CHEM 101-080 Fall 2004
Problem-Solving Session 4
Chapter 8
October 25, 2004

Ch. 8: Chemical Reactions

(1) Molecular Formula

(A) The following are empirical formulas and molecular weights for five compounds. What are their molecular formulas?

Compound	Molecular Weight (g/mol)	Molecular Formula
NaS_2O_3	270.4	$Na_2S_4O_6$
C_3H_2Cl	147.0	$C_6H_4Cl_2$
C_2HCl	181.4	$C_6H_3Cl_3$
Na_2SiO_3	732.6	$Na_{12}Si_6O_{18}$
$NaPO_3$	305.9	$Na_3P_3O_9$

(2) Empirical Formula

(A) Arsenic reacts with oxygen to form a compound that is 75.7% arsenic and 24.3% oxygen, by weight. What is the empirical formula of this compound?

Solution

$$0.757\,g\ As \times \frac{mol\ As}{74.922\,g\ As} = 0.0101\,mol\ As$$

$$0.243\,g\ O \times \frac{mol\ O}{15.999\,g\ O} = 0.0152\,mol\ O$$

$$As_{\frac{0.0101}{0.0101}}O_{\frac{0.0152}{0.0101}} = AsO_{1.50} = AsO_{\frac{3}{2}} \Rightarrow As_2O_3$$

(B) A substance was found to be composed of 60.8% sodium, 28.5% boron, and 10.5% hydrogen. What is the empirical formula of the compound?

Solution

$$0.608\,g\ Na \times \frac{mol\ Na}{22.990\,g\ Na} = 0.0264\,mol\ Na$$

$$0.285\,g\ B \times \frac{mol\ B}{10.81\,g\ B} = 0.0264\,mol\ B$$

$$0.105\,g\ H \times \frac{mol\ H}{1.0079\,g\ H} = 0.104\,mol\ H$$

$$Na_{\frac{0.0264}{0.0264}} B_{\frac{0.0264}{0.0264}} H_{\frac{0.104}{0.0264}} = NaBH_{3.94} \Rightarrow NaBH_4$$

(C) The addictive substance in cigarette smoke, Nicotine, is extracted from the dried leaves of the tobacco plant. Nicotine is composed of 74.0% carbon, 8.7% hydrogen, and 17.3% nitrogen, and its molecular weight is 162.23 g/mol. What are the empirical and molecular formulas of nicotine?

Solution

$$74.0\,g\ C \times \frac{mol\ C}{12.01\,g\ C} = 6.16\,mol\ C$$

$$8.7\,g\ H \times \frac{mol\ H}{1.0079\,g\ H} = 8.6\,mol\ H$$

$$17.3\,g\ N \times \frac{mol\ N}{14.01\,g\ N} = 1.23\,mol\ N$$

$$Empirical\ formula\ is:\ C_{\frac{6.16}{1.23}} H_{\frac{8.6}{1.23}} N_{\frac{1.23}{1.23}} = C_5H_7N$$

$$C_5H_7N\ empirical\ unit: molecular\ weight = 5\times 12.01 + 7\times 1.0079 + 14.01 = 81.115\,g/mol$$

$$\frac{162.23\,g/mol}{81.115\,g/mol} = 2 \Rightarrow Molecular\ formula\ is:\ C_{2x5}H_{2x7}N_{2x1} = C_{10}H_{14}N_2$$

(3) Stoichiometry: Problem #1

Chemical analysis* of the smoke generated by a popular brand of cigarettes yielded the following data.

Constituent	Concentration (mg/cig)
Nicotine	0.5
CO (carbon monoxide)	7
Tar (particulate matter)	6

* www.ash.org.uk/html/regulation/html/tartables.html#_Toc505880434

(A) If a person smokes 5 cigarettes per day, what mass of CO_2 is produced from the nicotine in one year? Assume that 95% of the nicotine (i.e. 9.5 mg) in each cigarette is combusted, that no carbon monoxide is produced, and that the only combustion products are $CO_{2\,(g)}$, $NO_{2\,(g)}$, and $H_2O_{(l)}$.

Solution

$$2C_{10}H_{14}N_{2(s)} + 31O_{2(g)} \rightarrow 20CO_{2(g)} + 4NO_{2(g)} + 14H_2O_{(l)}$$

$$\frac{0.5\,mg\text{ Nicotine}}{x} = \frac{5}{95} \quad \Rightarrow \quad x = 9.5\ mg\text{ Nicotine (this was given)}$$

$$1\,year \times \frac{365\,days}{year} \times \frac{5\,cigarettes}{day} \times \frac{9.5\,mg\text{ Nicotine}}{cigarette} \times \frac{g}{1000\ mg} = 17.3\ g\text{ Nicotine}$$

$$17.3\,g\,C_{10}H_{14}N_2 \times \frac{mol\,C_{10}H_{14}N_2}{162.23\,g\,C_{10}H_{14}N_2} \times \frac{20\ mol\,CO_2}{2\ mol\,C_{10}H_{14}N_2} \times \frac{44.01\,g\,CO_2}{mol\,CO_2} = 47\,g\,CO_2$$

(B) If a person smokes 5 cigarettes per day, what mass of tar is produced in one year?

Solution

$$1\,year \times \frac{365\,days}{year} \times \frac{5\,cigarettes}{day} \times \frac{6\,mg\ tar}{cigarette} \times \frac{g}{1000\,mg} = 11\ g\ tar$$

(4) Stoichiometry: Problem #2 - (Prob. 8-84)

Propane burns according to the following equation.

$$C_3H_8\,(g) + 5O_2\,(g) \rightarrow 3CO_2\,(g) + 4H_2O\,(l)$$

(a) How many moles of CO_2 are produced from the combustion of 0.450 mole of C_3H_8 ? How many moles of H_2O are produced? How many moles of O_2 are needed?

$$0.450\,mol\,C_3H_8 \times \frac{3\,mol\,CO_2}{mol\,C_3H_8} = 1.35\,mol\,CO_2$$

$$0.450\,mol\,C_3H_8 \times \frac{4\,mol\,H_2O}{mol\,C_3H_8} = 1.80\,mol\,H_2O$$

$$0.450\,mol\,C_3H_8 \times \frac{5\,mol\,O_2}{mol\,C_3H_8} = 2.25\,mol\,O_2$$

(b) What mass of H_2O is produced if 0.200 mol of CO_2 is also produced?

$$0.200\,mol\,CO_2 \times \frac{4\,mol\,H_2O}{3\,mol\,CO_2} \times \frac{18.01\,g\,H_2O}{mol\,H_2O} = 4.80\,g\,H_2O$$

(c) What mass of C_3H_8 is required to produce 1.80 g of H_2O?

$$1.80\,g\,H_2O \times \frac{mol\,H_2O}{18.01\,g\,H_2O} \times \frac{mol\,C_3H_8}{4\,mol\,H_2O} \times \frac{44.096\,g\,C_3H_8}{mol\,C_3H_8} = 1.10\,g\,C_3H_8$$

(d) What mass of C_3H_8 is required to react with 160 g of O_2 ?

$$160\,g\,O_2 \times \frac{mol\,O_2}{32.00\,g\,O_2} \times \frac{mol\,C_3H_8}{5\,mol\,O_2} \times \frac{44.096\,g\,C_3H_8}{mol\,C_3H_8} = 44.1\,g\,C_3H_8$$

(e) What mass of CO_2 is produced by the reaction of 1.20×10^{23} molecules of O_2?

$$1.20\times10^{23}\ molecules\ O_2 \times \frac{mol\ O_2}{6.0223\times10^{23}\ molecules\ O_2} \times \frac{3\ mol\ CO_2}{5\ mol\ O_2} \times \frac{44.01\ g\ CO_2}{mol\ CO_2} = 5.26\ g\ CO_2$$

(f) How many moles of H_2O are produced if 4.50×10^{22} molecules of CO_2 are produced?

$$4.50\times10^{22}\ molecules\ CO_2 \times \frac{mol\ CO_2}{6.0223\times10^{23}\ molecules\ CO_2} \times \frac{4\ mol\ H_2O}{3\ mol\ CO_2} = 0.0996\ mol\ H_2O$$

(5) Stoichiometry: Problem #3

Calculate the mass of CO_2 produced from one tank of gasoline. Assume that the gasoline is 100% octane (C_8H_{18}) and that the only combustion products are CO_2 and H_2O. Assume also that the size of the tank is 20 gallons and that the density of gasoline is 0.60 g/ml.

Solution

$$2C_8H_{18}\ (l)\ +\ 25O_2\ (g) \rightarrow 16CO_2\ (g)\ +\ 18H_2O\ (l)$$

$$20\ gal\ C_8H_{18} \times \frac{3.785\ l}{gal} \times \frac{1000\ ml}{l} \times \frac{0.60\ g}{ml} = 45{,}420\ g\ C_8H_{18}$$

$$45{,}420\ g\ C_8H_{18} \times \frac{mol\ C_8H_{18}}{114.22\ g\ C_8H_{18}} \times \frac{16\ mol\ CO_2}{2\ mol\ C_8H_{18}} \times \frac{44.01\ g\ CO_2}{mol\ CO_2} = 140{,}006\ g\ CO_2$$

$$140{,}006\ g\ CO_2 \times \frac{kg}{1000\ g} \times \frac{2.205\ lb}{kg} = 309\ lb\ CO_2$$

(6) Limiting Reactant - Problem #1

Identify the limiting reactant for each combination in the table given the following reaction equation.

$$C_2H_4\ (g)\ +\ 30_2\ (g)\ \rightarrow\ 2CO_2\ (g)\ +\ 2H_2O\ (l).$$

mols C_2H_4 (g)	**mols 0_2 (g)**	**Limiting reactant**
3	8	0_2 (g)
3	9	Neither - both are completely consumed
3	10	C_2H_4 (g)
0.5	3	C_2H_4 (g)
1	3	Neither - both are completely consumed
1.5	3	0_2 (g)

(7) Limiting Reactant - Problem #2

Ethylene, C_2H_4, burns in air to form CO_2 and H_2O. How many grams of CO_2 will be formed when a mixture containing 2.80 g C_2H_4 and 6.25 g O_2 is ignited? The reaction equation is

$$C_2H_4\ (g)\ +\ 30_2\ (g)\ \rightarrow\ 2CO_2\ (g)\ +\ 2H_2O\ (l).$$

Solution

(a) First convert grams to moles.

$$2.80\,g\,C_2H_4 \times \frac{mol\,C_2H_4}{28.0\,g\,C_2H_4} = 0.100\,mol\,C_2H_4$$

$$6.25\,g\,O_2 \times \frac{mol\,O_2}{32.0\,g\,O_2} = 0.195\,mol\,O_2$$

(b) Check whether enough O_2 is present to react with all of the C_2H_4 (or *vice-versa*).

$$0.100\, mol\, C_2H_4 \times \frac{3\, mol\, O_2}{1 mol\, C_2H_4} = 0.300\, mol\, O_2 \text{ required to consume all} C_2H_4$$

Because fewer than the required number of moles of O_2 are present, the limiting reactant is O_2.

(c) Calculate the mass of CO_2 based on the amount of limiting reactant.

$$0.195\, mol\, O_2 \times \frac{2\, mol\, CO_2}{3\, mol\, O_2} \times \frac{44.0\ g\, CO_2}{mol\, CO_2} = 5.72\, g\, CO_2 \text{ produced}$$