2023 WUCT: Chemistry of the Five Senses ANSWER KEY

This exam consists of 10 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, followed by 10 minutes of upload time during which you cannot make changes to your exam. The only allowed resources for this exam are a calculator and the provided equation sheet. You may NOT use any other notes, books, or websites (other than Gradescope and HopIn). 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 so that your writing clearly shows on your submitted document in Gradescope.

<u>Problem #1</u>: *(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:

$$E = hv = \frac{hc}{\lambda}$$

where v 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)***

3.06×10^{-19} J = (6.626×10^{-34} Js)(2.998×10^{8}) / λ

λ = 6.49×10^{-7} m

+1 correct substitution into the equation

+1 point for correct wavelength

3.06×10^{-19} J = (6.626×10^{-34} Js)(v)

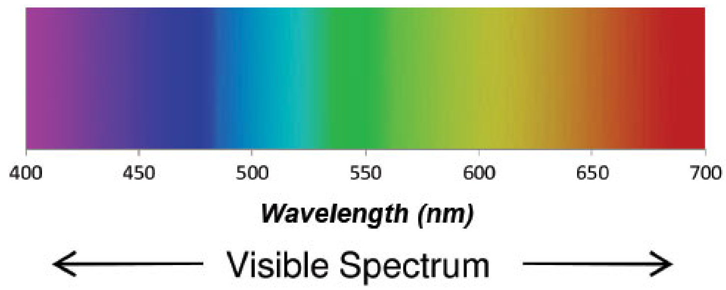
$v = 4.62 \times 10^{14}$ Hz

+1 correct substitution into the equation

+1 point for correct frequency

+1 for correct units (m for wavelength and Hz or 1/s for frequency)

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



Orange light

+1 for correct answer

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)***

596 kJ/mol x 1 mol/6.022 x 10^{23} atoms = 9.90 x 10^{-22} kJ = 9.90 x 10^{-19} J

+1 for correct calculation

No, the photon will not eject an electron because it does not have enough energy to overcome the ionization energy.

+1 for correct answer

+1 for correct explanation

d. Will a photon with 1.36 x 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)***

$KE_{electron}$ = 1.36 x 10^{-18} J - 9.90 x 10^{-19} J = ½ mv^2 = ½ (9.11 x 10^{-31} kg)(v^2)

+1 for correct substitution into KE equation

v = 9.02 x 10^5 m/s

+1 for correct calculation of v and units

Yes, the photon will eject an electron because it possesses more energy than that required to eject the electron

+1 for correct explanation

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

More energy because the same number of protons is spread across fewer valence electrons so they are held tighter (higher effective nuclear charge)

+1 for correct answer

+1 for correct explanation

xxx +1 only if they say less energy because it forms a stable noble gas configuration; this is true, but it is not the dominant effect

<u>Problem #2:</u> ***(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)***

150g ethanol x 1 mol ethanol/46.08g ethanol = 3.26 mol ethanol

3.26mol/0.500L = 6.52M ethanol

+1 for correct calculation steps

+1 for correct answer

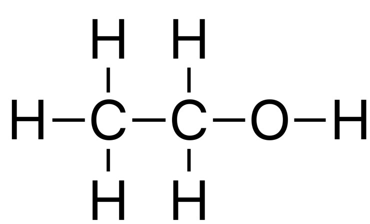
3.26mol/0.350kg H_2O = 9.3 mol/kg

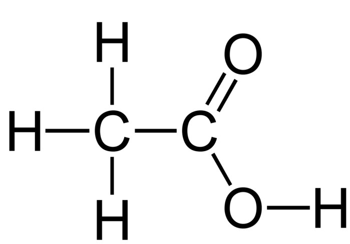
+1 for correct calculation steps

+1 for correct answer

+1 for correct units for both molarity and molality calculations

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)***





+1 for drawing any sort of carboxylic acid

+1 for maintaining 2 carbons

c. Given that the K_a of the acid mentioned above is $1.8x10^{-5}$, what is the pH of the final solution in David's cup assuming all reactions went to completion? ***(4 points)***

Acetic acid	acetate	H+
6.52M (from part a)	0	0
-x	+x	+x

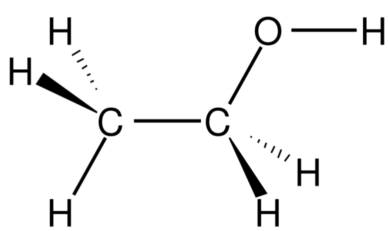
$1.8x10^{-5} = x^2/(6.52\text{-}x) \approx x^2/6.52$

$x = 1.08x10^{-2}$ M

pH = $-\log(1.08x10^{-2}) = 1.97$

+1 for correct use of ICE table
+1 for correct use of K_a
+1 for correct x concentration
+1 for correct final answer (plugging x into pH)

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



Carbon atoms are tetrahedral
+1 for tetrahedral
+1 for correct VSEPR structure

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

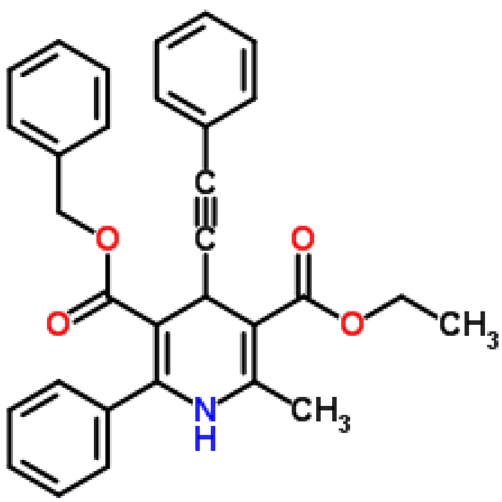
John is eating potatoes for Thanksgiving and finds that when he continues to chew a chunk of potato without swallowing it, it seems to taste sweeter. John later finds out that many other carbohydrates start to taste sweeter when they are left in the mouth.

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

Enzyme/protein

+1 for correct answer

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)*** circle around one of the hexagons
   ii. A triangle around a methyl group ***(1 point)*** triangle around a CH_3
   iii. A rectangle around an ester group ***(1 point)*** rectangle around O=C-O-R



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 7mL 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)***

+1 for identifying reaction between acid and base going to completion

+1 for correct use of ICE table

+1 for correct use of K_a

+1 for correct x calculation

+1 for identifying pH

+1 for correct final answer (not stable)

	CH3COOH	OH- ->	CH3COO-	H_2O
Before	0.50mmol	0.35mmol	0	0
Reaction	-0.35mmol	-0.35mmol	+0.35mmol	+0.35mmol
After	0.15mmol	0	0.35mmol	0.35mmol

	CH3COOH ->	CH3COO-	H+
I	0.0125M	0.0292M	0
C	-x	+x	+x
E	0.0125	0.0292	X = 7.7 x 10^-6

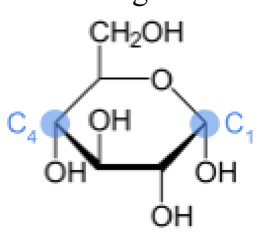
$1.8\times10^{-5} = x(0.0292)/0.0125$

$[H+] = x = 7.7 \times 10^{-6}$

pH = -log[H+] = 5.11

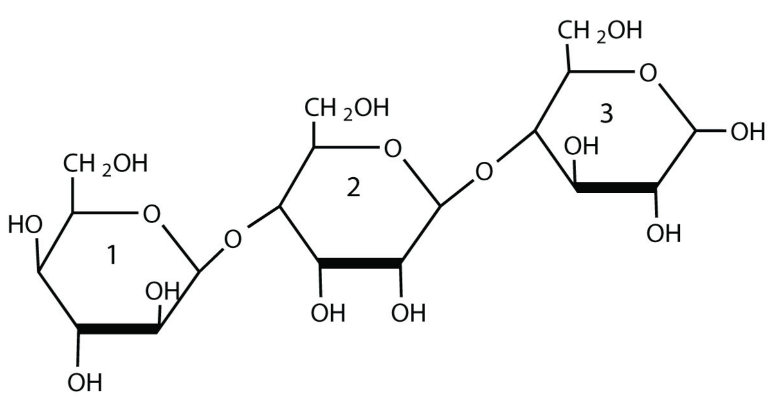
5.11 is out of the stable pH range so the molecule will not be stable in this range.

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)***



+1 for identifying molecule with correct chemical formula: $C_{18}H_{32}O_{16}$

+2 pt for drawing molecule



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)***

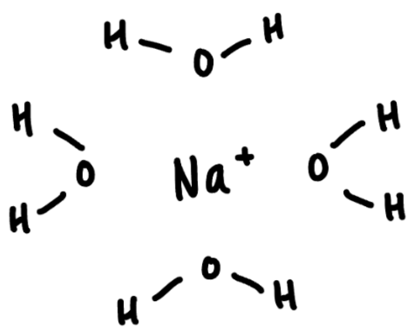
Ionic interaction

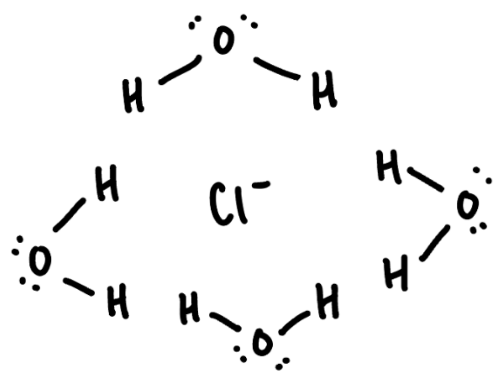
The positively charged Na^+ and negatively charged Cl^- are attracted to one another because of differences in electrostatic potential

+1 for correct identification of ionic interaction

+1 for correct description

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





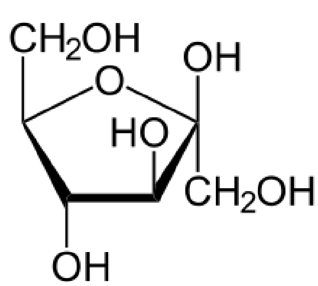
+1 for drawing NaCl as two separate ions

+1 for O facing Na+

+1 for H facing Cl-

+1 for using at least four water molecules

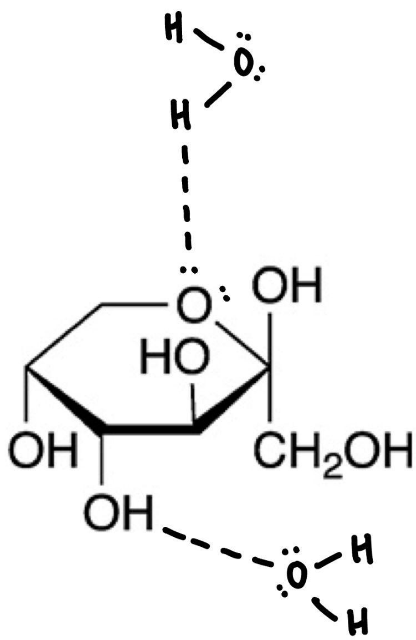
c. Fructose is a sugar found naturally in fruits, fruit juices, some vegetables and honey. The structure is shown below. What is the strongest type of intermolecular force present in fructose? ***(1 point)***



Hydrogen bond

+1 for correct answer

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)***



Yes, because of hydrogen bond formation, fructose is soluble in water.
+1 for saying it is soluble
+1 for explaining that is it due to hydrogen bond formation
+1 for drawing at least two water molecules hydrogen bonded

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

Acceptable answers
#1: O is much more electronegative than H, giving water a permanent dipole. This allows it to solvate other polar and ionic compounds. The partially negative dipoles of the water are attracted to positively charged components of the solute, and vice versa for the positive dipoles.
+1 for referencing polarity/dipole moment

#2: Water can be a hydrogen bond donor or acceptor, allowing it to complex with solute molecules.
+1 for referencing hydrogen bond donor/acceptor capabilities

#3: The relatively small size of water molecules typically allows many water molecules to surround one molecule of solute.
+1 for referencing size

******* *Reasonable answers will also be accepted*

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)***

$Graham's\ Law\ of\ Effusion$: $\frac{Rate\ A}{Rate\ B} = \sqrt{\frac{Molar\ Mass\ B}{Molar\ Mass\ A}}$

Ratio of effusion rates of Na^+ to K^+ = $\sqrt{\frac{39.098g}{22.990g}} = 1.304$

+1 for correct substitution into equation

+1 for correct final answer

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)***

Nernst equation: $\Delta Ecell = \Delta E°cell - (\frac{RT}{nF})\ln Q$

$\Delta Ecell = 1.20V - (\frac{0.0592V}{1})\log(\frac{0.10M}{0.90M}) = 1.26\ V$

+1 for finding correct formula

+1 for correct substitution into equation

+1 for correct final answer with units

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)***

$\Delta G°$ = 1.75kJ/mol = -RTlnK

K = 0.49

Forward reaction because Q < K

+1 for solving for K

+1 for comparing to Q

+1 for correct final answer

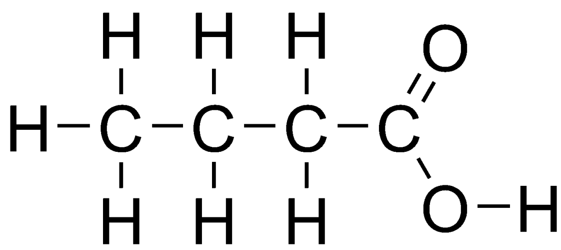
d. The formula for osmotic pressure is $\Pi = MRT$, where M is molarity. At the point in the reaction described in part b, determine which ion, Na^+ or K^+, would give the higher osmotic pressure given that they are at the same temperature. ***(2 points)***

K^+ would have a higher osmotic pressure because it has a higher molarity. R is the ideal gas constant and T is temperature, which are the same for both ions.
+1 for correct answer
+1 for correct justification

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)***



+1 for correct Lewis structure

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

Most acidic hydrogen: hydrogen on the carboxylic acid

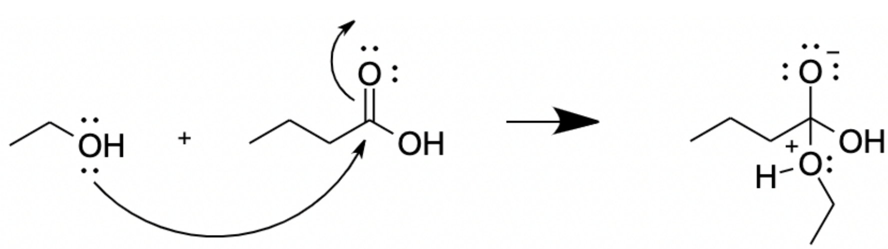
The anion that is left after the acidic hydrogen is removed is stabilized by resonance and puts the negative charge across to two electronegative oxygens.

+1 for circling carboxylic H

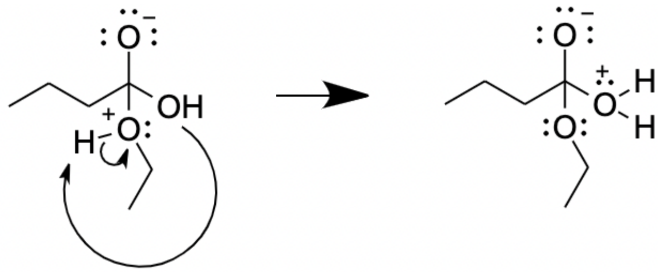
+1 for correct explanation that mentions resonance stabilization

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:

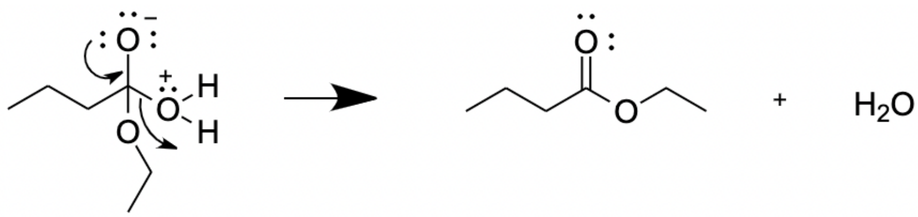


Step 2:



+1 for alcohol as nucleophile
+1 for carboxyl C as electrophile

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



+1 for first arrow correct
+1 for second arrow correct

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

Ester

+1 for correct answer

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

Greater than

S is more electronegative than Se, draws more e- density, more electron pair repulsion, leads to bigger angle

+1 for correct answer (H-S-H angle in H2S is greater than H-Se-H angle in SeH2)

+1 for correct justification (electronegativity)

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

No, electronegativity difference between H and S is not sufficiently large enough (hydrogen bondings are only possible between H and F, O, N where the electronegativity differences are sufficiency large)

+1 for correct answer saying that H_2S cannot participate in hydrogen bonding

+1 for correct explanation that the electronegativity difference between H and S is not sufficiently large

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)***

$2H_2S \rightarrow 2H_2 + S_2$

0.036g S_2 x 1 mol S_2 / 64.12g x 2 mol H_2S / 1 mol S_2 x 34.076 g H_2S / 1 mol H_2S x 1000 mg / 1 g = 38.264 mg H_2S

+1 for balanced equation

+1 for correct unit conversion

+1 for correct answer

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

	ΔH_f°	**S°**
$H_{2\ (g)}$	[redacted]	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

$\Delta H^\circ = 2(0) + (277.17 kJ/mol) - 2(-20.6 kJmol) = 318.37 kJ/mol$
+1 for correct answer
+1 for correct work/equation (products - reactants)

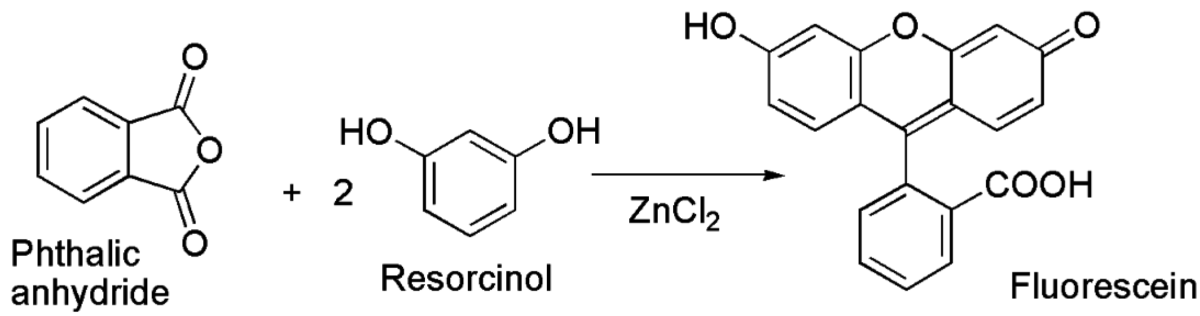
$\Delta S^\circ = 2(130.68 J/mol) + (167.829 J/mol) - 2(205.81 J/mol) = 17.569 J/mol$
+1 for correct answer
+1 for correct work/equation (products - reactants)

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

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = 318.37 kJ/mol - (298K)(0.017569 kJ/mol) = 313.13 kJ/mol$
+1 for correct work/equation calculating delta G
Not spontaneous because ΔG° is positive.
+1 for correct answer

<u>Problem 8:</u> ***(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)***

0.400g resorcinol x (1mol resorcinol/110.11g) x (1mol fluorescein/2mol resorcinol) = 0.001816mol
+1 for using unit conversion for phthalic anhydride
0.280g phthalic anhydride x (1mol phthalic anhydride/148.11g) x (1mol fluorescein/1mol phthalic anhydride) = 0.001890mol
+1 for using unit conversion for resorcinol

Resorcinol is limiting reagent +1 for identifying resorcinol as limiting reagent
0.001816mol fluorescein x (332.3g/1mol fluorescein) = 0.6036g
+1 for correct final yield with units

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 the reaction order? ***(4 points)***

Reaction rate stays the same regardless of [resorcinol] (trials 1 and 2).
However, the rate doubles with a doubling of [phthalic anhydride] and triples with a tripling of [phthalic anhydride]. This indicates the rate is first order with respect to [phthalic anhydride] (trials 1 and 3, trials 1 and 5, respectively).

Initial reaction rate = k[phthalic anhydride]

Use a set of the data to calculate k:
0.00287 = k(0.20 M)
k = 0.01435 hr^{-1}
+1 for zeroth order with regard to resorcinol
+1 for first order with regard to phthalic anhydride
+1 for first order overall
+1 for correct k value with units

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)***

ln[phthalic anhydride]
+2 for correct answer
+1 partial credit for saying just [phthalic anhydride]

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

$ZnCl_2$ increases rate of reaction (increases k)
+2 for increases rate of reaction (or k)

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)***

Higher intensity because at higher pH (basic pH) the structure/system is more conjugated due to the anionic oxygens present in fluorescein
+1 for correct answer
+1 for correct reasoning

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)***

ΔH is positive because it is given that the reaction requires input of energy

ΔS is negative because the reaction is going from 2 types of reactants to 1 type of product and also going from 3 moles of reactants to 1 mole of product

$\Delta G = \Delta H - T\Delta S$

Nonspontaneous because ΔG must be positive

+1 for correct ΔH observation

+1 for correct ΔS observation

+1 for correct ΔG observation, reaction is nonspontaneous