Read each problem thoroughly and show all your work for full credit.

1. **Butyric acid**, the odor in rancid butter, contains only carbon, hydrogen and oxygen. When 3.907 g of butyric acid are burned, the products of the combustion are 3.196 g of water and 7.807 g of **carbon dioxide**.

\[ 13.01 + 2(14.01) = 44.01 \]

\[ \text{C}_2 \text{H}_4 \text{O}_1 + \text{O}_2 (g) \rightarrow \text{CO}_2 (g) + \text{H}_2 \text{O} (l) = 18.02 \]

a. What is the mass percent of C in the butyric acid sample? (1 pt)

\[ \frac{7.807g \text{ CO}_2 \times \frac{1 \text{ mol CO}_2}{44.01g} \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} \times \frac{12.01g}{1 \text{ mol C}}}{3.907g} = 54.52\% \]

b. What is the mass percent of H in the butyric acid sample? (1 pt)

\[ \frac{3.196g \text{ H}_2 \text{O} \times \frac{1 \text{ mol H}_2 \text{O}}{18.02g} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2 \text{O}} \times \frac{1.008g}{1 \text{ mol H}}}{3.907g} = 9.162\% \]

c. What is the mass percent of O in the butyric acid? (1 pt)

\[ 100 - 54.52\% - 9.162\% = 36.32\% \]

d. What is the empirical formula of butyric acid? (1 pt)

\[ \text{C}_2 \text{H}_4 \text{O}_1 = \text{Emp} \]

\[ \frac{54.52g \text{ C}}{12.01g} = 4.5 \text{ mol C} \]

\[ \frac{9.162g \text{ H}}{1.008g} = 9.1 \text{ mol H} \]

\[ \frac{36.32g \text{ O}}{16.00g} = 2.27 \text{ mol O} \]

e. The molar mass of butyric acid is 88.10 g/mol. What is the formula for butyric acid? (1 pt)

\[ \text{C}_3 \text{H}_4 \text{O}_1 \text{ has a molar mass of} \]

\[ (3 \times 12) + (4 \times 1) + (1 \times 16) = 44 \]

\[ \frac{88.10g}{44} = 2 \]

**Molecular Formula:** \( \text{C}_4 \text{H}_8 \text{O}_2 \)
2. If 6.80 g of PH$_3$ and 6.80 g of O$_2$ are combined according to the (unbalanced) reaction shown below, (the molar mass of PH$_3$ = 33.99, O$_2$ = 32.00, P$_4$O$_{10}$ = 283.88)

$$4 \text{PH}_3 + 8 \text{O}_2 \rightarrow \_ \text{P}_4\text{O}_{10} + 6 \text{H}_2\text{O}$$

a. Balance the equation. Use this to answer the following questions. (1 pt)

b. Decide which reactant is the limiting reagent. (1 pt)

$$\frac{0.0500 \text{mol P}_4\text{O}_{10}}{4 \text{mol PH}_3} = 0.0125 \text{mol PH}_3 \text{consumed}$$

$$\frac{0.0366 \text{mol P}_4\text{O}_{10}}{8 \text{mol O}_2} = 0.0100 \text{mol O}_2 \text{consumed}$$

c. How many moles of the non-limiting reactant will be consumed? (1 pt)

$$0.0100 \text{mol P}_4\text{O}_{10}$$

From part b,

$$0.0025 \text{mol P}_4\text{O}_{10} \times \frac{283.88 \text{g}}{1 \text{mol P}_4\text{O}_{10}} = 7.55 \text{g P}_4\text{O}_{10}$$

d. How many grams of P$_4$O$_{10}$ will be formed? (1 pt)

f. When the experiment is carried out, only 6.58 g of P$_4$O$_{10}$ are formed. What is the percent yield? (1 pt)

$$\text{% yield} = \frac{\text{actual}}{\text{theor.}} \times 100 = \frac{6.58 \text{g P}_4\text{O}_{10}}{7.55 \text{g P}_4\text{O}_{10}} = 87.2\%$$

3. How many grams of NaOH (MM = 40.00 g/mol) must be weighed out to make 250.0 mL of a 0.100 M solution of NaOH? (1 pt)

$$250.0 \text{mL} \times \frac{1 \text{L}}{1,000 \text{mL}} \times \frac{0.100 \text{mol NaOH}}{1 \text{L}} \times \frac{40.00 \text{g}}{1 \text{mol NaOH}} = 1.00 \text{grams}$$

4. When 50.0 mL of 0.20 M Na$_2$CO$_3$ are combined with 30.0 mL of 0.50 M NaCl, what is the concentration of [Na$^+$] in the solution? (Assume both ionic compounds are 100% ionized in their solutions and no precipitate forms.) (1 pt)

$$[\text{Na}^+] = \frac{\text{mol}}{\text{L}} = \frac{0.030 + 0.015}{0.050 + 0.030} = 0.44 \text{M Na}^+$$
5. 100.0 mL of 1.0 M iron (III) nitrate is mixed with 100.0 mL of 1.0 M sodium hydroxide. A precipitate forms between the iron cation and the hydroxide anion. Write the molecular equation, ionic equation and net ionic equation for this reaction:

a. Write the balanced molecular equation (1 pt)

\[
\text{Fe(NO}_3\text{)}_3 (aq) + 3 \text{NaOH (aq)} \rightarrow \text{Fe(OH)}_3 (s) + 3 \text{NaNO}_3 (aq)
\]

b. Write the complete ionic equation (1/2 pt)

\[
\text{Fe}^{3+} (aq) + 3 \text{NO}_3^- (aq) + 3 \text{Na}^+ (aq) + 3 \text{OH}^- (aq) \rightarrow \text{Fe(OH)}_3 (s) + 3 \text{Na}^+ (aq) + 3 \text{NO}_3^- (aq)
\]

c. Write the net ionic equation (1/2 pt)

\[
\text{Fe}^{3+} (aq) + 3 \text{OH}^- (aq) \rightarrow \text{Fe(OH)}_3 (s)
\]

d. Determine the moles and mass of the precipitate formed. (2 pts)

\[
\text{Fe(NO}_3\text{)}_3 \quad 0.100 \text{ L} \times \frac{1 \text{ mol Fe(NO}_3\text{)}_3}{\text{L}} \times \frac{1 \text{ mol Fe(OH)}_3}{1 \text{ mol Fe(NO}_3\text{)}_3} = 0.100 \text{ mol Fe(OH)}_3
\]

\[
\text{NaOH} \quad 0.100 \text{ L} \times \frac{1 \text{ mol NaOH}}{\text{L}} \times \frac{1 \text{ mol Fe(OH)}_3}{3 \text{ mol NaOH}} = 0.0333 \text{ mol Fe(OH)}_3
\]

\[
0.0333 \text{ mol Fe(OH)}_3 \times \frac{106.89 \text{ g}}{\text{mol}} = 3.509 \text{ g Fe(OH)}_3
\]

6. Label each aqueous species as a strong, weak, or non-electrolyte. (Assume all are soluble in water.) (2 pts)

**Strong**  
\[
\text{H}_2\text{SO}_3 \\
\text{NaBr} \\
\text{NH}_4\text{Cl}
\]

**Non**  
\[
\text{C}_2\text{H}_5\text{OH} \\
\text{HNO}_3 \\
\text{HClO}_4
\]

**Weak**  
\[
\text{HF}
\]

7. An unknown diprotic acid is neutralized with NaOH. If 1.60 g of the acid is neutralized with exactly 23.90 mL of 0.750 M NaOH, what is the molecular mass of the acid? (2 pts)

\[
\text{H}_2\text{A (aq)} + 2 \text{NaOH (aq)} \rightarrow \text{Na}_2\text{A (aq)} + 2\text{H}_2\text{O}
\]

\[
\text{0.0239 L} \times \frac{0.750 \text{ mol NaOH}}{\text{L}} \times \frac{1 \text{ mol H}_2\text{A}}{2 \text{ mol NaOH}} = 0.00896 \text{ mol H}_2\text{A}
\]

\[
\frac{1.60 \text{ g H}_2\text{A}}{0.00896 \text{ mol H}_2\text{A}} = 178.5 \frac{\text{g}}{\text{mole H}_2\text{A}}
\]