Name _____ Individual ID # _____

Team Name _____

2025 WUCT: Individual Exam

April 5th, 2025
9:45 a.m. – 10:45 a.m.

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

Individual ID

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1 HOUR will be allowed for the exam. The examination contains **7** questions on **24** numbered pages, including the last **SCRATCH PAGE**.

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

Exam Points Breakdown:

1. (11 pts)
2. (19 pts)
3. (14 pts)
4. (16 pts)
5. (11 pts)
6. (19 pts)
7. (10 pts)
Total Points: (100 pts)

2025 WUCT: Individual Exam

This exam consists of 7 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.

Problem #1: *(11 points)*

Sulfuric acid, H_2SO_4, is a strong acid in water and has a unique structure from many of the other common acids. Sulfuric acid reacts with other compounds to form exceedingly reactive and dangerous products.

a. Draw the most preferred structure for sulfuric acid **and** one other valid Lewis structure. Please indicate all nonzero formal charges, if any. Circle your most preferred structure and label it as "most preferred." ***(2 points)***

b. Based on your **most preferred** structure in part a, report the number of electrons around the central sulfur atom **and** justify why this is allowed using an orbital argument. ***(3 points)***

_____

_____

_____

c. What is the orbital hybridization for the sulfur atom in sulfuric acid? ***(1 point)***

d. When concentrated sulfuric acid is combined with hydrogen peroxide in a 3:1 volume ratio, it produces Caro's Acid and water, commonly known as the Piranha Solution. This solution violently reacts with organic matter and is most often used as a cleaning agent for microelectronics. The reaction below is partially completed, but balanced properly:

$$H_2SO_4 + H_2O_2 \rightarrow H_2O + Caro's\ Acid$$

Write the formula for Caro's Acid and determine the oxidation state for its central sulfur. ***(2 points)***

Formula: _____

Sulfur Oxidation State: _____

e. Suppose you have 0.150 L of 30% aqueous hydrogen peroxide solution by weight. If you are preparing a Piranha Solution using the 3:1 volume ratio described above in part d, what concentration of sulfuric acid would you need to completely react with the hydrogen peroxide? *Note: the density of hydrogen peroxide in water is 1.45 g/mL.* ***(3 points)***

Problem #2: (*19 points*)

By adding different solutes to a solvent, we can observe changes in the solvent's vapor pressure, boiling point, freezing point, and osmotic pressure. These are referred to as colligative properties.

a. Consider a solution of sodium chloride ($NaCl$) dissolved in water and a solution of glucose ($C_6H_{12}O_6$) dissolved in water. Would you expect the boiling point elevation of the two solutions to differ or be equal? If they differ, which solution's boiling point elevation is greater? Assume the same amounts of solute and solvent are used in both. Circle your answers below. ***(2 points)***

Boiling Point Elevations:	**Differ**	**Equal**
If Differ:	**Sodium Chloride**	**Glucose**

b. Consider a solution of aqueous sucrose, $C_{12}H_{22}O_{11}$, at 25 ℃ and 760 torr. Predict how the **osmotic pressure** of the solution would be affected in the following scenarios. Fill in the blanks below with **increase**, **decrease**, or **stay the same**. ***(3 points)***

i. The temperature of the solution is **doubled**

_____

ii. The same mass of sucrose is dissolved in the same **mass** of hexane (a solvent **less dense** than water)

_____

iii. The sucrose is dissolved in water in a lab space at **800 torr**

_____

c. Sucrose was added into 355 g of ethanol (C_2H_5OH) instead of water (as in part b), and the concentration of the resulting solution was to be 1.50 M. What is the freezing point of this solution? *Note: freezing point of pure ethanol = -114.7 ℃, K_f of ethanol = 1.99 ℃/molality, density of ethanol = 0.789 g/mL.* ***(4 points)***

There are other various factors that affect boiling points of substances besides colligative properties. One such influence is the presence of different types of intermolecular forces.

d. For each of the following substances, list **all** intermolecular interactions (hydrogen bonding, dipole-dipole, and/or London dispersion) that exist within a solution of each type of particle, and determine if the substance is polar or not. Fill in the first blank with the **name(s) of the intermolecular force(s)** and the second blank with a **yes or no**. ***(4 points)***

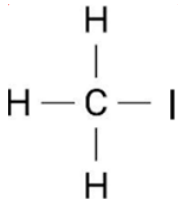
i. SO_2: _____ Polar? _____

ii. CH_2Cl_2: _____ Polar? _____

iii. PCl_5: _____ Polar? _____

e. Out of the following molecules, predict which one would have the **higher boiling point** and provide a brief justification as to why, referring to the intermolecular forces involved. ***(3 points)***

i.



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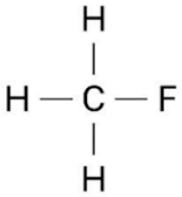


Justification:

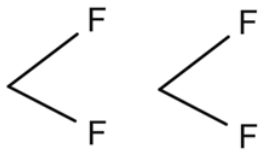
_____

_____

_____

f. Below are several orientations of two molecules of CH_2F_2. Using your knowledge of intermolecular forces, circle which orientation would be the **most stable**. Provide a brief justification as to why. ***(3 points)***

i.



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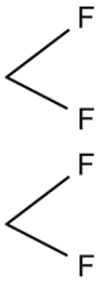

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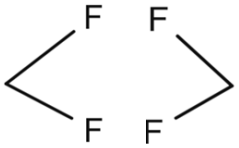


Justification:

_____

_____

_____

Problem #3: ***(14 points)***

In chemical engineering, a reaction chamber is a device or vessel within which chemical processes are carried out for experimental or manufacturing purposes. Consider the Haber process taking place in a simplified reaction chamber at a **constant volume**. This process **reversibly** manufactures ammonia gas from nitrogen gas and hydrogen gas. Ammonia is an important chemical component of fertilizers and cleaning supplies.

a. Write the complete balanced equation of the Haber process, including states for each species. ***(1 point)***

b. Given that K_p for this reaction is 1.45×10^{-5} at $500^{\circ}C$, calculate K_c at $500^{\circ}C$. *Note: this is a unitless quantity.* ***(3 points)***

c. Before the reaction has reached equilibrium, the partial pressures of each gas are as follows: nitrogen gas = 1.12 atm, hydrogen gas = 1.56 atm, and ammonia gas = 0.47 atm. Determine the reaction quotient at this moment **and** what direction the reaction will proceed in. Report your answers on the designated lines provided. *Note: this particular reaction is taking place at 500˚C.* ***(3 points)***

Reaction Quotient: _____

Reaction Direction: _____

d. When a chemist utilizing the Haber process to produce ammonia wants to increase the product yield, they lower the temperature of the reaction. Based off this information, is the Haber process endothermic or exothermic? Circle your answer. ***(1 point)***

Endothermic Exothermic

e. Use Le Chatêlier's Principle to determine which direction the reaction describing the Haber process shifts when the following stress is applied. Fill in the blanks with either **toward reactants**, **toward products**, or **no shift**. ***(4 points)***

   i. Increasing the pressure in the reaction chamber

   _____

   ii. Adding a catalyst

   _____

   iii. Adding gaseous hydrochloric acid

   _____

   iv. Adding argon gas

   _____

f. Before being used to produce ammonia, the gaseous nitrogen is stored in a 400 gallon chamber at atmospheric pressure and a temperature of 4˚C. If the chamber is filled to capacity, how many moles of nitrogen gas are present? Assume ideal gas behavior. ***(2 points)***

Problem #4: (*16 points*)

Use the following unbalanced 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.

$$Cr_2O_7^{2-} + H_2O_2 \rightarrow Cr^{3+} + O_2 + H_2O$$

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

$Cr_2O_7^{2-}$		+	H_2O_2		→	Cr^{3+}	+	O_2	+	H_2O	
Cr	O		H	O		Cr		O		H	O

b. Balance the **REDUCTION** half reaction **involving chromium** in basic medium. **(*3 points*)**

c. Balance the **REDUCTION** half reaction **involving the hydrogen peroxide** in basic medium. **(*3 points*)**

d. Balance the **OXIDATION** half reaction **involving the hydrogen peroxide** in basic medium. **(*3 points*)**

e. Write out the **fully balanced** redox reaction in <u>basic medium</u>. **(*3 points*)**

Problem #5: (*11 points*)

Acids and bases are very important in the study of chemistry and have a wide range of biological and analytical applications.

a. At room temperature, 20 mL of 2.0 M NaOH is added to 100 mL of a 1.0 M unknown weak acid, which creates a buffer solution. The solution reaches a pH of 2.96. Of the options listed below, determine the identity of the unknown acid. Circle your answer and show all necessary work to support it. **(*3 points*)**

A. Oxalic Acid ($K_{a1} = 5.4 \times 10^{-2}$)

B. Nitrous Acid ($K_a = 7.3 \times 10^{-4}$)

C. Benzoic Acid ($K_a = 6.3 \times 10^{-5}$)

D. Sulfurous Acid ($K_{a1} = 1.3 \times 10^{-2}$)

b. Describe two key characteristics of a buffer solution. ***(+2 points)***

c. **Quantitatively** describe how to prepare a buffer solution with a pH of 4.36 using 1.0 M acetic acid ($pK_a = 4.76$) and 1.0 M sodium hydroxide. **(*2 points*)**

d. $Ca(OH)_2$ is an insoluble salt in pure water at 25˚C. Why is the solubility of $Ca(OH)_2$ increased significantly when it is dissolved in an acidic solution? Justify your answer in 1-2 sentences by referencing the solubility equilibrium below. **(*2 points*)**

$$Ca(OH)_2\,(s) \rightleftharpoons Ca^{2+}\,(aq) + 2OH^-\,(aq)$$

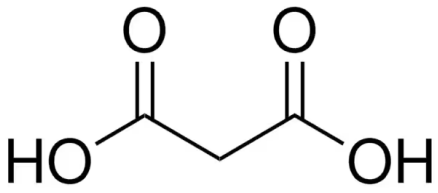
Justification:

_____

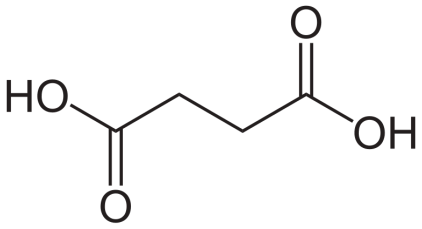
_____

_____

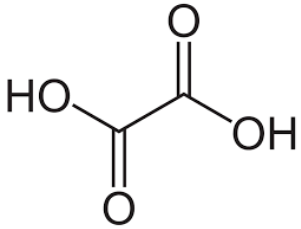
e. The inductive effect refers to the phenomenon of a highly electronegative atom pulling electron density away from nearby atoms. When the electron density is pulled away from an O-H bond, the bond is weakened and the acidity of the hydrogen increases. Using this principle, rank the acidity of the three acids below from **most acidic to least acidic** by filling in the blanks with the name of the acid. **(*2 points*)**



Malonic Acid



Succinic Acid



Oxalic Acid

_____ > _____ > _____

Most Acidic **Least Acidic**

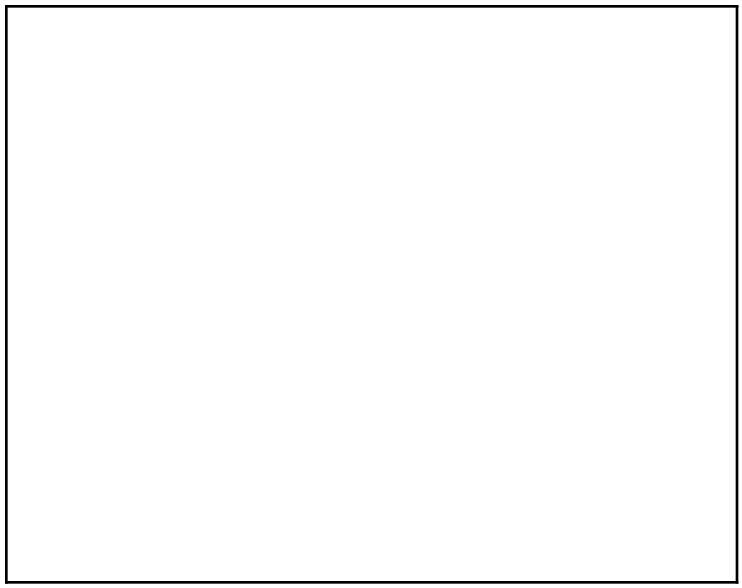
Problem #6: ***(19 points)***

Some compounds are labeled as insoluble, however, this is not entirely true. Even "insoluble" compounds still dissociate in some small amount to ions when in solution.

a. Silver chloride is an insoluble compound, but when put in water, an extremely small amount of it dissociates into ions. ***(4 points)***

   i. Write out the balanced **dissociation** equation describing this process, including the states of each species. ***(1 point)***

   ii. In the box provided, draw a diagram of solid silver chloride and its ions dissociated in water. Include properly oriented water molecules in your diagram, as well as qualitatively accurate amounts of solid vs. aqueous silver chloride. ***(3 points)***



b. 0.016 g of $AgCl$ is completely dissolved into 10 L of H_2O. ***(5 points)***

i. Given that the K_{sp} of the dissociation of $AgCl$ is 1.70×10^{-10} at 25℃, find the solubility, s, of $AgCl$ in mol/L. ***(2 points)***

ii. Ignoring your answer in part b(i), say the solubility of $AgCl$ is 1.50×10^{-5} mol/L. Will the $AgCl$ solution described in the preamble of part b be unsaturated, saturated, or supersaturated? Circle your final conclusion and show all work to support your answer. ***(3 points)***

Unsaturated **Saturated** **Supersaturated**

c. A 0.1 M solution of NaCl in water is prepared. Then, 2.0×10^{-6} g of $AgCl$ is mixed in. For each of the following situations, indicate which way the reaction you wrote out in part a(i) will shift based on Le Chatelier's Principle. Put an "**X**" in the box corresponding to your answer for each scenario. *Note: you should have one "**X**" per column.* ***(4 points)***

	$NaCl$ is added to the solution	**The solution is diluted with water**	**Some solid $AgCl$ is taken out**	**Adding a compound that precipitates out Ag^+ (e.g., Na_2S)**
Towards reactants				
Towards products				
No change				

d. Similarly, lead (II) iodide, PbI_2, is a sparingly soluble salt in water at 25˚C. The $\Delta H_f°$ for PbI_2(s) is -175.39 kJ/mol, the $\Delta H_f°$ for Pb^{2+}(aq) is 0.92 kJ/mol, and the $\Delta H_f°$ for I^-(aq) is -56.78 kJ/mol. The $\Delta S°$ of dissolution of the solubility equilibrium given below is 174.85 J/(mol K). ***(6 points)***

$$PbI_2\,(s) \rightleftharpoons Pb^{2+}\,(aq) + 2I^-\,(aq)$$

i. Calculate the $\Delta H_{RXN}°$ in kJ/mol. Is this reaction endothermic or exothermic? Circle your answers. ***(3 points)***

Endothermic **Exothermic**

ii. Explain why ΔS° is positive for the forward direction of this reaction. ***(2 points)***

_____

_____

_____

_____

iii. If the temperature of the solution is increased, how would that affect the solubility of lead (II) iodide? Circle your answer. ***(1 point)***

Increase **Decrease** **Stay the Same**

Problem #7: ***(10 points)***

Uric acid is a compound found in your urine at high concentrations if you don't drink enough water throughout the day.

a. Uric acid contains 35.7% C, 2.4% H, 33.3% N, and 28.6% O by mass. Determine the molecular formula for uric acid. *Hint: one mole of uric acid contains 3 moles of oxygen.* ***(3 points)***

b. Uric acid is an immune system stimulant and antioxidant. You decide to purify uric acid from your urine. ***(5 points)***

   i. The average, well-hydrated person has 0.04 g/L to 0.085 g/L of uric acid in their urine. Convert the range into molarity, M, and report your answer on the line below. *Note: use a molar mass of 168.11 g/mol for uric acid no matter the chemical formula you calculated in part a.* ***(2 points)***

   Range in Molarity: _____

   ii. You purify 0.003 moles of uric acid from a 500 mL sample of urine. Does the person need to drink more water, assuming they want to stay within the healthy limits given in part b(i)? Circle yes or no below, and show all work to support your answer. ***(3 points)***

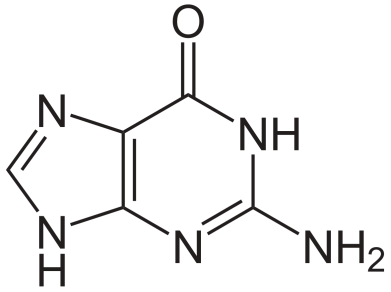
   Yes **No**

c. Your purification process for uric acid from a sample of urine fails. Instead, you decide to try to synthesize uric acid from a compound called Xanthine. The reaction below is partially complete (with common names rather than chemical formulae), but it is properly balanced:

$$xanthine + H_2O + O_2 \rightarrow uric\ acid + H_2O_2$$

Using your uric acid formula for part a, determine the chemical formula of xanthine. ***(1 point)***

d. In the human body, a precursor (a compound used to form another) of uric acid is guanine. Determine guanine's chemical formula from the following structure. *Reminder: bond-line structure depicts implicit carbons and hydrogens. At every vertex, there is a carbon, and each carbon always makes four bonds to complete its octet. Any bonds not explicitly shown with other atoms are made up with hydrogens.* ***(1 point)***



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