Empirical and Molecular Formulas

1. An unknown compound is found to be 40 % carbon, 6.7 % hydrogen, and 53.3 % oxygen by mass. If this compound has a molecular mass of 180.18 g mol^{-1}, what is this compound?

Strategy: Need to find the empirical formula first. Then compare the formula weight of the empirical formula to the molecular formula.

a. Assume 100 g of the unknown compound. What is the mass of:

carbon ___40___ g hydrogen ___6.7___ g oxygen ___53.3___ g

$40\% = \frac{x}{100} \times 100 \quad x = 40g$

b. How many moles of each element are in this compound?

carbon ___3.33___ mol hydrogen ___6.63___ mol oxygen ___3.33___ mol

$\frac{40 g \mid mol}{\mid 12.01 g} = 3.33$ $\frac{6.7 \mid mol}{\mid 1.01 g} = 6.63$ $\frac{53.3 \mid mol}{\mid 16 g} = 3.33$

c. What is the mole ratio of:

H:C ___2:1___ $\left(\frac{moles\ of\ H}{moles\ of\ C}\right)$ C:O ___1:1___ H:O ___2:1___

$\frac{6.63}{3.33} = 2:1$

d. What is the empirical formula?

$C_1H_2O_1$

e. Now calculate the molecular weight of the empirical formula. Does it match the molecular weight of the compound? $12.01 + 2(1.01) + 16 = 30.03 g/mol$

f. What is the ratio of M.F.W. to E.F.W.? This value is the multiplication factor that you can use to find the molecular formula from the empirical formula. For example, if your E.F. is C_3H_4 and your factor is 3, the MF is $C_{3x3}H_{4x3} = C_9H_{12}$

$\frac{180.18}{30.03} = 6$ $C_6H_{12}O_6$

2. Determine the molecular formula of an unknown compound that is 33.8% carbon, 2.84 % hydrogen, 30.04 % oxygen, and 33.28 % chlorine by mass. This compound has a molecular weight of 426.04 g mol^{-1}. What is the molecular formula?

$\frac{33.8 \text{ g C}}{} \Big| \frac{\text{mol}}{12.01 \text{ g}} = 2.84 \text{ C} \div 0.939 = 3$

$\frac{2.84 \text{ g H}}{} \Big| \frac{\text{mol}}{1.01 \text{ g}} = 2.81 \text{ H} \div 0.939 \approx 3$

$\frac{30.04 \text{ g O}}{} \Big| \frac{\text{mol}}{16 \text{ g}} = 1.878 \text{ O} \div 0.939 = 2$

$\frac{33.28 \text{ g Cl}}{} \Big| \frac{\text{mol}}{35.45 \text{ g}} = 0.939 \text{ Cl} \div 0.939 = 1$

$C_3H_3O_2Cl_1$

F.W. = 106.51

$\frac{426.04}{106.51} = 4$

$C_{12}H_{12}O_8Cl_4$

Reactions and Stoichiometry

This first section takes a stepwise approach to solving a complex stoichiometry problem. Subsequent problems require you to develop your own strategy to solve the problem.

3. Liquid chromium metal can be produced from a high temperature reaction between solid chromium (III) oxide and liquid aluminum. How much chromium metal can be produced if 10 grams of each reactant are mixed together and the reaction proceeds with a 68.2% yield.

Ok, so we need to break this down into pieces:

- Write a balanced reaction.
- Determine the limiting reactant.
- Account for % yield.

a. What type of reaction is this? Single replacement

b. Write the reactants and products. Make sure that you are careful about common charges (O^{2-} and Al^{3+}).

$Cr_2O_3(s) + 2Al(l) \rightarrow 2Cr(l) + Al_2O_3(s)$

c. Balance the reaction.

done above

To determine the limiting reactant, you need to calculate the amount of chromium metal that can be made from each reactant. To do this, you need to find out how many moles are present so that you can convert to moles of product.

d. Determine the molecular weight of each reactant substituent:

Cr_2O_3 152 g/mol   Al 26.98 g/mol   Cr 52 g/mol Al_2O_3 101.96 g/mol

You can do e → g and h → j as one step if you prefer.

e. Calculate the moles of Cr_2O_3 in 10 grams.

$\frac{10\text{ g} \mid \text{mol}}{\mid 152\text{ g}} = 0.0658\text{ mol}$

f. Calculate the moles of Cr that can be made.

$\frac{0.0658\text{ mol } Cr_2O_3 \mid 2\text{ mol Cr}}{\mid 1\text{ mol}} = 0.132\text{ mol Cr}$

g. What is the mass of Cr that can be produced from Cr_2O_3?

$\frac{0.132\text{ mol Cr} \mid 52\text{ g}}{\mid \text{mol}} = 6.84\text{ g Cr}$

h. Calculate the moles of Al in 10 grams.

$\frac{10\text{ g Al} \mid \text{mol}}{\mid 26.98\text{ g}} = 0.371\text{ mol Al}$

i. Calculate the moles of Cr that can be made.

$\frac{0.371\text{ mol Al} \mid 2\text{ Cr}}{\mid 2\text{ Al}} = 0.371\text{ mol Cr}$

j. What is the mass of Cr that can be produced from Al?

$\frac{0.371\text{ mol Cr} \mid 52\text{ g}}{\mid \text{mol}} = 19.27\text{ g Cr}$

k. Compare the values from g and j.
   i. How much Cr can be made? 6.84 g
   ii. What is the limiting reactant?
   Cr_2O_3

l. The value you reported in k is the theoretical yield – the maximum amount that can possibly be made. Noting that this reaction has a 68.2 % yield, how much Cr (ℓ) is actually made?

$68.2\% = \frac{\text{actual}}{6.84\text{ g}} \times 100$ actual = 4.66 g

This time a strategy will be presented, you will design the specific steps to accomplish that strategy.

4. Chromium metal can also be made through a high temperature reaction between solid chromium (III) oxide and liquid silicon. If 25 grams of each reactant are mixed together, determine the amount of chromium metal produced and the mass of silicon left over.

Strategy:

- Determine a balanced reaction
- Identify the limiting reactant
- Determine how much silicon was used.
- Determine how much silicon is left.

$$2Cr_2O_3(s) + 3Si(l) \rightarrow 4Cr(l) + 3SiO_2(s)$$

$\frac{152\ g}{mol}$ $\frac{28.09\ g}{mol}$ $\frac{52\ g}{mol}$ $\frac{60.09\ g}{mol}$

$$25\ g\ Cr_2O_3 \times \frac{mol}{152\ g} \times \frac{4\ Cr}{2\ Cr_2O_3} \times \frac{52\ g\ Cr}{1\ mol\ Cr} = 17.1\ g\ Cr$$

$$25\ g\ Si \times \frac{mol}{28.09\ g} \times \frac{4\ mol\ Cr}{3\ mol\ Si} \times \frac{52\ g}{mol} = 61.7\ g\ Cr$$

Cr_2O_3 is L.R. 17.1 g Cr is produced

$$17.1\ g\ Cr \times \frac{mol}{52\ g} \times \frac{3\ Si}{4\ Cr} \times \frac{28.09\ g}{mol} = 6.93\ g\ \text{used}$$

$$25\ g - 6.93 = 18.07\ g\ \text{left}$$

5. Oxygen tanks are heavy and cumbersome to carry around. An alternative to lugging around these big cylinders of gas would be to develop a chemical system capable of using carbon dioxide that you exhale to make oxygen. One such system uses solid potassium superoxide (superoxide is a polyatomic anion O_2^{-1}) to react with CO_2 gas. This reaction generates solid potassium carbonate and oxygen gas. If 29.86 g of O_2 is produced from 100 g of potassium superoxide, what is the % yield of this reaction?

$$4KO_2(s) + 2CO_2(g) \rightarrow 2K_2CO_3(s) + 3O_2(g)$$

$$\frac{100\text{ g }KO_2}{} \left| \frac{\text{mol}}{71.1\text{ g}} \right| \frac{3\,O_2}{4\,KO_2} \left| \frac{32\text{ g}}{\text{mol}} \right. = 33.76\text{ g possible}$$

$$\frac{29.86\text{ g}}{33.76\text{ g}} \times 100 = 88.46\%$$