NAME:_____

Student number: _____

Chemistry 2000 Spring 2019 Test 2
Version B

Time: 90 minutes

Aids permitted: calculator.

See page 10 for useful data and formulas.

Significant figures: All answers must be given to the correct number of significant figures unless otherwise stated.

Units should generally be shown in intermediate steps of a calculation. Failing to do so may result in reduced credit.

Overflow/scratch space: If you need the extra space at the end of this paper to continue an answer, **it is your responsibility to make it clear what I need to mark, i.e. what is your answer vs what is just scratch work.**

Confidentiality Agreement: I agree not to discuss (or in any other way divulge) the contents of this exam until after 8:30 p.m. Mountain Time on March 14th, 2019. I understand that breaking this agreement would constitute academic misconduct, and would result in significant academic sanction.

Signature: _____ Date: _____

Question	Mark
1	/5
2	/8
3	/4
4	/8
5	/9
6	/8
7	/12
Total:	/54
Percentage:	%

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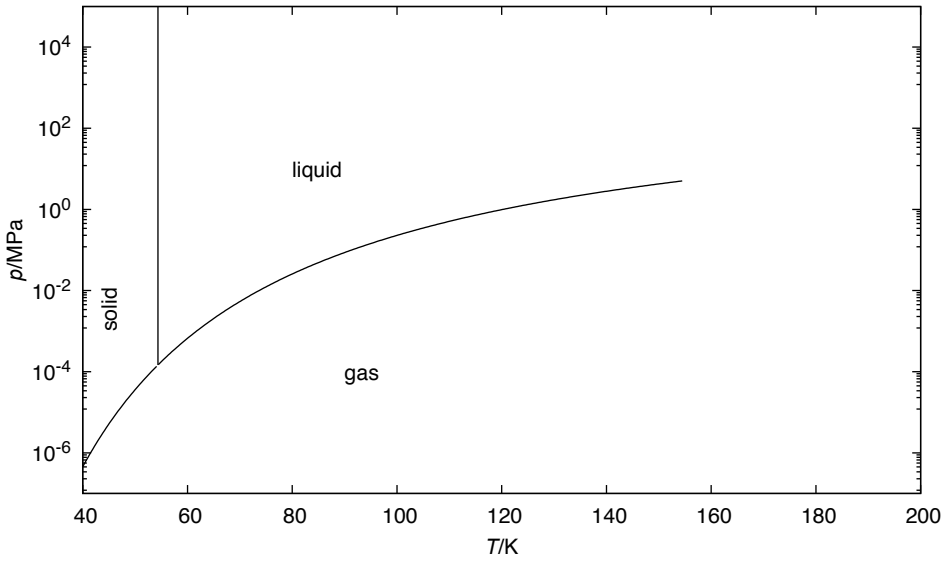
/5 1. Here is the phase diagram of oxygen:



(a) On the diagram, label the triple point and critical point. Show (roughly) where the supercritical region is located. [3 marks]

(b) While it looks vertical on the scale of this graph, the solid-liquid coexistence curve has a positive slope. What does this tell us? Explain briefly. [2 marks]

/8 2. When solid selenium and solid chromium(III) hydroxide are bathed in a basic solution, metallic chromium and selenite ions (SeO_3^{2-}) are formed. Balance the reaction. Include states of matter for all species. [8 marks]

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/4 3. In the gas phase, nitric oxide reacts with oxygen to form nitrogen dioxide:

$$2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}.$$

(a) Calculate the standard entropy change for this reaction. Make sure your answer has the correct number of significant figures. [2 marks]

(b) This reaction causes a decrease in entropy since the number of gas molecules will decrease. (Your calculation should confirm this.) The second law says that the entropy should increase, so this reaction is a counterexample to the second law, i.e. it proves that the second law is wrong.

What is wrong with this argument? A qualitative counter-argument is sufficient. [2 marks]

4. In this question, give your answers to a reasonable number of digits, but you do not need to track significant figures.

/8 (a) Calculate the equilibrium constant at 298.15 K for the reaction

$$2NO_{2(g)} \rightleftharpoons N_2O_{4(g)}.$$

[4 marks]

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(b) Is the reaction thermodynamically allowed if $p_{NO_2} = 0.043\,\text{bar}$ and $p_{N_2O_4} = 0.38\,\text{bar}$? [4 marks]

/9 5. At 500 °C, the equilibrium constant for the reaction

$$FeO_{(s)} + CO_{(g)} \rightleftharpoons Fe_{(s)} + CO_{2(g)}$$

is $K = 0.79$. If 2.9 bar of carbon monoxide is put into a sealed flask with an excess of FeO at 500 °C, what are the equilibrium pressures of the two gases? The final answer must be given to the correct number of significant figures. [9 marks]

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/8 6. 20.5513 g of captopril ($C_9H_{15}NO_3S$) is dissolved in 201.35 g of chloroform ($CHCl_3$) at 20 °C. The vapor pressure of pure chloroform at this temperature is 0.208 bar. What is the vapor pressure of the solution? (Captopril has a negligible vapor pressure.) [8 marks]

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/12 7. The solubility, s, of a molecular substance in water is the equilibrium concentration corresponding to the process

$$\mathrm{A_{(s)} \rightleftharpoons A_{(aq)}}.$$

The enthalpy change in this process is called (not surprisingly), the enthalpy of solution. The following table gives the solubility of theobromine, a caffeine-like compound found in chocolate, at two different temperatures:[1]

T/K	s/mol L^{-1}
288.07	1.71×10^{-3}
328.15	7.92×10^{-3}

In the questions that follow, try to give answers to a reasonable number of digits, but you do not need to track your significant

(a) What is the enthalpy of solution of theobromine? [4 marks]

[1] J. Zhong et al., *J. Chem. Eng. Data* **62**, 2570 (2017).

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(b) Iced chocolate drinks have become popular. What is the solubility of theobromine at 0 °C? [5 marks]

(c) An iced chocolate drink would actually have a temperature lower than 0 °C. Why? [1 marks]

We will ignore this effect in the rest of this question.

(d) Suppose that we prepare a hot chocolate drink with a theobromine concentration of $2.5 \times 10^{-3}\,\mathrm{mol\,L^{-1}}$. Is it possible to precipitate out some of the theobromine when the drink is cooled to make iced chocolate? Explain your reasoning in a few words. [2 marks]

Note: Assume that we cool the drink by putting the cup or caraffe on ice, and not by putting ice in the drink.

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Constants and conversion factors

$0\,\mathrm{K} = -273.15\,^{\circ}\mathrm{C}$
$R = 8.314\,463\,\mathrm{J\,K^{-1}mol^{-1}}$

Molar masses

Element	$M/\mathrm{g\,mol^{-1}}$
H	1.007 98
C	12.010 6
N	14.006 9
O	15.999 4
S	32.068
Cl	35.452

Standard thermodynamic properties

Substance	$\Delta_r H^{\circ}/\mathrm{kJ\,mol^{-1}}$	$\Delta_r G^{\circ}/\mathrm{kJ\,mol^{-1}}$	$S^{\circ}/\mathrm{J\,K^{-1}mol^{-1}}$
$NO_{(g)}$	90.29	86.60	210.65
$NO_{2(g)}$	33.2	51	239.9
$N_2O_{4(g)}$	9.16	97.7	304.3
$O_{2(g)}$	0	0	205.0

Formulas

$S = k_B \ln \Omega$ $\qquad$ $\Delta S = \dfrac{q_{\mathrm{rev}}}{T}$

$\Delta G = \Delta H - T\Delta S$ $\qquad$ $\Delta_r G_m = \Delta_r G_m^{\circ} + RT \ln Q$

$\Delta_r G_m^{\circ} = -RT \ln K$ $\qquad$ $\ln\left(\dfrac{K_2}{K_1}\right) = \dfrac{\Delta_r H_m^{\circ}}{R}\left(\dfrac{1}{T_1} - \dfrac{1}{T_2}\right)$

$p_A = p_A^{\bullet} X_A$ $\qquad$ $[\mathrm{A}] = k_H p_A$

Activities

State	Activity (a)
Solid	1
Pure liquid	1
Ideal solvent	X
Ideal solute	c/c°
Ideal gas	p/p°