SOLUTIONS CHAPTER 3 EXERCISES

1. In the table below, calculate the molecular weight in grams per mole for each of the elements or compounds listed. Also list the chemical symbol or formula for each element or compound in the table.

<table>
<thead>
<tr>
<th>Element or Compound</th>
<th>Symbol or Formula</th>
<th>Molecular Weight (g/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>14</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>39.1</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>24.3</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>55.85</td>
</tr>
<tr>
<td>Nitrate</td>
<td>NO$_3^-$</td>
<td>14 + 3 × 16 = 62</td>
</tr>
<tr>
<td>Sodium carbonate</td>
<td>Na$_2$CO$_3$</td>
<td>2 × 23 + 12 + 3 × 16 = 106</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
<td>54.94</td>
</tr>
</tbody>
</table>

2. In the table below, calculate the equivalent weight in grams per equivalent (g/eq) for each of the elements or compounds listed. Also list the chemical symbol or formula for each element, radical, or compound in the table.

<table>
<thead>
<tr>
<th>Element or Compound</th>
<th>Symbol or Formula</th>
<th>Equivalent Weight (g/eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfate</td>
<td>SO$_4^{2-}$</td>
<td>(32 + 4 × 16)/2 = 48</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>HCO$_3^-$</td>
<td>(1 + 12 + 3 × 16)/1 = 61</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>24.3/2 = 12.15</td>
</tr>
<tr>
<td>Iron (III)</td>
<td>Fe$^{3+}$</td>
<td>55.85/3 = 18.6</td>
</tr>
<tr>
<td>Nitrate</td>
<td>NO$_3^-$</td>
<td>(14 + 3 × 16)/1 = 62</td>
</tr>
<tr>
<td>Sodium carbonate</td>
<td>Na$_2$CO$_3$</td>
<td>(23 × 2 + 12 + 3 × 16)/2 = 53</td>
</tr>
<tr>
<td>Phosphate</td>
<td>PO$_4^{3-}$</td>
<td>(31 + 4 × 16)/3 = 31.7</td>
</tr>
</tbody>
</table>

3. This problem involves an understanding of Molarity and Normality.
   a. Calculate the grams of hydrochloric acid (HCL) that must be diluted to a volume of 1 Liter to produce a concentration of 0.5M.

   \[
   \frac{0.5 \text{ moles HCl}}{\text{L}} \left( \frac{36.5 \text{ g HCl}}{\text{mole}} \right) (1 \text{ L}) = 18.25 \text{ g HCl}
   \]

   b. Calculate the Normality of a 1 L of solution containing 45 grams of sodium hydroxide (NaOH).

   \[
   \frac{45 \text{ g NaOH}}{\text{L}} \left( \frac{\text{eq}}{40 \text{ g NaOH}} \right) = \frac{1.125 \text{ eq}}{\text{L}} = 1.125 \text{N}
   \]

4. Balance the following reactions.
a. \( \text{CH}_3\text{OH} + \text{NO}_3^- \rightarrow \text{N}_2 + \text{CO}_2 + \text{H}_2\text{O} + \text{OH}^- \)

\[
6\text{NO}_3^- + 5\text{CH}_3\text{OH} \rightarrow 3\text{N}_2 + 5\text{CO}_2 + 7\text{H}_2\text{O} + 6\text{OH}^- 
\]

b. \( \text{C}_6\text{H}_4\text{O}_2\text{N} + \text{O}_2 + \text{H}^+ \rightarrow \text{CO}_2 + \text{NH}_4^+ + \text{H}_2\text{O} \)

\[
\text{C}_6\text{H}_4\text{O}_2\text{N} + 7.75\text{O}_2 + \text{H}^+ \rightarrow 6\text{CO}_2 + \text{NH}_4^+ + 5.5\text{H}_2\text{O} 
\]

5. Calculate the pH and pOH of a 0.5N solution of hydrochloric acid (HCl) at 25ºC.

Assume complete dissociation of HCl to \(\text{H}^+\) and \(\text{Cl}^-\) since \(pK_a (-3) < 1\).

\[
\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^- 
\]

\[
0.5\text{N} = \frac{0.5 \text{ eq}}{\text{L}} \left( \frac{36.5 \text{ g}}{1 \text{ mole}} \right) \left( \frac{1 \text{ mole}}{36.5 \text{ g}} \right) = 0.5\text{M} 
\]

\[
[\text{H}^+] = 0.5\text{M} 
\]

\[
\text{pH} = -\log[\text{H}^+] = -\log[0.5] = 0.3 
\]

\[
\text{pH} + \text{pOH} = 14 
\]

\[
\text{pOH} = 14 - \text{pH} = 14 - 0.3 = 13.7 
\]

6. Calculate the pH and pOH of a 0.001M solution of sodium hydroxide (NaOH) at 25ºC.

Sodium hydroxide is a strong base so assume complete dissociation.

\[
\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^- 
\]

\[
[\text{Na}^+] = [\text{OH}^-] = 0.001\text{M} 
\]

\[
[\text{H}^+] [\text{OH}^-] = 10^{-14} \quad \quad [\text{H}^+] = \frac{10^{-14}}{[\text{OH}^-]} = \frac{10^{-14}}{0.001} = 1 \times 10^{-11} 
\]

\[
\text{pH} = -\log[\text{H}^+] = -\log[1 \times 10^{-11}] = 11 
\]

\[
\text{pOH} = 14 - \text{pH} = 14 - 11 = 3 
\]
7. Calculate the solubility of the following ionic compounds. Assume T = 25°C.

a. \( \text{Mg(OH)}_2 (s) \)

From Table 3.4, the \( K_{sp} \) for \( \text{Mg(OH)}_2 \) is \( 9 \times 10^{-12} \).

\[
\text{Mg(OH)}_2 (s) \leftrightarrow \text{Mg}^{2+} (aq) + 2(\text{OH}^-) (aq)
\]

\[ K_{sp} = 9 \times 10^{-12} = \left[ \text{Mg}^{2+} \right] \left[ \text{OH}^- \right]^2 \]

Let \( x \) represent the concentration of \( \text{Mg}^{2+} \) ions, then \( 2x \) represents the concentration of \( \text{OH}^- \) ions.

\[
9 \times 10^{-12} = (x)(2x)^2
\]

\[
4x^3 = 9 \times 10^{-12}
\]

\[
x = \sqrt[3]{\frac{9 \times 10^{-12}}{4}} = 1.31 \times 10^{-4} \text{ M}
\]

Therefore, \( x = \text{concentration of } \text{Mg}^{2+} \) and \( \text{Mg(OH)}_2 \). The solubility of \( \text{Mg(OH)}_2 \) expressed in g/L is calculated as follows:

\[
1.31 \times 10^{-4} \text{ mol } \text{Mg(OH)}_2 \left( \frac{58.3 \text{ g } \text{Mg(OH)}_2}{1 \text{ mol } \text{Mg(OH)}_2} \right) = 7.64 \times 10^{-3} \text{ g/L}
\]

b. \( \text{FeS} (s) \)

From Table 3.4, the \( K_{sp} \) for \( \text{FeS} \) is \( 6 \times 10^{-18} \).

\[
\text{FeS} (s) \leftrightarrow \text{Fe}^{2+} (aq) + \text{S}^{2-} (aq)
\]

\[ K_{sp} = 6 \times 10^{-18} = \left[ \text{Fe}^{2+} \right] \left[ \text{S}^{2-} \right] \]

Let \( x \) represent the concentration of \( \text{Fe}^{2+} \) ions and \( x \) represents the concentration of \( \text{S}^{2-} \) ions.

\[
6 \times 10^{-18} = (x)(x)
\]

\[
x^2 = 6 \times 10^{-18}
\]
\[
x = \sqrt[3]{6 \times 10^{-18}} = 2.45 \times 10^{-9} \text{ M}
\]

Therefore, \( x \) = concentration of \( \text{Fe}^{2+} \) and \( \text{FeS} \). The solubility of \( \text{FeS} \) expressed in g/L is calculated as follows:

\[
2.45 \times 10^{-9} \text{ mol FeS/L} \times \left( \frac{88 \text{ g FeS}}{1 \text{ mol FeS}} \right) = 2.16 \times 10^{-7} \text{ g/L}
\]

8. Determine the volume in cubic feet occupied by 120 pounds of carbon dioxide at 1.5 atm and 40ºC.

\[
P V = n R T \\
V = \frac{n R T}{P}
\]

\[
T = 40 + 273.15 = 313.15 \text{ K} \quad 1 \text{ mole of CO}_2 = 12 + 32 = 44 \text{ grams}
\]

The number of moles of \( \text{CO}_2 \) in 120 pounds is calculated as follows:

\[
n = 120 \text{ lb} \left( \frac{454 \text{ g}}{\text{ lb}} \right) \left( \frac{1 \text{ mol CO}_2}{44 \text{ g CO}_2} \right) = 1238 \text{ moles of CO}_2
\]

\[
V = \frac{n R T}{P} = \frac{1238 \text{ mol} \left(0.08206 \text{ atm} \cdot \text{L/mol} \cdot \text{K} \right)(313.15 \text{ K})}{1.5 \text{ atm}} = 2.12 \times 10^4 \text{ L}
\]

\[
V = 2.12 \times 10^4 \text{ L} \left( \frac{1 \text{ gal}}{3.785 \text{ L}} \right) \left( \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \right) = 749 \text{ ft}^3
\]

9. What volume of oxygen at 30ºC and 0.21 atm is required for combustion of 20 g of propane gas \((\text{C}_3\text{H}_8)\)?

\[
\text{C}_3\text{H}_8 + 5 \text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O}
\]

MW of \( \text{C}_3\text{H}_8 = 3(12) + 8(1) = 44 \)

\[
n = 20 \text{ g propane} \left( \frac{1 \text{ mol C}_3\text{H}_8}{44 \text{ g C}_3\text{H}_8} \right) = 0.45 \text{ moles of propane}
\]

Moles of oxygen required is equal to \( 0.45 \text{ moles of propane} \times 5 = 2.25 \text{ moles} \)

\[
T = 30 + 273.15 = 303.15 \text{ K}
\]
V = \frac{n \cdot R \cdot T}{P} = 2.25 \text{ mol} \cdot O_2 \left( \frac{0.08206 \text{ atm} \cdot \text{L/mol} \cdot \text{°K}}{0.21 \text{ atm}} \right) \left(303.15 \text{K} \right) = 267 \text{ L}

10. A VOC incinerator is to be designed to oxidize an off-gas containing 1600 ppmv of toluene vapor and 12,000 actual cubic feet per minute (acfm) of air at a temperature of 250ºF.
   
a. Determine the standard volumetric air flow rate (scfm) that must be treated by the VOC incinerator.

\[
\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad V_1 = 12,000 \text{ acfm} \quad T_1 = 250 + 460 = 710 \text{ R}
\]

\[
V_2 = x \text{ scfm} \quad T_2 = 68 + 460 = 528 \text{ R}
\]

\[
\frac{12,000 \text{ acfm}}{710 \text{ R}} = \frac{V_2}{528 \text{ R}} \quad V_2 = 8924 \text{ scfm}
\]

b. Determine the actual volumetric air flow rate that must be treated by the incinerator if the temperature was increased to 400ºF.

\[
\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad V_1 = 8924 \text{ scfm} \quad T_1 = 68 + 460 = 528 \text{ R}
\]

\[
V_2 = x \times \text{ scfm} \quad T_2 = 400 + 460 = 860 \text{ R}
\]

\[
\frac{8924 \text{ scfm}}{528 \text{ R}} = \frac{V_2}{860 \text{ R}} \quad V_2 = 14,535 \text{ scfm}
\]