FRONT PAGE FORMULA SHEET - TEAR OFF

1A	2A											3A	4A	5A	6A	7A	8A
1 H 1.01																	2 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc [98]	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	71 Lu 175.0	72 Hf 178.5	73 Ta 181.0	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po [209]	85 At [210]	86 Rn [222]
87 Fr [223]	88 Ra [226]	103 Lr [262]	104 Rf [261]	105 Db [262]	106 Sg [266]												

57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm [145]	62 Sm 150.4	63 Eu 152.0	64 Gd 157.2	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0
89 Ac [227]	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np [237]	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]

$N_A = 6.022 \times 10^{23}$

$1\ \text{amu} = 1.661 \times 10^{-27}\ \text{kg}$

1 atm = 760 torr = 760 mm Hg

R = 0.08206 L•atm/mol•K

R = 8.314 J/mol•K

F = 96485. C/mol

$°C = (^5/_9)\ (°F - 32)$

°C = K - 273.15

1 atm = 1.013 bar

1 L•atm = 101.3 J

$1\ \text{J} = 1\ \text{kg}\cdot\text{m}^2/\text{s}^2$

$°F = (^9/_5)(°C) + 32$

K = °C + 273.15

pV = nRT

$\ln(p) = -\dfrac{\Delta H°_{vap}}{T} + C$

$\ln(p_2/p_1) = -(\Delta H°_{vap}/R)\ \{ (1/T_2) - (1/T_1) \}$

$p_A = X_A\, p_A°$

$[B] = k\, p_B$

$\Delta p_A = X_B p_A°$

$\Delta T_b = K_b\, m_B$

$\Delta T_f = K_f\, m_B$

$\Pi = [B]RT$

$H = U + pV$

$G = H - TS$

$\Delta G_{rxn} = \Delta G°_{rxn} + RT \ln Q$

$\ln K = -\Delta G°_{rxn}/RT$

$K_p = K_C\, (RT)^{\Delta n}$

If $ax^2 + bx + c = 0$, then $x = \left(\dfrac{-b \pm [b^2 - 4ac]^{1/2}}{2a} \right)$

$K_a \cdot K_b = K_w = 1.0 \times 10^{-14}$ (at T = 25°C)

$pH = pK_a + \log_{10}\{[\text{base}]/[\text{acid}]\}$

$\Delta G = -nFE_{cell}$

$E_{cell} = E°_{cell} - (RT/nF) \ln Q$

$\ln K = nFE°_{cell}/RT$

$[A]_t = [A]_0\, e^{-kt}$

$\ln[A]_t = \ln[A]_0 - kt$

$t_{1/2} = \ln 2/k$

$[A]_t = [A]_0/(1 + kt[A]_0)$

$(1/[A]_t) = (1/[A]_0) + kt$

$t_{1/2} = 1/(k[A]_0)$

$k = A\, e^{-Ea/RT}$

$\ln k = \ln A - (E_a/R)(1/T)$

$\ln(k_2/k_1) = -(E_a/R)\ [(1/T_2) - (1/T_1)]$

GENERAL CHEMISTRY 2
FINAL EXAM

Name ____

Panthersoft ID ____

Signature ____

Part 1 ________________ **(48 points)**

Part 2 ________________ **(64 points)**

Part 3 ________________ **(88 points)**

TOTAL ________________ **(200 points)**

Do all of the following problems. <u>Show your work</u>.

Part 1. Multiple choice. Circle the letter corresponding to the correct answer. There is one and only one correct answer per problem. [4 points each]

1) Which of the following methods for expressing concentration have no units?

a) molality
b) molarity
C c) mole fraction
d) Both a and b
e) All of the above methods for expressing concentration have units

2) A solution is formed by adding 0.100 moles of a nonvolatile and nonionizing solute to 250.0 g of a volatile solvent. Compared to the pure solvent

a) the boiling point of the solution will be higher than the boiling point of the pure solvent
b) the freezing point of the solution will be higher than the freezing point of the pure solvent
A c) the vapor pressure of the solution will be higher than the vapor pressure of the pure solvent
d) Both a and b
e) Both b and c

3) For a spontaneous reaction which of the following must be true?

a) $\Delta G_{rxn} < 0$
b) $\Delta S_{rxn} < 0$
A c) $\Delta S_{rxn} > 0$
d) Both a and b
e) Both a and c

4) For which of the following reactions would we expect $\Delta S°_{rxn}$ to be large and negative?

a) $MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$
b) $C_6H_6(\ell) \rightarrow C_6H_6(g)$
C c) $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(\ell)$
d) both a and b
e) both a and c

5) Consider the reaction

$$I_2(g) + Cl_2(g) \leftrightarrows 2\ ICl(g)$$

A system containing I_2, Cl_2, and ICl is initially at equilibrium at some temperature T. The volume of the system is decreased to half of its initial value while keeping temperature constant. Which of the following will occur as the system re-establishes equilibrium?

a) The moles of I_2 in the system will increase
b) The moles of Cl_2 in the system will increase
E c) The moles of ICl in the system will increase
d) Both a and b
e) None of the above

6) Benzoic acid (C_6H_5COOH) is a weak acid, with $K_a = 6.5 \times 10^{-5}$ (at T = 25. °C). The $C_6H_5COO^-$ ion is

a) a strong acid
b) a weak acid
D c) a strong base
d) a weak base
e) None of the above, as ions have no acid or base properties

7) A Bronsted acid is

a) a proton acceptor
b) a proton donor
B c) an electron pair acceptor
d) an electron pair donor
e) both b and c

8) Consider the following three substances: HBr, H_2S, and H_2Se. Of these substances

a) HBr is the strongest acid and H_2S is the weakest acid
b) HBr is the strongest acid and H_2Se is the weakest acid
A c) H_2S is the strongest acid and HBr is the weakest acid
d) H_2Se is the strongest acid and HBr is the weakest acid
e) H_2Se is the strongest acid and H_2S is the weakest acid

9) Which of the following aqueous solutions will be a buffer solution?

a) A solution containing 0.100 M HBr (an acid) and 0.050 M NaBr.
b) A solution containing 0.100 M HNO_2 (an acid) and 0.050 M $NaNO_2$.
E c) A solution containing 0.100 M HNO_2 (an acid) and 0.050 M NaOH.
d) Both a and b
e) Both b and c

10) The standard reduction potential for the process

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

is E° = + 0.34 v. Based on this, we can say that the half-cell oxidation potential for the process

$$2\ Cu(s) \rightarrow 2\ Cu^{2+}(aq) + 4\ e^-$$

is

a) E° = + 0.68 v
b) E° = + 0.34 v
D c) E° = 0.00 v
d) E° = - 0.34 v
e) E° = - 0.68 v

11) A chemical reaction obeys the rate law

$$rate = k\ [A]\ [B]^2$$

The overall order of the reaction is

a) first order
b) second order
C c) third order
d) both a and b
e) both a and b and c

12) A catalyst

a) changes the rate of reaction and also changes the equilibrium constant for a reaction
b) changes the rate of reaction but does not change the equilibrium constant for a reaction
B c) does not change the rate of reaction but changes the equilibrium constant for a reaction
d) does not change the rate of reaction and also does not change the equilibrium constant for a reaction
e) cannot be present in a system at equilibrium

Part 2. Short answer.

1) Define the following terms [6 points each]

a) amphoteric – A substance that can act as either a Bronsted acid or a Bronsted base in an acid/base reaction. Example:

$HF(aq) + H_2O(\ell) \leftrightarrows H_3O^+(aq) + F^-(aq)$ water is a Bronsted base

$NH_3(aq) + H_2O(\ell) \leftrightarrows NH_4^+(aq) + OH^-(aq)$ water is a Bronsted acid

b) catalyst – A substance that when added to a system speeds up a chemical reaction without itself being produced or consumed. Enzymes are one example of biological catalysts.

2) 0.45 g of a nonvolatile pure chemical substance (a polymer) are dissolved in liquid benzene (C_6H_6, MW = 78.1 g/mol), to form a solution with final volume V = 200.0 mL. The osmotic pressure of the solution, measured at T = 20.0 °C, was 33.2 torr. Based on this information find the molecular weight of the polymer. [10 points]

$$\Pi = [B]RT \qquad [B] = \frac{\Pi}{RT} = \frac{33.2 \text{ torr } (1 \text{ atm}/760 \text{ torr})}{(0.08206 \text{ L}\bullet\text{atm/mol}\bullet\text{K})(293.\text{ K})} = 1.82 \times 10^{-3} \text{ mol/L}$$

$$\# \text{ moles} = (0.2000 \text{ L})(1.82 \times 10^{-3} \text{ mol/L}) = 3.63 \times 10^{-4} \text{ mol}$$

$$\text{MW} = \frac{\text{mass}}{\text{moles}} = \frac{0.45 \text{ g}}{3.63 \times 10^{-4} \text{ mol}} = 1240. \text{ g/mol}$$

3) For each of the following questions circle the correct answer. There is one and only one correct answer per problem. [4 points each]

a) The substance with $\Delta G°_f$ = 0.0 kJ/mol at T = 25. °C

$CuCl_2(s)$ $C_6H_{12}(\ell)$ **$O_2(g)$** $O_3(g)$

b) The acid that is a polyprotic acid

HBr $HBrO_2$ HNO_3 **H_3PO_4**

c) The hydroxide compound that is a strong soluble base

AgOH **$Ba(OH)_2$** $Cu(OH)_2$ $Fe(OH)_3$

d) The best indicator to use in the titration of a strong acid by a strong base

alizarin yellow	**bromothymol blue**	bromophenol blue	thymol blue
pK_{ind} = 11.0	**pK_{ind} = 6.8**	pK_{ind} = 3.8	pK_{ind} = 2.0

4) Equilibrium between sulfur oxides in the presence of molecular oxygen is difficult to study experimentally. Consider the following reaction

$$2\ SO_2(g) + O_2(g) \leftrightarrows 2\ SO_3(g) \qquad (K_C = 1.9 \times 10^{26} \text{ at } T = 25.0\ °C)$$

a) Give the expression for K_C, the equilibrium constant, in terms of reactant and product concentrations. [4 points]

$$K_C = \frac{[SO_3]^2}{[SO_2]^2\ [O_2]}$$

b) For a particular system the initial concentrations of SO_3 and O_2 are both 0.0400 mol/L. No SO_2 is initially present. Find the value for $[SO_2]$, the concentration of SO_2, when equilibrium is reached. [10 points]

	Initial	Change	Equilibrium
SO_2	0.0000	2x	2x
O_2	0.0400	x	0.0400 + x
SO_3	0.0400	- 2x	0.0400 – 2x

So $$\frac{(0.0400 - 2x)^2}{(2x)^2\ (0.0400 + x)} = 1.9 \times 10^{26}$$ If we assume x << 0.0400, then

$$\frac{(0.0400)^2}{(4x^2)(0.0400)} = 1.9 \times 10^{26} \qquad x^2 = 5.26 \times 10^{-29} \qquad x = 7.25 \times 10^{-15}$$

So at equilibrium, $[SO_2] = 2(7.25 \times 10^{-15}) = 1.45 \times 10^{-14}$ mol/L

5) Balance the following oxidation-reduction reaction for the indicated condition. [12 points each]

$H_3AsO_3(aq) + Cr_2O_7^{2-}(aq) \rightarrow H_3AsO_4(aq) + Cr^{3+}(aq)$ (in acid solution)

ox $H_3AsO_3(aq) + H_2O(\ell) \rightarrow H_3AsO_4(aq) + 2\ e^- + 2\ H^+(aq)$ x 3

red $Cr_2O_7^{2-}(aq) + 6\ e^- + 14\ H^+(aq) \rightarrow 2\ Cr^{3+}(aq) + 7\ H_2O(\ell)$

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net $3\ H_3AsO_3(aq) + Cr_2O_7^{2-}(aq) + 8\ H^+(aq) \rightarrow 3\ H_3AsO_4(aq) + 2\ Cr^{3+}(aq) + 4\ H_2O(\ell)$

Part 3. Problems.

1) Thermochemical data (at T = 25. °C) for several substances is given below, and may be of use in doing the following problems, which also take place at T = 25. °C.

Substance	ΔH°_f (kJ/mol)	ΔG°_f (kJ/mol)	S° (J/mol•K)
C(s)	0.00	0.00	5.74
CO_2(g)	- 393.51	- 394.36	213.74
$CO(NH_2)_2$(s)	- 333.51	- 197.33	104.60
H_2O(g)	- 241.82	- 228.57	188.83
NH_3(g)	- 46.11	- 16.45	192.45
O_2(g)	0.00	0.00	205.14

a) What is the value for ΔS°_{rxn} for the reaction [8 points]

$C(s) + O_2(g) \rightarrow CO_2(g)$

$\Delta S^\circ_{rxn} = [\ S^\circ(CO_2(g))\ ] - [\ S^\circ(C(s)) + S^\circ(O_2(g))\ ]$

$= [\ 213.74\ ] - [\ (5.74) + (205.14)\ ] = 2.86$ J/mol•K

b) What are the values for ΔG°_{rxn} and K for the reaction [16 points]

$CO(NH_2)_2(s) + H_2O(g) \leftrightarrows CO_2(g) + 2\ NH_3(g)$

$\Delta G^\circ_{rxn} = [\ \Delta G^\circ_f(CO_2(g) + 2\ \Delta G^\circ_f(NH_3(g))\ ] - [\ \Delta G^\circ_f(CO(NH_2)_2(s)) + \Delta G^\circ_f(H_2O(g))\ ]$

$= [\ (-\ 394.36) + 2\ (-\ 16.45)\ ] - [\ (-\ 197.33) + (-\ 228.57)\ ] = -\ 1.36$ kJ/mol

$$\ln K = -\frac{\Delta G^\circ_{rxn}}{RT} = -\frac{(-\ 1360.\ \text{J/mol})}{(8.314\ \text{J/mol•K})\ (298.\ \text{K})} = 0.55$$

$K = e^{0.55} = 1.73$

2) Titration is a common method for finding the concentration of stock solutions of acids or bases. The following problem concerns a titration carried out at T = 25. °C.

A student titrates a 25.00 mL sample of a 0.1814 M solution of hypochlorous acid (HClO, $K_a = 2.9 \times 10^{-8}$) with a stock solution of sodium hydroxide (KOH), a strong soluble base.

a) What is the initial pH of the sample HClO solution? [8 points]

$HClO(aq) + H_2O(\ell) \leftrightarrows H_3O^+(aq) + ClO^-(aq)$ $\qquad K_a = \frac{[H_3O^+][ClO^-]}{[HClO]}$

	Initial	Change	Equilibrium
H_3O^+	0	x	x
ClO^-	0	x	x
HClO	0.1814	-x	0.1814 - x

$\frac{(x)(x)}{(0.1814 - x)} = 2.9 \times 10^{-8}$ $\qquad$ If we assume x << 0.1814

$x^2 = (0.1814)(2.9 \times 10^{-8}) = 5.26 \times 10^{-9}$ $\qquad x = (5.26 \times 10^{-9})^{1/2} = 7.25 \times 10^{-5}$

$pH = - \log_{10}(7.25 \times 10^{-5}) = 4.14$

b) After 38.17 mL of sodium hydroxide solution is added the equivalence point for the titration is reached. Based on this result, what is the concentration of the sodium hydroxide stock solution? [8 points]

Neutralization reaction is $HClO(aq) + NaOH(aq) \rightarrow Na^+(aq) + ClO^-(aq) + H_2O(\ell)$

Since equal amounts of acid and base react, then at equivalence point moles acid = moles base

moles acid = moles base, and so $M_{acid} V_{acid} = M_{base} V_{base}$

$M_{base} = M_{acid} (V_{acid}/V_{base}) = (0.1814 \text{ M}) (25.00/38.17) = 0.1188 \text{ M}$

c) In the above titration, what is the pH at the equivalence point (when 25.00 mL of stock HClO solution has been mixed with 38.17 mL of stock NaOH solution)? [12 points]

The volume at this point is V = 25.00 mL + 38.17 mL = 63.17 mL

At this point, all the weak acid has been converted into weak base. So this is finding the pH of a weak base solution.

The moles of ClO^- is $\qquad n = (0.1188 \text{ M}) (0.03817 \text{ L}) = 4.54 \times 10^{-3}$ mol

The initial ClO^- concentration is $[ClO^-] = (4.54 \times 10^{-3} \text{ mol})/(0.06317 \text{ L}) = 0.0718 \text{ M}$

$K_b = 1.0 \times 10^{-14}/K_a = (1.0 \times 10^{-14})/(2.9 \times 10^{-8}) = 3.45 \times 10^{-7}$

$ClO^-(aq) + H_2O(\ell) \leftrightarrows HClO(aq) + OH^-(aq)$ $\qquad K_b = \frac{[HClO] [OH^-]}{[ClO^-]}$

	Initial	Change	Equilibrium
HClO	0	x	x
OH^-	0	x	x
ClO^-	0.0718	- x	0.0718 - x

$\frac{(x)(x)}{(0.0718 - x)} = 3.45 \times 10^{-7}$ $\qquad$ If we assume x << 0.0718

$x^2 = (0.0718)(3.45 \times 10^{-7}) = 2.48 \times 10^{-8}$ $\qquad x = 1.57 \times 10^{-4}$ $\qquad pOH = 3.80$ $\qquad pH = 10.20$

3) Consider the following galvanic cell (at T = 25. °C)

Cu^{2+}(0.5000 M) | Cu(s) || Ag(s) | Ag^{+}(0.00200 M)

Find the following. You may need to use some of the reduction data given below in doing part of this problem

$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$ E° = 0.80 v
$Cu^{+}(aq) + e^{-} \rightarrow Cu(s)$ E° = 0.52 v

$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$ E° = 0.34 v
$Cu^{2+}(aq) + e^{-} \rightarrow Cu^{+}(aq)$ E° = 0.16 v

a) The half cell oxidation reaction, the half cell reduction, and the net cell reaction [5 points]

ox $Cu(s) \rightarrow Cu^{2+}(aq) + 2\,e^{-}$ E° = - 0.34 v

red $Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$ x 2 E° = + 0.80 v

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cell $Cu(s) + 2\,Ag^{+}(aq) \rightarrow Cu^{2+}(aq) + 2\,Ag(s)$ $E°_{cell}$ = + 0.46 v

b) $E°_{cell}$ [5 points]

$E°_{cell}$ = 0.46 v (see above)

c) E_{cell} [6 points]

From Nernst

$$E_{cell} = E°_{cell} - (RT/nF)\ln(Q) \qquad Q = \frac{[Cu^{2+}]}{[Ag^{+}]^2} = \frac{(0.5000)}{(0.00200)^2} = 1.25 \times 10^5$$

$$E_{cell} = (0.46\text{ v}) - \frac{(8.314\text{ J/mol}\cdot\text{K})(298.\text{ K})}{(2)(96485\text{ C/mol})}\ln(1.25 \times 10^5) = 0.31\text{ v}$$

4) MPAN (peroxymethacryloyl nitrate) is one of a family of related compounds that are atmospheric pollutants. The reaction, given below, is for most conditions an irreversible first order reaction

MPAN $\rightarrow$ "products"

The rate constant for the reaction is $k = 5.6 \times 10^{-6}\ s^{-1}$ at T = 0.0 °C, and $k = 1.2 \times 10^{-2}\ s^{-1}$ at T = 50.0 °C

Find the following

a) The value for $t_{1/2}$ for MPAN at T = 0.0 °C. [5 points]

$$t_{1/2} = \frac{\ln(2)}{(5.6 \times 10^{-6}\ s^{-1})} = 1.24 \times 10^{5}\ s$$

b) The value for A and E_a, the Arrhenius parameters, for the above reaction (including correct units) [15 points]

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

$$E_a = - \frac{R \ln(k_2/k_1)}{\{ (1/T_2) - (1/T_1) \}} = - \frac{(8.314\ J/mol{\cdot}K) \ln(1.2 \times 10^{-2}/5.6 \times 10^{-6})}{\{ (1/323.\ K) - (1/273\ K) \}} = 112.5\ kJ/mol$$

We may use the rate constant at 0.0 °C to find A

$$k = A \exp(-E_a/RT)$$

$$A = k \exp(E_a/RT) = (5.6 \times 10^{-6}\ s^{-1}) \exp[(112500.\ J/mol)/(8.314\ J/mol{\cdot}K)(273.\ K)]$$

$$= (5.6 \times 10^{-6}\ s^{-1})\ e^{49.57} = 1.9 \times 10^{16}\ s^{-1}$$