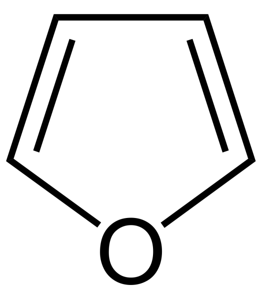
# 2023 WUCT: Chemistry of Desserts ANSWER KEY

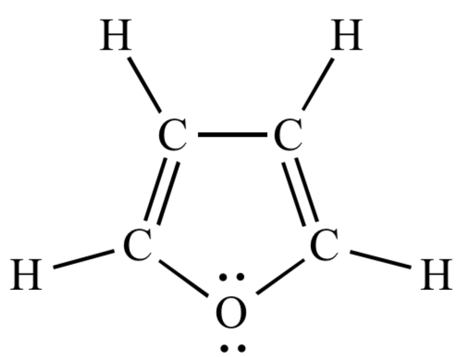
This exam consists of 7 questions and is worth 100 points. You will work together with a partner to answer the questions. You will have 1 hour to take the exam. The only allowed resources for this exam are a calculator and the provided equation sheet. You may NOT use any other notes or books. You must 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 scratch paper, but make sure to clearly indicate in the problem's designated space where the rest of your work can be found. 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)***

sp2

+1 for correct answer

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

One of the lone pairs is in resonance, so they must be in a pure p orbital. Therefore, the oxygen is also $sp^2$ hybridized

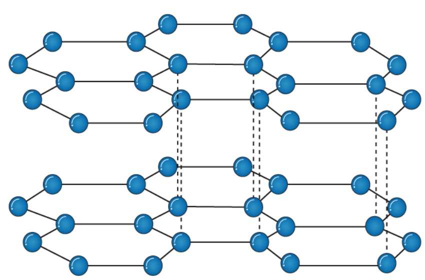
+1 for identifying a lone pair in resonance

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 $\Pi_n^m$, "$n$" 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 $\Pi_n^m$ form. ***(2 points)***

$\Pi_5^6$

+1 for m, +1 for n

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)***

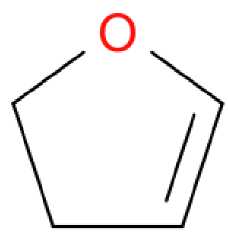


In each graphite molecule, a $\Pi_n^m$ bond exists (+1 point), which means that many electrons can freely (+1 point) move within the whole region of a planar graphite molecule. Since there are freely moving charged particles, graphite can conduct electricity, thus it is a conductor. (+1 point)

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

Because of the oxygen atom in furans, there is a difference in electronegativity between carbon and oxygen, which causes the electron cloud distribution to deviate from that in the benzene. (+1 point) Therefore, the electron cloud in furan is less evenly distributed (+1 point)

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

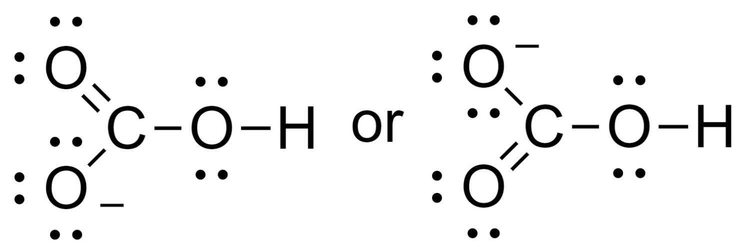


There is no delocalized π system in 2,3-dihydrofuran (+1). Therefore, there are more lone pair electrons on the oxygen atom that are available for formation of hydrogen bonds with water (+1). On the other hand, there is one pair of lone pair electron on the oxygen atom in furan will be involved in the delocalized π system, so its solubility will be slightly weaker.

**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)***



+1 for each resonance structure

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

0 and -½

+1 for each correct answer

*Also acceptable answer*: 0 and -1 (if designating formal charged based on a single resonance structure)

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)***

$H_2O$ (g)

+1 for correct answer

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)***

$50 \text{ mL } Na_2CO_3 * \frac{1L}{1000\,mL} * \frac{2\,mol}{L} = 0.1 \text{ mol } Na_2CO_3$

For 1 mole of $Na_2CO_3$, 2 moles of $Na^+$ ions are produced

$50 \text{ mL } NaHCO_3 * \frac{1L}{1000\,mL} * \frac{2\,mol}{L} = 0.1 \text{ mol } NaHCO_3$

For 1 mole of $NaHCO_3$, 1 mole of $Na^+$ ions are produced

Total number of moles of $Na^+$ ions: 0.1 moles * 2 + 0.1 * 1 = 0.3 moles of $Na^+$ ions
Total volume = 50 mL + 50 mL = 100 mL = 0.1 L

Sodium ion concentration: $\frac{0.3\ mol}{0.1\ L}$ = **3.0 M**

+2 for correct moles of Na+ ions (0.3 moles), +1 correct final answer

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 |

Amount of $H_2O$(g) absorbed into drying reagent: 3.598 g - 3.154 g = 0.444 g (+1 point)
From the balanced equation from part (b):
2 $NaHCO_3$(s) → 2 $Na_2CO_3$(s) + 1 $CO_2$ (g) + 1 $H_2O$ (g)
$0.444\ g\ H2O\ *\ \frac{1\ mol\ H2O}{18.02\ g\ H2O}\ *\ \frac{2\ mol\ NaHCO3}{1\ mol\ H2O}$ = 0.0493 mol $NaHCO_3$(s) (+1 point)
0.0493 mol $NaHCO_3$(s) * $\frac{84.01\ g\ NaHCO3}{1\ mol\ NaHCO3}$ = 4.142 g $NaHCO_3$(s) (+1 point)
4.142 g / 6.184 g = **66.98%** (+1 point)
*acceptable answer ranges that account for rounding differences*: 66% - 68%

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) → $NaC_2H_3O_2$ (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)***

5 grams $NaHCO_3$ * $\frac{1\ mol\ NaHCO3}{84.01g}$ = 0.0595 mol $NaHCO_3$

$\frac{1\ mol\ CH3COOH}{1000\ mL}$ * 50mL = 0.05 mol $CH_3COOH$

Because the two reactants react in a 1 to 1 ratio, the limiting reagent is $CH_3COOH$.
(+1 for baking soda calculation, +1 for vinegar calculation, +1 for correct final answer)

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 |

+1 for each circled answer (+3 max)

If the reaction occurs spontaneously, then ΔG is negative. (+1 point)
$\Delta G = \Delta H - T\Delta S$

Since the flask gets coolers, we know that the reaction is endothermic so ΔH is positive. (+1 point)

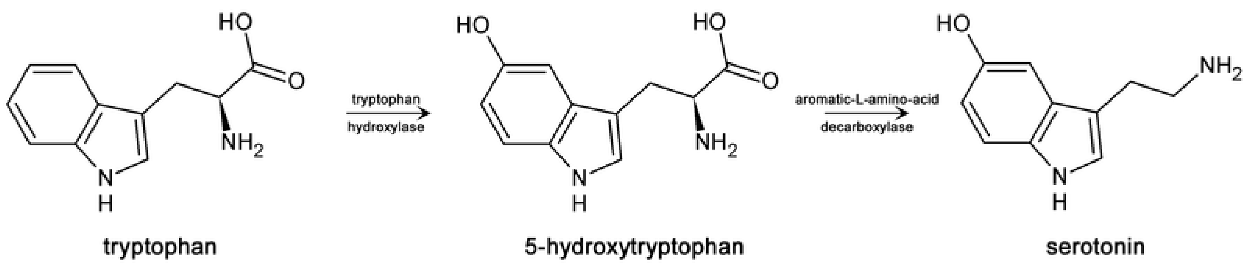
Since ΔG has to be negative, and ΔH is positive, ΔS must be positive to drive this reaction forward and make ΔG negative (+1 point)

*Final answers*: Gibbs free energy = negative, Entropy = positive, Enthalpy = positive

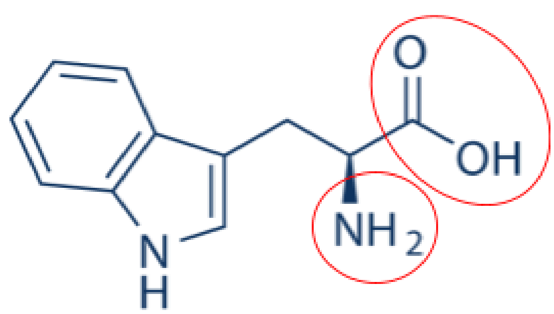
**Problem #3**: ***(10 points)***

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.



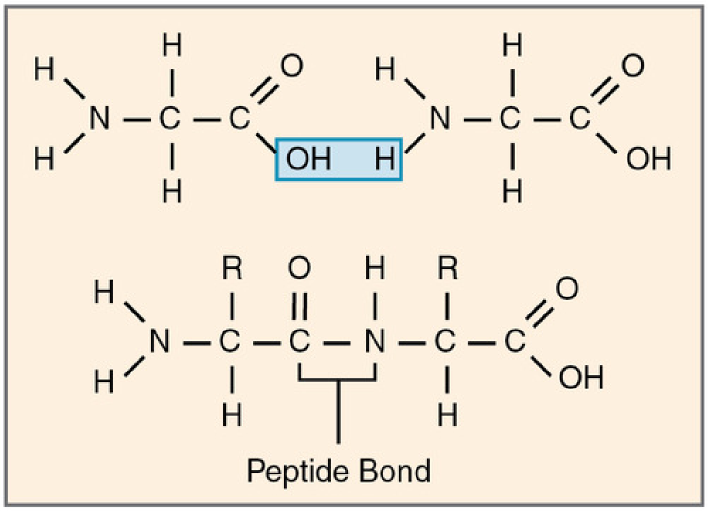

a. Name and circle the two functional groups in L-tryptophan that make it an amino acid. ***(2 points)***




Carboxyl and amine group

+1 for naming, +1 for circling

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)***




The answer key shows two general amino acids. Students should draw 2 tryptophan molecules (+1 point) connected with a peptide bond (+1 point).

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)***

$\frac{238\ mg}{100\ g}$ * (0.5 pounds * $\frac{453.6\ g}{1\ pound}$) * $\frac{1\ g}{1000\ mg}$ = 0.53978 = 0.540 g tryptophan

+1 for correct answer

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)***

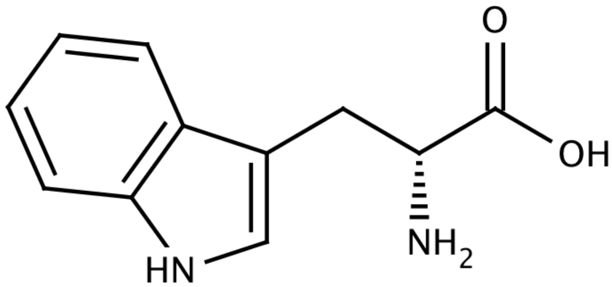
0.53978 g * $\frac{1\ mol}{204.23\ g}$ = 0.002643 mol tryptophan

0.002643 mol tryptophan * $\frac{1\ mol\ serotonin}{1\ mol\ tryptophan}$ = 0.002643 mol serotonin

0.002643 mol serotonin * $\frac{176.22\ g}{1\ mol}$ = 0.466 g serotonin

+1 for going from mol tryptophan to mol serotonin, +1 for correct answer

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)***

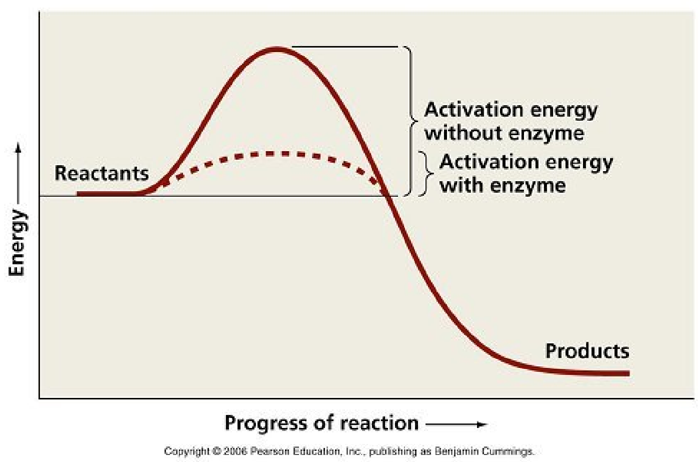



+1 for correct structure

f. Aromatic amino acid decarboxylase acid 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)***

An enzyme can lower the activation energy of a reaction to increase its rate without itself being consumed. (+1 point)

An enzyme only changes the kinetic rate of the reaction, but not the direction. Enzyme binding sites are usually specific to ligands and molecules.




(+1 point)

**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)***

The mixture isn't boiling due to boiling point elevation from mixing sugar and corn syrup into the water.
+1 for correct answer

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)***

$\Delta T_b = k_b \text{ x } m_{solute}$
Moles solute = 200g/(342.3g/mol) + 80mL*1.4g/mL/(198.17g/mol) = 1.15mol
Kilograms solvent = 40mL*1g/mL/(1000g/kg) = 0.04kg
1.15mol/0.04kg = 28.75mol/kg
$k_b = RT_b^2(MW_{solvent})/(1000\Delta H_{vap})$ = 8.314J/mol/K * 373K^2 * 18.02g/mol / 1000 / 40650J/mol = 0.5128K*g/mol
$\Delta T_b$ = 28.75mol/kg * (0.5128K*g/mol) / (1000g/kg) = 0.0147°K (same $\Delta T_b$ for C)
100.00°C + 0.0147°C = 100.0147°C

+1 for correct equation
+1 for correct molality of solute (moles solute/kg solvent)
+1 for correct kb
+1 for correct ΔTb
+1 for correct final temperature

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)***

As water is boiled off from solution, it becomes more concentrated with sugars, exacerbating the boiling point elevation effect.

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)***

$HCO_3^- + H^+ \leftrightarrow H_2CO_3 \rightarrow H_2O + CO_2$

Can just give: $HCO_3^- + H^+ \leftrightarrow H_2O + CO_2$

+1 for identifying reaction

+1 for identifying gas product $CO_2$

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)***

The extra water dilutes the sugar solution so when it cools, the sugar molecules can still move somewhat freely. This means the candy won't be fully hardened and can still be malleable.

+1 for recognizing diluted sugar solution

+1 for saying the candy won't fully harden

**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)***

   132-143°C or 270-289°F
   +1 point for correct answer

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)***

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

$$1\ C_6H_{12}O_6(s) + 6\ O_2(g) \Rightarrow 6\ CO_2(g) + 6\ H_2O\,(g)$$

   +2 point for correctly balancing the equation

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

   $H_2\,(g) + \frac{1}{2}\,O_2\,(g) \Rightarrow H_2O$ heat of formation of $H_2O$ = -241.8 kJ
   $C\,(s) + O_2 \Rightarrow CO_2$ 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)***

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

| | |
|---|---|
| $6CO_2(g) + 6H_2O(g) \Rightarrow C_6H_{12}O_6(s) + 6O_2(g)$ | x kJ |
| $H_2(g) + ½ O_2(g) \Rightarrow H_2O$ | heat of formation of water = -241.8 kJ |
| $C(s) + O_2 \Rightarrow CO_2$ | heat of formation of carbon dioxide = -393.5kJ |
| $6C(s) + 6H_2(g) + 3O_2(g) \Rightarrow C_6H_{12}O_6$ | enthalpy of formation of glucose = -985 kJ |

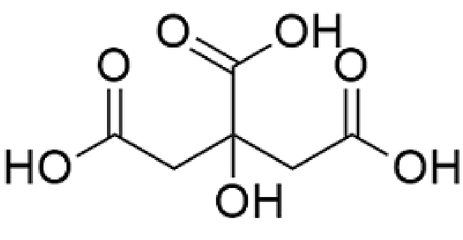
| | |
|---|---|
| $6CO_2(g) + 6H_2O(g) \Rightarrow C_6H_{12}O_6(s) + 6O_2(g)$ | x kJ |
| $(H_2(g) + ½ O_2(g) \Rightarrow H_2O) \times 6$ | -241.8 x 6 = -1450.8 kJ |
| $(C(s) + O_2 \Rightarrow CO_2) \times 6$ | -393.5 x 6 = - 2361.0 kJ |
| $6C(s) + 6H_2(g) + 3O_2(g) \Rightarrow C_6H_{12}O_6$ | -985 kJ |

x kJ - 1450.8 kJ - 2361.0 kJ = -985 kJ
x = 2826.8 kJ [for the reaction: $6CO_2(g) + 6H_2O(g) \Rightarrow C_6H_{12}O_6(s) + 6O_2(g)$]

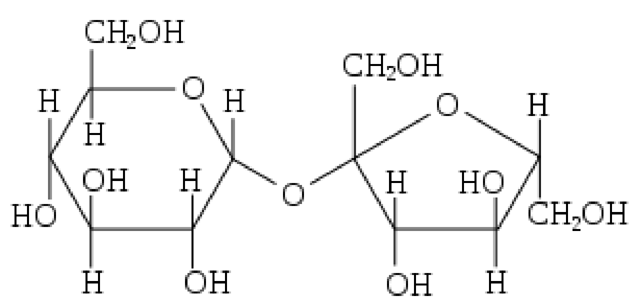
The equation asks for combustion of glucose [$C_6H_{12}O_6(s) + 6O_2(g) \Rightarrow 6CO_2(g) + 6H_2O$] = -2826.8 kJ

+1 for multiplying two given heats of formation by 6
+2 setting up equation to solve for combustion enthalpy
+1 for correct final answer
+1 for correct units

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)***

(+1) 660 grams in total ⇒ 20 grams of citric acid, 640 grams of sugar

To find grams of C in citric acid:
20 g $C_6H_8O_7$ * (1 mole of $C_6H_8O_7$/192.124 grams of $C_6H_8O_7$) * 6 moles of C/1 mole of $C_6H_8O_7$) * (12.01g of C/1 mole of C) = 7.501 grams of carbon
(+1 for setting up unit conversion, +1 for getting correct number)

To find grams of C in granulated sugar:
640 g $C_{12}H_{22}O_{11}$ * (1 mole of $C_{12}H_{22}O_{11}$/342.3 grams of $C_{12}H_{22}O_{11}$) * 12 moles of C/1 mole of $C_6H_8O_7$) * (12.01g of C/1 mole of C) = 269.383 grams of carbon
(+1 for setting up unit conversion, +1 for getting correct number)

269.383 + 7.501 = 276.884 total grams of carbon
(+1 for correct mass)

276.884/660 = 41.952% carbon
(+1 for correct final answer as %)

**<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)***

   K: $1s^22s^22p^63s^23p^64s^1$ OR $[Ar]4s^1$
   Fe: $1s^22s^22p^63s^23p^64s^23d^6$ OR $[Ar]4s^23d^6$
   Ca: $1s^22s^22p^63s^23p^64s^2$ OR $[Ar]4s^2$

Fe, all have same number of inner electrons, Fe has the most protons, greatest effective nuclear charge, valence electrons held tighter

+3 (+1 for each electron configuration)
+1 for correct answer (Fe)

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

   **K** is predicted to have a higher second ionization energy because after one electron is removed, its electron configuration becomes $1s^22s^22p^63s^23p^6$. It has 19 protons and 10 electrons in core orbitals, giving an approximate effective nuclear charge of 9. By contrast, when Ca has lost one electron, its configuration becomes

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$, and since it has 20 protons and 18 core electrons, its effective nuclear charge remains around 2. Since $K^+$ has a much higher effective nuclear charge compared to $Ca^+$, as well as a stable filled valence shell, the second ionization energy of K should be much greater than that of Ca.

+1 for correct answer

+1 for correct justification

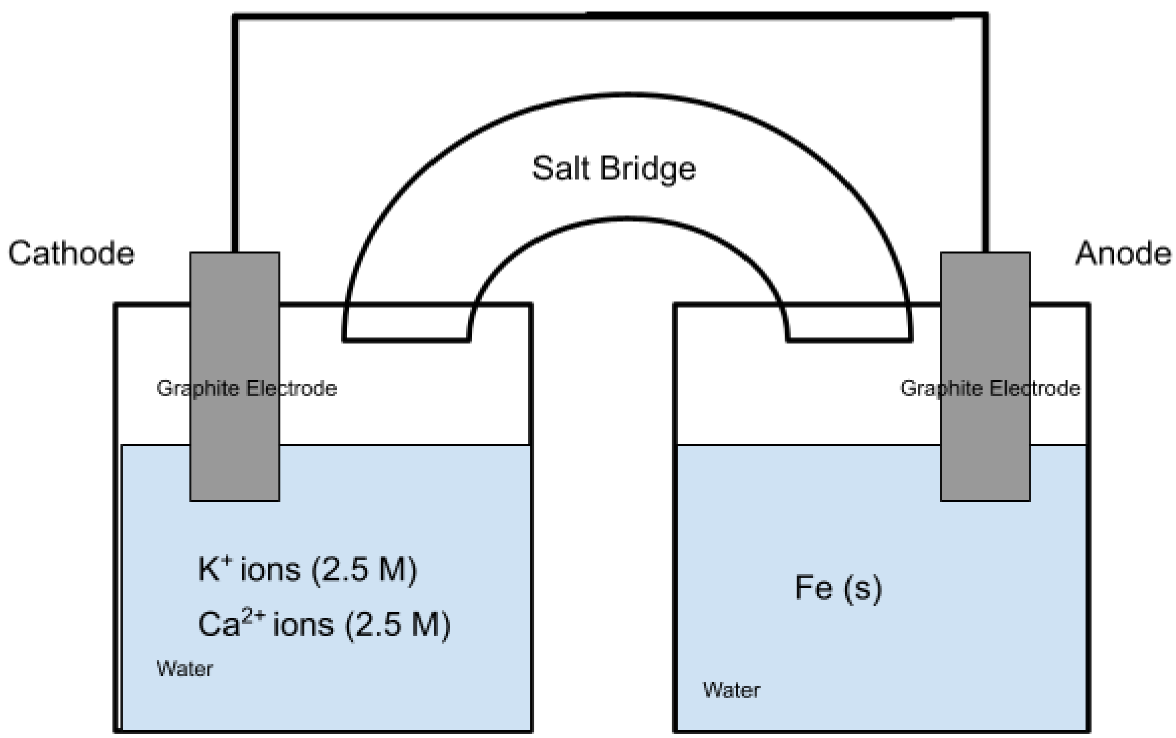
b. You are given a galvanic cell to explore the electrochemical properties of the metals calcium, iron, and potassium, and their corresponding ions. The galvanic cell contains graphite electrodes, solid potassium particles, calcium ions (2.5 M), solid iron particles, water, and a salt bridge. Draw a 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)***

+1 for anode

+1 for cathode

+1 for labeling salt bridge

+1 for labeling water



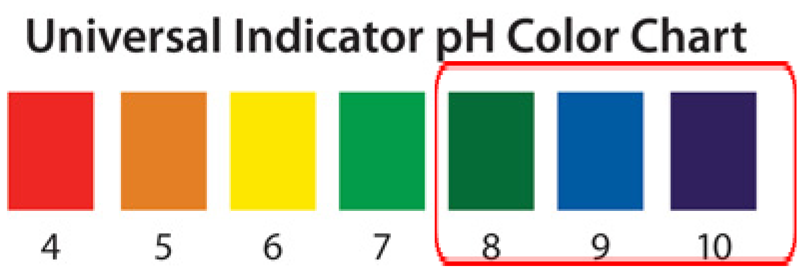
c. What reaction is most likely to occur at the anode? ***(1 point)***

$Fe\ (s) \rightarrow Fe^{2+}\ (aq) + 2\ e^-$   E = +0.45 V

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 points)***

$O_2\ (g) + 2\ H_2O\ (l) + 4\ e^- \rightarrow 4\ OH^-\ (aq)$   E = +0.40 V

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)***




Water in the presence of oxygen is reduced to hydroxide ions in the cathode cell. As more hydroxide ions are formed, its concentration increases, the pOH decreases, and the pH increases, leading to a pH greater than 7.

+1 for circling 8/9/10, +1 for saying hydroxide forms so pH increases

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)***

Nernst equation: $\Delta E = \Delta E^{o} - \frac{RT}{nF} lnQ$

+1 for using Nernst

$Fe\ (s) \rightarrow Fe^{2+}\ (aq) + 2\ e^-$   E = +0.45 V
$2\ Fe\ (s) \rightarrow 2\ Fe^{2+}\ (aq) + 4\ e^-$   E = +0.45 V
$O_2\ (g) + 2\ H_2O\ (l) + 4\ e^- \rightarrow 4\ OH^-\ (aq)$   E = +0.40 V

Complete equation: $2\ Fe\ (s) + O_2\ (g) + 2\ H_2O\ (l) \rightarrow 2\ Fe^{2+}\ (aq) + 4\ OH^-\ (aq)$

$\Delta E^{o} = 0.45\ V + 0.40\ V = 0.95\ V$

+1 for this calculation

$$\Delta E + \frac{RT}{nF} lnQ = \Delta E^o$$

$$\frac{RT}{nF} lnQ = \Delta E^o - \Delta E$$

$$T = \frac{nF}{RlnQ} (\Delta E^o - \Delta E)$$

$$T = \frac{(2\, mol\, e^-)(96485.31\, C/mol\, e^-)}{(8.31451\, J/mol\, K)(ln(\,((1.5)^2(1.5)^4)/(1.5))} (0.95\, V - 0.90\, V)$$

$$T = 572.401871238\, K$$

T = **572.402 K**

+1 for correct final answer

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

A salt bridge balances the charge in each of the half-cells. If the salt bridge was removed, a positive charge would build up in the anode, and a negative charge would build up in the cathode. Eventually, the charge build up will cause the reaction to stop.

+1 for saying positive charge builds up in anode, negative charge builds up in cathode

+1 for saying reaction stops eventually

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)***

2.5 M $Ca^{2+}$ ions

Q = It → t = Q/I (+1 for current equation)

1300 mg Ca

$$\times \frac{1\, g}{1000\, mg} \times \frac{1\, mol}{40.078\, g} = 0.03243674834\, mol\, Ca \times \frac{2\, mol\, e^-}{1\, mol\, e^-\, Ca} = 0.06487349668\, mol\, e^-$$

+1 for unit conversion

$$t = \frac{(0.06487349668\, mol\, e^-)(96485.31\, C/mol\, e-)}{400\, A} = 15.6483485949\, s$$

t = **15.65 s** (+1 for correct final answer)

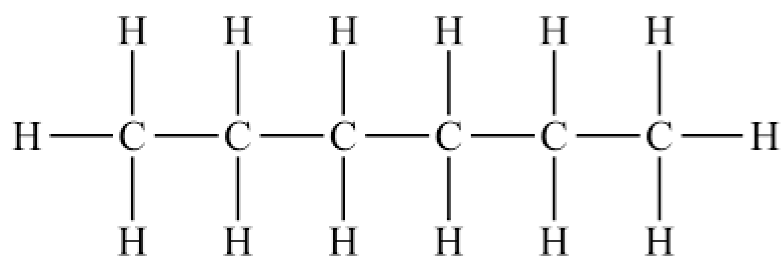
**<u>Problem #7</u>: *(10 points)***

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.

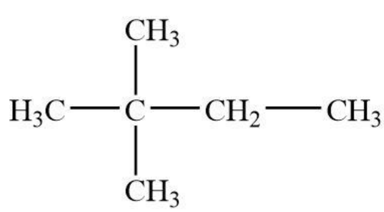
Here is an example comparing the lewis structure and line-angle formula of hexane

Lewis structure:

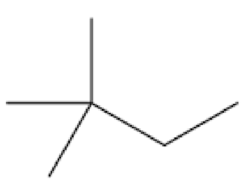


Line-angle formula:

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

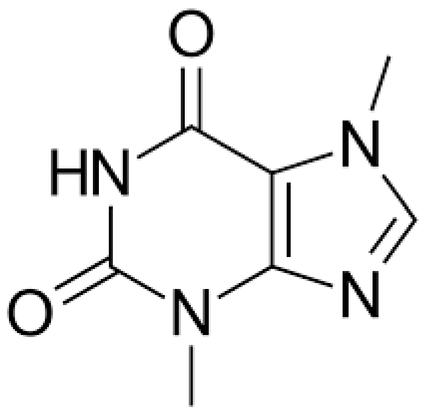


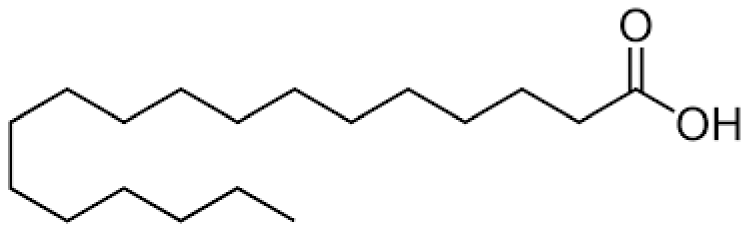
Line-angle formula:



+2 for correct answer

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)***



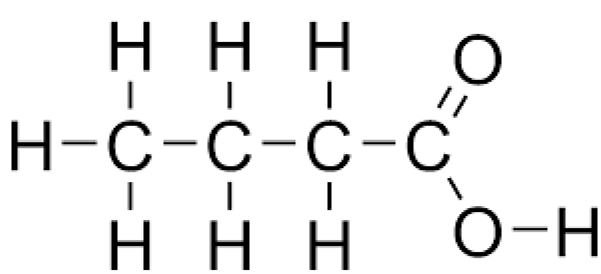




Theobromine

Stearic Acid

Theobromine has a melting point of 357˚C and stearic acid has a melting point of 69.3˚C. Theobromine has a higher melting point because of its intermolecular and intramolecular forces. Theobromine has much stronger intermolecular and intramolecular forces due to its many functional groups and strong dipole moments. (+1 for correct answer, +1 for justification)

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)***



+2 for correct structure

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)***

**3.239 g $CO_2$(g) x (1 mol $CO_2$)/(44.01 g $CO_2$) x (1 mol C)/(1 mol $CO_2$) x (12.01 g C)/(1 mol C) = 0.884 g C**
+2 for correct answer

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)***

Glucose: -2840 kJ/mol
Sucrose: -5645 kJ/mol

Sucrose is a disaccharide sugar made up of fructose and glucose while glucose is a monosaccharide hexose. As a result, sucrose has a higher enthalpy of combustion since it requires more heat to combust the disaccharide made up of glucose (hexose) and fructose (pentose) than a simple hexose.
+1 for correct answer +1 for justification