

# Exam 4A

## Chem 1142

### Spring 2019

Name: \_\_\_\_\_

**MULTIPLE CHOICE.** [2.5 pts ea.] Record the best response on the scantron sheet. [50 pts total.]

*Assume all solutions are aqueous and at a temperature of 25 °C, unless stated otherwise.*

- Q1. The second law of thermodynamics states that:
- A) The entropy of the reaction always increases
  - B) The entropy of the universe always increases
  - C) The entropy of the surroundings always increases
  - D) The entropy of the system always increases
- Q2. Which substance would we expect to have the greatest molar entropy at 25 °C?
- A) NaF(s)
  - B) N<sub>2</sub>(g)
  - C) H<sub>2</sub>O(l)
  - D) C(s, graphite)
- Q3. Which chemical equation would most likely have  $\Delta S_{\text{rxn}}^{\circ} < 0$ ?
- A)  $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$
  - B)  $\text{Na}(\text{s}) + \frac{1}{2} \text{Br}_2(\text{l}) \rightarrow \text{NaBr}(\text{s})$
  - C)  $\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{g})$
  - D)  $\text{C}(\text{s, graphite}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$
- Q4. A chemical reaction has  $\Delta H_{\text{rxn}} = -5.00 \text{ kJ}$  at 250 K. What will the entropy change of the **surroundings** be?
- A) + 20 J/K
  - B) - 20 J/K
  - C) + 1300 kJ-K
  - D) - 1300 kJ-K
- Q5. An endothermic reaction has  $\Delta S_{\text{rxn}} > 0$ . What can you say about its spontaneity?
- A) It will always be spontaneous
  - B) It will always be non-spontaneous
  - C) It will be spontaneous at low temperatures, but non-spontaneous at high temperatures
  - D) It will be non-spontaneous at low temperatures, but spontaneous at high temperatures
- Q6. When will the entropy of a substance be zero?
- A) When it is an ion at a molar concentration of 1 M
  - B) When it is an element in its standard state at 25 °C
  - C) When it is a substance under 1 atm pressure at its normal melting point
  - D) When it is a perfect crystal at 0 K

- Q7. A chemical reaction has  $\Delta G^\circ > 0$  and  $\Delta G < 0$ . This means that:
- It is spontaneous under standard conditions, but non-spontaneous under current conditions
  - It is non-spontaneous under standard conditions, but spontaneous under current conditions
  - It will always be non-spontaneous under any condition
  - It will always be spontaneous under any condition
- Q8. A chemical reaction with  $\Delta G^\circ \ll 0$  will likely have an equilibrium constant,  $K$ , such that:
- $K \gg 1$
  - $K \ll 1$
  - $K = 1$
  - $K = 0$
- Q9. Which of the following chemical equations corresponds to the standard Gibbs energy of formation of  $\text{NH}_3(\text{g})$ ?
- $\text{NH}_3(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{NO}_2(\text{g}) + \frac{3}{2} \text{H}_2(\text{g})$
  - $2\text{NH}_3(\text{g}) \rightarrow \text{N}_2(\text{g}) + 3 \text{H}_2(\text{g})$
  - $\frac{1}{2} \text{N}_2(\text{g}) + \frac{3}{2} \text{H}_2(\text{g}) \rightarrow \text{NH}_3(\text{g})$
  - $\text{NH}_2^-(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{NH}_3(\text{g})$
- Q10. Which pair of chemical equations, when coupled (added), give rise to a spontaneous reaction?
- $\text{A} \rightarrow \text{B} \quad \Delta G^\circ = -20 \text{ kJ}$**
  - $\text{B} \rightarrow \text{C} \quad \Delta G^\circ = +25 \text{ kJ}$**
  - $\text{A} \rightarrow \text{C} \quad \Delta G^\circ = +10 \text{ kJ}$**
  - $\text{B} \rightarrow \text{D} \quad \Delta G^\circ = -15 \text{ kJ}$**
- (ii) & (iii)
  - (ii) & (iv)
  - (i) & (ii)
  - (i) & (iii)
- Q11. Which of the following half-reactions is properly balanced?
- $\text{Br}_2(\text{l}) \rightarrow 2\text{Br}^-(\text{aq})$
  - $2\text{H}^+(\text{aq}) + \text{e}^- + \text{IO}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \frac{1}{2} \text{I}_2(\text{s})$
  - $2\text{e}^- + 2\text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g})$
  - $2\text{e}^- + \text{H}^+(\text{aq}) + \text{Pb}(\text{OH})_3^+ \rightarrow \text{Pb}(\text{OH})_2 + \text{H}_2\text{O}(\text{l})$
- Q12. Where does reduction take place in a voltaic (galvanic) cell?
- The salt bridge
  - The voltmeter
  - The cathode
  - The anode
- Q13. Given the following two electrode potentials:
- $$\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu} \quad E^\circ = +0.34 \text{ V}$$
- $$\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn} \quad E^\circ = -0.76 \text{ V}$$
- The best reducing agent would be:
- $\text{Cu}^{2+}$
  - $\text{Cu}$
  - $\text{Zn}^{2+}$
  - $\text{Zn}$

Q14. What is the cell reaction for the voltaic cell:



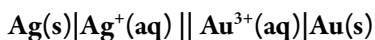
- A)  $2\text{Cr(s)} + 2\text{Cr}^{3+}(\text{aq}) \rightarrow 3\text{Mg}^{2+}(\text{aq}) + 3\text{Mg(s)}$
- B)  $2\text{Cr(s)} + 3\text{Mg}^{2+}(\text{aq}) \rightarrow 2\text{Cr}^{3+}(\text{aq}) + 3\text{Mg(s)}$
- C)  $2\text{Cr}^{3+}(\text{aq}) + 3\text{Mg(s)} \rightarrow 2\text{Cr(s)} + 3\text{Mg}^{2+}(\text{aq})$
- D)  $3\text{Mg}^{2+}(\text{aq}) + 2\text{Cr}^{3+}(\text{aq}) \rightarrow 3\text{Mg(s)} + 2\text{Cr(s)}$

Q15. Which of the following statements is true about a voltaic (galvanic) cell that has an  $E^\circ$  value of  $-0.50\text{ V}$ ?

- (i) **The reaction is spontaneous**
- (ii)  **$K > 1$**
- (iii)  **$\Delta G^\circ > 0$**

- A) (i) & (ii)
- B) (iii) only
- C) (ii) & (iii)
- D) (i) only

Q16. How would  $E_{\text{cell}}$  change if the concentration of  $\text{Ag}^+(\text{aq})$  was **increased** in the following voltaic (galvanic) cell?



- A) It would increase
- B) It would not change
- C) It would decrease
- D) There is not enough information to decide

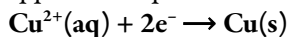
Q17. The reaction  $\text{MgCl}_2 \rightarrow \text{Mg} + \text{Cl}_2$  has a cell potential ( $E_{\text{cell}}$ ) of  $-3.5\text{ V}$ . This means that:

- A) The reaction is spontaneous and will produce  $3.5\text{ V}$  in a cell
- B) The reaction is non-spontaneous, and will produce  $3.5\text{ V}$  in a cell
- C) The reaction can be driven by applying a voltage of  $> 3.5\text{ V}$
- D) The reaction is spontaneous, but can be stopped by applying a voltage of  $< -3.5\text{ V}$

Q18. How many moles of electrons are produced when  $12.0\text{ A}$  flows for  $24.0\text{ min}$ ?

- A)  $288\text{ mol}$
- B)  $5.58\text{ mol}$
- C)  $0.500\text{ mol}$
- D)  $0.179\text{ mol}$

Q19. Copper can be plated out of a solution containing  $\text{Cu}^{2+}$  according to the half-reaction:



What mass of copper is formed when  $15.0\text{ A}$  of current flows for  $10.0\text{ min}$ ?

- A)  $2.96\text{ g}$
- B)  $5.92\text{ g}$
- C)  $8.15\text{ g}$
- D)  $12.6\text{ g}$

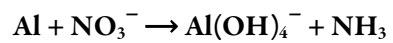
Q20. Which electrode is assigned a standard electrode potential of  $0.00\text{ V}$ ?

- A) The standard hydrogen electrode
- B) The standard pH electrode
- C) The standard acidic electrode
- D) The standard platinum electrode

**Short Response.**

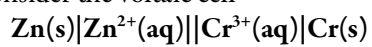
Show ALL work to receive credit.

Q21. [12 pts.] Using the half-reaction method, balance the following redox reaction that occurs in **basic** solution:



Be sure to identify oxidation states of each atom as part of your answer. Clearly indicate whether each half-reaction is an oxidation or reduction process.

Q22. [13 pts.] Consider the voltaic cell



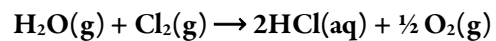
(i) Write the half-cell reactions and the overall cell reaction.

(ii) Make a sketch of this voltaic cell and label it. At a minimum, be sure to include labels showing the anode, cathode, and direction of electron flow.

(iii) Calculate  $E_{\text{cell}}^{\circ}$ .

(iv) What is  $E_{\text{cell}}$  if  $[\text{Zn}^{2+}] = [\text{Cr}^{3+}] = 0.10 \text{ M}$ ? Assume a temperature of 298 K.

Q23. [12 pts.] For the chemical reaction:



(i) Calculate  $\Delta H^\circ$ ,  $\Delta S^\circ$ , and  $\Delta G^\circ$  at 25 °C.

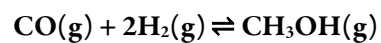
*(Hint: be sure to look at the data table at the bottom of this question!)*

(ii) Use this information to calculate the equilibrium constant at 25 °C.

(iii) Predict how the spontaneity of this reaction will change (if at all!) at low vs. high temperature.  
Be sure to explain your answer!

Substance	$\Delta H_f^\circ$ (kJ/mol)	$S^\circ$ (J/mol·K)
H <sub>2</sub> O(g)	-241.8	188.8
Cl <sub>2</sub> (g)	0	223.1
HCl(aq)	-167.2	56.5
O <sub>2</sub> (g)	0	205.2

Q24. [13 pts.] Consider the reaction:



Calculate  $\Delta G_{\text{rxn}}$  at 25 °C under each of the following conditions:  
(Hint: be sure to look at the data table at the bottom of this question!)

i) standard conditions

ii) at equilibrium

iii) under conditions of  $p_{\text{CH}_3\text{OH}} = 1.5 \text{ atm}$ , and  $p_{\text{CO}} = p_{\text{H}_2} = 0.020 \text{ atm}$ .

Substance	$\Delta G_f^\circ$ (kJ/mol)
CH <sub>3</sub> OH(g)	-162.3
H <sub>2</sub> (g)	0
CO(g)	-137.2





Periodic Table of the Elements

IA		IIA												IIIA	IVA	VA	VIA	VIIA	VIIIA												
1 <b>H</b> 1.008																		2 <b>He</b> 4.003													
3 <b>Li</b> 6.941	4 <b>Be</b> 9.012											5 <b>B</b> 10.81	6 <b>C</b> 12.01	7 <b>N</b> 14.01	8 <b>O</b> 16.00	9 <b>F</b> 19.00	10 <b>Ne</b> 20.18														
11 <b>Na</b> 22.99	12 <b>Mg</b> 24.31											13 <b>Al</b> 26.98	14 <b>Si</b> 28.09	15 <b>P</b> 30.97	16 <b>S</b> 32.07	17 <b>Cl</b> 35.45	18 <b>Ar</b> 39.95														
19 <b>K</b> 39.10	20 <b>Ca</b> 40.08	21 <b>Sc</b> 44.96	22 <b>Ti</b> 47.87	23 <b>V</b> 50.94	24 <b>Cr</b> 52.00	25 <b>Mn</b> 54.94	26 <b>Fe</b> 55.85	27 <b>Co</b> 58.93	28 <b>Ni</b> 58.69	29 <b>Cu</b> 63.55	30 <b>Zn</b> 65.39	31 <b>Ga</b> 69.72	32 <b>Ge</b> 72.61	33 <b>As</b> 74.92160	34 <b>Se</b> 78.96	35 <b>Br</b> 79.90	36 <b>Kr</b> 83.80														
37 <b>Rb</b> 85.47	38 <b>Sr</b> 87.62	39 <b>Y</b> 88.91	40 <b>Zr</b> 91.22	41 <b>Nb</b> 92.91	42 <b>Mo</b> 95.94	43 <b>Tc</b> [98]	44 <b>Ru</b> 101.1	45 <b>Rh</b> 102.9	46 <b>Pd</b> 106.4	47 <b>Ag</b> 107.9	48 <b>Cd</b> 112.4	49 <b>In</b> 114.8	50 <b>Sn</b> 118.7	51 <b>Sb</b> 121.8	52 <b>Te</b> 127.60	53 <b>I</b> 126.9	54 <b>Xe</b> 131.3														
55 <b>Cs</b> 132.9	56 <b>Ba*</b> 137.3	57 <b>Lu</b> 175.0	58 <b>Hf</b> 178.5	59 <b>Ta</b> 180.9	60 <b>W</b> 183.8	61 <b>Re</b> 186.2	62 <b>Os</b> 190.2	63 <b>Ir</b> 192.2	64 <b>Pt</b> 195.1	65 <b>Au</b> 197.0	66 <b>Hg</b> 200.6	67 <b>Tl</b> 204.4	68 <b>Pb</b> 207.2	69 <b>Bi</b> 209.0	70 <b>Po</b> [210]	71 <b>At</b> [210]	72 <b>Rn</b> [222]														
87 <b>Fr</b> [223]	88 <b>Ra**</b> [226]	89 <b>Lr</b> [262]	90 <b>Rf</b> [261]	91 <b>Db</b> [262]	92 <b>Sg</b> [266]	93 <b>Bh</b> [264]	94 <b>Hs</b> [265]	95 <b>Mt</b> [268]	96 <b>[269]</b>	97 <b>[272]</b>	98 <b>[277]</b>	99 <b>[285]</b>	100 <b>[285]</b>	101 <b>[289]</b>	102 <b>[289]</b>	103 <b>[293]</b>	104 <b>[293]</b>														
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$$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$$

$$R = 8.3145 \frac{\text{J}}{\text{mol} \cdot \text{K}} = 0.08206 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}}$$

$$M_1 V_1 = M_2 V_2$$

$$\Delta G = -nFE_{\text{cell}}$$

$$\Delta G^\circ = -nFE_{\text{cell}}^\circ$$

$$E_{\text{cell}}^\circ = \frac{RT}{nF} \ln K$$

$$E_{\text{cell}} = E_{\text{cell}}^\circ - \frac{RT}{nF} \ln Q$$

$$E_{\text{cell}}^\circ = E_{\text{cathode}}^\circ - E_{\text{anode}}^\circ$$

$$F = 96,500 \text{ C/mol } e^- \quad 1 \text{ V} = 1 \text{ J/C}$$

$$R = 8.3145 \text{ J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$$

$$Q (\text{charge}) = I \cdot t$$

$$\Delta G = \Delta H - T\Delta S$$

$$\Delta S_{\text{surr}} = q_{\text{surr}}/T$$

$$\Delta G = \Delta G^\circ + RT \ln Q$$

$$\Delta G^\circ = -RT \ln K$$

## Standard reduction potentials

Ion		$E^\circ(\text{V})$
$\text{F}_2(\text{g}) + 2 \text{e}^-$	$\longrightarrow 2 \text{F}^-(\text{aq})$	2.87
$\text{H}_2\text{O}_2(\text{aq}) + 2 \text{H}^+(\text{aq}) + 2 \text{e}^-$	$\longrightarrow 2 \text{H}_2\text{O}(\text{l})$	1.78
$\text{PbO}_2(\text{s}) + 4 \text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{PbSO}_4(\text{s}) + 2 \text{H}_2\text{O}(\text{l})$	1.69
$\text{MnO}_4^-(\text{aq}) + 4 \text{H}^+(\text{aq}) + 3 \text{e}^-$	$\longrightarrow \text{MnO}_2(\text{s}) + 2 \text{H}_2\text{O}(\text{l})$	1.68
$\text{MnO}_4^-(\text{aq}) + 8 \text{H}^+(\text{aq}) + 5 \text{e}^-$	$\longrightarrow \text{Mn}^{2+}(\text{aq}) + 4 \text{H}_2\text{O}(\text{l})$	1.51
$\text{Au}^{3+}(\text{aq}) + 3 \text{e}^-$	$\longrightarrow \text{Au}(\text{s})$	1.50
$\text{PbO}_2(\text{s}) + 4 \text{H}^+(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Pb}^{2+}(\text{aq}) + 2 \text{H}_2\text{O}(\text{l})$	1.46
$\text{Cl}_2(\text{g}) + 2 \text{e}^-$	$\longrightarrow 2 \text{Cl}^-(\text{aq})$	1.36
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14 \text{H}^+(\text{aq}) + 6 \text{e}^-$	$\longrightarrow 2 \text{Cr}^{3+}(\text{aq}) + 7 \text{H}_2\text{O}(\text{l})$	1.33
$\text{O}_2(\text{g}) + 4 \text{H}^+(\text{aq}) + 4 \text{e}^-$	$\longrightarrow 2 \text{H}_2\text{O}(\text{l})$	1.23
$\text{MnO}_2(\text{s}) + 4 \text{H}^+(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Mn}^{2+}(\text{aq}) + 2 \text{H}_2\text{O}(\text{l})$	1.21
$\text{IO}_3^-(\text{aq}) + 6 \text{H}^+(\text{aq}) + 5 \text{e}^-$	$\longrightarrow \frac{1}{2} \text{I}_2(\text{aq}) + 3 \text{H}_2\text{O}(\text{l})$	1.20
$\text{Br}_2(\text{l}) + 2 \text{e}^-$	$\longrightarrow 2 \text{Br}^-(\text{aq})$	1.09
$\text{VO}_2^+(\text{aq}) + 2 \text{H}^+(\text{aq}) + \text{e}^-$	$\longrightarrow \text{VO}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	1.00
$\text{NO}_3^-(\text{aq}) + 4 \text{H}^+(\text{aq}) + 3 \text{e}^-$	$\longrightarrow \text{NO}(\text{g}) + 2 \text{H}_2\text{O}(\text{l})$	0.96
$\text{ClO}_2(\text{g}) + \text{e}^-$	$\longrightarrow \text{ClO}_2^-(\text{aq})$	0.95
$\text{Ag}^+(\text{aq}) + \text{e}^-$	$\longrightarrow \text{Ag}(\text{s})$	0.80
$\text{Fe}^{3+}(\text{aq}) + \text{e}^-$	$\longrightarrow \text{Fe}^{2+}(\text{aq})$	0.77
$\text{O}_2(\text{g}) + 2 \text{H}^+(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{H}_2\text{O}_2(\text{aq})$	0.70
$\text{MnO}_4^-(\text{aq}) + \text{e}^-$	$\longrightarrow \text{MnO}_4^{2-}(\text{aq})$	0.56
$\text{I}_2(\text{s}) + 2 \text{e}^-$	$\longrightarrow 2 \text{I}^-(\text{aq})$	0.54
$\text{Cu}^+(\text{aq}) + \text{e}^-$	$\longrightarrow \text{Cu}(\text{s})$	0.52
$\text{O}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l}) + 4 \text{e}^-$	$\longrightarrow 4 \text{OH}^-(\text{aq})$	0.40
$\text{Cu}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Cu}(\text{s})$	0.34
$\text{SO}_4^{2-}(\text{aq}) + 4 \text{H}^+(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{H}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$	0.20
$\text{Cu}^{2+}(\text{aq}) + \text{e}^-$	$\longrightarrow \text{Cu}^+(\text{aq})$	0.16
$\text{Sn}^{4+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Sn}^{2+}(\text{aq})$	0.15
$2 \text{H}^+(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{H}_2(\text{g})$	0
$\text{Fe}^{3+}(\text{aq}) + 3 \text{e}^-$	$\longrightarrow \text{Fe}(\text{s})$	-0.036
$\text{Pb}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Ni}(\text{s})$	-0.23
$\text{Cd}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Cd}(\text{s})$	-0.40
$\text{Fe}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Fe}(\text{s})$	-0.45
$\text{Cr}^{3+}(\text{aq}) + \text{e}^-$	$\longrightarrow \text{Cr}^{2+}(\text{aq})$	-0.50
$\text{Cr}^{3+}(\text{aq}) + 3 \text{e}^-$	$\longrightarrow \text{Cr}(\text{s})$	-0.73
$\text{Zn}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Zn}(\text{s})$	-0.76
$2 \text{H}_2\text{O}(\text{l}) + 2 \text{e}^-$	$\longrightarrow \text{H}_2(\text{g}) + 2 \text{OH}^-(\text{aq})$	-0.83
$\text{Mn}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Mn}(\text{s})$	-1.18
$\text{Al}^{3+}(\text{aq}) + 3 \text{e}^-$	$\longrightarrow \text{Al}(\text{s})$	-1.66
$\text{Mg}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Mg}(\text{s})$	-2.37
$\text{Na}^+(\text{aq}) + \text{e}^-$	$\longrightarrow \text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Ca}(\text{s})$	-2.76
$\text{Ba}^{2+}(\text{aq}) + 2 \text{e}^-$	$\longrightarrow \text{Ba}(\text{s})$	-2.90
$\text{K}^+(\text{aq}) + \text{e}^-$	$\longrightarrow \text{K}(\text{s})$	-2.92
$\text{Li}^+(\text{aq}) + \text{e}^-$	$\longrightarrow \text{Li}(\text{s})$	-3.04