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 = 6.022×10^{23} $^{units}/_{l}$
$32.00^oF = 0.000^oC = 273.15K$
Density of Water = $1.000^{g}/_{mL}$
$R = 0.08206\ ^{L\bullet atm}/_{mol\bullet K} = 8.314\ ^{J}/_{mol\bullet K}$
$PV=nRT$
$\Delta T_{fp/bp} = k_{fp/bp}\bullet m\bullet i$
For water, $k_{fp} = -1.86\,^{^oC}/_{m}$; $k_{bp} = 0.52\,^{^oC}/_{m}$
$P_1 = X_1P_1^o$
$P = cRTi$
$C_1V_1 = C_2V_2$
Quadratic formula:

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

Integrated Rate Laws:

$$\ln[A]_t = -kt + \ln[A]_o$$
$$1/[A]_t = kt + 1/[A]_o$$
$$[A]_t = -kt + [A]_o$$

$$k = Ae^{-Ea/RT}$$
$$\ln(k) = \left(\frac{-E_a}{R}\right)\left(\frac{1}{T}\right) + \ln(A)$$
$$\ln\left(\frac{k_1}{k_2}\right) = \frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$
$$pH = pK_a + \log\left(\frac{[\text{conjugate base}]}{[\text{conjugate acid}]}\right)$$

$E_{cell} = E^o_{cell} - {}^{RT}/_{nF}\ lnQ$
$E^o_{cell} = {}^{RT}/_{nF}\ lnK^o$
$K^o = e^\wedge({}^{nF}/_{RT}\ E^o_{cell})$
$F = 96485\ ^{J}/_{V\bullet mol\ of\ electrons}$
$\Delta G^o = \Delta H^o_{system} - T\Delta S^o_{system}$
$\Delta G^o = -nFE^o_{cell} = -RTlnK^o$
$\Delta G = \Delta G^o + RTlnQ$
$F = 96485\ ^{C}/_{mol\ electrons}$
$1A = 1\ C / sec$

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

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

Score

Multiple Choice (5pts each)

1. A reaction will likely be reactant-favored/non-spontaneous/not naturally occurring if:
   a. **$\Delta G^o > 0$**
   b. $K_{eq} > 1$
   c. $\Delta H < 0$
   d. $\Delta S^o > 0$
   e. $K_{eq} < 0$

2. For which of the following reactions would you expect ΔS^o_{system} to be negative?
   a. $H_2CO_3(aq) \leftrightarrows H_2O(l) + CO_2(g)$
   b. **$3H_2(g) + N_2(g) \leftrightarrows 2NH_3(g)$**
   c. $BaSO_4(s) \leftrightarrows Ba^{2+}(aq) + SO_4^{2-}(aq)$
   d. $H_2O(l) \leftrightarrows H_2O(g)$
   e. $C_2H_4(l) + 3\ O_2(g) \leftrightarrows 2\ CO_2(g) + 2\ H_2O(g)$

3. A reaction will be non-spontaneous at all temperature if:
   a. $\Delta H^o_{system} > 0$ and $\Delta S^o_{system} > 0$
   b. $\Delta H^o_{system} = 0$ and $\Delta S^o_{system} > 0$
   c. **$\Delta H^o_{system} > 0$ and $\Delta S^o_{system} = 0$**
   d. $\Delta H^o_{system} < 0$ and $\Delta S^o_{system} > 0$
   e. $\Delta H^o_{system} < 0$ and $\Delta S^o_{system} < 0$

4. The symbol ΔH represents:
   a. Change in entropy
   b. Change in height
   c. **Change in enthalpy**
   d. Change in free energy
   e. Change in time

5. A large positive change in free energy means:
   a. The reaction is very slow
   b. The reaction is endothermic
   c. **The reaction is not spontaneous**
   d. The system is becoming more disordered
   e. The reaction is spontaneous

6. For a reaction with a large positive ΔS:
   a. Heat is required to make the reaction proceed
   b. The system is becoming much more ordered
   c. The reaction is not spontaneous
   d. **The disorder of the system is increasing**
   e. The reaction proceeds very slowly

Score

7. If the change in enthalpy for a reaction is negative and the change in entropy is positive:
   a. The reaction requires heat
   b. The reaction will never be spontaneous
   c. The system is becoming more ordered
   d. The reaction will always be spontaneous
   e. The reaction will be spontaneous only at high temperatures

8. How are the change in Gibb's Free Energy and the equilibrium constant for a reaction related?
   a. As K approaches zero, ΔG approaches zero
   b. They're not.
   c. The value of ΔG is equal to (-logK)
   d. As ΔG gets more positive, K approaches 1
   e. As ΔG gets more negative, K gets very large

9. Predict the sign of the change in entropy for each of the following reactions (3pts each):

Reaction	**Sign of ΔS^o_{rxn}**
$2\ CH_3OH(l)\ +\ 3\ O_2(g) \rightarrow 2\ CO_2(g)\ +\ 4\ H_2O(g)$	+ **or** -
$Mg(s) + F_2(g) \rightarrow MgF_2(s)$	+ **or** -
$H_2(g)\ +\ Br_2(l) \rightarrow 2\ HBr(g)$	+ **or** -

10. You react Compounds A and B to yield Compounds C and D. The temperature in your laboratory is 20.36ºC and you find that ΔG for this reaction is –6.394 $^{kJ}/_{mol}$. You have also determined that for this reaction ΔS = 186.9 $^{J}/_{mol\cdot K}$ (12pts)
    a. Is the reaction endothermic or exothermic? (*Explain your answer with explicit calculations.*)

$$\Delta G_{rxn} = \Delta H_{rxn} - T\Delta S_{rxn}$$
$$-6.394^{kJ}/_{mol} = \Delta H_{rxn} - (293.51K)(0.1869^{kJ}/_{mol\cdot K})$$
$$\Delta H_{rxn} = +48.46^{kJ}/_{mol}$$

Since ΔH_{rxn} is positive, this reaction is endothermic

    b. Over what temperature range is this reaction spontaneous?

In essence, we're looking for the temperature at which $\Delta G = 0$. Plugging in:

$$0^{kJ}/_{mol} = (48.46^{kJ}/_{mol}) - (x)(0.1869^{kJ}/_{mol\cdot K})$$
$$x = 259.30K$$

The reaction will be spontaneous at all temperatures above 259.30K

Score

11. Calculate the following values for the ***unbalanced*** reaction listed at 25ºC. (16pts)

Reaction 1: $COCl_2(g) + H_2O(l) \leftrightarrow H_2CO_3(aq) + HCl(g)$

$$COCl_2(g) + 2\,H_2O(l) \leftrightarrow H_2CO_3(aq) + 2\,HCl(g)$$

ΔH^o_{rxn}

$$219.1\,{}^{kJ}/_{mol} + 2(285.8\,{}^{kJ}/_{mol}) + (-699.7\,{}^{kJ}/_{mol}) + 2(-92.3\,{}^{kJ}/_{mol}) = -93.6\,{}^{kJ}/_{mol}$$

ΔS^o_{rxn}

$$-283.5\,{}^{J}/_{mol\bullet K} + 2(-70.0\,{}^{J}/_{mol\bullet K}) + (187.4\,{}^{J}/_{mol\bullet K}) + 2(186.9\,{}^{J}/_{mol\bullet K}) = +137.7\,{}^{J}/_{mol\bullet K}$$

ΔG^o_{rxn}

$$204.9\,{}^{kJ}/_{mol} + 2(237.1\,{}^{kJ}/_{mol}) + (-623.2\,{}^{kJ}/_{mol}) + 2(-95.3\,{}^{kJ}/_{mol}) = -134.7\,{}^{kJ}/_{mol}$$

or

$$\Delta G^o_{rxn} = (-93.6\,{}^{kJ}/_{mol}) - (298.15K)(0.1337\,{}^{kJ}/_{mol\bullet K}) = -134.7\,{}^{kJ}/_{mol}$$

Is the reaction spontaneous? **Yes** **No**

12. Hydrazine $\{N_2H_4(g)\}$ can be used as a rocket fuel by burning with oxygen to form nitrogen dioxide and water. How much energy can be liberated by burning 21.964g of hydrazine in an unlimited supply of oxygen? (14pts)

$$N_2H_4(g) + 3\,O_2(g) \leftrightarrow 2\,NO_2(g) + 2\,H_2O(g)$$

$$\Delta G^o_{rxn} = (-159.4\,{}^{kJ}/_{mol}) + 3(0\,{}^{kJ}/_{mol}) + 2(51.31\,{}^{kJ}/_{mol}) + 2(-228.6\,{}^{kJ}/_{mol}) = -513.98\,{}^{kJ}/_{mol}$$

$$\left(513.98\,\tfrac{kJ}{mol\,rxn}\right)\left(\frac{1mol\,rxn}{1mol\,N_2H_4}\right)\left(\frac{1mol\,N_2H_4}{32.046g\,N_2H_4}\right)\left(21.964g\,N_2H_4\right) = 352.28kJ$$

Score

13. How many grams of ethane {$C_2H_6(g)$} would you have to burn to liberate enough Gibb's Free Energy to break 14.227g of CaO(s) into Ca(s) and $O_2(g)$? (Assume 100% efficiency.) (16pts)

$$2\,C_2H_6(g) + 7\,O_2(g) \leftrightarrow 4\,CO_2(g) + 6\,H_2O(g)$$

$$\Delta G^o_{rxn} = 2(32.0^{kJ}/_{mol}) + 7(0^{kJ}/_{mol}) + 4(-394.359^{kJ}/_{mol}) + 6(-228.6^{kJ}/_{mol}) = -2885.036^{kJ}/_{mol}$$

$$2\,CaO(s) \leftrightarrow 2\,Ca(s) + O_2(g)$$

$$\Delta G^o_{rxn} = 2\,(603.3^{kJ}/_{mol}) + 2(0^{kJ}/_{mol}) + (0^{kJ}/_{mol}) = +1206.6^{kJ}/_{mol}$$

$$\left(1206.6\tfrac{kJ}{mol\,rxn}\right)\left(\frac{1 mol\ rxn}{2 mol\ CaO}\right)\left(\frac{1 mol\ CaO}{56.077 g\ CaO}\right)(14.227 g\ CaO) = 153.06 kJ \text{ needed}$$

$$(153.06kJ)\left(\frac{1 mol\ rxn}{2885.036 kJ}\right)\left(\frac{2 mol\ C_2H_6}{1 mol\ rxn}\right)\left(\frac{30.069 g\ C_2H_6}{1 mol\ C_2H_6}\right) = 3.1905g\ C_2H_6 \text{ needed}$$

14. For each of the following pairs of half-reactions/half-cells, determine the voltage of the spontaneous reaction/cell and write a balanced equation for the reaction that occurs, identifying the oxidation and reduction half-reactions. (12pts each)

$Sn^{2+}|Sn$ and $Cr^{3+}|Cr$

$$3\,\{\ 2e^- + Sn^{2+}(aq) \leftrightarrow Sn(s)\ \} \qquad E^o_{red} = -0.14V$$

$$2\,\{\ Cr(s) \leftrightarrow Cr^{3+}(aq) + 3e^-\ \} \qquad E^o_{ox} = +0.73V$$

$$3\,Sn^{2+}(aq) + 2\,Cr(s) \leftrightarrow 2\,Cr^{3+}(aq) + 3\,Sn(s) \qquad E^o_{cell} = +0.59V$$

$SO_4^{2-}|H_2SO_3$ and $Fe^{3+}|\ Fe^{2+}$

$$2\,\{\ 1e^- + Fe^{3+}(aq) \leftrightarrow Fe^{2+}(aq)\ \} \qquad E^o_{red} = +0.77V$$

$$H_2O(l) + H_2SO_3(aq) \leftrightarrow SO_4^{2-}(aq) + 2e^- + 4\,H^+(aq) \qquad E^o_{ox} = -0.20V$$

$$H_2O(l) + H_2SO_3(aq) + 2\,Fe^{3+}(aq) \leftrightarrow SO_4^{2-}(aq) + 4\,H^+(aq) + 2\,Fe^{2+}(aq) \qquad E^o_{cell} = +0.57V$$

Score

15. A lead-acid battery consists of a lead electrode {Pb(s)} and a lead(IV) oxide electrode in a sulfuric acid liquid phase, meaning that the half cell reactions are $PbO_2|PbSO_4$ and $PbSO_4|Pb$. Write the balanced chemical equation for the spontaneous cell constructed from these cells and calculate the cell voltage. Identify the anode and the cathode of the spontaneous cell. After the battery has been discharged, it can be recharged by passing 4.28amps of electricity backwards through the cell for 73.63minutes. How many grams of anode material are formed during this recharging process? (20pts)

$$SO_4^{2-}(aq) + Pb(s) \leftrightarrow PbSO_4(s) + 2e^- \qquad E^o_{ox} = +0.36V \text{ (anode)}$$

$$4\,H^+(aq) + SO_4^{2-}(aq) + 2e^- + PbO_2(s) \leftrightarrow PbSO_4(s) + 2\,H_2O(l) \qquad E^o_{red} = +1.69V \text{ (cathode)}$$

$$4\,H^+(aq) + 2\,SO_4^{2-}(aq) + Pb(s) + PbO_2(s) \leftrightarrow 2\,PbSO_4(s) + 2\,H_2O(l) \qquad E^o_{cell} = +2.05V$$

Recharging will generate Pb(s)

$$\left(4.28\,\tfrac{C}{sec}\right)(73.63\,min)\left(\frac{60\,sec}{1\,min}\right)\left(\frac{1\,mol\ electrons}{96485\,C}\right)\left(\frac{1\,mol\ Pb(s)}{2\,mol\ electrons}\right)\left(\frac{207.2\,g\ Pb(s)}{1\,mol\ Pb(s)}\right) = 20.3\,g\ Pb(s)$$

Thermodynamic Values at 25°C:

Substance	**ΔH^o_f ($^{kJ}/_{mol}$)**	**S^o ($^{J}/_{mol\cdot K}$)**	**ΔG^o_f ($^{kJ}/_{mol}$)**
$COCl_2(g)$	-219.1	283.5	-204.9
$H_2O(l)$	-285.8	70.0	-237.1
$H_2CO_3(aq)$	-699.7	187.4	-623.2
$HCl(g)$	-92.3	186.9	-95.3
$N_2H_4(g)$	95.4	238.5	159.4
$O_2(g)$	0	205.138	0
$NO_2(g)$	33.18	240.06	51.31
$H_2O(g)$	-241.8	188.8	-228.6
$CO_2(g)$	-393.509	213.74	-394.359
$C_2H_6(g)$	-84.68	229.2	-32.0
$Ca(s)$	0	41.6	0
$CaO(s)$	-634.9	38.1	-603.3

Standard Reduction Potentials at 25°C:

Half cell	**E^o_{red} (volts)**	**Half cell**	**E^o_{red} (volts)**
$Sn^{2+}(aq)|Sn(s)$	-0.14	$Fe^{3+}(aq)|Fe^{2+}(aq)$	+0.77
$Cr^{3+}(aq)|Cr(s)$	-0.73	$PbO_2(s)|PbSO_4(s)$	+1.69
$SO_4^{2-}(aq)|H_2SO_3(aq)$	+0.20	$PbSO_4(s)|Pb(s)$	-0.36

Score

Name: ____

Score