Chapter 5: Chemical Reactions

CHAPTER OUTLINE

5.1 Chemical Equations  5.5 Combination Reactions  5.9 The Mole and Chemical Equations
5.2 Types of Reactions  5.6 Replacement Reactions  5.10 The Limiting Reactant
5.3 Redox Reactions  5.7 Ionic Equations  5.11 Reaction Yields
5.4 Decomposition Reactions  5.8 Energy and Reactions

LEARNING OBJECTIVES/ASSESSMENT

When you have completed your study of this chapter, you should be able to:

1. Identify the reactants and products in written reaction equations, and balance the equations by inspection. (Section 5.1; Exercises 5.2 and 5.6)
2. Assign oxidation numbers to elements in chemical formulas, and identify the oxidizing and reducing agents in redox reactions. (Section 5.3; Exercises 5.10 and 5.15)
3. Classify reactions into the categories of redox or non-redox, then into the categories of decomposition, combination, single replacement, or double replacement. (Sections 5.4, 5.5, and 5.6; Exercise 5.20)
4. Write molecular equations in total ionic and net ionic forms. (Section 5.7; Exercise 5.30 a, b, & c)
5. Classify reactions as exothermic or endothermic. (Section 5.8; Exercise 5.34)
6. Use the mole concept to do calculations based on chemical reaction equations. (Section 5.9; Exercise 5.42)
7. Use the mole concept to do calculations based on the limiting-reactant principle. (Section 5.10; Exercise 5.52)
8. Use the mole concept to do percentage-yield calculations. (Section 5.11; Exercise 5.56)

LECTURE HINTS AND SUGGESTIONS

1. Do not get bogged down explaining and defining oxidation numbers. Oxidation numbers can easily be overemphasized. Their main roles are in recognizing redox reactions and in balancing redox equations. Focus on those roles as the purpose for learning the rules of oxidation numbers. Make certain that students understand that oxidation numbers are not charges.

2. Use some simple redox reactions and relate the oxidation number change with the loss and gain of electrons. For example, in the reaction, \( 2Na + Cl_2 \rightarrow 2NaCl \), each sodium atom loses one electron and its oxidation number goes from 0 to +1; and each chlorine atom gains an electron and its oxidation number goes from 0 to -1.

3. Sometimes a concrete example of a limiting reactant helps the student to visualize that concept. One can obtain individual flavors of Jelly Belly® jelly beans from most candy stores. The company also publishes various combinations that result in new flavors. One such flavor is ‘Orange Dream Bars’ produced by eating 2 orange sherbet and one cream soda at the same time. Purchase a pound of each flavor and have your students produce ‘Orange Dream Bars’ – by eating them. At some point, they will run out of orange sherbet – showing it to be the limiting reactant. Other combinations are listed at www.jellybelly.com.

4. Many double replacement reactions are easy to demonstrate in class. Simply mix two solutions, which will provide two ions that form a water insoluble product; for example, sodium carbonate and calcium chloride or barium chloride and sodium sulfate or silver nitrate and potassium chromate. Explain that when two ions can combine to form a water insoluble product, then a precipitate will always form upon mixing the ions. Try to pick examples that have some relevance such as in these cases where the formation of calcium carbonate would illustrate what is meant by hard water and where the insolubility of barium sulfate is related to its usefulness as a radio-opaque diagnostic.
material. The silver chromate is a chemical precursor to modern photography that has been important in neuroscience, as it is used in the “Golgi method” of staining neurons for microscopy. The reaction that produces silver chromate is also highly visible in a large lecture theater because the reaction involves a color change in addition to the formation of a precipitate.

### SOLUTIONS FOR THE END OF CHAPTER EXERCISES

#### CHEMICAL EQUATIONS (SECTION 5.1)

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. BaO₂ (s) + H₂SO₄ (l) → BaSO₄ (s) + H₂O₂ (l)</td>
<td>BaO₂, H₂SO₄ → BaSO₄, H₂O₂</td>
</tr>
<tr>
<td>b. 2 H₂O₂ (aq) → 2 H₂O (l) + O₂ (g)</td>
<td>H₂O₂ → H₂O, O₂</td>
</tr>
<tr>
<td>c. methane + water → carbon monoxide + hydrogen</td>
<td>methane, water → carbon monoxide, hydrogen</td>
</tr>
<tr>
<td>d. copper(II) oxide + hydrogen → copper + water</td>
<td>copper(II) oxide, hydrogen → copper, water</td>
</tr>
</tbody>
</table>

#### 5.2

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. H₂ (g) + Cl₂ (g) → 2 HCl (g)</td>
<td>H₂, Cl₂ → HCl</td>
</tr>
<tr>
<td>b. 2 KClO₃ (s) → 2 KCl (s) + 3 O₂ (g)</td>
<td>KClO₃ → KCl, O₂</td>
</tr>
<tr>
<td>c. magnesium oxide + carbon → magnesium + carbon monoxide</td>
<td>magnesium oxide, carbon → magnesium, carbon monoxide</td>
</tr>
<tr>
<td>d. ethane + oxygen → carbon dioxide + water</td>
<td>ethane, oxygen → carbon dioxide, water</td>
</tr>
</tbody>
</table>

#### 5.3

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 4 Al (s) + 3 O₂ (g) → 2 Al₂O₃ (s)</td>
<td>4 Al + 3 O₂ → 2 Al₂O₃</td>
</tr>
<tr>
<td>b. P₄ (s) + O₂ (g) → P₄O₁₀ (s)</td>
<td>P₄ + O₂ → P₄O₁₀</td>
</tr>
<tr>
<td>c. 3.20 g oxygen + 3.21 g sulfur → 6.41 g sulfur dioxide</td>
<td>3.20 g O₂ + 3.21 g S → 6.41 g SO₂</td>
</tr>
</tbody>
</table>

Notice, the number of moles of oxygen and sulfur are equal on both sides of the equation.

\[
\text{Reactants: } 3.20 \text{ g O}_2 \left( \frac{1 \text{ mole O}_2}{32.0 \text{ g O}_2} \right) = 0.100 \text{ moles O}_2; \\
3.21 \text{ g S} \left( \frac{1 \text{ mole S}}{32.1 \text{ g S}} \right) = 0.100 \text{ moles S} \\
\text{Products: } 6.41 \text{ g SO}_2 \left( \frac{1 \text{ mole SO}_2}{64.1 \text{ g SO}_2} \right) \left( \frac{2 \text{ moles O}}{1 \text{ mole SO}_2} \right) = 0.200 \text{ moles O}; \\
6.41 \text{ g SO}_2 \left( \frac{1 \text{ mole SO}_2}{64.1 \text{ g SO}_2} \right) \left( \frac{1 \text{ mole S}}{1 \text{ mole SO}_2} \right) = 0.100 \text{ moles S} \\
\]

#### 5.4

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ZnS (s) + O₂ (g) → ZnO (s) + SO₂ (g)</td>
<td>ZnS + O₂ → ZnO + SO₂</td>
</tr>
<tr>
<td>b. Cl₂ (aq) + 2 I⁻ (aq) → I₂ (aq) + 2Cl⁻ (aq)</td>
<td>Cl₂ + 2I⁻ → I₂ + 2Cl⁻</td>
</tr>
</tbody>
</table>
c. 1.50 g oxygen + 1.50 g carbon → 2.80 g carbon monoxide is not consistent with the law of conservation of matter because the mass of the reactants is 3.00 g, while the mass of the products is only 2.80 g.

Notice, the number of moles of oxygen and carbon are not equal on both sides of the equation either.

\[
\text{Reactants: } 1.50 \text{ g O}_2 \left( \frac{1 \text{ mole O}_2}{32.0 \text{ g O}_2} \right) = 0.0469 \text{ moles O}_2; \\
1.50 \text{ g C} \left( \frac{1 \text{ mole C}}{12.0 \text{ g C}} \right) = 0.125 \text{ moles C} \\
\text{Products: } 2.80 \text{ g CO} \left( \frac{1 \text{ mole CO}}{28.0 \text{ g CO}} \right) \left( \frac{1 \text{ mole O}}{1 \text{ mole CO}} \right) = 0.100 \text{ mole O}; \\
2.80 \text{ g CO} \left( \frac{1 \text{ mole CO}}{28.0 \text{ g CO}} \right) \left( \frac{1 \text{ mole C}}{1 \text{ mole CO}} \right) = 0.100 \text{ mole C}
\]

d. 2 C₂H₆ (g) + 7 O₂ (g) → 4 CO₂ (g) + 6 H₂O (g) is consistent with the law of conservation of matter.

5.5 a. H₂S (aq) + I₂ (aq) → 2 HI (aq) + S (s)

<table>
<thead>
<tr>
<th>Elements</th>
<th>H</th>
<th>S</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Product</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

This equation is balanced.

b. KClO₃ (s) → KCl (s) + O₂ (g)

<table>
<thead>
<tr>
<th>Elements</th>
<th>K</th>
<th>Cl</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Product</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

This equation is not balanced because the numbers of moles of oxygen atoms are not balanced.

c. SO₂ (g) + H₂O (l) → H₂SO₃ (aq)

<table>
<thead>
<tr>
<th>Elements</th>
<th>S</th>
<th>O</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Product</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

This equation is balanced.

d. Ba(ClO₃)₂ (aq) + H₂SO₄ (aq) → 2HClO₃ (aq) + BaSO₄ (s)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Ba</th>
<th>Cl</th>
<th>O</th>
<th>H</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Product</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

This equation is balanced.

5.6 a. 2 Ag₂O (s) → 2 Ag (s) + O₂ (g)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Ag</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Product</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

This equation is not balanced because the numbers of moles of silver atoms are not balanced.

b. Al (s) + O₂ (g) → Al₂O₃ (s)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Al</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Product</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

This equation is not balanced because the numbers of moles of aluminum and oxygen atoms are not balanced.
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c. 2 AgNO₃ (aq) + K₂SO₄ (aq) → Ag₂SO₄ (s) + 2 KNO₃ (aq)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Ag</th>
<th>N</th>
<th>O</th>
<th>K</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Product</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

This equation is balanced.

5.3)

5.7 a. Cl₂ (aq) + NaBr (aq) → NaCl (aq) + Br₂ (aq)

Cl₂ (aq) + 2 NaBr (aq) → 2 NaCl (aq) + Br₂ (aq)

b. CaF₂ (s) + H₂SO₄ (aq) → CaSO₄ (s) + HF (g)

CaF₂ (s) + H₂SO₄ (aq) → CaSO₄ (s) + 2 HF (g)

c. Cl₂ (g) + NaOH (aq) → NaClO (aq) + NaCl (aq) + H₂O (l)

Cl₂ (g) + 2 NaOH (aq) → NaClO (aq) + NaCl (aq) + H₂O (l)

d. KClO₃ (s) → KClO₄ (s) + KCl (s)

4 KClO₃ (s) → 3 KClO₄ (s) + KCl (s)

e. dinitrogen monoxide → nitrogen + oxygen

2 N₂O → 2 N₂ + O₂

f. dinitrogen pentoxide → nitrogen dioxide + oxygen

2 N₂O₅ → 4 NO₂ + O₂

g. P₄O₁₀ (s) + H₂O (l) → H₃P₂O₅ (aq)

P₄O₁₀ (s) + 4 H₂O (l) → 2 H₃P₂O₅ (aq)

h. CaCO₃ (s) + HCl (aq) → CaCl₂ (aq) + H₂O (l) + CO₂ (g)

CaCO₃ (s) + 2 HCl (aq) → CaCl₂ (aq) + H₂O (l) + CO₂ (g)

5.8 a. C₂H₆ (g) + O₂ (g) → CO₂(g) + H₂O (l)

2 C₂H₆ (g) + 7 O₂ (g) → 4 CO₂(g) + 6 H₂O (l)

b. hydrogen + chlorine → hydrogen chloride

H₂ (g) + Cl₂ (g) → 2 HCl (g)

c. H₂S (g) + O₂ (g) → SO₂ (g) + H₂O (l)

2 H₂S (g) + 3 O₂ (g) → 2 SO₂ (g) + 2 H₂O (l)

d. sulfur + oxygen → sulfur dioxide

S (s) + O₂ (g) → SO₂ (g)

e. Na₂CO₃ (aq) + Ca(NO₃)₂ (aq) → Na₂NO₃ (aq) + CaCO₃ (s)

Na₂CO₃ (aq) + Ca(NO₃)₂ (aq) → 2 NaNO₃ (aq) + CaCO₃ (s)

f. NaBr (aq) + Cl₂ (aq) → NaCl (aq) + Br₂ (aq)

2 NaBr (aq) + Cl₂ (aq) → 2 NaCl (aq) + Br₂ (aq)

g. Ag₂CO₃ (s) → Ag (s) + CO₂ (g) + O₂ (g)

2 Ag₂CO₃ (s) → 4 Ag (s) + 2 CO₂ (g) + O₂ (g)

h. H₂O₂ (aq) + H₂S (aq) → H₂O (l) + S (s)

H₂O₂ (aq) + H₂S (aq) → 2 H₂O (l) + S (s)

REDOX REACTIONS (SECTION 5.3)

5.9

a. Cl₂O₃

<table>
<thead>
<tr>
<th>Calculations</th>
<th>O.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl = ? O = -2</td>
<td>Cl₂O₃ = 0</td>
</tr>
<tr>
<td>2 (?)+5(-2) = 0</td>
<td>⇒ ? = +5</td>
</tr>
</tbody>
</table>

b. KClO₄

<table>
<thead>
<tr>
<th>Calculations</th>
<th>O.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>K = +1 Cl = ? O = -2</td>
<td>KClO₄ = 0</td>
</tr>
<tr>
<td>+1+?+4(-2) = 0</td>
<td>⇒ ? = +7</td>
</tr>
</tbody>
</table>

c. Ba²⁺

c. +2 |

d. F₂

c. 0 |

e. H₄P₂O₇

<table>
<thead>
<tr>
<th>Calculations</th>
<th>O.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>H = +1 P = ? O = -2</td>
<td>H₄P₂O₇ = 0</td>
</tr>
<tr>
<td>4(+1)+2(?)+7(-2) = 0</td>
<td>⇒ ? = +5</td>
</tr>
</tbody>
</table>

f. H₂S

<table>
<thead>
<tr>
<th>Calculations</th>
<th>O.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>H = +1 S = ?</td>
<td>H₂S = 0</td>
</tr>
<tr>
<td>2(+1)+? = 0</td>
<td>⇒ ? = -2</td>
</tr>
</tbody>
</table>
### 5.10 Calculations

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Calculation</th>
<th>Oxidation Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $\text{ClO}_3^-$</td>
<td>$\text{Cl} = ? \quad \text{O} = -2 \quad \text{ClO}_3^- = -1 \quad ? + 3(-2) = -1 \quad \Rightarrow \quad ? = +5$</td>
<td>$+5$</td>
</tr>
<tr>
<td>b. $\text{H}_2\text{SO}_4$</td>
<td>$\text{H} = +1 \quad \text{S} = ? \quad \text{O} = -2 \quad \text{H}_2\text{SO}_4 = 0 \quad 2(1) + 2(4(-2)) = 0 \quad \Rightarrow \quad ? = +6$</td>
<td>$+6$</td>
</tr>
<tr>
<td>c. $\text{NaNO}_3$</td>
<td>$\text{Na} = +1 \quad \text{N} = ? \quad \text{O} = -2 \quad \text{NaNO}_3 = 0 \quad (+1) + ? + 3(-2) = 0 \quad \Rightarrow \quad ? = +5$</td>
<td>$+5$</td>
</tr>
<tr>
<td>d. $\text{Na}_2\text{O}$</td>
<td>$\text{N} = ? \quad \text{O} = -2 \quad \text{Na}_2\text{O} = 0 \quad 2(?) + (-2) = 0 \quad \Rightarrow \quad ? = +1$</td>
<td>$+1$</td>
</tr>
<tr>
<td>e. $\text{KMnO}_4$</td>
<td>$\text{K} = +1 \quad \text{Mn} = ? \quad \text{O} = -2 \quad \text{KMnO}_4 = 0 \quad (+1) + ? + 4(-2) = 0 \quad \Rightarrow \quad ? = +7$</td>
<td>$+7$</td>
</tr>
<tr>
<td>f. $\text{HClO}_2$</td>
<td>$\text{H} = +1 \quad \text{Cl} = ? \quad \text{O} = -2 \quad \text{HClO}_2 = 0 \quad (+1) + ? + 2(-2) = 0 \quad \Rightarrow \quad ? = +3$</td>
<td>$+3$</td>
</tr>
</tbody>
</table>

### 5.11 Oxidation Numbers

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Oxidation Numbers</th>
<th>Highest O.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $\text{Na}_2\text{O}_3$</td>
<td>$\text{N} = +5, \text{O} = -2$</td>
<td>nitrogen</td>
</tr>
<tr>
<td>b. $\text{KHCO}_3$</td>
<td>$\text{K} = +1, \text{H} = +1, \text{C} = +4, \text{O} = -2$</td>
<td>carbon</td>
</tr>
<tr>
<td>c. $\text{NaOCl}$</td>
<td>$\text{Na} = +1, \text{O} = -2, \text{Cl} = +1$</td>
<td>sodium and chlorine</td>
</tr>
<tr>
<td>d. $\text{NaNO}_3$</td>
<td>$\text{Na} = +1, \text{N} = +5, \text{O} = -2$</td>
<td>nitrogen</td>
</tr>
<tr>
<td>e. $\text{HClO}_4$</td>
<td>$\text{H} = +1, \text{Cl} = +7, \text{O} = -2$</td>
<td>chlorine</td>
</tr>
<tr>
<td>f. $\text{Ca(NO}_3)_2$</td>
<td>$\text{Ca} = +2, \text{N} = +5, \text{O} = -2$</td>
<td>nitrogen</td>
</tr>
</tbody>
</table>

### 5.12 Oxidation Numbers

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Oxidation Numbers</th>
<th>Highest O.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $\text{Na}_2\text{Cr}_2\text{O}_7$</td>
<td>$\text{Na} = +1, \text{Cr} = +6, \text{O} = -2$</td>
<td>chromium</td>
</tr>
<tr>
<td>b. $\text{K}_2\text{S}_2\text{O}_3$</td>
<td>$\text{K} = +1, \text{S} = +2, \text{O} = -2$</td>
<td>sulfur</td>
</tr>
<tr>
<td>c. $\text{HNO}_3$</td>
<td>$\text{H} = +1, \text{N} = +5, \text{O} = -2$</td>
<td>nitrogen</td>
</tr>
<tr>
<td>d. $\text{P}_2\text{O}_5$</td>
<td>$\text{P} = +5, \text{O} = -2$</td>
<td>phosphorus</td>
</tr>
<tr>
<td>e. $\text{Mg(ClO}_4)_2$</td>
<td>$\text{Mg} = +2, \text{Cl} = +7, \text{O} = -2$</td>
<td>chlorine</td>
</tr>
<tr>
<td>f. $\text{HClO}_2$</td>
<td>$\text{H} = +1, \text{Cl} = +3, \text{O} = -2$</td>
<td>chlorine</td>
</tr>
</tbody>
</table>

### 5.13 Change in Oxidation Numbers

<table>
<thead>
<tr>
<th>Compounds</th>
<th>O.N.</th>
<th>Change</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$</td>
<td>$0 \rightarrow +2$</td>
<td>lost e\textsuperscript{−}</td>
<td>oxidized</td>
</tr>
<tr>
<td>b. $\text{CuO} + \text{H}_2 \rightarrow \text{Cu} + \text{H}_2\text{O}$</td>
<td>$+2 \rightarrow 0$</td>
<td>gained e\textsuperscript{−}</td>
<td>reduced</td>
</tr>
<tr>
<td>c. $\text{Ag}^+ + \text{Cl}^- \rightarrow \text{AgCl}$</td>
<td>$+1 \rightarrow +1$</td>
<td>no change</td>
<td>neither</td>
</tr>
<tr>
<td>d. $\text{BaCl}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{BaSO}_4 + 2\text{HCl}$</td>
<td>$+2 \rightarrow +2$</td>
<td>no change</td>
<td>neither</td>
</tr>
<tr>
<td>e. $\text{Zn} + 2\text{H}_2\text{O} \rightarrow \text{Zn}^{2+} + \text{H}_2$</td>
<td>$0 \rightarrow +2$</td>
<td>lost e\textsuperscript{−}</td>
<td>oxidized</td>
</tr>
</tbody>
</table>

### 5.14 Change in Oxidation Numbers

<table>
<thead>
<tr>
<th>Compounds</th>
<th>O.N.</th>
<th>Change</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$</td>
<td>$0 \rightarrow +3$</td>
<td>lost e\textsuperscript{−}</td>
<td>oxidized</td>
</tr>
<tr>
<td>b. $\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$</td>
<td>$+1 \rightarrow +1$</td>
<td>no change</td>
<td>neither</td>
</tr>
<tr>
<td>c. $2\text{KClO}_3 \rightarrow 2\text{KCl} + 3\text{O}_2$</td>
<td>$+5 \rightarrow -1$</td>
<td>gained e\textsuperscript{−}</td>
<td>reduced</td>
</tr>
<tr>
<td>d. $2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2$</td>
<td>$+2 \rightarrow +4$</td>
<td>lost e\textsuperscript{−}</td>
<td>oxidized</td>
</tr>
<tr>
<td>e. $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$</td>
<td>$0 \rightarrow +1$</td>
<td>lost e\textsuperscript{−}</td>
<td>oxidized</td>
</tr>
</tbody>
</table>
5.15  

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

<table>
<thead>
<tr>
<th>Elements</th>
<th>H</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Product</td>
<td>+1</td>
<td>-1</td>
</tr>
</tbody>
</table>

The oxidizing agent is Cl\(_2\).
The reducing agent is H\(_2\).

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

<table>
<thead>
<tr>
<th>Elements</th>
<th>Cr</th>
<th>O</th>
<th>H</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>+6</td>
<td>-2</td>
<td>+1</td>
<td>+2</td>
</tr>
<tr>
<td>Product</td>
<td>+3</td>
<td>-2</td>
<td>+1</td>
<td>+4</td>
</tr>
</tbody>
</table>

The oxidizing agent is Cr\(_2\text{O}_7^{2-}\).
The reducing agent is Mn\(^{2+}\).

5.16  

a. \( 2 \text{Cu} (s) + \text{O}_2 (g) \rightarrow 2 \text{CuO} (s) \)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Cu</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Product</td>
<td>+2</td>
<td>-2</td>
</tr>
</tbody>
</table>

The oxidizing agent is O\(_2\).
The reducing agent is Cu.

d. \( \text{Cl}_2 (aq) + 2 \text{KI} (aq) \rightarrow 2 \text{KCl} (aq) + \text{I}_2 (aq) \)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Cl</th>
<th>K</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>0</td>
<td>+1</td>
<td>-1</td>
</tr>
<tr>
<td>Product</td>
<td>-1</td>
<td>+1</td>
<td>0</td>
</tr>
</tbody>
</table>

The oxidizing agent is Cl\(_2\).
The reducing agent is KI.

e. \( 3 \text{MnO}_2 (s) + 4 \text{Al} (s) \rightarrow 2 \text{Al}_2\text{O}_3 (s) + 3 \text{Mn} (s) \)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Mn</th>
<th>O</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>+4</td>
<td>-2</td>
<td>0</td>
</tr>
<tr>
<td>Product</td>
<td>0</td>
<td>-2</td>
<td>+3</td>
</tr>
</tbody>
</table>

The oxidizing agent is MnO\(_2\).
The reducing agent is Al.
d. \[2 \text{H}^+ (aq) + 3 \text{SO}_4^{2-} (aq) + 2 \text{NO}_3^- (aq) \rightarrow 2 \text{NO} (g) + \text{H}_2\text{O} (l) + 3 \text{SO}_4^{2-} (aq)\]

<table>
<thead>
<tr>
<th>Elements</th>
<th>H</th>
<th>S</th>
<th>O</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>+1</td>
<td>+4</td>
<td>-2</td>
<td>+5</td>
</tr>
<tr>
<td>Product</td>
<td>+1</td>
<td>+6</td>
<td>-2</td>
<td>+2</td>
</tr>
</tbody>
</table>

The oxidizing agent is \(\text{NO}_3^-\).
The reducing agent is \(\text{SO}_4^{2-}\).

e. \(\text{Mg} (s) + 2 \text{HCl} (aq) \rightarrow \text{MgCl}_2 (aq) + \text{H}_2 (g)\)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Mg</th>
<th>H</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>0</td>
<td>+1</td>
<td>-1</td>
</tr>
<tr>
<td>Product</td>
<td>+2</td>
<td>0</td>
<td>-1</td>
</tr>
</tbody>
</table>

The oxidizing agent is \(\text{HCl}\).
The reducing agent is \(\text{Mg}\).

f. \(4 \text{NO}_2 (g) + \text{O}_2 (g) \rightarrow 2 \text{N}_2\text{O}_5 (g)\)

<table>
<thead>
<tr>
<th>Elements</th>
<th>N</th>
<th>O</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactant</td>
<td>+4</td>
<td>-2</td>
<td>0</td>
</tr>
<tr>
<td>Product</td>
<td>+5</td>
<td>-2</td>
<td>-2</td>
</tr>
</tbody>
</table>

The oxidizing agent is \(\text{O}_2\).
The reducing agent is \(\text{NO}_2\).

5.17

\[3 \text{Ag}_2\text{S} (s) + 2 \text{Al} (s) \rightarrow 6 \text{Ag} (s) + \text{Al}_2\text{S}_3 (s)\]
The oxidizing agent is \(\text{Ag}_2\text{S}\) because the oxidation number for the silver changes from +1 to 0. The reducing agent is \(\text{Al}\) because the oxidation number for the aluminum changes from 0 to +3.

5.18

\[6 \text{NaOH} (aq) + 2 \text{Al} (s) \rightarrow 3 \text{H}_2 (g) + 2 \text{Na}_2\text{AlO}_3 (aq) + \text{heat}\]
The oxidizing agent is \(\text{NaOH}\) because the oxidation number for the hydrogen changes from +1 to 0. The reducing agent is \(\text{Al}\) because the oxidation number for the aluminum changes from 0 to +3.

5.19

\[\text{N}_2 (g) + 3 \text{H}_2 (g) \rightarrow 2 \text{NH}_3 (g)\]
The oxidizing agent is \(\text{N}_2\) because the oxidation number for the nitrogen changes from 0 to -3. The reducing agent is \(\text{H}_2\) because the oxidation number for the hydrogen changes from 0 to +1.

**DECOMPOSITION, COMBINATION, AND REPLACEMENT REACTIONS (SECTION 5.4-5.6)**

\[5.20\]

<table>
<thead>
<tr>
<th>a. (\text{K}_2\text{CO}_3 (s) \rightarrow \text{K}_2\text{O} (s) + \text{CO}_2 (g))</th>
<th>nonredox: decomposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>b. (\text{Ca} (s) + 2 \text{H}_2\text{O} (l) \rightarrow \text{Ca(OH)}_2 (s) + \text{H}_2 (g))</td>
<td>redox: single-replacement</td>
</tr>
<tr>
<td>c. (\text{BaCl}_2 (aq) + \text{H}_2\text{SO}_4 (aq) \rightarrow \text{BaSO}_4 (s) + 2 \text{HCl} (aq))</td>
<td>nonredox: double-replacement</td>
</tr>
<tr>
<td>d. (\text{SO}_2 (g) + \text{H}_2\text{O} (l) \rightarrow \text{H}_2\text{SO}_3 (aq))</td>
<td>nonredox: combination</td>
</tr>
<tr>
<td>e. (2 \text{NO} (g) + \text{O}_2 (g) \rightarrow \text{NO}_2 (g))</td>
<td>redox: combination</td>
</tr>
<tr>
<td>f. (2 \text{Zn} (s) + \text{O}_2 (g) \rightarrow 2 \text{ZnO} (s))</td>
<td>redox: combination</td>
</tr>
</tbody>
</table>

| a. \(\text{Na}_2\text{O}_3 (g) + \text{H}_2\text{O} (l) \rightarrow 2 \text{HNO}_3 (aq)\) | nonredox: combination |
| b. \(\text{Cr}_2\text{O}_3 (s) + 2 \text{Al} (s) \rightarrow 2 \text{Cr} (s) + \text{Al}_2\text{O}_3 (s)\) | redox: single-replacement |
| c. \(\text{CaO} (s) + \text{SiO}_2 (s) \rightarrow \text{CaSiO}_3 (s)\) | nonredox: combination |
| d. \(\text{H}_2\text{CO}_3 (aq) \rightarrow \text{CO}_2 (g) + \text{H}_2\text{O} (l)\) | nonredox: decomposition |
| e. \(\text{PbCO}_3 (s) \rightarrow \text{PbO} (s) + \text{CO}_2 (g)\) | nonredox: decomposition |
| f. \(\text{Zn} (s) + \text{Cl}_2 (g) \rightarrow \text{ZnCl}_2 (s)\) | redox: combination |
5.22 2NaHCO$_3$ (s) $\xrightarrow{\text{Heat}}$ Na$_2$CO$_3$ (s) + H$_2$O (g) + CO$_2$ (g)
This reaction is a nonredox decomposition reaction.

5.23 NaHCO$_3$ (aq) + H$^+$ (aq) → Na$^+$ (aq) + H$_2$O (l) + CO$_2$ (g); This reaction is a nonredox reaction.

5.24 CH$_4$ (g) + 2 O$_2$ (g) → CO$_2$ (g) + 2 H$_2$O (g); This reaction is a redox reaction.

\[
\begin{array}{ccc}
-4 & +1 & +2 \\
0 & +4 & -2 \\
+1 & -2 & -2 \\
\end{array}
\]

5.25 2H$_2$O$_2$ (aq) → 2H$_2$O (g) + O$_2$ (g); This reaction is a redox reaction.

\[
\begin{array}{ccc}
+1 & +1 & +2 \\
-1 & -2 & +1 \\
+1 & +2 & -2 \\
\end{array}
\]

5.26 Cl$_2$ (aq) + H$_2$O (l) → HOCI (aq) + HCl (aq); This is a redox reaction.

IONIC EQUATIONS (SECTION 5.7)

5.28 a. LiNO$_3$ → Li$^+$, NO$_3^−$
           d. KOH → K$^+$, OH$^−$
           b. Na$_2$HPO$_4$ → 2Na$^+$, HPO$_4^{2−}$
           e. MgBr$_2$ → Mg$^{2+}$, 2Br$^−$
           c. Ca(ClO$_3$)$_2$ → Ca$^{2+}$, 2ClO$_3^{−}$
           f. (NH$_4$)$_2$SO$_4$ → 2NH$_4^+$, SO$_4^{2−}$

5.29 a. K$_2$Cr$_2$O$_7$ → 2K$^+$, Cr$_2$O$_7^{2−}$
           d. Na$_3$PO$_4$ → 3Na$^+$, PO$_4^{3−}$
           b. H$_2$SO$_4$ → 2H$^+$, SO$_4^{2−}$
           e. NH$_4$Cl → NH$_4^+$, Cl$^−$
           c. NaH$_2$PO$_4$ → Na$^+$, H$_2$PO$_4^{−}$
           f. KMnO$_4$ → K$^+$, MnO$_4^{−}$

5.30 a. Cl$_2$ (aq) + 2NaI (aq) → 2NaCl (aq) + I$_2$ (aq)
      Total ionic equation: Cl$_2$ (aq) + 2Na$^+$ (aq) + 2I$^−$ (aq) → 2Na$^+$ (aq) + 2Cl$^−$ (aq) + I$_2$ (aq)
      Spectator ions: 2Na$^+$ (aq)
      Net ionic equation: Cl$_2$ (aq) + 2I$^−$ (aq) → 2Cl$^−$ (aq) + I$_2$ (aq)

b. AgNO$_3$ (aq) + NaCl (aq) → AgCl (s) + NaNO$_3$ (aq)
   Total ionic equation:
   Ag$^+$ (aq) + NO$_3^{−}$ (aq) + Na$^+$ (aq) + Cl$^−$ (aq) → AgCl (s) + Na$^+$ (aq) + NO$_3^{−}$ (aq)
   Spectator ions: NO$_3^{−}$ (aq), Na$^+$ (aq)
   Net ionic equation: Ag$^+$ (aq) + Cl$^−$ (aq) → AgCl (s)

b. Zn (s) + 2 HCl (aq) → ZnCl$_2$ (aq) + H$_2$(g)
   Total ionic equation: Zn (s) + 2 H$^+$ (aq) + 2Cl$^−$ (aq) → Zn$^{2+}$ (aq) + 2Cl$^−$ (aq) + H$_2$(g)
   Spectator ions: Cl$^−$ (aq)
   Net ionic equation: Zn (s) + 2 H$^+$ (aq) → Zn$^{2+}$ (aq) + H$_2$(g)
d. \[ \text{BaCl}_2 (aq) + \text{H}_2\text{SO}_4 (aq) \rightarrow \text{BaSO}_4 (s) + 2 \text{HCl} (aq) \]

Total ionic equation: \[ \text{Ba}^{2+}(aq) + 2\text{Cl}^-(aq) + 2\text{H}^+(aq) + \text{SO}_4^{2-}(aq) \rightarrow \text{BaSO}_4(s) + 2\text{H}^+(aq) + 2\text{Cl}^-(aq) \]

Spectator ions: \[ 2\text{Cl}^-(aq) + 2\text{H}^+(aq) \]

Net ionic equation: \[ \text{Ba}^{2+}(aq) + \text{SO}_4^{2-}(aq) \rightarrow \text{BaSO}_4(s) \]

e. \[ \text{SO}_3 (aq) + \text{H}_2\text{O} (l) \rightarrow 2 \text{H}_2\text{SO}_4 (aq) \]

Total ionic equation: \[ \text{SO}_3 (aq) + \text{H}_2\text{O} (l) \rightarrow 4 \text{H}^+(aq) + 2 \text{SO}_4^{2-}(aq) \]

Spectator ions: none

Net ionic equation: \[ \text{SO}_3 (aq) + \text{H}_2\text{O} (l) \rightarrow 4 \text{H}^+(aq) + 2 \text{SO}_4^{2-}(aq) \]

f. \[ 2 \text{NaI} (aq) + 2 \text{H}_2\text{SO}_4 (aq) \rightarrow \text{I}_2 (aq) + \text{SO}_2 (aq) + \text{Na}_2\text{SO}_4 (aq) + 2 \text{H}_2\text{O} (l) \]

Total ionic equation: \[ 2 \text{Na}^+(aq) + 2\text{I}^-(aq) + 4 \text{H}^+(aq) + 2 \text{SO}_4^{2-}(aq) \rightarrow \text{I}_2(aq) + 2\text{SO}_2(aq) + 2\text{Na}^+(aq) + 2 \text{H}_2\text{O} (l) \]

Spectator ions: \[ 2\text{Na}^+(aq), 2\text{SO}_4^{2-}(aq) \]

Net ionic equation: \[ 2 \text{I}^-(aq) + 4 \text{H}^+(aq) + 2 \text{SO}_4^{2-}(aq) \rightarrow \text{I}_2(aq) + 2\text{SO}_2(aq) + 2 \text{H}_2\text{O} (l) \]
e. \(\text{MnO}_2\ (s) + 4 \text{HCl (aq)} \rightarrow \text{MnCl}_2\ (aq) + \text{Cl}_2\ (aq) + 2 \text{H}_2\text{O (l)}\)

Total ionic equation:
\[\text{MnO}_2\ (s) + 4\text{H}^+(aq) + 4\text{Cl}^- (aq) \rightarrow \text{Mn}^{2+} (aq) + 2 \text{Cl}^- (aq) + \text{Cl}_2\ (aq) + 2 \text{H}_2\text{O (l)}\]

Spectator ions: \(2\text{Cl}^- (aq)\)
Net ionic equation: \(\text{MnO}_2\ (s) + 4\text{H}^+(aq) + 2\text{Cl}^- (aq) \rightarrow \text{Mn}^{2+} (aq) + \text{Cl}_2\ (aq) + 2 \text{H}_2\text{O (l)}\)

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

Total ionic equation:
\[2\text{Ag}^+ (aq) + 2\text{NO}_3^- (aq) + \text{Cu (s)} \rightarrow \text{Cu}^{2+} (aq) + 2 \text{NO}_3^- (aq) + 2 \text{Ag (s)}\]

Spectator ions: \(2\text{NO}_3^- (aq)\)
Net ionic equation: \(2\text{Ag}^+ (aq) + \text{Cu (s)} \rightarrow \text{Cu}^{2+} (aq) + 2 \text{Ag (s)}\)

5.32 a. \(\text{HNO}_3\ (aq) + \text{KOH (aq)} \rightarrow \text{KNO}_3\ (aq) + \text{H}_2\text{O (l)}\)

Total ionic equation:
\[\text{H}^+(aq) + \text{NO}_3^- (aq) + \text{K}^-(aq) + \text{OH}^- (aq) \rightarrow \text{K}^+(aq) + \text{NO}_3^- (aq) + \text{H}_2\text{O (l)}\]

Spectator ions: \(\text{K}^+(aq), \text{NO}_3^- (aq)\)
Net ionic equation: \(\text{H}^+ (aq) + \text{OH}^- (aq) \rightarrow \text{H}_2\text{O (l)}\)

b. \(\text{H}_3\text{PO}_4\ (aq) + 3 \text{NH}_4\text{OH (aq)} \rightarrow (\text{NH}_4)_3\text{PO}_4\ (aq) + 3 \text{H}_2\text{O (l)}\)

Total ionic equation:
\[3\text{H}^+(aq) + \text{PO}_4^{3-} (aq) + 3\text{NH}_4^+ (aq) + 3\text{OH}^- (aq) \rightarrow 3\text{NH}_4^+ (aq) + \text{PO}_4^{3-} (aq) + 3 \text{H}_2\text{O (l)}\]

Spectator ions: \(3\text{NH}_4^+ (aq), \text{PO}_4^{3-} (aq)\)
Net ionic equation: \(3\text{H}^+ (aq) + 3\text{OH}^- (aq) \rightarrow 3 \text{H}_2\text{O (l)}\); \(\text{H}^+ (aq) + \text{OH}^- (aq) \rightarrow \text{H}_2\text{O (l)}\)

c. \(\text{HI (aq)} + \text{NaOH (aq)} \rightarrow \text{NaI (aq)} + \text{H}_2\text{O (l)}\)

Total ionic equation:
\[\text{H}^+ (aq) + \text{I}^- (aq) + \text{Na}^+(aq) + \text{OH}^- (aq) \rightarrow \text{Na}^+(aq) + \text{I}^- (aq) + \text{H}_2\text{O (l)}\]

Spectator ions: \(\text{Na}^+(aq), \text{I}^- (aq)\)
Net ionic equation: \(\text{H}^+ (aq) + \text{OH}^- (aq) \rightarrow \text{H}_2\text{O (l)}\)

The reactants and products are identical for all three net ionic equations.

5.33 a. \(\text{HBr (aq)} + \text{RbOH (aq)} \rightarrow \text{RbBr (aq)} + \text{H}_2\text{O (l)}\)

Total ionic equation:
\[\text{H}^+ (aq) + \text{Br}^- (aq) + \text{Rb}^+(aq) + \text{OH}^- (aq) \rightarrow \text{Rb}^+(aq) + \text{Br}^- (aq) + \text{H}_2\text{O (l)}\]

Spectator ions: \(\text{Br}^- (aq), \text{Rb}^+(aq)\)
Net ionic equation: \(\text{H}^+ (aq) + \text{OH}^- (aq) \rightarrow \text{H}_2\text{O (l)}\)

b. \(\text{H}_2\text{SO}_4\ (aq) + 2 \text{LiOH (aq)} \rightarrow \text{Li}_2\text{SO}_4\ (aq) + 2 \text{H}_2\text{O (l)}\)

Total ionic equation:
\[2\text{H}^+(aq) + \text{SO}_4^{2-} (aq) + 2\text{Li}^+(aq) + 2\text{OH}^- (aq) \rightarrow 2\text{Li}^+(aq) + \text{SO}_4^{2-} (aq) + 2 \text{H}_2\text{O (l)}\]

Spectator ions: \(\text{SO}_4^{2-} (aq), 2\text{Li}^+ (aq)\)
Net ionic equation: \(2\text{H}^+ (aq) + 2\text{OH}^- (aq) \rightarrow 2 \text{H}_2\text{O (l)}\); \(\text{H}^+ (aq) + \text{OH}^- (aq) \rightarrow \text{H}_2\text{O (l)}\)
c. \( \text{HCl (aq)} + \text{CsOH (aq)} \rightarrow \text{CsCl (aq)} + \text{H}_2\text{O (l)} \)

Total ionic equation:
\( \text{H}^+ \text{(aq)} + \text{Cl}^-(\text{aq}) + \text{Cs}^+(\text{aq}) + \text{OH}^- \text{(aq)} \rightarrow \text{Cs}^+(\text{aq}) + \text{Cl}^- \text{(aq)} + \text{H}_2\text{O (l)} \)

Spectator ions: \( \text{Cs}^+, \text{Cl}^- \)  

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

The reactants and products are identical for all three net ionic equations.

ENERGY AND REACTIONS (SECTION 5.8)

5.34 The emergency hot pack becoming warm is an exothermic process because, as water is mixed with the solid, heat is released.

5.35 The evaporation process is endothermic. The liquid requires heat to be converted into a gas.

5.36 By insulating the ice, the heat in the food will not be able to travel into the ice as easily. It would be better if the ice were not wrapped in a thick insulating blanket. Wrapping the blanket around the ice and the food would be a better arrangement for keeping the food cold.

5.37 The evaporation process is endothermic. The liquid requires heat to be converted into a gas.

THE MOLE AND CHEMICAL EQUATIONS (SECTION 5.9)

5.38 a. \( \text{Ca (s)} + 2 \text{H}_2\text{O (l)} \rightarrow \text{H}_2 \text{(g)} + \text{Ca(OH)}_2 \text{(s)} \)

Statement 1: 1 Ca atom + 2 H\(_2\)O molecules \(\rightarrow\) 1 H\(_2\) molecule + 1 Ca(OH)\(_2\) formula unit  
Statement 2: 1 mole Ca + 2 moles H\(_2\)O \(\rightarrow\) 1 mole H\(_2\) + 1 mole Ca(OH)\(_2\)  
Statement 3: 6.02\,\times\,10^{23} \text{Ca atoms} + 1.20\,\times\,10^{24} \text{H}_2\text{O molecules} \rightarrow 6.02\,\times\,10^{23} \text{H}_2 \text{molecules} + 6.02\,\times\,10^{23} \text{Ca(OH)}_2 \text{formula units}  
Statement 4: 40.1 g Ca + 36.0 g H\(_2\)O \(\rightarrow\) 2.02 g H\(_2\) + 74.1 g Ca(OH)\(_2\)

b. \( 2 \text{NO (g)} + \text{O}_2 \text{(g)} \rightarrow 2 \text{NO}_2 \text{(g)} \)

Statement 1: 2 NO molecules + 1 O\(_2\) molecules \(\rightarrow\) 2 NO\(_2\) molecule  
Statement 2: 2 moles NO + 1 mole O\(_2\) \(\rightarrow\) 2 moles NO\(_2\)  
Statement 3: 1.20\,\times\,10^{24} \text{NO molecules} + 6.02\,\times\,10^{23} \text{O}_2 \text{molecules} \rightarrow 1.20\,\times\,10^{24} \text{NO}_2 \text{molecules}  
Statement 4: 60.0 g NO + 32.0 g O\(_2\) \(\rightarrow\) 92.0 g NO\(_2\)

c. \( 2 \text{C}_2\text{H}_6 \text{(g)} + 7 \text{O}_2 \text{(g)} \rightarrow 4 \text{CO}_2 \text{(g)} + 6 \text{H}_2\text{O (l)} \)

Statement 1: 2 C\(_2\)H\(_6\) molecules + 7 O\(_2\) molecules \(\rightarrow\) 4 CO\(_2\) molecules + 6 H\(_2\)O molecules  
Statement 2: 2 moles C\(_2\)H\(_6\) + 7 moles O\(_2\) \(\rightarrow\) 4 moles CO\(_2\) + 6 moles H\(_2\)O  
Statement 3: 1.20\,\times\,10^{24} \text{C}_2\text{H}_6 \text{molecules} + 4.22\,\times\,10^{24} \text{O}_2 \text{molecules} \rightarrow 2.41\times\,10^{24} \text{CO}_2 \text{molecules} + 3.61\times\,10^{24} \text{H}_2\text{O molecules}  
Statement 4: 60.1 g C\(_2\)H\(_6\) + 224 g O\(_2\) \(\rightarrow\) 176 g CO\(_2\) + 108 g H\(_2\)O
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d. \( Zn (s) + 2 \text{AgNO}_3 (g) \rightarrow Zn(NO_3)_2 (aq) + 2 \text{Ag (s)} \)

Statement 1: 1 \( Zn \) atom + 2 \( \text{AgNO}_3 \) formula units \( \rightarrow \) 1 \( Zn(NO_3)_2 \) formula unit + 2 Ag atoms
Statement 2: 1 mole \( Zn \) + 2 moles \( \text{AgNO}_3 \) \( \rightarrow \) 1 mole \( Zn(NO_3)_2 \) + 2 moles Ag
Statement 3: \( 6.02\times10^{23} \) \( Zn \) atoms + \( 1.20\times10^{24} \) \( \text{AgNO}_3 \) formula units \( \rightarrow \)
\( 6.02\times10^{23} \) \( Zn(NO_3)_2 \) formula unit + \( 1.20\times10^{24} \) Ag atoms
Statement 4: 65.4 g \( Zn \) + 340 g \( \text{AgNO}_3 \) \( \rightarrow \) 189 g \( Zn(NO_3)_2 \) + 216 g Ag

e. \( 2 \text{HCl (aq)} + \text{Mg(OH)}_2 (s) \rightarrow \text{MgCl}_2 (aq) + 2 \text{H}_2\text{O (l)} \)

Statement 1: 2 \( \text{HCl} \) molecules + 1 \( \text{Mg(OH)}_2 \) formula unit \( \rightarrow \)
1 \( \text{MgCl}_2 \) formula unit + 2 \( \text{H}_2\text{O} \) molecules
Statement 2: 2 moles \( \text{HCl} \) + 1 mole \( \text{Mg(OH)}_2 \) \( \rightarrow \) 1 mole \( \text{MgCl}_2 \) + 2 moles \( \text{H}_2\text{O} \)
Statement 3: \( 1.20\times10^{24} \) \( \text{HCl} \) molecules + \( 6.02\times10^{23} \) \( \text{Mg(OH)}_2 \) formula units \( \rightarrow \)
\( 6.02\times10^{23} \) \( \text{MgCl}_2 \) formula units + \( 1.20\times10^{24} \) \( \text{H}_2\text{O} \) molecules
Statement 4: 73.0 g \( \text{HCl} \) + 58.3 g \( \text{Mg(OH)}_2 \) \( \rightarrow \) 95.3 g \( \text{MgCl}_2 \) + 36.0 g \( \text{H}_2\text{O} \)

5.39

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

Statement 1: 1 \( \text{N}_2 \) molecule + 3 \( \text{H}_2 \) molecules \( \rightarrow \) 2 \( \text{NH}_3 \) molecules
Statement 2: 1 mole \( \text{N}_2 \) + 3 moles \( \text{H}_2 \) \( \rightarrow \) 2 moles \( \text{NH}_3 \)
Statement 3: \( 6.02\times10^{23} \) \( \text{N}_2 \) molecules + \( 1.81\times10^{24} \) \( \text{H}_2 \) molecules \( \rightarrow \) \( 1.20\times10^{24} \) \( \text{NH}_3 \) molecules
Statement 4: 28.0 g \( \text{N}_2 \) + 6.06 g \( \text{H}_2 \) \( \rightarrow \) 34.1 g \( \text{NH}_3 \)

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

Statement 1: 2 \( \text{Na} \) atoms + 1 \( \text{Cl}_2 \) molecule \( \rightarrow \) 2 \( \text{NaCl} \) formula units
Statement 2: 2 moles \( \text{Na} \) + 1 mole \( \text{Cl}_2 \) \( \rightarrow \) 2 moles \( \text{NaCl} \)
Statement 3: \( 1.20\times10^{24} \) \( \text{Na} \) atoms + \( 6.02\times10^{23} \) \( \text{Cl}_2 \) molecules \( \rightarrow \) \( 1.20\times10^{24} \) \( \text{NaCl} \) formula units
Statement 4: 46.0 g \( \text{Na} \) + 71.0 g \( \text{Cl}_2 \) \( \rightarrow \) 117 g \( \text{NaCl} \)

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

Statement 1: 1 \( \text{BaCl}_2 \) formula unit + 1 \( \text{H}_2\text{SO}_4 \) molecule \( \rightarrow \)
1 \( \text{BaSO}_4 \) formula unit + 2 \( \text{HCl} \) molecules
Statement 2: 1 mole \( \text{BaCl}_2 \) + 1 mole \( \text{H}_2\text{SO}_4 \) \( \rightarrow \) 1 mole \( \text{BaSO}_4 \) + 2 moles \( \text{HCl} \)
Statement 3: \( 6.02\times10^{23} \) \( \text{BaCl}_2 \) formula units + \( 6.02\times10^{23} \) \( \text{H}_2\text{SO}_4 \) molecules \( \rightarrow \)
\( 6.02\times10^{23} \) \( \text{BaSO}_4 \) formula units + \( 1.20\times10^{24} \) \( \text{HCl} \) molecules
Statement 4: 208 g \( \text{BaCl}_2 \) + 98.1 g \( \text{H}_2\text{SO}_4 \) \( \rightarrow \) 233 g \( \text{BaSO}_4 \) + 73.0 g \( \text{HCl} \)

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

Statement 1: 2 \( \text{H}_2\text{O}_2 \) molecules \( \rightarrow \) 2 \( \text{H}_2\text{O} \) molecules + 1 \( \text{O}_2 \) molecule
Statement 2: 2 moles \( \text{H}_2\text{O}_2 \) \( \rightarrow \) 2 moles \( \text{H}_2\text{O} \) + 1 mole \( \text{O}_2 \)
Statement 3: \( 1.20\times10^{24} \) \( \text{H}_2\text{O}_2 \) molecules \( \rightarrow \)
\( 12.0\times10^{24} \) \( \text{H}_2\text{O} \) molecules + \( 6.02\times10^{23} \) \( \text{O}_2 \) molecules
Statement 4: 68.0 g \( \text{H}_2\text{O}_2 \) \( \rightarrow \) 36.0 g \( \text{H}_2\text{O} \) + 32.0 g \( \text{O}_2 \)
e. \[2 \text{C}_3\text{H}_6 \ (g) + 9 \text{O}_2 \ (g) \rightarrow 6 \text{CO}_2 \ (g) + 6 \text{H}_2\text{O} \ (g)\]

Statement 1: \[2 \text{C}_3\text{H}_6 \text{ molecules} + 9 \text{O}_2 \text{ molecules} \rightarrow 6 \text{CO}_2 \text{ molecules} + 6 \text{H}_2\text{O} \text{ molecules}\]

Statement 2: 2 moles \text{C}_3\text{H}_6 + 9 moles \text{O}_2 \rightarrow 6 moles \text{CO}_2 + 6 moles \text{H}_2\text{O}

Statement 3: \[1.20 \times 10^{24} \text{C}_3\text{H}_6 \text{ molecules} + 5.42 \times 10^{24} \text{O}_2 \text{ molecules} \rightarrow 3.61 \times 10^{24} \text{CO}_2 \text{ molecules} + 3.61 \times 10^{24} \text{H}_2\text{O} \text{ molecules}\]

Statement 4: 84.1 g \text{C}_3\text{H}_6 + 288 g \text{O}_2 \rightarrow 264 g \text{CO}_2 + 108 g \text{H}_2\text{O}

5.40 \[2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3 \ (g)\]

Statement 1: 2 \text{SO}_2 \text{ molecules} + 1 \text{O}_2 \text{ molecule} \rightarrow 2 \text{SO}_3 \text{ molecules}

Statement 2: 2 moles \text{SO}_2 + 1 mole \text{O}_2 \rightarrow 2 moles \text{SO}_3

Statement 3: \[12.0 \times 10^{23} \text{SO}_2 \text{ molecules} + 6.02 \times 10^{23} \text{O}_2 \text{ molecules} \rightarrow 12.0 \times 10^{23} \text{SO}_3 \text{ molecules}\]

Statement 4: 128 g \text{SO}_2 + 32.0 g \text{O}_2 \rightarrow 160 g \text{SO}_3

Factors:
\[
\frac{12.0 \times 10^{23} \text{SO}_2 \text{ molecules}}{6.02 \times 10^{23} \text{O}_2 \text{ molecules}} \cdot \frac{12.0 \times 10^{23} \text{SO}_2 \text{ molecules}}{12.0 \times 10^{23} \text{SO}_3 \text{ molecules}} = \frac{12.0 \times 10^{23} \text{SO}_3 \text{ molecules}}{12.0 \times 10^{23} \text{SO}_2 \text{ molecules}}
\]

\[
\frac{2 \text{moles SO}_2}{1 \text{mole O}_2} \cdot \frac{2 \text{moles SO}_2}{2 \text{moles SO}_3} \cdot \frac{2 \text{moles SO}_3}{2 \text{moles SO}_2} = \frac{1 \text{mole O}_2}{2 \text{moles SO}_3}
\]

\[
\frac{128 \text{g SO}_2}{32.0 \text{g O}_2} \cdot \frac{128 \text{g SO}_2}{160 \text{g SO}_3} \cdot \frac{160 \text{g SO}_3}{32.0 \text{g O}_2} = \frac{160 \text{g SO}_3}{128 \text{g SO}_2}
\]

This list does not include all possible factors.

5.41 \[2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3 \ (g)\]

Statement 1: 2 \text{SO}_2 \text{ molecules} + 1 \text{O}_2 \text{ molecule} \rightarrow 2 \text{SO}_3 \text{ molecules}

Statement 2: 2 moles \text{SO}_2 + 1 mole \text{O}_2 \rightarrow 2 moles \text{SO}_3

Statement 3: \[12.0 \times 10^{23} \text{SO}_2 \text{ molecules} + 6.02 \times 10^{23} \text{O}_2 \text{ molecules} \rightarrow 12.0 \times 10^{23} \text{SO}_3 \text{ molecules}\]

Statement 4: 128 g \text{SO}_2 + 32.0 g \text{O}_2 \rightarrow 160 g \text{SO}_3

\[
350 \text{g SO}_3 \left( \frac{128 \text{g SO}_2}{160 \text{g SO}_3} \right) = 280 \text{g SO}_2
\]

280 g \text{SO}_2 \text{ must react to produce } 350 \text{g SO}_3.

\[\text{5.42} \quad \text{CaCO}_3 \ (\text{s}) \rightarrow \text{CaO} \ (\text{s}) + \text{CO}_2 \ (\text{g})\]

\[
500 \text{g CaO} \left( \frac{100 \text{g CaCO}_3}{56.1 \text{g CaO}} \right) = 891.265997148 \text{g CaCO}_3
\]

\[
\approx 891 \text{g CaCO}_3
\]
5.43  \[ \text{CaCO}_3 (s) \rightarrow \text{CaO} (s) + \text{CO}_2 (g) \]
\[
500 \text{ g CaO} \left( \frac{1 \text{ mole CO}_2}{56.1 \text{ g CaO}} \right) = 8.91265597148 \text{ moles CO}_2
\]
\[ \approx 8.91 \text{ moles CO}_2 \]

5.44  \[ 2 \text{ Al} (s) + 3 \text{ Br}_2 (l) \rightarrow 2 \text{ AlBr}_3 (s) \]
\[
50.1 \text{ g Al} \left( \frac{479 \text{ g Br}_2}{54.0 \text{ g Al}} \right) = 444.4055556 \text{ g Br}_2
\]
\[ \approx 444 \text{ g Br}_2 \text{ with SF} \]

5.45  \[ 2 \text{ Al} (s) + 3 \text{ Br}_2 (l) \rightarrow 2 \text{ AlBr}_3 (s) \]
\[
50.1 \text{ g Al} \left( \frac{2 \text{ moles AlBr}_3}{54.0 \text{ g Al}} \right) = 1.8555556 \text{ moles AlBr}_3
\]
\[ \approx 1.86 \text{ moles AlBr}_3 \text{ with SF} \]

5.46  \[ 50.1 \text{ g Al} \left( \frac{533 \text{ g AlBr}_3}{54.0 \text{ g Al}} \right) = 494.5055556 \text{ g AlBr}_3
\]
\[ \approx 495 \text{ g AlBr}_3 \text{ with SF} \]

or
\[ 50.1 \text{ g Al} + 445 \text{ g Br}_2 = 495.1 \text{ g Al Br}_3 \approx 495 \text{ g AlBr}_3 \text{ (SF)} \]

5.47  \[ 3 \text{ Ag}_2S (s) + 2 \text{ Al} (s) \rightarrow 6 \text{ Ag} (s) + \text{Al}_2S_3 (s) \]
a. \[ 0.250 \text{ g Ag}_2S \left( \frac{54.0 \text{ g Al}}{744 \text{ g Ag}_2S} \right) = 0.01814516129 \text{ g Al} \]
\[ \approx 1.81 \times 10^{-2} \text{ g Al with SF} \]
b. \[ 0.250 \text{ g Ag}_2S \left( \frac{1 \text{ mole Al}_2S_3}{744 \text{ g Ag}_2S} \right) = 3.36021505 \times 10^{-4} \text{ moles Al}_2S_3 \]
\[ \approx 3.36 \times 10^{-4} \text{ moles Al}_2S_3 \text{ with SF} \]

5.48  \[ \text{TiCl}_4 (s) + 2 \text{ Mg} (s) \rightarrow \text{Ti} (s) + 2 \text{ MgCl}_2 (s) \]
\[
1.00 \text{ kg Ti} \left( \frac{1000 \text{ g Ti}}{1 \text{ kg Ti}} \right) \left( \frac{48.6 \text{ g Mg}}{47.9 \text{ g Ti}} \right) = 1014.61377871 \text{ g Mg} \]
\[ \approx 1.01 \times 10^3 \text{ g Mg with SF} \]

5.49  \[ \text{CaH}_2O_6 (aq) + 6 \text{ O}_2 (aq) \rightarrow 6 \text{ CO}_2 (aq) + 6 \text{ H}_2\text{O} (l) \]
a. \[ 1.00 \text{ mole glucose} \left( \frac{108 \text{ g H}_2\text{O}}{1 \text{ mole glucose}} \right) = 108 \text{ g H}_2\text{O} \]
\[ = 1.08 \times 10^2 \text{ g H}_2\text{O} \]
b. \[ 1.00 \text{ mole glucose} \left( \frac{192 \text{ g O}_2}{1 \text{ mole glucose}} \right) = 192 \text{ g O}_2 \]
\[ = 1.92 \times 10^2 \text{ g O}_2 \]
5.50 \[ \text{C}_6\text{H}_{12}\text{O}_2 \text{(aq)} + 8 \text{O}_2 \text{(aq)} \rightarrow 6 \text{CO}_2 \text{(aq)} + 6 \text{H}_2\text{O} \text{(l)} \]

\[
1.00 \text{ mol caprylic acid} \left( \frac{256 \text{ g O}_2}{1 \text{ mol caprylic acid}} \right) = 256 \text{ g O}_2
\]

THE LIMITING REACTANT (SECTION 5.10)

5.51 a. \[ \text{CH}_4 \text{(g)} + 4 \text{Cl}_2 \text{(g)} \rightarrow \text{CCl}_4 \text{(l)} + 4 \text{HCl} \text{(g)} \]

Cl\(_2\) is the limiting reactant because the amount of Cl\(_2\) available will produce less CCl\(_4\) product than the amount of CH\(_4\) could produce, as shown by the calculations below:

\[
4.00 \text{ g CH}_4 \left( \frac{154 \text{ g CCl}_4}{16.0 \text{ g CH}_4} \right) = 38.5 \text{ g CCl}_4
\]

\[
15.0 \text{ g Cl}_2 \left( \frac{154 \text{ g CCl}_4}{284 \text{ g Cl}_2} \right) = 8.13 \text{ g CCl}_4
\]

b. Only 8.13 g CCl\(_4\) can be produced because Cl\(_2\) is the limiting reactant. Enough CH\(_4\) is present to make 38.5 g of CCl\(_4\), but not enough chlorine is present to react with the excess amount of CH\(_4\). See the calculation in part a.

5.52 a. \[ \text{N}_2 \text{(g)} + 2 \text{O}_2 \text{(g)} \rightarrow 2 \text{NO}_2 \text{(g)} \]

O\(_2\) is the limiting reactant as shown by the calculations below:

\[
1.25 \text{ moles N}_2 \left( \frac{2 \text{ moles NO}_2}{1 \text{ mole N}_2} \right) = 2.50 \text{ moles NO}_2
\]

\[
50.0 \text{ g O}_2 \left( \frac{2 \text{ moles NO}_2}{64.00 \text{ g O}_2} \right) = 1.56 \text{ moles NO}_2
\]

b. Only 71.9 g NO\(_2\) can be produced because O\(_2\) is the limiting reactant. Enough N\(_2\) is present to make 115 g of NO\(_2\), but not enough oxygen is present to react with the excess amount of N\(_2\).

\[
50.0 \text{ g O}_2 \left( \frac{92.0 \text{ g NO}_2}{64.0 \text{ g O}_2} \right) = 71.9 \text{ g NO}_2
\]

\[
1.25 \text{ moles N}_2 \left( \frac{92.0 \text{ g NO}_2}{1 \text{ mole N}_2} \right) = 115 \text{ g NO}_2
\]

5.53 \[ 2 \text{C}_2\text{H}_2 \text{(g)} + 5 \text{O}_2 \text{(g)} \rightarrow 4 \text{CO}_2 \text{(g)} + 2 \text{H}_2\text{O} \text{(g)} \]

1.54 \times 10^3 \text{ g O}_2 is required to burn 500 g C\(_2\)H\(_2\). The cylinder that contains 2000 g of oxygen is more than enough to burn all the acetylene.

\[
500 \text{ g C}_2\text{H}_2 \left( \frac{160 \text{ g O}_2}{52.0 \text{ g C}_2\text{H}_2} \right) = 1538 \text{ g O}_2 \approx 1.54 \times 10^3 \text{ g O}_2
\]

5.54 \[ \text{NH}_3 \text{(aq)} + \text{CO}_2 \text{(aq)} + \text{H}_2\text{O} \text{(l)} \rightarrow \text{NH}_4\text{HCO}_3 \text{(aq)} \]

144 g NH\(_4\)HCO\(_3\) is the maximum mass in grams that can be produced by these reactants. CO\(_2\) is the limiting reactant because the amount given can produce less product than the amounts of either the NH\(_3\) or H\(_2\)O given. The NH\(_3\) and H\(_2\)O are both excess reactants.
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\[
50.0 \text{ g } \text{NH}_3 \left( \frac{79.1 \text{ g } \text{NH}_4\text{HCO}_3}{17.0 \text{ g } \text{NH}_3} \right) = 233 \text{ g } \text{NH}_4\text{HCO}_3
\]

\[
80.0 \text{ g } \text{CO}_2 \left( \frac{79.1 \text{ g } \text{NH}_4\text{HCO}_3}{44.0 \text{ g } \text{CO}_2} \right) = 144 \text{ g } \text{NH}_4\text{HCO}_3
\]

\[
2.00 \text{ moles } \text{H}_2\text{O} \left( \frac{79.1 \text{ g } \text{NH}_4\text{HCO}_3}{1 \text{ moles } \text{H}_2\text{O}} \right) = 158 \text{ g } \text{NH}_4\text{HCO}_3
\]

5.55 \(\text{Cr}_2\text{O}_3 (s) + 2 \text{ Al} (s) \rightarrow 2 \text{ Cr} (s) + \text{Al}_2\text{O}_3 (s)\)

53.3 g of Al are required to completely react with 150 g \(\text{Cr}_2\text{O}_3\). If 150 g \(\text{Cr}_2\text{O}_3\) are reacted with 150 g Al, then the final mixture will contain the products Cr and \(\text{Al}_2\text{O}_3\) as well as some unreacted Al.

\[
150 \text{ g } \text{Cr}_2\text{O}_3 \left( \frac{54.0 \text{ g } \text{Al}}{152 \text{ g } \text{Cr}_2\text{O}_3} \right) = 53.289 \text{ g } \text{Al} \approx 53.3 \text{ g } \text{Al}
\]

**REACTION YIELDS (SECTION 5.11)**

5.56 \[12.18 \text{ g } \times 100 = 76.46\% \text{ yield}\]
5.57 \[14.37 \text{ g } \div 17.55 \text{ g} = 81.88\% \text{ yield}\]
5.58 The theoretical yield is the sum of the masses of reactant A with reactant B because the amounts given are said to react exactly, which means both reactants will be completely used to make the product.

\[
\frac{9.04 \text{ g}}{7.59 \text{ g} + 4.88 \text{ g}} \times 100 = 72.5\% \text{ yield}
\]

5.59 \(2 \text{ Ca} (s) + \text{O}_2 (g) \rightarrow 2 \text{ CaO} (s)\)

\[2.00 \text{ g } \text{Ca} \left( \frac{112 \text{ g } \text{CaO}}{80.2 \text{ g } \text{Ca}} \right) = 2.7930 \text{ g } \text{CaO}\]

\[
\frac{2.26 \text{ g}}{2.7930 \text{ g } \text{CaO} \times 100 = 80.9\% \text{ yield}}
\]

or \[\frac{2.26 \text{ g}}{2.00 \text{ g } \text{Ca} \left( \frac{112 \text{ g } \text{CaO}}{80.2 \text{ g } \text{Ca}} \right) \times 100 = 80.9\% \text{ yield}}\]

5.60 \(2 \text{ HgO} (s) \rightarrow 2 \text{ Hg} (l) + \text{O}_2 (g)\)

\[7.22 \text{ g } \text{HgO} \left( \frac{402 \text{ g } \text{Hg}}{434 \text{ g } \text{HgO}} \right) = 6.6876 \text{ g } \text{Hg}\]

\[
\frac{5.95 \text{ g}}{6.6876 \text{ g } \text{Hg} \times 100 = 89.0\% \text{ yield}}
\]

or \[\frac{5.95 \text{ g}}{7.22 \text{ g } \text{HgO} \left( \frac{402 \text{ g } \text{Hg}}{434 \text{ g } \text{HgO}} \right) \times 100 = 89.0\% \text{ yield}}\]

**ADDITIONAL EXERCISES**

5.61 I would not expect argon to be involved in a redox reaction because it is a noble gas. Noble gases do not tend to form ions, and in order to participate in a redox reaction, argon would have to form ions.
5.62  barium chloride (aq) + sodium sulfate (aq) → sodium chloride (aq) + barium sulfate (s)
Molecular equation:
$$\text{BaCl}_2 \text{(aq)} + \text{Na}_2\text{SO}_4 \text{(aq)} \rightarrow 2 \text{NaCl} \text{(aq)} + \text{BaSO}_4 \text{(s)}$$
Total Ionic equation:
$$\text{Ba}^{2+} \text{(aq)} + 2 \text{Cl}^- \text{(aq)} + 2 \text{Na}^+ \text{(aq)} + \text{SO}_4^{2-} \text{(aq)} \rightarrow 2 \text{Na}^+ \text{(aq)} + 2 \text{Cl}^- \text{(aq)} + \text{BaSO}_4 \text{(s)}$$
Spectator Ions: 2 Na\(^+\) (aq) and 2 Cl\(^-\) (aq)
Net Ionic equation:
$$\text{Ba}^{2+} \text{(aq)} + \text{SO}_4^{2-} \text{(aq)} \rightarrow \text{BaSO}_4 \text{(s)}$$

5.63  Sodium is the element with an electron configuration of 1s\(^2\)2s\(^2\)2p\(^6\)3s\(^1\). Phosphorus is the element with 15 protons in its nucleus.
$$3\text{Na} \text{(s)} + \text{P} \text{(s)} \rightarrow \text{Na}_3\text{P} \text{(s)}$$

5.64  $$\begin{align*}
6.983 \text{ g naturally occurring elemental iron} \times & \frac{60 \text{ g } ^{60}\text{Fe}}{55.9 \text{ g naturally occurring elemental iron}} = 7.5 \text{ g } ^{60}\text{Fe}
\end{align*}$$

5.65  The formula of the sample that was decomposed was N\(_2\)O\(_5\), dinitrogen pentoxide.
$$80.0 \text{ g O} \times \frac{1 \text{ mole O}}{16.0 \text{ g O}} = 5.00 \text{ moles O}$$
$$1.20 \times 10^{24} \text{ atoms N} \times \frac{1 \text{ mole N}}{6.02 \times 10^{23} \text{ atoms N}} = 1.99 \text{ moles N}$$

**ALLIED HEALTH EXAM CONNECTION**

5.66  (c) is the balanced equation.
$$\text{Mg} \text{(s)} + 2 \text{H}_2\text{O} \text{(g)} \rightarrow \text{Mg(OH)}_2 \text{(s)} + \text{H}_2 \text{(g)}$$

5.67  (d) is the balanced equation.
$$2\text{HgO} \rightarrow 2 \text{Hg} + \text{O}_2$$

5.68  (c) is the balanced equation.
$$\text{C}_{12}\text{H}_{22}\text{O}_{11} \rightarrow 12 \text{C} + 11 \text{H}_2\text{O}$$

5.69  The coefficient before O\(_2\) is (b) 2 in the balanced equation, as shown below:
$$\text{CH}_4 + 2 \text{O}_2 \text{(g)} \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}$$

5.70  The coefficient before ammonia, NH\(_3\), is (b) 2 in the balanced equation, as shown below:
$$\text{N}_2 \text{(g)} + 3 \text{H}_2 \text{(g)} \rightarrow 2 \text{NH}_3 \text{(g)}$$

5.71  The oxidation number of sodium in NaI and NaNO\(_3\) is (a) +1.
5.72 The oxidation number for nitrogen in HNO₃ is (b) +5.
\[ H = +1 \quad N = ? \quad O = -2 \quad HNO₃ = 0 \]
\[ (+1) + ? + 3(-2) = 0 \]
\[ ? = +5 \]

5.73 The oxidation number for sulfur in SO₄²⁻ is (c) +6.
\[ S = ? \quad O = -2 \quad SO₄²⁻ = -2 \]
\[ ? + 4(-2) = -2 \]
\[ ? = +6 \]

5.74 The oxidation number for sulfur in Na₂S₂O₃ is (c) +2.
\[ Na = +1 \quad S = ? \quad O = -2 \quad Na₂S₂O₃ = 0 \]
\[ 2(+1) + 2(?) + 3(-2) = 0 \]
\[ 2(?) = +4 \]
\[ ? = +2 \]

5.75 (b) Bromine is oxidized (Br⁻ → Br₂; losing electrons) and Mn in reduced (MnO₄⁻ → Mn²⁺; gaining electrons).

5.76 (a) C₂H₄ (g) is oxidized and 3O₂ (g) is reduced, in the equation, C₂H₄ (g) + 3O₂ (g) → 2 CO₂ (g) + 2 H₂O (g). The oxygen changes from an oxidation number of 0 to -2 by gaining electrons (reduction). The carbon changes from an oxidation number of -2 to +4 by losing electrons (oxidation).

5.77 (b) Cu²⁺ (aq) is being oxidized because it is gaining electrons.

5.78 The answer is (b) oxidizing agent: 4 NO₃⁻ (aq), reducing agent: Sn(s).
\[ 8H⁺ (aq) + 6Cl⁻ (aq) + Sn (s) + 4 NO₃⁻ (aq) → SnCl₆²⁻ (aq) + 4 NO₂ (g) + 4 H₂O (l) \]
The tin changes from an oxidation number of 0 to +4 by losing electrons (oxidation); therefore, Sn is the reducing agent. The nitrogen changes from an oxidation number of +5 to +4 by gaining electrons (reduction); therefore, NO₃⁻ is the oxidizing agent.

5.79 The chemical reaction: 2 Zn + 2 HCl → 2 ZnCl₂ + H₂ is an example of (d) single displacement.

5.80 This equation, Cl₂ + 2e⁻ → 2Cl⁻, is (a) a reduction reaction because Cl₂ is gaining electrons.

5.81 The chemical reaction: 2 NaI + Cl₂ → 2 NaCl + I₂ is an example of a (c) single replacement reaction.

5.82 This equation, Mg(OH)₂ + 2 HCl → MgCl₂ + 2 H₂O, is (d) double replacement reaction because the reactants are trading partners.

5.83 Exergonic reactions are not (c) uphill reactions.
The net ionic equation is (b) \( \text{Ca}^{2+} (aq) + 2 \text{Cl}^- (aq) \rightarrow \text{CaCl}_2 (s) \).

molecular equation: \( \text{Ca(NO}_3\text{)}_2 (aq) + 2 \text{KCl} (aq) \rightarrow \text{CaCl}_2 (s) + 2 \text{KNO}_3 (aq) \)
total ionic equation:

\[
\text{Ca}^{2+} (aq) + 2 \text{NO}_3^- (aq) + 2 \text{K}^+ (aq) + 2 \text{Cl}^- (aq) \rightarrow \text{CaCl}_2 (s) + 2 \text{K}^+ (aq) + 2 \text{NO}_3^- (aq)
\]
spectator ions: \( 2 \text{NO}_3^- (aq), 2 \text{K}^+ (aq) \)
net ionic equation:

\[
\text{Ca}^{2+} (aq) + 2 \text{Cl}^- (aq) \rightarrow \text{CaCl}_2 (s)
\]

The chemical reaction: \( \text{N}_2 (g) + 3 \text{H}_2 (g) \rightarrow 2 \text{NH}_3 (g) \) shows that (b) 3 moles of hydrogen gas are needed to react with one mole of nitrogen.

(c) 53.5 g \( \text{NH}_4\text{Cl} \) can be produced.

\[
\text{NH}_3 + \text{HCl} \rightarrow \text{NH}_4\text{Cl}
\]

\[
17 \text{ g NH}_3 \left( \frac{1 \text{ mole NH}_3}{17.0 \text{ g NH}_3} \right) = 1.0 \text{ mole NH}_3
\]

\[
36.5 \text{ g HCl} \left( \frac{1 \text{ mole HCl}}{36.5 \text{ g HCl}} \right) = 1.0 \text{ mole HCl}
\]

\[
17 \text{ g NH}_3 + 36.5 \text{ g HCl} = 53.5 \text{ g NH}_4\text{Cl}
\]

The number of grams of hydrogen formed by the action of 6 grams of magnesium (atomic weight = 24) on an appropriate quantity of acid is (a) 0.5 g.

\[
\text{Mg} + 2\text{H}^+ \rightarrow \text{Mg}^{2+} + \text{H}_2
\]

\[
6 \text{ g Mg} \left( \frac{2 \text{ g H}_2}{24 \text{ g Mg}} \right) = 0.5 \text{ g H}_2
\]

(d) 0.25 mole of \( \text{CaCl}_2 \) is needed to form 0.5 mole of \( \text{NaCl} \).

\[
\text{CaCl}_2 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + 2\text{NaCl}
\]

\[
0.5 \text{ mole NaCl} \left( \frac{1 \text{ mole CaCl}_2}{2 \text{ moles NaCl}} \right) = 0.25 \text{ mole CaCl}_2
\]

\[
0.5 \text{ mole NaCl} \left( \frac{1 \text{ mole Na}_2\text{CO}_3}{2 \text{ moles NaCl}} \right) = 0.25 \text{ mole Na}_2\text{CO}_3
\]

\[
0.5 \text{ mole NaCl} \left( \frac{1 \text{ mole CaCO}_3}{2 \text{ moles NaCl}} \right) = 0.25 \text{ mole CaCO}_3
\]

In the reaction: \( 4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3 \) (b) 36 grams \( \text{O}_2 \) are needed to completely react with 1.5 moles of \( \text{Al} \).

\[
1.5 \text{ moles Al} \left( \frac{96 \text{ g O}_2}{4 \text{ moles Al}} \right) = 36 \text{ g O}_2
\]

**CHEMISTRY FOR THOUGHT**

5.90 When a yield of more than 100% occurs for a compound prepared by precipitation from water solutions, it is likely that the “dry” compound is still moist and contains extra water mass.

5.91 In rapid combustion, the oxidizing agent is oxygen and the reducing agent is the material that is being burned, like wood. A fire can be extinguished by making either the oxidizing agent
or the reducing agent the limiting reactant. By removing the reducing agent (fuel) from the fire, the fire can be extinguished. This technique is often used in wild fire suppression. By removing the oxidizing agent (oxygen) from the fire, the fire can be extinguished. The technique of smothering the fire can be done with a fire blanket, aqueous foam, or inert gas. By enclosing the fire to quickly use all the available oxygen, the fire can be extinguished.

5.92 The bubbles formed during the reaction of hydrogen peroxide indicate that at least one of the products is a gas. Another material that might provide the enzyme catalyst needed for hydrogen peroxide decomposition is blood.

5.93 NaCl and AgNO₃ are both water soluble. AgCl is not water soluble. If a few grams of solid AgCl were added to a test tube containing 3 mL of water and the mixture were shaken, the test tube would look cloudy white until the mixture had a chance to settle because AgCl is not water soluble. If a few grams of solid NaNO₃ were added to a test tube containing 3 mL of water and the mixture were shaken, the solid should dissolve leaving a clear solution because NaNO₃ is water soluble.

5.94 \[ 2 \text{CrO}_4^{2-} (aq) + 3 \text{CH}_3\text{CH}_2\text{OH} (aq) + 16 \text{H}^+ (aq) \rightarrow 4\text{Cr}^{3+} (aq) + 3 \text{CH}_3\text{COOH} (aq) + 11 \text{H}_2\text{O} (l) \]

The initial color of the solution is orange-colored, but as it reacts with alcohol, the solution becomes pale violet. The darker violet the solution becomes, the more alcohol that was present in the breath.

5.95 The process of vegetables and fruits darkening when sliced is the result of a redox reaction. Placing these slices in water slows the process because the contact with oxygen is decreased when the slices are in water.

5.96 Zinc changing from zinc metal into zinc ions is an oxidation reaction because the zinc atoms are losing electrons to become cations. This reaction is the source of electrons as shown in the following equation:

\[ \text{Zn} (s) \rightarrow \text{Zn}^{2+} (aq) + 2 \text{e}^- \]

EXAM QUESTIONS

MULTIPLE CHOICE

1. Which of the following statements is true about the reaction?
   \[ 2 \text{CH}_4 + 3 \text{O}_2 \rightarrow 2 \text{CO}_2 + 4 \text{H}_2\text{O} \]
   a. Water is a reactant.
   b. Methane and carbon dioxide are products.
   c. Methane is a product
   d. Water and carbon dioxide are products

   Answer: D

2. Which of the following reactions is correctly balanced?
   a. \( \text{N}_2 + \text{H}_2 \rightarrow 2\text{NH}_3 \)
   b. \( 2\text{H}_2\text{O} + \text{C} \rightarrow \text{CO} + 2\text{H}_2 \)
   c. \( \text{Zn} + 2\text{HCl} \rightarrow \text{H}_2 + \text{ZnCl}_2 \)
   d. \( \text{CO} + \text{O}_2 \rightarrow \text{CO}_2 \)

   Answer: C
3. Which set of coefficients balances the equation?

\[ \underline{} \text{CH}_4 \rightarrow \underline{} \text{C}_3\text{H}_8 + \underline{} \text{H}_2 \]

\[ \text{a. } 3,1,1 \quad \text{b. } 3,2,1 \quad \text{c. } 3,1,2 \quad \text{d. } 6,2,2 \]

Answer: \text{C}

4. When the equation below is properly balanced, what coefficient is in front of KCl?

\[ \text{KClO}_3 \rightarrow \text{KCl} + \text{O}_2 \]

\[ \text{a. } 1 \quad \text{b. } 2 \quad \text{c. } 3 \quad \text{d. } 4 \]

Answer: \text{B}

5. Propane, \( \text{C}_3\text{H}_8 \), burns to produce carbon dioxide and water by the equation below. What is the coefficient in front of the carbon dioxide in the balanced equation?

\[ \text{C}_3\text{H}_8 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

\[ \text{a. } 1 \quad \text{b. } 2 \quad \text{c. } 3 \quad \text{d. } 6 \]

Answer: \text{C}

6. Consider the reactants and propose the right side of the equation.

\[ \text{Mg} + \text{H}_2\text{SO}_4 \rightarrow \underline{} \]

\[ \text{a. no reaction} \quad \text{b. } \text{MgHSO}_4 \quad \text{c. } \text{MgSO}_4 + \text{H}_2 \quad \text{d. } \text{MgH}_2 + \text{SO}_4 \]

Answer: \text{C}

7. Consider the reactants in the partial equation given. Which choice is a product?

\[ \text{H}_3\text{PO}_4 + \text{Sr(OH)}_2 \rightarrow \underline{} \]

\[ \text{a. no reaction} \quad \text{b. } \text{SrH}_3\text{PO}_5 \quad \text{c. } \text{SrH}_5\text{PO}_6 \quad \text{d. } \text{Sr}_3(\text{PO}_4)_2 \]

Answer: \text{D}

8. Which species would be considered a spectator ion based on the following equation?

\[ \text{Ba}^{2+} + 2\text{NO}_3^- + 2\text{Na}^+ + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4(s) + 2\text{NO}_3^- + 2\text{Na}^+ \]

\[ \text{a. } \text{Ba}^{2+} \quad \text{b. } \text{SO}_4^{2-} \quad \text{c. } \text{BaSO}_4 \quad \text{d. } 2\text{NO}_3^- \]

Answer: \text{D}

9. A redox reaction can also be a:

\[ \text{a. combination reaction.} \quad \text{c. decomposition reaction.} \]

\[ \text{b. single replacement reaction.} \quad \text{d. more than one response is correct} \]

Answer: \text{D}

10. Which of the following is typically an oxidizing agent?

\[ \text{a. } \text{oxygen} \quad \text{b. } \text{hydrogen} \quad \text{c. } \text{water} \quad \text{d. } \text{hydrogen chloride} \]

Answer: \text{A}

11. Single replacement reactions are always:

\[ \text{a. } \text{redox reactions.} \quad \text{c. combination reactions.} \]

\[ \text{b. } \text{nonredox reactions.} \quad \text{d. decomposition reactions.} \]

Answer: \text{A}

12. Which of the following equations (not balanced) represents an oxidation-reduction process?

\[ \text{a. } \text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3 \quad \text{c. } \text{C}_3\text{H}_4 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

\[ \text{b. } \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \quad \text{d. more than one response is correct} \]

Answer: \text{D}
13. What is the oxidation number of Cl in HClO₃?
   a. +2  b. +3  c. +4  d. +5
   Answer: D

14. What is the oxidation number of Br in BrO₂⁻?
   a. -1  b. +1  c. +2  d. +3
   Answer: D

15. What is the oxidation number of Mn in KMnO₄?
   a. +9  b. +7  c. +5  d. +4
   Answer: B

16. In which of the following does an element have an oxidation number of +4?
   a. TiO₂  b. HBr  c. SO₃  d. SO₄²⁻
   Answer: A

17. Which of the following contains the metal with the highest oxidation number?
   a. CaCl₂  b. NaCl  c. FeCl₃  d. CuCl₂
   Answer: C

18. Refer to Reaction. What substance is oxidized?
   a. Cl in HCl  b. Mn in MnO₂  c. H in HCl  d. O in MnO₂
   Answer: A

19. Refer to Reaction. What substance is reduced?
   a. Cl in HCl  b. Mn in MnO₂  c. H in HCl  d. O in MnO₂
   Answer: B

20. Refer to Reaction. What is the oxidizing agent?
   a. HCl  b. Cl₂  c. MnO₂  d. MnCl₂
   Answer: C

21. Refer to Reaction. What is the reducing agent?
   a. HCl  b. Cl₂  c. MnO₂  d. MnCl₂
   Answer: A

22. Which of the following is a decomposition reaction?
   a. SO₂ + O₂ → 2SO₃
   b. 2C₂H₂ + 5O₂ → 4CO₂ + 2H₂O
   c. 2H₂O₂ → 2H₂O + O₂
   d. AgNO₃ + NaCl → AgCl + NaNO₃
   Answer: C
23. Which of the following is a combination reaction?
   a. $\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$
   b. $2\text{C}_2\text{H}_2 + 5\text{O}_2 \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O}$
   c. $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$
   d. $\text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3$

   Answer: A

24. Which of the following is a single replacement reaction?
   a. $\text{CuO} + \text{H}_2 \rightarrow \text{Cu} + \text{H}_2\text{O}$
   b. $\text{HBr} + \text{KOH} \rightarrow \text{H}_2\text{O} + \text{KBr}$
   c. $\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$
   d. $2\text{HI} \rightarrow \text{I}_2 + \text{H}_2$

   Answer: A

25. Which of the following is a double replacement reaction?
   a. $\text{CuO} + \text{H}_2 \rightarrow \text{Cu} + \text{H}_2\text{O}$
   b. $\text{HBr} + \text{KOH} \rightarrow \text{H}_2\text{O} + \text{KBr}$
   c. $\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$
   d. $2\text{HI} \rightarrow \text{I}_2 + \text{H}_2$

   Answer: B

26. Barium sulfate is often ingested to aid in the diagnosis of GI tract disorders. The equation for its production is $\text{Ba}^{2+} + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4(\text{s})$. What type of equation is this?
   a. a total ionic equation
   b. a full equation
   c. an oxidation-reduction equation
   d. a net ionic equation

   Answer: D

27. Which ions in the following reaction would be classified as spectator ions?
   $$\text{Zn} + 2\text{H}^+ + 2\text{Cl}^- \rightarrow \text{Zn}^{2+} + 2\text{Cl}^- + \text{H}_2$$
   a. $\text{Zn}^{2+}$
   b. $\text{H}^+$
   c. $\text{Cl}^-$
   d. more than one response is correct.

   Answer: C

28. Which ion or ions will appear in the following (total ionic) reaction when it is written in net ionic form? $\text{Ba}^{2+} + \text{CO}_3^{2-} + 2\text{H}^+ + \text{SO}_4^{2-} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{BaSO}_4$
   a. $\text{Ba}^{2+}$ and $\text{CO}_3^{2-}$
   b. $\text{H}^+$ and $\text{SO}_4^{2-}$
   c. $\text{Ba}^{2+}$, $\text{CO}_3^{2-}$, and $\text{H}^+$
   d. $\text{Ba}^{2+}$, $\text{CO}_3^{2-}$, $\text{H}^+$, and $\text{SO}_4^{2-}$

   Answer: D

29. For the reaction of HCl and NaOH, which of the following type of chemicals will appear in the net equation?
   a. weak acid
   b. weak base
   c. salt
   d. water

   Answer: D

30. In the equation for an endothermic reaction, the word "heat" appears:
   a. on the right side.
   b. on the left side.
   c. on both sides.
   d. on neither side.

   Answer: B

31. The energy involved in chemical reactions:
   a. always appears as heat.
   b. always appears as light.
   c. always appears as electricity.
   d. can take many forms.

   Answer: D
32. Given the equation \(2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2\), how many grams of \(\text{CO}_2\) form if 34.0 grams of \(\text{CO}\) are combined with excess oxygen?
   a. 53.4  
   b. 21.6  
   c. 145  
   d. 107
   Answer: A

33. Oxygen can be prepared in the lab by heating potassium chlorate in the presence of a catalyst. The reaction is \(2\text{KClO}_3 \rightarrow 2\text{KCl} + 3\text{O}_2\). How many moles of \(\text{O}_2\) could be obtained from one mole of \(\text{KClO}_3\)?
   a. 1.0  
   b. 1.5  
   c. 2.0  
   d. 3.0
   Answer: B

34. The Haber Process is a method for the production of ammonia, an important chemical intermediate. The reaction for this process is: \(\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3\). When the equation is correctly interpreted in terms of moles, how many moles of \(\text{H}_2\) will react with one mole of \(\text{N}_2\)?
   a. 1  
   b. 2  
   c. 3  
   d. 6
   Answer: C

35. How many grams of \(\text{N}_2\) are required to completely react with 3.03 grams of \(\text{H}_2\) for the following balanced chemical equation? \(\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3\)
   a. 1.00  
   b. 6.00  
   c. 14.0  
   d. 28.0
   Answer: C

36. Refer to Haber Process. According to the mole interpretation, how many grams of \(\text{NH}_3\) could be produced by the complete reaction of 2.80 grams of \(\text{N}_2\) and excess \(\text{H}_2\)?
   a. 34.0  
   b. 17.0  
   c. 3.10  
   d. 3.40
   Answer: D

37. In the reaction \(2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2\), 2.0 mol water will produce how many grams of \(\text{O}_2\)?
   a. 16  
   b. 32  
   c. 36  
   d. 64
   Answer: B

38. In the reaction \(2\text{CH}_4 + \text{O}_2 \rightarrow 2\text{CO} + 4\text{H}_2\), how many molecules of \(\text{CO}\) will be produced by the complete reaction of 1.60 grams of \(\text{CH}_4\)?
   a. \(12.0 \times 10^{23}\)  
   b. \(3.01 \times 10^{22}\)  
   c. \(6.02 \times 10^{22}\)  
   d. 2.00
   Answer: C

39. If 5 grams of \(\text{CO}\) and 5 grams of \(\text{O}_2\) are combined according to the reaction \(2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2\), which is the limiting reagent?
   a. \(\text{CO}_2\)  
   b. \(\text{O}_2\)  
   c. \(\text{CO}\)  
   d. \(\text{CO}\) and \(\text{O}_2\)
   Answer: C

40. Acetylene, \(\text{C}_2\text{H}_2\), burns according to the following reaction: \(\text{C}_2\text{H}_2+5\text{O}_2 \rightarrow 4\text{CO}_2+2\text{H}_2\text{O}\). Suppose 1.20 g of \(\text{C}_2\text{H}_2\) is mixed with 3.50 g of \(\text{O}_2\) in a closed, steel container, and the mixture is ignited. What substances will be found in the mixture when the burning is complete?
   a. \(\text{CO}_2\) and \(\text{H}_2\)  
   b. \(\text{O}_2\), \(\text{CO}_2\), and \(\text{H}_2\text{O}\)  
   c. \(\text{C}_2\text{H}_2\), \(\text{CO}_2\), and \(\text{H}_2\text{O}\)  
   d. \(\text{O}_2\), \(\text{C}_2\text{H}_2\), \(\text{CO}_2\), and \(\text{H}_2\text{O}\)
   Answer: C
41. Suppose 2.43 g of magnesium is reacted with 3.20 g of oxygen: \(2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}\). How many grams of MgO will be produced?
   a. 5.63 b. 1.27 c. 8.06 d. 4.03
   Answer: D

42. Tincture of iodine is an antiseptic. What is a tincture?
   a. iodine dissolved in water b. a substance dissolved in alcohol c. a 3% hydrogen peroxide solution d. an oxidizing antiseptic
   Answer: B

43. What coefficients are needed to balance the following reaction:
   \[\text{CH}_4 + \underline{\text{O}_2} \rightarrow \underline{\text{CO}_2} + \underline{\text{H}_2\text{O}}\]
   a. 4,1,2 b. 2,0.5,1 c. 2,1,2 d. none of these
   Answer: C

44. According to the law of conservation of matter, which of the following may NEVER occur as a result of a chemical reaction:
   a. creation of new chemical species. b. reaction of starting materials. c. rearranged to form new substances. d. reduction in total mass.
   Answer: D

45. Which of the following is not a common use of the term oxidation?
   a. to gain electrons b. to lose hydrogen c. to combine with oxygen d. to increase in oxidation number
   Answer: A

46. The modern definition of oxidation is a process:
   a. involving a reaction with oxygen. b. in which hydrogen is gained. c. in which electrons are gained. d. none of the above
   Answer: D

47. Tests are to be conducted on new anti-cancer drug and you are to prepare a fresh supply for the human subject studies. You discover that you were able to produce 1.345 g of this substance although it was theoretically possible to make 1.433 g. What was the percent yield for this synthesis?
   a. 93.859 % b. 93.86 % c. 94 %
   Answer: B

48. A percentage yield less than 100% is often obtained in a reaction. Which of the following could be the reason(s) for obtaining less than theoretically predicted?
   a. side reactions occurred b. poor laboratory technique c. reaction did not go to completion d. all of the above
   Answer: D
49. A percentage yield greater than 100% has been reported in a scientific paper you are assigned to read. What would be a reasonable explanation for this?
   a. A lack of training of the professor who published the study.
   b. The product was measured more than once.
   c. Small measurement errors could have caused this to occur.
   d. It must be a typographical error since yields can’t exceed 100%
   
   Answer: C

50. Which of the following types of chemical reaction classes always involve oxidation?
   a. single replacement
   b. double replacement
   c. combination
   d. decomposition

   Answer: A

TRUE-FALSE

1. The reaction \( \text{Mg} + 3\text{N}_2 \rightarrow \text{Mg}_3\text{N}_2 \) is correctly balanced as written.
   Answer: F

2. The reaction \( \text{Ca} + \text{Cl}_2 \rightarrow \text{CaCl}_2 \) is a redox reaction.
   Answer: T

3. Redox reactions may also be decomposition reactions.
   Answer: T

4. The oxidation number of iodine in \( \text{HIO}_4 \) is +6.
   Answer: F

5. In the reaction \( \text{Zn} + \text{Cu(NO}_3\text{)}_2 \rightarrow \text{Cu} + \text{Zn(NO}_3\text{)}_2 \), the Zn is reduced.
   Answer: F

6. In the reaction \( \text{CuCl}_2 + \text{Fe} \rightarrow \text{Cu} + \text{FeCl}_2 \) the \( \text{CuCl}_2 \) is the oxidizing agent.
   Answer: T

7. The reaction \( \text{AgNO}_3 + \text{HCl} \rightarrow \text{AgCl} + \text{HNO}_3 \) is a redox reaction.
   Answer: F

8. In an exothermic reaction, heat is liberated to the surroundings.
   Answer: T

9. All redox reactions are exothermic reactions.
   Answer: F

10. The net ionic equation for the reaction \( \text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O} \) is \( \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} \).
   Answer: T

11. The oxidation number of oxygen in \( \text{H}_2\text{O}_2 \) is -2.
   Answer: F
12. Products are always written on the right side of a chemical equation.
   Answer: T

13. In ionic compounds, metals have a positive oxidation number.
   Answer: T

14. The reducing agent is the substance that is reduced in the reaction.
   Answer: F

15. Some redox reactions involve only oxidation without any reduction.
   Answer: F

16. A net ionic equation may include one or more spectator ions.
   Answer: F

17. The following reactions have the same net ionic equation.
   NaOH (aq) + HCl (aq) → H₂O (l) + NaCl (aq) and Ca(OH)₂ (aq) + 2HBr (aq) → 2H₂O (l) + CaBr₂ (aq)
   Answer: T

18. Most reactions give a percent yield of almost 100%.
   Answer: F

19. Water is a product when any inorganic acid reacts with any inorganic base.
   Answer: T

20. The batteries in an automobile contain lead plates, water, PbSO₄ and H₂SO₄. The instructions with a battery charger state that when a car battery is being charged, there must be no flames or sparks. Hydrogen is liberated during the process and might explode on ignition. Therefore, the hydrogen released is an indication that a redox reaction occurs during the charging process.
   Answer: T