Score:_____ / 100 Name:_____KEY_____

Exam 3 – Chapters 16 & 17

1. (5 pts) Match the following thermodynamic laws:
   a. The First Law _ii__ i. The entropy of a pure crystalline substance is zero at absolute zero.
   b. The Second Law __iii__ ii. Energy is conserved in any process.
   c. The Third Law __i__ iii. The entropy of the universe increases during a spontaneous process.

2. (8 pts) Calculate $\Delta S°$ for the reaction: $2\ NaHCO_3\ (s) \rightarrow H_2O\ (l) + CO_2\ (g) + Na_2CO_3\ (aq)$.
   $\Delta S° = 215$ J/K

Substance	S°, J/mol K
$NaHCO_3$ (s)	102
H_2O (l)	69.9
CO_2 (g)	213.6
Na_2CO_3 (aq)	135.0

3. (8 pts) A student places a piece of ice on the bench top for ten minutes. The room temp is 25°C. Predict the correct sign (> 0 or < 0) for the following:
   a. entropy, ΔS, is ___> 0 ____
   b. enthalpy, ΔH, is ___> 0 ____
   c. Gibb's Free Energy, ΔG, is ___< 0 ____
   d. The equilibrium constant, K, is __ > 0 ____

4. (5 pts) Predict which of the following reactions would have a positive entropy change:
   a. $P_4\ (g) + 5\ O_2\ (g) \rightarrow P_4O_{10}\ (s)$
   b. $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$
   c. $CO_2\ (s) \rightarrow CO_2\ (g)$
   d. $Ag^+\ (aq) + Cl^-\ (aq) \rightarrow AgCl\ (s)$

5. (5 pts) If a process is exothermic and the process creates less order than existed before, the process is:
   a. always spontaneous $\Delta G° = \Delta H° - T\Delta S°$
   b. never spontaneous
   c. spontaneous at high T
   d. spontaneous at low T

6. (5 pts) Which of the following does not have a standard enthalpy of formation of zero?
   a. $Br_2\ (l)$
   b. Xe (g)
   c. Pt (s)
   d. $CO_2\ (g)$
   e. Hg (l)

7. (12 pts) For the chemical reaction, $NH_3(aq) + H_2O(l) \leftrightarrows NH_4^+(aq) + OH^-(aq)$,

a. Calculate $\Delta G°$ (in kJ) ***AND*** the equilibrium constant, K, at 25° C. $\Delta S° = 143.3$ J/K and $\Delta H° = 176.4$ kJ

$\Delta G° = +133.7$ kJ $K = 3.66 \times 10^{-24}$

b. Calculate ΔG at 298 K, when $[NH_4^+] = 0.20$ M, $[OH^-] = 0.10$ M and $[NH_3] = 0.050$ M.

$\Delta G = +131.4$ kJ

Is this reaction spontaneous? **YES** **NO** (circle one and show all work to receive credit!)

8. (6 pts) Rubidium has a heat of vaporization of 69.0 kJ/mol and an entropy of vaporization of 71.9 J/mol K. Calculate the boiling point of rubidium. *(Hint: what is ΔG during a phase change?)*

$T = \Delta H/\Delta S = 959$ K

For the following Electrochemistry problems, refer to the Reduction Potential Table on the last page of the exam.

9. (5 pts) Given the reduction potentials on the last page of the exam, determine which combination of metal electrodes will produce a battery with the largest voltage.

a. Ag (s) and Fe (s) b. Zn (s) and Sn (s) c. Mg (s) and Al (s) d. Cu (s) and Zn (s)

10. (5 pts) Circle the substance that is the strongest oxidizing agent:

a. Ni (s) b. $Mg^{2+}(aq)$ c. $Cu^{2+}(aq)$ d. Ag (s)

11. (6 pts) Assign oxidation numbers for every atom in the reaction. Write the number under each atom

$$5\ H_2C_2O_4(aq) + 2\ MnO_4^-(aq) + 6\ H^+(aq) \rightarrow 10\ CO_2(g) + 2\ Mn^{2+}(aq) + 8\ H_2O(l)$$

What is the oxidizing agent? _____MnO_4^-____ What is the reducing agent?__ $H_2C_2O_4$_____

12. (5 pts) Which of the following are true if ΔG has a negative value?

a. $E°_{cell}$ is (+) and $K < 1$

b. $E°_{cell}$ is (+) and $K > 1$

c. $E°_{cell}$ is (-) and $K < 1$

d. $E°_{cell}$ is (-) and $K > 1$

e. $E°_{cell}$ is zero and $K = 1$

13. (5 pts) $E°_{cell} = 0.60$ V for the spontaneous reaction $Ni(s) + Cu^{2+}(aq) \rightarrow Ni^{2+}(aq) + Cu(s)$

Which statement is **False** regarding this cell?

a. The reduction half reaction is $Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s)$

b. The electrons are flowing from the copper metal to the nickel metal through an external wire.

c. Cations from the salt bridge move towards the compartment containing the Cu.

d. The mass of the nickel electrode is decreasing as the nickel atoms become nickel ions.

14. (12 pts) Answer the following questions regarding the short-hand cell notation:

$$Mg\ (s)\ |\ Mg^{2+}\ (aq)\ \|\ Al^{3+}\ (aq)\ |\ Al\ (s)$$

a. (1 pt) Write the oxidation ½ reaction:

$Mg\ (s) \rightarrow Mg^{2+}\ (aq) + 2\ e^-$

b. (1 pt) Write the reduction ½ reaction:

$Al^{3+}\ (aq) + 3\ e^- \rightarrow Al\ (s)$

c. (1 pt) Write the overall, balanced reaction:

$3\ Mg\ (s) + 2\ Al^{3+}\ (aq) \rightarrow 2\ Al\ (s) + 3\ Mg^{2+}\ (aq)$

d. (1 pt) What is the anode? ___Mg_____

e. (1 pt) What is the cathode? ___Al_____

f. (2 pts) Calculate the total cell potential ($E°_{cell}$) for this reaction. 0.71 V

g. (5 pts) Calculate the EMF for the cell, E, when 0.100 M $Mg(NO_3)_2$ and 0.0100 M $Al(NO_3)_3$ are used at 25°C.

E = 0.70 V

15. (8 pts) Calculate ΔG° for the galvanic cell composed of Fe in $Fe(NO_3)_2$ solution and Sn in $Sn(NO_3)_4$ solution.

$\Delta G° = (4\ e^-)(96500(0.60\ V) = -230\ kJ$

Reduction half-reaction	E°,V
$Ag^+(aq) + e^- \rightarrow Ag(s)$	0.80
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	0.34
$Sn^{4+}(aq) + 4e^- \rightarrow Sn(s)$	0.15
$2H^+(aq) + 2e^- \rightarrow H_2(g)$	0
$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$	-0.26
$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$	-0.45
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	-0.76
$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$	-1.66
$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$	- 2.37

Extra credit: (5 pts)

Calculate the pH and percent ionization of a 0.300 M ammonia solution? $K_b = 1.75 \times 10^{-5}$ (show work on back)