**Chem 120** | **Name**________________________________
**Exam 3, Ch 7, 19** | **November 7, 2008**
**100 Points**

Please follow the instructions for each section of the exam. Show your work on all mathematical problems. Provide answers with the correct units and significant figures. Be concise in your answers to discussion questions. I have intentionally left a great deal of space for each problem. I do not expect each problem to take up all of the space provided!

**Part 0: Warmup. 4 points each**

1. The heat of solution of NaOH(s) in water is -41.6 kJ/mol NaOH. When NaOH is dissolved in water, the solution temperature

   a. increases.
   b. decreases.
   c. remains constant.
   d. either increases or decreases depending on the amount of NaOH dissolved.

   Answer ____________

2. A plausible final temperature when 75.0 mL of water at 80.0$^{o}$C is added to 100.0 mL of water at 20.0$^{o}$C is

   a. 28$^{o}$C.
   b. 40$^{o}$C.
   c. 46$^{o}$C.
   d. 50$^{o}$C.

   Answer ____________

3. For a process to occur spontaneously,

   a. the entropy of the system must increase.
   b. both the entropy of the system and surroundings must increase.
   c. the net change of the entropy of the system and surroundings must be a positive quantity.
   d. the entropy of the universe must remain constant.

   Answer ____________

4. Reactions with a positive $\Delta H^{o}$ and a positive $\Delta S^{o}$ are

   a. spontaneous at all temperatures.
   b. nonspontanteous at all temperatures.
   c. spontaneous at low temperatures but nonspontaneous at high temperatures.
   d. nonspontaneous at low temperaures but spontaneous at high temperatures.

   Answer ____________

5. Which of the processes below DOES NOT result in an increase in entropy?

   a. $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$
   b. $H_2O(s) \rightarrow H_2O(\ell)$ (The melting of ice.)
   c. $CO_2(s) \rightarrow CO_2(g)$ (The sublimation of dry ice.)
   d. $NH_4NO_3(s) \rightarrow N_2O(g) + 2\ H_2O(\ell)$

   Answer ____________

**Part I: Complete all of problems 6-9.**

6. Concisely discuss the validity of each of the following statements. Clearly justify your reasoning. A few sentences should be sufficient. (12 points)
   a. Reactions with a positive $\Delta H^o$ and a positive $\Delta S^o$ can never be product-favored.

   b. Free energy changes provide a good indication of which reactions are favorable and fast, as well as those that are unfavorable and slow.

7. An ice cube weighing 5.63 g originally at 0.0°C was dropped into an insulated cup. After a short period of time, the ice had all melted and the temperature of the remaining liquid water had reached 25.2°C. How much heat energy, in kJ, did the water lose to the surroundings as it melted and warmed? (For water, $\Delta H^o_{fusion}$ = 333 J/g, $\Delta H^o_{vaporization}$ = 2256 J/g) (12 points)

8. For the following processes, give the algebraic sign for $\Delta H^o$, $\Delta S^o$, and $\Delta G^o$. No calculations are necessary, use your common sense and briefly justify your decisions. A few sentences should be sufficient. (12 points)

   a. The splitting of liquid water to give gaseous oxygen and gaseous hydrogen, a process that requires a considerable amount of energy.

   b. The explosion of dynamite, a mixture of solid nitroglycerine and solid diatomaceous earth. The explosive decomposition gives gaseous products such as water, $CO_2$ and others and much heat is evolved.

9. Answer the following questions regarding the decomposition of sulfur trioxide to sulfur dioxide and oxygen. (16 points)

$$2\ SO_3(g) \rightarrow 2\ SO_2(g) + O_2(g)$$

| Species | $\Delta H_f^o$ (kJ/mol) | $S^o$ (J/mol K) |
|---|---|---|
| O (g) | 249.170 | 161.055 |
| $O_2$ (g) | 0 | 205.138 |
| S (s) | 0 | 31.80 |
| S (g) | 278.805 | 167.821 |
| $SO_2$ (g) | -296.830 | 248.22 |
| $SO_3$ (g) | -395.72 | 256.76 |

a. Calculate the $\Delta G^o$ for this reaction at 298K. (10 points)

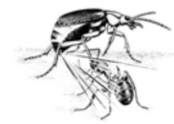
b. Calculate the minimum temperature required for the reaction to be product-favored. (6 points).

**Part II. Answer two (2) of problems 10-13. Clearly mark the problems you do not want graded. 14 points each.**

10. Solid ammonium nitrate can decompose to dintrogen oxide gas and liquid water. What is the $\Delta G^o$ at 298K? At what temperature, if any, does spontaneity of the reaction change? Is the reaction more or less spontaneous at high temperatures?

| Species | $\Delta G^o_f$ (kJ/mol) | $\Delta H^o_f$ (kJ/mol) | $S^o_f$ (J/mol) |
|---|---|---|---|
| $NH_4NO_3$ (*s*) | -183.9 | -365.6 | 151.1 |
| $N_2O$ (g) | +104.2 | +82.05 | 219.9 |
| $H_2O$ ($\ell$) | -237.1 | -285.8 | 69.91 |

*For problems 11-13, consider the Bombardier Beetle, who defends itself by spraying nearly boiling water on its predators. It has two glands on the tip of its abdomen, with each gland containing two compartments. The inner compartment holds an aqueous solution of hydroquinone and hydrogen peroxide. The outer compartment holds a mixture of enzymes that catalyze the following reaction:*



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $C_6H_4(OH)_2$ (*aq*) | + | $H_2O_2$ (*aq*) | $\rightarrow$ | $C_6H_4O_2$ (*aq*) | + | 2 $H_2O$ ($\ell$) |
| hydroquinone | | hydrogen peroxide | | benzoquinone | | water |

*When threatened, the beetle squeezes some fluid from the inner compartment into the outer compartment, and sprays the mixture (which is near its boiling point) onto the predator.*

11. Calculate the $\Delta H^o$ for the Bombardier Beetle reaction using the following data:

| **Reaction** | **$\Delta H^o$** |
|---|---|
| $C_6H_4(OH)_2$ (*aq*) $\rightarrow$ $C_6H_4O_2$ (*aq*) + $H_2$ (*g*) | +177.4 kJ |
| $H_2$ (*g*) + $O_2$ (*g*) $\rightarrow$ $H_2O_2$ (*aq*) | -191.2 kJ |
| $2H_2$ (*g*) + $O_2$ (*g*) $\rightarrow$ $2H_2O$ (*g*) | -483.6 kJ |
| $H_2O$ (*g*) $\rightarrow$ $H_2O$ ($\ell$) | -43.8 kJ |

12. Using the table of $\Delta H^o_f$ below and your result from number 11, calculate the $\Delta H^o_f$ ,of hydroquinone, $C_6H_4(OH)_2$., in kJ/mol. (Note: if you did not get an answer to number 11, you may use -200 kJ as a reasonable estimate for $\Delta H^o_{rxn}$).

$$\underset{\text{hydroquinone}}{C_6H_4(OH)_2\,(aq)} + \underset{\text{hydrogen peroxide}}{H_2O_2\,(aq)} \rightarrow \underset{\text{benzoquinone}}{C_6H_4O_2\,(aq)} + \underset{\text{water}}{2\,H_2O\,(\ell)}$$

| **Species** | **$\Delta H^o_f$ (kJ/mol)** | **Species** | **$\Delta H^o_f$ (kJ/mol)** |
|---|---|---|---|
| $H_2O_2$ (*aq*) | -191.2 | $H_2O$ (*g*) | -241.8 |
| $H_2O_2$ ($\ell$) | -187.8 | $H_2O$ ($\ell$) | -285.8 |
| $C_6H_4O_2$ (*aq*) | -50.4 | | |

13. Assume a beetle emits 0.90 mL of 3.0 M hydroquinone and 1.10 mL of 3.0 M peroxide. If the initial temperature of this solution is 25.0$^{O}$C, what will the solution temperature be after the reaction? Assume the specific heat of the solution is 4.184 J/gK and that the density of solution is 1.00 g/mL. (Note: if you did not get an answer to number 11, you may use -200 kJ as a reasonable estimate for $\Delta H^{o}_{rxn}$).

## Possibly Useful Information

| | |
|---|---|
| $\Delta G = \Delta H - T\Delta S$ | $^{o}C = K - 273.15$ |
| $q_{rxn} = n\Delta H_{rxn}$ | $q = mc\Delta T$ |
| henway = ~5-6 lbs | $q_{released} = -q_{absorbed}$ |

| Compound | Molar Mass (g/mol) | Compound | Molar Mass (g/mol) |
|---|---|---|---|
| $H_2O$ | 18.0153 | $SO_2$ | 64.065 |
| $H_2O_2$ | 34.0147 | $SO_3$ | 80.064 |
| $C_6H_4O_2$ | 108.097 | $NH_4NO_3$ | 80.0434 |
| $C_6H_4(OH)_2$ | 110.112 | $N_2O$ | 44.0129 |
| $H_2$ | 2.01588 | $CO_2$ | 44.010 |
| $O_2$ | 31.9988 | | |

| Material | Specific Heat Capacity (J/gK) |
|---|---|
| $H_2O$ (s) | 2.050 |
| $H_2O$ (l) | 4.184 |
| $H_2O$ (g) | 2.080 |

| 1 1A | 2 2A | 3 3B | 4 4B | 5 5B | 6 6B | 7 7B | 8 8B | 9 8B | 10 8B | 11 1B | 12 2B | 13 3A | 14 4A | 15 5A | 16 6A | 17 7A | 18 8A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H 1.00794 | | | | | | | | | | | | | | | | | 2 He 4.00260 |
| 3 Li 6.941 | 4 Be 9.01218 | | | | | | | | | | | 5 B 10.811 | 6 C 12.011 | 7 N 14.0067 | 8 O 15.9994 | 9 F 18.9984 | 10 Ne 20.1797 |
| 11 Na 22.9898 | 12 Mg 24.3050 | | | | | | | | | | | 13 Al 26.9815 | 14 Si 28.0855 | 15 P 30.9738 | 16 S 32.066 | 17 Cl 35.4527 | 18 Ar 39.948 |
| 19 K 39.0983 | 20 Ca 40.078 | 21 Sc 44.9559 | 22 Ti 47.88 | 23 V 50.9415 | 24 Cr 51.9961 | 25 Mn 54.9381 | 26 Fe 55.847 | 27 Co 58.9332 | 28 Ni 58.693 | 29 Cu 63.546 | 30 Zn 65.39 | 31 Ga 69.723 | 32 Ge 72.61 | 33 As 74.9216 | 34 Se 78.96 | 35 Br 79.904 | 36 Kr 83.80 |
| 37 Rb 85.4678 | 38 Sr 87.62 | 39 Y 88.9059 | 40 Zr 91.224 | 41 Nb 92.9064 | 42 Mo 95.94 | 43 Tc (98) | 44 Ru 101.07 | 45 Rh 102.906 | 46 Pd 106.42 | 47 Ag 107.868 | 48 Cd 112.411 | 49 In 114.818 | 50 Sn 118.710 | 51 Sb 121.757 | 52 Te 127.60 | 53 I 126.904 | 54 Xe 131.29 |
| 55 Cs 132.905 | 56 Ba 137.327 | 57 *La 138.906 | 72 Hf 178.49 | 73 Ta 180.948 | 74 W 183.84 | 75 Re 186.207 | 76 Os 190.23 | 77 Ir 192.22 | 78 Pt 195.08 | 79 Au 196.967 | 80 Hg 200.59 | 81 Tl 204.383 | 82 Pb 207.2 | 83 Bi 208.980 | 84 Po (209) | 85 At (210) | 86 Rn (222) |
| 87 Fr (223) | 88 Ra 226.025 | 89 †Ac 227.028 | 104 Rf (261) | 105 Db (262) | 106 Sg (266) | 107 Bh (264) | 108 Hs (277) | 109 Mt (268) | 110 Ds (271) | 111 Rg (272) | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lanthanide series | 58 Ce 140.115 | 59 Pr 140.908 | 60 Nd 144.24 | 61 Pm (145) | 62 Sm 150.36 | 63 Eu 151.965 | 64 Gd 157.25 | 65 Tb 158.925 | 66 Dy 162.50 | 67 Ho 164.930 | 68 Er 167.26 | 69 Tm 168.934 | 70 Yb 173.04 | 71 Lu 174.967 |
| †Actinide series | 90 Th 232.038 | 91 Pa 231.036 | 92 U 238.029 | 93 Np 237.048 | 94 Pu (244) | 95 Am (243) | 96 Cm (247) | 97 Bk (247) | 98 Cf (251) | 99 Es (252) | 100 Fm (257) | 101 Md (258) | 102 No (259) | 103 Lr (262) |