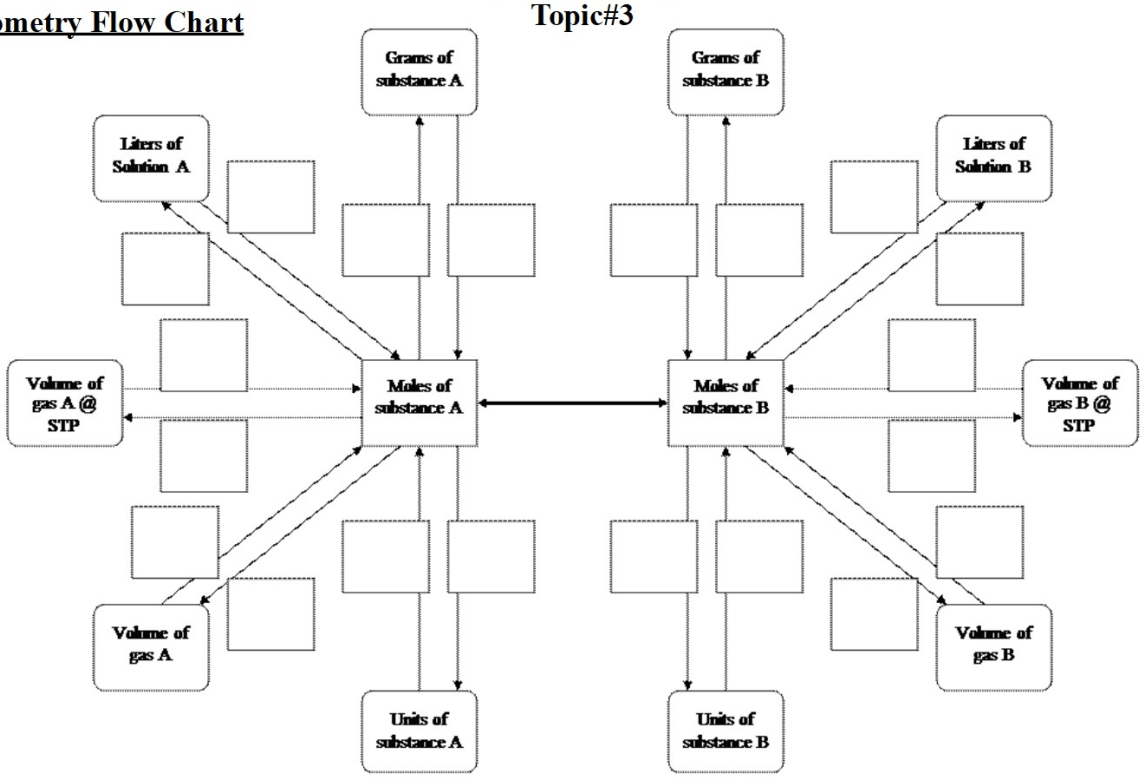
MyAP Code
Per#3: PXD9R6
Per#4: 7JNRGW
Per#7: 7XJ2RY

Unit#1

AP Chem
Topic#3
Stoichiometry

Stoichiometry
Topic#3

Stoichiometry Flow Chart



Stoichiometry
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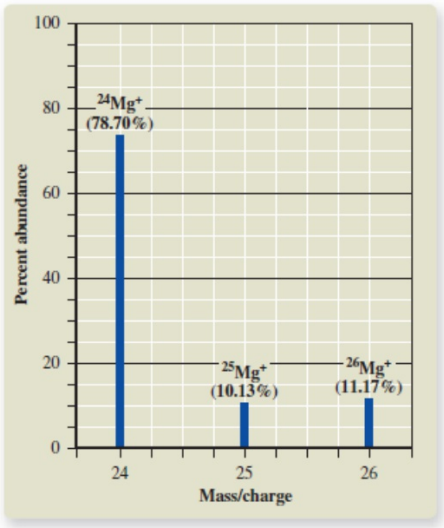
Average Atomic Mass (AAM)

The average atomic mass of an element is the weighted average of the masses of the naturally occurring isotopes in a 100g sample.

Isotope	Abundance	Atomic mass (amu)
^{24}Mg	78.99%	23.98504
^{25}Mg	10.00%	24.98584
^{26}Mg	11.01%	25.98259



Naturally occurring magnesium has isotopic abundances as shown.

(a) What is the average atomic mass of Mg?

(b) Sketch the mass spectrum of Mg.

(a) $(0.7899)(23.98504) + (0.10)(24.98584) + (0.1101)(25.98259) = 24.30505026$

24.30 amu

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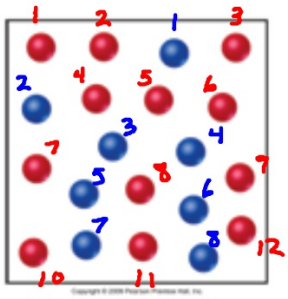
Average Atomic Mass (AAM)



red - 293
blue - 295

The diagram is a representation of 20 atoms of a fictitious element, which we will call nevadium (Nv). The red spheres are ^{293}Nv, and the blue spheres are ^{295}Nv.

(a) Assuming that this sample is a statistically representative sample of the element, calculate the percent abundance of each isotope.

red: (12) $12/20 = 60.0\%$

blue: (8) $8/20 = 40.0\%$

(b) If the mass of ^{293}Nv is 293.15 amu and that of ^{295}Nv is 295.15 amu, what is the atomic weight of Nv?

$AW_{Nv} = (0.6)(293.15) + (0.4)(295.15)$

$= 293.95 \text{ amu}$

(a) red (293) - (12/20) x 100% = 60%
blue (295) - (8/20) x 100% = 40%
(b) (293.15)(0.6) + (295.15)(0.4) = 293.95amu

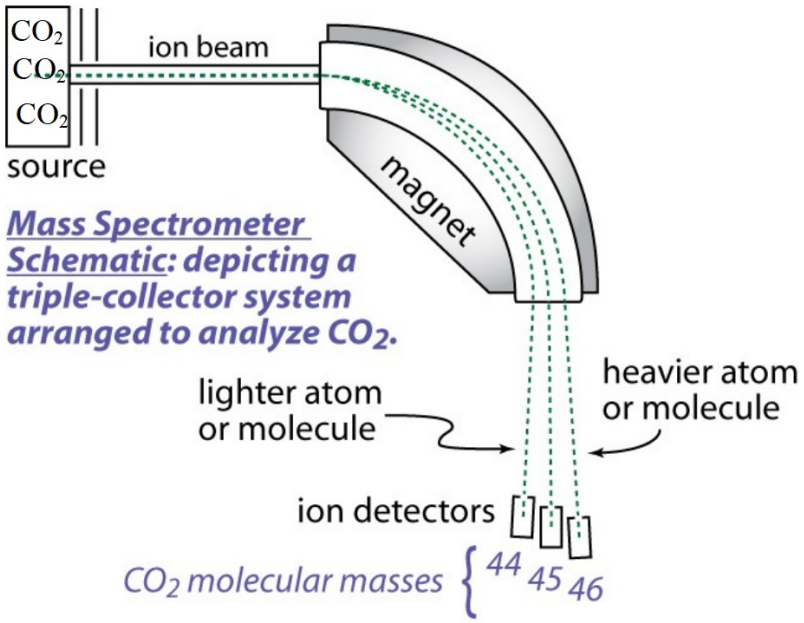
Mass Spectroscopy

- **A process that isolates and counts the isotopes of the element in a given mass.**
- **Percentage of isotope**

carbon - 12 (*MM* = 44.01g/mol)
$^{12}_{6}C$

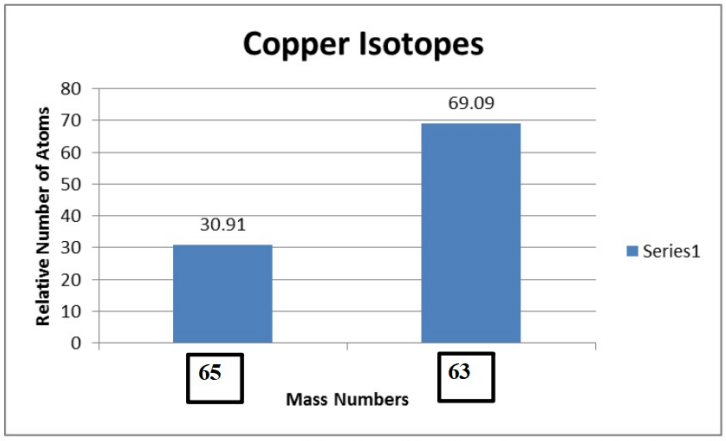
carbon - 13 (*MM* = 45.01g/mol)
$^{13}_{6}C$

carbon - 14 (*MM* = 46.01g/mol)
$^{14}_{6}C$



Mass Spectrometer Schematic: depicting a triple-collector system arranged to analyze CO_2.

Mass Spectroscopy



neutron	**1.008 664 u**
proton	**1.007 276 u**

$AAM = (0.3091)(65) + (0.6909)(63) = 63.62 \text{ amu}$

x y

$x + y = 1$

$x = y - 1$

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Mass Spectroscopy

Insert the video

Bozeman Video on Mass Spectroscopy

Sample WS#1: Mass Spectroscopy

1. Element "E" is present with the following mass values and natural abundance.

Isotope	Mass Number (amu)	Percent Abundance (%)
^{10}E	10.01	19.78
^{11}E	11.01	80.22

What is the average atomic mass of the element, E? What is the element? (Ans: 10.81amu, boron)

$$AAM = (\%)_1(\text{mass \#})_1 + (\%)_2(\text{mass \#})_2$$

$$= (0.1978)(10.01) + (0.8022)(11.01)$$

$$= 10.812\ u = \boxed{10.81\ u}$$

$^{10}_{5}B$

$^{11}_{5}B$

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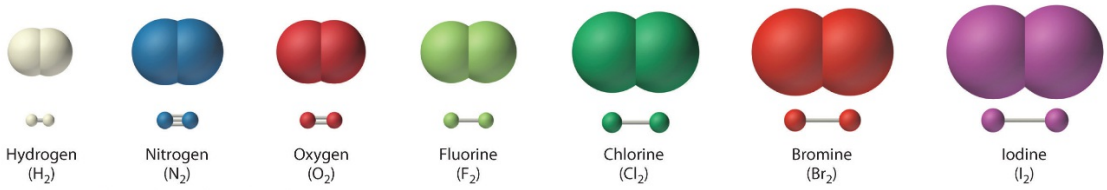
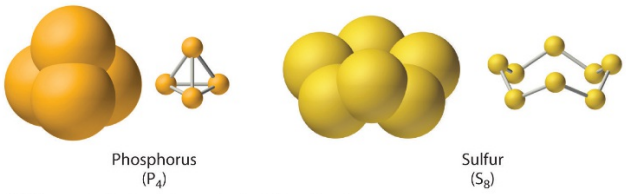
Polyatomic Elements

Polyatomic Elements

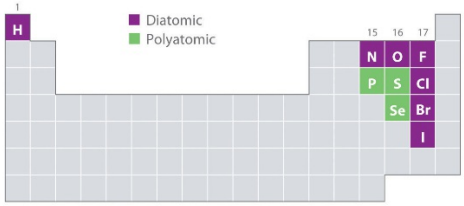
Diatomic: H_2, N_2, O_2, F_2, Cl_2, I_2, Br_2



(a) Elements that exist as diatomic molecules



(b) Elements that exist as polyatomic molecules



Elemental phosphorus: P_4
Elemental Sulfur: S_8

Chemical equations using molecular elements:

$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

$P_4(s) + 6Cl_2(g) \rightarrow 4PCl_3(g)$

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Balancing Chemical Equations

2. $NH_3(g) + O_2(g) \rightarrow NO(g) + H_2O(g)$

3. $(NH_4)_2Cr_2O_7(s) \rightarrow Cr_2O_3(s) + N_2(g) + H_2O(g)$

4. $C_3H_8(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

5. $Ca(OH)_2(aq) + H_3PO_4(aq) \rightarrow H_2O(l) + Ca_3(PO_4)_2(s)$

6. $MoS_2(s) + O_2(g) \rightarrow MoO_3(s) + SO_2(g)$

7. (OYO) $C_{12}H_{22}O_{11}(s) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

8. (OYO) $Cr(s) + S_8(s) \rightarrow Cr_2S_3(s)$

Stoichiometry
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Mole Conversions

Sample WS#2 - Mole-*MM*-Particles-Molar Volume

1. Americium is an element that does not occur naturally. It can be made in very small amounts in a device known as a particle accelerator. Compare the mass in grams of a sample of americium containing 6 atoms. (Ans: 2.42×10^{-21}g)

Gvn
6 atoms

NTK
Atomic mass = 243 amu (g/mol)
1 mol = 6.022×10^{23} atoms

Unk
mass = _____ g

Solve: $6 \text{ atoms Am} \left| \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ atoms}} \right| \frac{243 \text{ g}}{1 \text{ mol}} = \boxed{2 \times 10^{-21} \text{ g}}$

2. Calculate the molar mass of juglone ($C_{10}H_6O_3$). Juglone is a dye made from the husks of black walnuts. What is the percent composition by mass of each element in juglone.

Gvn
$C_{10}H_6O_3$

NTK
MM = 174.16 g/mole

Unk
%C = 69.0 %
%H = 3.5 %
%O = 27.6 %

Solve:
$\%C = \frac{10(12.01)}{174.16} \times 100 = 69.0\ \%$
$\%H = \frac{6(1.01)}{174.16} \times 100 = 3.5\ \%$
$\%O = \frac{3(16)}{174.16} \times 100 = 27.6\ \%$

Stoichiometry
Topic#3

Mole Conversions

3. What is the molar mass of a compound where 5.69 grams contains 7.79×10^{22} molecules? (Ans: 43.99g/mol)

Given
5.69 g
7.79×10^{22} molecules

NTK
$\text{moles} = \frac{\text{parts}}{\text{Avogadro's \#}} = \frac{7.79 \times 10^{22}}{6.022 \times 10^{23}}$
$= 0.129$ moles

Unk
MM = _____ g/mol

Solve: $MM = \frac{\text{mass}}{\text{moles}} = \frac{5.69\text{ g}}{0.129\text{ moles}} =$ **44.11 g/mol**

4. How many moles, parts, and liters are in 2.45g of CO_2? (Ans: 0.0557moles, 3.35×10^{22} molecules, and 1.25L)

Given
2.45 g CO_2

NTK
$MM_{CO_2} = 44.01$ g/mol
1 mol = 22.4 L

Unk
moles = _____ mol
parts = _____ molecules
V = _____ L

Solve:
$2.45\text{ g} \mid \frac{1\text{ mole}}{44.01\text{ g}} =$ **0.0557 mol**

$0.0557\text{ mol} \mid \frac{6.022 \times 10^{23}\text{ molecules}}{1\text{ mol}} =$ **3.35×10^{22} molecules**

$0.0557\text{ moles} \mid \frac{22.4\text{ L}}{1\text{ mole}} =$ **1.25 L**

Stoichiometry
Topic#3

Mole Conversions

5. How many grams, parts, and liters are 0.589moles of CO_2?
(Ans: 25.9g, $3.55x10^{23}$molecules, and 13.2L

Gun
0.589 moles CO_2

NTK
$MM_{CO_2} = 44.01\ g/mol$

Unk
mass: _____ g
parts: _____ molecules
volume: _____ L

Solve:

$$0.589\ moles \left| \frac{44.01\ g}{mol} \right. = \boxed{25.9\ g}$$

$$0.589\ mol \left| \frac{6.022 \times 10^{23}\ molecules}{moles} \right. = \boxed{3.55 \times 10^{23}\ molecules}$$

$$0.589\ mol \left| \frac{22.4\ L}{mol} \right. = \boxed{13.2\ L}$$

Mole Conversions

6. (OYO) How many moles, grams, and liters are in 7.12×10^{21} molecules of CO_2?
(Ans: 0.0118moles, 0.520g, and 0.265L)

Stoichiometry
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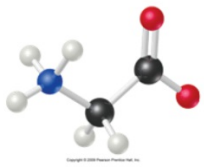
Compositional Stoichiometry



Glycine, an amino acid used by organisms to make proteins, is represented by the molecular model.

(a) Write its molecular formula. $CH_2NH_3CO_2$ or $C_2H_5NO_2$

(b) Determine its molar mass. $2C + 5H + N + 2O = 2(12.01) + 5(1.01) + 14.01 + 2(16) = 75.08 \frac{g}{mol}$

(c) Calculate the mass of 3 moles of glycine. $3 \text{ mol} \left| \frac{75.08 g}{1 \text{ mol}} \right. = 225.24 g$

(d) Calculate the percent nitrogen by mass in glycine.

$$\%N: \frac{N}{CH_2NH_3CO_2} \times 100\% = \frac{14.01}{75.08} \times 100\% = 18.7\%$$

(a) $C_2H_5NO_2$ (b) 75.08g/mol (c) 225.24 grams (d) %N = (14.01/75.08) x 100% = 18.66%

Compositional Stoichiometry

Sample WS#3 - Percent Composition and Hydrates

1. What is the percent composition by mass of the elements in SO_3?

$$\%\,S : \frac{S}{SO_3} = \frac{32.06}{(32.06+48.00)} \times 100\% = 40.0\%$$

$$\%\,O : \frac{3O}{SO_3} = \frac{48.00}{(32.06+48.00)} \times 100\% = 60.0\%$$

2. (OYO) Determine the percent of water in $BaCO_3 \bullet 5H_2O$. What is the percent of barium in the hydrate?

Stoichiometry
Topic#3

Compositional Stoichiometry

A hydrate is an ionic compound that absorbs a specific ratio of waters into its crystal lattice.
Nomenclater: ionic name plus *prefix*hydrate
Ex. $CuSO_4 \bullet 5H_2O$

3. A 15.67 g sample of a hydrate of magnesium carbonate was heated, without decomposing the carbonate, to drive off the water. The mass was reduced to 7.58 g. What is the formula of the hydrate?
(Ans: $MgCO_3 \bullet 5H_2O$)

Given
$15.67\text{g}\ MgCO_3 \cdot x H_2O$
$7.58\text{g}\ MgCO_3$

Need
$MM_{MgCO_3} = 84.31$
$MM_{H_2O} = 18.02$

Unk
$x = \dfrac{5}{MgCO_3 \cdot 5H_2O}$

Solve:

mass $_{H_2O}$: $15.67 - 7.58 = 8.09\text{g}\ H_2O$

moles $_{H_2O}$: $\dfrac{8.09}{18.02} = \dfrac{0.449\ \text{moles}}{0.090\ *} = 4.99$

molees $\dfrac{7.58}{84.31} = \dfrac{0.090}{0.090\ *} = 1$

* divide through by smallest # of moles

$1\ MgCO_3 \cdot 4.99\ H_2O$

$MgCO_3 \cdot 5H_2O$

Stoichiometry
Topic#3

Compositional Stoichiometry

4. (OYO) A hydrate of Na_2CO_3 has a mass of 4.31g before heating. After heating, the mass of the anhydrous compound is found to be 3.22g. Determine the formula of the hydrate and then write out the name of the hydrate.

Stoichiometry
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Compositional Stoichiometry

$Na_2CO_3 + 2HCl \rightarrow CO_2(g) + H_2O + 2NaCl$

5. When you react 3.9267 grams of $Na_2CO_3 \cdot nH_2O$ with excess HCl(aq), 0.6039 grams of a gas is given off. What is the number of water molecules bonded to Na_2CO_3 (value of n)? (5) $Na_2CO_3 \cdot 10H_2O$

Gvn
3.9267 g $Na_2CO_3 \cdot nH_2O$
$m_{gas} = 0.6039\ (CO_2)$

NTK
1 mol CO_2 = 1 mol CO_3^{2-}
1 mol CO_3^{2-} = 1 mol Na_2CO_3
$MM_{CO_2} = 44.01$
$MM_{Na_2CO_3} = 105.99$
$MM_{H_2O} = 18.02$

Unk
n = 10
$Na_2CO_3 \cdot 10H_2O$

Solve:

moles $CO_2 = \frac{0.6039}{44.01} = 0.0137$ moles CO_2 = moles CO_3^{2-} = moles Na_2CO_3

mass Na_2CO_3: $0.0137 \times 105.99 = 1.452$ g Na_2CO_3

mass H_2O: $m_T - m_{Na_2CO_3} = 3.9267 - 1.452 = 2.515$ g H_2O

moles H_2O: $\frac{2.515}{18.02} = 0.1396$ mole H_2O

Na_2CO_3	$\cdot n\ H_2O$
$\frac{0.0137}{0.0137}$	$\frac{0.1396}{0.0137}$
1	10.19
1 ≈	10

Compositional Stoichiometry

6. (OYO) If 1.951g $BaCl_2 \cdot nH_2O$ yields 1.864 g of anhydrous $BaSO_4$ after treatment with sulfuric acid, calculate n. (Ans: $BaCl_2 \bullet 2H_2O$)

Stoichiometry
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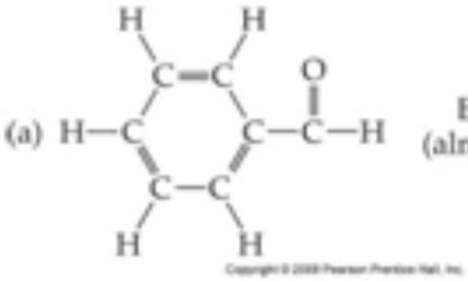
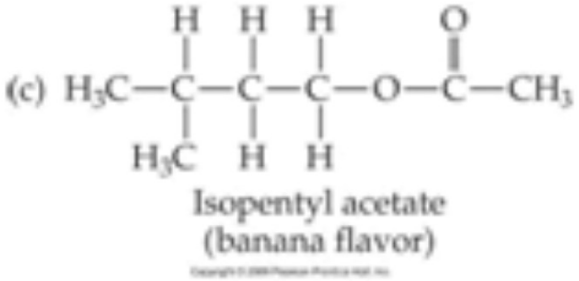
Compositional Stoichiometry





Based on the structural formula, calculate the percentage of carbon by mass percent in the compounds.

C_7H_6O = 79.21% carbon by mass

$$\%C: \frac{7C}{C_7H_6O} = \frac{7(12.01)}{106.13} = \frac{84.07}{106.13} \times 100\% = \boxed{79.21\%}$$

$C_7H_{14}O_2$ = 64.6% carbon by mass

$$\%C: \frac{7C}{C_7H_{14}O_2} = \frac{7(12.01)}{130.21} = \frac{84.07}{130.21} \times 100\% = \boxed{64.6\%}$$

Stoichiometry
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Compositional Stoichiometry

Empirical formula (EF): the simplest whole number ratio formula for a compound.
- True formula for an ionic compound (TiO_2 not Ti_2O_4)

Molecular Formula (MF): the simplest formula for a molecule, cannot be simplified.
- $C_6H_{12}O_6$ cannot be simplified to CH_2O (empirical formula)

$C_6H_{12}O_6$

Formulas

- Empirical mass (EM) = the mass of the EF
- Molecular mass (MM) = the mass of the MF
- **n = MM/EM**
- MF = n(EF)

EF = CH_2O = 12.01 + 2.02 + 16 = 30.03

Sample WS#4 - Empirical and Molecular Formulas

1. What is the empirical formula of a compound containing 40.0% sulfur and 60.0% oxygen by mass?

	S_x	O_y
mass	40.0 g	60.0 g
÷ MM	÷ 32.07	÷ 16
moles	1.25	3.75
÷ smallest amt	÷ 1.25	÷ 1.25
ratio	1	3

E.F. SO_3

Stoichiometry
Topic#3

Compositional Stoichiometry

2. A sample of an oxide of nitrogen is found to contain 30.4% nitrogen. What is its empirical formula?

N_x	O_y
30.4	69.6
14.01	16
2.17	4.35
2.17	2.17
1	2

E.F.

NO_2

Stoichiometry
Topic#3

Compositional Stoichiometry

3. Determine the empirical and molecular formulas for a compound that gives the following percentages upon analysis (in mass percents): 71.65%Cl, 24.27%C, 4.07% H. The molar mass (MM) is known to be 98.96g/mol

Given
71.65% Cl
24.27% C
4.07% H
MM = 98.96 g/mol

Solve:

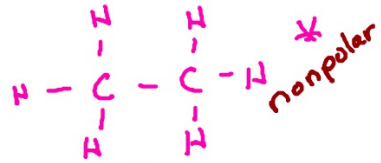
C_x	H_y	Cl_z
24.27	4.07	71.65
12.01	1.01	35.45
2.02	4.03	2.02
2.02	2.02	2.02
1	2	1

NTK
$C_x H_y Cl_z$
E.M. = 12.01 + 2.02 + 35.45
$n = \frac{MM}{EM} = \frac{98.96}{49.48} = 2$

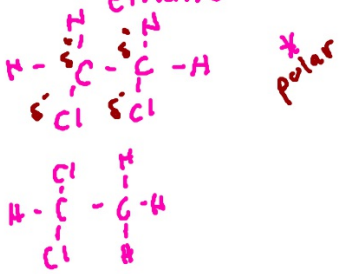
MF = n (EF)
= 2 (CH_2Cl)
= $C_2H_4Cl_2$

3. EF = $ClCH_2$, MF = $Cl_2C_2H_4$

UnK
E.F. = CH_2Cl
M.F. = $C_2H_4Cl_2$



ethane



Compositional Stoichiometry

4. Ans: P_2O_5 and P_4O_{10}

4. A white powder is analyzed and found to contain 43.64% phosphorus and 56.36% oxygen by mass. The compound has a MM of 283.88g/mol. What are the compound's empirical and molecular formula?

Given
43.64% P
56.36% O
MM = 283.88

Solve

P_x	O_y
43.64	56.36
30.97	16
1.41	3.52
1.41	1.41
1	2.5
x2	x2
2	5

UNK
P_xO_y

EM = $n = \frac{MM}{EM} = \frac{283.88}{141.94} = 2$

EF = P_2O_5
EM = 2(30.97) + 5(16) = 141.94

MF = n(EF)
= 2(P_2O_5)
= P_4O_{10}

Unk
EF: P_2O_5
MF: P_4O_{10}

Method #2
P_x: (MM)(.4364) = (283.88)(0.4364)
= 124 g P / 30.97 = (4) = x

O_y: (MM)(0.5636) = (283.88)(0.5636)
= 160 g O / 16 = (10) = y

$P_xO_y = P_4O_{10}$

Stoichiometry
Topic#3

Compositional Stoichiometry

5. (OYO) Caffeine, a stimulant found in coffee, tea, and chocolate, contains 49.48% carbon, 5.15% hydrogen, 28.87% nitrogen, and 16.49% oxygen by mass and has a molar mass of 194.2g/mol. Determine the molecular formula of caffeine. (Ans: $C_8H_{10}N_4O_2$)

Stoichiometry
Topic#3

Compositional Stoichiometry

Starter - Molecular Formulas

1. Epinephrine (adrenaline) is a hormone secreted into the bloodstream in times of danger and stress. It is 59.0% carbon, 7.1% hydrogen, 26.2% oxygen, and 7.7% nitrogen by mass. Its molar mass is about 180g/mol. What is its molecular formula?

   Ans: $C_9H_{13}O_3N$

2. Phenyl magnesium bromide is used as a Grignard reagent in organic synthesis. Determine its empirical and molecular formula if its molar mass is 181.313 g/mol and it contains 39.7458% carbon, 2.77956% hydrogen, 13.4050% magnesium, and 44.0697% bromine.

   Ans: EF=MF=C_6H_5MgBr

Stoichiometry
Topic#3

Compositional Stoichiometry

Combustion Analysis

The analyis of a combustion reaction where a hydrocarbon reacts with oxygen to produce carbon dioxide and water. Hydrogen is 11.2% (0.112) by mass of water and carbon is 27.3% (0.273) by mass of carbon dioxide.

Sample WS#5 - Combustion Analysis

1. After combustion with excess oxygen, a 12.501g of a petroleum compound produced 38.196g of carbon dioxide and 18.752 of water. A previous analysis determined that the compound does not contain oxygen. Establish the empirical formula of the compound. (Ans: C_5H_{12})

Gun

12.501 g C_xH_y
38.196 g CO_2
18.752 g H_2O

NTK

$C_xH_y + O_2 \rightarrow CO_2 + H_2O$
12.501 | 38.196 | 18.752
x 0.273 | x 0.112
10.428 g C | 2.1002 g H

Unk

E.F.: C_5H_{12}
(pentane)

Check

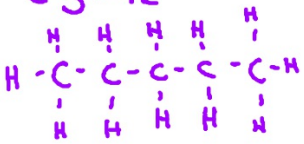
Does $m_C + m_H = m_{comp}$? (12.501)

10.428 + 2.1002 = 12.528 ✓

Solve:

	C_x	H_y
	10.428 g	2.1002 g
	12.01	1.01
	0.868	2.08
	0.868	0.868
	1	2.40

$C_1H_{2.40}$
x5 x5
C_5H_{12}



Stoichiometry
Topic#3

Compositional Stoichiometry

$\%N \text{ in } NO_2 = \frac{14.01}{(14.01+32)} = 0.304$

2. In the course of the combustion analysis of an unknown compound, 12.923g of carbon dioxide, 6.608g of water and 6.755g of nitrogen dioxide was measured. The complete combustion of 11.014g of the compound needed 15.256g of oxygen. What the compound's empirical formula? (Ans: $C_2H_5NO_2$)

Given
$12.923\,g\ CO_2$
$6.608\,g\ H_2O$
$6.755\,g\ NO_2$
$11.014\,g\ C_xH_yN_z$
$15.256\,g\ O_2$

Check
Does $m_C + m_H + m_N = m_{comp}$?
$3.528 + 0.740 + 2.054 = 6.322$ (no)
* indicate oxygen is in compound (O_ω)

NTK

$$C_xH_yN_zO_\omega + O_2 \longrightarrow CO_2 + H_2O + NO_2$$

$11.014\,g - 6.322 = m_O = 4.692\,g\ O$

$12.923 \times 0.273 = 3.528\,g\ C$
$6.608 \times 0.112 = 0.740\,g\ H$
$6.755 \times 0.304 = 2.054\,g\ N$

Solve

C_x	H_y	N_z	O_ω
3.528	0.740	2.054	4.692
12.01	1.01	14.01	16
0.294	0.734	0.147	0.293
0.147	0.147	0.147	0.147
2	4.99	1	1.99

$C_2H_{4.99}N_1O_{1.99}$

$\Downarrow$

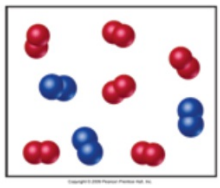
$\boxed{C_2H_5NO_2}$

Compositional Stoichiometry

3. (OYO) 12.915g of a biochemical substance was burned in an atmosphere of 50.123g of oxygen. Subsequent analysis of the gaseous result yielded 18.942g carbon dioxide, 7.749g of water and 36.347g of oxygen. Determine the empirical formula of the substance. (Ans: CH_2O)

Stoichiometry
Topic#3

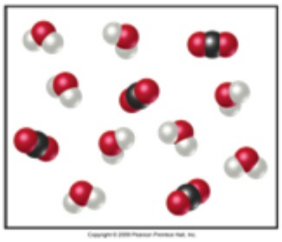
Compositional Stoichiometry



The diagram represents the collection of elements formed by a decomposition reaction. (a) If the blue spheres represent N atoms and the red ones represent O atoms, what was the empirical formula of the original compound? (b) Could you draw a diagram representing the molecules of the compound that had been decomposed? Why or why not?

Stoichiometry
Topic#3

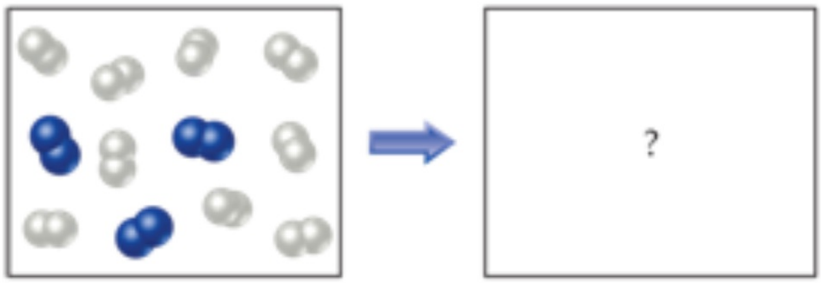
Compositional Stoichiometry



The diagram represents the collection of CO_2 and H_2O molecules formed by complete combustion of a hydrocarbon. What is the empirical formula of the hydrocarbon?

Stoichiometry
Topic#3

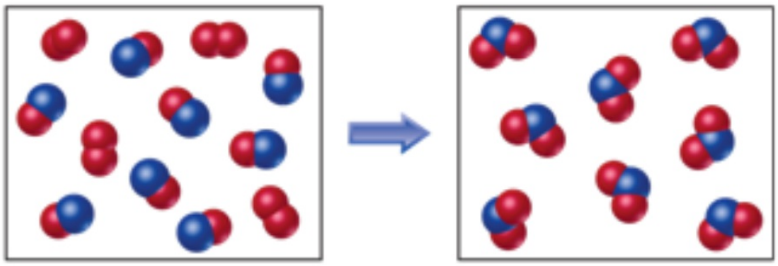
Compositional Stoichiometry



In the diagram, the white spheres represent hydrogen atoms, and the blue spheres represent nitrogen atoms. To be consistent with the law of conservation of mass, how many NH_3 molecules should be shown in the right box?

Stoichiometry
Topic#3

Compositional Stoichiometry



The diagram represents a chemical reaction in which the red spheres are oxygen atoms and the blue spheres are nitrogen atoms. (a) Write the chemical formulas for the reactants and products. (b) Write a balanced equation for the reaction. (c) Is the diagram consistent with the law of conservation of mass?

Stoichiometry
Topic#3

Reaction Stoichiometry

1. Balanced equation
2. Determine limiting reactant
3. Solve for unknown

$$\text{mass}_{gvn} * \frac{(\text{Coeff}_{unk})(MM_{unk})}{(\text{Coeff}_{gvn})(MM_{gvn})} = \text{mass}_{unk}$$

Sample WS#6 - Reaction Stoichiometry

1. Solid lithium hydroxide is used in space vehicles to remove exhaled carbon dioxide from the living environment by forming solid lithium carbonate and liquid water. What mass of gaseous carbon dioxide can be absorbed by 1.00kg of lithium hydroxide? Ans: 920.g of $CO_2(g)$

Gvn
1.00kg LiOH
(1000 g LiOH)

NTK
$2LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$
1000g (?)g

Unk
$m_{CO_2} = \underline{\quad 919 \quad}$ g

$MM_{LiOH} = 23.95\ g/mol$
$MM_{CO_2} = 44.01\ g/mol$

Solve:

$$1000\ g\ LiOH \left(\frac{(1)(44.01)}{(2)(23.95)}\right) = 918.8\ g\ CO_2\ (3sf)$$

$\boxed{919\ g\ CO_2}$

Stoichiometry
Topic#3

Reaction Stoichiometry

$$\text{mass}_{gvn} * \frac{(\text{Coeff}_{unk})(MM_{unk})}{(\text{Coeff}_{gvn})(MM_{gvn})} = \text{mass}_{unk}$$

2. Baking soda ($NaHCO_3$) is often used as an antacid. It neutralizes excess hydrochloric acid secreted by the stomach: $NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(aq)$. Milk of magnesia, which is an aqueous suspension of magnesium hydroxide, is also used as an antacid: $Mg(OH)_2(s) + 2HCl(aq) \rightarrow 2H_2O(l) + MgCl_2(aq)$. Which is the more effective antacid per gram, $NaHCO_3$ or $Mg(OH)_2$? Ans: $Mg(OH)_2$

Gvn
1g $NaHCO_3$
1g $Mg(OH)_2$

NTK
$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(aq)$
$Mg(OH)_2(s) + 2HCl(aq) \rightarrow 2H_2O(l) + MgCl_2(aq)$
$MM_{NaHCO_3} = 84.01 g/mol$
$MM_{Mg(OH)_2} = 58.33 g/mol$
$MM_{HCl} = 36.46 g/mol$

Unk
$Mg(OH)_2$ / $NaHCO_3$

$$1g\ NaHCO_3 \left(\frac{(1)(36.46)}{(1)(84.01)}\right) = 0.43g$$

$$1g\ Mg(OH)_2 \left(\frac{(2)(36.46)}{(1)(58.33)}\right) = 1.25g$$

$$1g\ NaHCO_3 \left| \frac{1mol}{84.01g} \right| \frac{1HCl}{1NaHCO_3} \left| \frac{36.46g}{mol} \right.$$

Stoichiometry
Topic#3

Reaction Stoichiometry

$$\text{mass}_{gvn} * \frac{(\text{Coeff}_{unk})(MM_{unk})}{(\text{Coeff}_{gvn})(MM_{gvn})} = \text{mass}_{unk}$$

3. Nitrogen gas can be prepared by passing gaseous ammonia over solid copper (II) oxide at high temperatures. The other products of the reaction are solid copper and water vapor. If a sample containing 18.1g of NH_3 is reacted with 90.4g of CuO, which is the LR? How many grams of N_2 would be formed? How much of the excess reactant remains? (Ans: LR is CuO; 10.6g N_2, 5.23g NH_3)

Gvn
18.1 g NH_3
90.4g CuO

$2\,NH_3(g) + 3\,CuO(s) \rightarrow N_2(g) + 3\,Cu(s) + 3\,H_2O(g)$
A1 A2 NTK B
18.1g 90.4g ?g

$MM_{N2} = 28.02$g/mol
$MM_{NH3} = 17.04$g/mol
$MM_{CuO} = 79.55$g/mol

Unk
grams: 10.6g N_2
LR: CuO
mass_{ER}: ____

Solve:

A_1: $18.1\text{g}\,NH_3\left(\frac{(1)(28.02)}{(2)(17.09)}\right) = 14.9\text{g}\,N_2$

$14.9 - 10.6 = 4.3\text{g}\,N_2$ (excess)

A_2: $90.4\text{g}\,CuO\left(\frac{(1)(28.02)}{(3)(79.55)}\right) = \boxed{10.6\text{g}\,N_2}$

$4.3\text{g}\,N_2\left(\frac{(2)(17.04)}{(1)(28.02)}\right) = 5.23\text{g}\,NH_3$ in excess

Stoichiometry
Topic#3

Reaction Stoichiometry

Percent Yield = actual x 100%
theo

4. Methanol (CH_3OH), also called methyl alcohol, is the simplest alcohol. It is used as a fuel in race cars and is a potential replacement for gasoline. Methanol can be manufactured by combination of gaseous carbon monoxide and hydrogen. Suppose 68.5kg CO(g) is reacted with 8.60kg H_2(g). Calculate the theoretical yield of methanol. If 3.57×10^4g CH_3OH is actually produced, what is the percent yield of methanol?

Ans: 6.82×10^4g CH_3OH; 52.0%

Given
68.5 Kg CO
8.60Kg H_2
3.57×10^4 g (actual)

MM_{CO} = 28.01g/mol
MM_{H2} = 2.02g/mol
MM_{CH3OH} = 32.05g/mol

A_1 A_2 NTK

$CO + 2H_2 \rightarrow CH_3OH$

6.85×10^4 g 8.600×10^3 g (?) (theo)

Unk
%yield: _____

%yield = act / theo x 100 %

Solve:

A_1: 6.85×10^4 g CO $\left(\frac{(1)(32.05)}{(1)(28.01)}\right) = 78{,}380$ g CH_3OH

A_2: 8.60×10^3 g H_2 (LR) $\left(\frac{(1)(32.05)}{(2)(2.02)}\right) = 68{,}225$ g CH_3OH theoretical amount

%yield = act / theo x 100%
$= \frac{3.57 \times 10^4}{6.8225 \times 10^4}$
= 52.3%

Reaction Stoichiometry

5. (OYO) Bornite (Cu_3FeS_3) is a copper ore used in the production of copper. When heated, the following reaction occurs: $Cu_3FeS_3(s) + O_2(g) \rightarrow Cu(s) + FeO(s) + SO_2(g)$. If 2.50 metric tons of bornite is reacted with 1.25 metric tons of oxygen and the process has an 86.3% yield of copper, what mass of copper is produced? Ans: 1.20 metric tons (1.20×10^3kg)

Reaction Stoichiometry

Reaction Stoichiometry Starter

The reaction of ethane gas (C_2H_6) with chlorine gas produces C_2H_5Cl as its main product (along with HCl). In addition, the reaction invariably produces a variety of other minor products, including $C_2H_4Cl_2$, $C_2H_3Cl_3$, and others. Naturally, the production of these minor products reduces the yield of the main product. Calculate the percent yield of C_2H_5Cl if the reaction of 300.g of ethane with 650.g of chlorine produced 490.g of C_2H_5Cl. (Ans: 82.8%)

Gas Stoichiometry

Standard Temperature and Pressure (STP)
1 atm and 0°C (273K)

Molar Volume (gases @ STP): 1 mol of any gas = 22.4L

1 atm (atmosphere) = 101.3kPa = 101,300Pa = 760mmHg = 760torr = 14.7psi

Ideal Gas Law

$PV = nRT$

R = ideal gas constant (depends on pressure)

Pressure	R value
atm	0.0821
kPa	8.314
mm Hg torr	62.4

Mole Fraction

$$X_a = \frac{n_a}{n_T}$$

$$X_a = \frac{P_a}{P_T}$$

Daltons' Law of Partial Pressures - the total pressure (P_T) is equal to the sum of the individual pressures of all the gases in the mixture including the collection of a gas over water (water displacement). $P_T = P_a + P_b + P_c + \ldots$ or $P_T = P_{H2O} + P_{gas}$

Note: the temperature of water relates to the partial pressure of the water vapor
You will need to be given this pressure or a table to find it. @ 100°C the P_{H2O} = 1.00atm

Gas Stoichiometry

$PV = nRT$ 1mol = 22.4L $P_T = P_{gas} + P_{H2O}$

Sample WS#7 - Ideal Gas Law, Molar Volume, and Gas Stoichiometry

1. How many moles of gas are in an 85.5L cylinder of oxygen gas? (Ans: 3.82 moles O_2)

Gun: 85.5 L O_2 (3 sf); assume STP

NTK: 1mol O_2 = 22.4 L

Unk: moles$_{O_2}$ = _____ mol

Solve:

$$85.5\text{ L } O_2 \times \frac{1\text{ mol}}{22.4\text{ L}} = 3.817\text{ mol} = \boxed{3.82\text{ mol } O_2}$$

2. A container holds 0.8790 moles of carbon dioxide gas at 273K and 101.3kPa. What is the volume of the container? (Ans: 19.69L of CO_2)

Gun: P = 101.3 kPa; V = ? L; n = 0.8790; R = 8.314; T = 273 K ✓ (3 sf)

NTK: $PV = nRT$, $V = \frac{nRT}{P}$

Unk: V = 19.7 L

Solve:

$$V = \frac{(0.8790)(8.314)(273)}{(101.3)} = 19.685\text{ L} = \boxed{19.7\text{ L}}$$

or $0.8790 \times \frac{22.4\text{ L}}{1\text{ mol}} = 19.6896 = \boxed{19.7\text{ L}}$

Gas Stoichiometry

$PV = nRT$ 1mol = 22.4L $P_T = P_{gas} + P_{H2O}$

3. 355mL of a gas, at 56.3°C, has a pressure of 789.2 torr. How many moles of gas are present? (Ans: 0.0136 mole)

Gun
P = 789.2 torr
V = 355mL = 0.355L
n = ? mol
R = 0.0821
T = 273 + 56.3

NTK
PV = nRT
n = PV/RT

Solve
$n = \frac{(789.2/760)(0.355)}{(0.0821)(273+56.3)} = 0.01363$ mol

Unk
n = 0.0136 mol

4. If the gas in question #3 had a mass of 0.598g, what is its molar mass? (Ans: 44.0g/mol)

Gun
m = 0.598g
mol = 0.0136 mol

UTk
mm = g/mol

Unk
mm = 44.0 g/mol

Solve: $MM = \frac{0.598g}{0.0136mol} = 43.97$ g/mol
(44.0)

Stoichiometry
Topic#3

Gas Stoichiometry

$PV = nRT$ 1mol = 22.4L $P_T = P_{gas} + P_{H2O}$

5. In the combustion of sulfur, how many liters of sulfur dioxide are produced from 25.8g of sulfur? The gas is collected at standard temperature and pressure. (Ans: 18.0L SO_2)

Given
25.8 g S_8
@ STP

NTK

$S_8 + 8O_2 \rightarrow 8SO_2$
25.8 g ? L

Unk
$V_{SO_2} =$ 18.0 L

1 mol = 22.4 L

$MM_{S_8} = 256.56$ g/mol

Solve:

$$25.8\text{ g } S_8 \left| \frac{1\text{ mol}}{256.56\text{ g}} \right. \text{①} \left| \frac{8\,SO_2}{S_8} \right. \text{②} \left| \frac{22.4\text{ L}}{\text{mol}} \right. \text{③} = 18.0206\text{ L}$$

3 s.f.

18.0 L SO_2

① Convert mass S_8 into moles S_8
② Convert moles S_8 into moles SO_2
③ Convert moles SO_2 into liters SO_2 (molar volume)

Gas Stoichiometry

$PV = nRT$ 1mol = 22.4L $P_T = P_{gas} + P_{H2O}$

6. If 101.58 liters of SO_2 was produced in the reaction from question #5, how many grams of oxygen were used? (Ans: 145.11 grams of O_2)

Given
101.58L SO_2

NTK
$S_8 + 8O_2 \rightarrow 8SO_2$

@ STP use 1mol = 22.4L

UNK
mass O_2 = 145.11 g

Solve:

① convert L SO_2 to moles O_2

② $8O_2$

③ 32.00 g

① 101.58L | 1mol | ② $8O_2$ | ③ 32.00 g = 145.11 g O_2
22.4L | $8SO_2$ | 1mol

② Convert moles of SO_2 into moles of O_2

③ Convert moles of O_2 into grams O_2

Gas Stoichiometry

$PV = nRT$ 1mol = 22.4L $P_T = P_{gas} + P_{H2O}$

7. Consider the unbalanced chemical equation for the combustion of propane:

$$C_3H_8(g) + O_2(g) \rightarrow H_2O(g) + CO_2(g)$$

What volume of oxygen at 25°C and 1.04atm is needed for the complete combustion of 5.53grams of propane? (Ans: 14.7L O_2)

Gun

P = 1.04 atm (3sf)

T = 25+273 = 298K

R = 0.0821

5.53g C_3H_8

n = ? (3sf)

NTK

$C_3H_8 + 5O_2 \rightarrow 4H_2O + 3CO_2$ (moles)

5.53g ? L

$MM_{C_3H_8}$ = 44.11g/mol

UNK

V_{O_2} = 14.7 L

$PV = nRT$

$V = \frac{nRT}{P}$

Solve:

$$\frac{5.53\text{g } C_3H_8}{44.11\text{g}} \left| \frac{\text{mol}}{C_3H_8} \right| \frac{5O_2}{\text{mol}} = 0.6268 \text{ moles } O_2 \text{ (n)}$$

$$V_{O_2} = \frac{(0.6268)(0.0821)(298)}{(1.04)} = 14.745 \text{ L } O_2$$

14.7L O_2

Gas Stoichiometry

$PV = nRT$ 1mol = 22.4L $P_T = P_{gas} + P_{H2O}$

8. (OYO) Ammonia and gaseous hydrogen chloride combine to form ammonium chloride. If 4.21L of ammonia at 27°C and 1.02atm is combined with 5.35L hydrogen chloride at 26°C and 0.998atm, what mass of ammonium chloride will be produced? Which gas is the limiting reactant? Which gas is the excess reactant? How many liters of the excess gas are left over? (Ans: 9.32g; NH_3; HCl; 1.06L HCl)

Stoichiometry

Topic#3

Solution Stoichiometry

M = moles/liters = mol/L = $\frac{g/MM}{L}$

[X] = moles of X/liters

If X is a soluble ionic compound then the [ion] equals the [X] multiplied by the subscript of the ion

Sample WS#8 - Solution Stoichiometry

1. What is the molarity of a solution of magnesium chloride made from dissolving 15.00g in 450.mL of water? What are the concentrations of the ions in solution? (Ans: $[MgCl_2]=0.350M$; $[Mg^{2+}]=0.350M$; $[Cl^{1-}]=0.700M$

Given
15.00 g
450.mL = 0.450L

$M = \frac{mol}{L} = \frac{g/MM}{L}$ NTK

$MM_{MgCl_2} = 95.21$

$MgCl_2 \rightarrow Mg^{2+} + 2Cl^-$
$-x \quad +x \quad +2x$

Unk
$[MgCl_2] =$ _____ M
$[Mg^{2+}] =$ _____ M
$[Cl^-] =$ _____ M

Solve
$[MgCl_2] = \frac{\left(\frac{15}{95.21}\right)}{0.450} = 0.350\,M$

$[MgCl_2] = x = [Mg^{2+}] = 0.350\,M$

$[Cl^-] = 2x = 2[MgCl_2] = 2(0.350) = 0.700\,M$

Solution Stoichiometry

2. How many grams of potassium dichromate are needed to make a 25.6mL of a 0.1054*M* solution? (Ans: 0.794g)

g s.s.

Given
25.6mL = 0.0256L
$[K_2Cr_2O_7] = 0.1054M$

NTK
$M = \frac{g/MM}{L}$
$MM_{K_2Cr_2O_7} = 294.2\ g/mol$

UNK
mass = 0.794 g

Solve:

$$0.1054 = \frac{(g/294.2)}{0.0256}$$

$$g = (0.1054)(0.0256)(294.2) = 0.7938\ g$$

$0.794\ g$

Solution Stoichiometry

3. What is the volume of a 0.498*M* sodium sulfate solution that contains 94.27 grams?
(Ans: 1.33L or 1330mL)

Given

$[Na_2SO_4] = 0.498M$

$94.27g\ Na_2SO_4$

$M = \frac{g/MM}{L}$ (NTK)

$MM_{Na_2SO_4} = 142.05$

$V_{H_2O} = \underset{(1330mL)}{1.33}\ L$ (UNK)

Solve:

$$L = \frac{g/MM}{M} = \frac{94.27\,g}{\frac{142.05\,g/mol}{0.498\,\frac{mol}{L}}} = 1.33|4\ L$$

3 s.f.

Stoichiometry
Topic#3

Solution Stoichiometry

Dilution Equation
$M_1V_1 = M_2V_2$
moles 1st = moles 2nd

moles = moles

(Note: For 4th row transition metals, assume a charge of 2+ if no charge is given. Except V.)

4. A biologist needs to make 50.0mL of a 0.250*M* solution of sodium chloride. The storeroom has 10.0mL of an unopened certified container of 0.750*M* solution of sodium chloride. Is this enough to make her solution?

Given

$M_1 = 0.250\ M$

$V_1 = 50.0\ mL$

$M_2 = 0.750\ M$

* V_T is 50.0mL

$V_T = V_{soln} + V_{H_2O}$ (dilution)

$V_T - V_{soln} = V_{H_2O}$

$V_{H_2O} = 50 - 16.7$

$= 33.3\ mL\ H_2O$

NTK

$M_1V_1 = M_2V_2$

$\frac{M_1V_1}{M_2} = V_2$

Solve: $V_2 = \frac{(0.250)(50)}{(0.750)} = 16.7\ mL$

UNK

Y / (N)

- needs 16.7mL of the 0.750 M soln dissolved in 33.3* mL of distilled water to make 50.0mL of a 0.250M soln.

Solution Stoichiometry

5. When you use 25.0mL of 4.0*M* HCl(*aq*) to produce hydrogen gas , how many grams of zinc does it react with? What volume of hydrogen gas is produced if the temperature of the gas is 37°C under a pressure of 975mmHg? (Ans: 3.3g zinc; 0.99L)

Given ↙ 2 s.f.

25.0mL of 4.0M HCl

T = 273 + 37 = 310K

P = 975 mm Hg / 760 = 1.283 atm

R = 0.0821

NTK

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

moles HCl = V × M

mol HCl = $(25 \times 10^{-3})(4.0)$

= 0.1 mol HCl

UNK

$mass_{Zn}$ = 3.3g g

V_{H_2} = 0.99 L

Solve: (a) $\frac{0.1 \text{ mol HCl}}{2HCl} \left| \frac{Zn}{} \right| \frac{65.39 g}{mol} = 3.2695 g\ Zn = \boxed{3.3 g\ Zn}$ (2 s.f.)

(b) $\frac{0.1 \text{ mol HCl}}{2HCl} \left| \frac{H_2}{} \right| = 0.05 \text{ moles } H_2 = n$

$V = \frac{nRT}{P} = \frac{(0.05)(0.0821)(310)}{(1.283)} = 0.9919 = \boxed{0.99 L}$ (2 s.f.)

Solution Stoichiometry

6. How much 0.80*M* HCl would be needed to dissolve a $CaCC_3$ pearl with a mass of 4.0grams? (Ans: 0.10L or 100mL)

Gun
0.80 M HCl
$mass_{CaCO_3} = 4.0\,g$
(2 s.f.)

NTK
$2\,HCl + CaCO_3 \rightarrow H_2CO_3 + CaCl_2$
4.0 g
UNK
$V_{HCl} = 0.10\ L$

$MM_{CaCO_3} = 100.09\ g/mol$

$M = \frac{mol}{L}$

Solve:

$$\frac{4.0\,g\,CaCO_3}{1}\left|\frac{mol}{100.09\,g}\right|\frac{2\,HCl}{CaCO_3} = 0.07993\ moles\ HCl$$

(2 sf)

$$L = \frac{mol}{M} = \frac{0.07993\ mol}{0.80\ \frac{mol}{L}} = 0.09991$$

$$= \boxed{0.10\,L}$$

Solution Stoichiometry

7. Throwing some scrap iron in a gold (III) nitrate solution causes gold metal to precipitate. How much 0.50*M* gold (III) nitrate solution would react with 224 grams of iron metal (the Fe(s) becomes the Fe^{2+} ion)? (Ans: 5.34L $Au(NO_3)_3$)

Given
0.50M $Au(NO_3)_3$
224 g Fe
(2sf)

NTK
$2\,Au(NO_3)_3 + 3\,Fe \rightarrow 2\,Au + 3\,Fe(NO_3)_2$
$M = \frac{mol}{L}$
$MM_{Fe} = 55.85\ g/mol$

UNK
V = 5.3 L

Solve:

$$224\ g\ Fe \left| \frac{1\ mol}{55.85\ g} \right| \frac{2\ Au(NO_3)_3}{3\ Fe} = 2.674\ moles\ Au(NO_3)_3$$

$$L = \frac{mol}{M} = \frac{2.674}{0.50} = 5.3|48\ L = \boxed{5.3\ L}$$

Solution Stoichiometry

8. When aqueous solutions of Na_2SO_4 and $Pb(NO_3)_2$ are mixed, $PbSO_4$ precipitates. Calculate the mass of $PbSO_4$ formed when 1.25L of 0.0500*M* $Pb(NO_3)_2$ and 2.00L of 0.0250*M* Na_2SO_4 are mixed (Ans: 15.2g)

Given

1.25L of 0.0500 M $Pb(NO_3)_2$ (S_1)

2.00L of 0.0250 M Na_2SO_4 (S_2)

(3sf)

NTK

$Na_2SO_4 + Pb(NO_3)_2 \rightarrow 2NaNO_3 + PbSO_4$

$L \times M = moles$

Unk

$m_{ppt} = 15.2$ g

Solve:

(S_1) $1.25L \times 0.05 = 0.0625 mol\ Pb(NO_3)_2 \left| \frac{PbSO_4}{Pb(NO_3)_2} \right| \frac{303.27g}{1mol} = 19.0g\ PbSO_4$

(S_2) $2.00 \times 0.0250 = 0.05 mol\ Na_2SO_4 \left| \frac{PbSO_4}{Na_2SO_4} \right| \frac{303.27g}{1mol} = 15.1635$

$= 15.2g\ PbSO_4$

Solution Stoichiometry

9. (OYO) Sea water is about 0.5*M* NaCl. To produce Cl_2 gas, a company evaporates sea water, melts the NaCl, and runs electricity through it. How many kilograms of NaCl are needed to fill a tank car with 1,120,000 liters of chlorine gas at a pressure of 89.5atm, and a temperature of 32°C? How many liters of sea water are needed? (Ans: 4.68×10^5kg NaCl; 1.60×10^7L)

Solution Stoichiometry

29. Three volatile compounds X, Y, and Z each contain element Q. The percent by weight of element Q in each compound was determined. Some of the data obtained are given below.

Compound	Percent by weight of Element Q	Molecular Weight
X	64.8%	88.1
Y	73.0%	104.
Z	59.3%	64.0

a. Determine the mass of element Q contained in 1.00 mole of each of the three compounds.

b. Calculate the most probable value of the atomic weight of element Q.

c. Compound Z contains carbon, hydrogen, and element Q. When 1.00 gram of compound Z is oxidized and all of the carbon and hydrogen are converted to oxides, 1.37 grams of CO_2 and 0.281 gram of water are produced. Determine the most probable molecular formula of compound Z.

Solution Stoichiometry

In-Class Stoichiometry FRQ

A 10.0 g sample containing calcium carbonate and an inert material was placed in excess hydrochloric acid. A reaction occurred producing calcium chloride, water, and carbon dioxide.

(a) Write a balanced equation for the reaction.

(b) When the reaction was complete, 1.55 g of carbon dioxide gas was collected. How many moles of calcium carbonate were consumed in the reaction?

(c) If all the calcium carbonate initially present in the sample was consumed in the reaction, what percent by mass of the sample was due to calcium carbonate?

(d) If the inert material was only silicon dioxide, what was the mole fraction of silicon dioxide in the mixture? mole fraction = N1 = n1 ntotal

(e) Perhaps there had been some other material present in the original sample that was not so inert and generated a gas during the reaction. Would this have caused the calculated percentage of calcium carbonate in the sample to be higher, lower or have no effect? Justify your response

Solution Stoichiometry

In-Class Stoichiometry FRQ

A 10.0 g sample containing calcium carbonate and an inert material was placed in excess hydrochloric acid. A reaction occurred producing calcium chloride, water, and carbon dioxide.

(a) Write a balanced equation for the reaction.

(b) When the reaction was complete, 1.55 g of carbon dioxide gas was collected. How many moles of calcium carbonate were consumed in the reaction?

Ans: (

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Solution Stoichiometry

In-Class Stoichiometry FRQ

A 10.0 g sample containing calcium carbonate and an inert material was placed in excess hydrochloric acid. A reaction occurred producing calcium chloride, water, and carbon dioxide.

(c) If all the calcium carbonate initially present in the sample was consumed in the reaction, what percent by mass of the sample was due to calcium carbonate?

An

Solution Stoichiometry

$$X_A = \frac{n_A}{n_{TOT}}$$

In-Class Stoichiometry FRQ

A 10.0 g sample containing calcium carbonate and an inert material was placed in excess hydrochloric acid. A reaction occurred producing calcium chloride, water, and carbon dioxide.

(d) If the inert material was only silicon dioxide, what was the mole fraction of silicon dioxide in the mixture?

Ans:

Solution Stoichiometry

In-Class Stoichiometry FRQ

A 10.0 g sample containing calcium carbonate and an inert material was placed in excess hydrochloric acid. A reaction occurred producing calcium chloride, water, and carbon dioxide.

(e) Perhaps there had been some other material present in the original sample that was not so inert and generated a gas during the reaction. Would this have caused the calculated percentage of calcium carbonate in the sample to be higher, lower or have no effect? Justify your response

End of Topic#3 - Stoichiometry