Pearson

7.6: Three Examples of Chemical Reactions: Combustion, Alkali Metals, and Halogens

In this section, we examine three types of reactions. The first is combustion reactions, which we encountered in Section 7.1. The second is the reactions of the alkali metals. As we discussed in Chapter 3, alkali metals have low first ionization energies and are among the most active metals. Alkali metals reactions are good examples of the types of reactions that many metals undergo. The third type of reactions involves the halogens. Halogens have among the most negative (most exothermic) electron affinities and are therefore among the most active nonmetals.

Combustion Reactions

A **combustion reaction** involves the reaction of a substance with O_2 to form one or more oxygen-containing compounds, often including water. Combustion reactions also emit heat. For example, as you saw earlier in this chapter, natural gas (CH_4) reacts with oxygen to form carbon dioxide and water:

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

Ethanol, the alcohol in alcoholic beverages, also reacts with oxygen in a combustion reaction to form carbon dioxide and water:

$$C_2H_5OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O\ (g)$$

Compounds containing carbon and hydrogen—or carbon, hydrogen, and oxygen—always form carbon dioxide and water upon complete combustion. Other combustion reactions include the reaction of carbon with oxygen to form carbon dioxide:

$$C(s) + O_2(g) \rightarrow CO_2\ (g)$$

and the reaction of hydrogen with oxygen to form water:

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O\ (g)$$

We can write chemical equations for most combustion reactions by noticing the pattern of reactivity. Any carbon in a combustion reaction reacts with oxygen to produce carbon dioxide, and any hydrogen reacts with oxygen to form water.

Example 7.9 Writing Equations for Combustion Reactions

Write a balanced equation for the combustion of liquid methyl alcohol (CH_3OH).

SOLUTION Begin by writing an unbalanced equation showing the reaction of CH_3OH with O_2 to form CO_2 and H_2O.

$$CH_3OH(l) + O_2(g) \rightarrow CO_2(g) + H_2O\ (g)$$

Balance the equation using the guidelines from Section 7.3.

$$2\ CH_3OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 4\ H_2O\ (g)$$

FOR PRACTICE 7.9 Write a balanced equation for the complete combustion of liquid C_2H_5SH.

Alkali Metal Reactions

The alkali metals (group 1A) have ns^1 outer electron configurations. The single valence electron that prevents these metals from having noble gas configurations is easily removed (the metals have low ionization energies), making these elements the most active metals in the periodic table. The reactions of the alkali metals with nonmetals are vigorous. For example, the alkali metals (M) react with halogens (X) according to the reaction:

$$2\,M + X_2 \rightarrow 2\,MX$$

The reaction of sodium and chlorine to form sodium chloride is typical:

$$2\,Na(s) + Cl_2(g) \rightarrow 2\,NaCl\,(s)$$

This reaction emits heat and sparks as it occurs (Figure 7.6). Each successive alkali metal reacts even more vigorously with chlorine.

Figure 7.6 Reaction of Sodium and Chlorine to Form Sodium Chloride

The alkali metals also react with water to form the dissolved alkali metal ion, the hydroxide ion, and hydrogen gas:

$$2\,M\,(s) + 2\,H_2O\,(l) \rightarrow 2\;\;M^+\,(aq) + 2\,OH^-(aq) + H_2\,(g)$$

The reaction is highly exothermic and can be explosive because the heat from the reaction can ignite the hydrogen gas. The reaction becomes more explosive as we move down the column from one metal to the next, as shown in Figure 7.7.*

Figure 7.7 Reactions of the Alkali Metals with Water

The reactions become progressively more vigorous as we move down the group.

Lithium Sodium Potassium

Halogen Reactions

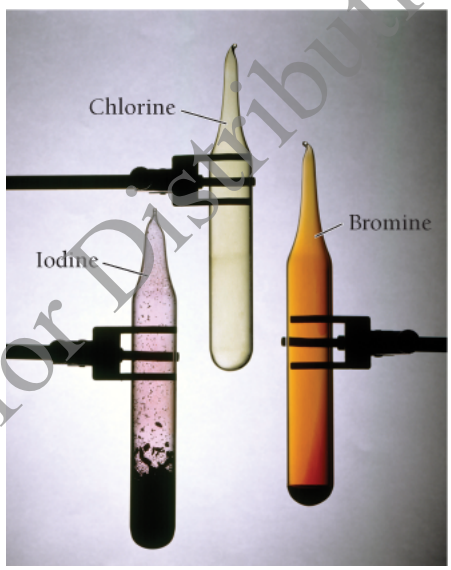
The halogens (group 7A) have ns^2np^5 outer electron configurations. The one electron needed to attain a noble gas configuration is easily acquired (the halogens have highly negative electron affinities), making these elements among the most active nonmetals in the periodic table. The halogens all react with many metals to form *metal halides* according to the equation:

$$2\,\mathrm{M} + n\,\mathrm{X_2} \rightarrow 2\,\mathrm{MX}_n$$

where M is the metal, X is the halogen, and MX_n is the metal halide. For example, chlorine reacts with iron according to the equation:

$$2\,\mathrm{Fe}(s) + 3\,\mathrm{Cl_2}(g) \rightarrow 2\,\mathrm{FeCl_3}\,(s)$$

Since metals tend to lose electrons and the halogens tend to gain them, the metal halides—like all compounds that form between metals and nonmetals—contain ionic bonds.



Three Halogens

The halogens also react with hydrogen to form *hydrogen halides* according to the equation:

$$\mathrm{H_2}(g) + \mathrm{X_2} \rightarrow 2\,\mathrm{HX}\,(g)$$

The hydrogen halides—like all compounds that form between two nonmetals—contain covalent bonds. As we will see in Chapter 8, all of the hydrogen halides form acidic solutions when combined with water.

The halogens also react with each other to form *interhalogen compounds*. For example, bromine reacts with fluorine according to the equation:

$$\mathrm{Br_2}(l) + \mathrm{F_2}(g) \rightarrow 2\,\mathrm{BrF}\,(g)$$

Again, like all compounds that form between two nonmetals, the interhalogen compounds contain covalent

bonds.

Example 7.10 Alkali Metal and Halogen Reactions

Write a balanced chemical equation for each reaction.

a. the reaction between potassium metal and bromine gas
b. the reaction between rubidium metal and liquid water
c. the reaction between gaseous chlorine and solid iodine

SOLUTION

a. Alkali metals react with halogens to form metal halides. Write the formulas for the reactants and the metal halide product (making sure to write the correct ionic chemical formula for the metal halide, as outlined in Section 4.6), and then balance the equation.

$$2\,\mathrm{K}(s) + \mathrm{Br_2}(g) \rightarrow 2\,\mathrm{KBr}\,(s)$$

b. Alkali metals react with water to form the dissolved metal ion, the hydroxide ion, and hydrogen gas. Write the skeletal equation including these and then balance it.

$$2\,\mathrm{Rb}\,(s) + 2\,\mathrm{H_2O}\,(l) \rightarrow 2\,\mathrm{Rb^+}\,(aq) + 2\,\mathrm{OH^-}\,(aq) + \mathrm{H_2}\,(g)$$

c. Halogens react with each other to form interhalogen compounds. Write the skeletal equation with the halogens as the reactants and the interhalogen compound as the product and balance the equation.

$$\mathrm{Cl_2}(g) + \mathrm{I_2}(s) \rightarrow 2\,\mathrm{ICl}\,(g)$$

FOR PRACTICE 7.10 Write a balanced chemical equation for each reaction.

a. the reaction between aluminum metal and chlorine gas
b. the reaction between lithium metal and liquid water
c. the reaction between gaseous hydrogen and liquid bromine

*The rate of the alkali metal reaction with water, and therefore its vigor, is enhanced by the successively lower melting points of the alkali metals as we move down the column. The low melting points of the heavier metals allow the emitted heat to actually melt the metal, increasing the reaction rate.