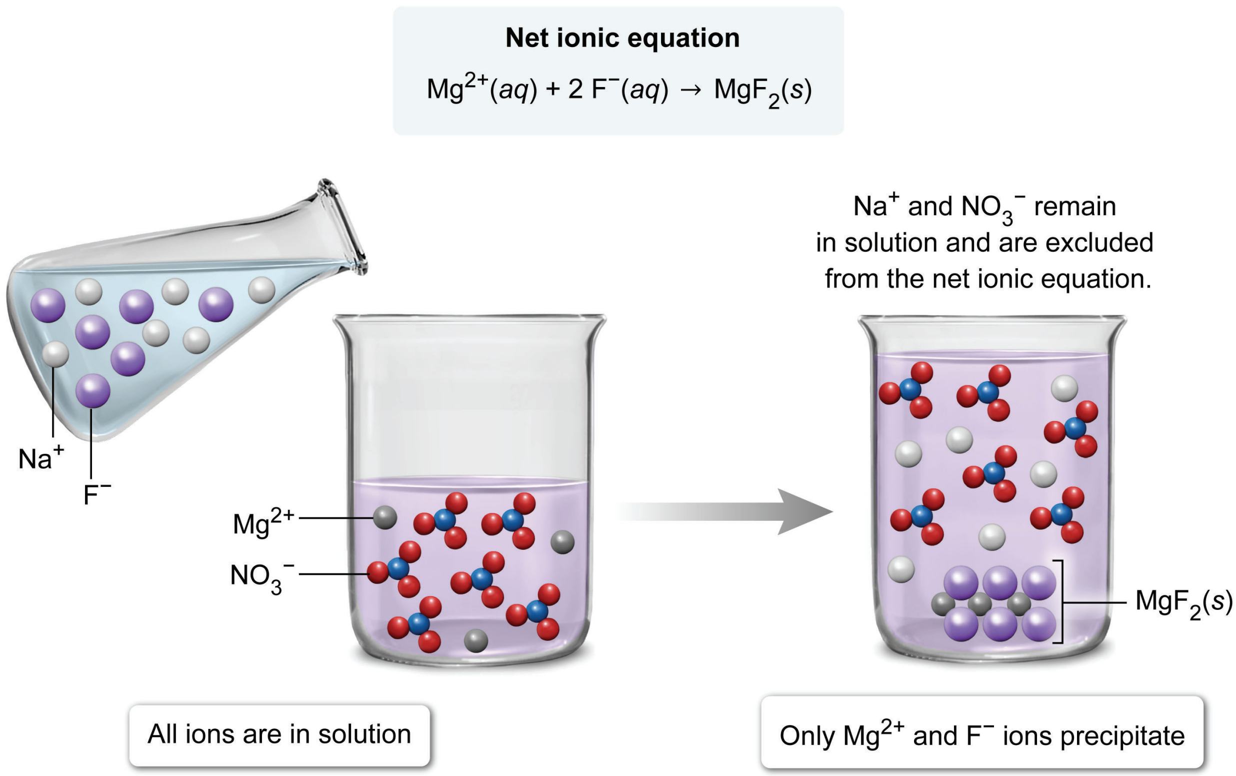


Figure 4.13 The net ionic equation for the reaction of $Mg(NO_3)_2$(*aq*) and NaF(*aq*).

4.3.01 Representations of Reactions

[TRA-1.C.1]

For any chemical reaction, a **particle diagram** can be used to represent the amount of each substance involved in the reaction process. A particle diagram that shows a chemical reaction must illustrate the characteristics of the reaction, and the atoms must be balanced according to the mole ratios of the reaction.

For example, consider the particle diagram shown in Figure 4.14 representing the combustion reaction of toluene (C_7H_8) with O_2 to produce CO_2 and H_2O.

$$C_7H_8(g) + 9\ O_2(g) \rightarrow 7\ CO_2(g) + 4\ H_2O(g)$$

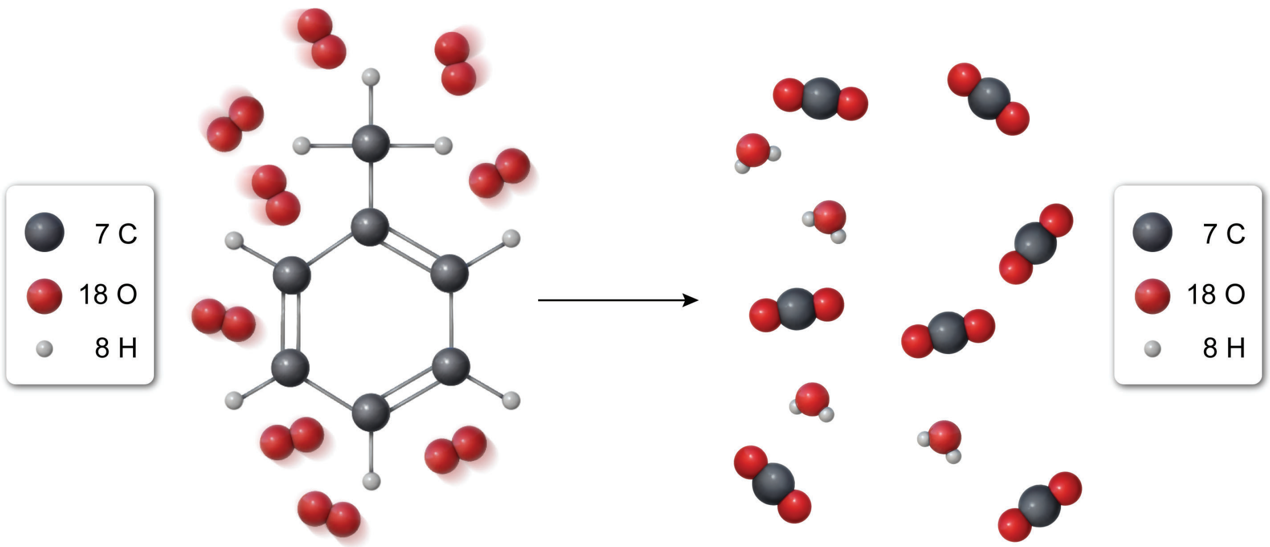


Figure 4.14 Particle diagram of the combustion reaction of toluene.

Note that the number of atoms of each element on each side of the reaction arrow are equal. In addition, the number of each type of molecule exactly represents the lowest whole-number ratio of molecules expressed in the balanced chemical equation. However, it is also common for particle diagrams of chemical reactions to represent a multiple (eg, double, triple) of the numbers given for each substance in a balanced chemical equation. For example, consider the balanced equation for the reaction of magnesium metal with oxygen:

$$2\ \mathrm{Mg}(s) + \mathrm{O}_2(g) \rightarrow 2\ \mathrm{MgO}(s)$$

Suppose 10 moles of Mg(*s*) react with 5 moles of $O_2(g)$ to form 10 moles of MgO(*s*). A particle diagram that shows a multiple of the balanced equation can be used to represent the amounts in this reaction, as shown in Figure 4.15.

$$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$$

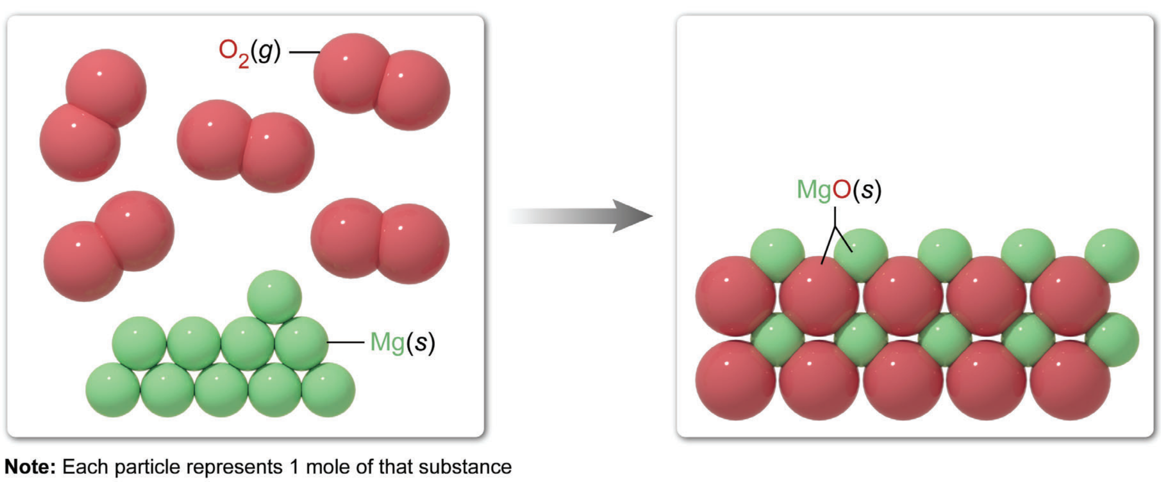


Figure 4.15 Particle diagram for the reaction of 10 moles of Mg(*s*) with 5 moles of $O_2(g)$.

In this case, the amounts represented in the particle diagram are five times the amounts in the balanced equation. The particle diagram still represents a balanced chemical reaction because the ratio of elements is the same.

Topic 4.1-4.4 Introduction to Reactions
Check for Understanding Quiz

1. The combustion of hexene (C_6H_{12}) proceeds according to the unbalanced chemical reaction equation:

$$C_6H_{12}(l) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

   What is the coefficient in front of the oxygen gas when the reaction is balanced?

   A. 3

   B. 6

   C. 9

   D. 18

2. Which of the following is *not* evidence of a chemical reaction in a mixture of two substances?

   A. Production of heat

   B. Permanent color change

   C. Phase change from a liquid to a gas

   D. Formation of a precipitate

3. Identify the two spectator ions in the following balanced chemical reaction:

$$3\ AgNO_3(aq) + CrCl_3(aq) \longrightarrow 3\ AgCl(s) + Cr(NO_3)_3(aq)$$

   A. Cr^{3+} and NO_3^-

   B. Cr^{3+} and Cl^-

   C. Cl^- and NO_3^-

   D. Ag^+ and Cl^-

Note: Answers to this quiz are in the back of the book (appendix).