Name _____

Attending Section _____

CHM 1045
Spring 2020
March 11

EXAMINATION TWO – SOLUTIONS

I _____ /2 II _____ /15 III _____ /28 IV.A _____ /16 V _____ /28 IV.B _____ /11 Total _____

This exam consists of four problems. Rough point values are given. The total will be scaled to 100% after the exams are marked. For questions with multiple parts, you do not necessarily need the answer to Part A in order to work Part B, Part B to Part C, etc. If you do need a previous answer, the next question will be marked assuming the previous question is correct. Glance over the entire exam, and then attempt the problems in the order of your choice. For calculations, give your answer to the correct number of ***significant figures***, and be sure to include the ***correct units*** for your answer. ***You must show your work to receive any credit for a calculated answer.*** Additional information is provided in a separate information handout; you can use the back for scratch work. Good luck!

I. (1 point) Circle the recitation section that you attend....

Drake Beery	Sujin Lee	Emmanuel Ogunkunle
Section 28, 11:00a, 219 HTL	Section 25, 2:00p, 214 HTL	Section 22, 5:00p, 213 HTL
Section 29, 12:00p, 219 HTL	Section 26, 3:00p, 214 HTL	Section 23, 6:00p, 213 HTL
Section 30, 1:00p, 219 HTL	Section 27, 4:00p, 214 HTL	Section 24, 7:00p, 213 HTL

(1 point) and ***write the section number you circled in the box at the top of this page***.

II. (15~~18~~ points) An aqueous solution of potassium permanganate reacts with $Fe(NO_3)_2$ according to the following chemical equation:

$$KMnO_4(aq) + 8HNO_3(aq) + 5Fe(NO_3)_2(aq) \rightarrow Mn(NO_3)_2(aq) + 5Fe(NO_3)_3(aq) + KNO_3(aq) + 4H_2O(l)$$

A solution of $Fe(NO_3)_2(aq)$ was formed by reacting the product from a thermite reaction in $HNO_3(aq)$. That solution was titrated with a 0.537 M solution of $KMnO_4(aq)$ according to the above equation, and it took 121 mL to convert all of the Fe^{2+} to Fe^{3+}.

How many moles of Fe^{2+} were contained in the original solution?

$$\frac{121\ mL}{1000\ mL} \times \frac{1\ L}{1\ L} \times \frac{0.537\ mol\ KMnO_4}{1\ mol\ KMnO_4} \times \frac{5\ mol\ Fe(NO_3)_2}{1\ mol\ KMnO_4} = 0.324885$$

$$\Rightarrow \boxed{0.324_9\ mol\ Fe^{2+}}$$

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III. (28 points) When we considered the complete combustion reactions of hydrocarbons (C_xH_y) and oxyhydrocarbons ($C_xH_yO_z$) we noted that the products – carbon dioxide and water – are the same products as when carbohydrates and fats are metabolized. Proteins contain nitrogen, however, so the products are different. Because proteins are made up of amino acids, we can simplify the process by looking at the combustion of a single amino acid. For example, glycine is $NH_2CH_2COOH(s)$. The structural formula can be written more concisely as $C_2H_5NO_2(s)$. The generally accepts chemical equation for the combustion of glycine is shown below.

$$C_2H_5NO_2(s) + {}^9/_2O_2(g) \rightarrow 2CO_2(g) + {}^5/_2H_2O(\ell) + {}^1/_2N_2(g)$$

A. (2 pts) Do you expect this reaction to be endothermic or exothermic?

exothermic

B. (Part 1, 12 pts) Determine $\Delta H°$ for the combustion of glycine. Here, and for the rest of the exam, be sure to show your work and include units in your final answer.

$\Delta H°_{rxn} = \Sigma n\Delta H°_f(\text{products}) - \Sigma m\Delta H°_f(\text{reactants})$

$= 2\Delta H°_f[CO_2(g)] + {}^5/_2\Delta H°_f[H_2O(\ell)] + {}^1/_2\Delta H°_f[N_2(g)] - \{\Delta H°_f[C_2H_5NO_2(s)] + {}^9/_2\Delta H°_f[O_2(g)]\}$

$= 2[-393.5\ \text{kJ/mol}] + {}^5/_2[-285.8\ \text{kJ/mol}] + 0 - \{-528\ \text{kJ/mol} + 0\}$

$= \boxed{-973.5\ \text{kJ/mol}}$

(Part 2, 2 pt) Does your answer to Part B agree with your prediction in Part A? Yes

Award points based on comparing their answer above(Part B.1) to their answer to Part A.

C. (6 pts) Use your answer to Part B to calculate the amount of energy gained or lost by the combustion of 1.0 g of glycine. The molar mass of $C_2H_5NO_2$ is 75.07 g/mol. Part C will be marked assuming your answer to Part B is correct. (If you did not get an answer for Part B, then use either 100 or −100 with the proper energy units to answer Part C. Circle the value you are using: 100 or −100.)

$1.0\ g\ C_2H_5NO_2 \times (1\ mol\ C_2H_5NO_2/75.07\ g\ C_2H_5NO_2) \times (973.5\ kJ\ lost/mol\ C_2H_5NO_2) = \boxed{12.9\ kJ\ lost}$

D. (Part 1, 4 pts) Convert the energy you calculated in Part C to food Calorie units.

$12.9\ kJ \times (1\ kcal/4.184\ kJ) \times (1\ food\ Calorie/1\ kcal) = \boxed{3.1\ food\ Calories}$

(Part 2, 2 pts) How does this value compare to what you would expect for the energy content of one gram of protein?

Good, but not great, compared to the 4 Cal/g generally used for the "energy" content of protein.

Mark assuming the value calculated above is correct. Accept any reasonable comparison of the value in Part 1 to 4 Cal/g expected for proteins. For example, if they calculated 10 food Calories above and said the calculated value was significantly higher than 4 Cal/g, they would receive full credit for Part 2.

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IV. (27 points) A new molybdenum-doped nickel catalyst for producing synthesis gas from by "dry" reforming of methane was reported last month; see *Science* **2020**, *367*, 777-78.

A. (16 pts total) The introduction to the paper stated that "[c]ontrol of carbon dioxide (CO_2) emissions through avoidance, storage, and utilization has not yet been able to make an impact on excess CO_2 emissions, which already passed 40 metric gigatons per year (Gt/year)" or 40×10^{15} g/year. What would be the corresponding volume of CO_2 if stored at 1.0 atm and 25°C? The molar mass of CO_2 is 44.01 g/mol.

40×10^{15} g CO_2 x (1 mol CO_2 / 44.01 g CO_2) = 9.1×10^{14} mol CO_2

$PV = nRT \Rightarrow V = nRT/P = [9.1 \times 10^{14}$ mol x (0.08206 L·atm/K·mol) x (25 + 273.15K) / (1.0 atm)

= $\boxed{2.2 \times 10^{16}$ L (!)}

B. (11 points) Synthetic gas usually refers to a mixture of carbon monoxide and hydrogen, often called "syngas." Syngas can be burned directly, or it can be converted to a liquid fuel. In the paper referenced here, the authors state that "in principle," dry reforming of methane can be used to produce dimethyl ether, CH_3OCH_3, a liquid that can be used as fuel.

$$3CH_4(g) + CO_2(g) \rightarrow 2CH_3OCH_3(g)$$

The following chemical equations and enthalpies of formation are given in the paper.

$$3CH_4(g) + 2H_2O(g) + CO_2(g) \rightarrow 4CO(g) + 8H_2(g) \qquad \Delta H° = 659 \text{ kJ/mol}$$

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(g) \qquad \Delta H° = -91 \text{ kJ/mol}$$

$$2CH_3OH(g) \rightarrow CH_3OCH_3(g) + H_2O(g) \qquad \Delta H° = -24 \text{ kJ/mol}$$

1. Determine $\Delta H°$ for the chemical equation to concert methane into dimethyl ether,

$$3CH_4(g) + CO_2(g) \rightarrow 2CH_3OCH_3(g)$$

$3CH_4(g) + 2H_2O(g) + CO_2(g) \rightarrow 4CO(g) + 8H_2(g)$ $\quad \Delta H° = 659$ kJ/mol

$4CH_3OH(g) \rightarrow 2CH_3OCH_3(g) + 2H_2O(g)$ $\quad \Delta H° = 2(-24$ kJ/mol)

$4CO(g) + 8H_2(g) \rightarrow 4CH_3OH(g)$ $\quad \Delta H° = 4(-91$ kJ/mol)

$3CH_4(g) + CO_2(g) \rightarrow 2CH_3OCH_3(g)$

$\Delta H° = 659$ kJ/mol + 2(-24 kJ/mol) + 4(-91 kJ/mol) = 47 kJ/mol

2. The paper claims that their process is based on <u>dry</u> reforming of methane, meaning H_2O in any form (gas or liquid) is not involved. But two of the chemical equations you used in Part B.1 contain H_2O. Is it okay to use these reactions to determine $\Delta H°$ for the reaction? Explain why or why not.

Yes, the reactions above are not the mechanism of the overall reaction. Enthalpy is a state function, so you can use any reactions that sum to the overall reaction to determine $\Delta H°$, but that does not mean that those reactions actually occur during the reaction.

3. And if syngas can be burned as a fuel, why do we want to convert it to a liquid fuel?

Liquid fuels occupy less volume and do not need to be stored in heavy high-pressure tanks.

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V. (28 ~~25~~ points) Write balanced formula equations (FE) and net ionic equations (NIE) for the following reactions. *Be sure to include the correct states in your final equations and charges for ions in the NIE.* If you have written several equations, draw a box around the one you want to be marked for credit.

A. $HCl(aq) + Mg(NO_2)_2(aq) \rightarrow$

FE: $2HCl(aq) + Mg(NO_2)_2(aq) \rightarrow 2HNO_2(aq) + MgCl_2(aq)$

IE: $2H^+ + 2Cl^- + Mg^{2+} + 2NO_2^- \rightarrow 2HNO_2(aq) + Mg^{+} + 2Cl^-$

Note that HNO2(aq) is a weak acid so it does not dissociate.

NIE: $2H^+(aq) + 2NO_2^-(aq) \rightarrow 2HNO_2(aq)$ or simply $H^+(aq) + NO_2^-(aq) \rightarrow HNO_2(aq)$

(2 pts) What term best describes this reaction:
precipitation reaction, acid-base reaction, or redox reaction? acid-base reaction

B. $HCl(aq) + Pb(NO_3)_2(aq) \rightarrow$

FE: $2HCl(aq) + Pb(NO_3)_2(aq) \rightarrow 2HNO_3(aq) + PbCl_2(s)$

IE: $2H^+ + 2Cl^- + Pb^{2+} + 2NO_3^- \rightarrow 2H^+ + 2NO_3^- + PbCl_2(s)$

NIE: $Pb^{2+}(aq) + 2Cl^-(aq) \rightarrow PbCl_2(s)$

(2 pts) What term best describes this reaction:
precipitation reaction, acid-base reaction, or redox reaction? precipitation reaction

C. A proverbial tin (Sn) cup was filled with a solution of $FeCl_2$(aq), and an iron cup was filled with a solution of Sn(aq). A reaction occurred in only one of the cups.

(3 pts) In which cup did the reaction occur? the iron cup

(2 pts) Write the formula equation.

If answered iron cup:
$Fe(s) + SnCl_2(aq) \rightarrow FeCl_2(aq) + Sn(s)$

If answered tin cup:
$Sn(s) + FeCl_2(aq) \rightarrow SnCl_2(aq) + Fe(s)$

(2 pts) and net ionic equation for the reaction that occurred.

If answered iron cup:
$Fe(s) + Sn^{2+}(aq) \rightarrow Fe^{2+}(aq) + Sn(s)$

If answered tin cup:
$Sn(s) + Fe^{2+}(aq) \rightarrow Se^{2+}(aq) + Fe(s)$

D. (3 pts, 1 pt each) Name the following acids.

$H_2S(aq)$ hydrosulfuric acid

$H_2SO_4(aq)$ sulfuric acid

$H_2SO_3(aq)$ sulfurous acid