Name _____ Topics ID # _____

Team Name _____

2023 WUCT: Chemistry of the Five Senses

April 1st, 2023
11:00 a.m. – 12:00 p.m.

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

Topics ID

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1 HOUR will be allowed for the exam. The examination contains **8** questions on **20** numbered pages, including the last **SCRATCH PAGE**.

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

Exam Points Breakdown:

1. (14 pts)
2. (13 pts)
3. (13 pts)
4. (12 pts)
5. (10 pts)
6. (8 pts)
7. (13 pts)
8. (17 pts)
Total Points: (100 pts)

2023 WUCT: Chemistry of the Five Senses

This exam consists of 8 questions and is worth 100 points. You will complete this exam as a team. 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: *(14 points)*

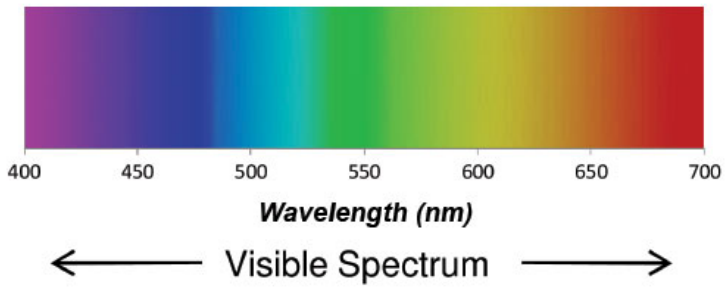
A photon is a particle representing light or other electromagnetic radiation. It can be used to shine light on a compound and eject an electron from that compound. The energy of a photon can be represented by the following equation:

$$E = h\nu = \frac{hc}{\lambda}$$

where ν represents frequency and λ represents wavelength.

a. What is the wavelength and frequency of a photon with 3.06×10^{-19} J of energy? Please include units. ***(5 points)***

b. According to the visible light spectrum below, what color light does this photon emit? ***(1 point)***



c. Will this photon be able to eject an electron from a singular calcium atom, given the first ionization energy of calcium is 596 kJ/mol? If so, what is the kinetic energy of the ejected electron? Explain your answer. ***(3 points)***

d. Will a photon with 1.36×10^{-18} J of energy be able to eject an electron from the same calcium atom? If so, what is the speed of the ejected electron? Explain your answer. ***(3 points)***

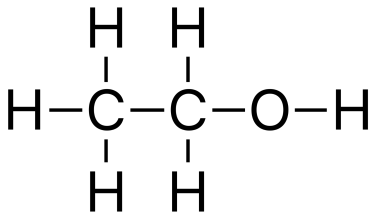
e. Does it take more or less energy to remove a second electron from Ca? Explain your reasoning. ***(2 points)***

Problem #2: ***(13 points)***

David orders a 500 mL glass of alcohol (30% ethanol, 70% H_2O by mass) at a restaurant but when he drinks it, he finds that it tastes very sour. Sam, his chemist friend, pulls out an emergency chemical testing kit and finds a trace of oxidizing catalyst in David's drink. Sam calls 911 and the ambulance rushes to bring David to the emergency room.

a. Assuming the solution has a density of 1g/mL, find the molarity and molality of ethanol in the original solution. Show your work. ***(5 points)***

b. The oxidizing catalyst converts the hydroxyl group (-OH) in ethanol to a carboxylic acid group (-COOH), maintaining the same number of carbons. Carboxylic acids are a class of organic compounds with a carbon atom bonded to an oxygen atom by a double bond and to a hydroxyl group by a single bond. Given the structure of ethanol below, draw the structure of the oxidized acid which produced the sour taste of the drink. ***(2 points)***



c. Given that the K_a of the acid mentioned above is 1.8×10^{-5}, what is the pH of the final solution in David's cup assuming all reactions went to completion? ***(4 points)***

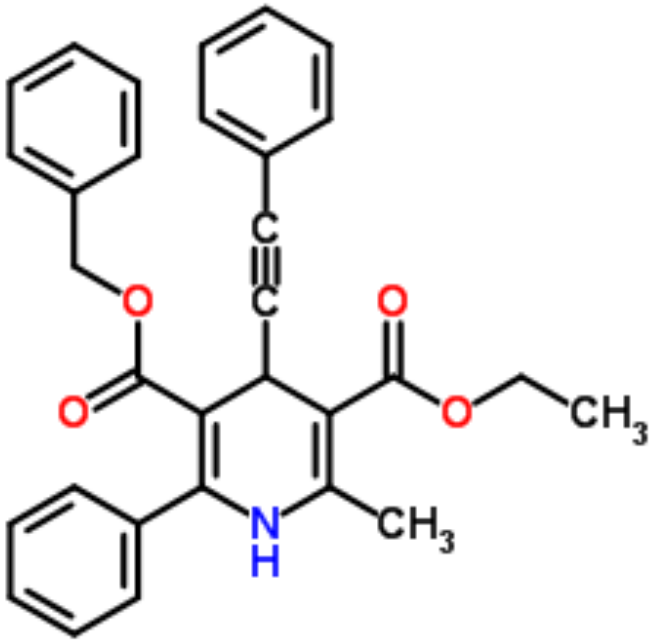
d. Draw the VSEPR structure of ethanol and name the geometry about the two central carbon atoms. ***(2 points)***

Problem #3: ***(13 points)***

John is eating potatoes for Thanksgiving and finds that when he continues to chew a chunk of potato without swallowing it, it seems to taste sweeter. John later finds out that many other carbohydrates start to taste sweeter when they are left in the mouth.

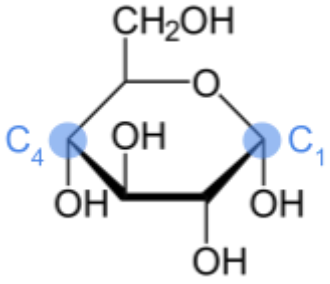
a. What class of macromolecule most likely causes the carbohydrates to start tasting sweeter? ***(1 point)***

b. Below is a diagram of the molecule that seems to make carbohydrates 'sweet.' On this diagram, each vertex represents a carbon atom. On the diagram, draw:
   i. A circle around a benzene ring ***(1 point)***
   ii. A triangle around a methyl group ***(1 point)***
   iii. A rectangle around an ester group ***(1 point)***



c. Suppose that the molecule above is stable at a pH range between 6.5-7.5. If a solution is created by mixing 5 mL of 0.10M acetic acid (CH_3COOH) ($K_a = 1.8 \times 10^{-5}$) and 7 mL of 0.05M NaOH at 25℃, will the molecule above be stable in the resulting solution if we only consider the effects of pH? Support your work with relevant calculations. ***(6 points)***

d. Suppose that one of the carbohydrate molecules from the potato were broken down and the products are 3 molecules of glucose. First, write the chemical formula of the original carbohydrate before it is broken down. Then, draw the structure of the molecule before it is broken down given the structure of glucose below. (hint: the glucose molecules were connected with one another by C_1-C_4 bonds, and the formation of a bond between 2 glucose molecules results in a release of a single water molecule. C_1 and C_4 are labeled on the glucose molecule below.) ***(3 points)***



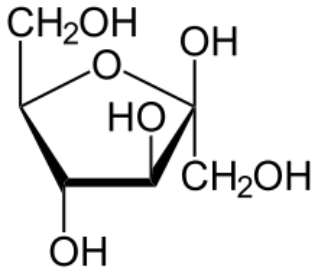
Problem 4: ***(12 points)***

Table salt is a compound represented by the formula NaCl.

a. Identify and describe the strongest type of intramolecular force present in NaCl. ***(2 points)***

b. NaCl dissolves readily in water. Demonstrate how this occurs using a sketch with at least four water molecules surrounding each ion. ***(4 points)***

c. Fructose is a sugar found naturally in fruits, fruit juices, some vegetables and honey. The structure is shown below. What is the strongest type of intermolecular force present in fructose? ***(1 point)***



d. Demonstrate what happens when fructose is added to water using a sketch with at least two water molecules around fructose. Does it dissolve? Explain your answer. ***(3 points)***

e. Based on your answers to the previous questions, list two reasons why water is a good solvent. ***(2 points)***

Problem #5: ***(10 points)***

Afferent neurons are responsible for transmitting information gathered by the senses to the brain. This is done by way of action potentials, a continuous propagating chain of the neuron's resting membrane potential. When an action potential occurs, the positively charged ions, Na^+ and K^+, effuse through small channels in the neuron's membrane.

a. Using Graham's Law of Effusion, $\frac{Rate\ A}{Rate\ B} = \sqrt{\frac{Molar\ Mass\ B}{Molar\ Mass\ A}}$, calculate the ratio of effusion rates of Na^+ to K^+, the ions responsible for action potentials present in neurons. Show your work. ***(2 points)***

b. Using Na^+ and K^+ ions, we create the redox reaction: $Na_{(s)} + K^+_{(aq)} \leftrightarrow Na^+_{(aq)} + K_{(s)}$
For this reaction, the $E°_{cell} = 1.20$ V and T = 298 K. At a certain point in the reaction, assume $[Na^+] = 0.10$ M and $[K^+] = 0.90$ M. Using the Nernst equation, calculate the cell potential at this point. Show your work. ***(3 points)***

c. Suppose $\Delta G°$ for this reaction equals 1.75kJ/mol, in which direction will this reaction proceed to reach equilibrium at room temperature (298K)? Justify your answer. ***(3 points)***

d. The formula for osmotic pressure is $\Pi=MRT$, where M is molarity. At the point in the reaction described in part b, determine which ion, Na^+ or K^+, would give the higher osmotic pressure given that they are at the same temperature. ***(2 points)***

Problem #6: ***(8 points)***

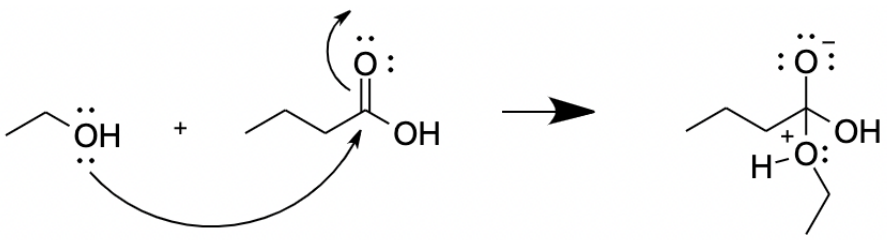
Butyric acid has a signature smell of sour milk and spoiled butter, where it was first sampled from rancid butter by French chemist Michel Eugène Chevreul. Its chemical formula is $CH_3CH_2CH_2COOH$.

a. Draw the molecule's Lewis structure. ***(1 point)***

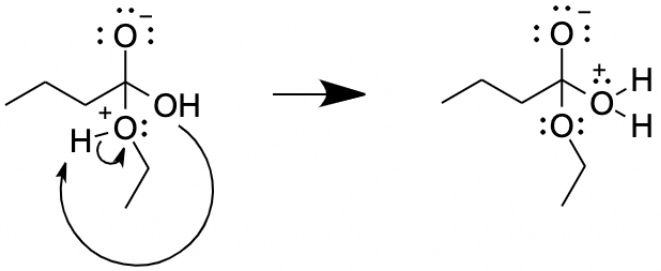
b. On your Lewis structure, circle the most acidic hydrogen. Please explain your reasoning. ***(2 points)***

c. Butyric acid can react with ethanol to form ethyl butyrate and water through a reaction mechanism consisting of three steps. The first two steps are illustrated below. Arrows represent the movement of electrons. Chemists define a nucleophile as electron-rich species and electrophiles as electron-deficient species. In step 1, identify which reactant is the nucleophile and which reactant is the electrophile by labeling them below. ***(2 points)***

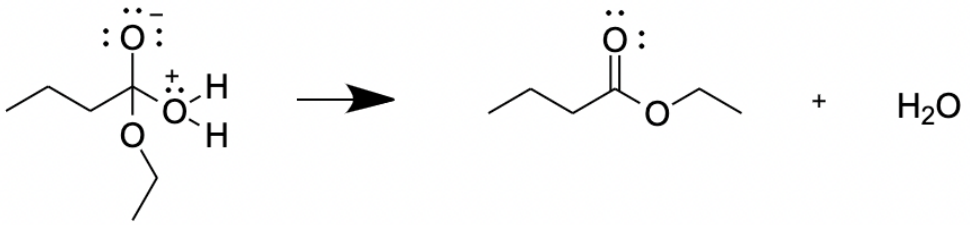
Step 1:



Step 2:



d. For step 3, please fill in the arrows to show electron movement that results in the two products depicted. ***(2 points)***



e. Identify the functional group that has been formed at the end of step 3. ***(1 point)***

Problem #7: ***(13 points)***

The chemical hydrogen sulfide (H_2S) is known to smell like rotten eggs.

a. Based on the molecule's geometry, is the H-S-H angle in H_2S greater, less, or the same than the H-Se-H angle in SeH_2? Justify your answer. ***(2 points)***

b. Can H_2S participate in hydrogen bonding? Explain your reasoning. ***(2 points)***

c. The decomposition reaction of H_2S can occur on metal catalysts with the products of the reaction being H_2 and S_2. If 0.036 g of S_2 gas is collected, how much H_2S (in mg) was reacted to begin with? ***(3 points)***

d. Given the information below, calculate the standard enthalpy change and standard entropy change for this reaction. ***(4 points)***

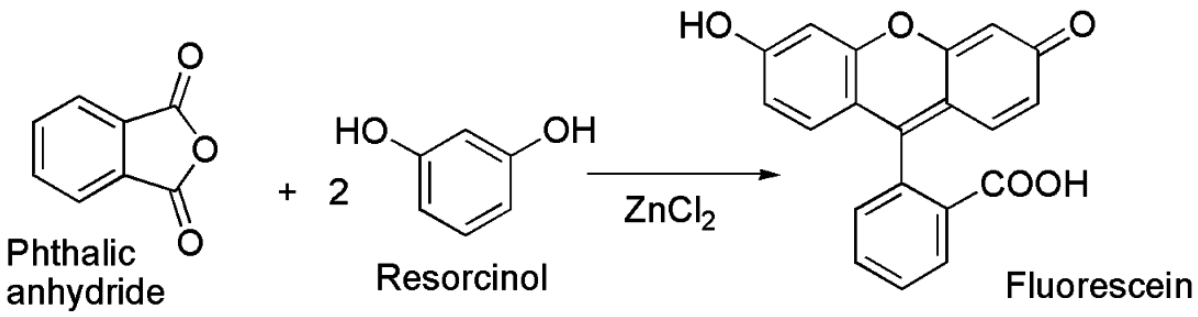
	ΔH_f°	S°
$H_{2\,(g)}$		130.68 J/mol
$S_{2\,(g)}$	277.17 kJ/mol	167.829 J/mol
H_2S	-20.6 kJ/mol	205.81 J/mol

e. Is this reaction spontaneous at 298K under standard state conditions? Explain your reasoning. ***(2 points)***

Problem 8: ***(17 points)***

Fluorescein is an organic compound and dye used widely as a fluorescent tracer in many applications, particularly in ophthalmic procedures, such as checking for any corneal or vessel abnormalities.

Fluorescein can be synthesized via Friedel Crafts acylation in the following reaction:



a. If 0.280 g of phthalic anhydride and 0.400 g of resorcinol are used, what is the expected yield of the product by mass? ***(4 points)***

In a hypothetical experiment, a group of scientists collected the following data for the reaction:

Trial	[phthalic anhydride]	[resorcinol]	Reaction Rate
1	0.20	0.50	0.287×10^{-2} M/hr
2	0.20	0.75	0.290×10^{-2} M/hr
3	0.20	1.0	0.286×10^{-2} M/hr
4	0.40	0.50	0.576×10^{-2} M/hr
5	0.60	0.50	0.870×10^{-2} M/hr

b. Given this information, write out the rate-law expression. What is reaction order? ***(4 points)***

c. You are constructing a plot that shows the reaction progress over time. What measure of reaction progress would you use to obtain a linear relationship when plotted against time? ***(2 points)***

d. In the reaction above, $ZnCl_2$ serves as a catalyst. Describe how $ZnCl_2$ affects reaction kinetics. ***(2 points)***

e. Given the structure of the product, fluorescein, would you expect the intensity of light emitted to be higher or lower at more basic pH values? Explain your reasoning. ***(2 points)***

f. Given that the reaction requires an input of energy, assess whether, in the forward direction, this reaction is spontaneous, nonspontaneous, or if you do not have information. (hint: please reference enthalpy and entropy in your answer). ***(3 points)***

Scratch Page