

LAST NAME: _____

FIRST NAME: _____

Student Number: _____

CHM 1311 B

Midterm #1

Fall 2016

Please keep your work covered at all times and keep your eyes on your own paper! Cheating or any appearance of cheating will result in an F in the course and possible expulsion from the university.

There are 8 pages in this test, for a total of 40 marks. A periodic table and data sheets are provided at the end. You may rip these pages off of the exam and use them to cover your work during the test. Any scratch work should be done on the back of these pages.

Please show all work to receive partial credit.

Make sure that units are included in your final answer.

You have 90 minutes to complete the test.

Question 1. Short answer questions (1 mark each)

- a) The specifications for a 10 mL volumetric flask state that it is guaranteed to contain the specified volume to within 0.01 mL when filled. How many significant figures should you use to record the volume contained in this flask?

4 sig figs

- b) Compute the total number of hydrogen atoms present in 0.55 mol H₂O.

$$N_{\text{H}} = n_{\text{H}_2\text{O}} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} N_A = (0.55 \text{ mol})(2)(6.022 \times 10^{23} \text{ atoms mol}^{-1})$$

$$= 6.6 \times 10^{23} \text{ H atoms}$$

- c) In an open-end mercury manometer the mercury was 35 mm lower on the side connected to the gas, and the atmospheric pressure was 755 mmHg. What was the pressure of the gas?

$$p_{\text{gas}} = p_{\text{atm}} + p_{\text{gas}} = 755 \text{ mmHg} + 35 \text{ mmHg} = 790 \text{ mmHg}$$

- d) An object has a mass of 200 g and a speed of 10 m/s. What is the kinetic energy of the object in units of Joules?

$$E = \frac{1}{2} mv^2 = \frac{1}{2} (0.200 \text{ kg})(10 \text{ m/s})^2 = 10 \text{ J}$$

- e) What is the nuclear symbol for the iron isotope that contains 28 neutrons?



- f) If the gas tank of a car holds 45.4 L, what is the mass of gasoline required to fill it (density = 0.70 g/mL)?

$$m = \text{density} \times V = (0.70 \text{ g/mL})(45.4 \text{ L})(10^3 \text{ mL L}^{-1}) = 32000 \text{ g} = 32 \text{ kg}$$

- g) There are _____ 10 _____ electrons and _____ 12 _____ protons in Mg²⁺. (Fill in the numbers.)

- h) If ammonium nitrate is dissolved in water the temperature of the solution decreases. The reaction is (circle one):

Exothermic

Endothermic

- i) Energy is released when a high energy bond is broken.

True

False

Question 2. Short calculations (2 mark each)

- a) A 50.0 mL sample of 0.50 M K_3PO_4 is diluted with 450.0 mL of water. What is the concentration of potassium in this new solution?

$$c_{\text{K}^+} = \frac{c_{\text{K}_3\text{PO}_4} V_{\text{K}_3\text{PO}_4}}{V_{\text{K}_3\text{PO}_4} + V_{\text{H}_2\text{O}}} \times \frac{3 \text{ mol K}^+}{1 \text{ mol K}_3\text{PO}_4} = \frac{(50.0 \text{ mL})(0.50 \text{ M})}{50.0 \text{ mL} + 450.0 \text{ mL}} \times 3 = 0.15 \text{ M}$$

- b) What is the molecular mass of an unknown gas if argon gas effuses at a rate 2.634 times faster than this unknown gas?

$$2.634 = \sqrt{\frac{M_x}{M_{\text{Ar}}}}$$

$$M_x = (2.634)^2 M_{\text{Ar}} = (2.634)^2 (39.95 \text{ g mol}^{-1}) = 277.2 \text{ g mol}^{-1}$$

- c) Calculate the work in units of Joules that is done by an ideal gas in a balloon that expands under a constant pressure of 2.0×10^5 Pa from a volume of 5.0 L to 10.0 L.

$$w = -p\Delta V = -(2.0 \times 10^5 \text{ Pa})(10.0 \text{ L} - 5.0 \text{ L})(10^{-3} \text{ m}^3 \text{ L}^{-1}) = -1000 \text{ J}$$

- d) The diameter of an argon atom is 7.1×10^1 pm. How many argon atoms lined up end to end would form a line 1.25 cm long?

$$\text{distance} = N \times \text{diameter}$$

$$N = \frac{\text{distance}}{\text{diameter}} = \frac{1.25 \text{ cm}}{7.1 \times 10^1 \text{ pm}} \left(\frac{1 \text{ m}}{100 \text{ cm}} \right) \left(\frac{10^{12} \text{ pm}}{1 \text{ m}} \right) = 1.8 \times 10^8 \text{ atoms}$$

- e) Given reaction $\text{A} + 2 \text{B} \rightarrow 3 \text{C}$, with standard enthalpies of formation ΔH_f° of:

$$\text{A} = 10.0 \text{ kJ/mol}, \text{B} = 5.0 \text{ kJ/mol}, \text{C} = 2.0 \text{ kJ/mol}$$

What is the enthalpy change if 2 moles of A are used in the reaction?

$$\Delta H_{\text{reaction}}^\circ = \sum \nu_p \Delta H_{f,p}^\circ - \sum \nu_r \Delta H_{f,r}^\circ$$

$$= 3(2.0 \text{ kJ mol}^{-1}) - (10 \text{ kJ mol}^{-1}) - 2(5.0 \text{ kJ mol}^{-1}) = -14 \text{ kJ mol}^{-1}$$

$$\text{For 2 moles of A: } \Delta H_{\text{reaction}}^\circ = (2 \text{ mol})(-14 \text{ kJ mol}^{-1}) = -28 \text{ kJ mol}^{-1}$$

Question 3.

A 47.9 g sample of an unknown crystalline compound containing carbon, oxygen and hydrogen is subjected to airproof combustion analysis. The sample gives 134.4 g of CO₂ and 27.5 g of H₂O.

a) What is the empirical formula of the compound? (6 marks)

$$n_{\text{CO}_2} = \frac{m_{\text{CO}_2}}{M_{\text{CO}_2}} = \frac{134.4 \text{ g}}{(12.01 + 2 \times 16.00) \text{ g mol}^{-1}} = 3.053\bar{9} \text{ mol} = n_C$$

$$n_{\text{H}_2\text{O}} = \frac{m_{\text{H}_2\text{O}}}{M_{\text{H}_2\text{O}}} = \frac{27.5 \text{ g}}{(16.00 + 2 \times 1.008) \text{ g mol}^{-1}} = 1.52\bar{6} \text{ mol}$$

$$n_H = n_{\text{H}_2\text{O}} \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2\text{O}} = 3.05\bar{2} \text{ mol}$$

$$m_C = n_C M_C = (3.053\bar{9} \text{ mol})(12.01 \text{ g mol}^{-1}) = 36.67\bar{8} \text{ g}$$

$$m_H = n_H M_H = (3.05\bar{2} \text{ mol})(1.008 \text{ g mol}^{-1}) = 3.07\bar{6} \text{ g}$$

$$m_O = m_{\text{compound}} - m_H - m_C = (47.9 - 36.67\bar{8} - 3.07\bar{6}) \text{ g} = 8.1\bar{5} \text{ g}$$

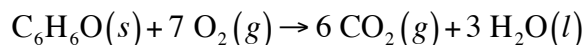
$$n_O = \frac{m_O}{M_O} = \frac{8.1\bar{5} \text{ g}}{16.00 \text{ g mol}^{-1}} = 0.50\bar{9} \text{ mol}$$

Formula is:

$$\begin{aligned} & \text{C} \frac{3.053\bar{9}}{0.50\bar{9}} \text{H} \frac{3.05\bar{2}}{0.50\bar{9}} \text{O} \frac{0.50\bar{9}}{0.50\bar{9}} \\ & = \text{C}_6\text{H}_6\text{O} \end{aligned}$$

- b) A combustion reaction was done on 3.88×10^{-2} mol of this organic compound in a bomb calorimeter with a heat capacity of 11.24 kJ K^{-1} . As a result of the reaction, the temperature of the calorimeter increased from $25.0 \text{ }^\circ\text{C}$ to $35.5 \text{ }^\circ\text{C}$. Calculate the heat of the reaction per mole of water formed. (4 marks)

To find the stoichiometric relationship between moles of compound burned and moles of water formed, we need to write a balanced chemical equation for the combustion reaction:



Therefore, for 2.88×10^{-2} mol of compound, the number of moles of water formed is:

$$n_{\text{H}_2\text{O}} = n_{\text{compound}} \times \frac{3 \text{ mol H}_2\text{O}}{1 \text{ mol compound}} = 3.88 \times 10^{-2} \text{ mol} \times 3 = 0.1164 \text{ mol}$$

Total heat absorbed by the calorimeter:

$$q_{\text{calorimeter}} = C_{\text{calorimeter}} \Delta T = (11.24 \text{ kJ K}^{-1})(35.5 - 25.0) \text{ K} = 118.02 \text{ kJ}$$

The heat of reaction is:

$$q_{\text{reaction}} = -q_{\text{calorimeter}} = -118.02 \text{ kJ}$$

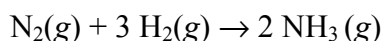
Heat of reaction per mole of water produced:

$$\frac{q_{\text{reaction}}}{n_{\text{H}_2\text{O}}} = \frac{-118.02 \text{ kJ}}{0.1164 \text{ mol}} = -1014 \text{ kJ mol}^{-1}$$

Question 4.

Nitrogen fixation is done industrially through the reaction of hydrogen and nitrogen gas to form ammonia gas (NH_3). Suppose a 500.0 L reaction vessel contains nitrogen at 358 bar and 595 K , and 4500 mol of H_2 .

- a) Write the balanced chemical equation for this reaction. (1 mark)



- b) Based on your balanced chemical reaction use bond energies to estimate ΔE for this reaction. (Data on last page.) (2 marks)

$$\Delta E_{\text{reaction}} = \sum BE_{\text{reactant bonds broken}} - \sum BE_{\text{product bonds formed}}$$

$$\begin{aligned} \Delta E_{\text{reaction}} &= \text{BE}(\text{N}_2) + 3\text{BE}(\text{H}_2) - 2 \times 3 \times \text{BE}(\text{NH}_3) \\ &= (945 + 3(435) - 6(390)) \text{ kJ mol}^{-1} \\ &= -90 \text{ kJ mol}^{-1} \end{aligned}$$

- c) After the reaction is allowed to run to completion, the temperature is brought down to 233 K, which is below the boiling point of ammonia, and the liquid ammonia removed from the vessel. What is the pressure inside the reaction vessel after the liquid ammonia has been removed? (7 marks)

Need to identify the limiting reagent.

Moles of ammonia produced from complete reaction of H₂:

$$n_{\text{NH}_3} = n_{\text{H}_2} \times \frac{2 \text{ mol NH}_3}{3 \text{ mol H}_2} = 4500 \text{ mol} \times \frac{2 \text{ mol NH}_3}{3 \text{ mol H}_2} = 3000 \text{ mol}$$

Moles of ammonia produced from complete reaction of N₂:

$$\begin{aligned} n_{\text{NH}_3} &= n_{\text{N}_2} \times \frac{2 \text{ mol NH}_3}{1 \text{ mol N}_2} = \frac{pV}{RT} \times \frac{2 \text{ mol NH}_3}{3 \text{ mol H}_2} \\ &= \frac{(358 \text{ bar})(500.0 \text{ L})}{(0.08314 \text{ bar L mol}^{-1} \text{ K}^{-1})(595 \text{ K})} \times \frac{2 \text{ mol NH}_3}{1 \text{ mol H}_2} = (361\bar{8} \text{ mol})(2) = 723\bar{6} \text{ mol} \end{aligned}$$

Therefore H₂ is limiting, and is completely consumed ($p_{\text{H}_2} = 0$ at end of reaction).

Since NH₃ is removed, we need to only calculate the number of moles of N₂ that is in excess.

$$\begin{aligned} n_{\text{N}_2, \text{ excess}} &= n_{\text{N}_2, \text{ initial}} - n_{\text{N}_2, \text{ reacted}} \\ &= n_{\text{N}_2, \text{ initial}} - n_{\text{NH}_3, \text{ produced}} \times \frac{1 \text{ mol N}_2}{2 \text{ mol NH}_3} \\ &= 3618 \text{ mol} - 3000 \text{ mol} \times \frac{1 \text{ mol N}_2}{2 \text{ mol NH}_3} \\ &= 211\bar{8} \text{ mol} \end{aligned}$$

$$p_{\text{N}_2} = \frac{nRT}{V} = \frac{(211\bar{8} \text{ mol})(0.08314 \text{ bar L mol}^{-1} \text{ K}^{-1})(233 \text{ K})}{(500.0 \text{ L})} = 82 \text{ atm}$$

Constants and Conversion Factors

$$\begin{array}{lll}
 1 \text{ mmHg} = 1 \text{ torr} & 760 \text{ mmHg} = 1 \text{ atm} & 1 \text{ atm} = 101.325 \text{ kPa} & 1 \text{ atm} = 1.013125 \text{ bar} \\
 1 \text{ bar} = 10^5 \text{ Pa} & 1 \text{ cm}^3 = 1 \text{ mL} & 1 \text{ dm}^3 = 1000 \text{ mL} = 1 \text{ L} & 1 \text{ m}^3 = 1000 \text{ L} \\
 1 \text{ cal} = 4.184 \text{ J} & 1 \text{ L} = 1000 \text{ mL} & 1 \text{ m} = 100 \text{ cm} & 1 \text{ m} = 10^{12} \text{ pm}
 \end{array}$$

Avogadro's Number	N_A	$6.022 \times 10^{23} \text{ mol}^{-1}$
Gas constant	R	$8.31451 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
	R	$0.08206 \text{ atm} \cdot \text{L} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
	R	$8.31451 \text{ L} \cdot \text{kPa} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
	R	$0.0831451 \text{ bar} \cdot \text{L} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$

Average Bond Energies

$$\text{H—H } 435 \text{ kJ mol}^{-1} \quad \text{N}\equiv\text{N } 945 \text{ kJ mol}^{-1} \quad \text{N—H } 390 \text{ kJ mol}^{-1} \quad \text{C—H } 412 \text{ kJ mol}^{-1}$$

Equations

$$T(\text{in K}) = T(\text{in } ^\circ\text{C}) + 273.15 \text{ K}$$

$$n = \frac{m}{M} = \frac{N}{N_A}$$

$$\% \text{ Yield} = \frac{\text{actual yield}}{\text{theoretical yield}}$$

$$c(\text{mol/L}) = \frac{n}{V}$$

$$c_1 V_1 = c_2 V_2 = n$$

$$p = \frac{mg}{A}$$

$$p = dgh$$

$$pV = nRT$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$p_T = p_1 + p_2 + p_3 + \dots$$

$$p_A = X_A \times p_T$$

$$X_A = \frac{n_A}{n_T}$$

$$d = \frac{m}{V} = \frac{p \cdot M}{RT}$$

$$E_K = \frac{1}{2} m v^2$$

$$\bar{E} = \frac{3RT}{2N_A}$$

$$\bar{v} = \sqrt{\frac{3RT}{M}}$$

$$\frac{\text{Rate } A}{\text{Rate } B} = \sqrt{\frac{M_B}{M_A}}$$

$$p = \frac{nRT}{(V - nb)} - a \frac{n^2}{V^2}$$

$$\Delta E = w + q$$

$$w = F \times d = -p\Delta V$$

$$q_{\text{calorimeter}} = C_{\text{cal}} \Delta T$$

$$\Delta E_{\text{reaction}} = \sum BE_{\text{reactant bonds broken}} - \sum BE_{\text{product bonds formed}}$$

$$\Delta E_{\text{molar}} = \frac{\Delta E}{n}$$

$$\Delta H_{\text{reaction}}^{\circ} = \sum \nu_p \Delta H_{f,p}^{\circ} - \sum \nu_r \Delta H_{f,r}^{\circ}$$

$$\Delta H_{\text{reaction}} = \Delta E_{\text{reaction}} + RT \Delta n_{\text{gas}}$$

$$H = E + pV$$

