Name _____ Topics ID # _____

Team Name _____

2023 WUCT: Chemistry of Desserts

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 **7** questions on **21** 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. (21 pts)
3. (10 pts)
4. (11 pts)
5. (15 pts)
6. (22 pts)
7. (10 pts)
Total Points: (100 pts)

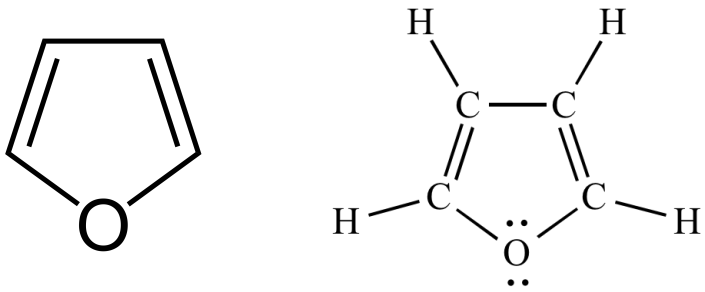
2023 WUCT: Chemistry of Desserts

This exam consists of 7 questions and is worth 100 points. You will work together as a team to answer the questions. 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>: ***(11 points)***

The Maillard reaction is one of the most important reactions in food chemistry. From cooking steak to making cupcakes, the Maillard reaction takes place in countless cooking and baking processes. In general, the Maillard reaction makes food more flavorful and look more appealing.

a. The Maillard reaction has hundreds of possible products. One of the possible products of the Maillard reaction is furan, which is a flavor compound that contributes to the caramel-like appearance in food. The structure is shown below:

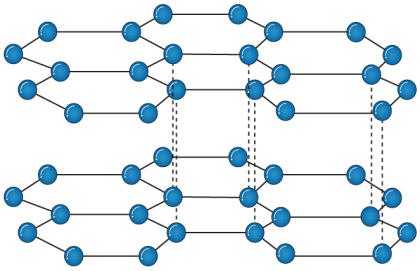


i. Identify the hybridizations of the C atoms in this molecule. ***(1 point)***

ii. The O atom in this molecule has the same hybridization as the C atoms. Justify this observation. ***(1 point)***

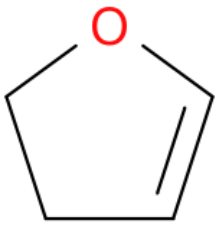
iii. A delocalized π bond is a type of bond that is formed by the overlapping of p orbitals of atoms on the same plane. A common notation to represent the delocalized π bonds is Π_n^m, "n" represents the number of molecular orbitals in the delocalized π bond or the number of p orbitals that contribute to the delocalized π bonding. "m" represents the number of delocalized π electrons in a molecule. Identify the delocalized π bond in furans and represent it in the Π_n^m form. ***(2 points)***

b. Using delocalized π bonds, justify graphite as either a conductor or an insulator. The blue spheres in the image below represent carbons. ***(3 points)***



c. Compared to benzene (C_6H_6), is the electron cloud in furan more or less evenly distributed? Justify your answer. ***(2 points)***

d. Explain why furan is less soluble in water than 2,3-dihydrofuran (pictured below). ***(2 points)***



Problem #2: ***(21 points)***

Baking soda ($NaHCO_3$), also known as sodium bicarbonate, is found in almost every household and it is commonly used to make goods like cakes, muffins, and cookies.

a. Draw the most preferred Lewis structure of HCO_3^- ion below. If equivalent resonance forms exist for the most-preferred Lewis structure, draw each of them. Circle your final answer(s). ***(2 points)***

b. What is the formal charge on O? (hint: there may be more than one answer) ***(2 points)***

c. When 2 moles of $NaHCO_3$ are heated, $NaHCO_3$ decomposes to form 1 mole of $Na_2CO_3(s)$, 1 mole of gaseous CO_2 (g), and 1 mole of another gaseous product. What is this product? ***(1 point)***

d. Calculate the sodium ion concentration when 50.0 mL of 2.0 M sodium carbonate ($Na_2CO_3(s)$) is added to 50.0 mL of 2.0 M sodium bicarbonate ($NaHCO_3$). **(*3 points)***

e. A student receives a flask with a random mixture of $NaHCO_3$(s) and Na_2CO_3(s). The student moves this mixture into a test tube that contains a drying reagent and heats the test tube under a Bunsen burner at 170°C for 15 minutes. We can assume that all of the H_2O (g) that is produced in the reaction is captured by the drying reagent. The results of the experiments are shown below. Determine the mass percent of $NaHCO_3$(s) that was in the original mixture. ***(4 points)***

Molar mass of $NaHCO_3$ (s)	84.01 g/mol
Molar mass of Na_2CO_3(s)	105.99 g/mol
Mass of random mixture of $NaHCO_3$(s) and Na_2CO_3(s)	6.184 g
Mass of the drying reagent before heating	3.154 g
Mass of drying reagent after heating	3.598 g

f. Baking soda acts as a base when it gets in contact with acids, like vinegar (CH_3COOH). A student decides to mix baking soda with vinegar in a flask. The reaction is shown below:

$$NaHCO_3\ (s) + CH_3COOH\ (l) \rightarrow NaC_2H_3O_2\ (aq) + CO_2\ (g) + H_2O\ (g)$$

A student decides to add 5 grams of baking soda into 50 mL of 1 M vinegar. Determine the limiting reagent of the reaction. ***(3 points)***

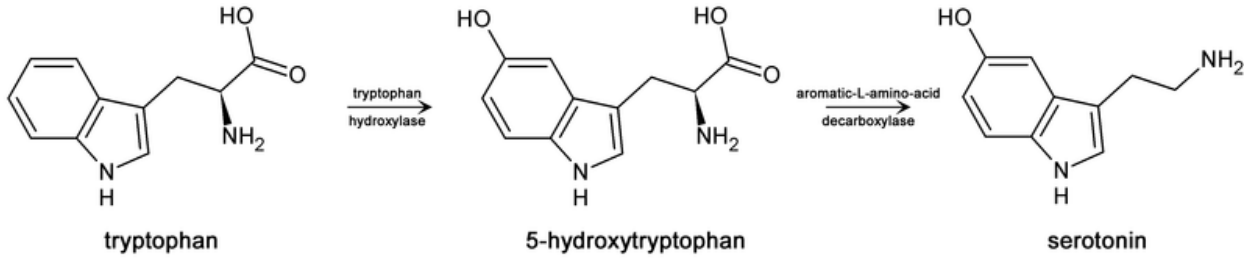
g. The reaction between baking soda and vinegar occurs spontaneously. The student observes that the flask gets cooler as the reaction proceeds. What does this tell us about the signs of Gibbs free energy, entropy and enthalpy of the system? Circle the correct signs and explain your reasoning below in 2-3 sentences. ***(6 points)***

Gibbs free energy:	positive	negative
Entropy:	positive	negative
Enthalpy:	positive	negative

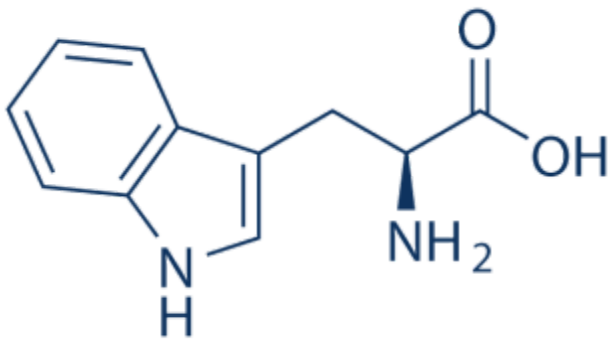
Problem #3: ***(10 points)***

Sugar in desserts facilitates the transportation of tryptophan ($C_{11}H_{12}N_2O_2$), an amino acid that can be converted to serotonin ($C_{10}H_{12}N_2O$) in our body. Serotonin is a neurotransmitter that helps regulate mood and makes our brain temporarily "feels" happier, which causes our brain to crave this chemical more and more in the long term. The structures of tryptophan and serotonin are shown below.

There are two steps in the process of converting tryptophan to serotonin, which happens in our brain and gut. The reaction is provided below.



a. Name and circle the two functional groups in L-tryptophan that make it an amino acid. ***(2 points)***



b. A peptide bond between carbon and nitrogen can be formed between two tryptophan molecules. This bond is formed by a condensation reaction where a carboxyl group (-COOH) of one tryptophan reacts with an amino group (-NH_2) of another tryptophan molecule, resulting in a release of water. Draw two tryptophan molecules connected with a peptide bond. ***(2 points)***

c. Humans are not able to self-produce tryptophan, so it must be obtained through diet. Some common foods that contain a high level of tryptophan include egg white, cheese, and chicken/turkey (you get lots of tryptophan during Thanksgiving!). Given that there are 238 milligrams of tryptophan per 100 grams of turkey, calculate how many grams of tryptophan there are in 1/2 pound of turkey (round your answers to 3 significant figures). (1 pound = 453.6 grams) ***(1 point)***

d. After eating the 1/2 pound of turkey as your Thanksgiving dinner, how many grams of serotonin are produced in your bloodstream? For the purposes of this question, assume that all of the L-tryptophan gets converted to serotonin. ***(2 points)***

e. The structure given above, L-tryptophan, is one of the two enantiomers of tryptophan. The other enantiomer is called D-tryptophan and the two molecules are mirror images of each other that can not be reoriented so as to appear identical. Draw the structure of D-tryptophan (Hint: you have to make changes to the amino group). ***(1 point)***

f. Aromatic amino acid decarboxylase is a catalyst enzyme that is used in the second step of transforming 5-hydroxy-L-tryptophan to serotonin. Explain the properties and function of an enzyme in a reaction. Draw an activation energy diagram to support your answer. ***(2 points)***

Problem #4: *(11 points)*

a. A candymaker is making honeycomb candy for the first time. For the first step, they mix water, sugar, and corn syrup together and bring the solution up to 100.00°C precisely. The candymaker is confused why the solution isn't boiling. Explain this phenomenon to the candymaker. ***(1 point)***

b. This is the recipe the candymaker is using:

40.00mL water
200.0g sugar ($C_{12}H_{22}O_{11}$)
80.00mL of corn syrup ($C_6H_{14}O_7$)

Knowing the density of corn syrup is 1.4 g/mL and pure water's heat of vaporization is 40.65kJ/mol, at what temperature will the solution begin to boil in Celcius? ***(5 points)***

c. Once the mixture starts to boil, the candymaker continues to heat it and watches as the temperature of the solution continues to climb. Why does this happen? ***(1 point)***

d. Once the solution is up to temperature, the candymaker adds baking soda ($NaHCO_3$). It causes the solution to bubble up. This creates the classic honeycomb effect when the candy hardens. Write out the reaction that is occurring and identify what the bubbles are. (Hint: it's an acid-base reaction) ***(2 points)***

e. The candymaker is ready to add the baking soda and turns to get it when their cat walks along the overhead shelf and knocks a cup of water over. This results in some water being splashed into the pot. Unfortunately, the candymaker is oblivious to their clumsy cat and finishes the recipe leaving it to cool in a pan. The candymaker expects to return to a hard but light candy with a glassy finish. What do they find instead and why? ***(2 points)***

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

Many candies are made by boiling sugar (made of sucrose crystals) and water. Depending on the temperature you heat a sugar solution to, it can create different types of candies (shown in the table below).

Stage	Temp (°C/°F)	Sugar conc.	Candy examples
Thread	110-112/230-234	80%	Sugar syrup, fruit liqueur
Soft ball	112-116/234-241	85%	Fudge, pralines
Firm ball	118-120/244-248	87%	Caramel candies
Hard ball	121-130/250-266	90%	Nougat, toffee, rock candy
Soft crack	132-143/270-289	95%	Taffy, butterscotch
Hard crack	146-154/295-309	99%	Brittles, hard candy/lollipop
Clear liquid	160/320	100%	
Brown liquid	170/338	100%	Liquid caramel
Burnt sugar	177/351	100%	Oops...

a. In order to make butterscotch, what temperature should you heat a sugar solution to? ***(1 point)***

b. Table sugar is made out of sucrose which consists of glucose and fructose. Below is the chemical equation for the formation of glucose. Balance this equation. ***(2 points)***

$$\_\_\_\_\_\ C_6H_{12}O_6\,(s) + \_\_\_\_\_\ O_2\,(g) \Rightarrow \_\_\_\_\_\ CO_2\,(g) + \_\_\_\_\_\ H_2O\,(g)$$

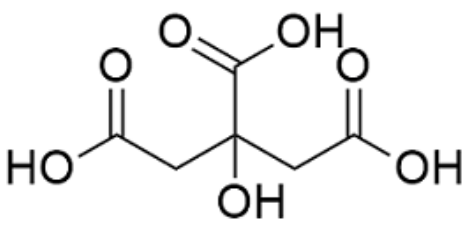
c. Below are the formulas for the heat of formation of glucose's products are given below

$H_2\,(g) + ½\ O_2\,(g) \Rightarrow H_2O\,(l)$ heat of formation of H_2O = -241.8 kJ
$C\,(s) + O_2\,(g) \Rightarrow CO_2\,(g)$ heat of formation of CO_2 = -393.5 kJ

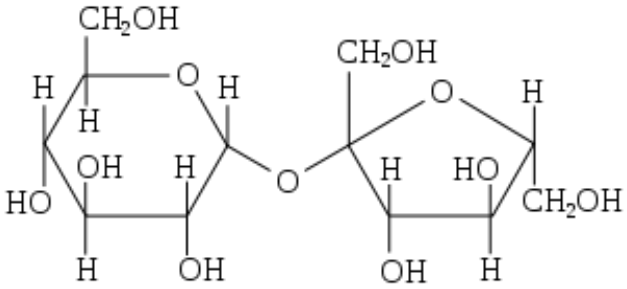
It is found that the enthalpy of formation of glucose is -985 kJ/mol (equation shown below). Determine the heat of combustion of glucose. (Hint: You will need to use the equation from part b). ***(5 points)***

$$6\ C\,(s) + 6\ H_2\,(g) + 3\ O_2\,(g) \Rightarrow C_6H_{12}O_6$$

d. Citric acid is a common ingredient used with granulated sugar to give hard candies a coating of sour flavor. A common ratio that is used to make a sour coating is 1 teaspoon (~4.0 grams) of citric acid mixed with 1 cup (~128 grams) of sugar. Below are the Lewis structures for citric acid and table sugar.



Citric acid



A candy maker creates 660 grams in total of the sugar coating mix using the measurements above. Determine what percent of this sample is carbon. ***(7 points)***

<u>Problem #6</u>: ***(22 points)***

A HERSHEY's Milk Chocolate Candy Bar is made from cocoa butter, milk, milk fat, chocolate, sugar, lecithin, and natural flavor. However, it also contains small amounts of metals that serve as important nutrients in our daily diet. For instance, one bar contains 56.5 mg of calcium, 1.1 mg of iron, and 100.1 mg of potassium. This question will focus on the electrochemistry involved with these specific metals.

a. Let's first consider the electron properties of these metals.
   i. Write the full electron configuration of potassium, iron, and calcium. Which do you predict to have a higher first ionization energy? ***(4 points)***

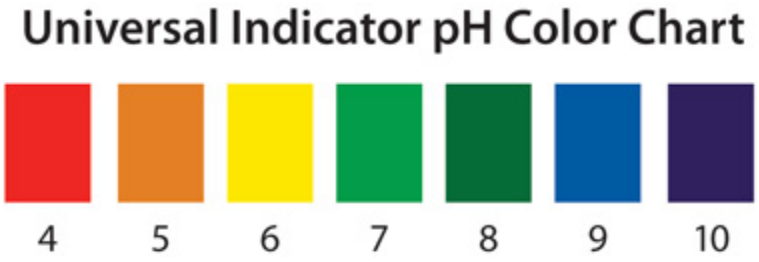
   ii. Is potassium or calcium predicted to have a higher second ionization energy? Justify your answer in 2-3 sentences. ***(2 points)***

b. You are given a galvanic cell to explore the electrochemical properties of the metals calcium, iron, and potassium, and their corresponding ions. The galvanic cell contains graphite electrodes, solid potassium particles, calcium ions (2.5 M), solid iron particles, water, and a salt bridge. Draw a galvanic cell in the space below, placing each of the components mentioned above in the appropriate place and labeling which electrode is the cathode and which is the anode. ***(4 points)***

c. What reaction is most likely to occur at the anode? ***(1 point)***

d. The galvanic cell is open to the air, and the water is assumed to have negligible amounts of hydroxide and hydronium ions.
   i. What reaction is most likely to occur at the cathode? ***(1 point)***

ii. Using the chart below showing the color of the universal indicator at different pH values, circle all the colors the solution in the cathode cell could be once the universal indicator has been added. Justify your reasoning in 1-2 sentences. ***(2 points)***



e. If the difference in electric potential is 0.90 V, at what temperature is the galvanic cell running? Assume you start with 1.5 M concentration of all gases or ions. ***(3 points)***

f. What would happen if the salt bridge was removed? Be sure to justify your answer in 2-3 sentences. ***(2 points)***

g. The NIH recommends that individuals between 14 and 18 years old ingest approximately 1,300 mg of calcium per day. You want to use your galvanic cell to convert enough calcium ions to meet this recommended amount of solid calcium in your daily diet. The half-reaction used to reduce calcium ions is given below:

$$Ca^{2+} + 2\ e^- \rightarrow Ca\ (s) \quad E^o = -\ 2.76\ V$$

Assuming you will not run out of the starting material being oxidized or reduced, how long will it take you to produce the requisite amount of solid calcium if the current is 400 A? ***(3 points)***

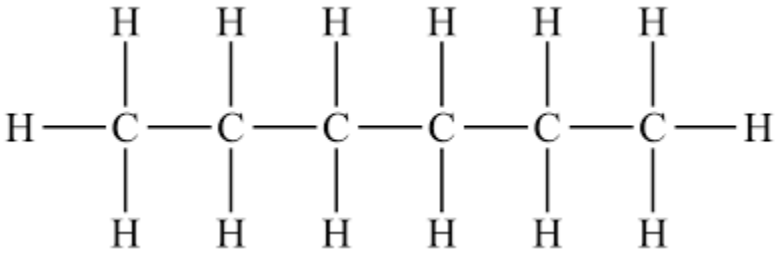
Problem #7: *(10 points)*

Dark chocolate has a high cocoa content and is known to consist of the molecule theobromine. White chocolate, on the other hand, contains almost no cocoa and consists mainly of fats such as stearic acid.

Note: In part a), line-angle formulas are given for the two molecules. In a line-angle formula, it is implied that a carbon atom exists at the end of each line and at all corners. Hydrogens bound to carbons are not drawn in but are also implied. Assume all carbons are tetravalent.

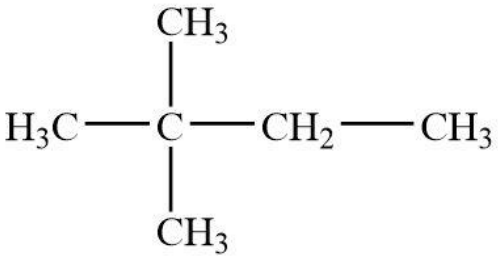
Here is an example comparing the lewis structure and line-angle formula of hexane

Lewis structure:

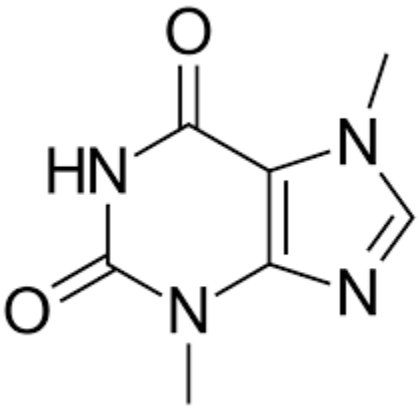


Line-angle formula:

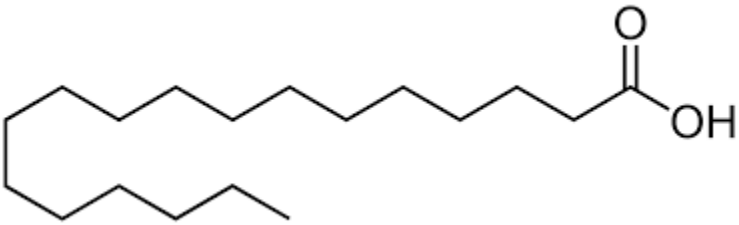
a. Draw the line-angle formula of 2,2 dimethylbutane. The lewis structure of 2,2 dimethylbutane is shown below. ***(2 points)***



b. Below are the molecular structures of theobromine and stearic acid. Which molecule would you expect to have a higher melting point and why? ***(2 points)***



Theobromine



Stearic Acid

c. Milk chocolate contains less than 30% cocoa solids and can be made slightly sour with the addition of butyric acid ($C_4H_8O_2$). Draw the Lewis structure for butyric acid. (Hint: it is a carboxylic acid). ***(2 points)***

d. The primary sugars found in both dark chocolate and milk chocolate are fructose, sucrose, and glucose. The chemical formula of glucose is $C_6H_{12}O_6$ and the burning of sugar is a process known as combustion.

   A 2.21 g sample of glucose is burned in the presence of excess oxygen, yielding 3.239 g of CO_2 and 1.403 g of H_2O. What is the mass of C in the 2.21g sample of glucose? Answer should be in grams. ***(2 points)***

e. Comparing the combustion of glucose and the combustion of sucrose, determine which has the more exothermic enthalpy of combustion (Hint: glucose reacts with fructose to produce sucrose). Explain your reasoning. ***(2 points)***

Scratch Page