IV. ANSWERS AND SOLUTIONS TO ODD-NUMBERED PROBLEMS:

Chemical Equations (Section 5.1)

5.1 Identify the reactants and products in each of the following reactions:
   a) $\text{BaO}_2(s) + \text{H}_2\text{SO}_4(l) \rightarrow \text{BaSO}_4(s) + \text{H}_2\text{O}_2(l)$
   b) $2\text{H}_2\text{O}_2(aq) \rightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g)$
   c) methane + water $\rightarrow$ carbon monoxide + hydrogen
   d) copper(II) oxide + hydrogen $\rightarrow$ copper + water

Solution:
   a) reactants = $\text{BaO}_2(s)$ and $\text{H}_2\text{SO}_4(l)$
   b) reactant = $\text{H}_2\text{O}_2(aq)$
   c) reactants = methane and water
   d) reactants = copper(II) oxide and hydrogen

   products = $\text{BaSO}_4(s)$ and $\text{H}_2\text{O}_2(l)$
   products = $\text{H}_2\text{O}(l)$ and $\text{O}_2(g)$
   products = carbon monoxide and hydrogen
   products = copper and water

5.3 Identify which of the following are consistent with the law of conservation of matter. For those that are not, explain why they are not.
   a) $4\text{Al}(s) + 3 \text{O}_2(g) \rightarrow 2\text{Al}_2\text{O}_3(s)$
   b) $\text{P}_4(s) + \text{O}_2(g) \rightarrow \text{P}_4\text{O}_{10}(s)$
   c) $3.20 \text{ g oxygen} + 3.21 \text{ g sulfur} \rightarrow 6.41 \text{ g sulfur dioxide}$
   d) $\text{CH}_4(g) + 2 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g)$

Solution:
   a) consistent
   b) not consistent; the number of oxygen atoms is greater in the product than in the reactant
   c) consistent
   d) consistent
5.5 Determine the number of atoms of each element on each side of the following equations and decide which equations are balanced:

a) \( \text{H}_2\text{S}(aq) + \text{I}_2(aq) \rightarrow 2\text{HI}(aq) + \text{S(s)} \)

b) \( \text{KClO}_3(s) \rightarrow \text{KCl}(s) + \text{O}_2(g) \)

c) \( \text{SO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_3(aq) \)

d) \( \text{Ba(ClO}_3)_2(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow 2\text{HClO}_3(aq) + \text{BaSO}_4(s) \)

**SOLUTION:**

a) Balanced. There are 2 H atoms, 1 S atom, and 2 I atoms on each side.

b) Not balanced. There are 1 K atom and 1 Cl atom on each side, but 3 O atoms on the left and 2 O atoms on the right.

c) Balanced. There are 2 H atoms, 1 S atom and 3 O atoms on each side.

d) Balanced. There are 1 Ba atom, 2 Cl atoms, 10 O atoms, 2 H atoms and 1 S atom on each side.

5.7 Balance the following equations:

a) \( \text{Cl}_2(aq) + \text{NaBr}(aq) \rightarrow \text{NaCl}(aq) + \text{Br}_2(aq) \)

b) \( \text{CaF}_2(s) + \text{H}_2\text{SO}_4(l) \rightarrow \text{CaSO}_4(s) + \text{HF}(g) \)

c) \( \text{Cl}_2(g) + \text{NaOH}(aq) \rightarrow \text{NaClO}_3(aq) + \text{NaCl}(aq) + \text{H}_2\text{O}(l) \)

d) \( \text{KClO}_4(s) \rightarrow 3\text{KClO}_3(s) + \text{KCl}(s) \)

e) Dinitrogen monoxide \( \rightarrow \) nitrogen + oxygen

f) Dinitrogen pentoxide \( \rightarrow \) nitrogen dioxide + oxygen

g) \( \text{P}_2\text{O}_5(s) + \text{H}_2\text{O}(l) \rightarrow 2\text{H}_3\text{P}_2\text{O}_5(aq) \)

h) \( \text{CaCO}_3(s) + \text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \)

**SOLUTION:**

a) \( \text{Cl}_2(aq) + 2\text{NaBr}(aq) \rightarrow 2\text{NaCl}(aq) + \text{Br}_2(aq) \)

b) \( \text{CaF}_2(s) + \text{H}_2\text{SO}_4(l) \rightarrow \text{CaSO}_4(s) + 2\text{HF}(g) \)

c) \( \text{Cl}_2(g) + 2\text{NaOH}(aq) \rightarrow \text{NaClO}_3(aq) + \text{NaCl}(aq) + \text{H}_2\text{O}(l) \)

d) \( 4\text{KClO}_4(s) \rightarrow 3\text{KClO}_3(s) + \text{KCl}(s) \)

e) \( 2\text{N}_2\text{O}_5(g) \rightarrow 2\text{N}_2(g) + 5\text{O}_2(g) \)

f) \( 2\text{N}_2\text{O}_3(g) \rightarrow 4\text{NO}_2(g) + \text{O}_2(g) \)

g) \( \text{P}_2\text{O}_5(s) + 4\text{H}_2\text{O}(l) \rightarrow 2\text{H}_3\text{P}_2\text{O}_5(aq) \)

h) \( \text{CaCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \)

Redox Reactions (Section 5.3)

5.9 Assign oxidation numbers to the underlined element in each of the following formulas:

a) \( \text{Cl}_2\text{O}_3 \)

b) \( \text{KClO}_4 \)

c) \( \text{Ba}^{2+} \)

d) \( \text{Fe}^{3+} \)

e) \( \text{H}_2\text{P}_2\text{O}_7 \)

f) \( \text{H}_2\text{S} \)

**SOLUTION:**

a) \( \text{Cl} = +5, \ (\text{O} = -2) \)

b) \( \text{Cl} = +7, \ (\text{K} = +1, \ \text{O} = -2) \)

c) \( \text{Ba} = +2, \ \text{simple ion} \)

d) \( \text{P} = +5, \ (\text{H} = +1, \ \text{O} = -2) \)

f) \( \text{S} = -2, \ (\text{H} = +1) \)

5.11 Find the element with the highest oxidation number in each of the following formulas:

a) \( \text{N}_2\text{O}_3 \)

b) \( \text{KHCO}_3 \)

c) \( \text{NaClO} \)

d) \( \text{NaNO}_3 \)

e) \( \text{HClO}_4 \)

f) \( \text{Ca(NO}_3)_2 \)

**SOLUTION:**

a) \( \text{O} = -2, \ \text{N} = +5 \)

b) \( \text{K} = +1, \ \text{H} = +1, \ \text{O} = -2, \ \text{C} = +4 \)

c) \( \text{Na} = +1, \ \text{O} = -2, \ \text{Cl} = +1 \)

d) \( \text{Na} = +1, \ \text{O} = -2, \ \text{N} = +5 \)

e) \( \text{H} = +1, \ \text{O} = -2, \ \text{C} = +4 \)

5.13 For each of the following equations, indicate whether the underlined element has been oxidized, reduced, or neither oxidized or reduced.

a) \( 2\text{Mg}(s) + \text{O}_2(g) \rightarrow 2\text{MgO}(s) \)

b) \( \text{CuO}(s) + \text{H}_2(g) \rightarrow \text{Cu}(s) + \text{H}_2\text{O}(g) \)
c) $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl(s)}$

d) $\text{BaCl}_2(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + 2\text{HCl(}\text{aq})$

e) $\text{Zn}(s) + 2\text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2(g)$

**SOLUTION:**

a) oxidized (0 to +2)  

b) reduced (+2 to 0)  

c) neither  

d) neither  

e) oxidized (0 to +2)

5.15 Assign oxidation numbers to each element in the following equations and identify the oxidizing and reducing agents:

a) $\text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow 2\text{HCl(}\text{g})$

b) $\text{H}_2\text{O(}g\text{)} + \text{CH}_4(\text{g}) \rightarrow \text{CO(}\text{g}) + 3\text{H}_2(\text{g})$

c) $\text{CuO(}s\text{)} + \text{H}_2(\text{g}) \rightarrow \text{Cu(}s\text{)} + \text{H}_2\text{O(}g\text{)}$

d) $\text{B}_2\text{O}_3(\text{s}) + 3\text{Mg(}s\text{)} \rightarrow 2\text{Mg(}s\text{)} + 3\text{MgO(}s\text{)}$

e) $\text{Fe}_2\text{O}_3(\text{s}) + \text{CO(}g\text{)} \rightarrow 2\text{Fe(}s\text{)} + \text{CO}_2(\text{g})$

f) $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) + 3\text{Mn}^{2+}(\text{aq}) \rightarrow 2\text{Cr}^{3+}(\text{aq}) + 3\text{MnO}_2(\text{s}) + \text{H}_2\text{O(}l\text{)}$

**SOLUTION:**

a) $\text{H}_2 + \text{Cl}_2 \rightarrow 2\text{HCl}$

$\begin{array}{ccc}
\text{H}_2 & \text{Cl}_2 & \text{HCl} \\
0 & 0 & +1 -1 \\
\end{array}$

$\text{H}_2$ is the reducing agent; $\text{Cl}_2$ is the oxidizing agent.

b) $\text{H}_2\text{O} + \text{CH}_4 \rightarrow \text{CO} + 3\text{H}_2$

$\begin{array}{ccc}
\text{H}_2\text{O} & \text{CH}_4 & \text{CO} + 3\text{H}_2 \\
+1 -2 & +1 & +4 -1 +2 -2 0 \\
\end{array}$

$\text{H}_2\text{O}$ is the oxidizing agent; $\text{CH}_4$ is the reducing agent.

c) $\text{CuO} + \text{H}_2 \rightarrow \text{Cu} + \text{H}_2\text{O}$

$\begin{array}{ccc}
\text{CuO} & \text{H}_2 & \text{Cu} + \text{H}_2\text{O} \\
+2 -2 & 0 & 0 +1 -2 \\
\end{array}$

$\text{CuO}$ is the oxidizing agent; $\text{H}_2$ is the reducing agent.

d) $\text{B}_2\text{O}_3 + 3\text{Mg} \rightarrow 2\text{B} + 3\text{MgO}$

$\begin{array}{ccc}
\text{B}_2\text{O}_3 & 3\text{Mg} & 2\text{B} + 3\text{MgO} \\
3 & -2 & 0 0 0 +2 -2 \\
\end{array}$

$\text{B}_2\text{O}_3$ is the oxidizing agent; $\text{Mg}$ is the reducing agent.

e) $\text{Fe}_2\text{O}_3 + \text{CO} \rightarrow 2\text{FeO} + \text{CO}_2$

$\begin{array}{ccc}
\text{Fe}_2\text{O}_3 & \text{CO} & 2\text{FeO} + \text{CO}_2 \\
+3 -2 & +2 & +3 -2 +2 -2 +4 -2 \\
\end{array}$

$\text{Fe}_2\text{O}_3$ is the oxidizing agent; CO is the reducing agent.

f) $\text{Cr}_2\text{O}_7^{2-} + 2\text{H}^+ + 3\text{Mn}^{2+} \rightarrow 2\text{Cr}^{3+} + 3\text{MnO}_2 + \text{H}_2\text{O}$

$\begin{array}{ccc}
\text{Cr}_2\text{O}_7^{2-} & 2\text{H}^+ + 3\text{Mn}^{2+} & 2\text{Cr}^{3+} + 3\text{MnO}_2 + \text{H}_2\text{O} \\
+6 -2 & +1 & +2 0 +3 +4 -2 +1 -2 \\
\end{array}$

$\text{Cr}_2\text{O}_7^{2-}$ is the oxidizing agent; Mn is the reducing agent.

5.17 The tarnish of silver objects is a coating of silver sulfide (Ag$_2$S), which can be removed by putting the silver in contact with aluminum metal in a dilute solution of baking soda or salt. The equation for the cleaning reaction is:

$3\text{Ag}_2\text{S(s)} + 2\text{Al(s)} \rightarrow 6\text{Ag(s)} + \text{Al}_2\text{S}_3(\text{s})$

The sulfur in these compounds has a -2 oxidation number. What are the oxidizing and reducing agents in the cleaning reaction?

**SOLUTION:**

The oxidation number of silver goes from +1 to 0. The Ag$_2$S is the oxidizing agent. The oxidation number of aluminum goes from 0 to +3. The Al is the reducing agent. Silver is reduced and the aluminum is oxidized.

5.19 Identify the oxidizing and reducing agents in the Haber process for producing ammonia from elemental nitrogen and hydrogen. The equation for the reaction is:

$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$
SOLUTION:
The oxidation number of nitrogen changes from 0 to -3. The N₂ is the oxidizing agent. The oxidizing number of hydrogen changes from 0 to +1. The H₂ is the reducing agent.

Decomposition, Combination, and Replacement Reactions (Sections 5.4 - 5.6)

5.21 Classify each of the reactions represented by the following equations first as a redox or nonredox reaction. Then further classify each redox reaction as a decomposition, single-replacement, or combination reaction; and each nonredox reaction as a decomposition, double-replacement, or combination reaction.

\[
\begin{align*}
\text{a)} & \quad \text{N}_2\text{O}_5(g) + \text{H}_2\text{O}(l) \rightarrow 2\text{HNO}_3(aq) \\
\text{b)} & \quad \text{Cr}_2\text{O}_7^{2-}(aq) + 2\text{Al}(s) \rightarrow 2\text{Cr}(s) + \text{Al}_2\text{O}_3(s) \\
\text{c)} & \quad \text{CaO}(s) + \text{SiO}_2(s) \rightarrow \text{CaSiO}_3(s) \\
\text{d)} & \quad \text{H}_2\text{CO}_3(aq) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) \\
\text{e)} & \quad \text{PbCO}_3(s) \rightarrow \text{PbO}(s) + \text{CO}_2(g) \\
\text{f)} & \quad \text{Zn}(s) + \text{Cl}_2(g) \rightarrow \text{ZnCl}_2(s)
\end{align*}
\]

SOLUTION:

\[
\begin{align*}
\text{a)} & \quad \text{nonredox, combination} \\
\text{b)} & \quad \text{redox, single-replacement} \\
\text{c)} & \quad \text{nonredox, combination} \\
\text{d)} & \quad \text{nonredox, decomposition} \\
\text{e)} & \quad \text{nonredox, decomposition} \\
\text{f)} & \quad \text{redox, combination}
\end{align*}
\]

5.23 Baking soda may serve as a source of CO₂ in bread dough. It causes the dough to raise. The CO₂ is released when NaHCO₃ reacts with an acidic substance:

\[
\text{NaHCO}_3(aq) + \text{H}^+(aq) \rightarrow \text{Na}^+(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)
\]

Classify the reaction as redox or nonredox.

SOLUTION:

\[
\text{nonredox}
\]

5.25 Hydrogen peroxide will react and liberate oxygen gas. In commercial solutions, the reaction is prevented to a large degree by the addition of an inhibitor. The equation for the oxygen-liberating reaction is

\[
2\text{H}_2\text{O}_2(aq) \rightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g)
\]

Classify the reaction as redox or nonredox.

SOLUTION:

\[
\text{redox; The oxidation number of the oxygen changes. It goes from -1 in peroxide to -2 in H}_2\text{O and to 0 in O}_2.
\]

5.27 Triple superphosphate, an ingredient in some fertilizers, is prepared by reacting rock phosphate (calcium phosphate) and phosphoric acid. The equation for the reaction is

\[
\text{Ca}_3(\text{PO}_4)_2(s) + 4\text{H}_3\text{PO}_4(aq) \rightarrow 3\text{Ca}(\text{H}_2\text{PO}_4)_2(s)
\]

Classify the reaction into the categories used in Exercise 5.21.

SOLUTION:

\[
\text{nonredox, combination}
\]

Ionic Equations (Section 5.7)

5.29 Consider all of the following ionic substances to be water soluble and write the formulas of the ions that would be formed if the substances were dissolved in water. Table 4.6 will be helpful.

\[
\begin{align*}
a) & \quad \text{K}_2\text{Cr}_2\text{O}_7 \\
b) & \quad \text{H}_2\text{SO}_4 \\
c) & \quad \text{NaH}_2\text{PO}_4 \\
d) & \quad \text{Na}_3\text{PO}_4 \\
e) & \quad \text{NH}_4\text{Cl} \\
f) & \quad \text{KMnO}_4
\end{align*}
\]

SOLUTION:

\[
\begin{align*}
a) & \quad 2\text{K}^+ \text{ and } \text{Cr}_2\text{O}_7^{2-} \\
b) & \quad 2\text{H}^+ \text{ and } \text{SO}_4^{2-} \\
c) & \quad \text{Na}^+ \text{ and } \text{H}_2\text{PO}_4^- \\
d) & \quad 3\text{Na}^+ \text{ and } \text{PO}_4^{3-} \\
e) & \quad \text{NH}_4^+ \text{ and } \text{Cl}^- \\
f) & \quad \text{K}^+ \text{ and } \text{MnO}_4^{-}
\end{align*}
\]
5.31 Reactions represented by the following equations take place in water solutions. Write each full equation in total ionic form, then identify spectator ions and write the equations in net ionic form. Solids that do not dissolve are designated by (s); and gases that do not dissolve are designated by (g); and those substances that dissolve but do not dissociate are underlined.

a) \( \text{H}_2\text{O}(l) + \text{Na}_2\text{SO}_4(aq) + \text{SO}_2(aq) \rightarrow 2\text{NaHSO}_4(aq) \)

b) \( 3\text{Cu}(s) + 8\text{HNO}_3(aq) \rightarrow 3\text{Cu(NO}_3)_2(aq) + 2\text{NO}(g) + 4\text{H}_2\text{O}(l) \)

c) \( 2\text{HCl}(aq) + \text{CaO}(s) \rightarrow \text{CaCl}_2(aq) + \text{H}_2\text{O}(l) \)

d) \( \text{CaCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{CO}_2(aq) + \text{H}_2\text{O}(l) \)

e) \( \text{MnO}_2(s) + 4\text{HCl}(aq) \rightarrow \text{MnCl}_2(aq) + \text{Cl}_2(aq) + 2\text{H}_2\text{O}(l) \)

f) \( 2\text{AgNO}_3(aq) + \text{Cu}(s) \rightarrow \text{Cu(NO}_3)_2(aq) + 2\text{Ag}(s) \)

**SOLUTION:**

a) total ionic: \( \text{H}_2\text{O}(l) + 2\text{Na}^+(aq) + \text{SO}_4^{2-}(aq) + \text{SO}_2(aq) \rightarrow 2\text{Na}^+(aq) + 2\text{HSO}_4(aq) \)

The \( 2\text{Na}^+ \) ions are spectator ions.

net ionic: \( \text{H}_2\text{O}(l) + \text{SO}_4^{2-}(aq) + \text{SO}_2(aq) \rightarrow 2\text{HSO}_4(aq) \)

b) total ionic: \( 3\text{Cu}^+(s) + 8\text{H}^+(aq) + 8\text{NO}_3^-(aq) \rightarrow 3\text{Cu}^{2+}(aq) + 6\text{NO}_3^-(aq) + 2\text{NO}(g) + 4\text{H}_2\text{O}(l) \)

Six of the eight \( \text{NO}_3^- \) are spectator ions.

net ionic: \( 3\text{Cu}^+(s) + 8\text{H}^+(aq) + 2\text{NO}_3^-(aq) \rightarrow 3\text{Cu}^{2+}(aq) + 2\text{NO}(g) + 4\text{H}_2\text{O}(l) \)

c) total ionic: \( 2\text{H}^+(aq) + 2\text{Cl}^-(aq) + \text{CaO}(s) \rightarrow \text{Ca}^{2+}(aq) + 2\text{Cl}^-(aq) + \text{H}_2\text{O}(l) \)

The \( 2\text{Cl}^- \) are spectator ions.

net ionic: \( 2\text{H}^+(aq) + \text{CaO}(s) \rightarrow \text{Ca}^{2+}(aq) + \text{H}_2\text{O}(l) \)

d) total ionic: \( \text{CaCO}_3(s) + 2\text{H}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(aq) + \text{H}_2\text{O}(l) \)

The \( 2\text{Cl}^- \) are spectator ions.

net ionic: \( \text{CaCO}_3(s) + 2\text{H}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(aq) + \text{H}_2\text{O}(l) \)

e) total ionic: \( \text{MnO}_2(s) + 4\text{H}^+(aq) + 4\text{Cl}^-(aq) \rightarrow \text{Mn}^{2+}(aq) + 2\text{Cl}^-(aq) + \text{Cl}_2(aq) + 2\text{H}_2\text{O}(l) \)

Two of the four \( \text{Cl}^- \) are spectator ions.

net ionic: \( \text{MnO}_2(aq) + 4\text{H}^+(aq) + 2\text{Cl}^-(aq) \rightarrow \text{Mn}^{2+}(aq) + \text{Cl}_2(aq) + 2\text{H}_2\text{O}(l) \)

f) total ionic: \( 2\text{Ag}^+(aq) + 2\text{NO}_3^-(aq) + \text{Cu}(s) \rightarrow \text{Cu}^{2+}(aq) + 2\text{NO}_3^-(aq) + 2\text{Ag}(s) \)

The \( 2\text{NO}_3^- \) are spectator ions.

net ionic: \( 2\text{Ag}^+(aq) + \text{Cu}(s) \rightarrow \text{Cu}^{2+}(aq) + 2\text{Ag}(s) \)

5.33 The following full equations all represent neutralization reactions of acid and bases. These reactions are discussed further in Chapter 9. Write each equation in total ionic form, identify the spectator ions, then write the net ionic equation. Water is the only substance that does not dissociate. What do you notice about all the net ionic equations?

a) \( \text{H}_2\text{PO}_4(aq) + 3\text{LiOH}(aq) \rightarrow \text{Li}_3\text{PO}_4(aq) + 3\text{H}_2\text{O}(l) \)

b) \( \text{HNO}_2(aq) + \text{RbOH}(aq) \rightarrow \text{RbNO}_3(aq) + \text{H}_2\text{O}(l) \)

c) \( \text{HI}(aq) + \text{CsOH}(aq) \rightarrow \text{CsI}(aq) + \text{H}_2\text{O}(l) \)

**SOLUTION:**

a) total ionic: \( 3\text{H}^+(aq) + \text{PO}_4^{3-}(aq) + 3\text{Li}^+(aq) + 3\text{OH}^-(aq) \rightarrow 3\text{Li}^+(aq) + \text{PO}_4^{3-}(aq) + 3\text{H}_2\text{O}(l) \)

The \( 3\text{Li}^+ \) and \( \text{PO}_4^{3-} \) are spectator ions.

net ionic: \( 3\text{H}^+(aq) + 3\text{OH}^-(aq) \rightarrow 3\text{H}_2\text{O}(l) \)

simplified: \( \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} \)

b) total ionic: \( \text{H}^+(aq) + \text{NO}_2^-(aq) + \text{Rb}^+(aq) + \text{OH}^-(aq) \rightarrow \text{Rb}^+(aq) + \text{NO}_3^-(aq) + \text{H}_2\text{O}(l) \)

The \( \text{Rb}^+ \) and \( \text{NO}_2^- \) are spectator ions.

net ionic: \( \text{H}^+(aq) + \text{OH}^-(aq) \rightarrow \text{H}_2\text{O}(l) \)

c) total ionic: \( \text{H}^+(aq) + \Gamma(aq) + \text{Cs}^+(aq) + \text{OH}^-(aq) \rightarrow \text{Cs}^+(aq) + \Gamma(aq) + \text{H}_2\text{O}(l) \)

The \( \text{Cs}^+ \) and \( \Gamma \) are spectator ions.

net ionic: \( \text{H}^+(aq) + \text{OH}^-(aq) \rightarrow \text{H}_2\text{O}(l) \)

The net ionic equations are all the same: \( \text{H}^+(aq) + \text{OH}^-(aq) \rightarrow \text{H}_2\text{O}(l) \).
Energy and Reactions (Section 5.8)

5.35 In refrigeration systems, the area to be cooled has pipes running through it. Inside the pipes, a liquid evaporates and becomes a gas. Is the evaporation process exothermic or endothermic? Explain.

**SOLUTION:**
Endothermic; the evaporation takes heat from the surroundings and cools the surroundings.

**NOTE:** From the liquid point of view, evaporation absorbs heat from the surroundings, so the change is endothermic. From the surroundings point of view, the surroundings lose heat, so the change is exothermic.

5.37 The human body cools itself by the evaporation of perspiration. Is the evaporation process endothermic or exothermic? Explain.

**SOLUTION:**
Endothermic; the evaporation takes heat from the liquid and cools the liquid. (See the note in the problem above.)

The Mole and Chemical Equations (Section 5.9)

5.39 For the reactions represented by the following equations, write statements equivalent to statements 1, 4, 5, and 6 given in the chapter (section 5.9).

a) \( \text{N}_2(g) + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g) \)

b) \( 2\text{Na}(s) + \text{Cl}_2(g) \rightarrow 2\text{NaCl}(s) \)

c) \( \text{BaCl}_2(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{BaSO}_4(s) + 2\text{HCl}(aq) \)

d) \( 2\text{H}_2\text{O}_2(aq) \rightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g) \)

e) \( 2\text{C}_2\text{H}_6(g) + 9\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}(g) \)

**SOLUTION:**

a) 1 N\(_2\) molecule + 3 H\(_2\) molecules \( \rightarrow \) 2 NH\(_3\) molecules

\[ 6.02 \times 10^{23} \text{N}_2\text{ molecules} + 18.06 \times 10^{23} \text{H}_2\text{ molecules} \rightarrow 12.04 \times 10^{23} \text{NH}_3\text{ molecules} \]

1 mol N\(_2\) + 3 mol H\(_2\) \( \rightarrow \) 2 mol NH\(_3\)

28.02 g N\(_2\) + 6.05 g H\(_2\) \( \rightarrow \) 34.07 g NH\(_3\)

Note: Non-standard scientific notation has been used to illustrate the commonality of the coefficients in all parts of the statements in the problem.

b) 2 Na atoms + 1 Cl\(_2\) molecule \( \rightarrow \) 2 NaCl formulas

\[ 12.04 \times 10^{23} \text{Na atoms} + 6.02 \times 10^{23} \text{Cl}_2\text{ molecules} \rightarrow 12.04 \times 10^{23} \text{NaCl formulas} \]

2 mol Na + 1 mol Cl\(_2\) \( \rightarrow \) 2 mol NaCl

45.98 g Na + 71.44 g Cl\(_2\) \( \rightarrow \) 117.42 g NaCl

Note: The distinction between formulas and molecules for HCl and H\(_2\)SO\(_4\) in water solutions is somewhat arbitrary. Since these compounds form ions in solution, we have used formulas, but the term "molecule" would be also correct.

c) 1 BaCl\(_2\) formula + 1 H\(_2\)SO\(_4\) formula* \( \rightarrow \) 1 BaSO\(_4\) formula + 2 HCl formulas*

\[ 6.02 \times 10^{23} \text{BaCl}_2\text{ formulas} + 6.02 \times 10^{23} \text{H}_2\text{SO}_4\text{ formulas} \rightarrow 6.02 \times 10^{23} \text{BaSO}_4\text{ formulas} + 12.04 \times 10^{23} \text{HCl formulas} \]

1 mol BaCl\(_2\) + 1 mol H\(_2\)SO\(_4\) \( \rightarrow \) 1 mol BaSO\(_4\) + 2 mol HCl

207.2 g BaCl\(_2\) + 98.1 g H\(_2\)SO\(_4\) \( \rightarrow \) 235.3 g BaSO\(_4\) + 73.9 g HCl

* Note: The distinction between formulas and molecules for HCl and H\(_2\)SO\(_4\) in water solutions is somewhat arbitrary. Since these compounds form ions in solution, we have used formulas, but the term "molecule" would be also correct.

d) 2 H\(_2\)O\(_2\) molecules \( \rightarrow \) 2 H\(_2\)O molecules + 1 O\(_2\) molecule

\[ 12.04 \times 10^{23} \text{H}_2\text{O}_2\text{ molecules} \rightarrow 12.04 \times 10^{23} \text{H}_2\text{O}\text{ molecules} + 6.02 \times 10^{23} \text{O}_2\text{ molecules} \]

2 mol H\(_2\)O\(_2\) \( \rightarrow \) 2 mol H\(_2\)O + 1 mol O\(_2\)

68.0 g H\(_2\)O\(_2\) \( \rightarrow \) 36 g H\(_2\)O + 32 g O\(_2\)

e) 2 C\(_2\)H\(_6\) molecules + 9 O\(_2\) molecules \( \rightarrow \) 6 CO\(_2\) molecules + 6 H\(_2\)O molecules

\[ 12.04 \times 10^{23} \text{C}_2\text{H}_6\text{ molecules} + 54.18 \times 10^{23} \text{O}_2\text{ molecules} \rightarrow 36.12 \times 10^{23} \text{CO}_2\text{ molecules} + 36.12 \times 10^{23} \text{H}_2\text{O}\text{ molecules} \]

2 mol C\(_2\)H\(_6\) + 9 mol O\(_2\) \( \rightarrow \) 6 mol CO\(_2\) + 6 mol H\(_2\)O

84.0 g C\(_2\)H\(_6\) + 288.0 g O\(_2\) \( \rightarrow \) 264.0 g CO\(_2\) + 108.0 g H\(_2\)O
5.41 Calculate the number of grams of CO that must react to produce 350 g CO₂. Use the equation from and statements written in Exercise 5.40 and express your answer using the correct number of significant figures.

\[
\text{SOLUTION:} \quad 350 \text{ g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.0 \text{ g CO}_2} \times \frac{2 \text{ mol CO}}{2 \text{ mol CO}_2} \times \frac{28.0 \text{ g CO}}{1 \text{ mol CO}} = 223 \text{ g CO}
\]

5.43 Calculate the number of moles of CO₂ generated by the reaction of Exercise 5.42 when 500 g CaO is produced.

\[
\text{SOLUTION:} \quad 500 \text{ g CaO} \times \frac{1 \text{ mol CaO}}{56.1 \text{ g CaO}} \times \frac{1 \text{ mol CO}_2}{1 \text{ mol CaO}} = 8.91 \text{ mol CO}_2
\]

5.45 Calculate the moles of acetylene (C₂H₂) produced by the process of Exercise 5.44.

\[
\text{SOLUTION:} \quad 96.0 \text{ g CaC}_2 \times \frac{1 \text{ mol CaC}_2}{64.1 \text{ g CaC}_2} \times \frac{1 \text{ mol C}_2\text{H}_2}{1 \text{ mol CaC}_2} = 1.50 \text{ mol C}_2\text{H}_2
\]

5.47 In Exercise 5.17, you were given an equation for the reaction used to clean tarnish from silver. The equation for the reaction is:

\[
3\text{Ag}_2\text{S(s)} + 2\text{Al(s)} \rightarrow 6 \text{ Ag(s)} + \text{ Al}_2\text{S}_3\text{(s)}
\]

a) How many grams of aluminum would need to react to remove 0.250 g Ag₂S tarnish?

b) How many moles of Al₂S₃ would be produced by the reaction described in part a)?

\[
\text{SOLUTION:}
\]

a) \[
0.250 \text{ g Ag}_2\text{S} \times \frac{1 \text{ mol Ag}_2\text{S}}{247.9 \text{ g Ag}_2\text{S}} \times \frac{2 \text{ mol Al}}{3 \text{ mol Ag}_2\text{S}} \times \frac{27.0 \text{ g Al}}{1 \text{ mol Al}} = 0.0182 \text{ g Al}
\]

b) \[
0.250 \text{ g Ag}_2\text{S} \times \frac{1 \text{ mol Ag}_2\text{S}}{247.9 \text{ g Ag}_2\text{S}} \times \frac{1 \text{ mol Al}_2\text{S}_3}{3 \text{ mol Ag}_2\text{S}} = 3.36 \times 10^{-4} \text{ mol Al}_2\text{S}_3
\]

5.49 An important metabolic process of the body is the oxidation of glucose to water and carbon dioxide. The equation for the reaction is:

\[
\text{C}_6\text{H}_12\text{O}_6\text{(aq)} + 6 \text{ O}_2\text{(aq)} \rightarrow 6 \text{CO}_2\text{(aq)} + 6\text{H}_2\text{O(l)}
\]

a) What mass of water in grams is produced when the body oxidizes 1.00 mol of glucose?

b) How many grams of oxygen are needed to oxidize 1.00 mol of glucose?

\[
\text{SOLUTION:}
\]

a) \[
1.00 \text{ mol C}_6\text{H}_12\text{O}_6 \times \frac{6 \text{ mol H}_2\text{O}}{1 \text{ mol C}_6\text{H}_12\text{O}_6} \times \frac{18.0 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 108 \text{ g H}_2\text{O}
\]

b) \[
1.00 \text{ mol O}_2 \times \frac{6 \text{ mol O}_2}{1 \text{ mol C}_6\text{H}_12\text{O}_6} \times \frac{32.0 \text{ g O}_2}{1 \text{ mol O}_2} = 192 \text{ g O}_2
\]

The Limiting Reactant (Section 5.10)

5.51 A sample of 4.00 g of methane (CH₄) is mixed with 15.0 g of chlorine (Cl₂).

a) Determine which is the limiting reactant according to the following equation:

\[
\text{CH}_4\text{(g)} + 4\text{Cl}_2\text{(g)} \rightarrow \text{CCl}_4\text{(l)} + 4\text{HCl(g)}
\]
b) What is the maximum mass of CCl₄ that could be formed?

**SOLUTION:**

a) If all the CH₄ were to react, the amount of CCl₄ formed would be:

\[
4.00 \text{ g CH}_4 \times \frac{1 \text{ mol CH}_4}{16.0 \text{ g CH}_4} \times \frac{1 \text{ mol CCl}_4}{1 \text{ mol CH}_4} \times \frac{155.8 \text{ g CCl}_4}{1 \text{ mol CCl}_4} = 39.0 \text{ g CCl}_4
\]

If all the CH₄ were to react, the amount of CCl₄ formed would be:

\[
15.0 \text{ g Cl}_2 \times \frac{1 \text{ mol Cl}_2}{71.9 \text{ g Cl}_2} \times \frac{1 \text{ mol CCl}_4}{4 \text{ mol Cl}_2} \times \frac{155.8 \text{ g CCl}_4}{1 \text{ mol CCl}_4} = 8.13 \text{ g CCl}_4
\]

The Cl₂ is the limiting reactant.

b) The maximum mass of CCl₄ possible is the amount made using all of the limiting reactant or 8.13 g.

5.53 Suppose you want to use acetylene (C₂H₂) as a fuel. You have a cylinder that contains 500 g C₂H₂ and a cylinder that contains 2000 g of oxygen (O₂). Do you have enough oxygen to burn all the acetylene? The equation for the reaction is:

\[
2\text{C}_2\text{H}_2(g) + 5\text{O}_2(g) \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O}(g)
\]

**SOLUTION:**

If all the C₂H₂ were to be used, the mass of O₂ used would be:

\[
500 \text{ g C}_2\text{H}_2 \times \frac{1 \text{ mol C}_2\text{H}_2}{26.0 \text{ g C}_2\text{H}_2} \times \frac{5 \text{ mol O}_2}{2 \text{ mol C}_2\text{H}_2} \times \frac{32.0 \text{ g O}_2}{1 \text{ mol O}_2} = 1538 \text{ g O}_2
\]

Since the cylinder contains 2000 g O₂, there is more than enough O₂ to burn the 500 g of C₂H₂.

5.55 Chromium metal (Cr) can be prepared by reacting the oxide with aluminum. The equation for the reaction is:

\[
\text{Cr}_2\text{O}_3(s) + 2\text{Al}(s) \rightarrow 2\text{Cr}(s) + 3\text{Al}_2\text{O}_3(s)
\]

What three substances will be found in the final mixture if 150 g Cr₂O₃ and 150 g Al are reacted?

**SOLUTION:**

After reacting, the mixture will consist of the two products plus the excess of the reactant that is not the limiting reactant. (The limiting reactant is completely used up.)

If all of the Cr₂O₃ were used, the mass of Al that reacts would be:

\[
150 \text{ g Cr}_2\text{O}_3 \times \frac{1 \text{ mol Cr}_2\text{O}_3}{152 \text{ g Cr}_2\text{O}_3} \times \frac{2 \text{ mol Al}}{1 \text{ mol Cr}_2\text{O}_3} \times \frac{27.0 \text{ g Al}}{1 \text{ mol Al}} = 53.3 \text{ g Al}
\]

The Cr₂O₃ is the limiting reactant. When 53.3 g Al is used, all of the Cr₂O₃ is used up.

The final mixture consists of the leftover Al, plus the Cr and Al₂O₃ produced.

Reaction Yields (Section 5.11)

5.57 A product weighing 14.37 g was isolated from a reaction. The amount of product possible according to a calculation was 17.55 g. What is the percentage yield?

**SOLUTION:**

\[
\text{% yield} = \frac{14.37 \text{ g (actual)}}{17.55 \text{ g (theoretical)}} \times 100 = 81.88 \%
\]

5.59 A sample of calcium metal with a mass of 2.00 g was reacted with excess oxygen. The following equation represents the reaction that took place:

\[
2\text{Ca}(s) + \text{O}_2(g) \rightarrow 2\text{CaO}(s)
\]

The isolated product (CaO) weighed 2.26 g. What is the percentage yield of the reaction?
SOLUTION:
The theoretical yield of CaO is calculated by:

\[ \frac{2.00 \text{ g Ca}}{40.08 \text{ g Ca}} \times \frac{1 \text{ mol Ca}}{40.08 \text{ g Ca}} \times \frac{2 \text{ mol CaO}}{1 \text{ mol Ca}} \times \frac{56.08 \text{ g CaO}}{1 \text{ mol CaO}} = 2.80 \text{ g CaO (theoretical)} \]

\[ \% \text{ yield} = \frac{2.26 \text{ g (actual)}}{2.80 \text{ g (theoretical)}} \times 100 = 80.7 \% \]