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)

Relative Atomic Mass

Mass Spectrometry

Atoms and the Mole

Composition of Compounds

Determining the Formulas of Compounds

CHEMICAL EQUATIONS
- Balancing
- Stoichiometry Calculations
- Yields

MONDAY Labor Day holiday

% Composition => by mass

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: $2(1.0079)/98.0768 \times 100 = 2.055328069$

S: $32.065/98.0768 \times 100 = 32.69376652$

O: $4(15.999)/98.0768 \times 100 = 65.25090541$

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 (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 => $C_4H_5N_2O$

REVIEW FROM WEDNESDAY

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

4 12 6 10 1

$\underline{\ 1\ }C_3H_5N_3O_9 \rightarrow \underline{\ 3\ }CO_2 + \underline{\ 3/2\ }N_2 + \underline{\ 5/2\ }H_2O + \underline{\quad}O_2$

balance O: 9 = 6 + 5/2 + 2x; 2x = (18 – 12 – 5)/2 = ½ => 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

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

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

REVIEW FROM WEDNESDAY

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

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

EX 12. For the reaction [H = 1.0079, C = 12.011 => M = 70.134]

a) How many g of oxygen needed to completely oxidize 37.00 g of C_5H_{10}? g C_5H_{10} -> g O_2

$$(37.00 \text{ g} / 70.134 \text{ g/mol})(15 \text{ mol } O_2 / 2 \text{ mol } C_5H_{10})(2\times15.000 \text{ g } O_2 / \text{mol } O_2) = 126.6 \text{ g}$$

minimum amount

b) How many grams of carbon dioxide are formed?

$$(37.00 \text{ g} / 70.134 \text{ g/mol})(10 \text{ mol } CO_2 / 2 \text{ mol } C_5H_{10})(44.009 \text{ g } CO_2 / \text{mol } CO_2) = 116.1 \text{ g}$$

maximum yield

c) How many grams of water are formed?

$$(37.00 \text{ g} / 70.134 \text{ g/mol})(10 \text{ mol } H_2O / 2 \text{ mol } C_5H_{10})(18.014 \text{ g } H_2O / \text{mol } H_2O) = 47.52 \text{ g}$$

maximum yield

d) In another reaction 1.25 L of O_2 were consumed, how many liters of CO_2 were produced? *T, P* same before and after the reaction. (Gay-Lussac 's Law of Combining Volumes)

$$(1.25 \text{ L } O_2) (10 \text{ L } CO_2 / 15 \text{ L } O_2) = 0.833 \text{ L } CO_2$$

Solving Stoichiometry Problems

EX 13. A mixture containing 20.0 g of methane (CH_4) and 100. g of oxygen is ignited and burned. What substances will be found in the mixture after the reaction stops?

$$\mathbf{1}\ CH_4(g) + \mathbf{2}\ O_2(g) \rightarrow CO_2(g) + \mathbf{2}\ H_2O(l)$$

[C = 12.011, H = 1.0079 => M_{CH_4} = 12.011 + 4(1.0079) = 16.0426
O = 15.999 => M_{O_2} = 2(15.999) = 31.998; M_{CO_2} = 12.011 + 2(15.999) = 44.009]

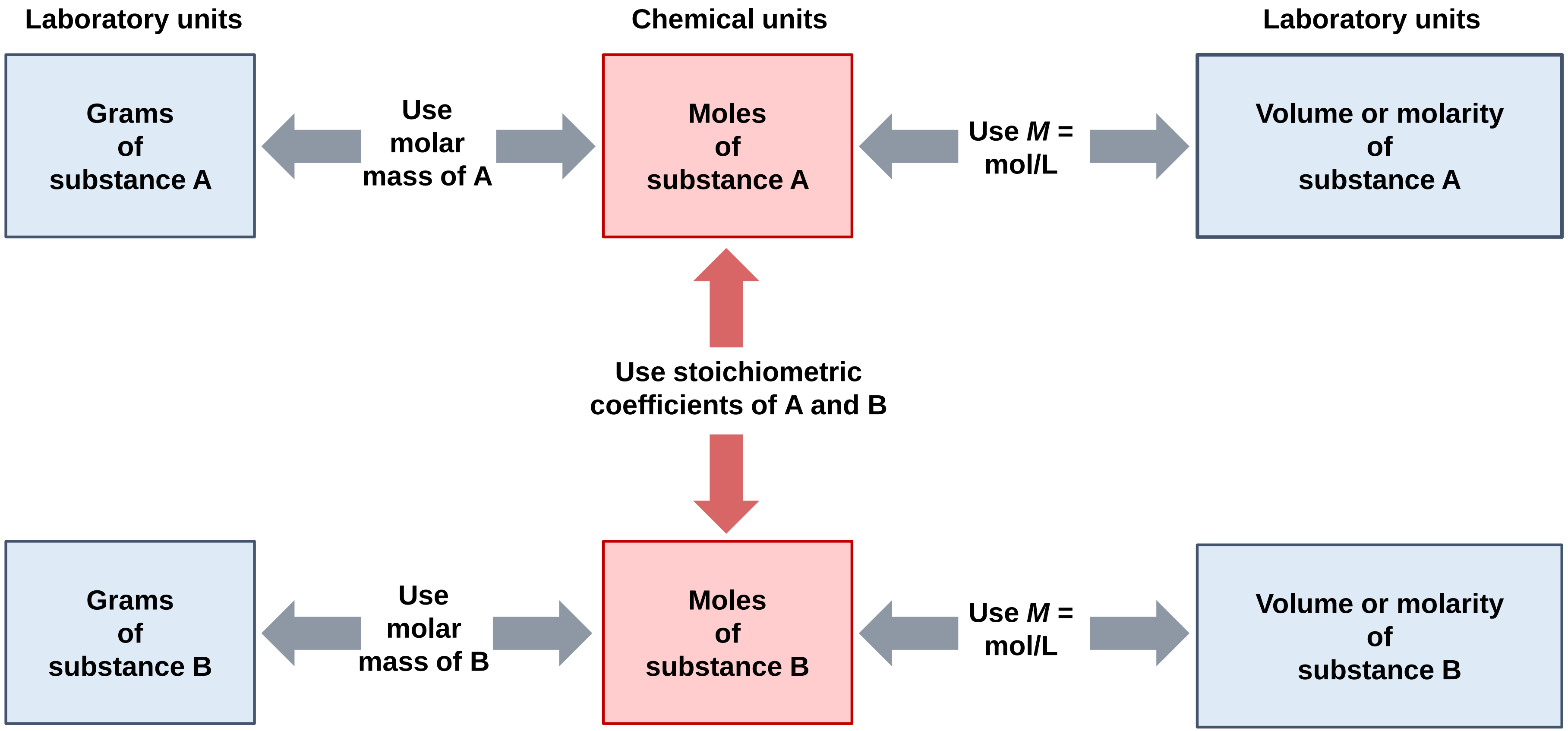
CH_4: (20.0 g / 16.0426 g/mol)(2 mol H_2O / 1 mol CH_4) = **2.493 mol H_2O** **limiting**

O_2: (100. g / 31.1998 g/mol)(2 mol H_2O / 2 mol O_2) = **3.125 mol H_2O**

could have used CO_2

mixture after reaction contains CO_2, H_2O, and unreacted O_2

Solving Stoichiometry Problems



Solving Stoichiometry Problems

EX 14. When hydrogen sulfide gas is bubbled into a solution of sodium hydroxide, sodium sulfide and water are produced. How many grams of sodium sulfide are formed if 2.50 g of hydrogen sulfide is bubbled into a solution containing 1.85 g of sodium hydroxide?

$$[M_{NaOH} = 39.996,\ M_{H_2S} = 34.080,\ M_{Na_2S} = 78.04]$$

$$\mathbf{1}\ H_2S(g) + \mathbf{2}\ NaOH(aq) \rightarrow \mathbf{1}\ Na_2S(aq) + 2\ H_2O(l)$$

Which **limits** reaction? g reactant -> mol reactant -> mol any product (Na_2S)

H_2S: (2.50 g / 34.081 g/mol)(1 mol Na_2S / 1 mol H_2S) = 0.0733 mol Na_2S

NaOH: (1.85 g / 39.997 g/mol)(1 mol Na_2S / 2 mol NaOH) = 0.0231 mol

(0.02312)(78.04 g/mol) = **1.80 g Na_2S**