***Chemistry 101 - Exam II*** ***Name _______________________***

***26 October 2016***

Show all work for credit. State any assumptions made to solve a problem. Give all numerical answers with the correct number of significant figures. All answers in scientific notation must be in correct scientific notation (i.e., $6.022\times10^{23}$ not 6.022E23 or 6.022e23). All instances of incorrect scientific notation will result in the loss of 3 points each. All numbers that require units should have the units written. All instances of numbers without units will result in the loss of 3 points each.

1. (26 points) Cetane, $C_{16}H_{34}$, is a typical petrodiesel with a standard enthalpy of combustion of −10 699.1 kJ $mol^{-1}$. Methyl linoleate, $C_{19}H_{34}O_2$, is a biodiesel with a standard enthalpy of combustion of −11 690.1 kJ $mol^{-1}$. What volume of methyl linoleate provides the same energy as one liter of cetane? The densities of cetane and methyl linoleate are 0.773 and 0.885 g $mL^{-1}$, respectively.

$$1\text{ L }C_{16}H_{34}\times\frac{1\text{ mL }C_{16}H_{34}}{10^{-3}\text{ L }C_{16}H_{34}}\times\frac{0.773\text{ g }C_{16}H_{34}}{1\text{ mL }C_{16}H_{34}}\times\frac{1\text{ mol }C_{16}H_{34}}{226.4412\text{ g }C_{16}H_{34}}\times\frac{-10699.1\text{ kJ}}{1\text{ mol }C_{16}H_{34}}$$
$$\times\frac{1\text{ kJ }C_{19}H_{34}O_2}{1\text{ kJ }C_{16}H_{34}}\times\frac{1\text{ mol }C_{19}H_{34}O_2}{-11690.1\text{ kJ}}\times\frac{294.4721\text{ g }C_{19}H_{34}O_2}{1\text{ mol }C_{19}H_{34}O_2}\times\frac{1\text{ mL }C_{19}H_{34}O_2}{0.885\text{ g }C_{19}H_{34}O_2}$$
$$\times\frac{10^{-3}\text{ L }C_{19}H_{34}O_2}{1\text{ mL }C_{19}H_{34}O_2}=1.04\text{ L }C_{19}H_{34}O_2$$

2. (23 points) Propan-2-ol has an enthalpy of combustion of −2005.8 kJ mol$^{-1}$. What is the ***enthalpy of formation, $\Delta_f H°$***, of propan-2-ol in kJ mol$^{-1}$? ($\Delta_f H°$ = −393.5 kJ mol$^{-1}$ for carbon dioxide and −285.8 kJ mol$^{-1}$ for liquid water.)

$$C_4H_{10}O_{(l)} + 6\ O_{2\,(g)} \rightarrow 4\ CO_{2\,(g)} + 5\ H_2O_{(l)} \quad \Delta_c H° = -2005.8\ \text{kJ mol}^{-1}$$

$$\Delta H_{rxn} = \sum_{\text{products}} n\Delta H_f^\circ - \sum_{\text{reactants}} n\Delta H_f^\circ$$

$$= \left[\left(\frac{4\ \text{mol CO}_2}{\text{mol}}\right)\left(\frac{-393.5\ \text{kJ}}{\text{mol CO}_2}\right) + \left(\frac{5\ \text{mol H}_2\text{O}}{\text{mol}}\right)\left(\frac{-285.8\ \text{kJ}}{\text{mol H}_2\text{O}}\right)\right] - \left[\left(\frac{1\ \text{mol C}_4\text{H}_{10}\text{O}}{\text{mol}}\right)\left(\frac{x\ \text{kJ}}{\text{mol C}_4\text{H}_{10}\text{O}}\right) + \left(\frac{6\ \text{mol O}_2}{\text{mol}}\right)\left(\frac{0.00\ \text{kJ}}{\text{mol O}_2}\right)\right]$$

$$= -2005.8\ \text{kJ mol}^{-1}$$

$$\frac{-2005.8\ \text{kJ}}{\text{mol}} = \left(\frac{-3003.0\ \text{kJ}}{\text{mol}}\right) - \frac{x\ \text{kJ}}{\text{mol}}$$

$$x = -997.2\ \text{kJ mol}^{-1}$$

3. (24 points) A compound contains 40.684 %C, 5.122 %H by mass and the rest is oxygen. The root-mean-square speed of the gas at 250.26 °C is 332.50 m s$^{-1}$. What is the molecular formula of the compound?

$$40.684 \text{ g C} \times \frac{1 \text{ mol C}}{12.0107 \text{ g C}} = 3.38731 \text{ mol C} / 3.38725 = 1.00002 \times 2 = 2$$

$$5.122 \text{ g H} \times \frac{1 \text{ mol H}}{1.00794 \text{ g H}} = 5.08165 \text{ mol H} / 3.38725 = 1.50023 \times 2 = 3$$

$$(100.000 - 40.684 - 5.122) \text{ g O} \times \frac{1 \text{ mol O}}{15.9994 \text{ g O}} = 3.38725 \text{ mol O} / 3.38725 = 1.000 \times 2 = 2$$

The empirical formula is $C_2H_3O_2$. It has an empirical mass of 59.0440 g mol$^{-1}$ and a molar mass of:

$$u_{rms} = \sqrt{\frac{3RT}{M}}$$

$$M = \frac{3RT}{u_{rms}^2} = \frac{3(8.314472 \text{ J mol}^{-1} \text{ K}^{-1})(523.41 \text{ K})}{(332.50 \text{ m s}^{-1})^2} = 0.11809 \text{ kg mol}^{-1} = 118.09 \text{ g mol}^{-1}$$

$$n = \frac{M}{E} = \frac{118.09 \text{ g mol}^{-1}}{59.0440 \text{ g mol}^{-1}} = 2$$

The molecular formula is therefore, $C_4H_6O_4$.

4. (28 points) 163.4 g of ammonium nitrate ($\Delta_f H° = -339.87$ kJ mol$^{-1}$) is placed into a cylinder fitted with a piston. All of the ammonium nitrate decomposes into nitrogen gas, oxygen gas, and liquid water ($\Delta_f H° = -285.8$ kJ mol$^{-1}$). The pressure outside of the cylinder is 1.553 bar. The density of nitrogen gas is 1.755 g L$^{-1}$ and the density of oxygen gas is 2.005 g L$^{-1}$. Calculate:
   a) The amount of heat transferred by the system.
   b) The amount of work done on or by the system.
   c) The change in enthalpy of the system
   d) The change in internal energy of the system.

$$NH_4NO_{3\,(s)} \rightarrow N_2 + \tfrac{1}{2} O_2 + 2\, H_2O$$

$$\Delta_r H^\circ = \sum_{\text{products}} \nu \Delta_f H^\circ - \sum_{\text{reactants}} \nu \Delta_f H^\circ$$

a. $$= \left[\left(\frac{1 \text{ mol } N_2}{1 \text{ mol rxn}}\right)\left(\frac{0 \text{ kJ}}{\text{mol } N_2}\right) + \left(\frac{\tfrac{1}{2} \text{ mol } O_2}{1 \text{ mol rxn}}\right)\left(\frac{0 \text{ kJ}}{\text{mol } O_2}\right) + \left(\frac{2 \text{ mol } H_2O}{1 \text{ mol rxn}}\right)\left(\frac{-285.8 \text{ kJ}}{\text{mol } H_2O}\right)\right] - \left[\left(\frac{1 \text{ mol } NH_4NO_3}{1 \text{ mol rxn}}\right)\left(\frac{-339.87 \text{ kJ}}{\text{mol } NH_4NO_3}\right)\right]$$

$$= -231.7 \text{ kJ mol}^{-1}$$

$$q = 163.4 \text{ g } NH_4NO_3 \times \frac{1 \text{ mol } NH_4NO_3}{80.04335 \text{ g } NH_4NO_3} \times \frac{1 \text{ mol rxn}}{1 \text{ mol } NH_4NO_3} \times \frac{-231.7 \text{ kJ}}{1 \text{ mol rxn}} = -473.0 \text{ kJ}$$

b. The work done is due to the creation of the nitrogen and oxygen gases. The initial volume is 0 L and the final volume is the volume of the two gases.

$$163.4 \text{ g } NH_4NO_3 \times \frac{1 \text{ mol } NH_4NO_3}{80.04335 \text{ g } NH_4NO_3} \times \frac{1 \text{ mol } N_2}{1 \text{ mol } NH_4NO_3} \times \frac{28.0134 \text{ g } N_2}{1 \text{ mol } N_2} \times \frac{1 \text{ L}}{1.755 \text{ g } N_2} = 32.58 \text{ L}$$

$$163.4 \text{ g } NH_4NO_3 \times \frac{1 \text{ mol } NH_4NO_3}{80.04335 \text{ g } NH_4NO_3} \times \frac{\tfrac{1}{2} \text{ mol } O_2}{1 \text{ mol } NH_4NO_3} \times \frac{31.9988 \text{ g } O_2}{1 \text{ mol } O_2} \times \frac{1 \text{ L}}{2.005 \text{ g } O_2} = 16.29 \text{ L}$$

$$V_{total} = 32.58 \text{ L} + 16.29 \text{ L} = 48.87 \text{ L}$$

$$w = -P_{ext}\Delta V = -(1.553 \text{ bar})(48.87 \text{ L} - 0 \text{ L})\left(\frac{100.00 \text{ J}}{1 \text{ L bar}}\right)\left(\frac{1 \text{ kJ}}{10^3 \text{ J}}\right) = -7.590 \text{ kJ}$$

c. The change in enthalpy is the heat transferred at constant pressure so this the same as answer to a. (−473.0 kJ)

d. The change in internal energy is equal to the heat transferred plus the work done.

$$\Delta U = q + w = -473.0 \text{ kJ} + (-7.590 \text{ kJ}) = -480.6 \text{ kJ}$$

5. (25 points) Alkanes have the general formula $C_nH_{2n+2}$. In an effusion apparatus sulfur dioxide gas effuses 1.1598 times faster than an alkane. Assume the alkane has two methyl branches on different carbons. ***Name*** the alkane.

$$\frac{R_{SO_2}}{R_{alk}} = \sqrt{\frac{M_{alk}}{M_{SO_2}}}$$

$$M_{alk} = \left(\frac{R_{SO_2}}{R_{alk}}\right)^2 M_{H_2} = (1.1598)^2\left(64.064 \text{ g mol}^{-1}\right) = 86.175 \text{ g mol}^{-1}$$

$$n(12.0107) + (2n+2)(1.00794) = 86.175$$

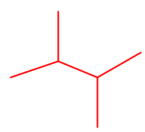
$$12.0107n + 2.0158n + 2.0158 = 86.175$$

$$14.0265n = 84.159$$

$$n = 5.9998 \approx 6$$

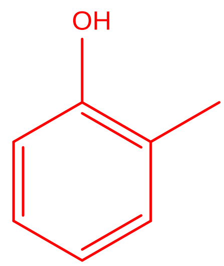
$$C_6H_{14}$$

The alkane is 2,3-dimethylbutane.



6. (24 points) In a bomb calorimetric experiment, 0.6347 g of liquid 2-methylphenol was burned completely. The temperature of the calorimeter rose from 19.682°C to 21.334°C. The heat capacity of the calorimeter and its contents is 11.88 kJ/°C. What is ***ΔU and ΔH for the combustion process***?

2-methylphenol




$C_7H_8O_{(l)} + 17/2\ O_{2(g)} \rightarrow 7\ CO_{2(g)} + 4\ H_2O_{(l)}$ $\Delta n = -1.5$ mol gas/mol

$$q_{cal} = C\Delta T = \left(11.88\text{ kJ }^{\circ}\text{C}^{-1}\right)\left(21.334\ ^{\circ}\text{C} - 19.682\ ^{\circ}\text{C}\right) = 19.6\underline{2}576\text{ kJ}$$

$$q_{rxn} = -q_{cal}$$

$$\Delta U = \frac{q_{rxn}}{n_{rxn}} = \frac{-19.6\underline{2}576\text{ kJ}}{0.6347\text{ g } C_7H_8O} \times \frac{108.1378\text{ g } C_7H_8O}{1\text{ mol } C_7H_8O} \times \frac{1\text{ mol } C_7H_8O}{1\text{ mol rxn}} = -334\underline{3}.76383\text{ kJ mol}^{-1}$$

$$= -3344\text{ kJ mol}^{-1}$$

$$\Delta H = \Delta U + \Delta nRT$$

$$= -334\underline{3}.76383\text{ kJ mol}^{-1} + \left(\frac{-1.5\text{ mol gas}}{\text{mol}}\right)\left(\frac{8.314472\times10^{-3}\text{ kJ}}{\text{mol gas}\quad\text{K}}\right)\left(298.15\text{ K}\right)$$

$$= -334\underline{7}.48227\text{ kJ mol}^{-1}$$

$$= -3347\text{ kJ mol}^{-1}$$