

# Chemistry 210

# Exam 4

Be sure to put your name on each page. This page can be removed from your exam so that you will have a Periodic Table handy throughout the exam, it does not need to be turned in. Show all your work for problems which require any sort of calculation, no credit will be given for answers without work shown. If you have shown a significant amount of work or multiple drawings for a problem, draw a box around what you consider your final answer.

Avogadro's Number =  $6.022 \times 10^{23}$  units/mol

$32.00^\circ\text{F} = 0.000^\circ\text{C} = 273.15\text{K}$

Density of Water =  $1.000^{\text{g}}/\text{mL}$

$R = 0.08206 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K} = 8.314 \text{ J}/\text{mol}\cdot\text{K}$

$PV = nRT$

$\Delta T_{\text{fp/bp}} = k_{\text{fp/bp}} \cdot m \cdot i$

For water,  $k_{\text{fp}} = -1.86^\circ\text{C}/m$ ;  $k_{\text{bp}} = 0.52^\circ\text{C}/m$

$P_1 = X_1 P_1^\circ$

$\Pi = MRTi$

$C_1 V_1 = C_2 V_2$

Quadratic formula:

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

Integrated Rate Laws:

0<sup>th</sup> order  $[A]_t = -kt + [A]_o$

1<sup>st</sup> order  $\ln[A]_t = -kt + \ln[A]_o$

2<sup>nd</sup> order  $1/[A]_t = kt + 1/[A]_o$

$k = Ae^{-E_a/RT}$

$$\ln(k) = \left( \frac{-E_a}{R} \right) \left( \frac{1}{T} \right) + \ln(A)$$

$$\ln\left( \frac{k_1}{k_2} \right) = \frac{E_a}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)$$

$$\text{pH} = \text{pK}_a + \log\left( \frac{[\text{conjugate base}]}{[\text{conjugate acid}]} \right)$$

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

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

$K^\circ = e^{(nF/RT) E^\circ_{\text{cell}}}$

$F = 96485 \text{ J}/\text{V}\cdot\text{mol of electrons}$

$\Delta G^\circ = \Delta H^\circ_{\text{system}} - T\Delta S^\circ_{\text{system}}$

$\Delta G^\circ = -nFE^\circ_{\text{cell}} = -RT \ln K^\circ$

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

$F = 96485 \text{ C}/\text{mol electrons}$

$1A = 1 \text{ C} / \text{sec}$

1 <b>H</b> 1.0079																2 <b>He</b> 4.0026	
3 <b>Li</b> 6.941	4 <b>Be</b> 9.0122											5 <b>B</b> 10.811	6 <b>C</b> 12.011	7 <b>N</b> 14.007	8 <b>O</b> 15.999	9 <b>F</b> 18.998	10 <b>Ne</b> 20.180
11 <b>Na</b> 22.990	12 <b>Mg</b> 24.305											13 <b>Al</b> 26.982	14 <b>Si</b> 28.086	15 <b>P</b> 30.974	16 <b>S</b> 32.066	17 <b>Cl</b> 35.453	18 <b>Ar</b> 39.948
19 <b>K</b> 39.098	20 <b>Ca</b> 40.078	21 <b>Sc</b> 44.956	22 <b>Ti</b> 47.88	23 <b>V</b> 50.942	24 <b>Cr</b> 51.996	25 <b>Mn</b> 54.938	26 <b>Fe</b> 55.847	27 <b>Co</b> 58.933	28 <b>Ni</b> 58.69	29 <b>Cu</b> 63.546	30 <b>Zn</b> 65.39	31 <b>Ga</b> 69.723	32 <b>Ge</b> 72.61	33 <b>As</b> 74.922	34 <b>Se</b> 78.96	35 <b>Br</b> 79.904	36 <b>Kr</b> 83.80
37 <b>Rb</b> 85.468	38 <b>Sr</b> 87.62	39 <b>Y</b> 88.906	40 <b>Zr</b> 91.224	41 <b>Nb</b> 92.906	42 <b>Mo</b> 95.94	43 <b>Tc</b> (98)	44 <b>Ru</b> 101.07	45 <b>Rh</b> 102.91	46 <b>Pd</b> 106.42	47 <b>Ag</b> 107.87	48 <b>Cd</b> 112.41	49 <b>In</b> 114.82	50 <b>Sn</b> 118.71	51 <b>Sb</b> 121.76	52 <b>Te</b> 127.60	53 <b>I</b> 126.90	54 <b>Xe</b> 131.29
55 <b>Cs</b> 132.91	56 <b>Ba</b> 137.33	57 <b>La</b> 138.91	72 <b>Hf</b> 178.49	73 <b>Ta</b> 180.95	74 <b>W</b> 183.84	75 <b>Re</b> 186.21	76 <b>Os</b> 190.23	77 <b>Ir</b> 192.22	78 <b>Pt</b> 195.08	79 <b>Au</b> 196.97	80 <b>Hg</b> 200.59	81 <b>Tl</b> 204.38	82 <b>Pb</b> 207.2	83 <b>Bi</b> 208.98	84 <b>Po</b> (209)	85 <b>At</b> (210)	86 <b>Rn</b> (222)
87 <b>Fr</b> (223)	88 <b>Ra</b> 226.03	89 <b>Ac</b> 227.03	104 <b>Rf</b> (261)	105 <b>Db</b> (262)	106 <b>Sg</b> (263)	107 <b>Bh</b> (262)	108 <b>Hs</b> (265)	109 <b>Mt</b> (266)	110 (269)	111 (272)	112 (277)		114		116		

58 <b>Ce</b> 140.12	59 <b>Pr</b> 140.91	60 <b>Nd</b> 144.24	61 <b>Pm</b> (145)	62 <b>Sm</b> 150.36	63 <b>Eu</b> 151.97	64 <b>Gd</b> 157.25	65 <b>Tb</b> 158.93	66 <b>Dy</b> 162.50	67 <b>Ho</b> 164.93	68 <b>Er</b> 167.26	69 <b>Tm</b> 168.94	70 <b>Yb</b> 173.04	71 <b>Lu</b> 174.97
90 <b>Th</b> 232.04	91 <b>Pa</b> 231.04	92 <b>U</b> 238.03	93 <b>Np</b> 237.05	94 <b>Pu</b> (244)	95 <b>Am</b> (243)	96 <b>Cm</b> (247)	97 <b>Bk</b> (247)	98 <b>Cf</b> (251)	99 <b>Es</b> (252)	100 <b>Fm</b> (258)	101 <b>Md</b> (258)	102 <b>No</b> (259)	103 <b>Lr</b> (260)

**Multiple Choice (5pts each):** Circle the letter of the most correct response.

- A large negative change in free energy means:
  - The reaction is very slow
  - The reaction is exothermic
  - The reaction is not spontaneous
  - The system is becoming more disordered
  - The reaction is spontaneous**
- For a reaction with a small negative  $\Delta S$ :
  - Heat is liberated by the reaction
  - The system is becoming more ordered**
  - The reaction is not spontaneous
  - The disorder of the system is increasing
  - The reaction proceeds very quickly
- If the change in enthalpy for a reaction is positive and the change in entropy is negative:
  - The system is becoming more disordered
  - The reaction releases heat
  - The reaction will be spontaneous at all temperatures
  - The reaction will be non-spontaneous at all temperatures**
  - The reaction will be spontaneous only at low temperatures
- A reaction will be product-favored/spontaneous if:
  - $\Delta G < 0$**
  - $\Delta S > 0$
  - $K_{eq} < 1$
  - $\Delta H > 0$
  - $\Delta S < 0$
- How are the change in Gibb's Free Energy and the equilibrium constant for a reaction related?
  - As K approaches zero,  $\Delta G$  approaches zero
  - The value of  $\Delta G$  is equal to  $(-\log K)$
  - As  $\Delta G$  gets more positive, K approaches 1
  - They're not.
  - As  $\Delta G$  gets more negative, K gets very large**

6. Give the oxidation number for each atom in the following formulas. (5pts each formula)



K  $\rightarrow$  +1  
S  $\rightarrow$  +4  
O  $\rightarrow$  -2

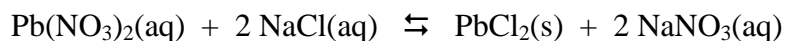


C  $\rightarrow$  +4  
O  $\rightarrow$  -2

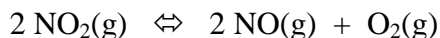


C  $\rightarrow$  -4  
H  $\rightarrow$  +1

7. For each of the following reactions, predict whether the sign of  $\Delta S^\circ$  will be positive or negative and explain your answer. (12pts)



Negative. Aqueous solutions are forming a solid so the disorder of the system is decreasing.



Positive. Two gas particles are forming three gas particles so the system is becoming more disordered.

8. For liquid water  $S^\circ = +69.91 \text{ J/mol}\cdot\text{K}$  and for gaseous water  $S^\circ = +188.825 \text{ J/mol}\cdot\text{K}$ . Explain this difference. (10pts)

Gases are more disordered than liquids {for the same substance}.  $S^\circ$  is a measure of the disorder of a system or substance, so the value of  $S^\circ$  for gaseous water should be higher than the value of  $S^\circ$  for liquid water.

9. Methane,  $\text{CH}_4(\text{g})$ , burns in oxygen to form carbon dioxide and water. How much energy is released during the formation of 21.95g of water by this reaction? (20pts)

$$\begin{aligned} & \text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightleftharpoons \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g}) \\ \Delta G^\circ_{\text{rxn}} &= 1(50.8 \text{ kJ/mol}) + 2(0 \text{ kJ/mol}) + 1(-394.359 \text{ kJ/mol}) + 2(-228.572 \text{ kJ/mol}) = -800.7 \text{ kJ/mol} \\ E &= (21.95 \text{ g H}_2\text{O}(\text{g})) (1 \text{ mol H}_2\text{O} / 18.015 \text{ g H}_2\text{O}) (1 \text{ mol rxn} / 2 \text{ mol H}_2\text{O}) (800.7 \text{ kJ} / \text{mol rxn}) = 487.8 \text{ kJ} \end{aligned}$$

$$\begin{aligned} & \text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightleftharpoons \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l}) \\ \Delta G^\circ_{\text{rxn}} &= 1(50.8 \text{ kJ/mol}) + 2(0 \text{ kJ/mol}) + 1(-394.359 \text{ kJ/mol}) + 2(-237.129 \text{ kJ/mol}) = -817.8 \text{ kJ/mol} \\ E &= (21.95 \text{ g H}_2\text{O}(\text{l})) (1 \text{ mol H}_2\text{O} / 18.015 \text{ g H}_2\text{O}) (1 \text{ mol rxn} / 2 \text{ mol H}_2\text{O}) (817.8 \text{ kJ} / \text{mol rxn}) = 498.2 \text{ kJ} \end{aligned}$$

10. You are studying the reaction of benzoic acid  $\{\text{C}_6\text{H}_5\text{CO}_2\text{H}(\text{s})\}$  with methanol  $\{\text{CH}_3\text{OH}(\text{l})\}$  to produce methylbenzoate  $\{\text{C}_8\text{H}_8\text{O}_2(\text{l})\}$  and water. When you run the reaction at  $17.61^\circ\text{C}$ , you find that  $\Delta G$  for this reaction is  $-47.92 \text{ kJ/mol}$  and  $\Delta S = +34.18 \text{ J/mol}\cdot\text{K}$ . (20pts)

- a. Is the reaction endothermic or exothermic? (Explain your answer with explicit calculations.)  
b. Over what temperature range is this reaction spontaneous?

We could write a balanced equation for this problem, but we don't need one. We can just plug into

$$\begin{aligned} \Delta G &= \Delta H - T\Delta S \\ (-47.92 \text{ kJ/mol}) &= \Delta H - (17.61 + 273.15 \text{ K})(0.03418 \text{ kJ/mol}\cdot\text{K}) \\ \Delta H &= -37.98 \text{ kJ/mol} \rightarrow \text{exothermic} \end{aligned}$$

Since  $\Delta H$  is negative and  $\Delta S$  is positive, this reaction will be spontaneous at all temperatures.

11. You have burned 65.95g of ethane {C<sub>2</sub>H<sub>6</sub>(g)} in oxygen to form carbon dioxide and water. If all of the Gibb's Free Energy liberated by this reaction is used to decompose iron(III) chloride to iron metal and chlorine gas, how many grams of iron metal will be formed? (25pts)

$$2 \text{C}_2\text{H}_6(\text{g}) + 7 \text{O}_2(\text{g}) \rightleftharpoons 4 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{g})$$

$$\Delta G^\circ_{\text{rxn}} = 2(32.89^{\text{kJ/mol}}) + 7(0^{\text{kJ/mol}}) + 4(-394.359^{\text{kJ/mol}}) + 6(-228.572^{\text{kJ/mol}}) = -2883.09^{\text{kJ/mol}}$$

$$E = (65.95\text{g C}_2\text{H}_6(\text{g})) (1\text{mol C}_2\text{H}_6 / 30.069\text{g C}_2\text{H}_6) (1\text{mol rxn} / 2\text{mol C}_2\text{H}_6) (2883.09\text{kJ} / \text{mol rxn}) = 3161.7\text{kJ}$$

$$2 \text{C}_2\text{H}_6(\text{g}) + 7 \text{O}_2(\text{g}) \rightleftharpoons 4 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{l})$$

$$\Delta G^\circ_{\text{rxn}} = 2(32.89^{\text{kJ/mol}}) + 7(0^{\text{kJ/mol}}) + 4(-394.359^{\text{kJ/mol}}) + 6(-237.129^{\text{kJ/mol}}) = -2934.43^{\text{kJ/mol}}$$

$$E = (65.95\text{g C}_2\text{H}_6(\text{g})) (1\text{mol C}_2\text{H}_6 / 30.069\text{g C}_2\text{H}_6) (1\text{mol rxn} / 2\text{mol C}_2\text{H}_6) (2934.43\text{kJ} / \text{mol rxn}) = 3218.0\text{kJ}$$

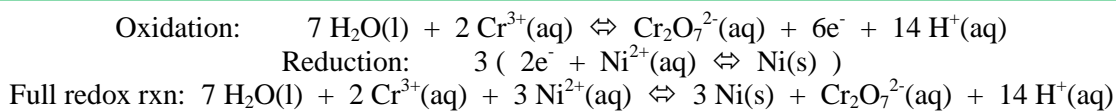
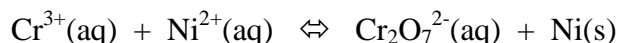
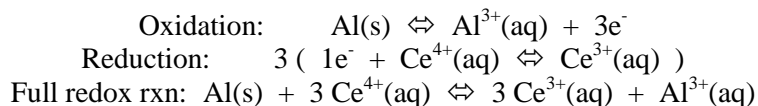
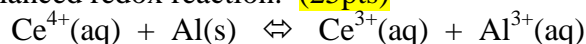
$$2 \text{FeCl}_3(\text{s}) \rightleftharpoons 2 \text{Fe}(\text{s}) + 3 \text{Cl}_2(\text{g})$$

$$\Delta G^\circ_{\text{rxn}} = 2(334.18^{\text{kJ/mol}}) + 2(0^{\text{kJ/mol}}) + 3(0^{\text{kJ/mol}}) = 668.36^{\text{kJ/mol}}$$

$$\text{g Fe}(\text{s}) = (3161.8\text{kJ}) (1\text{mol rxn} / 668.36\text{kJ}) (2\text{mol Fe}(\text{s}) / 1\text{mol rxn}) (55.847\text{g Fe} / 1\text{mol Fe}) = 528.4\text{g Fe}(\text{s})$$

$$\text{g Fe}(\text{s}) = (3218.0\text{kJ}) (1\text{mol rxn} / 668.36\text{kJ}) (2\text{mol Fe}(\text{s}) / 1\text{mol rxn}) (55.847\text{g Fe} / 1\text{mol Fe}) = 537.8\text{g Fe}(\text{s})$$

12. For each of the following **unbalanced** chemical reactions, identify and write the oxidation and reduction half-reactions, and write the balanced redox reaction. (25pts)



**Thermodynamic Values at 25°C:**

Substance	$\Delta H^\circ_f$ (kJ/mol)	$S^\circ$ (J/mol·K)	$\Delta G^\circ_f$ (kJ/mol)
CH <sub>4</sub> (g)	-74.8	186.3	-50.8
O <sub>2</sub> (g)	0	205.138	0
CO <sub>2</sub> (g)	-393.509	213.74	-394.359
H <sub>2</sub> O(l)	-285.83	69.91	-237.129
H <sub>2</sub> O(g)	-241.818	188.825	-228.572
C <sub>2</sub> H <sub>6</sub> (g)	-84.68	229.5	-32.89
FeCl <sub>3</sub> (s)	-400.39	142.3	-334.18
Fe(s)	0	27.15	0
Cl <sub>2</sub> (g)	0	222.96	0