NAME:_____ Section:____ Student Number:_____

Spring 2020 **Chemistry 2000 Midterm #2A** ____/ 65 marks

INSTRUCTIONS:
1) Please read over the test carefully before beginning. You should have 8 pages of questions, a blank "overflow" page and two pages of data sheets with periodic table.
2) If your work is not legible, it will be given a mark of zero.
3) Marks will be deducted for incorrect information added to an otherwise correct answer.
4) Marks will be deducted for improper use of significant figures and for missing or incorrect units.
5) Show your work for all calculations. Numerical answers without supporting calculations will not be given full credit.
6) You may use a calculator but only for the purposes of calculation. No text-capable calculators are allowed.
7) You have 90 minutes to complete this test.

Confidentiality Agreement:
I agree not to discuss (or in any other way divulge) the contents of this exam until after 8:30 pm Mountain Time on Tuesday, March 17th, 2020. I understand that breaking this agreement would constitute academic misconduct, a serious offense with serious consequences. The minimum punishment would be a mark of 0/65 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 2020
The University of Lethbridge

Question Breakdown

Q1	/ 7
Q2	/ 6
Q3	/ 13
Q4	/ 10
Q5	/ 3
Q6	/ 8
Q7	/ 18

Total	/ 65

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1. **[7 marks]**

(a) Complete each statement with one of the following symbols: >, < or = *[4 marks]*

For an allowed process at constant temperature and pressure,

i. $\Delta S_{universe}$ _____ 0

ii. ΔG _____ 0

iii. E _____ 0

iv. K _____ Q

(b) One of the statements in part (a) is true under any conditions (not just at constant temperature and pressure). Which one? *[1 mark]*

(c) In statement i. in part (a), why do we have to write $\Delta S_{universe}$? Why can't we just write ΔS? *[1 mark]*

(d) In statement ii. in part (a), can ΔG be replaced by $\Delta G°$? Why or why not? *[1 mark]*

2. Consider the following reaction that takes place in aqueous acid. **[6 marks]**

$$Cr_2O_{7(aq)}^{2-} + Zn_{(s)} \rightarrow Zn_{(aq)}^{2+} + Cr_{(aq)}^{3+}$$

(a) Balance this equation under acidic conditions. *[3 marks]*

For full marks, your answer must include balanced half reactions.

(b) Identify the oxidizing agent. *[1 mark]*

(c) Identify the reducing agent. *[1 mark]*

(d) What is ν_e for this reaction? *[1 mark]*

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3. Ethene, essential in making plastics, can be produced electrolytically from carbon dioxide and water using surplus electricity. The two half-reactions involved are shown below. **[13 marks]**

Water is written in the gas phase for consistency with later parts of the question which will deal with this process at high temperature.

$$2\,CO_{2(g)} + 8\,H_2O_{(g)} + 12\,e^- \rightarrow C_2H_{4(g)} + 12\,OH^-_{(aq)}$$

$$4\,OH^-_{(aq)} \rightarrow O_{2(g)} + 2\,H_2O_{(g)} + 4\,e^-$$

(a) Clearly label which half-reaction occurs at the anode and which occurs at the cathode. *[1 mark]*

(b) Write the overall balanced reaction for this process. *[1 mark]*

(c) What is ν_e for this process? *[1 mark]*

(d) Calculate the standard Gibbs free energy change for this process. *[2 marks]*

For consistency with later parts of the question, please use data for water in the gas phase.

(e) Calculate the standard cell potential (or standard emf) for this process. *[2 marks]*

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3. *...continued*

(f) Calculate Q for this process when it is performed at 800 ℃ and the partial pressures of carbon dioxide and water vapour are both 1.00 $kbar$ while the partial pressures of ethene and oxygen are both 1.00 $mbar$. *[3 marks]*

(g) Calculate the cell potential (or emf) for this process under the conditions described in part (f). The standard cell potential for this process at 800 ℃ is -1.120 V. *[3 marks]*

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4. **[10 marks]**

(a) Draw a phase diagram for water. Your diagram must include: *[8 marks]*

- Labeled axes
- Labeled phases
- Labeled triple point
- Labeled critical point

You do not need to include numerical values on your diagram.

(b) On your phase diagram, draw a line of constant pressure where only sublimation occurs. Label your line "sublimation". *[1 mark]*

(c) On your phase diagram, draw a line of constant temperature where condensation is followed by melting. Label your line "condensation/melting". *[1 mark]*

5. The dissociation of water into $H^+_{(aq)}$ and $OH^-_{(aq)}$ is an endothermic process. Would you expect the pH of water to increase or decrease as the temperature of water increases at constant pressure? Justify your answer. **[3 marks]**

Hint: remember that $pH = -log\left(a_{H^+_{(aq)}}\right)$

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6. In CHEM 1000, you would have learned that the following reaction does NOT occur (unlike the analogous reaction of water with any of the other Group 2 metals): **[8 marks]**

$$Be_{(s)} + 2\,H_2O_{(l)} \rightarrow Be(OH)_{2(s)} + H_{2(g)}$$

(a) Is this reaction thermodynamically allowed at 25 ℃ if the pressure of $H_{2(g)}$ is 0.05 bar? *[6 marks]*

(b) Discuss briefly the agreement or disagreement between the result of your calculation and the observation that beryllium does not react with water. *[2 marks]*

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7. The Boudouard reaction is the following: **[18 marks]**

$$2\,CO_{(g)} \rightleftharpoons CO_{2(g)} + C_{(s)}$$

This reaction is a serious nuisance in industrial processes involving carbon monoxide since it results in the deposition of graphite, which leads to fouling of the lines transporting this gas.

(a) Is this a redox reaction? Justify your answer. *[1 mark]*

(b) Calculate the equilibrium constant for this reaction at 25 ℃. Is the reaction reactant-favoured or product-favoured under standard conditions? *[5 marks]*

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7. *...continued*

(c) Estimate the equilibrium constant for this reaction at 250 ℃. *[6 marks]*

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7. *...continued*

(d) At 975 K, the equilibrium constant for the Boudouard reaction is 1. Suppose that a container holds 58 bar of CO at 975 K. What will the partial pressures of CO and CO_2 be when the system reaches equilibrium in this container? *[6 marks]*

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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

Some Useful Constants and Formulae

Fundamental Constants and Conversion Factors

Atomic mass unit (u)	$1.660\ 539 \times 10^{-27}$ kg	Kelvin temperature scale	0 K = -273.15 °C
Avogadro's number (N_A)	$6.022\ 141 \times 10^{23}$ mol^{-1}	K_w (at 25 °C)	10^{-14}
Boltzmann constant (k_B)	$1.380\ 649 \times 10^{-23}$ J·K^{-1}	Planck's constant (h)	$6.626\ 070 \times 10^{-34}$ J·Hz^{-1}
Charge of electron	$-1.602\ 176 \times 10^{-19}$ C	Speed of light in vacuum (c)	$2.997\ 925 \times 10^{8}$ m·s^{-1}
Faraday's constant (F)	96 485 C·mol^{-1}	Volume conversion	1000 L = 1 m^3
Ideal gas constant (R)	8.314 462 J·mol^{-1}·K^{-1}	Pressure conversions	1 bar = 100 kPa
	8.314 462 m^3·Pa·mol^{-1}·K^{-1}		1 atm = 1.01325 bar

Formulae

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad PV = nRT$$

$$S = k_B \ln \Omega \qquad \Delta S = \frac{q_{rev}}{T} \qquad \Delta_r G = \Delta_r H - T\Delta_r S$$

$$\Delta_r G = \Delta_r G^\circ + RT \ln Q \qquad \Delta_r G^\circ = -RT \ln K \qquad \ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta_r H^o}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$P_A = X_A P_A^\bullet \qquad [A] = k_H P_A \qquad X = \frac{n}{\sum n} \qquad \Delta_r G = -\upsilon_e F E \qquad E = E^\circ - \frac{RT}{\upsilon_e F} \ln Q$$

$$pH = -\log a_{H^+} \qquad pK_a = -\log K_a \qquad pK_b = -\log K_b \qquad K_w = K_a \cdot K_b \qquad pH = pK_a + \log\left(\frac{a_{A^-}}{a_{HA}}\right)$$

$$\Delta H^0_{rxn} = \sum(\Delta H^0_f(products) - \sum(\Delta H^0_f(reactants) \qquad \Delta S^0_{rxn} = \sum(S^0(products) - \sum(S^0(reactants)$$

$$\Delta G^0_{rxn} = \sum(\Delta G^0_f(products) - \sum(\Delta G^0_f(reactants)$$

Activities

Solid	$a = 1$
Pure liquid	$a = 1$
Ideal Solvent	$a = X$
Ideal Solute	$a = \frac{c}{c^\circ}$
Ideal Gas	$a = \frac{P}{P^\circ}$

CHEM 2000 Standard Periodic Table

1												13	14	15	16	17	18
1.0079 **H** 1	2											10.811 **B** 5	12.011 **C** 6	14.0067 **N** 7	15.9994 **O** 8	18.9984 **F** 9	4.0026 **He** 2
6.941 **Li** 3	9.0122 **Be** 4											26.9815 **Al** 13	28.0855 **Si** 14	30.9738 **P** 15	32.066 **S** 16	35.4527 **Cl** 17	20.1797 **Ne** 10
22.9898 **Na** 11	24.3050 **Mg** 12	3	4	5	6	7	8	9	10	11	12	69.723 **Ga** 31	72.61 **Ge** 32	74.9216 **As** 33	78.96 **Se** 34	79.904 **Br** 35	39.948 **Ar** 18
39.0983 **K** 19	40.078 **Ca** 20	44.9559 **Sc** 21	47.88 **Ti** 22	50.9415 **V** 23	51.9961 **Cr** 24	54.9380 **Mn** 25	55.847 **Fe** 26	58.9332 **Co** 27	58.693 **Ni** 28	63.546 **Cu** 29	65.39 **Zn** 30	114.82 **In** 49	118.710 **Sn** 50	121.757 **Sb** 51	127.60 **Te** 52	126.905 **I** 53	83.80 **Kr** 36
85.4678 **Rb** 37	87.62 **Sr** 38	88.9059 **Y** 39	91.224 **Zr** 40	92.9064 **Nb** 41	95.94 **Mo** 42	(98) **Tc** 43	101.07 **Ru** 44	102.906 **Rh** 45	106.42 **Pd** 46	107.868 **Ag** 47	112.411 **Cd** 48	204.383 **Tl** 81	207.19 **Pb** 82	208.980 **Bi** 83	(210) **Po** 84	(210) **At** 85	131.29 **Xe** 54
132.905 **Cs** 55	137.327 **Ba** 56	**La-Lu**	178.49 **Hf** 72	180.948 **Ta** 73	183.85 **W** 74	186.207 **Re** 75	190.2 **Os** 76	192.22 **Ir** 77	195.08 **Pt** 78	196.967 **Au** 79	200.59 **Hg** 80	114.82 **In** 49	118.710 **Sn** 50	121.757 **Sb** 51	127.60 **Te** 52	126.905 **I** 53	131.29 **Xe** 54
(223) **Fr** 87	226.025 **Ra** 88	**Ac-Lr**	(265) **Rf** 104	(268) **Db** 105	(271) **Sg** 106	(270) **Bh** 107	(277) **Hs** 108	(276) **Mt** 109	(281) **Ds** 110	(280) **Rg** 111	(285) **Cn** 112	(284) **Nh** 113	(289) **Fl** 114	(288) **Mc** 115	(293) **Lv** 116	(294) **Ts** 117	(294) **Og** 118

138.906 **La** 57	140.115 **Ce** 58	140.908 **Pr** 59	144.24 **Nd** 60	(145) **Pm** 61	150.36 **Sm** 62	151.965 **Eu** 63	157.25 **Gd** 64	158.925 **Tb** 65	162.50 **Dy** 66	164.930 **Ho** 67	167.26 **Er** 68	168.934 **Tm** 69	173.04 **Yb** 70	174.967 **Lu** 71
227.028 **Ac** 89	232.038 **Th** 90	231.036 **Pa** 91	238.029 **U** 92	237.048 **Np** 93	(240) **Pu** 94	(243) **Am** 95	(247) **Cm** 96	(247) **Bk** 97	(251) **Cf** 98	(252) **Es** 99	(257) **Fm** 100	(258) **Md** 101	(259) **No** 102	(262) **Lr** 103

Developed by Prof. R. T. Boeré (updated 2016)

Some Useful Thermodynamic Properties

Substance	$\Delta_f H°\left(\frac{kJ}{mol}\right)$	$\Delta_f G°\left(\frac{kJ}{mol}\right)$
$Be(OH)_{2(s)}$	-904	-818
$C_2H_{4(g)}$	52.47	68.36
$CO_{(g)}$	-110.53	-137.17
$CO_{2(g)}$	-393.51	-394.37
$H_2O_{(g)}$	-241.8	-228.6
$H_2O_{(l)}$	-285.830	-237.140