Spring 2023 **Chemistry 2000 Final Exam** ____/108 marks

Confidentiality Agreement:
I agree not to discuss (or in any other way divulge) the contents of this exam with (or in the presence of) any CHEM 2000 student who has yet to write it. I understand that breaking this agreement would constitute academic misconduct. The minimum penalty would be a mark of 0/108 on this exam.

Signature: _____ Date: _____

1) Please read the test carefully before starting. It has 12 pages of questions (six pages double-sided).
2) You have also been given a data sheet. It does not have a QR code, so nothing written on it will be graded.
3) **DO NOT WRITE ON ANY QR CODE!!!** Work on pages without a QR code will not be graded.
4) You may use a calculator but only for calculation. No other electronic devices are allowed. Any non-trivial use of a calculator must be described. For example, if you use a calculator to solve a nonlinear equation, you need to make it clear what equation was solved and provide any other inputs you used to the calculation.
5) If your work is not legible, it will be given a mark of zero.
6) Show your work. Answers without supporting reasoning or calculations will not get full credit
7) Marks will be deducted for incorrect information added to an otherwise correct answer.
8) Marks will be deducted for improper use of significant figures and for missing or incorrect units. Show units in every step of all calculations. Significant figures will only be checked in final answers. If a question has subparts (a, b, c, etc.), the answer to each subpart is considered a "final answer".
9) You have 3 hours to complete this test.

Question Breakdown

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15			Total
/ 4	/ 4	/ 3	/ 5	/ 2	/ 2	/ 5	/ 4	/ 2	/ 18	/ 11	/ 8	/ 15	/ 24	/ 1			/ 108

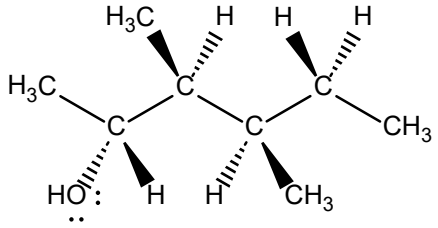
1. Draw and label a band diagram for germanium (Ge). Identify whether Ge is a conductor, a semiconductor or an insulator, and explain how this is shown by your diagram. **[4 marks]**

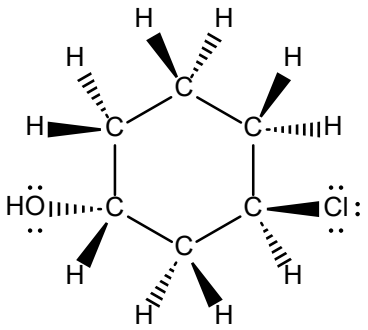
2. Sketch and label a phase diagram for a substance that can undergo pressure-induced melting. Clearly show this phase change on your diagram, and give an example of one substance that can undergo pressure-induced melting. **[4 marks]**

3. Compare solid H_2 and solid HD at the same temperature. Which of the two substances will have a higher entropy? Justify your answer using any relevant equations. **[3 marks]**

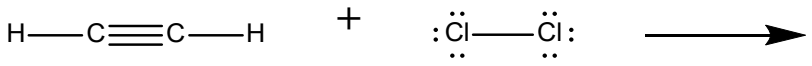
4. Circle all the chiral carbon atoms in each of the substances drawn below. **[5 marks]**

Marks will be deducted for incorrectly circled atoms.





5. Draw the product of the reaction below. Pay attention to stereochemistry. **[2 marks]**



6. Draw a Lewis diagram for carbon dioxide (CO_2). What is the hybridization of the carbon atom in CO_2? **[2 marks]**

7. What happens to the freezing point of water when you dissolve an equimolar amount of a nonvolatile solute in it? In other words, when you add 1 mole of solute for every 1 mole of water. **[5 marks]**

Your answer should include any relevant equations; however, you are not being asked to calculate the new freezing point – just to indicate whether it's higher, lower or the same as the freezing point of pure water and explain why that is the case.

8. For the electrochemical cell described below, identify which species is the cathode, which species is the anode and write a balanced half-reaction for each half-cell. **[4 marks]**

$$Ag(s) \mid Ag^{+}(aq) \parallel H^{+}(aq) \mid H_2(g) \mid Pt(s)$$

The cathode is made of _____. The anode is made of _____.

The oxidation half-reaction is:

The reduction half-reaction is:

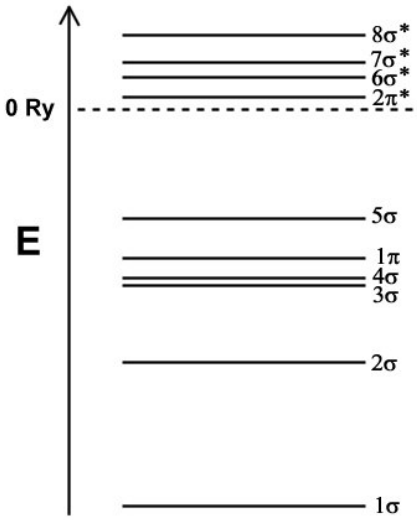
9. O_2 is ionized in a UV-photoelectron spectroscopy experiment. Use your knowledge of molecular orbital labeling conventions to answer the following questions. **[2 marks]**

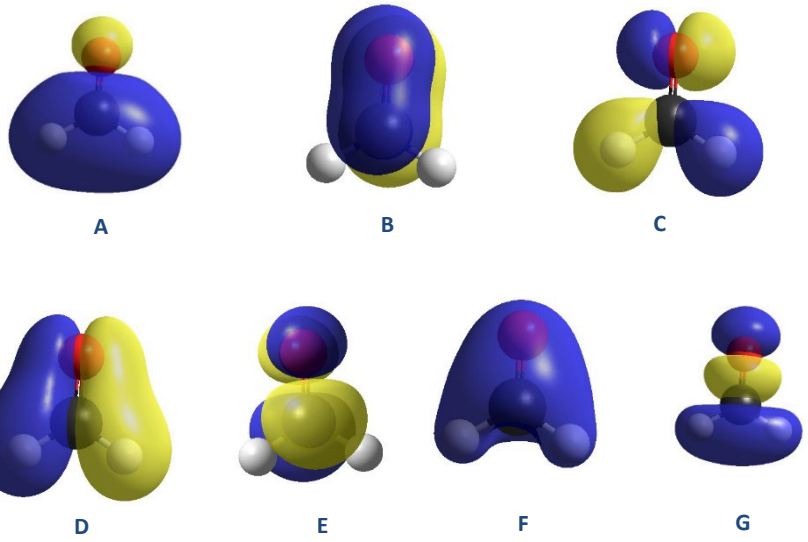
(a) Signals are observed for ionization from various molecular orbitals including 1σ, 1π and $2\pi^*$. Which of the three listed MOs will require the highest energy light for one of its electrons to be ionized?

(b) Signals are observed for ionization from various molecular orbitals including 1σ, 1π and $2\pi^*$. Which of the three listed MOs will give a signal with the widest spacing between its lines?

10. The valence molecular orbital energy level diagram for formaldehyde $(H_2C = O)$ is shown below. Drawings of some MOs have also been provided (each labeled with a letter for easy reference). **[18 marks]**

In all MO drawings, oxygen is at the top and carbon is at the bottom (with two hydrogen atoms attached).





(a) Complete the energy level diagram by adding the appropriate number of valence electrons. *[1 mark]*

(b) Identify which of the MO drawings corresponds to the 1σ orbital. Explain your choice and indicate which atomic orbitals combine to make this molecular orbital. *[2 marks]*

(c) Identify which of the MO drawings corresponds to the 1π orbital. Explain your choice and indicate which atomic orbitals combine to make this molecular orbital. *[2 marks]*

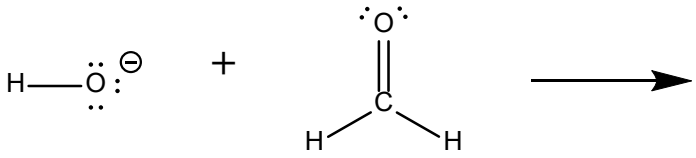
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10. *…continued*

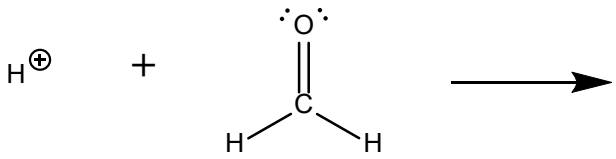
(d) Drawing **C** corresponds to the HOMO of formaldehyde. Identify which MO that is and indicate which atomic orbitals combine to make this molecular orbital. *[2 marks]*

(e) Drawing **E** corresponds to the LUMO of formaldehyde. Identify which MO that is and indicate which atomic orbitals combine to make this molecular orbital. *[2 marks]*

(f) When formaldehyde acts as an electrophile, which MO accepts the electrons? Which atom is attacked? Does adding electrons to this MO make the bond order of an existing bond increase or decrease? Add curved arrows to the reaction below and draw the resulting product. Then comment on how the relevant MO helps us determine what happens in this reaction. *[5 marks]*



(g) When formaldehyde acts as a nucleophile, which MO donates the electrons? Which atom attacks? Add curved arrows to the reaction below and draw the resulting product. Then comment on how the relevant MO helps us determine what happens in this reaction. *[4 marks]*



11. Compare the molecular orbital energy level diagrams (MO diagrams) for HF and HCl. **[11 marks]**

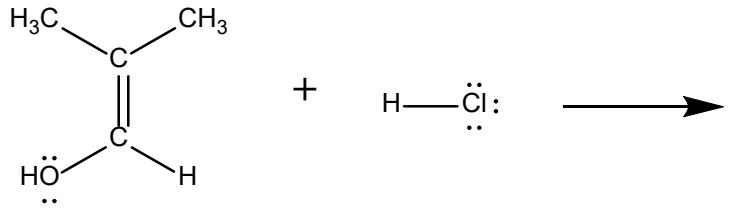
(a) Draw MO diagrams for HF and HCl side by side on the same scale. Your diagrams should include labeled energy levels (clearly indicating whether each MO is bonding, nonbonding or antibonding) and the appropriate number of electrons, but you do not need to include drawings of the orbitals. *[6 marks]*
For simplicity, DO NOT invoke sp-mixing when building the MO diagram for HCl.

Atomic Orbital Energies					
$1s(H)$	-1.00 Ry	$2s(F)$	-2.95 Ry	$3s(Cl)$	-1.86 Ry
		$2p(F)$	-1.37 Ry	$3p(Cl)$	-1.01 Ry

(b) Calculate the bond order for HF and for HCl. Even though these bonds have the same bond order, it requires more energy to break the $H-F$ bond. With reference to the MO diagrams, explain why this is the case. *[2 marks]*

(c) When a base reacts with HF, it attacks the hydrogen atom not the fluorine atom. With reference to the MO diagram, explain why that is the case. *[3 marks]*

12. Consider the following addition reaction: **[8 marks]**



(a) Draw the two possible organic products of this reaction. Label one as **A** and the other as **B**. *[2 marks]*

(b) According to Markovnikov's rule, which of your answers to part (a) is predicted to be the major product? Briefly explain your choice. *[2 marks]*

(c) In fact, the product predicted by the traditional version of Markovnikov's rule is not the major product in this case. Explain why the other product is actually favoured for this particular alkene. You should find it helpful to draw the two possible carbocation intermediates as part of your explanation. *[4 marks]*

13. The pK_a of acetic acid (CH_3CO_2H) is 4.74. The pK_a of nitroacetic acid ($NO_2CH_2CO_2H$) is 1.68. **[15 marks]**

(a) Briefly explain why the pK_a of nitroacetic acid is so much smaller than that of acetic acid. *[2 marks]*

(b) Calculate the pH of a solution prepared by adding 100.0 g acetic acid to 1.000 L water. *[9 marks]*

(c) Calculate the pH of a solution prepared by adding both 100.0 g acetic acid and 200.0 g sodium acetate (CH_3CO_2Na) to 1.000 L water. *[4 marks]*

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13. *…continued*

14. The partial electrochemical oxidation of methanol produces formaldehyde and water: **[24 marks]**

$$____\ CH_3OH_{(l)} + ____\ O_{2(g)} \rightarrow ____\ CH_2O_{(g)} + ____\ H_2O_{(l)}$$

(a) Balance this reaction using the method of half reactions. *[5 marks]*
For full credit, you must show both balanced half reactions.

(b) Using the thermodynamic data provide, calculate $\Delta H°$ and $\Delta S°$ for this reaction. *[5 marks]*

(c) Calculate $\Delta G°$ for this reaction at 25 ℃. Is the reaction product- or reactant-favoured at this temperature? *[4 marks]*

(d) Calculate the equilibrium constant for this reaction at 25 ℃. *[3 marks]*

(e) Calculate the potential for an electrochemical cell based on this reaction at 25 ℃ in which the pressure of oxygen is 10.0 bar and the pressure of formaldehyde is 0.0020 bar. *[7 marks]*

	$\Delta_f H°$	$S°$
$CH_3OH_{(l)}$	$-238.7\ \frac{kJ}{mol}$	$126.8\ \frac{J}{mol \cdot K}$
$O_{2(g)}$		$205.0\ \frac{J}{mol \cdot K}$
$CH_2O_{(g)}$	$-108.6\ \frac{kJ}{mol}$	$218.8\ \frac{J}{mol \cdot K}$
$H_2O_{(l)}$	$-285.83\ \frac{kJ}{mol}$	$69.9\ \frac{J}{mol \cdot K}$

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14. *…continued*

15. What was the most useful and/or interesting thing you learned in CHEM 2000? **[1 mark]**

…AND THAT'S ALL FOR CHEM 2000.
HAVE A GREAT SUMMER!