Ch 3 Reactions, Moles, & Stoichiometry

1. Empirical Formulas from Analysis

mass % elements $\xrightarrow[\text{100g}]{\text{Assume}}$ g of each element $\xrightarrow[\text{molar mass}]{\text{use}}$ moles of each element $\xrightarrow[\text{mole Ratio}]{\text{Calculate}}$ Empirical Formula

Ex) A sample of methyl benzoate, used in perfume manufacturing, contains 70.57% carbon, 5.93% hydrogen, and 23.49% oxygen. What is its empirical formula?

C: $\frac{70.57g}{12.01\ g/mol} = \frac{5.875936\ mol}{1.468125\ mol} = 4C$

H: $\frac{5.93g}{1.01\ g/mol} = \frac{5.8771287\ mol}{1.468125\ mol} = 4H$

O: $\frac{23.49g}{16.00\ g/mol} = 1.468125\ mol = 1O$

EF = $C_4H_4O$

Ex) Ascorbic acid, vitamin C, contains 40.92% carbon, 4.58% hydrogen, and the rest is oxygen. What is the empirical formula?

C: $\frac{40.92g}{12.01\ g/mol} = \frac{3.40716\ mol}{3.40625\ mol} = (1C)3 = 3C$

H: $\frac{4.58g}{1.01\ g/mol} = \frac{4.53465\ mol}{3.40625\ mol} = (1.33H)3 = 4H$

O: $100 - 40.92 - 4.58 = \frac{54.5g}{16.00\ g/mol} = \frac{3.40625\ mol}{3.40625\ mol} = (1O)3 = 3O$

EF = $C_3H_4O_3$

Ex) A compound is found to contain 32.79% sodium, 13.02% aluminum, and 54.19% fluorine. What is the empirical formula?

$Na_3AlF_6$

2. Molecular Formula from Empirical Formula

- The subscripts in a molecular formula are always a whole-number multiple of the subscripts in an empirical formula.

∴ The mass of the molecular formula is always a multiple of the empirical formula.

EF $CH_2O$ MF $C_6H_{12}O_6$

$C = 12$
$2H = 2$
$1O = 16$
$+$ ___
$30$

$6C = 72$
$12H = 12$
$6O = 96$
___
$180$

This is 6 x's heavier than this!

Ex) Mesitylene has an empirical formula of $C_3H_4$. The experimentally determined molecular weight is 121 amu. What is the molecular formula?

$C_3H_4$

$36 + 4 = 40$

$\frac{121}{40} = 3$ $3(C_3H_4) =$ MF $C_9H_{12}$

Ex) Ethylene glycol, known as antifreeze, is composed of 38.7% carbon, 9.7% hydrogen, and 51.6% oxygen. Its molar mass is 62.1 g/mol. Determine its molecular formula.

$EF = CH_3O$

$12 + 3 + 16$

$= 31$

$MF = C_2H_6O_2$

$\frac{62}{31} = 2$

3. Combustion Analysis to determine an empirical formula

- when a substance (commonly containing mostly carbon & hydrogen), is completely combusted, all of the C is changed to $CO_2$ & all the H to $H_2O$. From the masses of $CO_2$ and $H_2O$ produced, the moles of C & H in the original compound can be determined & then the empirical formula can be found.
  - If a 3rd element is in the original compound, its mass can be determined by subtracting the C & H masses from the mass of the original compound.

Ex) caproic acid, responsible for the foul odor of dirty socks, is composed of C, H, & O. Combustion of a .225g sample of acid produces .512g $CO_2$ and .209 g $H_2O$. What is the empirical formula?

grams of C $\quad .512\cancel{g\,CO_2}\left(\frac{1\cancel{mol\,CO_2}}{44\cancel{g\,CO_2}}\right)\left(\frac{1\,mol\,\cancel{C}}{1\cancel{mol\,CO_2}}\right)\left(\frac{12\,g\,C}{1\,mol\,C}\right) = .139\,g\,C$ (12 +32)

grams of H $\quad .209\cancel{g\,H_2O}\left(\frac{1\cancel{mol\,H_2O}}{18\cancel{g\,H_2O}}\right)\left(\frac{2\,mol\,H}{1\cancel{mol\,H_2O}}\right)\left(\frac{1\,g\,H}{1\,mol\,H}\right) = .0232\,g\,H$

mass of O $\quad .225g - .139g - .0232g = \quad .0628\,g\,O$

| C | H | O |
|---|---|---|
| $\frac{.139\,g}{12.01\,g/mol}$ | $\frac{.0232\,g}{1.01\,g/mol}$ | $\frac{.0628\,g}{16.00\,g/mol}$ |
| $= \frac{.011574\,mol}{.003925\,mol}$ | $= \frac{.02297\,mol}{.003925\,mol}$ | $= \frac{.003925\,mol}{.003925\,mol}$ |
| = 3 C | = 6 H | = 1 O |

EF = $C_3H_6O$

Ex) isopropyl alcohol, is composed of C, H, and O. Combustion of .255g is isopropyl alcohol produces .561g of $CO_2$ and .306g of $H_2O$. What is the empirical formula?

grams C: $.561 \cancel{g\,CO_2}\left(\frac{1\,\cancel{mol\,CO_2}}{44\,\cancel{g\,CO_2}}\right)\left(\frac{1\,mol\,C}{1\,\cancel{mol\,CO_2}}\right)\left(\frac{12\,g\,C}{1\,mol\,C}\right) = .153\,g\,C$

grams H = $.306\,\cancel{g\,H_2O}\left(\frac{1\,mol\,H_2O}{18\,\cancel{g\,H_2O}}\right)\left(\frac{2\,\cancel{mol\,H}}{1\,mol\,H_2O}\right)\left(\frac{1\,g\,H}{1\,mol\,H}\right) = .0340\,g\,H$

grams O = $.255g - .153g - .0340g = .0680\,g\,O$

$\frac{.153\,g\,C}{12.01\,g/mol}$ $\quad$ $\frac{.0340\,g\,H}{1\,g/mol}$ $\quad$ $\frac{.0680\,g\,O}{16.00\,g/mol}$

$= \frac{.01274\,mol\,C}{.00425\,mol}$ $\quad$ $= \frac{.0340\,mol\,H}{.00425\,mol}$ $\quad$ $= \frac{.00425\,mol\,O}{.00425\,mol}$

3C $\quad$ 8H $\quad$ 1O $\quad$ EF = $C_3H_8O$

Ex) washing soda, a compound used to prepare hard water for washing laundry, is a hydrate, which means that a certain number of water molecules are included in the solid structure. Its formula can be written as $Na_2CO_3 \cdot xH_2O$, where x is the number of moles of water molecules per mole of $Na_2CO_3$. When a 2.55g sample is heated at 25°C, all the water of hydration is lost, leaving .948g of $Na_2CO_3$. What is the value of x?

$$Na_2CO_3 \cdot xH_2O_{(s)} \xrightarrow{\Delta} \underset{.948g}{Na_2CO_{3(s)}} + xH_2O_{(g)}$$

1st Calculate # moles $Na_2CO_3$ → # mols $Na_2CO_3 \cdot xH_2O$

$.948\,\cancel{g\,Na_2CO_3}\left(\frac{1\,\cancel{mol\,Na_2CO_3}}{106\,\cancel{g}}\right)\left(\frac{1\,mol\,Na_2CO_3 \cdot xH_2O}{1\,\cancel{mol\,Na_2CO_3}}\right)$

$.00894\,mol\,Na_2CO_3 \cdot xH_2O$

2nd Find the molar mass of the hydrate $\frac{2.55g}{.00894\,mol} = 285.23\,g/mol$

3rd $mm(Na_2CO_3 \cdot xH_2O) = MM(Na_2CO_3) + x(MM\,H_2O)$

$285.23\,g/mol = 106\,g/mol + x(18\,g/mol)$

$10 = x$

$Na_2CO_3 \cdot 10H_2O$

$$285.23 - 106 = \cancel{106} - \cancel{106} + x(18)$$

$$\frac{179.23}{18} = \frac{x(\cancel{18})}{\cancel{18}}$$

$$10 = x$$