Pearson

# 7.3: Writing and Balancing Chemical Equations

**Key Concept Video** **Writing and Balancing Chemical Equations**

Chemical changes occur via **chemical reactions**. For example, fossil fuels form carbon dioxide via combustion reactions. A *combustion reaction*, which we discuss in more detail in Section 7.6, is a particular type of chemical reaction. In this type of reaction, a substance combines with oxygen to form one or more oxygen-containing compounds. Combustion reactions also emit heat. The heat produced in fossil fuel combustion reactions supplies much of our society's energy needs. For example, the heat from the combustion of gasoline expands the gaseous combustion products in a car engine's cylinders, which push the pistons and propel the car. We use the heat released by the combustion of *natural gas* to cook food and to heat our homes.

We represent a chemical reaction with a **chemical equation**. For example, we represent the combustion of natural gas with the equation:

$$\underbrace{CH_4 + O_2}_{\text{reactants}} \rightarrow \underbrace{CO_2 + H_2O}_{\text{products}}$$

The substances on the left side of the equation are the **reactants**, and the substances on the right side are the **products**. We often specify the state of each reactant or product in parentheses next to the formula as shown here:

$$CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O\,(g)$$

The (g) indicates that these substances are gases in the reaction. Table 7.1 summarizes the common states of reactants and products and their symbols used in chemical equations.

**Table 7.1** **States of Reactants and Products in Chemical Equations**

| Abbreviation | State |
|---|---|
| (*g*) | Gas |
| (*l*) | Liquid |
| (*s*) | Solid |
| (*aq*) | Aqueous (water solution) |

The equation just presented for the combustion of natural gas is not complete, however.

$$CH_4(g) + \underbrace{O_2(g)}_{\text{2 O atoms}} \longrightarrow \underbrace{CO_2(g) + H_2O(g)}_{\text{2 O atoms + 1 O atom = 3 O atoms}}$$

The left side of the equation has two oxygen atoms, while the right side has three. The reaction as written violates the law of conservation of mass because it makes it seem as if an oxygen atom formed out of nothing. Notice also that the left side has four hydrogen atoms, while the right side has only two. Two hydrogen atoms appear to have vanished, again violating mass conservation.

appear to have vanished, again violating mass conservation.

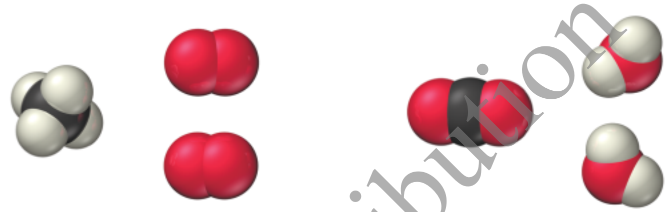
$$\underbrace{CH_4(g)}_{\text{4 H atoms}} + O_2(g) \longrightarrow CO_2(g) + \underbrace{H_2O(g)}_{\text{2 H atoms}}$$

To correct these problems—that is, to write an equation that more closely represents *what actually happens*—we must *balance* the equation. We change the coefficients (the numbers *in front of* the chemical formulas), not the subscripts (the numbers within the chemical formulas), to ensure that the number of each type of atom on the left side of the equation is equal to the number on the right side. New atoms do not form during a reaction, nor do atoms vanish—matter must be conserved.

> We cannot change the subscripts when balancing a chemical equation because changing the subscripts changes the substances themselves, while changing the coefficients changes the numbers of molecules of the substances. For example, $2\ H_2O$ is two water molecules, but $H_2O_2$ is hydrogen peroxide, a drastically different compound.

When we add coefficients to the reactants and products to balance an equation, we change the number of molecules in the equation but not the *kind of* molecules. To balance the equation for the combustion of methane, we put the coefficient 2 before $O_2$ in the reactants, and the coefficient 2 before $H_2O$ in the products.

$$CH_4(g) + 2\ O_2(g) \longrightarrow CO_2(g) + 2\ H_2O(g)$$



The equation is now balanced because the numbers of each type of atom on either side of the equation are equal. The balanced equation tells us that one $CH_4$ molecule reacts with two $O_2$ molecules to form one $CO_2$ molecule and two $H_2O$ molecules. We can verify that the equation is balanced by summing the number of each type of atom on each side of the equation.

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$$

| Reactants | Products |
|---|---|
| 1 C atom (1 × $CH_4$) | 1 C atom (1 × $CO_2$) |
| 4 H atoms (1 × $CH_4$) | 4 H atoms (2 × $H_2O$) |
| 4 O atoms (2 × $O_2$) | 4 O atoms (1 × $CO_2$ + 2 × $H_2O$) |



The number of each type of atom on both sides of the equation is equal—we have balanced the equation.

We can balance many chemical equations simply by trial and error. However, some guidelines are useful. For example, balancing the atoms in the most complex substances first and the atoms in the simplest substances (such as pure elements) last often makes the process shorter. The following illustrations of how to balance chemical equations are presented in a three-column format. The general guidelines are shown on the left, with two examples of how to apply them on the right. This procedure is meant only as a flexible guide, not a rigid set of steps.

### Example 7.1 Balancing Chemical Equations

**PROCEDURE FOR Balancing Chemical Equations**

Write a balanced equation for the reaction between solid cobalt(III) oxide and solid carbon that produces solid cobalt and carbon dioxide gas.

1. Write a skeletal (unbalanced) equation by writing chemical formulas for each of the reactants and products. Review Sections 4.6 and 4.8 for nomenclature rules. (If a skeletal equation is provided, proceed to Step 2.)

$$Co_2O_3(s) + C(s) \rightarrow Co(s) + CO_2(g)$$

2. Balance atoms that occur in more complex substances first. Always balance atoms in compounds before atoms in pure elements.

**Begin with O:**

$$Co_2O_3(s) + C(s) \longrightarrow Co(s) + CO_2(g)$$

$$3\text{ O atoms} \longrightarrow 2\text{ O atoms}$$

To balance O, put a 2 before $Co_2O_3(s)$ and a 3 before $CO_2(g)$.

$$2\ Co_2O_3(s) + C(s) \longrightarrow Co(s) + 3\ CO_2(g)$$

$$6\text{ O atoms} \longrightarrow 6\text{ O atoms}$$

3. Balance atoms that occur as free elements on either side of the equation last. Always balance free elements by adjusting the coefficient on the free element.

**Balance Co:**

$$2\ Co_2O_3(s) + C(s) \longrightarrow Co(s) + 3\ CO_2(g)$$

$$4\text{ Co atoms} \longrightarrow 1\text{ Co atom}$$

To balance Co, put a 4 before Co(s).

$$2\ Co_2O_3(s) + C(s) \longrightarrow 4\ Co(s) + 3\ CO_2(g)$$

$$4\text{ Co atoms} \longrightarrow 4\text{ Co atoms}$$

**Balance C:**

$$2\ Co_2O_3(s) + C(s) \longrightarrow 4\ Co(s) + 3\ CO_2(g)$$

$$1\text{ C atom} \longrightarrow 3\text{ C atoms}$$

To balance C, put a 3 before C(s).

$$2\ Co_2O_3(s) + 3\ C(s) \rightarrow 4\ Co(s) + 3\ CO_2(s)$$

4. If the balanced equation contains coefficient fractions, clear these by multiplying the entire equation by the denominator of the fraction.

This step is not necessary in this example. Proceed to Step 5.

**5.** Check to make certain the equation is balanced by summing the total number of each type of atom on both sides of the equation.

$$2\,Co_2O_3(s) + 3\,C(s) \rightarrow 4\,Co(s) + 3\,CO_2(g)$$

| Left | Right |
|---|---|
| 4 Co atoms | 4 Co atoms |
| 6 O atoms | 6 O atoms |
| 3 C atoms | 3 C atoms |

The equation is balanced.

**FOR PRACTICE 7.1** Write a balanced equation for the reaction between solid silicon dioxide and solid carbon that produces solid silicon carbide (SiC) and carbon monoxide gas.

## Example 7.2 Balancing Chemical Equations

**PROCEDURE FOR Balancing Chemical Equations**

Write a balanced equation for the combustion of gaseous butane ($C_4H_{10}$), a fuel used in portable stoves and grills, in which it combines with gaseous oxygen to form gaseous carbon dioxide and gaseous water.



**1.** Write a skeletal (unbalanced) equation by writing chemical formulas for each of the reactants and products. Review Sections 4.6 and 4.8 for nomenclature rules. (If a skeletal equation is provided, proceed to Step 2.)

**2.** Balance atoms that occur in more complex substances first. Always balance atoms in compounds before atoms in pure elements.

**Begin with C:**

$$C_4H_{10}(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

$$4\text{ C atoms} \longrightarrow 1\text{ C atom}$$

To balance C, put a 4 before $CO_2(g)$.

$$C_4H_{10}(g) + O_2(g) \longrightarrow 4\,CO_2(g) + H_2O(g)$$

$$4\text{ C atoms} \longrightarrow 4\text{ C atoms}$$

**Balance H:**

$$C_4H_{10}(g) + O_2(g) \longrightarrow 4\,CO_2(g) + H_2O(g)$$

$$10\text{ H atoms} \longrightarrow 2\text{ H atoms}$$

10 H atoms $\longrightarrow$ 2 H atoms

To balance H, put a 5 before $H_2O\,(g)$:

$$C_4H_{10}(g) + O_2(g) \longrightarrow 4\,CO_2(g) + 5\,H_2O(g)$$

10 H atoms $\longrightarrow$ 10 H atoms

3. Balance atoms that occur as free elements on either side of the equation last. Always balance free elements by adjusting the coefficient on the free element.

**Balance O:**

$$C_4H_{10}(g) + O_2(g) \longrightarrow 4\,CO_2(g) + 5\,H_2O(g)$$

2 O atoms $\longrightarrow$ 8 O + 5 O = 13 O atoms

To balance O, put a 13/2 before $O_2\,(g)$:

$$C_4H_{10}(g) + 13/2\,O_2(g) \longrightarrow 4\,CO_2(g) + 5\,H_2O(g)$$

13 O atoms $\longrightarrow$ 13 O atoms

4. If the balanced equation contains coefficient fractions, clear these by multiplying the entire equation by the denominator of the fraction.

$$[C_4H_{10}\,(g) + 13/2\;O_2\,(g) \to 4\;CO_2\,(g) + 5\;H_2O\,(g)] \times 2$$

$$2\;C_4H_{10}(g) + 13\;O_2(g) \to 8\;CO_2(g) + 10\;H_2O\,(g)$$

5. Check to make certain the equation is balanced by summing the total number of each type of atom on both sides of the equation.

$$2\;C_4H_{10}(g) + 13\;O_2(g) \to 8\;CO_2(g) + 10\;H_2O\,(g)$$

| Left | Right |
|---|---|
| 8 C atoms | 8 C atoms |
| 20 H atoms | 20 H atoms |
| 26 O atoms | 26 O atoms |

The equation is balanced.

**FOR PRACTICE 7.2** Write a balanced equation for the combustion of gaseous ethane ($C_2H_6$), a minority component of natural gas, in which it combines with gaseous oxygen to form gaseous carbon dioxide and gaseous water.

Interactive Worked Example 7.2 **Balancing Chemical Equations**

Conceptual Connection 7.3 **Balanced Chemical Equations**

### Example 7.3 Balancing Chemical Equations Containing Ionic Compounds with Polyatomic Ions

Write a balanced equation for the reaction between aqueous strontium chloride and aqueous lithium phosphate to form solid strontium phosphate and aqueous lithium chloride.

**SOLUTION**

1. Write a skeletal equation by writing chemical formulas for each of the reactants and products. Review Sections 4.6 and 4.8 for naming rules. (If a skeletal equation is provided, proceed to Step 2.)

$$SrCl_2(aq) + Li_3PO_4(aq) \rightarrow Sr_3(PO_4)_2(s) + LiCl(aq)$$

2. Balance metal ions (cations) first. If a polyatomic cation exists on both sides of the equation, balance it as a unit.

**Begin with $Sr^{2+}$:**

$$SrCl_2(aq) + Li_3PO_4(aq) \longrightarrow Sr_3(PO_4)_2(s) + LiCl(aq)$$
$$1\ Sr^{2+}\ \text{ion} \longrightarrow 3\ Sr^{2+}\ \text{ions}$$

To balance $Sr^{2+}$, put a 3 before $SrCl_2(aq)$.

$$3\ SrCl_2(aq) + Li_3PO_4(aq) \longrightarrow Sr_3(PO_4)_2(s) + LiCl(aq)$$
$$3\ Sr^{2+}\ \text{ions} \longrightarrow 3\ Sr^{2+}\ \text{ions}$$

**Balance $Li^+$:**

$$3\ SrCl_2(aq) + Li_3PO_4(aq) \longrightarrow Sr_3(PO_4)_2(s) + LiCl(aq)$$
$$3\ Li^{+}\ \text{ions} \longrightarrow 1\ Li^{+}\ \text{ion}$$

To balance $Li^+$, put a 3 before $LiCl(aq)$.

$$3\ SrCl_2(aq) + Li_3PO_4(aq) \longrightarrow Sr_3(PO_4)_2(s) + 3\ LiCl(aq)$$
$$3\ Li^{+}\ \text{ions} \longrightarrow 3\ Li^{+}\ \text{ions}$$

3. Balance nonmetal ions (anions) second. If a polyatomic anion exists on both sides of the equation, balance it as a unit.

**Balance $PO_4^{3-}$:**

$$3\ SrCl_2(aq) + Li_3PO_4(aq) \longrightarrow Sr_3(PO_4)_2(s) + 3\ LiCl(aq)$$
$$1\ PO_4^{3-}\ \text{ion} \longrightarrow 2\ PO_4^{3-}\ \text{ions}$$

To balance $PO_4^{3-}$, put a 2 before $Li_3PO_4(aq)$.

$$3\ SrCl_2(aq) + 2\ Li_3PO_4(aq) \longrightarrow Sr_3(PO_4)_2(s) + 3\ LiCl(aq)$$
$$2\ PO_4^{3-}\ \text{ions} \longrightarrow 2\ PO_4^{3-}\ \text{ions}$$

**Balance $Cl^-$:**

$$3\ SrCl_2(aq) + 2\ Li_3PO_4(aq) \longrightarrow Sr_3(PO_4)_2(s) + 3\ LiCl(aq)$$
$$6\ Cl^{-}\ \text{ions} \longrightarrow 1\ Cl^{-}\ \text{ion}$$

To balance $Cl^-$, replace the 3 before $LiCl(aq)$ with a 6. This also corrects the balance for $Li^+$, which was thrown off in the previous step.

$$3\,SrCl_2(aq) + 2\,Li_3PO_4(aq) \longrightarrow Sr_3(PO_4)_2(s) + 6\,LiCl(aq)$$
$$6\,Cl^-\text{ ions} \longrightarrow 6\,Cl^-\text{ ions}$$

**4.** Check to make certain the equation is balanced by summing the total number of each type of ion on both sides of the equation.

$$3\,SrCl_2(aq) + 2\,Li_3PO_4(aq) \rightarrow Sr_3(PO_4)_2(s) + 6\,LiCl(aq)$$

| Left | Right |
|---|---|
| 3 $Sr^{2+}$ ions | 3 $Sr^{2+}$ ions |
| 6 $Li^+$ ions | 6 $Li^+$ ions |
| 2 $PO_4^{3-}$ ions | 2 $PO_4^{3-}$ ions |
| 6 $Cl^-$ ions | 6 $Cl^-$ ions |

The equation is balanced.

**FOR PRACTICE 7.3** Write a balanced equation for the reaction between aqueous lead(II) nitrate and aqueous potassium chloride to form solid lead(II) chloride and aqueous potassium nitrate.