

CHM1311 B: Principles of Chemistry

Prof. N. Goto
Assignment #2

Due Oct 3rd, at the beginning of class

Solutions must be written legibly, in the space provided. Adequate detail to the calculation (including units, appropriate sig figs) must be provided to make it possible for other students to understand how you arrived at the final solution. If more space is needed, use the back of the page. Do not add extra pages, as they will not be marked. Assignment pages must be stapled together.

Assignments can be submitted individually, or by groups of up to 4 students.

1) Name: _____ Student ID: _____

2) Name: _____ Student ID: _____

3) Name: _____ Student ID: _____

4) Name: _____ Student ID: _____

NOTE: For each question a hint, or reference to an Office Hours video in WileyPLUS is given in brackets.

Question 1. (Office hours video 2.7)

A balloon, when filled, holds 4.25 L of air at 1.03 bar at a temperature of 25.5 °C.

- a) How many moles of air is contained in the full balloon? (2 marks)

$$V = 4.25 \text{ L} \quad p = 1.03 \text{ bar} \quad T = 25.5^\circ\text{C} = 298.65 \text{ K}$$

$$n = \frac{pV}{RT} = \frac{(1.03 \text{ bar})(4.25 \text{ L})}{(0.08314 \text{ L bar K}^{-1} \text{ mol}^{-1})(298.65 \text{ K})}$$
$$= \underline{\underline{0.176 \text{ mol}}}$$

- b) The balloon was filled using compressed air at 25.5 °C and 34.6 bar. What volume of compressed air was required to fill the balloon at this temperature? (1 mark)

$$\therefore n, T \text{ ARE CONSTANT}$$
$$p_1 V_1 = p_2 V_2$$
$$V_2 = \frac{(1.03 \text{ bar})(4.25 \text{ L})}{(34.6 \text{ bar})}$$
$$= \underline{\underline{0.127 \text{ L}}}$$

Question 2. (Video problem 2.17)

Prior to the discovery of the Tanzania helium fields, there were fears of a world-wide helium shortage, which would have spelled big trouble for technology in medicine and science that requires this element for cryogenic cooling. Helium is usually purified from natural gas, the composition of which depends on the source. Suppose a 36.26 g sample of extracted gas was found to contain 32.2 g methane (CH₄), 2.95 g ethane (C₂H₆), and 0.923 g propane (C₃H₈), along with helium. What would be the partial pressure of helium in extracted gas at 2.65 atm? (4 marks)

$$\begin{aligned}
 P_{\text{He}} &= \chi_{\text{He}} P_T \\
 &= \frac{n_{\text{He}}}{n_T} P_T \\
 P_T &= 2.65 \text{ atm}
 \end{aligned}$$

$$\begin{aligned}
 m_{\text{CH}_4} &= 32.2 \text{ g} & m_{\text{C}_2\text{H}_6} &= 2.95 \text{ g} & m_{\text{C}_3\text{H}_8} &= 0.923 \text{ g} & m_{\text{He}} &= m_T - m_{\text{CH}_4} - m_{\text{C}_2\text{H}_6} - m_{\text{C}_3\text{H}_8} \\
 M_{\text{CH}_4} &= (12.01 + 4 \times 1.008) \frac{\text{g}}{\text{mol}} & M_{\text{C}_2\text{H}_6} &= (2 \times 12.01 + 6 \times 1.008) \frac{\text{g}}{\text{mol}} & M_{\text{C}_3\text{H}_8} &= (3 \times 12.01 + 8 \times 1.008) \frac{\text{g}}{\text{mol}} & &= (36.26 - 32.2 - 2.95 - 0.923) \text{ g} \\
 &= 16.042 \frac{\text{g}}{\text{mol}} & &= 30.068 \frac{\text{g}}{\text{mol}} & &= 44.094 \frac{\text{g}}{\text{mol}} & &= 0.187 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 n_{\text{CH}_4} &= \frac{m_{\text{CH}_4}}{M_{\text{CH}_4}} & n_{\text{C}_2\text{H}_6} &= \frac{2.95 \text{ g}}{30.068 \frac{\text{g}}{\text{mol}}} & n_{\text{C}_3\text{H}_8} &= \frac{0.923 \text{ g}}{44.094 \frac{\text{g}}{\text{mol}}} & n_{\text{He}} &= \frac{0.187 \text{ g}}{4.003 \frac{\text{g}}{\text{mol}}} \\
 &= \frac{32.2 \text{ g}}{16.042 \frac{\text{g}}{\text{mol}}} & &= 0.09811 \text{ mol} & &= 0.02093 \text{ mol} & &= 0.04671 \text{ mol} \\
 &= 2.007 \text{ mol} & & & & & &
 \end{aligned}$$

$$\begin{aligned}
 n_T &= n_{\text{CH}_4} + n_{\text{C}_2\text{H}_6} + n_{\text{C}_3\text{H}_8} + n_{\text{He}} = 2.007 + 0.09811 + 0.02093 + 0.04671 = 2.173 \text{ mol} \\
 P_{\text{He}} &= \frac{n_{\text{He}}}{n_T} P_T = \frac{0.04671 \text{ mol}}{2.173 \text{ mol}} \times 2.65 \text{ atm} = \underline{\underline{0.0570 \text{ atm}}}
 \end{aligned}$$

Question 3. (Video 25)

A 25.5 L reactor at 25.0 °C is charged with 1.00 bar of O₂(g). The reactor is then pressurized with butanol to give a total pressure of 4.35 bar. The reactor is sealed, and the mixture ignited to start combustion reaction. Once the reaction has gone to completion, it is cooled back to 25.0 °C. Compute the final partial pressure of each gas (in bar) after the reaction has occurred. (6 marks)

CONSTANT V = 25.5 L CONSTANT T = 25 °C = 298.15 K

$P_{\text{O}_2} = 1.00 \text{ bar}$ $P_{T,1} = 4.35 \text{ bar}$

$M_{\text{C}_4\text{H}_{10}\text{O}} = (4 \times 12.01 + 10 \times 1.008 + 16.00) \frac{\text{g}}{\text{mol}} = 74.12 \frac{\text{g}}{\text{mol}}$

BALANCED CHEMICAL EQUATION:

$$\text{C}_4\text{H}_{10}\text{O}(\text{g}) + 6\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 5\text{H}_2\text{O}(\text{g})$$

WHAT IS LIMITING? ∴ V, T ARE CONSTANT $n \propto P$ ∴ CAN USE P IN PLACE OF n TO IDENTIFY LIMITING REAGENT

FROM C₄H₁₀O: $P_{\text{CO}_2} = P_{\text{C}_4\text{H}_{10}\text{O}} \times \frac{4 \text{ mol CO}_2}{1 \text{ mol C}_4\text{H}_{10}\text{O}} = 4.35 \text{ bar} \times 4 = 17.4 \text{ bar}$

FROM O₂: $P_{\text{CO}_2} = P_{\text{O}_2} \times \frac{4 \text{ mol CO}_2}{6 \text{ mol O}_2} = 0.6667 \text{ bar}$ ∴ O₂ LIMITING

$P_{\text{H}_2\text{O}} = P_{\text{O}_2} \times \frac{5 \text{ mol H}_2\text{O}}{4 \text{ mol CO}_2} = 0.8333 \text{ bar}$ $P_{\text{C}_4\text{H}_{10}\text{O, REACTED}} = P_{\text{O}_2, \text{ REACTED}} \times \frac{1 \text{ mol C}_4\text{H}_{10}\text{O}}{6 \text{ mol O}_2} = 0.6667 \text{ bar} \times \frac{1}{6} = 0.1111 \text{ bar}$

	C ₄ H ₁₀ O	O ₂	CO ₂	H ₂ O
Final pressure (in bar)	3.35 - 0.1111 = 3.23	∅	0.667 bar	0.833 bar

Question 4. (Chapter 1 lecture, slide 32, Chapter 2 lecture, slide 21)

The pressure of 334 mg of an unknown compound that was vaporized in a 100.0-mL flask at 262 °C was found to be 0.2929 atm. From elemental analysis mass percent values were found to be; H, 5.649 %; C, 52.78 %; N, 22.39 % and O, 19.18 %. What is the molecular formula of the compound? (6 marks)

$$n_H = \frac{5.649\text{g}}{1.008\text{g/mol}} = 5.6042\text{ mol}$$

$$n_C = \frac{52.78\text{g}}{12.01\text{g/mol}} = 4.3947\text{ mol}$$

$$n_N = \frac{22.39\text{g}}{14.01\text{g/mol}} = 1.5981\text{ mol}$$

$$n_O = \frac{19.18\text{g}}{16.00\text{g/mol}} = 1.1988\text{ mol}$$

$$\text{EMPIRICAL FORMULA} = C_{\frac{4.3947}{1.1988}} H_{\frac{5.6042}{1.1988}} N_{\frac{1.5981}{1.1988}} O_{\frac{1.1988}{1.1988}} \Rightarrow C_{3.666} H_{4.675} N_{1.333} O \xrightarrow{\times 3} C_{11} H_{14} N_4 O_3$$

$$\text{EMPIRICAL MOLECULAR WEIGHT} \\ = 11 \times 12.01 + 14 \times 1.008 + 4 \times 14.01 + 3 \times 16.08 \\ = 250.262\text{ g mol}^{-1}$$

WHAT IS M_{gas} ?

$$n = \frac{m}{M} = \frac{PV}{RT} \quad \therefore M = \frac{mRT}{PV} = \frac{(0.334\text{g})(0.08206\text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(262+273)\text{K}}{(0.2929\text{ atm})(0.100\text{ L})} \\ = 500.6\text{ g/mol}$$

$$\frac{M_{\text{gas}}}{M_{\text{EMPIRICAL}}} = \frac{500.6}{250.262} = 2$$

$$\therefore \text{MOLECULAR FORMULA} \\ C_{11 \times 2} H_{14 \times 2} N_{4 \times 2} O_{3 \times 2} \\ = \underline{\underline{C_{22} H_{28} N_8 O_6}}$$

Question 6.

At an altitude of 51 km above the Earth's surface, the temperature is about -38°C, and the pressure is about 0.45 Torr.

a) What is the root mean squared speed of O₂ at this altitude? (2 marks)

$$\bar{v} = \sqrt{\frac{3RT}{M}} = \left(\frac{3(8.314\text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(273-38)\text{K}}{(32.00\text{ g/mol})(10^{-3}\text{ kg/g})} \right)^{\frac{1}{2}} \\ = \underline{\underline{436\text{ m/s}}}$$

b) Under these conditions, will the average kinetic energy of ozone (O₃) be greater than, less than, or equal to the average kinetic energy of O₂? Explain why in one sentence. (2 marks)

$$\text{AVERAGE KINETIC ENERGY} = \bar{E} = \frac{3RT}{N_A}$$

∴ AVERAGE KINETIC ENERGY ONLY DEPENDS ON TEMP, NOT MOLECULAR WEIGHT.

Question 5. (You will need to use what you have learned in Chapter 1 and 2 to do this question.)

A mixture of oxygen gas and hydrogen gas is prepared by electrolysis of 1.32 g of liquid water. The mixture was collected over water at 30°C, 748 mmHg. The volume of 'wet' gas was found to be 2.90 L.

a) How many moles of gas are in the mixture? (2 marks)

$$n = \frac{pV}{RT} = \frac{(748 \text{ mmHg}) \left(\frac{1 \text{ atm}}{760 \text{ mmHg}}\right) (2.90 \text{ L})}{(0.08206 \text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}) (273.15 + 30.0) \text{ K}}$$

$$= \underline{\underline{0.1148 \text{ mol}}}$$

b) How many moles of gas were produced by the reaction? (3 marks)



$$n_{\text{H}_2} = n_{\text{H}_2\text{O}} = \frac{m_{\text{H}_2\text{O}}}{M_{\text{H}_2\text{O}}} = \frac{1.32 \text{ g}}{(18.016 \text{ g/mol})} = 0.07327 \text{ mol}$$

$$n_{\text{O}_2} = n_{\text{H}_2\text{O}} \times \frac{\frac{1}{2} \text{ mol O}_2}{1 \text{ mol H}_2\text{O}} = 0.07327 \text{ mol} \times \frac{1}{2} = 0.03663 \text{ mol}$$

$$\therefore n_{\text{H}_2} + n_{\text{O}_2} = \underline{\underline{0.1099 \text{ mol}}} \text{ GAS PRODUCED IN RXN}$$

c) What is the vapour pressure of water at 30°C? (3 marks)

$$P_{\text{H}_2 + \text{O}_2} = \frac{n_T RT}{V} = \frac{(0.1099 \text{ mol})(0.08206 \text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(303.15 \text{ K})}{2.90 \text{ L}}$$

$$= 0.9423 \text{ atm} \times \frac{760 \text{ mmHg}}{1 \text{ atm}}$$

$$= 716.5 \text{ mmHg}$$

$$P_{\text{H}_2\text{O}} = P_T - P_{\text{H}_2 + \text{O}_2} = 748 \text{ mmHg} - 716.5 \text{ mmHg} = \underline{\underline{32 \text{ mmHg}}}$$

d) What is the mass percent of water in the gas phase? (3 marks)

$$n = \frac{pV}{RT} = \frac{m}{M}$$

$$m_{\text{H}_2\text{O}} = \frac{pVM}{RT} = \frac{(18.016 \text{ g/mol}) (32 \text{ mmHg}) \left(\frac{1 \text{ atm}}{760 \text{ mmHg}}\right) (2.90 \text{ L})}{(0.08206 \text{ L}\cdot\text{atm}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}) (303.15 \text{ K})}$$

$$= 0.8843 \text{ g}$$

$$\text{MASS \% H}_2\text{O} = \frac{m_{\text{H}_2\text{O}}}{m_T} \times 100\% = \frac{0.8843 \text{ g}}{1.32 \text{ g}} \times 100\%$$

$$= \underline{\underline{6.70\%}}$$

