Review

1. What are the empirical formulas of the following compounds?

a) H_2O_2 b) $C_6H_3(NO_2)_3$ c) P_4O_{10} molecular formula

$\downarrow$ $\downarrow$ $\downarrow$

HO $C_2H(NO_2)$ P_2O_5 empirical formula

2. A compound with empirical formula C_4H_4S has molecular molar mass 168 g/mol. What is its molecular formula?

empirical molar mass $(C_4H_4S) = 4(12.011) + 4(1.0079) + 1(32.06) = 84.\cancel{8}2$ g/mol

$$\frac{\text{molecular molar mass}}{\text{empirical molar mass}} = \frac{168 \text{ g/mol}}{84.\cancel{8}2 \text{ g/mol}} = 1.99 \approx 2$$

Molecular formula is $C_{4\times2}H_{4\times2}S_{1\times2} = C_8H_8S_2$

3. A compound has a molar mass of 98.96 g/mol and a percent composition of

% (Cl) = 71.65% , % (C) = 24.27% , % (H) = 4.07%

What is the empirical formula of the compound? What is the molecular formula?

Assume you have 100g of the compound. Then, in 100g of the compound you have

$$(100\text{ g})(.7165) = 71.65\text{ g Cl} \times \frac{1\text{ mol Cl}}{35.453\text{ g Cl}} = 2.021 \approx 2 \text{ mol Cl}$$

$$(100\text{ g})(.2427) = 24.27\text{ g C} \times \frac{1\text{ mol C}}{12.011\text{ g C}} = 2.021 \approx 2 \text{ mol C}$$

$$(100\text{ g})(.0407) = 4.07\text{ g H} \times \frac{1\text{ mol H}}{1.0079\text{ g H}} = 4.038 \approx 4 \text{ mol H}$$

地址: 北京市海淀区玉泉路66号 邮编: 100039
Add: No.66 Yuquan Road. Haidian Dist. Beijing. China P.C: 100039
电话 / Tel: 010-88625824 传真 / Fax: 010-88625824
Http://www.bjshiyi.org.cn

So, the empirical formula of the compound is $C_{2/2}H_{4/2}Cl_{2/2} = CH_2Cl$.

To find the molecular formula...

empirical molar mass (CH_2Cl) $= 1(12.011) + 2(1.0079) + 1(35.453) = 48.567$ g/mol

$$\frac{\text{molecular molar mass}}{\text{empirical molar mass}} = \frac{98.96 \text{ g/mol}}{48.57 \text{ g/mol}} = 2.037 \approx 2$$

So, molecular formula is $C_{1\times2}H_{2\times2}Cl_{1\times2} = C_2H_4Cl_2$.

Leaving classroom, into the kitchen...

To make 1 cake, you need 2 eggs, 3 cups flour, 1 cup milk.

How many cakes can you make w/ 3 eggs and unlimited flour + milk?

$$3 \text{ eggs} \times \frac{1 \text{ cake}}{2 \text{ eggs}} = 1.5 \text{ cakes}$$

How many cakes can you make w/ 3 eggs, 2 cups flour, 10 cups milk?

$$3 \text{ eggs} \times \frac{1 \text{ cake}}{2 \text{ eggs}} = 1.5 \text{ cakes}$$

$$2 \text{ cups flour} \times \frac{1 \text{ cake}}{3 \text{ cups flour}} = 0.67 \text{ cakes}$$

$$10 \text{ cups milk} \times \frac{1 \text{ cake}}{1 \text{ cup milk}} = 10 \text{ cakes}$$

So we can only make 0.67 cakes!

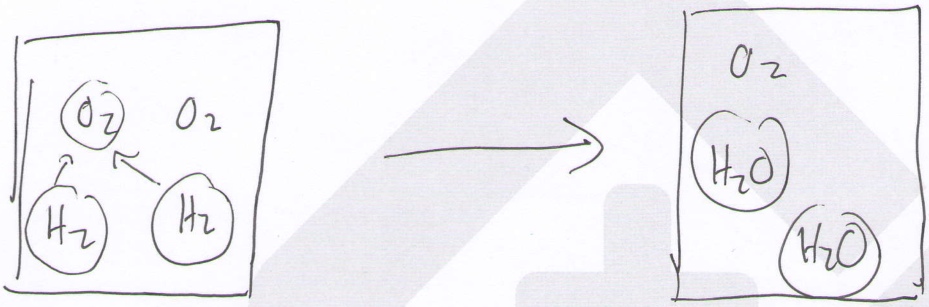
$2 \text{ eggs} + 3 \text{ flour} + \text{milk} \rightarrow \text{cake}$

In this example, flour is the $\boxed{\text{limiting reagent}}$.

Limiting Reagent: the reactant that runs out first, limiting the total amount of product formed.

Back to the lab... Consider reaction $2H_2 + O_2 \rightarrow 2H_2O$

2 mol O_2, 2 mol H_2 → 2 mol H_2O, 1 mol O_2



all H_2 used
extra O_2 remains

H_2 = limiting reagent

2 mol O_2, 4 mol H_2 → 4 mol H_2O

all H_2 used
all O_2 used

no limiting reagent

2 mol O_2, 6 mol H_2 → 4 mol H_2O, 2 mol H_2

all O_2 used
extra H_2 remains

O_2 = limiting reagent

地址: 北京市海淀区玉泉路66号 邮编: 100039
Add: No.66 Yuquan Road. Haidian Dist. Beijing. China P.C: 100039
电话 / Tel: 010-88625824 传真 / Fax: 010-88625824

Back to our combustion example...

$$5.467\ \underset{}{\overset{(Z)}{C_5H_4O}} + O_2 \rightarrow 15.02\,g\ CO_2 + 2.458\,g\ H_2O$$

We found the empirical formula of Z by burning in unlimited O_2.

What mass of CO_2 would be produced if we only had 10 g O_2?

What mass of H_2O would be produced if we only had 10 g of O_2?

How much extra C_5H_4O would be left over?

First, write balanced equation:

$$C_5H_4O + \frac{11}{2}O_2 \rightarrow 5\,CO_2 + 2\,H_2O$$

$$2\,C_5H_4O + 11\,O_2 \rightarrow 10\,CO_2 + 4\,H_2O$$

Assuming unlimited O_2 and 5.467 g C_5H_4O...

$$5.467\,g\ C_5H_4O \times \frac{1\ mol\ C_5H_4O}{80.561\,g\ C_5H_4O} \times \frac{10\ mol\ CO_2}{2\ mol\ C_5H_4O} \times \frac{44.011\,g\ CO_2}{1\ mol\ CO_2} = 14.93\,g\ CO_2$$

Assuming unlimited C_5H_4O and 10 g O_2 ...

$$10\,g\ O_2 \times \frac{1\ mol\ O_2}{32\,g\ O_2} \times \frac{10\ mol\ CO_2}{11\ mol\ O_2} \times \frac{44.011\,g\ CO_2}{1\ mol\ CO_2} = 12.50\,g\ CO_2$$

So, limiting reagent is... O_2!

Is it a good idea to do combustion analysis in a closed container w/ only 10 g of O_2? Why not?

地址: 北京市海淀区玉泉路66号 邮编: 100039
Add: No.66 Yuquan Road. Haidian Dist. Beijing. China P.C: 100039
电话 / Tel: 010-88625824 传真 / Fax: 010-88625824

No! Remember, in combustion analysis, we assume all C in unknown is accounted for by C in CO_2.

However, if we only use 10 g O_2 (if O_2 is limiting) we only use...

$$10\text{ g } O_2 \times \frac{1\text{ mol } O_2}{32\text{ g } O_2} \times \frac{2\text{ mol } C_5H_4O}{11\text{ mol } O_2} \times \frac{80.561\text{ g } C_5H_4O}{1\text{ mol } C_5H_4O} = 4.577\text{ g } C_5H_4O \text{ consumed}$$

... so $(5.467\text{ g} - 4.577\text{ g}) = 0.89$ g of C_5H_4O are unused

... and not all C in unknown went into CO_2!

New Idea: % yield (percent yield)

$$\%\text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

$Mg + 2HCl \rightarrow MgCl_2 + H_2$

Ex. 48.6 g of Mg react with 10^5 g of HCl, producing 100 g $MgCl_2$. What is the % yield.

Theoretical yield = maximum amount of product produced, assuming reaction goes to completion and all of limiting reactant is consumed.

$$\text{theoretical yield} = 48.6\text{ g Mg} \times \frac{1\text{ mol Mg}}{24.3\text{ g Mg}} \times \frac{1\text{ mol } MgCl_2}{1\text{ mol Mg}} \times \frac{95.206\text{ g } MgCl_2}{1\text{ mol } MgCl_2} = 190.412\text{ g } MgCl_2$$

Actual yield = amount of product actually measured

actual yield = 100 g $MgCl_2$

$$\%\text{ yield} = \frac{100\text{ g } MgCl_2}{190.412\text{ g } MgCl_2} \times 100 = 52.52\%\text{ yield}$$

地址: 北京市海淀区玉泉路66号 邮编: 100039
Add: No.66 Yuquan Road. Haidian Dist. Beijing. China P.C: 100039
电话 / Tel: 010-88625824 传真 / Fax: 010-88625824
Http://www.bjshiyi.org.cn

Summary Problem

$$50\text{ g } Z + O_2 \rightarrow 20\text{ g } CO_2 + 30\text{ g } H_2O$$

a) The % yield is 20% for this reaction. The molar mass of Z is 400.26 g/mol. What is the empirical formula of Z? What is the molecular formula of Z?

b) If 50 g Z are burned in a closed container w/ 20 g O_2, what remains in the container after the reaction goes to completion? Assume the % yield = 100%.

(a) Since the % yield $= \dfrac{\text{actual yield}}{\text{theoretical yield}}$

theoretical yield (CO_2) $= \dfrac{\text{actual yield } (CO_2)}{\text{\% yield}} = \dfrac{20\text{ g}}{.2} = 100\text{ g}$

theoretical yield (H_2O) $= \dfrac{\text{actual yield} (H_2O)}{\text{\% yield}} = \dfrac{30\text{ g}}{.2} = 150\text{ g}$

$100\text{ g } CO_2 \times \dfrac{1\text{ mol } CO_2}{44.011\text{ g } CO_2} \times \underbrace{\dfrac{1\text{ mol C}}{1\text{ mol } CO_2}}_{2.27\text{ mol C in Z}} \times \dfrac{12.011\text{ g C}}{1\text{ mol C}} = 27.291\text{ g C in Z}$

$150\text{ g } H_2O \times \dfrac{1\text{ mol } H_2O}{18.0158\text{ g } H_2O} \times \underbrace{\dfrac{2\text{ mol H}}{1\text{ mol } H_2O}}_{16.65\text{ mol H in Z}} \times \dfrac{1.0079\text{ g H}}{1\text{ mol H}} = 16.784\text{ g H in Z}$

$50\text{ g} - (27.291\text{ g} - 16.784\text{ g}) = 5.925\text{ g O in Z} \times \dfrac{1\text{ mol O}}{16\text{ g O}} = 0.370\text{ mol O in Z}$

(molecular)
$C_{18}H_{135}O_3$

$C_{2.27}H_{16.65}O_{0.37} \rightarrow C_6H_{45}O_1$ (empirical)

$\dfrac{\text{molecular molar mass}}{\text{empirical molar mass}} = \dfrac{400.2645\text{ g/mol}}{133.4215\text{ g/mol}} = 3$

(b) $50g\ C_{18}H_{135}O_3 + 20g\ O_2 \rightarrow ?CO_2 + ?H_2O$

$$C_{18}H_{135}O_3 + \frac{201}{4}O_2 \rightarrow 18CO_2 + \frac{135}{2}H_2O$$

$$\downarrow$$

$$4C_{18}H_{135}O_3 + 201O_2 \rightarrow 72CO_2 + 270H_2O$$

$$50g\ C_{18}H_{135}O_3 \times \frac{\overset{(Z)}{1\text{ mol } C_{18}H_{135}O_3}}{\underset{(Z)}{400.2645g\ C_{18}H_{135}O_3}} \times \frac{72\text{ mol } CO_2}{4\text{ mol } Z} = 2.249\text{ mol } CO_2$$

$$20g\ O_2 \times \frac{1\text{ mol } O_2}{32g\ O_2} \times \frac{72\text{ mol } CO_2}{201\text{ mol } O_2} = 0.224\text{ mol } CO_2$$

$0.224\text{ mol } CO_2 < 2.249\text{ mol } CO_2 \Rightarrow O_2$ is limiting reactant

$$0.224\text{ mol } CO_2 \times \frac{44.011g\ CO_2}{1\text{ mol } CO_2} = \boxed{9.85g\ CO_2 \text{ remaining in container}}$$

$$20g\ O_2 \times \frac{1\text{ mol } O_2}{32g\ O_2} \times \frac{270\text{ mol } H_2O}{201\text{ mol } O_2} \times \frac{18.0153g\ H_2O}{1\text{ mol } H_2O} = \boxed{15.13g\ H_2O \text{ remaining in container}}$$

$$20g\ O_2 \times \frac{1\text{ mol } O_2}{32g\ O_2} \times \frac{4\text{ mol } Z}{201\text{ mol } O_2} \times \frac{400.2645g\ Z}{1\text{ mol } Z} = \boxed{4.978g\ Z \text{ consumed}}$$

so... $50g - 4.978g = \boxed{45.022g\ Z \text{ remaining in container}}$