Spring 2018 **Chemistry 2000 Final Exam A** ____/116 marks

1) Please read over the test carefully before beginning. You should have 13 pages of questions, a blank "overflow" page and a double-sided data sheet with periodic table.
2) **DO NOT WRITE ON THE QR CODE!!!** Work on pages without a QR code will not be graded.
3) If your work is not legible, it will be given a mark of zero. Show your work for all calculations.
4) Marks will be deducted for incorrect information added to an otherwise correct answer.
5) You may use a calculator but only for calculation. No text-capable calculators are allowed.
6) You have 3 hours to complete this test.

Confidentiality Agreement:

I agree not to discuss (or in any other way divulge) the contents of this exam until after 12:00 noon Mountain Time on Wednesday, April 18th, 2018. I understand that breaking this agreement would constitute academic misconduct. The minimum punishment would be a mark of 0/116 on this exam and removal of the "overwrite midterm mark with final exam mark" option for my grade in this course; the maximum punishment would include expulsion from this university.

Signature: _____ Date: _____

Course: CHEM 2000 (General Chemistry II)
Semester: Spring 2018
The University of Lethbridge

Question Breakdown

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Total
/ 9	/ 5	/ 6	/ 12	/ 12	/ 14	/ 4	/ 6	/ 6	/ 10	/ 12	/ 12	/ 7	/ 1	/ 116

1. Fill in each blank with the word or phrase that best completes the sentence. **[9 marks]**

(a) The second law of thermodynamics states that for a reaction to be thermodynamically allowed, _____. *[3 marks]*

(b) On a phase diagram, the critical point lies at the end of the curve separating the _____ phase and the _____ phase. At pressures and temperatures above the critical point, the substance is a _____.

(c) A semiconductor consisting of one pure substance is a(n) _____ semiconductor.

(d) In an electrochemical cell, the electrode at which oxidation occurs is called the _____.

(e) Two molecules that are nonsuperimposable mirror images of each other are a pair of _____.

2. The overall reaction in the lead-acid battery involves $Pb_{(s)}$ reacting with $PbO_{2(s)}$. The main product in both half-reactions is $PbSO_{4(s)}$. **[5 marks]**

(a) Which lead species gets oxidized? *[1 mark]*

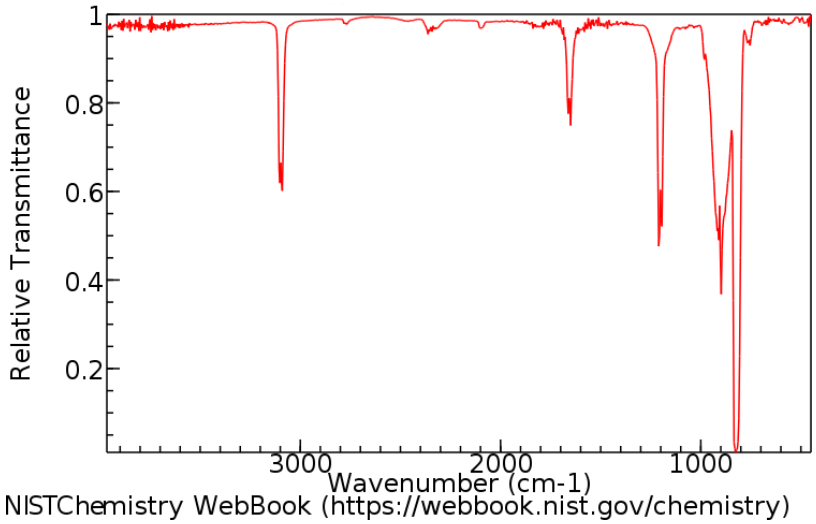
(b) Which lead species gets reduced? *[1 mark]*

(c) Unbalanced half-reactions are provided below. Balance them then use the balanced half-reactions to write a balanced equation for the overall reaction. *[3 marks]*

$$Pb_{(s)} + HSO_{4(aq)}^{-} \rightarrow PbSO_{4(s)}$$

$$PbO_{2(s)} + HSO_{4(aq)}^{-} \rightarrow PbSO_{4(s)}$$

3. A compound has the formula $C_2H_2Cl_2$. This compound is non-polar. **[6 marks]**
The IR spectrum for this compound is shown below.
Note that this spectrum shows transmittance rather than absorbance, so the bands appear upside-down. This is of no real consequence.
Also note that the wavenumber ("frequency") axis runs from right to left.



(a) Draw the structure of this compound. Explain how the information provided supports your answer. You must reference the IR spectrum in your answer. *[3 marks]*

(b) According to Valence Bond theory, what is the hybridization of the carbon atoms in this compound? *[1 mark]*

(c) Draw one structural isomer of this compound. *[1 mark]*

(d) Draw one stereoisomer of this compound. *[1 mark]*

4. As we saw in class, an amino acid consists of a central carbon atom attached to: **[12 marks]**

- a carboxylic acid,
- an amine,
- a variable (R) group, and
- a hydrogen atom.

In the amino acid valine, the variable group is an isopropyl group $(-CH(CH_3)_2)$.

(a) Draw a line-bond structure for valine. *Include lone pairs.* *[3 marks]*

(b) Is valine chiral? Demonstrate whether or not it is chiral using appropriate drawings. *[3 marks]*

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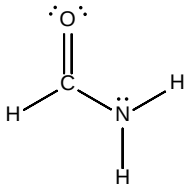
4. *…continued*

(c) In amino acids, the carboxylic acid functional group is more acidic (pK_a ~2) than is typical of carboxylic acids (pK_a between 3 and 5). Explain why. *[2 marks]*

(d) What is a zwitterion, and why would valine (and the other amino acids) be a zwitterion under physiological (pH ~7) conditions? Distribution curves may be helpful for answering this question. *[4 marks]*

5. A Lewis structure for formamide is shown below. **[12 marks]**



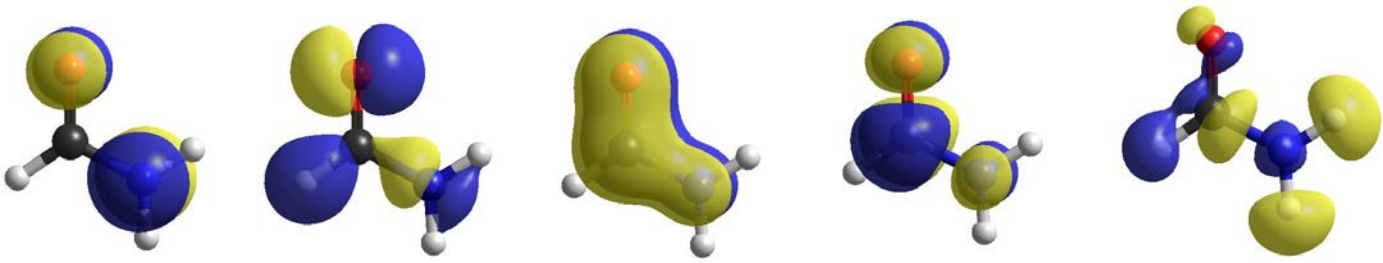
VSEPR suggests that the nitrogen should be trigonal pyramidal but, in fact, it's trigonal planar.

(a) How many valence σ-symmetric MOs does formamide have? *[1 mark]*

(b) How many valence π-symmetric MOs does formamide have? *[1 mark]*

(c) Draw a valence π MO energy level diagram for formamide. Your diagram should include energy levels, electrons and labels for the MOs. You do **not** need to include atomic orbitals. *[4 marks]*

(d) The pictures below show some of the MOs of formamide. Circle the pictures showing π MOs, and label each π MO, matching it to an energy level in your answer to part (c). You do **not** need to label the σ MOs. *[3 marks]*



(e) How would your answers to parts (a), (b) and (c) have changed if the nitrogen atom in formamide had been trigonal pyramidal? *[3 marks]*

6. **[14 marks]**

(a) Draw a valence molecular orbital energy level diagram for the hypofluorite anion (OF^-).
Your diagram should include: *[10 marks]*

- energy levels for atomic and molecular orbitals
- tie lines connecting MOs to the appropriate AOs
- labels for atomic and molecular orbitals (including whether MOs are bonding, nonbonding or antibonding)
- electrons in the molecular orbitals
- identification of the HOMO and LUMO

You do not need to draw pictures of the orbitals.

Atomic Orbital		Energy (Ry)
O	2s	−2.38
	2p	−1.17
F	2s	−2.95
	2p	−1.37

(b) Calculate the $O - F$ bond order in OF^-. *[1 mark]*

(c) The hypofluorite anion would be a very powerful Lewis base. Based on your MO diagram, which end of the ion (O or F) is most strongly basic? Explain briefly. Your explanation should include a picture of the relevant MO. *[3 marks]*

7. Explain how a light-emitting diode (LED) works using a band diagram. What feature of the diagram is related to the color of the LED? **[4 marks]**

8. The entropy of N_2O at $0\ K$ is $4.7\ \frac{J}{mol \cdot K}$. This is called the residual entropy. **[6 marks]**

(a) Draw a Lewis diagram for N_2O. The connectivity is $N - N - O$. *[2 marks]*
Include all non-zero formal charges.

(b) According to VSEPR, what is the geometry of N_2O? *[1 mark]*

(c) Explain the probable origin of the residual entropy of N_2O. Support your argument with a calculation. *Do not expect a perfect match with the measured entropy reported above. [3 marks]*

9. In the gas phase, toluene $(C_6H_5CH_3)$ can react with itself to make benzene (C_6H_6) and xylenes $(C_6H_4(CH_3)_2)$. **[6 marks]**

$$2\ C_6H_5CH_{3(g)} \rightleftharpoons C_6H_{6(g)} + C_6H_4(CH_3)_{2(g)}$$

At 25 °C, the equilibrium constant for this reaction is 0.16.

If we start with a rigid container holding 0.75 bar of toluene, what will the pressures of all reactants and products be once the system reaches equilibrium?

10. **[10 marks]**

(a) Calculate the pH of a solution prepared by adding 0.71 g HCl to 1.00 L water. *[2 marks]*
Assume that the addition of HCl does not significantly affect the volume of the solution.

(b) Calculate the pH of a solution prepared by adding 0.15 g acetic acid (CH_3CO_2H) to 1.00 L water.
Assume that the addition of acetic acid does not significantly affect the volume of the solution.
[8 marks]

11. The reformation of coal to hydrogen using high pressure steam can be described by the following chemical equation: **[12 marks]**

$$3\ C_{(s)} + O_{2(g)} + 4\ H_2O_{(g)} \rightleftharpoons 3\ CO_{2(g)} + 4\ H_{2(g)}$$

Use thermodynamic data for graphite (standard state of carbon) as approximate values for coal. The values are not exactly the same, but coal is complex enough that getting exact data is difficult.

(a) Calculate K for this reaction performed at 25 ℃. *[8 marks]*

(b) Calculate K for this reaction performed at 125 ℃. *[4 marks]*

12. The hydrogen fuel cell is governed by the following reaction: **[12 marks]**

$$2\ H_{2(g)} + O_{2(g)} \rightleftharpoons 2\ H_2O_{(g)}$$

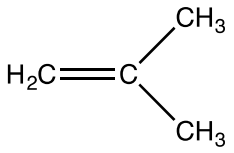
For the purposes of this question, consider a hydrogen fuel cell operating under acidic conditions.

(a) What is the stoichiometric coefficient for electrons (ν_e) for this reaction? *[2 marks]*

(b) Calculate the standard cell potential for this reaction at 25 ℃. *[4 marks]*

(c) Calculate the cell potential for this reaction at 25 ℃ if the input stream provides 66 bar $H_{2(g)}$ and 33 bar $O_{2(g)}$ while the pressure of water vapour is kept at 0.001 bar.
Is this reaction product-favoured under those conditions. Why or why not? *[6 marks]*

13. What is the product in the acid-catalyzed addition of water to the following molecule? Show the mechanism, including the electron movement using the curved arrow notation. **[7 marks]**



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

Overflow Page

If you use this page for any answers, please clearly indicate which question is being answered and make sure you note on the page for the question itself that the answer continues here.