CHEMICAL REACTIONS

1

Reactants: $Zn + I_2$ ⟶ Product: $Zn\ I_2$

Note 1 to 1 recipe

Syllabus Learning Outcomes : 6, 8, and 10

42

Be Sure to Know

- Charges for atoms and polyatomic ions
- How to write correct formulas
- Names for ionic and molecular compounds
- How to write a formula given a name

Once you write a correct formula

- Don't change the subscripts

Write Compounds Between

- Lithium and Bromine _____________
- Ammonium and Sulfur ______________
- Potassium and Phosphate _____________
- Calcium and Acetate _______________
- Magnesium and Dichromate __________
- Strontium and Phosphate _____________

Write Compounds Between

- Iron (III) and perchlorate _____________
- Aluminum and oxygen ______________
- Chromium (III) and phosphate_________
- Carbon and hydrogen _______________
- Tin (IV) and carbonate ______________
- Lead(IV) phosphate _____________

6

Write Chemical Equations

Coefficients show relative amounts of reactants and products.

$\underline{4}\ Al(s) + \underline{3}\ O_2(g) \rightarrow \underline{2}\ Al_2O_3(s)$

The numbers in the front are called stoichiometric coefficients

The letters (s), (g), (l), and (aq) are the physical states of compounds.

Stoichiometry is like a recipe, so the atom count remains the same on both sides of the chemical reaction

7

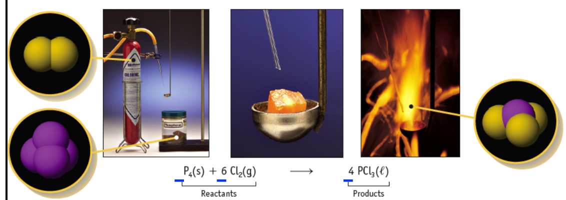
Chemical Equations Say

$\underline{4}Al(s) + \underline{3}O_2(g) \rightarrow \underline{2}Al_2O_3(s)$

4 Al atoms + 3 O_2 molecules
---give--->
2 formula units of Al_2O_3
And/Or
4 moles of Al + 3 moles of O_2
---give--->
2 moles of Al_2O_3

8

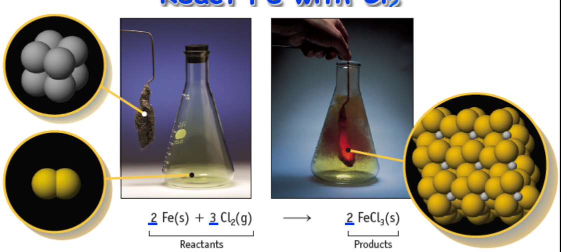
React P with Cl_2



Notice the stoichiometric coefficients and the physical states of the reactants and products.

9

React Fe with Cl_2

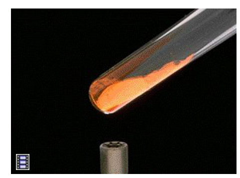


Notice the stoichiometric coefficients and the physical states of the reactants and products.

10

Law of Conservation of Matter

Chemical reactions have the same amount of matter on both sides.



$2HgO(s) \rightarrow 2\ Hg(l) + O_2(g)$

11

Balanced Chemical Equations

Law of Conservation of Matter

A chemical equation must be balanced:
same number of atoms of the same kind on both sides.

Lavoisier, 1788

12

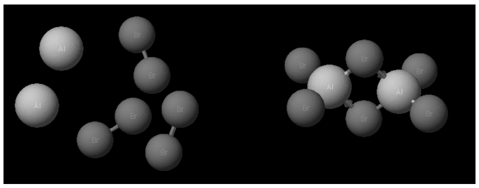
General Balancing Strategy

- First balance metals, if any
- Second, balance nonmetals other than hydrogen and oxygen
- If a polyatomic ion does not change from one side to the other, treat it as a group
- Third, balance oxygen
- Fourth, balance hydrogen
- Last, check it again!!!

13

Balancing Equations

___ Al(s) + ___ Br_2(liq) → ___ Al_2Br_6(s)



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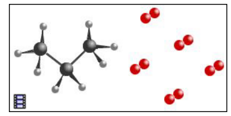


Balancing Equations

Combustion

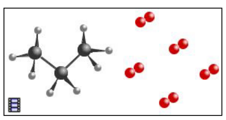
____C_3H_8(g) + _____ O_2(g) →

_____CO_2(g) + _____ H_2O(g)

_____B_4H_{10}(g) + _____ O_2(g) →

___ B_2O_3(g) + _____ H_2O(g)

15



Balancing Equations

Ionic compounds, acids

___Na_2CO_3(aq) + ___ $CaCl_2$(aq) →

____$CaCO_3$ (s) + ____ NaCl(aq)

___H_2SO_4 (aq) + ___ NaOH(aq) →

___ Na_2SO_4(aq) + _____ H_2O(l)

Explain how to predict products and tracking

16

STOICHIOMETRY

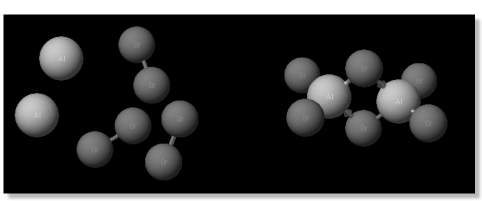
The study of the quantitative aspects of chemical reactions.

Recipe

17

STOICHIOMETRY

Rests on Law of Conservation of Matter



2 Al(s) + 3 Br_2(liq) → Al_2Br_6(s)

Recipe

18

If 1 mol of ammonium nitrate decomposes, how much N_2O and H_2O are formed?

- Step 1: Write the balance chemical reaction
- NH_4NO_3(s) → N_2O(g) + $2H_2O$(g)

If 1 mol of ammonium nitrate decomposes, how much N_2O and H_2O are formed?

- Step 2: Balanced reaction gives equivalence by moles when reactants convert completely to products
- $NH_4NO_3(s) \rightarrow N_2O(g) + 2H_2O(g)$
- 1 mol NH_4NO_3 reacted = 1 mol N_2O formed,
- 1 mol NH_4NO_3 reacted = 2 mol H_2O formed, and
- 1 mol N_2O formed = 2 mol H_2O formed

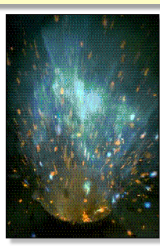
If 1 mol of ammonium nitrate decomposes, how much N_2O and H_2O are formed?

- Step 3: Calculate product formed using stoichiometric ratios (factors)
- $NH_4NO_3(s) \rightarrow N_2O(g) + 2H_2O(g)$
- Before Reaction
- 1 mol 0 mol 0 mol
- After Reaction
- 0 mol 1 mol 2 mol

$$\frac{1 \text{ mol } NH_4NO_3}{1} * \frac{1 \text{ mol } N_2O}{1 \text{ mol } NH_4NO_3} = 1 \text{ mol } N_2O$$

$$\frac{1 \text{ mol } NH_4NO_3}{1} * \frac{2 \text{ mol } H_2O}{1 \text{ mol } NH_4NO_3} = 2 \text{ mol } H_2O$$

If 454 g of NH_4NO_3 decomposes, how much N_2O and H_2O are formed? What is the theoretical yield of products?



Step 1: Write balanced chemical equation

$\_NH_4NO_3 \rightarrow \_N_2O + \_2H_2O$

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Step 2: Convert mass of reactant to moles

$$454 \text{ g} \cdot \frac{1 \text{ mol}}{80.04 \text{ g}} = 5.68 \text{ mol } NH_4NO_3$$

Mass from lab balance

Count molecules

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Step 3: Convert moles of reactant to moles of product

Stoichiometric Factors

1 mol NH_4NO_3 <--> 2 mol H_2O

$$\frac{2\,mol\ H_2O}{1\,mol\ NH_4NO_3} \quad \text{Or} \quad \frac{1\,mol\ NH_4NO_3}{2\,mol\ H_2O}$$

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Step 3: Convert moles of reactant to moles of product

$$5.68 \text{ mol } NH_4NO_3 \cdot \frac{2 \text{ mol } H_2O \text{ produced}}{1 \text{ mol } NH_4NO_3 \text{ used}}$$

$= 11.4$ mol H_2O produced

Count molecules formed

25

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Step 4: Convert moles of product to grams

Called the **THEORETICAL YIELD**

$$11.4 \text{ mol } H_2O \cdot \frac{18.02 \text{ g}}{1 \text{ mol}} = 204 \text{ g } H_2O$$

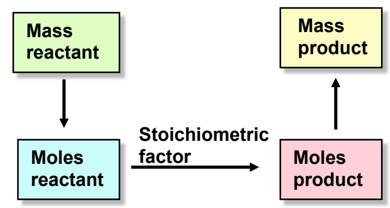
Count molecules formed

Mass, measured on a lab balance

ALWAYS FOLLOW THESE STEPS IN SOLVING STOICHIOMETRY PROBLEMS!

26

GENERAL PLAN FOR STOICHIOMETRY CALCULATIONS



27

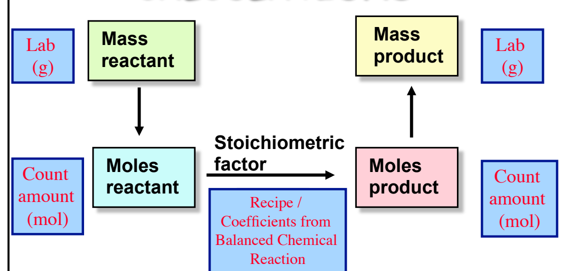
Why These Steps?

- Atoms and molecules are too small to count out individually (unlike eggs for a recipe)
- In the lab, we determine the mass of a large number of atoms or molecules using a balance
- Figure out how many atoms or molecules we have using the mass per mole of atoms/molecules
- Apply stoichiometry (the recipe) from a balanced chemical reaction to figure how many atoms/molecules we get
- Convert how many atoms/molecules back to a mass so we can measure how well we did using a balance

What could we use other than mass to measure?

28

GENERAL PLAN FOR STOICHIOMETRY CALCULATIONS



29

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Step 5: How much N_2O is formed?

Mass of reactants = Mass of products

454 g NH_4NO_3 = ___ g N_2O + 204 g H_2O

mass of N_2O = 250. g

Or repeat Steps 3 and 4 for N_2O instead of H_2O

30

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Amounts Table – Used in Chem II

- Compound — NH_4NO_3 — N_2O — H_2O
- Before (g)
- Before (mol)
- Change (mol)
- After (mol)
- After (g)

Note that matter is conserved!

31

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Amounts Table – Used in Chem II

Compound	NH_4NO_3	N_2O	H_2O	
Before (g)	454	0	0	
Before (mol)	5.68	0	0	
Change (mol)	-5.68	+5.68	+2(5.68)	
After (mol)	0	5.68	11.4	
After (g)	0	250	204	= 454 g

Note that matter is conserved!

32

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Step 6: Calculate percent yield

If you isolated only 131 g of N_2O, what is the percent yield?

This compares the theoretical (250. g) and actual (131 g) yields.

33

454 g of $NH_4NO_3 \rightarrow N_2O + 2\ H_2O$

Step 6: Calculate percent yield

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

$$\%\ \text{yield} = \frac{131\ \text{g}}{250.\ \text{g}} \cdot 100\% = 52.4\%$$

34

PROBLEM: Using 5.00 g of H_2O_2, what mass of O_2 and of H_2O can be obtained?

$2\ H_2O_2(liq)$ ---> $2\ H_2O(g)\ +\ O_2(g)$

Reaction is catalyzed by MnO_2

Step 1: moles of H_2O_2

Step 2: use STOICHIOMETRIC FACTOR to calculate moles of O_2

Step 3: mass of O_2

35

Remember - Effort

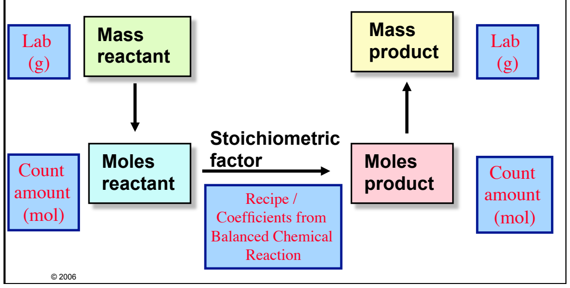
- Study 9-12 hours weekly to keep up with the course material
- Work/rework the homework problems in the book and Chemistry Is Not A Spectator Sport
- Make study guides from lecture notes and worked problems to help learn concept material.

36

PROBLEM: Using 5.00 g of H_2O_2, what mass of O_2 and of H_2O can be obtained?

37

GENERAL PLAN FOR STOICHIOMETRY CALCULATIONS



38

PROBLEM: Using 5.00 g of H_2O_2, what mass of O_2 and of H_2O can be obtained?

- Calculate mol H_2O_2

$5.00\ g\ H_2O_2 * \frac{mol\ H_2O_2}{34.0\ g\ H_2O_2} = 0.147\ mol\ H_2O_2$

- Calculate mol O_2

$0.147\ mol\ H_2O_2 * \frac{1\ mol\ O_2}{2\ mol\ H_2O_2} = 0.0735\ mol\ O_2$

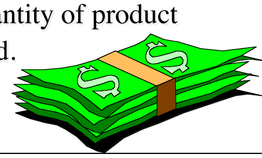
- Calculate g of O_2

$0.0735\ mol\ O_2 * \frac{32.0g\ O_2}{mol\ O_2} = 2.35\ g\ O_2$

39

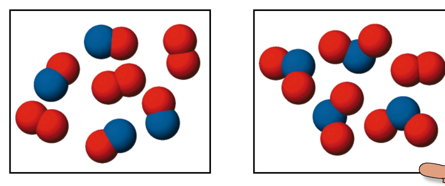
Reactions Involving a LIMITING REACTANT

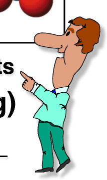
- In a given reaction, there is not enough of one reagent to use up the other reagent completely.
- The reagent in short supply LIMITS the quantity of product that can be formed.



40

LIMITING REACTANTS





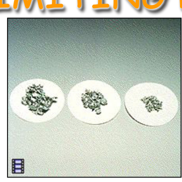
$2\ NO(g) + O_2\ (g) \longrightarrow 2\ NO_2(g)$

Limiting reactant = ____________

Excess reactant = ____________

41

LIMITING REACTANTS



React solid Zn with 0.100 mol HCl (aq)

$Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

1 2 3

Rxn 1: Balloon inflates fully, some Zn left

* More than enough Zn to use up the 0.100 mol HCl

Rxn 2: Balloon inflates fully, no Zn left

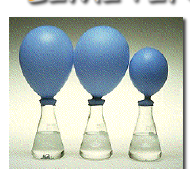
* Right amount of each (HCl and Zn)

Rxn 3: Balloon does not inflate fully, no Zn left.

* Not enough Zn to use up 0.100 mol HCl

42

LIMITING REACTANTS



React solid Zn with 0.100 mol HCl (aq)

$Zn + 2\ HCl \rightarrow ZnCl_2 + H_2$

0.10 mol HCl [1 mol Zn/2 mol HCl] = 0.050 mol Zn

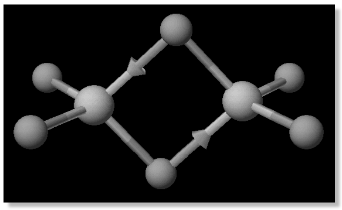
	Rxn 1	Rxn 2	Rxn 3
mass Zn (g)	7.00	3.27	1.31
mol Zn	0.107	0.050	0.020
mol HCl	0.100	0.100	0.100
mol HCl/mol Zn	0.93/1	2.00/1	5.00/1
Lim Reactant	LR = HCl	no LR	LR = Zn

MM=65.39 g/mol

43

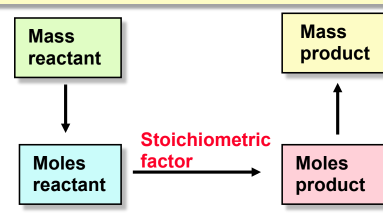
Reaction to be Studied

$$2\ Al\ +\ 3\ Cl_2 \rightarrow Al_2Cl_6$$



44

PROBLEM: Mix 5.40 g of Al with 8.10 g of Cl_2. What mass of Al_2Cl_6 can form?



45

Step 1 of LR problem: Calculate moles of each reactant

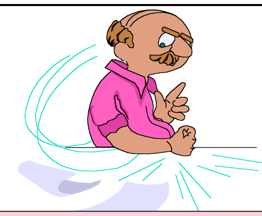
We have 5.40 g of Al and 8.10 g of Cl_2

$$5.40\text{ g Al} \cdot \frac{1\text{ mol}}{27.0\text{ g}} = 0.200\text{ mol Al}$$

$$8.10\text{ g } Cl_2 \cdot \frac{1\text{ mol}}{70.9\text{ g}} = 0.114\text{ mol } Cl_2$$

LR = limiting reactant or limiting reagent

46



Step 2 of LR problem: Calculate product formed for each reactant. LR makes the least product.

Pick a single product if more than one product is formed

47

Step 2: Calculate how much product you could make

$$2\ Al\ +\ 3\ Cl_2 \rightarrow Al_2Cl_6$$

Have 0.200 mol Al and 0.114 mol Cl_2

$$0.200\text{ mol Al} * \frac{1\text{ mol } Al_2Cl_6}{2\text{ mol Al}} = 0.1\text{ mol } Al_2Cl_6\text{ formed}$$

$$0.114\text{ mol } Cl_2 * \frac{1\text{ mol } Al_2Cl_6}{3\text{ mol } Cl_2} = 0.038\text{ mol } Al_2Cl_6\text{ formed}$$

LR is Cl_2

Because Cl_2 forms less Al_2Cl_6

48

Method 1: Find mole ratio of reactants

Step 1 of LR problem: compare actual mole ratio of reactants to theoretical mole ratio.

$$2\ Al\ +\ 3\ Cl_2\ \text{--->}\ Al_2Cl_6$$

Reactants must be in the mole ratio

$$\frac{\text{mol } Cl_2}{\text{mol Al}} = \frac{3}{2}$$

49

Deciding on the Limiting Reactant

$2\ Al + 3\ Cl_2$ ---> Al_2Cl_6

If $\frac{\text{mol } Cl_2}{\text{mol Al}} > \frac{3}{2}$

There is not enough Al to use up all the Cl_2

Lim reag = Al

50

Deciding on the Limiting Reactant

$2\ Al + 3\ Cl_2$ ---> Al_2Cl_6

If $\frac{\text{mol } Cl_2}{\text{mol Al}} < \frac{3}{2}$

There is not enough Cl_2 to use up all the Al

Lim reag = Cl_2

51

Method 1: Find mole ratio of reactants

$2\ Al + 3\ Cl_2$ ---> Al_2Cl_6

$$\frac{\text{mol } Cl_2}{\text{mol Al}} = \frac{0.114 \text{ mol}}{0.200 \text{ mol}} = 0.57$$

This should be 3/2 or 1.5/1 if reactants are present in the exact stoichiometric ratio.

Limiting reactant is Cl_2

52

Method 3: Calculate how much of the other reactant you need

$2\ Al + 3\ Cl_2$ ---> Al_2Cl_6

Have 0.200 mol Al and 0.114 mol Cl_2

0.200 mol Al * $\frac{3 \text{ mol } Cl_2}{2 \text{ mol Al}}$ = 0.3 mol Cl_2 needed

Only have 0.114 mol Cl_2, need 0.3 mol, so

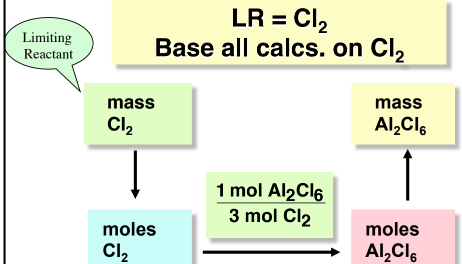
Limiting reactant is Cl_2

53

Mix 5.40 g of Al with 8.10 g of Cl_2. What mass of Al_2Cl_6 can form?

$2\ Al + 3\ Cl_2 \rightarrow Al_2Cl_6$

LR = Cl_2
Base all calcs. on Cl_2



After finding LR, approach is same as before

54

CALCULATIONS: calculate mass of Al_2Cl_6 expected.

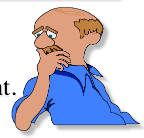
Step 1: Calculate moles of Al_2Cl_6 using LR.

$$0.114 \text{ mol } Cl_2 \cdot \frac{1 \text{ mol } Al_2Cl_6}{3 \text{ mol } Cl_2} = 0.0380 \text{ mol } Al_2Cl_6$$

Step 2: Calculate mass of Al_2Cl_6 using LR.

$$0.0380 \text{ mol } Al_2Cl_6 \cdot \frac{266.4 \text{ g } Al_2Cl_6}{\text{mol}} = 10.1 \text{ g } Al_2Cl_6$$

How much of reactants will remain when reaction is complete?



- Cl_2 was the LR.
  Therefore, excess Al was present.
  But how much?
- First find the Al that was used.
- Then find the Al that remains.

Calculating Excess Al

$$2\ Al + 3\ Cl_2 \longrightarrow \text{products}$$

0.200 mol (Al) **0.114 mol = LR** (Cl_2)

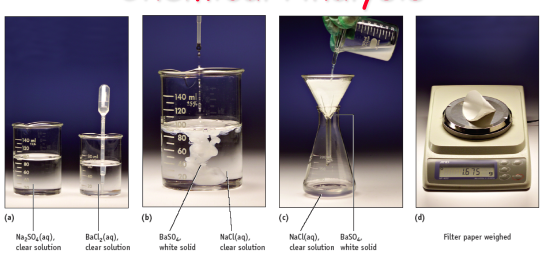
$$0.114 \text{ mol } Cl_2 \bullet \frac{2 \text{ mol Al}}{3 \text{ mol } Cl_2} = 0.0760 \text{ mol Al used}$$

Excess Al = Al available - Al used

= 0.200 mol - 0.0760 mol

= 0.124 mol Al in excess

Chemical Analysis



Chemical Analysis

- An impure sample of the mineral thenardite contains Na_2SO_4.
- Mass of mineral sample = 0.123 g
- The Na_2SO_4 in the sample is converted to insoluble $BaSO_4$.
- The mass of $BaSO_4$ is 0.177 g
- What is the mass percent of Na_2SO_4 in the mineral?

Chemical Analysis

1) Balance the Chemical Reaction

Na_2SO_4(aq) + $BaCl_2$(aq) --> 2 NaCl(aq) + $BaSO_4$(s)

2) Calculate moles of $BaSO_4$ formed

$$0.177 g\ BaSO_4 \bullet \frac{1 mol\ BaSO_4}{233.4 g\ BaSO_4} = 7.58x10^{-4} mol\ BaSO_4$$

3) Calculate moles of Na_2SO_4 in the mineral

$$7.58x10^{-4} mol\ BaSO_4 \bullet \frac{1 mol\ Na_2SO_4}{1 mol\ BaSO_4} = 7.58x10^{-4} mol\ Na_2SO_4$$

Chemical Analysis

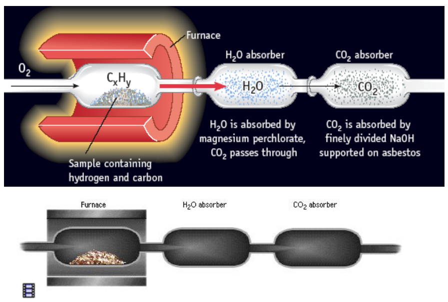
4) Calculate the mass of Na_2SO_4 in sample

$$7.58x10^{-4} mol\ Na_2SO_4 \bullet \frac{142.0 g\ Na_2SO_4}{1 mol\ Na_2SO_4} = 0.108 g\ Na_2SO_4$$

5) Calculate the percent by mass of Na_2SO_4 in the sample, the percent purity.

$$\%Na_2SO_4 = \frac{0.108 g\ Na_2SO_4}{0.123 g\ sample} \bullet 100\% = 87.8\%\ pure\ Na_2SO_4$$

Determining the Formula of a Hydrocarbon by Combustion



Determine Empirical Formula by Combustion

Burn 0.115 g of a hydrocarbon, C_xH_y, and produce 0.379 g of CO_2 and 0.1035 g of H_2O.

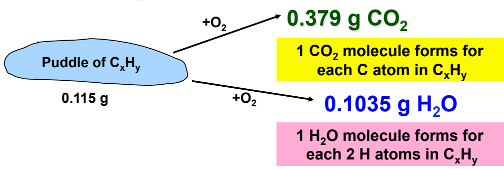
C_xH_y + some oxygen →
0.379g CO_2 + 0.1035g H_2O

What is the empirical formula of C_xH_y?

Empirical Formula by Combustion

C_xH_y + some oxygen → 0.379 g CO_2 + 0.1035 g H_2O

First, note that all C goes to CO_2 and all H goes to H_2O.



Empirical Formula by Combustion

C_xH_y + some oxygen → 0.379 g CO_2 + 0.1035 g H_2O

1. Calculate amount of C in CO_2 — 1 mol C for 1 mol CO_2

   8.61×10^{-3} mol CO_2 --> 8.61×10^{-3} mol C

2. Calculate amount of H in H_2O — 2 mol H for 1 mol H_2O

   5.744×10^{-3} mol H_2O → 1.149×10^{-2} mol H

Empirical Formula by Combustion

C_xH_y + some oxygen → 0.379 g CO_2 + 0.1035 g H_2O

3) Find ratio of mol H/mol C to get x and y in C_xH_y.

1.149×10^{-2} mol H/ 8.61×10^{-3} mol C

1.33 mol H and 1.00 mol C — Multiply by 3 / 3

4 mol H and 3 mol C

Empirical formula is C_3H_4

Determine a Formula by Combustion