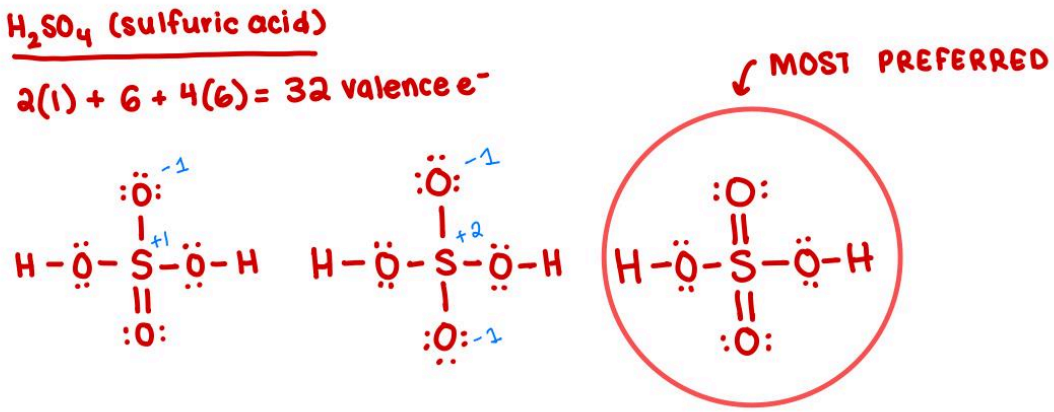
2025 WUCT: Individual Exam

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)***



+1 point for fully correct most preferred structure (connectivity and number of bonds, no formal charges)

+1 point for one other resonance structure with correct connectivity, number of bonds, and formal charges

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)***

Number of electrons: 12 e^- **(+1 point)**

Sulfur is located in the third row of the periodic table, therefore it can accept electrons into its empty **d-orbitals (+2 points)** to have an expanded octet and form 6 bonds.

+1 point for correct number of electrons about the central sulfur (note: can receive this point as long as the number of electrons they report is consistent with the number of electrons around the sulfur in the structure they circled as most preferred in part a)
+2 points for the Key Concept: sulfur has access to empty d-orbitals
(Note: students do not need to say "expanded octet" to receive full points)

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

Hybridization: sp^3 **(+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: ___H_2SO_5 ____ **(+1 point)**

Sulfur Oxidation State: ________+8_______________________________ **(+1 point)**

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)***

Finding moles of H_2SO_4:

$$0.150\ L\ solution \times \frac{1000\ mL\ solution}{1\ L\ solution} \times \frac{1.45\ g\ solution}{1\ mL\ solution} \times \frac{30\ g\ H_2O_2}{100\ g\ solution} = 65.3\ \mathrm{g}\ H_2O_2$$

$$65.3\ g\ H_2O_2 \times \frac{1\ mol\ H_2O_2}{34.014\ g\ H_2O_2} \times \frac{1\ mol\ H_2SO_4}{1\ mol\ H_2O_2} = 1.92\ \mathrm{mol}\ H_2SO_4\ \textbf{(+1 point)}$$

Finding liters of H_2SO_4:

$$0.150\ L\ H_2O_2 \times \frac{3\ L\ H_2SO_4}{1\ L\ H_2O_2} = 0.450\ \mathrm{L}\ H_2SO_4\ \textbf{(+1 point)}$$

Concentration of H_2SO_4:

$$\frac{moles\ of\ H_2SO_4}{liters\ of\ H_2SO_4} = \frac{1.92\ mol\ H_2SO_4}{0.450\ L\ H_2SO_4} = 4.26\ \mathrm{M}\ \textbf{(+1 point)}$$

+1 point for correct moles of H_2SO_4, including factoring in the density

+1 point for correct liters of H_2SO_4, including factoring in the 3:1 ratio

+1 point for correct concentration of H_2SO_4

(Note: students may choose to do this in one long step of dimensional analysis. As long as the substitution and final answer are correct, we will take this for full credit.)

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** **(+1 point)**

If Differ: **Sodium Chloride** **Glucose** **(+1 point)**

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**

____________________________**increase**____________________ **(+1 point)**

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

____________________________**decrease**____________________ **(+1 point)**

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

____________________________**stay the same**____________________ **(+1 point)**

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)***

$$\Delta T_f = -K_f m_{solute}$$

$$\frac{1.50\ mol\ sucrose}{1\ L\ ethanol} \times \frac{1\ L\ ethanol}{1000\ mL\ ethanol} \times \frac{1\ mL\ ethanol}{0.789\ g\ ethanol} \times 355\ g\ ethanol = 0.675\ mol\ sucrose$$

(+1 point)

$$m_{solute} = \frac{0.675\ mol\ sucrose}{355\ g\ ethanol} \times \frac{1000\ g\ ethanol}{1\ kg\ ethanol} \times \frac{1\ particle}{1\ mol\ sucrose} = 1.9\ particles/kg\ ethanol$$

(+1 point)

$$\Delta T_f = -K_f m_{solute} = -1.99\frac{℃}{molality}\left(\frac{1.9\ particles}{1\ kg\ ethanol}\right) = -3.78\ ℃$$ **(+1 point)**

$$Resultant\ Freezing\ Point = -114.7\ ℃ - 3.78\ ℃ = -118.48\ ℃$$ **(+1 point)**

+1 point for correctly calculating the new moles of sucrose
+1 point for calculating molality (even if it is not correct)
+1 point for calculating the freezing point depression (even using an incorrect molality)
+1 point for correct new freezing point

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: ________dipole-dipole, London dispersion______ Polar? ___yes______

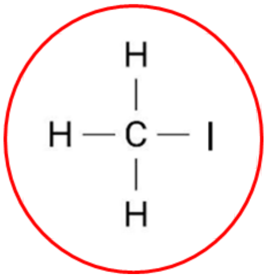
ii. CH_2Cl_2: _____dipole-dipole, London disperson______ Polar? ___yes______

iii. PCl_5: _____________London dispersion____________ Polar? ___no_______

+1 point for each intermolecular forces blank (3 points total for all 3 answers)
+1 point for a fully correct set of polar blanks (1 point total for all 3 answers)

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)***

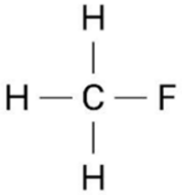
i.



CH_3I

(+1 point)

ii.



CH_3F

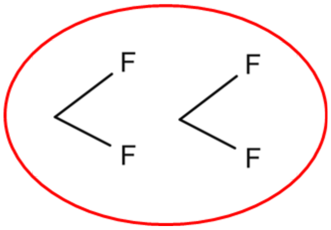
Justification:

The greater size and polarizability of the electron cloud on iodine (+1 point) allows for **greater london dispersion forces (+1 point)** and therefore higher boiling point

+1 point for correct circle
+1 point for Key Concept 1: some discussion of size/polarizability (for either molecule)
+1 point for Key Concept 2: relating this to LDF and boiling point

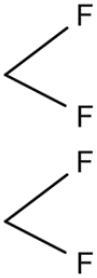
f. Below are several orientations of two molecules of CH_2F_2. Using your knowledge of intermolecular forces, circle which orientation would be the **most stable**. Provide a brief justification as to why. ***(3 points)***

i.

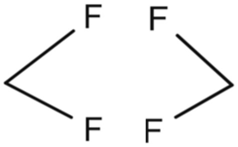


(+1 point)

ii.



iii.



Justification:

In this arrangement, the **dipoles of the two molecules line up (+1 point)** head-to-tail allowing for a **greater total dipole moment and therefore stronger dipole-dipole intermolecular interactions (+1 point)** and an overall more stable molecule.

+1 point for correct circle
+1 point for Key Concept 1: some discussion on the alignment of molecular dipoles
+1 point for Key Concept 2: relating this alignment to stronger dipole-dipole

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)***

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ **(+1 point)**

Note: reaction must have reactants and products on their respective sides, all gas phases, and reversible arrows to get credit

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)***

$K_p = K_c(RT)^{\Delta n} \quad \rightarrow \quad K_c = \frac{K_p}{(RT)^{\Delta n}}$ **(+1 point)**

$\Delta n\ (Haber) = product\ moles - reactant\ moles = 2 - 4 = -2$

$K_c = \frac{(1.45 \times 10^{-5})}{((0.08206\ L\ atm\ mol^{-1}\ K^{-1})(273.15\ K + 500^{\circ}C))^{-2}}$ **(+1 point)** $= 0.0584$ **(+1 point)**

+1 point for using the correct equation
+1 point for correct substitution, including a correct Δn (can leave R as "R")
+1 point for correct final answer

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: ____Q = 0.05195____

Reaction Direction: ____Toward reactants or Left______________________________

$P_{N_2} = 1.12\ atm$

$P_{H_2} = 1.56\ atm$

$P_{NH_3} = 0.47\ atm$

Equilibrium Expression: $Q_p = \frac{P_{NH_3}^{\ 2}}{P_{N_2}^{\ 1} P_{H_2}^{\ 3}} = \frac{(0.47)^2}{(1.12)\,(1.56)^3} = 0.051952$ **(+1 point)**

$K_p = 1.45 \times 10^{-5}$

$Q_p > K_p$ **(+1 point)**

Therefore, the reaction proceeds **toward the reactants** (to the left). **(+1 point)**

+1 point for correct reaction quotient

+1 point for some comparison between Q and K_p (does not need to be correct Q)

+1 point for correct direction based on Q vs. K_p comparison (toward reactants if their calculated Q is greater than K, toward products if their calculated Q is less than K)

Note: some students may compare their Q to the K_c they calculated in part b (i.e. $Q_p < K_c$). This is conceptually incorrect, as this is a gas phase Q. Students who do this can only receive the first point here for correct Q and no others.

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

(+1 point)

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 **(+1 point)**

________________Toward products______________

ii. Adding a catalyst **(+1 point)**

________________No shift_____________________

iii. Adding gaseous hydrochloric acid **(+1 point)**

________________Toward products______________

iv. Adding argon gas **(+1 point)**

________________No shift_____________________

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)***

$$P = 1\ atm$$
$$V = 400\ gal \times \frac{3.78541\ L}{1\ gal} = 1514.164\ L$$
$$R = 0.08206\ \frac{L\ atm}{mol\ K}$$
$$T = 4^{\circ}C + 273.15\ K = 277.15\ K$$

$$PV = nRT$$
$$n = \frac{PV}{RT} = \frac{(1\ atm)\ (1514.164\ L)}{(0.08206\ \frac{L\ atm}{mol\ K})\ (277.15\ K)}\ \textbf{(+1 point)} = 66.577\ mol\ N_2\ \textbf{(+1 point)}$$

+1 point for correct substitution into the Ideal Gas Law (not including the unit conversion from gallons to liters)
+1 point for correct moles of nitrogen gas

<u>Problem #4</u>: (*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
+6	-2		+1	-1		+3		0		+1	-2

+0.5 points for each correct oxidation state

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

$Cr_2O_7^{2-} \rightarrow Cr^{3+}$ **(+1 point)**	Reduction half reaction
$Cr_2O_7^{2-} \rightarrow 2Cr^{3+}$	Balance all species that are not O and H (the Cr)
$Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 7H_2O$	Balance the O's with H_2O
$Cr_2O_7^{2-} + 14H^{+} \rightarrow 2Cr^{3+} + 7H_2O$	Balance the H's with H^{+}
$Cr_2O_7^{2-} + 14H^{+} + 14OH^{-} \rightarrow 2Cr^{3+} + 7H_2O + 14OH^{-}$	Add OH^{-} to both sides to get rid of the H^{+}
$Cr_2O_7^{2-} + 14H_2O \rightarrow 2Cr^{3+} + 7H_2O + 14OH^{-}$ **(+1 point)**	Combine the H^{+} and OH^{-} to form water (H_2O)
$Cr_2O_7^{2-} + 7H_2O \rightarrow 2Cr^{3+} + 14OH^{-}$	Cancel out as many waters as possible on both sides
$Cr_2O_7^{2-} + 7H_2O + 6e^{-} \rightarrow 2Cr^{3+} + 14OH^{-}$ **(+1 point)**	Balance the charges with electrons

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

$H_2O_2 \rightarrow H_2O$ **(+1 point)**	Reduction half reaction
$H_2O_2 \rightarrow 2H_2O$	Balance the O's with H_2O
$H_2O_2 + 2H^+ \rightarrow 2H_2O$	Balance the H's with H^+
$H_2O_2 + 2H^+ + 2OH^- \rightarrow 2H_2O + 2OH^-$	Add OH^- to both sides to get rid of the H^+
$H_2O_2 + 2H_2O \rightarrow 2H_2O + 2OH^-$ **(+1 point)**	Combine the H^+ and OH^- to form water (H_2O)
$H_2O_2 \rightarrow 2OH^-$	Cancel out as many waters as possible on both sides
$H_2O_2 + 2e^- \rightarrow 2OH^-$ **(+1 point)**	Balance the charges with electrons

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

$H_2O_2 \rightarrow O_2$ **(+1 point)**	Oxidation half reaction
$H_2O_2 \rightarrow O_2$	Balance the O's with H_2O (already balanced)
$H_2O_2 \rightarrow O_2 + 2H^+$	Balance the H's with H^+
$H_2O_2 + 2OH^- \rightarrow O_2 + 2H^+ + 2OH^-$	Add OH^- to both sides to get rid of the H^+
$H_2O_2 + 2OH^- \rightarrow O_2 + 2H_2O$ **(+1 point)**	Combine the H^+ and OH^- to form water (H_2O)
$H_2O_2 + 2OH^- \rightarrow O_2 + 2H_2O$	Cancel out as many waters as possible on both sides (nothing to cancel)
$H_2O_2 + 2OH^- \rightarrow O_2 + 2H_2O + 2e^-$ **(+1 point)**	Balance the charges with electrons

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

$Cr_2O_7^{2-} + 7H_2O + 6e^- \rightarrow 2Cr^{3+} + 14OH^-$	Balanced reduction half reaction involving chromium
$H_2O_2 + 2e^- \rightarrow 2OH^-$	Balanced reduction half reaction involving H_2O_2
$[H_2O_2 + 2OH^- \rightarrow O_2 + 2H_2O + 2e^-] \times 4$ **(+1 point)**	Balanced oxidation half reaction involving H_2O_2 multiplied by 4 to balance the electrons
--	
$Cr_2O_7^{2-} + 7H_2O + 6e^- \rightarrow 2Cr^{3+} + 14OH^-$	Rewrite
$H_2O_2 + 2e^- \rightarrow 2OH^-$	Rewrite
$4H_2O_2 + 8OH^- \rightarrow 4O_2 + 8H_2O + 8e^-$	Rewrite multiplied by 4
+ -- **(+1 point for adding the separate reactions together)**	Add them together
$Cr_2O_7^{2-} + 7H_2O + 6e^- + H_2O_2 + 2e^-$ $+ 4H_2O_2 + 8OH^- \rightarrow 2Cr^{3+} + 14OH^- + 2OH^-$ $+ 4O_2 + 8H_2O + 8e^-$	Added together
$Cr_2O_7^{2-} + 5H_2O_2 \rightarrow 2Cr^{3+} + 8OH^- + 4O_2 + H_2O$ **(+1 point)**	Combine like terms on the same side and cancel out like terms on opposite sides

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 ($K_{a1} = 1.3 \times 10^{-2}$)

Starting moles:

$mol\ OH^- = 2.0\ M \times 0.02\ L = 0.04\ mol$
$mol\ HA = 1.0\ M \times 0.100\ L = 0.10\ mol$

Ending moles:

$mol\ HA = 0.10\ mol - 0.04\ mol = 0.06\ mol$
$mol\ A^- = mol\ OH^- = 0.04\ mol$ **(+1 point)**

Henderson-Hasselbach:

$pH = pKa - log(\frac{[HA]}{[A^-]})$ **(+1 point)**
$2.96 = pKa - log(\frac{0.06}{0.04})$
$pKa = 2.96 + log(\frac{0.06}{0.04}) = 3.136$
$Ka = 10^{-3.136} = 7.30 \times 10^{-4}$ **(+1 point)**

+1 point for determining the moles of the acid and conjugate base after the addition of the NaOH
+1 point for correctly choosing to use the Henderson-Hasselbalch equation
+1 point for correct K_a of the acid and for circling nitrous acid

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

Key Concept 1: A buffer solution consists of a weak acid-base conjugate pair
Key Concept 2: A buffer solution exists for pH = pKa $\mp$ 1
Key Concept 3: A buffer solution resists changes to pH
Key Concept 4: A buffer solution is prepared using nearly equal number of moles the of conjugate acid/base pair (between 0.1 - 10 mole ratio)

+1 point for each correct characteristic

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*)**

$4.36 = 4.76 + log\frac{[A^-]}{[HA]}$ **(+1 point)**

$log\frac{[A^-]}{[HA]} = -0.4$

$\frac{[A]^-}{[HA]} = 10^{-0.4} = 0.398$

To prepare a buffer solution, acetic acid and sodium hydroxide would be combined in either of the following ratios:

$[A^-]:[HA] = 0.398:1$ (sodium hydroxide to acetic acid)

$[HA]:[A^-] = 2.513:1$ (acetic acid to sodium hydroxide) **(+1 point)**

+1 point for correctly substituting the two pH values into Henderson-Hasselbach
+1 point for either ratio, but work must support final answer (Note: look at the fraction within the log to confirm)

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*)**

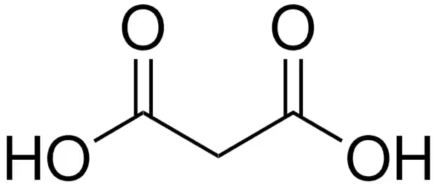
$$Ca(OH)_2\,(s) \rightleftharpoons Ca^{2+}\,(aq) + 2OH^{-}\,(aq)$$

Justification:

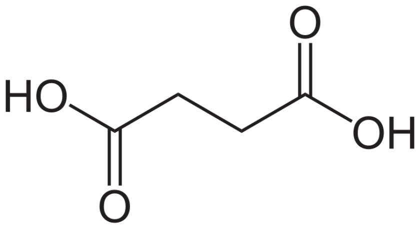
The **hydronium ions from the acid will neutralize/consume the hydroxide ions (+1 point)** from the calcium hydroxide and **shift the solubility equilibrium to the right**, which increases the solubility of the calcium hydroxide **(+1 point)**.

+1 point Key Concept 1: mentioning that a neutralization is happening and hydroxide is disappearing
+1 point Key Concept 2: a decrease in hydroxide shifts the reaction to the right
(Note: students do not necessarily have the state that a shift to the right increases solubility)

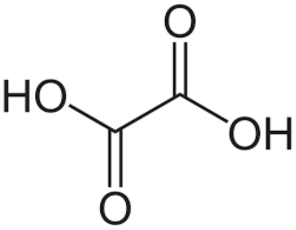
e. The inductive effect refers to the phenomenon of a highly electronegative atom pulling electron density away from nearby atoms. When the electron density is pulled away from an O-H bond, the bond is weakened and the acidity of the hydrogen increases. Using this principle, rank the acidity of the three 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**

Oxalic Acid (pKa = 1.25) > Malonic Acid (pKa = 2.83) > Succinic Acid (pKa = 4.21)

+1 point for correctly determining that Succinic Acid is the least acidic
+1 point for correctly determining that Oxalic Acid is the most acidic and Malonic Acid is in the middle

Score of 1 out of 2 if they switch the first two

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.

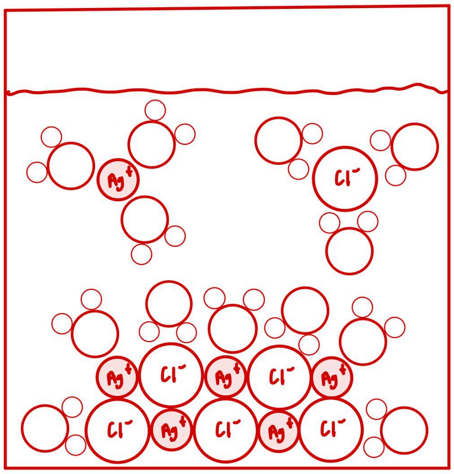
a. Silver chloride is an insoluble compound, but when put in water, an extremely small amount of it dissociates into ions. ***(4 points)***

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

$AgCl\ (s) \rightleftharpoons Ag^{+}(aq)\ +\ Cl^{-}(aq)$

Note: reaction must be as written here with reactants and products on their respective sides, correct states, and reversible arrows to receive full credit

  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)***



+1 point for drawing Ag^{+} and Cl^{-} ions in solution
+1 point for drawing solid $AgCl$ at the bottom of the container (must be more particles represented in the solid than represented as ions)
+1 point for correct orientation of water molecules around the solid/ions
Note: ions do not need to be the correct size relative to each other, but the correct orientation of the water molecules must be clear

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)***

	$AgCl$	$\rightleftharpoons$	Ag^{+}	Cl^{-}
Initial	—		0	0
Change	—		+x	+x
Equilibrium	—		x	x

$Ksp = [Ag^{+}][Cl^{-}]$ **(+1 point)**

$Ksp = (x)(x) = x^{2}$

$x^{2} = 1.70 \times 10^{-10}$

$x = 1.3038 \times 10^{-5}$ M **(+1 point)**

+1 point for correct K_{sp} equation
+1 point for correct final answer with correct units (M or mol/L)

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**

$0.016\ g\ AgCl \times \frac{1\ mol\ AgCl}{143.323\ g\ AgCl} = 1.1164 \times 10^{-4}\ mol\ AgCl$ **(+1 point)**

$1.1164 \times 10^{-4}\ mol\ AgCl \times \frac{1}{10\ L} = 1.1164 \times 10^{-5}\ mol/L$

$1.1164 \times 10^{-5}\ mol/L < 1.50 \times 10^{-5}\ mol/L$ **(+1 point)**

Since the amount of $AgCl$ in solution is **less than** the solubility of $AgCl$, the solution is **unsaturated (+1 point)**

+1 point for correct conversion from g of $AgCl$ to mol $AgCl$
+1 point for comparing the amount of $AgCl$ in solution to the solubility of $AgCl$
+1 point for correctly concluding that the solution is unsaturated

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	X **(+1 point)**			
Towards products		X **(+1 point)**		X **(+1 point)**
No change			X **(+1 point)**	

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 ΔS° 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**

(+1 point)

$$\Delta H^\circ_{RXN} = \sum n_{product}\Delta H^\circ_f(products) - \sum n_{reactant}\Delta H^\circ_f(reactants)$$

$$\Delta H^\circ_{RXN} = (0.92\,\frac{kJ}{mol} + 2(-56.78\,\frac{kJ}{mol})) - (-175.39\,\frac{kJ}{mol})$$ **(+1 point)**

$$\Delta H^\circ_{RXN} = 62.75\frac{kJ}{mol}$$ **(+1 point)**

+1 point for correct substitution into the equation

+1 point for correct ΔH°_{RXN}

+1 point for correct circle, based on ΔH°_{RXN} (positive = endo, negative = exo)

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

As the reaction proceeds to the right (in the forward direction), **a solid PbI_2 particle dissociates into separate Pb^{2+} and I^- ions**. This is an **increase in disorder** of the system, making ΔS° positive.

+2 points for a correct connection between dissociation and disorder

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**

+1 point for an answer that corresponds to their answer in part d(i)

Endothermic → Increase
Exothermic → Decrease

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)***

For 100 g of Uric Acid:

$35.7\ g\ C \times \frac{1\ mol\ C}{12.011\ g\ C} = 2.97$ mol C

$2.4\ g\ H \times \frac{1\ mol\ H}{1.008\ g\ H} = 2.38$ mol H

$33.3 g\ N \times \frac{1\ mol\ N}{14.01\ g\ N} = 2.38$ mol N

$28.6\ O \times \frac{1\ mol\ O}{15.999\ g\ O} = 1.79$ mol O **(+1 point)**

$1.79\ mol\ O \times \frac{1\ mol\ uric\ acid}{3\ mol\ O} = 0.597$ mol uric acid **(+1 point)**

$2.97\ mol\ C\ /\ 0.597\ mol\ uric\ acid = 5\ C$

$2.4\ mol\ H /\ 0.597 = 4\ H$

$2.38\ mol\ N\ /\ 0.597 = 4\ N$

Uric Acid Formula: $C_5H_4N_4O_3$ **(+1 point)**

+1 point for determining the moles of each element using their percent by mass
+1 point for determining the moles of uric acid present using what you know about oxygen
+1 point for correct uric acid molecular formula

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: ________$2.38 \times 10^{-4} M$ to $5.056 \times 10^{-4} M$__________

Lower Bound:

$M = \frac{0.04\ g/L}{168.11\ g/mol} = 2.38 \times 10^{-4} M$ **(+1 point)**

Upper Bound:

$M = \frac{0.085\ g/L}{168.11\ g/mol} = 5.056 \times 10^{-4} M$ **(+1 point)**

Full Range: $2.38 \times 10^{-4} M$ to $5.056 \times 10^{-4} M$

+1 point for correctly calculating the lower bound of the range in molarity
+1 point for correctly calculating the upper bound of the 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 **(+1 point)** **No**

$M\ of\ uric\ acid = \frac{0.003\ mol}{0.5\ L} = 6 \times 10^{-3} M\ urine > upper\ bound\ (5.056 \times 10^{-4})$

(+1 point)

Therefore, **yes**, the person needs to drink more water to dilute their urine, as it is too concentrated with uric acid. **(+1 point)**

+1 point for calculating the concentration of uric acid
+1 point for comparing their calculated value to the upper bound of the healthy range
+1 point for circling whatever their work supports (greater than the upper bound = yes, loess than the upper bound = 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:

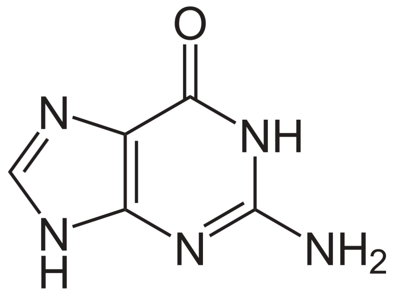
$$xanthine + H_2O + O_2 \rightarrow uric\,acid + H_2O_2$$

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

$Xanthine = C_5H_4N_4O_2$ **(+1 point)**

+1 point for a formula consistent with what it should be to make the equation properly balanced, using their uric acid formula from part a
(Note: if the student did not obtain a formula in part a, they are not eligible for this point - i.e. they are not allowed to guess)
(Note: if the student got the wrong uric acid formula and used that to determine a wrong xanthine formula, they can still receive this 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)***



$Guanine = C_5H_5N_5O$ **(+1 point)**

SCRATCH PAGE