Stoichiometry________________________________ Z Ch 3, H Ch 1-4, 22-1

"Stoichiometry is the science of measuring the quantitative proportions or mass ratios in which chemical elements stand to one another." **Jeremias Benjamin Richter, 1792**

Richter introduced the word stoichiometry (Greek, *stoicheion*- element and *metron*- measure)

emails – include course #

Relative Atomic Mass

Mass Spectrometry

Atoms and the Mole

Composition of Compounds

Determining the Formulas of Compounds

CHEMICAL EQUATIONS
- Balancing
- Stoichiometry Calculations
- Yields

Quiz on Friday – material through M lecture

Harris text will soon be needed

Balancing Equations - PRACTICE

Academic Integrity

As an academic community, UIC is committed to providing an environment in which research, learning, and scholarship can flourish and in which all endeavors are guided by academic and professional integrity. All members of the campus community – students, staff, faculty, and administrators – share the responsibility of insuring that these standards are upheld so that such an environment exists. Instances of academic misconduct by students will be handled pursuant to the Student Disciplinary Policy: http://www.uic.edu/depts/dos/studentconduct.html

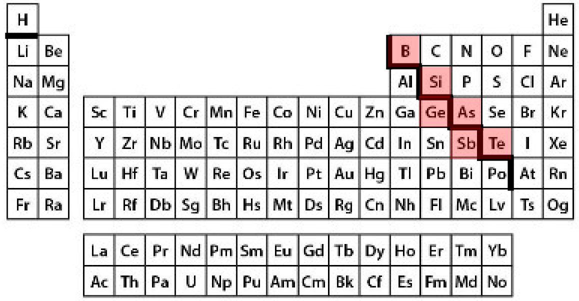
For quizzes and exams

1. cell phones and all other electronic devices **turned off**
2. **work area free** of all notes, texts, other written or printed material
3. work area may only contain a calculator, pens/pencils, and few BLANK pages for working on
4. **only one window open** on your computer/laptop which is accessing OWL through Blackboard
5. **no communication with any other person** during the assessment except with permission of the TA/instructor
5. **no communication about the quiz/exam** with anyone until after 5 pm on the day the assessment is given

Compounds (Metalloid Can Be Substituted for Nonmetal)

REVIEW FROM MONDAY

Ionic (Cation-Anion)	Covalent (Nonmetals)		
	Nonmetal-Nonmetal	Compounds Containing Hydrogen	
		H-Nonmetal	H-Oxyanion
Rule: Name of cation + name of anion (word "ion" dropped). **Examples:** $ZnSO_4$ zinc sulfate $NaNO_2$ sodium nitrite $CaCl_2$ calcium chloride Fe_3N_2 iron(II) nitride Li_2CO_3 lithium carbonate NH_4I ammonium iodide $Cu(IO_3)_2$ copper(II) iodate BaH_2 barium hydride **Comment:** The name does not indicate the numbers of cations and anions because there is only one possibility for the ions to combine to form a compound.	**Rule:** a) Less electronegative element generally first (exception: when one of the elements is hydrogen) b) Greek prefixes give number of atoms of each kind c) Initial prefix mono dropped **Prefixes:** 1 = mono 6 = hexa 2 = di 7 = hepta 3 = tri 8 = octa 4 = tetra 9 = nona 5 = penta 10 = deca **Examples:** SCl_6 sulfur hexachloride N_2O_4 dinitrogen tetroxide CO carbon monoxide CO_2 carbon dioxide NO_2 nitrogen dioxide N_2O dinitrogen monoxide **Comment:** Tetraoxide becomes tetroxide, monooxide becomes monoxide, etc., so name sounds better	**Rule 1:** (without the presence of H_2O) hydrogen _ide **Examples**: HCl hydrogen chloride HF hydrogen fluoride H_2S hydrogen sulfide H_2Se hydrogen selenide **Rule 2:** H acids (when dissolved in H_2O) hydro_ic acid **Examples:** HCl hydrochloric acid HF hydrofluoric acid H_2S hydrosulfuric acid H_2Se hydroselenic acid **Comment:** (a) These H-containing compounds are named as if they were ionic. (b) Often the (aq) in the formulas of the acids is omitted when it is obvious from the context that they are acids.	**Rule 1:** (without the presence of H_2O) like ionic compounds: cation + anion hydrogen hypo_ite hydrogen _ite hydrogen _ate hydrogen per_ate **Rule 2:** HO acids (when dissolved in H_2O) hypo_ous acid _ous acid _ic acid per_ic acid **Examples:** HClO hypochlorous acid $HClO_2$ chlorous acid $HClO_3$ chloric acid $HClO_4$ perchloric acid HNO_2 nitrous acid HNO_3 nitric acid H_2SO_3 sulfurous acid H_2SO_4 sulfuric acid H_3PO_4 phosphoric acid **Comment:** The *(aq)* is usually omitted.



ordering of elements in formula of binary molecular compounds: order according to Group number, bottom to top; for any pair, element furthest right behaves as the “anion” (H, O need to be memorized):

H_2SO_4
hydrogen sulfate!

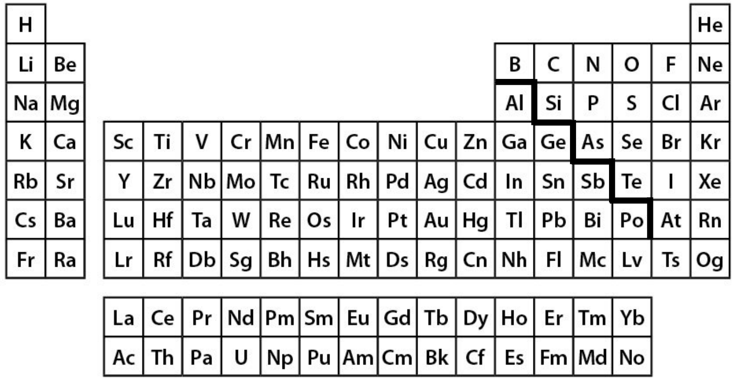
FOR LATER

Ordering Elements in Binary Molecular Compounds

Ordering of elements in formula of binary molecular compounds: order according to Group number, bottom to top; for any pair, element furthest right behaves as the “anion” (**H**, **O** need to be memorized):

semimetals (metalloids) and nonmetals

	B	Ge Si C	Sb As P N	**H**	Te Se S	I Br Cl	**O**	F
Group #:	3A	4A	5A		6A	7A		



C, Si **SiC**

H, Te **H_2Te**

Relative Atomic Masses

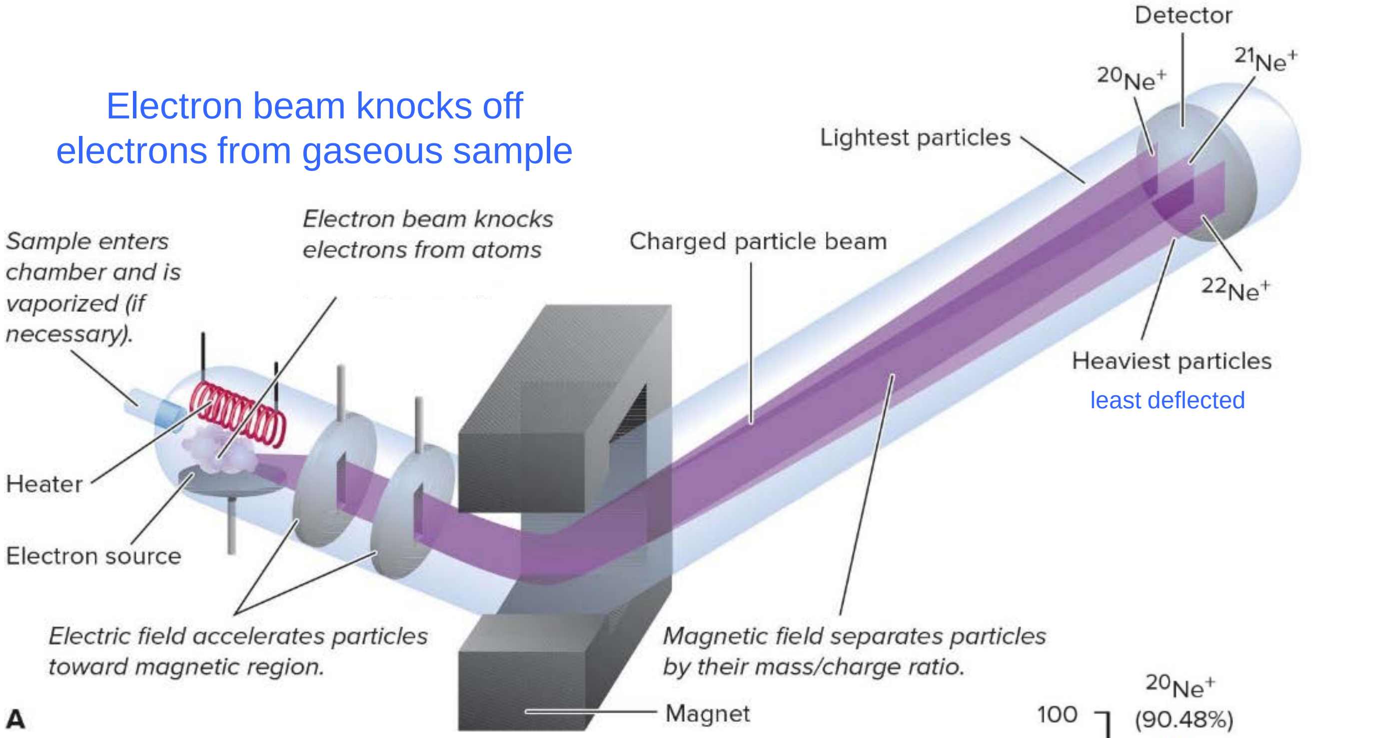
particle	charge	mass (u)
electron	-1	0.00054857
proton	+1	1.00727646
neutron	0	1.00866491

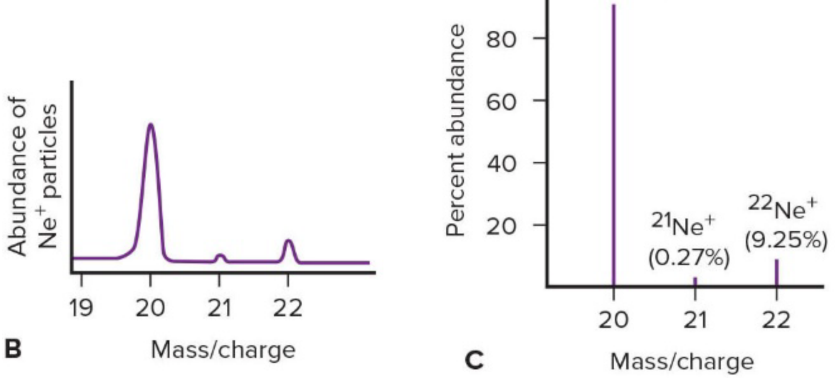
isotope	#p	#n	mass (u)	mol fract
^{20}Ne	10	10	19.992440	0.9048
^{21}Ne	10	11	20.993846	0.0027
^{22}Ne	10	12	21.991385	0.0925

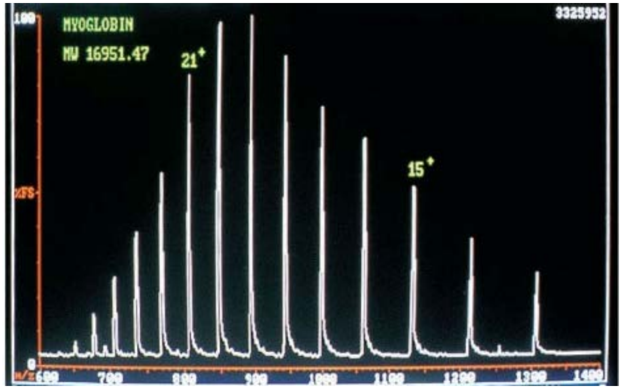
Relative **A**tomic **M**ass

$$\text{RAM} = \sum_i m_i f_i$$

Separating the Neon Isotopes







Horse myoglobin – common MW calibrant for mass spectrometers

REVIEW FROM MONDAY

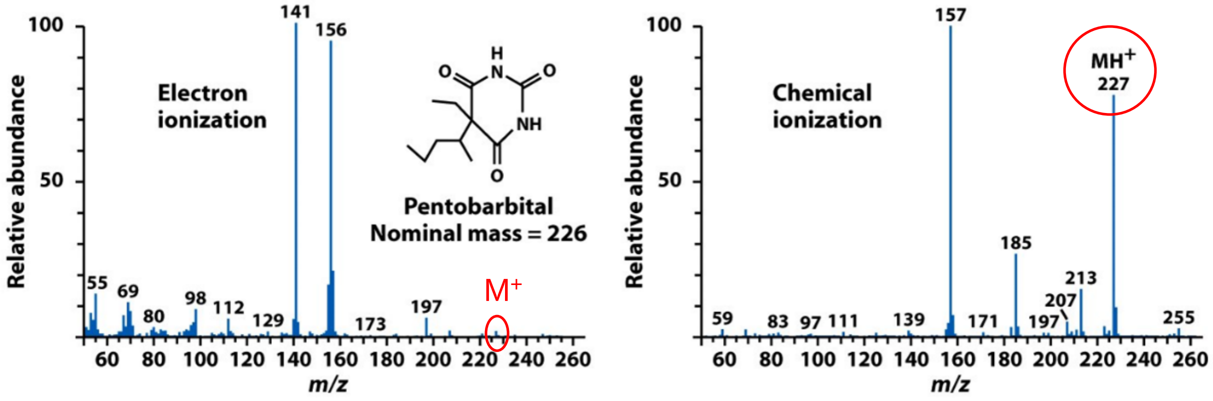
Some Types of Mass Spec

EI – electron ionization

impact by very high energy e^-

$M + e^- \rightarrow M^{+\cdot} + e^-$ (lower energy)

$M^{+\cdot}$ detected, fragments



CI – chemical ionization

reagent gas (CH_4, NH_3) in ionization source, protonates molecule

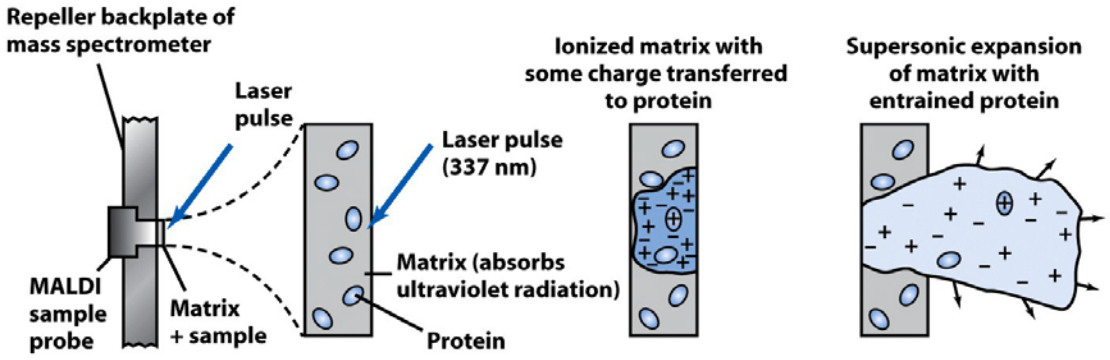
$M + (gas^+) \rightarrow MH^+ + gas$

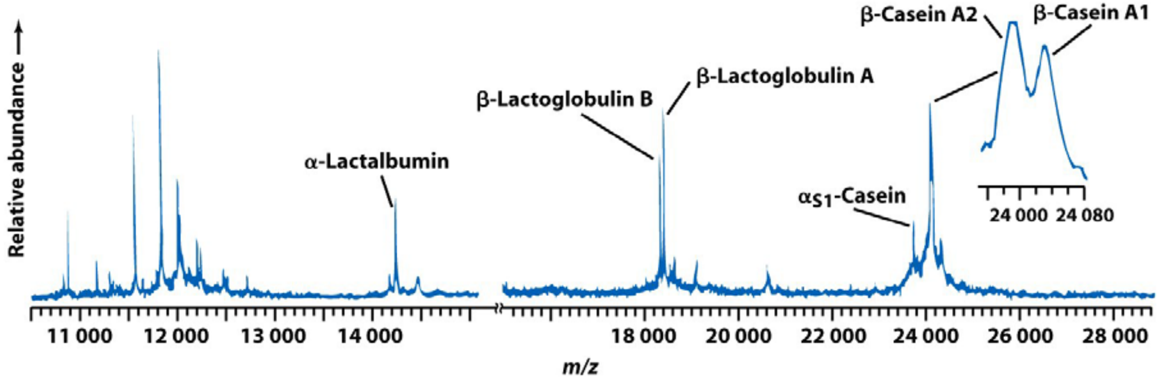
less fragmentation

MALDI – matrix-assisted laser desorption/ionization

M dissolved in UV absorbing compd, evaporated, UV laser vaporizes matrix into gas phase, M^+ formed

$M \sim 10^6$ g/mol - biomolecules





REVIEW FROM MONDAY

Working with Isotopic Data

RAM = 10.811

EX 1. From the following data and your periodic table determine the percent natural abundance of the following two isotopes:

isotope	mass	f_i
boron-10	10.01294	x
boron-11	11.00931	$1-x$

fractions sum to 1

RAM = $\sum_i m_i f_i$ => $10.811 = 10.01294x + 11.00931(1-x)$

$x = (11.00931-10.811)/(11.00931-10.01294)$

3 decimals

significant figures

$= 0.19831/0.99837$

$= 0.1990324$ => 19.9% ^{10}B

80.1% ^{11}B

Working with Isotopic Data

EX 2. Copper has two isotopes. 30.91% of the mass of copper is due to ^{65}Cu whose isotopic mass is 64.9278. Calculate the mass of the other isotope and give its complete symbol.

$$\text{RAM} = \sum_i m_i f_i = m_{\text{Cu-65}} f_{\text{Cu-65}} + m_x f_x = 63.55 \qquad \sum_i f_i = 1$$

$$m_x = \frac{65.55 - (0.3091)(64.9278)}{1.0000 - 0.3091}$$

$$= (63.55 - 20.0618)/0.6909$$

$$= 62.93$$

Atoms and the Mole

EX 4. A single atom of an element has a mass of 2.10730×10^{-22} g. What is the element assuming it has only one isotope?

ratio of RAMs = ratio of masses of atoms

$$\frac{\text{RAM x}}{12} = \frac{2.10730 \times 10^{-22}}{(12\text{ g} / N_o)}$$

$$\text{RAM x} = 2.10730 \times 10^{-22} N_o$$

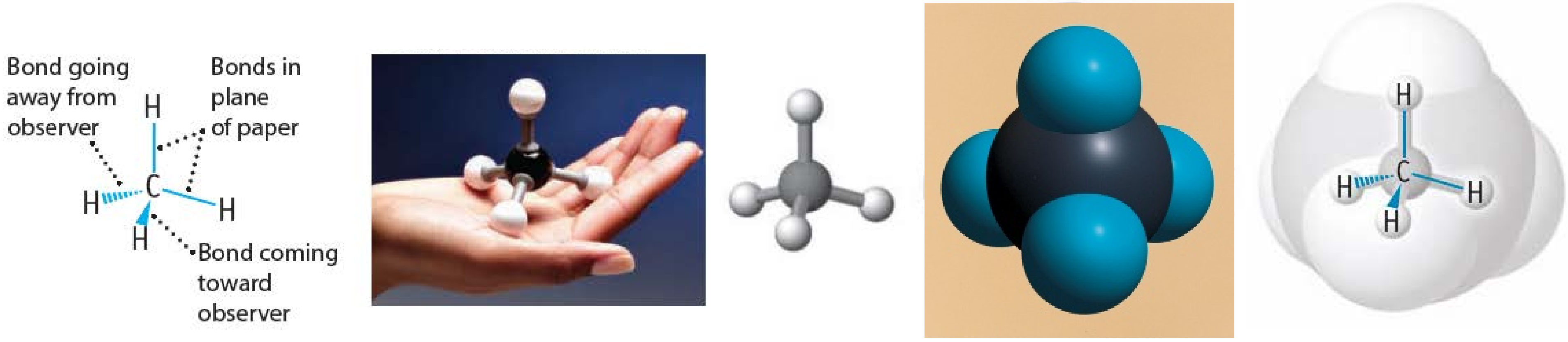
$$= 126.904 \quad \Rightarrow \quad \text{iodine}$$

Atoms and the Mole – Composition of Compounds

relative atomic mass (RAM) => actual mass of one atom (Lorenzo Romano Amadeo Carlo **Avogadro,** Conte di Quarequa e di Cereto)

Avogado's Number defined to be the number of atoms in exactly 12 g of ^{12}C (1 mole) $No = 6.02214 \times 10^{23}\ \text{mol}^{-1}$

molar mass: atoms <=> mole <=> mass



Simple perspective drawing | Plastic model | Ball-and-stick model | Space-filling model | The three representations in a single drawing.

% Composition

EX 8. Find the percent composition of sulfuric acid, H_2SO_4 ; [H = 1.0079, S = 32.065, O = 15.999]

$$M_{H_2SO_4} = 2(1.0079) + 32.065 + 4(15.999) = 98.0768$$

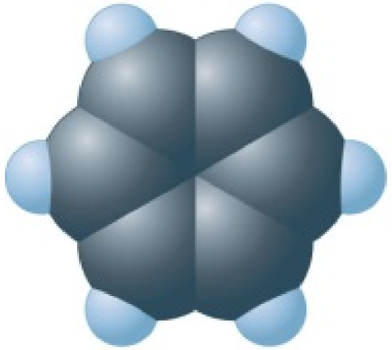
H: 2(1.0079)/98.0768 × 100 = 2.055328069

S: 32.065/98.0768 × 100 = 32.69376652

O: 4(15.999)/98.0768 × 100 = 65.25090541

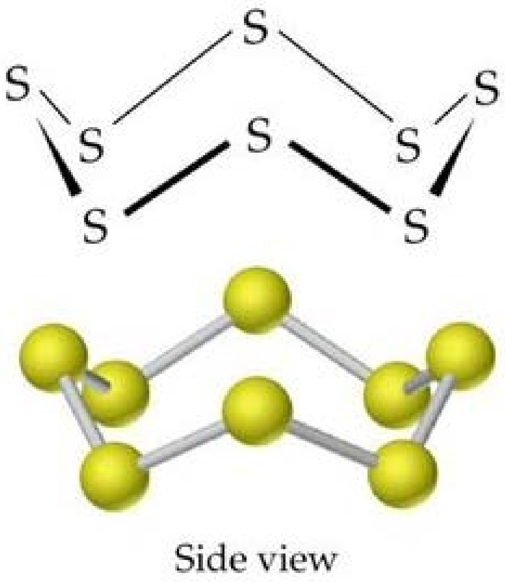
Determining the Formula of a Compound

empirical and **molecular formulas**



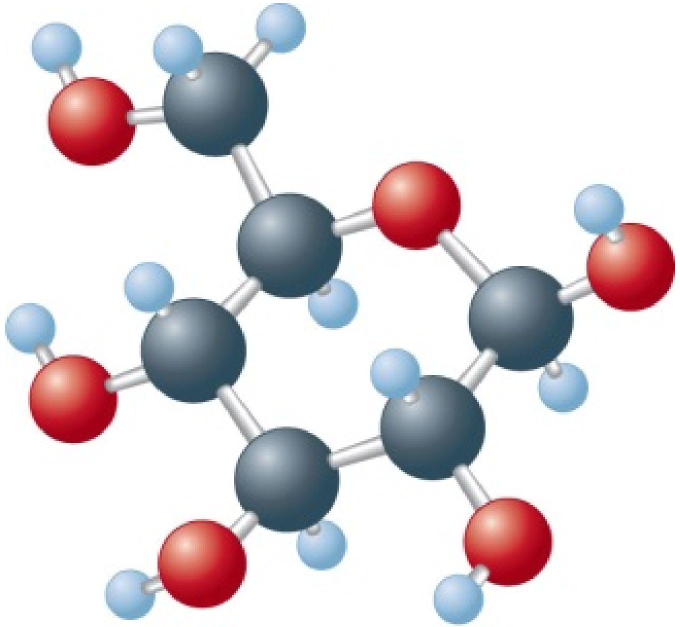
$C_6H_6 = (CH)_6$

benzene



$S_8 = (S)_8$

elemental sulfur



$C_6H_{12}O_6 = (CH_2O)_6$

glucose

Formula from Mass Data

EX 9. Find the empirical formula of an iron oxide if 1.596 g of the oxide contains 1.116 g of iron. [Fe= 55.845, O = 15.999]

find moles then ratio

Fe: 1.116/55.845 = 0.01998388

O: (1.596 – 1.116)/15.999 = 0.03000187

whole number ratio

O / Fe = 0.03000187 / 0.019998388 = 1.5013 × 2 / 2 = 3.002 / 2

= 3O / 2 Fe => Fe_2O_3

Formula from % Composition

EX 10. A compound of sulfur and fluorine contains 25.2% S. [S = 32.065, F = 18.998]

a) What is its empirical formula? find moles then ratio, assume a mass

S: 25.2/32.065 = 0.78590
F: (100 – 25.2)/18.998 = 3.93725 difference

S : F = 0.78590 / 3.93725 => 1 / 5.01 => SF_5

b) If 0.0450 moles has a mass of 11.4 g what is its molecular formula?

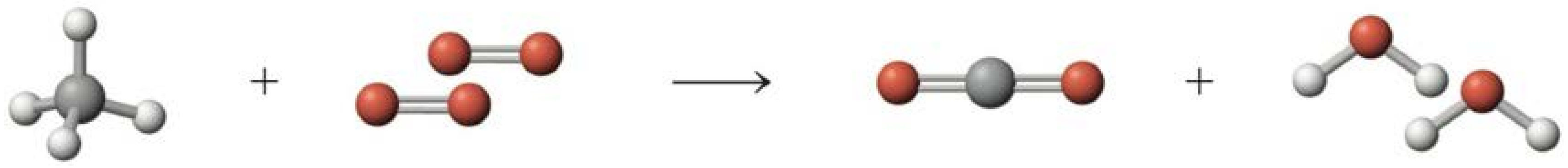
M_{SF_5} = 32.065 + 5(18.998) = 127.05 (empirical formula mass)

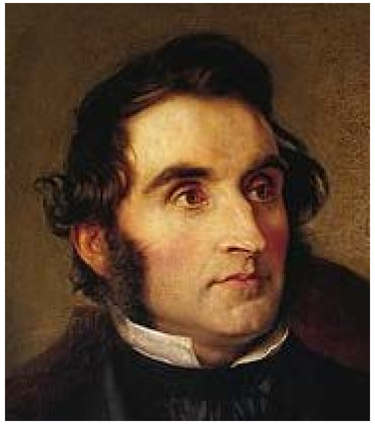
M => g / mol = 11.4/0.0450 = 253.3 g/mol (molecular formula mass)

ratio: 253.3/127.055 = 1.993 => S_2F_{10}

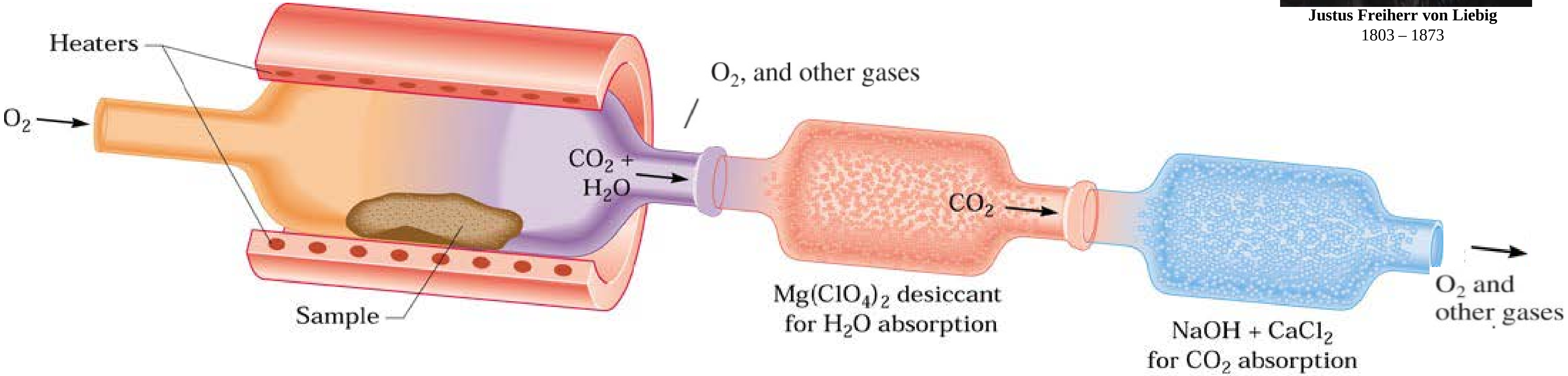
Formula from Chemical Analysis

$$CH_4(g) + 2\ O_2(g) \longrightarrow CO_2(g) + 2\ H_2O(\ell)$$





Justus Freiherr von Liebig
1803 – 1873



A combustion train for measuring the amounts of carbon and hydrogen in a compound

Formula from Chemical Analysis (Combustion)

EX 11. Compound contains only C, H, N, O. Burning 1.261 g in excess O_2 produced 2.286 g CO_2 and 0.5805 g water vapor. 0.364 g N_2 gas also collected. What is its empirical formula? [C = 12.011, H = 1.0079, N = 14.0067, O = 15.999; M_{CO_2} = 44.009; M_{H_2O} = 18.0148]

{ C, H, O, N } -> CO_2 + H_2O + N_2

CO_2: (2.286 g CO_2 / 44.009 g/mol) (1 mol C/1 mol CO_2) = 0.05194 mol C 0.062389 g C

H_2O: (0.5805 / 18.0148) (2 mol H/1 mol H_2O) = 0.0644 mol H 0.06495 g H

N_2: (0.364 / 14.007) = 0.02598 mol N

O: 1.261 – (0.62389 + 0.06495 + 0.364) = 0.013 mol O 0.2081 g O

C : H : N : O = 0.0519 : 0.0644 : 0.0259 : 0.013

3.99 : 4.96 : 2.00 : 1.00 => $C_4H_5N_2O$

Chemical Equations

"Nothing is created ... and it may be considered as a general principle that in every operation [reaction] there exists an equal quantity of matter before and after the operation ... It is on this principle that is founded all the art of per forming chemical experiments ..." **Antoine Laurent de Lavoisier, 1785**

Lavosier's **Law of Conservation of Mass** - in a chemical reaction matter is neither created nor destroyed:

Chemical Equations

indicate the **physical state**

$HCl(aq) + NaHCO_3(s) \Rightarrow NaCl(aq) + CO_2(g) + H_2O(l)$

(*g*)	The substance is in the gaseous state or vapor state.
(*ℓ*)	The substance is in the liquid state.
(*fl*)	The substance is in a fluid state (either gas or liquid).
(*s*)	The substance is in the solid state.
(*cr*)	The substance is crystalline.
(*aq*)	The substance is dissolved in water (in aqueous solution).
(*sln*)	The substance is in solution.

Conservation of Mass => Balance Equations

by inspection

$$\underline{\ 3\ }\,NaBr + \underline{\ 1\ }\,H_3PO_4 \rightarrow \underline{\ 3\ }\,HBr + \underline{\ 1\ }\,Na_3PO_4$$

most complicated first

$$\underset{\underline{\ 1\ }}{4}\,C_3H_5N_3O_9 \rightarrow \underset{\underline{\ 3\ }}{12}\,CO_2 + \underset{\underline{\ 3/2\ }}{6}\,N_2 + \underset{\underline{\ 5/2\ }}{10}\,H_2O + \underset{\underline{\quad}}{1}\,O_2$$

balance O: $9 = 6 + 5/2 + 2x$; $2x = (18 - 12 - 5)/2 = ½ \Rightarrow x = 1/4$

algebraic method

$$\underline{\ \mathbf{a}\ }\,HNO_2 + \underline{\ \mathbf{b}\ }\,HI \rightarrow \underline{\ \mathbf{c}\ }\,NO + \underline{\ \mathbf{d}\ }\,I_2 + \underline{\ \mathbf{e}\ }\,H_2O$$

Conservation of Mass => Balance Equations

algebraic method

$\overset{2}{\underline{\ a\ }}HNO_2 + \overset{2}{\underline{\ 2d\ }}HI \rightarrow \overset{2}{\underline{\ a\ }}NO + \overset{1}{\underline{\ d\ }}I_2 + \overset{2}{\underline{\ e\ }}H_2O$

unique atoms: N a => c = a

I => b = 2d d

(**5 unknowns → 3**)

balancing atoms : H: a + 2d = 2e 2d = a

N: a = a

O: 2a = a + e => a = e

I: 2d = 2d

so a = 2d = e; let d = 1 then a = 2

d = 1

e = 2

a chemical equation requiring complicated algebraic manipulations is best solved by matrix methods

Stoichiometry – Mass Relationship between Reactants and Products

$$2\ C_5H_{10}(l)\ +\ 15\ O_2(g)\ \rightarrow\ 10\ CO_2(g)\ +\ 10\ H_2O(l)$$

LOTS OF INFORMATION

2 C_5H_{10} molecules + 15 O_2 molecules $\rightarrow$ 10 CO_2 molecules + 10 H_2O molecules

4 C_5H_{10} molecules + 30 O_2 molecules $\rightarrow$ 20 CO_2 molecules + 20 H_2O molecules

$2N_o$ C_5H_{10} molecules + $15N_o$ O_2 molecules $\rightarrow$ $10N_o$ CO_2 molecules + $10N_o$ H_2O molecules

2 mol C_5H_{10} + 15 mol O_2 $\rightarrow$ 10 mol CO_2 + 10 mol H_2O

140.268 g C_5H_{10} + 479.97 g O_2 $\rightarrow$ 440.09 g CO_2 + 180.148 g H_2O

620.24 g $\rightarrow$ 620.24 g