Name ____________________________ Individual ID # _____________________

Team Name ____________________________________

2023 WUCT: INDIVIDUAL EXAM

April 1st, 2023
9:45 – 10:45 a.m.

Please fill in the numbers of your 6-digit individual ID:

Individual ID

⑨	⑨	⑨	⑨	⑨	⑨
⑧	⑧	⑧	⑧	⑧	⑧
⑦	⑦	⑦	⑦	⑦	⑦
⑥	⑥	⑥	⑥	⑥	⑥
⑤	⑤	⑤	⑤	⑤	⑤
④	④	④	④	④	④
③	③	③	③	③	③
②	②	②	②	②	②
①	①	①	①	①	①
⓪	⓪	⓪	⓪	⓪	⓪

1 HOUR will be allowed for the exam. The examination contains **6** questions on **18** numbered pages, including the last **SCRATCH PAGE**.

TURN IN THE ENTIRE EXAM (INCLUDING THE SCRATCH PAGE) WHEN YOU ARE FINISHED!

Exam Points Breakdown:

1. (13 pts)
2. (10 pts)
3. (15 pts)
4. (22 pts)
5. (16 pts)
6. (24 pts)
Total Points: (100 pts)

2023 WUCT: Individual Exam

This exam consists of 6 questions and is worth 100 points. You will complete this exam individually. You will have 1 hour to take the exam. The only allowed resources for this exam are a calculator and the provided equation sheet. You may NOT use any other notes or books. 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 the blank scratch page at the end of the exam. Make sure to clearly indicate in the problem's designated space where the rest of your work can be found. Any work anywhere other than the exam or the scratch page will not be graded. Dark pencil or pen is preferred.

<u>Problem #1</u>: ***(13 points)***

When acetic acid is added to water, it reacts with water in a reversible manner to form acetate ions and hydronium. The equation can be modeled below:

$$CH_3COOH + H_2O \rightleftarrows CH_3COO^- + H_3O^+ \qquad K_a = 1.8 \times 10^{-5}$$

a. Draw the most preferred Lewis structure for CH_3COOH. Include all lone pairs and any non-zero formal charges on appropriate atoms if applicable. ***(3 points)***

b. Write the general expression for the equilibrium constant, K_a, for the reaction above. ***(1 point)***

c. The reaction above is a Brønsted–Lowry acid/base reaction. Define a Brønsted–Lowry acid and base. ***(2 points)***

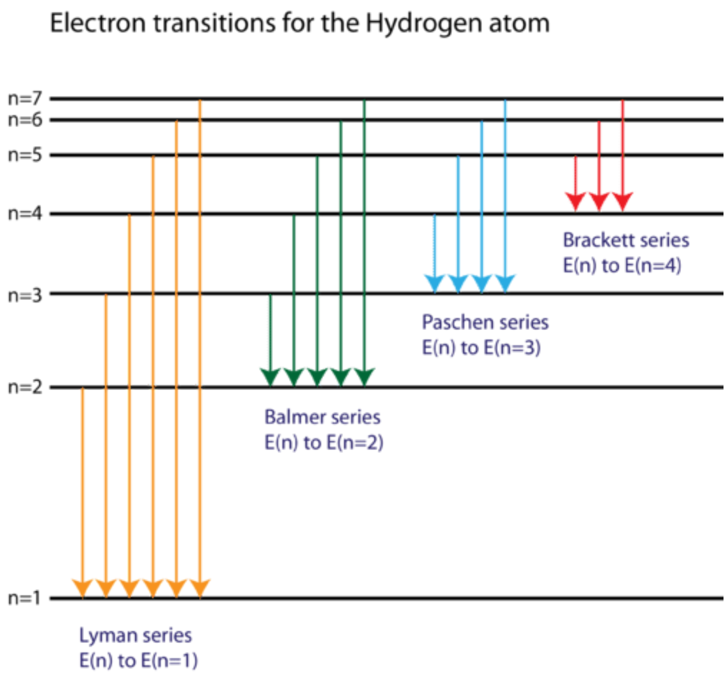
d. Calculate the pH of a 0.43 M solution of acetic acid (CH_3COOH). Round to two decimal places. ***(4 points)***

e. If a 100 mL sample of 0.50 M CH_3COOH was mixed with a 100 mL sample of 0.50 M NaOH, would the pH be less than 7, equal to 7, or greater than 7? Explain. ***(2 points)***

f. List two common laboratory techniques/procedures a student can use to determine the $[H_3O^+]$ of a solution. ***(1 point)***

<u>Problem #2</u>: *(10 points)*

Lyman, Balmer, Paschen, and Bracket series describe different transition states that arise from the hydrogen atom. The relative length of the arrow represents the amount of energy released when the electron undergoes the transition, with longer arrows representing more energy being released. The energy diagram for a hydrogen atom is shown below:



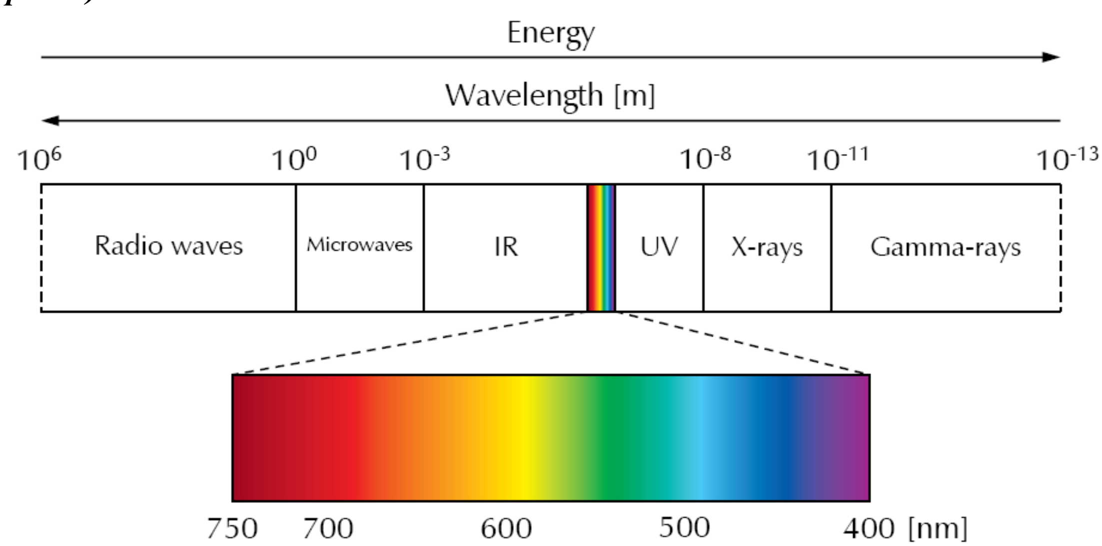
a. The n = 2 to n = 1 transition emits a wave with a wavelength of 122 nm. Calculate the energy of the wave. (Planck's constant, $h = 6.626 \times 10^{-34}\ m^2\ kg/s$) ***(3 points)***

b. Calculate the frequency of the wave that is released from the n = 2 to n = 1 transition. ***(3 points)***

c. Which of the following transitions will result in the emission of waves with the smallest energy? Circle one answer and explain your reasoning. ***(2 points)***

i. n = 4 to n = 2
ii. n = 5 to n = 2
iii. n = 3 to n = 1
iv. n = 6 to n = 5
v. Unable to determine due to not enough information.

d. The electromagnetic spectrum is shown below. The Lyman series produces waves with wavelengths of around 90 - 120 nm. The Balmer series produces waves with wavelengths of around 400 - 650 nm. Paschen series produces waves with wavelengths of around 1000 - 1900 nm. Which of the 3 transition series falls in the infrared (IR) region? ***(2 points)***



<u>Problem #3</u>: *(15 points)*

Use the following redox reaction to answer the questions below. Round all numerical answers to three decimal places. Work must be shown to support your answers for all parts of this question.

$$MnO_4^{\ -} + C_2O_4^{\ 2-} \rightarrow Mn^{2+} + CO_2$$

a. Assign oxidation states to each of the elements. ***(4 points)***

$MnO_4^{\ -}$		+	$C_2O_4^{\ 2-}$		→	Mn^{2+}	+	CO_2	
Mn	O		C	O		Mn		C	O

b. Balance the REDUCTION half reaction in acidic medium. ***(2 points)***

c. Balance the OXIDATION half reaction in acidic medium. ***(2 points)***

d. Write out the fully balanced redox reaction. ***(1 point)***

e. If 500 mL of a 2.5 M MnO_4^- solution and 250 mL of a 1.0 M $C_2O_4^-$ solution are combined, what are the new concentrations of each species before any reaction occurs? ***(2 points)***

f. What is the limiting reactant of the reaction described in (e)? ***(2 points)***

g. How much CO_2 gas is produced (in grams) from the reaction, using the quantities described in (e,f)? ***(1 point)***

h. If the CO_2 gas was collected using water displacement, what would be the problem with the gas collected? ***(1 point)***

<u>Problem #4</u>: *(22 points)*

Plants use photosynthesis to produce their own foods. This process can be modeled by the equation below:

$$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$$

a. Write out the balanced equation by adding the correct coefficients below. ***(2 points)***

$$\_\_\_\_ \ CO_2 + \_\_\_\_ \ H_2O \rightarrow \_\_\_\_ \ C_6H_{12}O_6 + \_\_\_\_ \ O_2$$

Raw data was collected for photosynthesis at a particular temperature as shown below:

Experiment	**CO_2 (mol/L)**	**H_2O (mol/L)**	**Change in [O_2] Rate (M/s)**
1	2.14×10^{-6}	3.01×10^{-6}	3.41×10^{-12}
2	6.42×10^{-6}	3.01×10^{-6}	1.02×10^{-11}
3	2.14×10^{-6}	6.02×10^{-6}	6.82×10^{-12}
4	4.28×10^{-6}	3.01×10^{-6}	6.82×10^{-12}

b. Write the rate-law expression for photosynthesis. Show all of your work. ***(3 points)***

c. Calculate the value of the rate constant, *k*, with the correct units. ***(2 points)***

d. When temperature is increased, the rate of photosynthesis increases. Circle ALL of the correct reasons for why increased temperature results in a faster rate of photosynthesis. ***(3 points)***

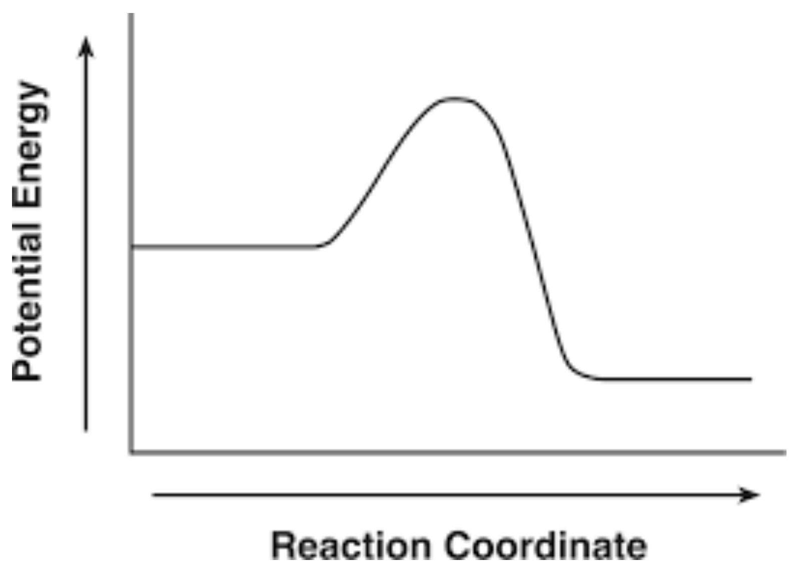
i) Lowering of activation energy
ii) Raising of activation energy
iii) Increased surface area of CO_2 and H_2O
iv) Increased number of collisions
v) Promotes proper orientation of collision between reactants
vi) Decrease in volume of the system
vii) A change from inelastic collisions to elastic collisions among reactants

e. Using the given values, calculate the ΔH, ΔS, and ΔG of photosynthesis at 25°C. Does the data indicate that photosynthesis is a spontaneous process? ***(7 points)***

	ΔH_f	ΔS^o
$C_6H_{12}O_6$	-1273.3 kJ/mol	212 J/K•mol
O_2	0 kJ/mol	205 J/K•mol
H_2O	-285.8 kJ/mol	69.9 J/K•mol
CO_2	-393.5 kJ/mol	213.5 J/K•mol

f. Rubisco is an enzyme present in plants that serve as an initial catalyst for photosynthesis. What happens to the speed of the reaction when rubisco is present? What happens to the equilibrium constant of the reaction? ***(2 points)***

g. The potential energy graph below shows the reaction without rubisco. On the diagram below, draw out what the graph would look like in the presence of rubisco. ***(3 points)***



<u>Problem #5</u>: *(16 points)*

a. Draw the Lewis structure for phosphorus pentachloride (PCl_5) and classify its VSEPR geometry. ***(3 points)***

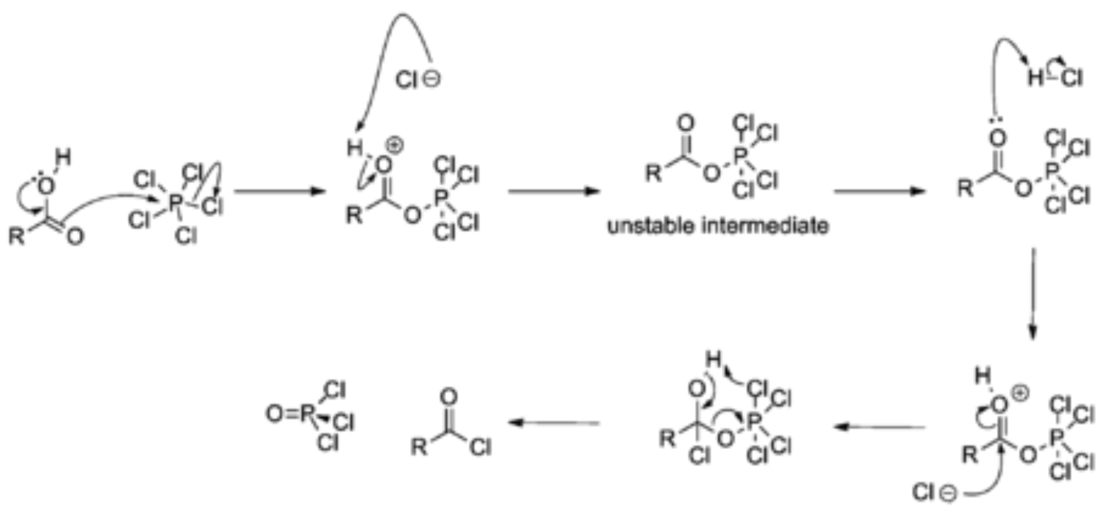
b. In addition to VSEPR geometry, inorganic chemists can classify molecules based on their symmetry elements. To contain a certain symmetry element, the molecule must look exactly the same after performing an operation, such as rotation, inversion, or reflection.

   A C_n rotation axis describes rotation through 360°/n. What is the highest value of n present in PCl_5? Write your answer in the format C_n. ***(3 points)***

c. Given that there are 2 axial Cls and 3 equatorial Cls in PCl_5, which bond length is longer: Cl_{eq}-P-Cl_{eq} or Cl_{ax}-P-Cl_{ax}? Explain your answer using bonding pair repulsion properties. ***(3 points)***

d. If a chlorine atom was replaced by fluorine, predict which position this substitution would be most stable (axial or equatorial)? Explain your answer using electronegativity and bonding pair repulsion properties and include a Lewis structure of this new molecule. ***(4 points)***

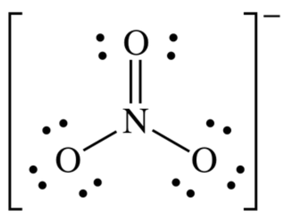
e. PCl_5 is commonly used as a chlorinating agent for carboxylic acids to make acid chlorides. Below is the mechanism for this reaction:



Does the carbon on the carboxylic acid become more reactive, less reactive, or neither? ***(3 points)***

<u>Problem #6</u>: *(24 points)*

Sodium nitrate ($NaNO_3$), a white salt that is soluble in water, serves as a source of the nitrate ion (NO_3^-). This anion is commonly used in industrial reactions for explosives, fertilizer, food preservatives, and rocket propellant. The lewis structure of nitrate is shown below:



a. What is the bond order of the nitrogen-oxygen bonds in the nitrate ion? ***(1 point)***

b. What is the basic geometry and molecular geometry of the nitrate ion? ***(2 points)***

c. One common synthesis to produce sodium nitrate is shown below:

$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$$

This reaction utilizes a Brønsted-Lowry base and a Brønsted-Lowry acid. Identify the acid, base, conjugate acid, and conjugate base of the reaction. ***(4 points)***

d. Another type of acid-base definition is given by the Lewis acids and bases. Identify the Lewis acid and the Lewis base on the reactant side of the chemical equation. ***(2 points)***

e. Assume the reaction goes to completion at 25°C. What is the pOH of the reaction solution at that point? ***(1 point)***

f. Your lab instructor gives you some nitric acid (HNO_3) of unknown concentration to use for this reaction. However, in order to know how much of 10% NaOH solution to add (grams per Liter of solution), you need to do a titration to find the concentration of the nitric acid stock solution. You place 35 mL of HNO_3 into an Erlenmeyer flask. The solution of HNO_3 changes color after you add 40 mL of the NaOH solution. What is the percent of the HNO_3 solution (mass per Liter of solution)? ***(4 points)***

g. Sketch a titration curve below for this titration (described above in part (f)), with the NaOH solution as the titrant. Be sure to label the axes. The only numerical values you need to include are the pH at the equivalence point, the volume of titrant added at the equivalence point, and the volume of titrant added at the half-equivalence point. ***(3 points)***

h. Given the table below of indicators and their pK_{In} values, what indicator is your instructor most likely to have included in the HNO_3 solution they gave you? Be sure to justify your answer in 1-2 sentences. ***(2 points)***

Acid-Base Indicator	pK_{In}
Thymol Blue	1.7
Methyl Orange	3.7
Methyl Red	5.0
Bromothymol Blue	7.1
Phenolphthalein	9.6

i. After the reaction goes to completion so that there are no more reactants left, you place two graphite electrodes into the solution. You hook these electrodes up to a battery, and current starts running through the wires.

   i) What current do you need to observe sodium metal form in this hydrolytic cell? Assume you are working under conditions of standard temperature and pressure and at a temperature of 25℃. In addition, keep in mind that the amounts of hydronium and hydroxide ions present are considered negligible relative to the quantities of the other species in solution. ***(3 points)***

   ii) Alkali metals are known to explode in water. If you did not run a current in this solution, would it be dangerous to leave the solution alone for a couple of hours? Why or why not? ***(2 points)***

Scratch Page