2022 WUCT: Chemistry of Climate Change

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, 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.

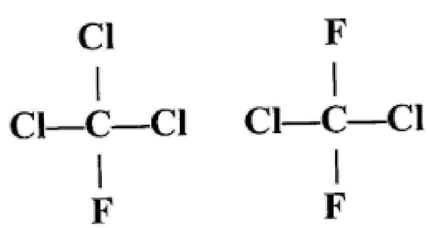
Problem #1: ***(13 points)***

One large contributor to climate change is CFCs, or chlorofluorocarbons. They were discovered to have been depleting the ozone layer in the 1970s by chemists Mario Molina and F. Sherwood Rowland. We will be retracing their steps in this important discovery.

a. What major class of chemical compounds do CFCs belong to? (Hint: think back to organic compound naming conventions.) ***(1 point)***

b. Rowland and Molina began their collaboration in understanding how CFCs move through the atmosphere. At high altitudes, solar radiation is much more intense and is, therefore, able to break apart any molecule.

   i. Predict whether chlorine or fluorine will break apart from CFCs at high altitudes. Explain your reasoning in 1-2 sentences. For reference, the pictures below show two examples of CFCs. ***(2 points)***



Freon-11 Freon-12

ii. Give the chemical equation that occurs when Freon-11 reacts with UV light. (Hint: the reaction results in the formation of reactive but neutral radicals) ***(2 points)***

c. Reaction with Ozone:

   i. Show the chemical reaction (including all possible propagation steps) that occurs between ozone (O_3) and the atom that breaks apart from the CFC in part b. Given: the reactions results in the formation of O_2 ***(4 points)***

   ii. What is special about the atom that breaks apart from the CFC in part b that makes it react with ozone? ***(2 points)***

d. Does the atom that breaks apart from the CFC in part b change after it reacts with ozone? How does this explain why CFCs are so harmful to the environment? ***(2 points)***

<u>Problem #2</u>: ***(13 points)***

One way scientists can determine the rate of climate change is through climate change indicators. Ocean acidity is one such indicator.

a. Ocean acidity is primarily caused by the diffusion of CO_2 molecules from the atmosphere into the ocean. Write a chemical equation to show this dissolution of carbon dioxide. The first part of the equation is shown below. ***(4 points)***

   $CO_2 + H_2O \Leftrightarrow H_2CO_3$

b. Use the chemical reaction in your answer to part (a) explain why the dissolution of CO_2 molecules causes ocean acidity. ***(2 points)***

c. Explain how the equilibrium of the chemical reaction changes as more and more carbon dioxide is released into the atmosphere. ***(2 points)***

d. Explain what occurs when too much carbon dioxide is absorbed by the ocean. (Hint: think buffers). ***(3 points)***

e. If the ocean has such a large buffering capacity, why is ocean acidification a big problem? ***(2 points)***

<u>Problem #3</u>: ***(16 points)***

High levels of air pollution have been linked to more respiratory and heart diseases. We'll begin to explore how redox reactions are central to creating pollution.

a. Ozone can be helpful for the environment, but too much of it can also cause many problems due to it being a very powerful oxidizing agent.

   i. Draw the Lewis Structure of ozone (O_3). If there are resonance structures, draw all of them. Draw the Lewis structure of molecular oxygen (O_2). **(*5 points)***

   ii. Using the Lewis Structure, explain why ozone is able to more readily react with other molecules, especially in comparison to molecular oxygen (Hint: think about bond order and bond strength). **(*3 points)***

   iii. Based on the chemical formula of ozone, hypothesize what ozone reduces into. Write out the reduction half-reaction that shows this. **(*2 points)***

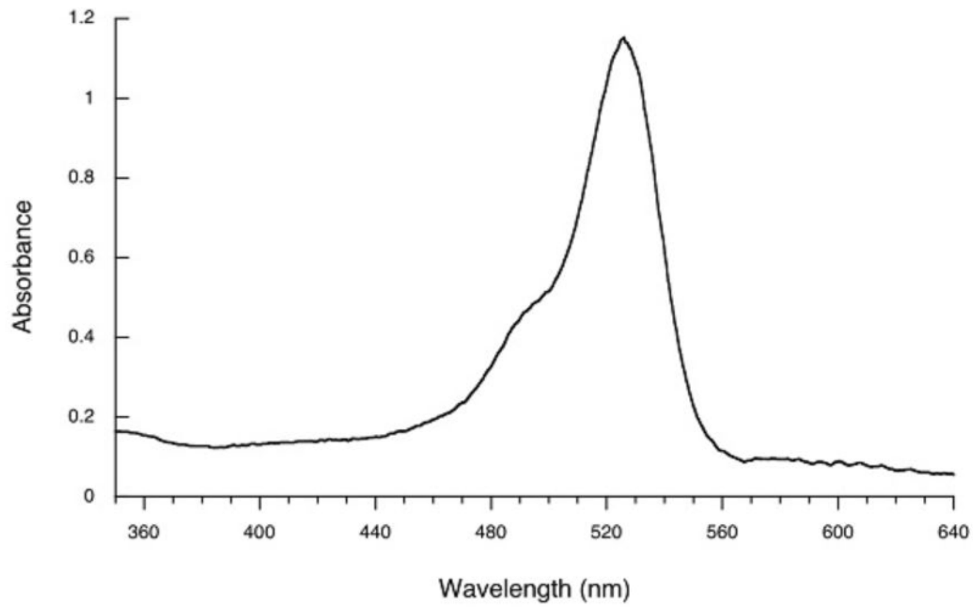
b. Ozone is so dangerous because it is able to react without lung tissue, causing airway damage and inflammation. However, our bodies do have a defense against oxidizing agents - antioxidants that line the surface of our lungs. One of these antioxidants is ascorbic acid ($C_6H_8O_6$).

   i. Write out a balanced redox reaction of hydrogen peroxide (H_2O_2, another strong oxidizing agent) and ascorbic acid ($C_6H_8O_6$) to show why ascorbic acid is a good defense. (Hint: hydrogen peroxide gets neutralized to become H_2O) ***(4 points)***

   ii. Write out the oxidation numbers for each of the participating atoms in the redox reaction in part bi. **(*2 points)***

<u>Problem #4</u>: *(12 points)*

One greenhouse gas, carbon dioxide (CO_2), is constantly being released into the atmosphere through different combustion reactions (like the burning of gasoline). An increase in atmospheric CO_2 has been found to increase the average temperature of Earth. We'll explore why this is through spectroscopy and Beer Lambert's Law.



a. Based on this plot of absorbance, A, vs wavelength in nm, what is the optimum wavelength for CO_2? Explain. ***(3 points)***

b. The concentration of CO_2 in the atmosphere was 150 ppm in 1850. Now, the concentration of CO_2 is more than 240 ppm. How does the absorbance compare with this increase in concentration? ***(4 points)***

c. If CO_2 contributed 4.7 K to the global temperature in 1850, predict how much the global temperature rose due to the increase in concentration of CO_2 using the absorbance values. ***(2 points)***

d. An experimenter puts CO_2 in a 2.00 L container at 1,050 K. Calculate the number of moles of CO_2 (g) placed in the container if the pressure from the CO_2 in the container is 5.00 atm. ***(3 points)***

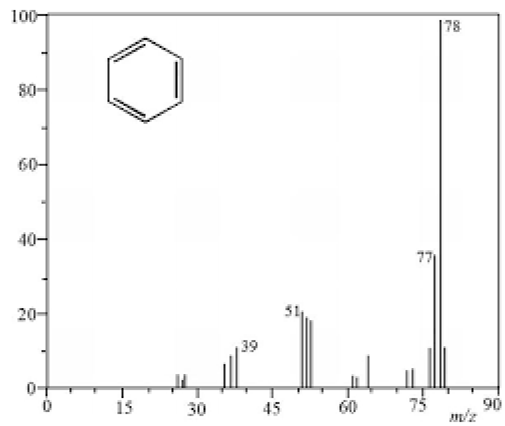
<u>Problem #5</u>: *(14 points)*

When hydrocarbon fuels undergo a process of combustion, they release carbon dioxide and other greenhouse gases that heavily contribute to global warming and atmospheric pollution.

a. Write the balanced chemical equation when the hydrocarbon fuel propane (C_3H_8) is fully combusted. ***(3 points)***

b. Another hydrocarbon, benzene, can react with other chemicals in the atmosphere to induce smog formation. Given that a sample of benzene is fully combusted to yield 34.677 g of CO_2 and 7.0935 g of H_2O, what is the empirical formula of benzene? ***(4 points)***

c. Given the mass spectra presented below, what is the molecular formula of benzene? HINT: Benzene is a hydrocarbon with 6 carbons. ***(3 points)***



d. Answer the following multiple choice questions and explain your reasoning below in 1 - 2 sentences.

  i. Which of the following reactions will have the greatest exothermic heat of reaction? ***(2 points)***
  (a) The combustion of propane (C_3H_8)
  (b) The combustion of butane (C_4H_{10})
  (c) The combustion of methylene (CH_2)
  (d) The combustion of benzene (C_6H_6)
  (e) All of the reactions above will have the same exothermic heat of reaction

  ii. Combustion reactions can have either a positive or negative ΔH. True or False? ***(2 points)***
  (a) True
  (b) False

Problem #6: ***(17 points)***

Photochemical smog is a type of air pollution formed when nitrogen oxides (NO_x) react with sunlight, creating a brown haze above cities. Nitrogen oxides are produced primarily from the combustion of fossil fuels, particular from automobile engines.

Below is a simplified explanation of photochemical smog formation.

$$NO_2\ (g) + \text{sunlight} \rightarrow NO\ (g) + O\ (g)$$
$$O\ (g) + O_2\ (g) \rightarrow O_3\ (g)$$

a. Explain why the first reaction is considered a redox reaction. In your answer, please refer to specific oxidation numbers and identify the oxidizing and reducing agents. ***(3 points)***

b. Suppose the first reaction is carried out in a sealed flask, where volume is constant. Calculate $\Delta H_{rxn}°$, $\Delta S_{rxn}°$, and $\Delta G_{rxn}°$ at 298K. ***(4 points)***

Compound	**NO_2**	**NO**	**O**
$\Delta H_f°$, kJ mol^{-1}	33.18	90.25	249.18
S°, J mol^{-1} K^{-1}	240.1	210.8	161.1

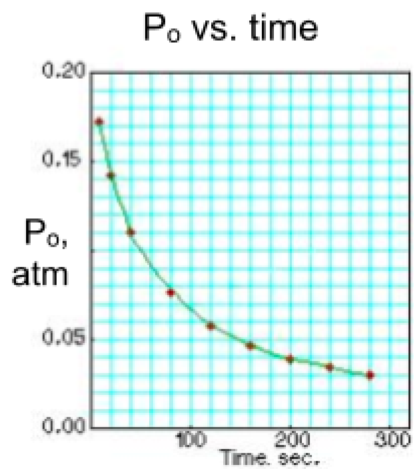
c. Calculate $K_{eq.}$ **(*2 points*)**

d. Would K_{eq} for the dimerization at 308K be greater than, less than, or equal to K_{eq} at 298K? Justify your answer based on the above data. **(*2 points*)**

e. Given the atomic oxygen product formed in the first reaction and consumed in the second reaction is a free radical, draw its Lewis structure. **(*2 points*)**

f. Why is atomic oxygen especially reactive in comparison to molecular oxygen? **(*1 point*)**

g. Doubling the concentration of either O or O_2 doubles the rate of the second reaction. Assuming O and O_2 combine in equal proportions to form O_3, how can you manipulate the following graph to observe a linear relationship? Please justify your answer. **(*3 points)***



<u>Problem #7</u>: *(15 points)*

The gaseous form of water, water vapor, is a greenhouse gas that traps heat inside the Earth's atmosphere. Greenhouse gases play a key role in the warming of Earth's climate, which has substantial negative consequences, such as causing more severe storm systems. This question will explore different chemical concepts involving water vapor.

a. What is the molecular geometry of a water molecule? Is this different from or similar to its electron geometry? The electron geometry assumes that lone pairs are like atoms in determining the geometry of the molecule. ***(2 points)***

b. Methanol (CH_3OH) is very similar in structure to H_2O, yet methanol's melting point is -97.6℃, as opposed to the melting point of ice, 0℃. What is the reason for this disparity? ***(2 points)***

c. You are given a 50 g sample of water with a temperature of 140℃. The water is kept in a closed 100 mL graduated cylinder. 0.07 g of the water evaporates. What is the pressure of the water vapor in this sample? Assume the water vapor behaves as an ideal gas. ***(3 points)***

d. What is the average kinetic energy of the water vapor molecules in the sample from part (c)? ***(2 points)***

e. You heat your 50 g sample of water to 200℃ and wait until it evaporates completely. What is the average velocity of one gram of water molecules? ***(2 points)***

f. In the plot below, the y-axis represents the number of water molecules in your sample, and the x-axis represents speed in m/s. Fill in the plot below with the average velocity of the water molecules and the most probable speed. Be sure to include numerical values. ***(4 points)***