Chemical Quantities and Aqueous Reactions

Review Questions

4.1 Reaction stoichiometry is the numerical relationships between chemical amounts in a balanced chemical equation. The coefficients in a chemical reaction specify the relative amounts in moles of each of the substances involved in the reaction.

4.2 The limiting reactant is the reactant that is completely consumed in a chemical reaction and limits the amount of product. The theoretical yield is the amount of product that can be made in a chemical reaction based on the amount of limiting reactant. The percent yield is calculated as \[ \text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 \]. The reactant in excess is any reactant that occurs in a quantity greater than that required to completely react with the limiting reactant. Some of this reactant will be left over when the reaction is complete.

4.3 No, the percent yield would not be different if the actual yield and theoretical yield were calculated in moles. The relationship between grams and moles is the molar mass. This would be the same value for the actual yield and the theoretical yield.

4.4 An aqueous solution is a solution in which water acts as the solvent. The solvent is the majority component of the mixture, and the solute is the minority component in the mixture.

4.5 Molarity is a concentration term. It is the amount of solute (in moles) divided by the volume of solution (in liters). The molarity of a solution can be used as a conversion factor between moles of the solute and liters of the solution.

4.6 Substances that completely dissociate into ions when they dissolve in water are called strong electrolytes and conduct electricity easily. Substances that do not completely dissociate in water are called weak electrolytes and conduct electricity only weakly. Compounds that do not dissociate into ions when dissolved in water are called non-electrolytes and do not conduct electricity.

4.7 Acids are molecular compounds that ionize—form ions—when they dissolve in water. A strong acid is one that completely ionizes in solution. A weak acid is one that does not completely ionize in water. A solution of a weak acid is composed mostly of the non-ionized acid.

4.8 A compound is termed soluble if it dissolves in water. A compound is insoluble if it does not dissolve in water.

4.9 The solubility rules are a set of empirical rules that have been inferred from observations on many ionic compounds. The solubility rules allow us to predict if a compound is soluble or insoluble.

4.10 Cations that usually form soluble compounds are Li⁺, Na⁺, K⁺, and NH₄⁺. The anions that usually form soluble compounds are NO₃⁻ and C₂H₅O₂⁻, which have no exceptions; Cl⁻, Br⁻, I⁻ except when these ions pair with Ag⁺, Hg₂²⁺, or Pb²⁺, which result in insoluble compounds; and SO₄²⁻ except with Sr²⁺, Ba²⁺, Pb²⁺, Ag⁺ or Ca²⁺, which form insoluble compounds. The
anions that usually form insoluble compounds are OH\(^{-}\) and S\(^{2-}\) except with Li\(^{+}\), Na\(^{+}\), K\(^{+}\), and NH\(_{4}\)^{+}, which form soluble compounds and when S\(^{2-}\) pairs with Ca\(^{2+}\), Sr\(^{2+}\) or Ba\(^{2+}\) the compounds are soluble; CO\(_{3}\)^{2-} and PO\(_{4}\)^{3-} are insoluble except when paired with Li\(^{+}\), Na\(^{+}\), K\(^{+}\), and NH\(_{4}\)^{+}.

4.11 A precipitation reaction is one in which a solid or precipitate forms upon mixing two solutions. An example is 2 KI(aq) + Pb(NO\(_{3}\))\(_{2}\)(aq) \rightarrow PbI\(_{2}\)(s) + 2 KNO\(_{3}\)(aq).

4.12 The key to predicting precipitation reactions is to understand that only insoluble compounds form precipitates. In a precipitation reaction, two solutions containing soluble compounds combine and an insoluble compound precipitates.

4.13 A molecular equation is an equation showing the complete neutral formulas for each compound in the reaction as if they existed as molecules. Equations that list individually all of the ions present as either reactants or products in a chemical reaction are complete ionic equation. Equations that show only the species that actually change during the reaction are net ionic equations.

4.14 An Arrhenius acid is a substance that produces H\(^{+}\) ions in aqueous solutions. An Arrhenius base is a substance that produces OH\(^{-}\) ions in aqueous solutions.

4.15 When an acid and base are mixed, the H\(^{+}\)(aq) from the acid combines with the OH\(^{-}\) from the base to form H\(_{2}\)O(l). An example is HCl(aq) + NaOH(aq) \rightarrow H\(_{2}\)O(l) + NaCl(aq).

4.16 In a titration, a substance in a solution of known concentration is reacted with another substance in a solution of unknown concentration. The acid-base titration is continued until the neutralization is complete. At the equivalence point, the point when the number of moles of OH\(^{-}\) equals the number of moles of H\(^{+}\), the titration is complete. An indicator is a dye whose color depends on the acidity or basicity of the solution.

4.17 Aqueous reactions that form a gas upon mixing two solutions are called gas-evolution reactions. An example is H\(_{2}\)SO\(_{4}\)(aq) + Li\(_{2}\)S(aq) \rightarrow H\(_{2}\)S(g) + Li\(_{2}\)SO\(_{4}\)(aq).

4.18 The reactant types that give rise to gas-evolution reactions are sulfides, carbonates, bicarbonate, sulfites, bisulfites, and ammonium compounds.

4.19 Oxidation-reduction reactions or redox reactions are reactions in which electrons are transferred from one reactant to the other. An example is 4 Fe(s) + 3 O\(_{2}\)(g) \rightarrow 2 Fe\(_{2}\)O\(_{3}\)(s).

4.20 The oxidation state or oxidation number is a number given to each atom based on the electron assignments. It is the charge an atom would have if all shared electrons were assigned to the atom with a greater attraction for those electrons.

4.21 To identify redox reactions by using oxidation states, begin by assigning oxidation states to each atom in the reaction. A change in oxidation state for the atoms indicates a redox reaction.

4.22 When a substance is oxidized it loses electrons and there is an increase in oxidation state. When a substance is reduced it gains electrons and there is a reduction in oxidation state.

4.23 A substance that causes the oxidation of another substance is called an oxidizing agent. A substance that causes the reduction of another substance is called a reducing agent.

4.24 Combustion reactions are characterized by the reaction of a substance with O\(_{2}\) to form one or more oxygen containing compounds, often including water. Combustion reactions emit heat. Combustion reactions are important because most of our society's energy is derived from them. An example is CH\(_{4}\)(g) + 2 O\(_{2}\)(g) \rightarrow CO\(_{2}\)(g) + 2 H\(_{2}\)O(g).
Problems by Topic

Reaction Stoichiometry

4.25 Given: 7.2 moles CgH^ Find: balanced reaction, moles O₂ required
Conceptual Plan: balance the equation then mol CgH₁₄ —> mol O₂

\[
2 \text{C}_g\text{H}_x(g) + 19 \text{O}_2(g) \rightarrow 12 \text{CO}_2(g) + 14 \text{H}_2\text{O}(g)
\]

Solution: 7.2 mol CgH₁₄ \times \frac{19 \text{ mol O}_2}{2 \text{ mol C}_g\text{H}_x} = 68.4 \text{ mol O}_2 \approx 68 \text{ mol O}_2

Check: The units of the answer (mol O₂) are correct. The magnitude is reasonable because much more O₂ is needed than CgH₁₄.

4.26 Given: 0.461 moles HC₂H₃O₂ Find: balanced reaction, moles Ba(OH)₂ required
Conceptual Plan: balance the reaction then mol HC₂H₃O₂ —* mol Ba(OH)₂

\[
2 \text{HC}_2\text{H}_3\text{O}_2(aq) + \text{Ba(OH)}_2(aq) \rightarrow \text{Ba(OH)}_2 + 2 \text{H}_2\text{O}(aq)
\]

Solution: 0.461 mol HC₂H₃O₂ \times \frac{1 \text{ mol Ba(OH)}_2}{2 \text{ mol HC}_2\text{H}_3\text{O}_2} = 0.2305 \text{ mol Ba(OH)}_2 \approx 0.231 \text{ mol Ba(OH)}_2

Check: The units of the answer (mol Ba(OH)₂) are correct. The magnitude is reasonable because much less Ba(OH)₂ is needed than HC₂H₃O₂.

4.27 (a) Given: 2.5 mol N₂O₅ Find: mol NO₂
Conceptual Plan: mol N₂O₅ \rightarrow mol NO₂

\[
4 \text{NO}_2
\]

Solution: 2.5 mol N₂O₅ \times \frac{4 \text{ mol NO}_2}{2 \text{ mol N}_2\text{O}_5} = 5.0 \text{ mol NO}_2

Check: The units of the answer (mol NO₂) are correct. The magnitude is reasonable since it is greater than mol N₂O₅.

(b) Given: 6.8 mol N₂O₅ Find: mol NO₂
Conceptual Plan: mol N₂O₅ \rightarrow mol NO₂

\[
4 \text{NO}_2
\]

Solution: 6.8 mol N₂O₅ \times \frac{4 \text{ mol NO}_2}{2 \text{ mol N}_2\text{O}_5} = 13.6 \text{ mol NO}_2 \approx 14 \text{ mol NO}_2

Check: The units of the answer (mol NO₂) are correct. The magnitude is reasonable since it is greater than mol N₂O₅.

(c) Given: 15.2 g N₂O₅ Find: mol NO₂
Conceptual Plan: g N₂O₅ \rightarrow mol N₂O₅ \rightarrow mol NO₂

\[
\frac{1 \text{ mol NO}_2}{4 \text{ NO}_2}
\]

Solution: 15.2 g N₂O₅ \times \frac{1 \text{ mol N}_2\text{O}_5}{108.02 \text{ g N}_2\text{O}_5} \times \frac{4 \text{ mol NO}_2}{2 \text{ mol N}_2\text{O}_5} = 0.2814 \text{ mol NO}_2 \approx 0.281 \text{ mol NO}_2

Check: The units of the answer (mol NO₂) are correct. The magnitude is reasonable since 15 g is about 0.13 mol N₂O₅ and the answer is greater than mol N₂O₅.

(d) Given: 2.87 kg N₂O₅ Find: mol NO₂
Conceptual Plan: kg N₂O₅ \rightarrow g N₂O₅ \rightarrow mol N₂O₅ \rightarrow mol NO₂

\[
\frac{1000 \text{ g N}_2\text{O}_5}{1 \text{ mol N}_2\text{O}_5} \times \frac{1 \text{ mol NO}_2}{4 \text{ NO}_2}
\]

Solution: 2.87 kg N₂O₅ \times \frac{108.02 \text{ g N}_2\text{O}_5}{1 \text{ mol N}_2\text{O}_5} \times \frac{1 \text{ mol NO}_2}{4 \text{ NO}_2} \approx 0.281 \text{ mol NO}_2

Check: The units of the answer (mol NO₂) are correct. The magnitude is reasonable since 15 g is about 0.13 mol N₂O₅ and the answer is greater than mol N₂O₅.
4.28 (a) Given: 2.6 mol \( \text{N}_2\text{H}_4 \) Find: mol NH\(_3\)

Conceptual Plan: mol \( \text{N}_2\text{H}_4 \) \( \rightarrow \) mol NH\(_3\)

\[
\frac{4 \text{ mol NH}_3}{3 \text{ mol} \text{N}_2\text{H}_4} \times \frac{4 \text{ mol} \text{N}_2\text{H}_4}{2.6 \text{ mol}} = \frac{4 \times 4}{3 \times 2.6} \text{ mol NH}_3 = \text{5.34 mol NH}_3
\]

Check: The units of the answer (mol NH\(_3\)) are correct. The magnitude is reasonable since 2.87 kg is about 27 mol N\(_2\)O and the answer is greater than mol N\(_2\)O.

(b) Given: 3.55 mol N\(_2\)H\(_4\) Find: mol NH\(_3\)

Conceptual Plan: mol N\(_2\)H\(_4\) \( \rightarrow \) mol NH\(_3\)

\[
\frac{4 \text{ mol NH}_3}{3 \text{ mol N}_2\text{H}_4} \times \frac{3.55 \text{ mol N}_2\text{H}_4}{4 \text{ mol}} = \frac{4 	imes 3.55}{3 	imes 4} \text{ mol NH}_3 = \text{4.73 mol NH}_3
\]

Check: The units of the answer (mol NH\(_3\)) are correct. The magnitude is reasonable since it is greater than mol N\(_2\)H\(_4\).

(c) Given: 65.3 g N\(_2\)H\(_4\) Find: mol NH\(_3\)

Conceptual Plan: g N\(_2\)H\(_4\) \( \rightarrow \) mol N\(_2\)H\(_4\) \( \rightarrow \) mol NH\(_3\)

\[
\frac{32.05 \text{ g N}_2\text{H}_4}{1 \text{ mol}} \times \frac{4 \text{ mol NH}_3}{3 \text{ mol N}_2\text{H}_4} \times \frac{1 \text{ mol N}_2\text{H}_4}{65.3 \text{ g N}_2\text{H}_4} = \frac{32.05 	imes 4}{3 	imes 65.3} \text{ mol NH}_3 = \text{2.71 mol NH}_3
\]

Check: The units of the answer (mol NH\(_3\)) are correct. The magnitude is reasonable since there is about 2 mol N\(_2\)H\(_4\) and the answer is greater than mol N\(_2\)H\(_4\).

(d) Given: 4.88 kg N\(_2\)H\(_4\) Find: mol NH\(_3\)

Conceptual Plan: kg N\(_2\)H\(_4\) \( \rightarrow \) g N\(_2\)H\(_4\) \( \rightarrow \) mol N\(_2\)H\(_4\) \( \rightarrow \) mol NH\(_3\)

\[
\frac{4.88 \text{ kg N}_2\text{H}_4}{1000 \text{ g N}_2\text{H}_4} \times \frac{1 \text{ mol N}_2\text{H}_4}{32.05 \text{ g N}_2\text{H}_4} \times \frac{4 \text{ mol NH}_3}{1 \text{ mol N}_2\text{H}_4} = \frac{4.88 	imes 1 	imes 4}{32.05 	imes 1} \text{ mol NH}_3 = \text{203 mol NH}_3
\]

Check: The units of the answer (mol NH\(_3\)) are correct. The magnitude is reasonable since 4.88 kg is about 150 mol N\(_2\)H\(_4\) and the answer is greater than mol N\(_2\)H\(_4\).
Check: The units of the answers (g HBr, g H2) are correct. The magnitude of the answers is reasonable because molar mass HBr is greater than Fe and molar mass H2 is much less than Fe.

4.32 Given: 15.2 g Al Find: g H2SO4; g H2

Conceptual Plan: g Al \rightarrow mol Al \rightarrow mol H2SO4 \rightarrow g H2SO4

\[
\begin{align*}
g \text{Al} & \rightarrow mol \text{Al} \rightarrow 3 \text{mol H}_2\text{SO}_4 \rightarrow 98.09 \text{g H}_2\text{SO}_4 \\
26.98 \text{g Al} & \rightarrow 2 \text{mol Al} \rightarrow 1 \text{mol H}_2\text{SO}_4 \\
\text{g} \text{Al} & \rightarrow \text{mol Al} \rightarrow 2 \text{mol H}_2 \rightarrow g \text{H}_2
\end{align*}
\]

Solution: 

\[
\begin{align*}
15.2 \text{g Al} \times \frac{1 \text{mol Al}}{26.98 \text{g Al}} \times \frac{3 \text{mol H}_2\text{SO}_4}{1 \text{mol Al}} & = 98.09 \text{g H}_2\text{SO}_4 \\
15.2 \text{g Al} & \rightarrow 3 \text{mol H}_2 \rightarrow 0.016 \text{g H}_2
\end{align*}
\]

Check: The units of the answers (g H2SO4, g H2) are correct. The magnitude of the answers is reasonable because molar mass H2SO4 is greater than Al and molar mass H2 is much less than Al.

(a) Given: 3.67 g Ba Find: g BaCl2

Conceptual Plan: g Ba \rightarrow mol Ba \rightarrow mol BaCl2 \rightarrow g BaCl2

\[
\begin{align*}
g \text{Ba} & \rightarrow \text{mol Ba} \rightarrow 1 \text{mol BaCl2} \rightarrow 208.23 \text{g BaCl2} \\
137.33 \text{g Ba} & \rightarrow 1 \text{mol Ba} \\
1 \text{mol Ba} & \rightarrow 1 \text{mol BaCl2} \\
208.23 \text{g BaCl2} & \rightarrow 1 \text{mol BaCl2}
\end{align*}
\]

Solution: 

\[
3.67 \text{g Ba} \times \frac{1 \text{mol Ba}}{137.33 \text{g Ba}} \times \frac{1 \text{mol BaCl2}}{1 \text{mol Ba}} \times \frac{208.23 \text{g BaCl2}}{1 \text{mol BaCl2}} = 5.56 \text{g BaCl2}
\]

Check: The units of the answer (g BaCl2) are correct. The magnitude of the answer is reasonable because it is larger than grams Ba.

(b) Given: 3.67 g CaO Find: g CaCO3

Conceptual Plan: g CaO \rightarrow mol CaO \rightarrow mol CaCO3 \rightarrow g CaCO3

\[
\begin{align*}
g \text{CaO} & \rightarrow \text{mol CaO} \rightarrow 1 \text{mol CaCO3} \rightarrow 100.09 \text{g CaCO3} \\
56.08 \text{g CaO} & \rightarrow 1 \text{mol CaO} \\
1 \text{mol CaO} & \rightarrow 1 \text{mol CaCO3} \\
100.09 \text{g CaCO3} & \rightarrow 1 \text{mol CaCO3}
\end{align*}
\]

Solution: 

\[
3.67 \text{g CaO} \times \frac{1 \text{mol CaO}}{56.08 \text{g CaO}} \times \frac{1 \text{mol CaCO3}}{1 \text{mol CaO}} \times \frac{100.09 \text{g CaCO3}}{1 \text{mol CaCO3}} = 6.55 \text{g CaCO3}
\]

Check: Units of answer (g CaCO3) are correct. The magnitude of the answer is reasonable because it is larger than grams CaO.

(c) Given: 3.67 g Mg Find: g MgO

Conceptual Plan: g Mg \rightarrow mol Mg \rightarrow mol MgO \rightarrow g MgO

\[
\begin{align*}
g \text{Mg} & \rightarrow \text{mol Mg} \rightarrow 2 \text{mol MgO} \rightarrow 40.30 \text{g MgO} \\
24.30 \text{g Mg} & \rightarrow 1 \text{mol Mg} \\
1 \text{mol Mg} & \rightarrow 2 \text{mol MgO} \\
40.30 \text{g MgO} & \rightarrow 1 \text{mol MgO}
\end{align*}
\]

Solution: 

\[
3.67 \text{g Mg} \times \frac{1 \text{mol Mg}}{24.30 \text{g Mg}} \times \frac{2 \text{mol MgO}}{1 \text{mol Mg}} \times \frac{40.30 \text{g MgO}}{1 \text{mol MgO}} = 6.09 \text{g MgO}
\]

Check: The units of the answer (g MgO) are correct. The magnitude of the answer is reasonable because it is larger than grams Mg.

(d) Given: 3.67 g Al Find: g Al2O3

Conceptual Plan: g Al \rightarrow mol Al \rightarrow mol Al2O3 \rightarrow g Al2O3

\[
\begin{align*}
g \text{Al} & \rightarrow \text{mol Al} \rightarrow 2 \text{mol Al2O3} \rightarrow 101.96 \text{g Al2O3} \\
26.98 \text{g Al} & \rightarrow 2 \text{mol Al} \\
1 \text{mol Al} & \rightarrow 2 \text{mol Al2O3} \\
101.96 \text{g Al2O3} & \rightarrow 1 \text{mol Al2O3}
\end{align*}
\]

Solution: 

\[
3.67 \text{g Al} \times \frac{1 \text{mol Al}}{26.98 \text{g Al}} \times \frac{2 \text{mol Al2O3}}{1 \text{mol Al}} \times \frac{101.96 \text{g Al2O3}}{1 \text{mol Al2O3}} = 6.93 \text{g Al2O3}
\]

Check: The units of the answer (g Al2O3) are correct. The magnitude of the answer is reasonable because it is larger than grams Al.
Given: 4.2 mol ZnS, 6.8 mol O<sub>2</sub>  
Find: Mole amount of excess reactant left

Conceptual Plan: mol ZnS → mol ZnO 

\[ \frac{2 \text{ mol ZnO}}{2 \text{ mol ZnS}} \rightarrow \text{ smallest mol amount determines limiting reactant} \]

mol O<sub>2</sub> → mol ZnO

\[ \frac{2 \text{ mol ZnO}}{3 \text{ mol O}_2} \]

then: mol limiting reactant → mol excess reactant required → mol excess reactant left

\[ \frac{2 \text{ mol ZnS}}{3 \text{ mol O}_2} \]

Solution: 

\[ 4.2 \text{ mol ZnS} \times \frac{2 \text{ mol ZnO}}{2 \text{ mol ZnS}} = 4.2 \text{ mol ZnO} \]

\[ 6.8 \text{ mol O}_2 \times \frac{2 \text{ mol ZnO}}{3 \text{ mol O}_2} = 4.5 \text{ mol ZnO} \]

ZnS is the limiting reactant, therefore, O<sub>2</sub> is the excess reactant.

\[ 4.2 \text{ mol ZnS} \times \frac{3 \text{ mol O}_2}{2 \text{ mol ZnS}} = 6.3 \text{ mol O}_2 \text{ required} \]

\[ 6.8 \text{ mol O}_2 - 6.3 \text{ mol O}_2 = 0.5 \text{ mol O}_2 \text{ left} \]

Check: The units of the answer (mol O<sub>2</sub>) are correct and the magnitude is reasonable since it is less than the original amount of O<sub>2</sub>.

Given: 0.223 mol FeS, 0.652 mol HCl  
Find: Mole amount of excess reactant left

Conceptual Plan: mol FeS → mol FeCl<sub>2</sub> 

\[ \frac{1 \text{ mol FeCl}_2}{1 \text{ mol FeS}} \rightarrow \text{ smallest mol amount determines limiting reactant} \]

mol HCl → mol FeCl<sub>2</sub>

\[ \frac{1 \text{ mol FeCl}_2}{2 \text{ mol HCl}} \]

then: mol limiting reactant → mol excess reactant required → mol excess reactant left

\[ \frac{1 \text{ mol FeS}}{2 \text{ mol HCl}} \]

Solution: 

\[ 0.223 \text{ mol FeS} \times \frac{1 \text{ mol FeCl}_2}{1 \text{ mol FeS}} = 0.223 \text{ mol FeCl}_2 \]

\[ 0.652 \text{ mol HCl} \times \frac{1 \text{ mol FeCl}_2}{2 \text{ mol HCl}} = 0.326 \text{ mol FeCl}_2 \]

FeS is the limiting reactant, therefore, HCl is the excess reactant.

\[ 0.223 \text{ mol FeS} \times \frac{2 \text{ mol HCl}}{1 \text{ mol FeS}} = 0.446 \text{ mol HCl required} \]

\[ 0.652 \text{ mol HCl} - 0.446 \text{ mol HCl} = 0.206 \text{ mol HCl left} \]

Check: The units of the answer (mol HCl) are correct and the magnitude is reasonable since it is less than the original amount of HCl.

(a) Given: 2.0 g Al, 2.0 g Cl<sub>2</sub>  
Find: Theoretical yield in g AlCl<sub>3</sub>

Conceptual Plan: g Al → mol Al → mol AlCl<sub>3</sub> 

\[ \frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \rightarrow \text{ smallest mol amount determines limiting reactant} \]

g Cl<sub>2</sub> → mol Cl<sub>2</sub> → mol AlCl<sub>3</sub>

\[ \frac{1 \text{ mol Cl}_2}{70.90 \text{ g Cl}_2} \]

then: mol AlCl<sub>3</sub> → g AlCl<sub>3</sub>

\[ \frac{133.3 \text{ g AlCl}_3}{\text{ mol AlCl}_3} \]

Solution: 

\[ 2.0 \text{ g Al} \times \frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \times \frac{2 \text{ mol AlCl}_3}{1 \text{ mol Al}} \times \frac{133.3 \text{ g AlCl}_3}{\text{ mol AlCl}_3} = 0.074 \text{ mol AlCl}_3 \]
Chapter 4 Chemical Quantities and Aqueous Reaction.

4.46 (a) Given: 5.0 g Ti, 5.0 g F₂

**Conceptual Plan:**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Molar Mass</th>
<th>Moles</th>
<th>Theoretical Yield in g TiF₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti</td>
<td>47.85 g/mol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F₂</td>
<td>38.01 g/mol</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Check: The units of the answer (g TiF₄) are correct. The answer is reasonable since Ti produced the smallest amount of product and is the limiting reactant.

(b) Given: 7.5 g Al, 24.8 g Cl₂

**Conceptual Plan:**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Molar Mass</th>
<th>Moles</th>
<th>Theoretical Yield in g AlCl₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>26.98 g/mol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl₂</td>
<td>70.90 g/mol</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Check: The units of the answer (g AlCl₃) are correct. The answer is reasonable since Cl₂ produced the smallest amount of product and is the limiting reactant.

(c) Given: 0.235 g Al, 1.15 g Cl₂

**Conceptual Plan:**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Molar Mass</th>
<th>Moles</th>
<th>Theoretical Yield in g AlCl₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>26.98 g/mol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl₂</td>
<td>70.90 g/mol</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Check: The units of the answer (g AlCl₃) are correct. The answer is reasonable since Al produced the smallest amount of product and is the limiting reactant.
Solution: $5.0 \text{ g Ti} \times \frac{1 \text{ mol Ti}}{47.87 \text{ g Ti}} \times \frac{1 \text{ mol TiF}_4}{1 \text{ mol Ti}} = 0.104 \text{ mol TiF}_4$

$5.0 \text{ g F}_2 \times \frac{1 \text{ mol F}_2}{38.00 \text{ g F}_2} \times \frac{1 \text{ mol TiF}_4}{2 \text{ mol F}_2} = 0.0658 \text{ mol TiF}_4$

$0.0658 \text{ mol TiF}_4 \times \frac{123.87 \text{ g TiF}_4}{1 \text{ mol TiF}_4} = 8.1 \text{ g TiF}_4$

Check: The units of the answer (g TiF$_4$) are correct. The answer is reasonable since F$_2$ produced the smallest amount of product and is the limiting reactant.

(b) Given: 2.4 g Ti, 1.6 g F$_2$ Find: Theoretical yield in g TiF$_4$

Conceptual Plan: TI $\rightarrow$ mol Ti $\rightarrow$ mol TiF$_4$ $\rightarrow$ smallest mol amount determines limiting reactant

$g \text{ F}_2 \rightarrow \text{ mol F}_2 \rightarrow \text{ mol TiF}_4$

$1 \text{ mol F}_2 \times \frac{1 \text{ mol TiF}_4}{38.00 \text{ g F}_2} \times \frac{1 \text{ mol TiF}_4}{2 \text{ mol F}_2}$

then: $\text{ mol TiF}_4 \rightarrow g \text{ TiF}_4$

Solution: $2.4 \text{ g Ti} \times \frac{1 \text{ mol Ti}}{47.87 \text{ g Ti}} \times \frac{1 \text{ mol TiF}_4}{1 \text{ mol Ti}} = 0.0501 \text{ mol TiF}_4$

$1.6 \text{ g F}_2 \times \frac{1 \text{ mol F}_2}{38.00 \text{ g F}_2} \times \frac{1 \text{ mol TiF}_4}{2 \text{ mol F}_2} = 0.0210 \text{ mol TiF}_4$

$0.0210 \text{ mol TiF}_4 \times \frac{123.87 \text{ g TiF}_4}{1 \text{ mol TiF}_4} = 2.6 \text{ g TiF}_4$

Check: The units of the answer (g TiF$_4$) are correct. The answer is reasonable since F$_2$ produced the smallest amount of product and is the limiting reactant.

(c) Given: 0.233 g Ti, 0.288 g F$_2$ Find: Theoretical yield in g TiF$_4$

Conceptual Plan: TI $\rightarrow$ mol Ti $\rightarrow$ mol TiF$_4$ $\rightarrow$ smallest mol amount determines limiting reactant

$g \text{ F}_2 \rightarrow \text{ mol F}_2 \rightarrow \text{ mol TiF}_4$

$1 \text{ mol F}_2 \times \frac{1 \text{ mol TiF}_4}{38.00 \text{ g F}_2} \times \frac{1 \text{ mol TiF}_4}{2 \text{ mol F}_2}$

then: $\text{ mol TiF}_4 \rightarrow g \text{ TiF}_4$

Solution: $0.233 \text{ g Ti} \times \frac{1 \text{ mol Ti}}{47.87 \text{ g Ti}} \times \frac{1 \text{ mol TiF}_4}{1 \text{ mol Ti}} = 0.004867 \text{ mol TiF}_4$

$0.288 \text{ g F}_2 \times \frac{1 \text{ mol F}_2}{38.00 \text{ g F}_2} \times \frac{1 \text{ mol TiF}_4}{2 \text{ mol F}_2} = 0.003789 \text{ mol TiF}_4$

$0.003789 \text{ mol TiF}_4 \times \frac{123.87 \text{ g TiF}_4}{1 \text{ mol TiF}_4} = 0.469 \text{ g TiF}_4$

Check: The units of the answer (g TiF$_4$) are correct. The answer is reasonable since F$_2$ produced the smallest amount of product and is the limiting reactant.

4.47 Given: 22.55 Fe$_2$O$_3$, 14.78 g CO Find: Mole amount of excess reactant left

Conceptual Plan: g Fe$_2$O$_3$ $\rightarrow$ mol Fe$_2$O$_3$ $\rightarrow$ mol Fe

$g \text{ CO} \rightarrow \text{ mol CO} \rightarrow \text{ mol Fe}$

$\frac{1 \text{ mol Fe}_2\text{O}_3}{159.7 \text{ g Fe}_2\text{O}_3} \times \frac{2 \text{ mol Fe}}{1 \text{ mol Fe}_2\text{O}_3}$

$\frac{1 \text{ mol CO}}{28.01 \text{ g CO}} \times \frac{3 \text{ mol CO}}{1 \text{ mol Fe}}$
then: mol limiting reactant → mol excess reactant required → mol excess reactant left → g excess reactant left

\[
\begin{align*}
\text{mol Fe}_2\text{O}_3 & \quad \text{mol CO} \\
1 \text{ mol Fe}_2\text{O}_3 & \quad 2 \text{ mol Fe} \\
1 \text{ mol CO} & \quad 2 \text{ mol Fe} \\
159.7 \text{ g Fe}_2\text{O}_3 & \quad 28.01 \text{ g CO} \\
\end{align*}
\]

Solution: 22.55 g Fe$_2$O$_3 \times \frac{1 \text{ mol Fe}_2\text{O}_3}{159.7 \text{ g Fe}_2\text{O}_3} = 0.141 \text{ mol Fe}_2\text{O}_3$

14.78 g CO \times \frac{1 \text{ mol CO}}{28.01 \text{ g CO}} = 0.528 \text{ mol CO}

Fe$_2$O$_3$ is the limiting reactant, therefore, CO is the excess reactant.

\[
\begin{align*}
22.55 \text{ g Fe}_2\text{O}_3 & \quad 159.7 \text{ g Fe}_2\text{O}_3 \\
3 \text{ mol CO} & \quad 28.01 \text{ g CO} \\
\end{align*}
\]

= 11.865 g CO required

14.78 g CO \quad 11.87 g CO = 2.91 g CO left

Check: The units of the answer (g CO) is correct and the magnitude is reasonable since it is less than the original amount of CO.

4.48 Given: 45.69 g P$_4$; 131.3 g Cl$_2$ Find: Mole amount of excess reactant left

Conceptual Plan: g P$_4$ → mol P$_4$ → mol PCl$_3$

\[
\begin{align*}
1 \text{ mol P}_4 & \quad 4 \text{ mol PCl}_3 \\
123.88 \text{ g P}_4 & \quad 1 \text{ mol P}_4 \\
\end{align*}
\]

→ smallest mol amount determines limiting reactant

\[
\begin{align*}
g \text{ Cl}_2 & \quad \text{ mol Cl}_2 \quad \text{ mol PCl}_3 \\
1 \text{ mol Cl}_2 & \quad 1 \text{ mol PCl}_3 \\
70.90 \text{ g Cl}_2 & \quad 6 \text{ mol Cl}_2 \\
\end{align*}
\]

then: mol limiting reactant → mol excess reactant required → mol excess reactant left → g excess reactant left

\[
\begin{align*}
6 \text{ mol Cl}_2 & \quad 123.88 \text{ g P}_4 \\
\quad & \quad \frac{70.90 \text{ g Cl}_2}{\text{ 6 mol Cl}_2} \\
\end{align*}
\]

Solution: 45.69 g P$_4$ \times \frac{4 \text{ mol PCl}_3}{1 \text{ mol P}_4} = 1.83 mol PCl$_3$

131.3 g Cl$_2$ \times \frac{1 \text{ mol PCl}_3}{70.90 \text{ g Cl}_2} = 1.83 mol PCl$_3$

Cl$_2$ is the limiting reactant, therefore, P$_4$ is the excess reactant.

\[
\begin{align*}
1 \text{ mol Cl}_2 & \quad 1 \text{ mol P}_4 \\
\quad & \quad 123.88 \text{ g P}_4 \\
70.90 \text{ g Cl}_2 & \quad 6 \text{ mol Cl}_2 \\
\quad & \quad 1 \text{ mol P}_4 \\
45.69 \text{ g P}_4 & \quad 7.45 \text{ g P}_4 \quad \text{ left} \\
\end{align*}
\]

Check: Units of the answer (g P$_4$) is correct and the magnitude is reasonable since it is less than the original amount of P$_4$.

4.49 Given: 28.5 g KCl; 25.7 g Pb$^{2+}$; 29.4 g PbCl$_2$ Find: limiting reactant, theoretical yield PbCl$_2$, % yield

Conceptual Plan: g KCl → mol KCl → mol PbCl$_2$

\[
\begin{align*}
1 \text{ mol KCl} & \quad 1 \text{ mol PbCl}_2 \\
74.55 \text{ g KCl} & \quad 2 \text{ mol KCl} \\
\end{align*}
\]

→ smallest mol amount determines limiting reactant

\[
\begin{align*}
g \text{ Pb}^{2+} & \quad \text{ mol Pb}^{2+} \quad \text{ mol PbCl}_2 \\
1 \text{ mol Pb}^{2+} & \quad 1 \text{ mol PbCl}_2 \\
207.2 \text{ g Pb}^{2+} & \quad 1 \text{ mol PbCl}_2 \\
\end{align*}
\]

then: mol PbCl$_2$ → g PbCl$_2$ then: determine % yield

\[
\begin{align*}
278.1 \text{ g PbCl}_2 & \quad \text{actual yield g PbCl}_2 \\
\quad & \quad \text{theoretical yield g PbCl}_2 \times 100 \\
\end{align*}
\]

Solution: 28.5 g KCl \times \frac{1 \text{ mol KCl}}{74.55 \text{ g KCl}} = 0.381 mol KCl

25.7 g Pb$^{2+}$ \times \frac{1 \text{ mol Pb}^{2+}}{207.2 \text{ g Pb}^{2+}} = 0.121 mol PbCl$_2$

Pb$^{2+}$ is the limiting reactant.
4.52 Given: 155.8 kg SiO\(_2\); 78.3 kg C; 66.1 kg Si

Find: limiting reactant, theoretical yield Si, % yield

Conceptual Plan: write and balance the reaction, then

\[
\text{kg SiO}_2 \rightarrow g \text{ SiO}_2 \rightarrow \text{mol SiO}_2 \rightarrow \text{mol Si}
\]

\[
1000 g \quad 1 \text{ mol SiO}_2 \quad 60.09 g \text{ SiO}_2 \quad 1 \text{ mol Si} \quad 2 \text{ mol SiO}_2
\]

smallest amount determines limiting reactant

\[
\text{kg C} \rightarrow g \text{ C} \rightarrow \text{mol C} \rightarrow \text{mol Si}
\]

\[
1000 g \quad 1 \text{ mol CO}_2 \quad 44.01 g \text{ CO}_2 \quad 2 \text{ mol C}
\]

then: \(\text{mol Si} \rightarrow g \text{ Si} \rightarrow kg \text{ CH}_4\text{N}_2\text{O}\) then: determine % yield

\[
\frac{28.09 g \text{ Si}}{1 \text{ kg}} \times \frac{1 \text{ mol Si}}{1000 g} \times \frac{12.01 g \text{ Si}}{1 \text{ mol Si}} \times \frac{1000 g}{2592.8 \text{ mol Si}} = 72.831 kg \text{ Si}
\]

Check: The theoretical yield has the correct units (kg Si) and has a reasonable magnitude compared to the mass of \text{SiO}_2, the limiting reactant. The % yield is reasonable, under 100%.

Solution Concentration and Solution Stoichiometry

4.53 (a) Given: 3.25 mol LiCl; 2.78 L solution

Find: Molarity LiCl

Conceptual Plan: mol LiCl, L solution \(\rightarrow\) Molarity

\[
\text{molality (M)} = \frac{\text{amount of solute (in moles)}}{\text{volume of solution (in L)}}
\]

Solution: Molar concentration

\[
3.25 \text{ mol LiCl} \quad \frac{3.25 \text{ mol LiCl}}{2.78 \text{ L solution}} = 1.169 \text{ M} \quad 1.17 \text{ M}
\]

Check: The units of the answer (M) are correct. The magnitude of the answer is reasonable. Concentrations are usually between 0 M and 18 M.

(b) Given: 28.33 g \text{C}_6\text{H}_8\text{O}_6; 1.28 L solution

Find: Molarity \text{C}_6\text{H}_8\text{O}_6

Conceptual Plan: g \text{C}_6\text{H}_8\text{O}_6 \rightarrow \text{mol \text{C}_6\text{H}_8\text{O}_6}, \text{L solution} \rightarrow \text{Molarity}

\[
\text{molarity (M)} = \frac{\text{amount of solute (in moles)}}{\text{volume of solution (in L)}}
\]

Solution: Molar concentration

\[
28.33 g \text{C}_6\text{H}_8\text{O}_6 \times \frac{1 \text{ mol C}_6\text{H}_8\text{O}_6}{180.16 g \text{C}_6\text{H}_8\text{O}_6} \times \frac{1.28 \text{ L solution}}{0.15724 \text{ mol C}_6\text{H}_8\text{O}_6} = 0.128 M \quad 0.123 M
\]

Check: The units of the answer (M) are correct. The magnitude of the answer is reasonable. Concentrations are usually between 0 M and 18 M.

(c) Given: 32.4 mg NaCl; 122.4 mL solution

Find: Molarity NaCl

Conceptual Plan: mg NaCl \rightarrow \text{g NaCl} \rightarrow \text{mol NaCl}, and mL solution \rightarrow \text{L solution} \rightarrow \text{Molarity}

\[
\text{mol NaCl} = \frac{\text{mass (g NaCl)}}{\text{molar mass (g/mol NaCl)}} \times \frac{1 \text{ mol NaCl}}{1 \text{ L solution}} \times \frac{\text{mass (g NaCl)}}{\text{volume (mL solution)}}
\]

Solution: Molar concentration

\[
32.4 \text{ mg NaCl} \times \frac{1 \text{ g NaCl}}{1000 \text{ mg}} \times \frac{58.45 g \text{ NaCl}}{1000 \text{ mL solution}} = 5.543 \times 10^{-4} \text{ mol NaCl}
\]
122.4 mL solution \times \frac{1 L}{1000 mL} = 0.1224 L

5.543 \times 10^{-4} \text{ mol NaCl} \div 0.1224 \text{ L} = 0.0045287 \text{ M NaCl} = 0.00453 \text{ M NaCl}

Check: The units of the answer (M) are correct. The magnitude of the answer is reasonable. Concentrations are usually between 0 M and 18 M.

4.54 (a) Given: 0.38 mol LiNO\(_3\); 6.14 L solution Find: Molarity LiNO\(_3\)

Conceptual Plan: \(\frac{\text{mol LiNO}_3}{\text{L solution}} \rightarrow \text{Molarity}\)

\[
\text{molarity (M)} = \frac{\text{amount of solute (in moles)}}{\text{volume of solution (in L)}}
\]

Solution: \(\frac{0.38 \text{ mol LiNO}_3}{6.14 \text{ L solution}} = 0.06189 \text{ M} = 0.062 \text{ M}\)

Check: The units of the answer (M) are correct. The magnitude of the answer is reasonable. Concentrations are usually between 0 M and 18 M.

(b) Given: 72.8 g C\(_2\)H\(_6\)O; 2.34 L solution Find: Molarity C\(_2\)H\(_6\)O

Conceptual Plan: \(\frac{\text{g C\(_2\)H\(_6\)O}}{\text{L solution}} \rightarrow \text{Molarity}\)

\[
\text{molarity (M)} = \frac{\text{amount of solute (in moles)}}{\text{volume of solution (in L)}}
\]

Solution: \(\frac{72.8 \text{ g C\(_2\) H\(_6\)O}}{2.34 \text{ L solution}} = \frac{1.580 \text{ mol C\(_2\)H\(_6\)O}}{46.068 \text{ g C\(_2\)H\(_6\)O}} = 0.06753 \text{ M} = 0.0675 \text{ M}\)

Check: The units of the answer (M) are correct. The magnitude of the answer is reasonable. Concentrations are usually between 0 M and 18 M.

(c) Given: 12.87 mg KI; 112.4 mL solution Find: Molarity KI

Conceptual Plan: \(\frac{\text{mg KI}}{\text{L solution}} \rightarrow \text{Molarity}\)

\[
\text{molarity (M)} = \frac{\text{amount of solute (in moles)}}{\text{volume of solution (in L)}}
\]

Solution: \(\frac{12.87 \text{ mg KI}}{112.4 \text{ mL solution}} = 0.1124 \text{ L} = \frac{7.7530 \times 10^{-5} \text{ mol KI}}{166.00 \text{ g KI}} = 0.06897 \times 10^{-4} \text{ M KI} = 0.069 \times 10^{-4} \text{ M}\)

Check: The units of the answer (M) are correct. The magnitude of the answer is reasonable. Concentrations are usually between 0 M and 18 M.

(a) Given: 0.556 L; 2.3 M KCl Find: mol KCl

Conceptual Plan: \(\frac{\text{volume solution x M}}{\text{mol}} = \text{mol}\)

\[
\text{solution volume (L) x M = mol}
\]

Solution: \(\frac{0.556 \text{ L solution}}{2.3 \text{ mol KCl}} = 1.3 \text{ mol KCl}\)

Check: The units of the answer (mol KCl) are correct. The magnitude is reasonable since it is less than 1 L solution.

(b) Given: 1.8 L; 0.85 M KCl Find: mol KCl

Conceptual Plan: \(\frac{\text{volume solution x M}}{\text{mol}} = \text{mol}\)

\[
\text{solution volume (L) x M = mol}
\]

Solution: \(\frac{1.8 \text{ L solution}}{0.85 \text{ mol KCl}} = 2.1 \text{ mol KCl}\)
Check: The units of the answer (mol KCl) are correct. The magnitude is reasonable since it is less than 2 L solution.

(c) Given: 114 mL; 1.85 M KCl Find: mol KCl
Conceptual Plan: ml solution → L solution, then volume solution x M = mol

\[
\frac{114 \text{ mL}}{1000 \text{ mL}} \times 1.85 \text{ mol KCl} = 0.211 \text{ mol KCl}
\]

Check: The units of the answer (mol KCl) are correct. The magnitude is reasonable since it is less than 1 L solution.

4.56 (a) Given: 0.45 mol C\textsubscript{2}H\textsubscript{5}OH, 0.200 M C\textsubscript{2}H\textsubscript{5}OH Find: volume solution
Conceptual Plan: mol C\textsubscript{2}H\textsubscript{5}OH → volume solution

\[
\frac{0.45 \text{ mol C}_2\text{H}_5\text{OH}}{0.200 \text{ L solution}} = 2.25 \text{ L C}_2\text{H}_5\text{OH}
\]

Check: The units of the answer (L C\textsubscript{2}H\textsubscript{5}OH) are correct. The magnitude is reasonable for the amount and volume of solution.

(b) Given: 1.12 mol C\textsubscript{2}H\textsubscript{5}OH, 0.200 M C\textsubscript{2}H\textsubscript{5}OH Find: volume solution
Conceptual Plan: mol C\textsubscript{2}H\textsubscript{5}OH → volume solution

\[
\frac{1.22 \text{ mol C}_2\text{H}_5\text{OH}}{0.200 \text{ L solution}} = 6.10 \text{ L C}_2\text{H}_5\text{OH}
\]

Check: The units of the answer (L C\textsubscript{2}H\textsubscript{5}OH) are correct. The magnitude is reasonable for the amount and volume of solution.

(c) Given: 1.2 × 10\textsuperscript{-2} mol C\textsubscript{2}H\textsubscript{5}OH, 0.200 M C\textsubscript{2}H\textsubscript{5}OH Find: volume solution
Conceptual Plan: mol C\textsubscript{2}H\textsubscript{5}OH → volume solution

\[
\frac{1.2 \times 10^{-2} \text{ mol C}_2\text{H}_5\text{OH}}{0.200 \text{ L solution}} = 0.060 \text{ L C}_2\text{H}_5\text{OH}
\]

Check: The units of the answer (L C\textsubscript{2}H\textsubscript{5}OH) are correct. The magnitude is reasonable for the amount and volume of solution.

4.57 Given: 400.0 mL; 1.1 M NaNO\textsubscript{3} Find: g NaNO\textsubscript{3}
Conceptual Plan: ml solution → L solution, then volume solution x M = mol NaNO\textsubscript{3}

\[
\frac{400.0 \text{ mL}}{1000 \text{ mL}} \times 1.1 \text{ M NaNO}_3 = 0.44 \text{ mol NaNO}_3
\]

Check: The units of the answer (g NaNO\textsubscript{3}) are correct. The magnitude is reasonable for the concentration and volume of solution.
Solution: 95.4 mL CuCl₂ x 1 L / 1000 mL x 0.102 mol CuCl₂ / 1 L x 2 mol Na₃PO₄ / 3 mol CuCl₂ x 0.175 mol Na₃PO₄ / 1 L = 37.1 mL Na₃PO₄

Check: The units of the answer (mL Na₃PO₄) are correct. The magnitude of the answer is reasonable since the concentration of Na₃PO₄ is greater.

4.64 Given: 125 mL, 0.150 M Co(NO₃)₂; 0.150 M Li₂S Find: volume Li₂S

Conceptual Plan: mL Co(NO₃)₂ → L Co(NO₃)₂ → mol Co(NO₃)₂ → mol Li₂S → L Li₂S → mL Li₂S

Solution:

125 mL Co(NO₃)₂ x 1 L / 1000 mL x 0.150 mol Co(NO₃)₂ / 1 L x 1 mol Li₂S / 1 mol Co(NO₃)₂ x 0.150 mol Li₂S / 1 L x 1000 mL / 1 L

= 125 mL Li₂S

Check: The units of the answer (mL Li₂S) are correct. The magnitude of the answer is reasonable since the concentrations are the same and the mole ratio is 1:1.

4.65 Given: 25.0 g H₂, 6.0 M H₂SO₄ Find: volume H₂SO₄

Conceptual Plan: g H₂ → mol H₂ → mol H₂SO₄ → L H₂SO₄

Solution: 25.0 g H₂ x 2.016 g H₂ / 1 mol H₂ x 3 mol H₂SO₄ / 2 mol H₂ x 1 L / 3 mol H₂SO₄ = 2.1 L H₂SO₄

Check: The units of the answer (L H₂SO₄) are correct. The magnitude is reasonable since there are approximately 12 mol H₂ and the mole ratio is 1:1.

4.66 Given: 25.0 g Zn, 275 mL solution Find: M ZnCl₂

Conceptual Plan: g Zn → mol Zn → mol ZnCl₂ → M ZnCl₂

Solution: 25.0 g Zn x 65.41 g Zn / 1 mol Zn x 1 mol ZnCl₂ / 65.41 g Zn x 1 mol ZnCl₂ / volume solution

= 0.3822 mol ZnCl₂

Check: The units of the answer (M ZnCl₂) are correct. The magnitude is reasonable because the stoichiometry is 1:1 and the mol Zn is less than 0.5.

Types of Aqueous Solutions and Solubility

4.67 (a) CsCl is an ionic compound. An aqueous solution is an electrolyte solution, so it conducts electricity.

(b) CH₃OH is a molecular compound that does not dissociate. An aqueous solution is a nonelectrolyte solution, so it does not conduct electricity.

(c) Ca(NO₃)₂ is an ionic compound. An aqueous solution is an electrolyte solution, so it conducts electricity.

(d) C₂H₄O₂ is a molecular compound that does not dissociate. An aqueous solution is a nonelectrolyte solution, so it does not conduct electricity.

4.68 (a) MgBr₂ is an ionic compound. An aqueous solution is a strong electrolyte.

(b) C₂H₂O₁₁ is a molecular compound that does not dissociate. An aqueous solution is a nonelectrolyte.

(c) Na₂CO₃ is an ionic compound. An aqueous solution is a strong electrolyte.

(d) KOH is a strong base. An aqueous solution is a strong electrolyte.
4.69 (a) AgNO₃ is soluble. Compounds containing NO₃⁻ are always soluble with no exceptions. The ions in the solution are Ag⁺(aq) and NO₃⁻(aq).

(b) Pb(C₂H₃O₂)₂ is soluble. Compounds containing C₂H₃O₂⁻ are always soluble with no exceptions. The ions in the solution are Pb²⁺(aq) and C₂H₃O₂⁻(aq).

(c) KNO₃ is soluble. Compounds containing K⁺ are always soluble with no exceptions. The ions in solution are K⁺(aq) and NO₃⁻(aq).

(d) (NH₄)₂S is soluble. Compounds containing NH₄⁺ are always soluble with no exceptions. The ions in solution are NH₄⁺(aq) and S²⁻(aq).

4.70 (a) AgI is insoluble. Compounds containing I⁻ are normally soluble but Ag⁺ is an exception.

(b) Cu₃(PO₄)₂ is insoluble. Compounds containing PO₄³⁻ are normally insoluble and Cu²⁺ is not an exception.

(c) CoCO₃ is insoluble. Compounds containing CO₃²⁻ are normally insoluble and Co²⁺ is not an exception.

(d) K₃PO₄ is soluble. Compounds containing PO₄³⁻ are normally insoluble, but K⁺ is an exception. The ions in solution are K⁺(aq) and PO₄³⁻(aq).

**Precipitation Reactions**

4.71 (a) LiI(aq) + BaS(aq) → Possible products: Li₂S and BaI₂. Li₂S is soluble. Compounds containing S²⁻ are normally insoluble but Li⁺ is an exception. BaI₂ is soluble. Compounds containing I⁻ are normally soluble and Ba²⁺ is not an exception. LiI(aq) + BaS(aq) → No Reaction

(b) KCl(aq) + CaS(aq) → Possible products: K₂S and CaCl₂. K₂S is soluble. Compounds containing S²⁻ are normally insoluble but K⁺ is an exception. CaCl₂ is soluble. Compounds containing Cl⁻ are normally soluble and Ca²⁺ is not an exception. KCl(aq) + CaS(aq) → No Reaction

(c) CrBr₃(aq) + Na₂CO₃(aq) → Possible products: CrCO₂ and NaBr. CrCO₂ is insoluble. Compounds containing CO₃²⁻ are normally insoluble and Cr³⁺ is not an exception. NaBr is soluble. Compounds containing Br⁻ are normally soluble and Na⁺ is not an exception. CrBr₃(aq) + Na₂CO₃(aq) → CrCO₂(s) + 2 NaBr(aq)

(d) NaOH(aq) + FeCl₃(aq) → Possible products NaCl and Fe(OH)₃. NaCl is soluble. Compounds containing Na⁺ are normally soluble, no exceptions. Fe(OH)₃ is insoluble. Compounds containing OH⁻ are normally insoluble and Fe³⁺ is not an exception. 3 NaOH(aq) + FeCl₃(aq) → 3 NaCl(aq) + Fe(OH)₃(s)

4.72 (a) NaNO₃(aq) + KCl(aq) → Possible products: NaCl and KNO₃. NaCl is soluble. Compounds containing Na⁺ are always soluble, no exceptions. KNO₃ is soluble. Compounds containing K⁺ are always soluble, no exceptions. NaNO₃(aq) + KCl(aq) → No Reaction

(b) NaCl(aq) + Hg₂(C₂H₃O₂)₂(aq) → Possible products: NaC₂H₃O₂ and Hg₂Cl₂. NaC₂H₃O₂ is soluble. Compounds containing Na⁺ are always soluble, no exceptions. Hg₂Cl₂ is insoluble. Compounds containing Cl⁻ are normally soluble but Hg₂²⁺ is an exception. 2 NaCl(aq) + Hg₂(C₂H₃O₂)₂(aq) → 2 NaC₂H₃O₂(aq) + Hg₂Cl₂(s)

(c) (NH₄)₂SO₄(aq) + SrCl₂(aq) → Possible products: NH₄Cl and SrSO₄. NH₄Cl is soluble. Compounds containing NH₄⁺ are always soluble, no exceptions. SrSO₄ is insoluble. Compounds containing SO₄²⁻ are normally soluble but Sr²⁺ is an exception. (NH₄)₂SO₄(aq) + SrCl₂(aq) → 2 NH₄Cl(aq) + SrSO₄(s)

(d) NH₄Cl(aq) + AgNO₃(aq) → Possible products: NH₄NO₃ and AgCl. NH₄NO₃ is soluble. Compounds containing NH₄⁺ are always soluble, no exceptions. AgCl is insoluble. Compounds containing Cl⁻ are normally soluble, but Ag⁺ is an exception. NH₄Cl(aq) + AgNO₃(aq) → NH₄NO₃(aq) + AgCl(s)
Ionic and Net Ionic Equations

4.76
(a) \( \text{CaCl}_2(\text{aq}) + \text{Na}_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + 2\text{NaCl}(\text{aq}) \)
(b) \( \text{Na}_2\text{HCO}_3(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{aq}) + \text{NaCl}(\text{aq}) \)
(c) \( \text{Ag}^+ (\text{aq}) + \text{NO}_3^- (\text{aq}) + \text{Na}^+ (\text{aq}) + \text{Cl}^- (\text{aq}) \rightarrow \text{AgCl}(\text{s}) + \text{Na}^+ (\text{aq}) + \text{NO}_3^- (\text{aq}) \)
(d) \( \text{Ag}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow 2\text{Ag}_2\text{SO}_4(\text{s}) \)
Chapter 4 Chemical Quantities and Aqueous Reactions

(d) \[ 2H^+(aq) + 2\text{C}_2\text{H}_5\text{O}_2^-(aq) + 2\text{K}^+(aq) + \text{CO}_3^{2-}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{CO}_2(g) + 2\text{K}^+(aq) + 2\text{C}_2\text{H}_5\text{O}_2^-(aq) \]

\[ 2H^+(aq) + \text{CO}_3^{2-}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{CO}_2(g) \]

4.77 \[ \text{Hg}_2^{2+}(aq) + 2\text{NO}_3^-(aq) + 2\text{Na}^+(aq) + 2\text{Cl}^-(aq) \rightarrow \text{Hg}_2\text{Cl}_2(s) + 2\text{Na}^+(aq) + 2\text{NO}_3^-(aq) \]

4.78 \[ \text{Pb}^{2+}(aq) + \text{SO}_4^{2-}(aq) \rightarrow \text{PbSO}_4(s) + 2\text{K}^+(aq) + 2\text{NO}_3^-(aq) \]

Acid-Base and Gas-Evolution Reactions

4.79 Skeletal reaction: \( \text{HBr}(aq) + \text{KOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{KBr}(aq) \)

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

4.80 Skeletal reaction: \( \text{HNO}_3(aq) + \text{Ca(OH)}_2(aq) \rightarrow \text{H}_2\text{O}(l) + \text{Ca(NO}_3)_2(aq) \)

Balanced reaction: \( 2 \text{HNO}_3(aq) + \text{Ca(OH)}_2(aq) \rightarrow 2 \text{H}_2\text{O}(l) + \text{Ca(NO}_3)_2(aq) \)

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

4.81 (a) Skeletal reaction: \( \text{H}_2\text{SO}_4(aq) + \text{Ca(OH)}_2(aq) \rightarrow \text{H}_2\text{O}(l) + \text{CaSO}_4(s) \)

Balanced reaction: \( 2 \text{H}_2\text{SO}_4(aq) + \text{Ca(OH)}_2(aq) \rightarrow 2 \text{H}_2\text{O}(l) + \text{CaSO}_4(s) \)

(b) Skeletal reaction: \( \text{HClO}_4(aq) + \text{KOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{KClO}_4(aq) \)

Balanced reaction: \( \text{HClO}_4(aq) + \text{KOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{KClO}_4(aq) \)

(c) Skeletal reaction: \( \text{H}_2\text{SO}_4(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{Na}_2\text{SO}_4(aq) \)

Balanced reaction: \( 2 \text{H}_2\text{SO}_4(aq) + \text{2NaOH}(aq) \rightarrow 2 \text{H}_2\text{O}(l) + \text{Na}_2\text{SO}_4(aq) \)

4.82 (a) Skeletal reaction: \( \text{HI}(aq) + \text{LiOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{LiI}(aq) \)

Balanced reaction: \( \text{HI}(aq) + \text{LiOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{LiI}(aq) \)

(b) Skeletal reaction: \( \text{HCl}_2\text{H}_3\text{O}_2(aq) + \text{Ca(OH)}_2(aq) \rightarrow \text{H}_2\text{O}(l) + \text{Ca(C}_2\text{H}_3\text{O}_2)_2(aq) \)

Balanced reaction: \( 2 \text{HCl}_2\text{H}_3\text{O}_2(aq) + \text{Ca(OH)}_2(aq) \rightarrow 2 \text{H}_2\text{O}(l) + \text{Ca(C}_2\text{H}_3\text{O}_2)_2(aq) \)

(c) Skeletal reaction: \( \text{HCl}(aq) + \text{Ba(OH)}_2(aq) \rightarrow \text{H}_2\text{O}(l) + \text{BaCl}_2(aq) \)

Balanced reaction: \( 2 \text{HCl}(aq) + \text{Ba(OH)}_2(aq) \rightarrow 2 \text{H}_2\text{O}(l) + \text{BaCl}_2(aq) \)

4.83 Given: 22.62 mL, 0.2000 M NaOH solution; 25.00 mL HClO\textsubscript{4} solution Find: M HClO\textsubscript{4} solution

Conceptual Plan: mL NaOH \rightarrow \text{L} \text{NaOH} \rightarrow \text{mol NaOH} \rightarrow \text{mol HClO}_4

\[ \text{mol HClO}_4 = \frac{\text{volume HClO}_4 \text{solution} \times \text{M NaOH}}{\text{L HClO}_4 \text{solution}} \]

Solution: \[ 22.62 \text{mL} \times \frac{1 \text{L}}{1000 \text{mL}} \times \frac{0.2000 \text{mol NaOH}}{1 \text{mol NaOH}} = 0.004524 \text{mol HClO}_4 \]

\[ \frac{0.004524 \text{mol HClO}_4 \times 1 \text{L}}{25.00 \text{mL HClO}_4} = 0.18096 \text{M HClO}_4 = 0.1810 \text{M HClO}_4 \]

Check: The units of the answer (M HClO\textsubscript{4}) are correct. The magnitude of the answer is reasonable since it is less than the M of NaOH.
(c) $\text{ClO}_3^-$. The oxidation state of Cl is +5, and the oxidation state of O is normally -2. The oxidation state of O is normally -2, and the oxidation state of Cl is deduced from the formula since the sum of the oxidation states must equal the charge of the ion. $(\text{Cl ox state}) + 3(\text{O ox state}) = -1; (\text{Cl ox state}) + 3(-2) = -1$, so Cl = +5.

(d) $\text{ClO}_4^-$. The oxidation state of Cl is +7, and the oxidation state of O is normally -2. The oxidation state of O is normally -2, and the oxidation state of Cl is deduced from the formula since the sum of the oxidation states must equal the charge of the ion. $(\text{Cl ox state}) + 4(\text{O ox state}) = -1; (\text{Cl ox state}) + 4(-2) = -1$, so Cl = +7.

(a) $4 \text{Li}(s) + \text{O}_2(g) \rightarrow 2 \text{Li}_2\text{O}(s)$

Oxidation states: $0$ $0$ $+1$ $-2$

This is a redox reaction since Li increases in oxidation number (oxidation) and O decreases in number (reduction). $\text{O}_2$ is the oxidizing agent, and Li is the reducing agent.

(b) $\text{Mg}(s) + \text{Fe}^{2+}(aq) \rightarrow \text{Mg}^{2+}(aq) + \text{Fe}(s)$

Oxidation states: $0$ $+2$ $+2$ $0$

This is a redox reaction since Mg increases in oxidation number (oxidation) and Fe decreases in number (reduction). $\text{Fe}^{2+}$ is the oxidizing agent, and Mg is the reducing agent.

(c) $\text{Pb(NO}_3)_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow \text{PbSO}_4(s) + 2 \text{NaNO}_3(aq)$

Oxidation states: $+2$ $+5$ $-2$ $+1$ $+6$ $-2$ $+1$ $+5$ $-2$

This is not a redox reaction since none of the atoms undergoes a change in oxidation number.

(d) $\text{HBr}(aq) + \text{KOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{KBr}(aq)$

Oxidation states: $+1$ $-1$ $+1$ $-2$ $+1$ $-2$ $+1$ $-2$

This is not a redox reaction since none of the atoms undergoes a change in oxidation number.

4.92

(a) $\text{Al}(s) + 3 \text{Ag}^+(aq) \rightarrow \text{Al}^{3+}(aq) + 3 \text{Ag}(s)$

Oxidation states: $0$ $+1$ $+3$ $0$

This is a redox reaction since Al increases in oxidation number (oxidation) and Ag decreases in number (reduction). $\text{Ag}^+$ is the oxidizing agent, and Al is the reducing agent.

(b) $\text{SO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq)$

Oxidation states: $-2$ $+1$ $-2$ $+1$ $-2$

This is not a redox reaction since none of the atoms undergoes a change in oxidation number.

(c) $\text{Ba}(s) + \text{Cl}_2(g) \rightarrow \text{BaCl}_2(s)$

Oxidation states: $0$ $0$ $+2$ $-1$

This is a redox reaction since Ba increases in oxidation number (oxidation) and Cl decreases in number (reduction). $\text{Cl}_2$ is the oxidizing agent, and Ba is the reducing agent.

(d) $\text{Mg}(s) + \text{Br}_2(l) \rightarrow \text{MgBr}_2(s)$

Oxidation states: $0$ $0$ $+2$ $-1$

This is a redox reaction since Mg increases in oxidation number (oxidation) and Br decreases in number (reduction). $\text{Br}_2$ is the oxidizing agent, and Mg is the reducing agent.

4.93

(a) Skeletal reaction: $\text{S}(s) + \text{O}_2(g) \rightarrow \text{SO}_2(g)$

Balanced reaction: $\text{S}(s) + \frac{1}{2}\text{O}_2(g) \rightarrow \text{SO}_2(g)$

(b) Skeletal reaction: $2\text{C}_3\text{H}_4(g) + \text{O}_2(g) \rightarrow 2\text{CO}_2(g) + \text{H}_2\text{O}(g)$

Balance C:
$2\text{C}_3\text{H}_4(g) + 3\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}(g)$

Balance H:
$2\text{C}_3\text{H}_4(g) + 3\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}(g)$

Balance O:
$2\text{C}_3\text{H}_4(g) + 3\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}(g)$

Clear fraction:
$2\text{C}_3\text{H}_4(g) + 9/2\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}(g)$

(c) Skeletal reaction: $\text{Ca}(s) + \text{O}_2(g) \rightarrow \text{CaO}(s)$

Balance O:
$\text{Ca}(s) + \text{O}_2(g) \rightarrow 2\text{CaO}(s)$

Balance Ca:
$2\text{Ca}(s) + \text{O}_2(g) \rightarrow 2\text{CaO}(s)$