2022 WUCT: Individual Exam

This exam consists of 7 questions and is worth 100 points. You will have 1 hour to take the exam, followed by 10 minutes of upload time during which you cannot make changes to your exam. The only allowed resources for this exam are a calculator and the provided equation sheet. You may NOT use any other notes, books, people, or websites (other than Gradescope and HopIn). You must show your work and box your final answer to receive credit for a problem. NOTE: If you get the answer to an early part of a question incorrect but later use that answer for a subsequent part of the question, you can still earn full credit for those subsequent parts. Please write your answer in the designated space on the answer sheet. If you need additional space for a problem, you may use scratch paper, but make sure to clearly indicate in the problem's designated space where the rest of your work can be found. Dark pencil or pen is preferred so that your writing clearly shows on your submitted document in Gradescope.

<u>Problem #1</u>: ***(11 points)***

A rough estimate of the radius, r, of a nucleus is provided by the formula $r = kA^{1/3}$, where k is approximately 1.3×10^{-13} cm and A is the mass number of the nucleus.

a) Calculate the density of the nucleus of ^{192}Ir atom in grams per cubic centimeter. ^{192}Ir has a nuclear mass of 3.19×10^{-22} g. Volume of a sphere is given by the equation: $\frac{4}{3}\pi r^3$. ***(4 points)***

b) Compare the density of the nucleus of a ^{192}Ir atom with solid iridium sample (22.65 g/cm^3). Which has a higher density? What does this say about the nucleus? Write your answer in 2 - 3 sentences. ***(4 points)***

c) Iridium has two stable isotopes, one of which is iridium-191. The relative abundance of iridium-191 is 37.2%. Calculate the atomic mass of the second stable isotope of iridium. Report your answer in amu. ***(3 points)***

Problem #2: ***(10 points)***

When 3g of pure phenol, C_6H_5OH*(s)* goes through a combustion reaction as shown in the equation below, 97.47 kJ of heat is released. Using the information in the table below, answer the following equations.

$$C_6H_5OH(s) + 7\ O_2(g) \rightarrow 6\ CO_2(g) + 3\ H_2O(l)$$

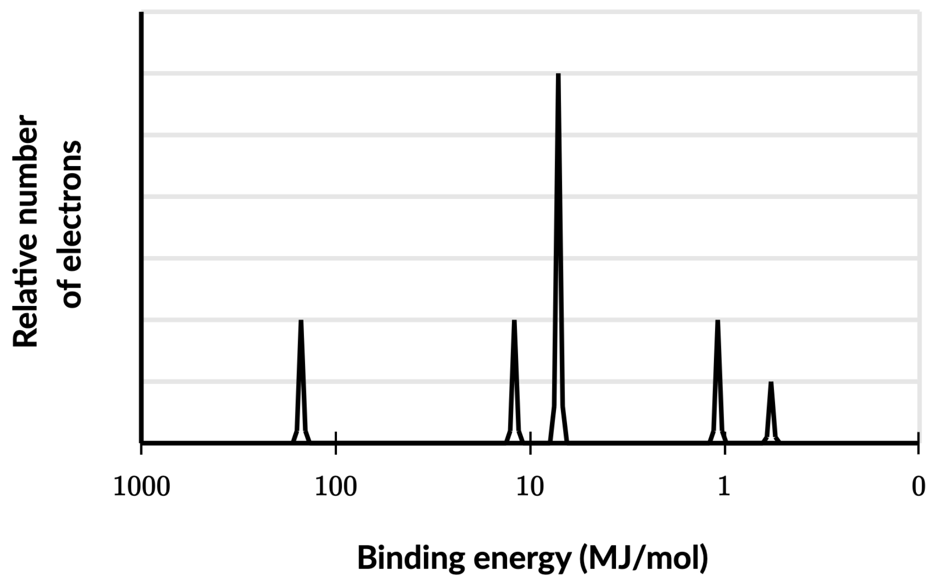
Substance	Standard Heat of Formation, ΔH^o_f at 25°C (kJ/mol)
$H_2O(l)$	-285.85
$CO_2(g)$	-393.5

a) Calculate the molar heat of combustion of phenol in kJ/mol at 25°C. ***(5 points)***

b) Calculate the standard heat of formation, ΔH^o_f, of phenol in kJ/mol at 25°C. ***(5 points)***

Problem #3: ***(16 points)***

The complete photoelectron spectrum of an element in its ground state is shown below.



a) Based on the spectrum,
   1) write the full electronic configuration of this element. ***(3 points)***

   2) describe in words which peak on the spectrum above corresponds to the 2s shell of this element. ***(2 points)***

   3) identify the element. ***(1 point)***

b) The binding energy of the outermost electron was measured to be 3.3×10^{-19}J. Using the reference table below, identify the color of the electromagnetic radiation needed to remove the outermost electron from the valence shell of an atom of the element. ***(6 points)***

Color	**Wavelengths**
Red	620 - 750 nm
Orange	590 - 620 nm
Yellow	570 - 590 nm
Green	495 - 570 nm
Blue	450 - 495 nm
Violet	380 - 450 nm

c) The photoelectron spectroscopies of fluorine and oxygen were performed. Compare the placement of the 1s electron peak of fluorine to the 1s electron peak of oxygen. In other words, would the 1s electron peak of fluorine be positioned to the right or left of the 1s electron peak for oxygen? Briefly explain your reasoning in 1-2 sentences. ***(4 points)***

Problem #4: ***(15 points)***

For proper functioning of our body, it is critical that we maintain a constant blood pH that stays within a certain range at around 7.4. The carbonic acid (H_2CO_3) and bicarbonate ion (HCO_3^-) buffer system in our blood, modeled by the equation below, helps maintain that stable pH.

$$H_2CO_{3\,(aq)} \Leftrightarrow H^+_{(aq)} + HCO_{3\,(aq)}^- \qquad K_a = 4.3 * 10^{-7}$$

a) Draw the most preferred Lewis structure of carbonic acid (H_2CO_3). ***(2 points)***

b) On the basis of the diagram you completed in part (b), can all six nuclei on carbonic acid lie in the same plane? Explain your answer in 1 - 2 sentences. ***(2 points)***

c) Calculate the pKa of the blood buffer system. ***(2 points)***

d) Write the equilibrium constant expression for the reaction. ***(2 points)***

e) Calculate the *pH* of a 0.00120M carbonic acid (H_2CO_3) aqueous solution and the equilibrium concentrations of the species H_2CO_3, HCO_3^-, and H^+. Use 3 significant figures in your final answers. Show all your work to receive full credit. ***(7 points)***

Problem #5: ***(15 points)***

The Haber process is used in manufacturing ammonia (NH_3) from nitrogen and can be modeled by the equation below:

$$N_2\,(g) + H_2\,(g) \rightarrow NH_3\,(g)$$

a) Write out the balanced equation of the Haber process by adding the correct coefficients below. ***(3 points)***

$$\_\_\_\ N_2\,(g) + \_\_\_\ H_2\,(g) \rightarrow \_\_\_\ NH_3\,(g)$$

Rate data was collected for the Haber process at a particular temperature as shown below:

Experiment	**N_2 (mol/L)**	**H_2 (mol/L)**	**Initial Rate (M/s)**
1	0.018	0.018	3.105×10^{-4}
2	0.036	0.018	1.242×10^{-3}
3	0.018	0.036	6.210×10^{-4}
4	0.036	0.036	2.484×10^{-3}

b) Write the rate-law expression for the Haber process. ***(3 points)***

c) Describe the order of the reaction with respect to each reactant and to the overall order. ***(2 points)***

d) Calculate the value of the rate constant, *k*, with the correct units. ***(3 points)***

e) From the perspective of collision theory, explain how increasing the temperature will result in an increase in the rate of reaction in 1 - 2 sentences. ***(2 point)***

f) Iron is often used as a catalyst to accelerate the Haber Reaction. Circle all of the answers that correctly finish the following sentence: Iron will… ***(2 points)***

   a. lower the activation energy of the reaction
   b. lower the equilibrium constant
   c. be consumed up during the reaction
   d. accelerate the rate of reaction
   e. initiate the reaction
   f. work best in any temperature

<u>Problem #6</u>: *(15 points)*

A titration is an analytical method used by chemists to determine the concentration of a substance by titrating, or mixing, the substance with a reagent of known concentration.

For example, a titration can be used to calculate the amount of citric acid ($C_6H_8O_7$) present in orange juice by adding the strong base, NaOH. When the citric acid interacts with NaOH, an acid-base reaction occurs.

a) Write the balanced net ionic equation of the acid-base reaction between citric acid and NaOH. Assume that citric acid is monoprotic ***(2 points)***

b) Suppose we start with a 100 mL sample of citric acid and titrate it with 1M NaOH. After 10 mL of NaOH have been added, how many moles of citric acid have been consumed, given that the equivalence point has not been reached yet? ***(2 points)***

c) The equivalence point is reached when 15.2 mL of NaOH has been added. Given this information, what was the concentration (in g/L) of citric acid in the original orange juice sample? ***(2 points)***

d) The pKa of citric acid is 2.79. Using this information, calculate the pOH and pH of the solution at the equivalence point of the titration. ***(6 points)***

e) Which of the following indicators is best suited for this titration? Explain your answer in 1 - 2 sentences. ***(3 points)***

Indicator	**Approximate pH Range for Color Change**	**Color Change**
Methyl Orange	3.2 - 4.4	Red to yellow
Bromocresol green	3.8 - 5.4	Yellow to blue
Bromothymol blue	6.0 - 7.5	Yellow to blue
Thymol blue	7.9 - 9.5	Yellow to blue

<u>Problem #7</u>: *(18 points)*

A chemist was given an aqueous acidic solution containing Ba^{2+} ions, Mn solid, Ga^{3+} ions, Ag solid, Cl^- ions, and Cu solid. The mixture was open to the air. They had a battery and two inert graphite electrodes: an anode and a cathode. After connecting the electrodes to a battery, they stuck them into the mixture. Use the Table of Standard Reduction Potentials given below for the following questions.

Standard Reduction Half-Reaction	Standard Reduction Potential (E°) (Volts)
$O_3\ (g) + 2H^+\ (aq) + 2e^- \rightarrow O_2\ (g) + H_2O\ (l)$	2.07
$H_2O_2\ (aq) + 2H^+\ (aq) + 2e^- \rightarrow 2H_2O\ (l)$	1.763
$Cl_2\ (g) + 2e^- \rightarrow 2Cl^-\ (aq)$	1.396
$MnO_2\ (s) + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O\ (l)$	1.23
$O_2\ (g) + 4H^+\ (aq) + 4e^- \rightarrow 2H_2O\ (l)$	1.229
$Ag^+\ (aq) + e^- \rightarrow Ag\ (s)$	0.7996
$O_2\ (g) + 2H^+ + 2e^- \rightarrow H_2O_2$	0.695
$Cu^+\ (aq) + Cl^- + e^- \rightarrow CuCl\ (s)$	0.559
$Cu^+\ (aq) + e^- \rightarrow Cu\ (s)$	0.52
$O_2\ (g) + 2H_2O\ (l) + 4e^- \rightarrow 4OH^-$	0.401
$Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$	0.3419
$AgCl\ (s) + e^- \rightarrow Ag\ (s) + Cl^-\ (aq)$	0.2223
$2H^+\ (aq) + 2e^- \rightarrow H_2\ (g)$	0.000
$Ga^{3+} + 3e^- \rightarrow Ga\ (s)$	-0.56
$2H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2OH^-\ (aq)$	-0.828
$Mn^{2+} + 2e^- \rightarrow Mn\ (s)$	-1.17
$Ba^{2+} + 2e^- \rightarrow Ba\ (s)$	-2.92

a) What products are most thermodynamically favored at the electrode sites? Make sure to include their phases. ***(2 points)***

b) Write the net ionic equation of the complete reaction that takes place. ***(2 points)***

c) Assuming that the reaction takes place while the reactants and products are in their standard states at a temperature of 25℃, what is the equilibrium constant of the reaction that takes place? If you were unable to solve parts (a) and (b), use the value E° = 3.00 V for the cell and assume that 3 moles of electrons were used in both the reduction and oxidation half-reactions. Leave the answer in exponential form. ***(4 points)***

d) The hydrolytic cell was allowed to run for 5 hours. What was the current through the electrode wires during that time? Use the same assumptions as part (c) if you were unable to solve parts (a) and (b). ***(2 point)***

e) The chemist removed the electrodes from the mixture. Does the reaction continue? Be sure to justify your answer. ***(2 points)***

f) Assuming that ΔH° for the reaction that takes place is -571.6 kJ/mol when the reaction occurs at a temperature of 25℃, what is the standard molar entropy change of the reaction? Report your answer in J/mol K. ***(2 points)***

g) Another chemist has a mixture with the same exact materials but in non-standard state amounts. Using a voltmeter, they measure the potential of the cell to be 4.051 V. The temperature in the lab is a warm 29.3℃. Is the reaction at equilibrium? If not, which direction must the reaction go to reach equilibrium? If you were unable to solve parts (a) and (b), use the value E° = 3.00 V for the cell and assume that 3 moles of electrons were used in both the reduction and oxidation half-reactions. ***(4 points)***