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]

$N_A = 6.022 \times 10^{23}$ $\quad$ $°C = (^5/_9)(°F - 32)$ $\quad$ $°F = (^9/_5)(°C) + 32$

$1\text{ amu} = 1.661 \times 10^{-27}\text{ kg}$ $\quad$ $°C = K - 273.15$ $\quad$ $K = °C + 273.15$

$1\text{ atm} = 760\text{ torr} = 760\text{ mm Hg}$ $\quad$ $1\text{ atm} = 1.013\text{ bar}$ $\quad$ $pV = nRT$

$R = 0.08206\text{ L}\cdot\text{atm/mol}\cdot\text{K}$ $\quad$ $1\text{ L}\cdot\text{atm} = 101.3\text{ J}$ $\quad$ (1 volt) (1 Coulomb) = 1 Joule

$R = 8.314\text{ J/mol}\cdot\text{K}$ $\quad$ $1\text{ J} = 1\text{ kg}\cdot\text{m}^2/\text{s}^2$

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

$p_A = X_A\, p_A°$ $\quad$ $[B] = k\, p_B$ $\quad$ $\Delta p_A = X_B p_A°$

$\Delta T_b = K_b\, m_B$ $\quad$ $\Delta T_f = K_f\, m_B$ $\quad$ $\Pi = [B]RT$

$H = U + pV$ $\quad$ $G = H - TS$

$\Delta G_{rxn} = \Delta G°_{rxn} + RT \ln Q$ $\quad$ $\ln K = -\Delta G°_{rxn}/RT$ $\quad$ $K_p = K_C (RT)^{\Delta n}$

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

$K_a \cdot K_b = K_w = 1.0 \times 10^{-14}$ (at T = 25°C) $\quad$ $pH = pK_a + \log_{10}\{[\text{base}]/[\text{acid}]\}$

$\Delta G = -nFE_{cell}$ $\quad$ $E_{cell} = E°_{cell} - (RT/nF) \ln Q$ $\quad$ $\ln K = nFE°_{cell}/RT$

$[A]_t = [A]_0\, e^{-kt}$ $\quad$ $\ln[A]_t = \ln[A]_0 - kt$ $\quad$ $t_{1/2} = \ln 2/k$

$[A]_t = [A]_0/(1 + kt[A]_0)$ $\quad$ $(1/[A]_t) = (1/[A]_0) + kt$ $\quad$ $t_{1/2} = 1/(k[A]_0)$

$k = A\, e^{-E_a/RT}$ $\quad$ $\ln k = \ln A - (E_a/R)(1/T)$ $\quad$ $\ln(k_2/k_1) = -(E_a/R)\,[\,(1/T_2) - (1/T_1)\,]$

GENERAL CHEMISTRY 2
FINAL EXAM
June 14, 2019

Name ____

Panthersoft ID ____

Signature ____

Part 1 ________________ **(50 points)**

Part 2 ________________ **(59 points)**

Part 3 ________________ **(91 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. [5 points each]

1) Which of the following mixtures of liquids is likely to form a solution?

a) A mixture of two polar liquids
b) A mixture of two nonpolar liquids
D c) A mixture of a polar liquid and a nonpolar liquid
d) Both a and b
e) Both a and c

2) For a process to be spontaneous, which of the following must be true?

a) $\Delta S_{univ} > 0$
b) $\Delta S_{syst} > 0$
A c) $\Delta S_{surr} > 0$
d) Both b and c
e) Both a and b and c

3) The numerical value for the equilibrium constant for the reaction

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

is $K_C = 3.6 \times 10^{-7}$ at T = 350. °C. The numerical value for the equilibrium constant for the reaction

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

measured at the same temperature, is

a) $K_C = 3.6 \times 10^{-7}$
b) $K_C = 1.8 \times 10^{-5}$
E c) $K_C = 6.0 \times 10^{-4}$
d) $K_C = 1.7 \times 10^{3}$
e) $K_C = 2.8 \times 10^{6}$

4) For an acidic aqueous solution at T = 25. °C

a) $[H_3O^+] > 1.0 \times 10^{-7}$
b) $[H_3O^+] > [OH^-]$
D c) pH > 7.0
d) Both a and b
e) Both a and b and c

5) Which of the following is a strong acid?

a) $HClO_4$
b) HI
D c) HF
d) Both a and b
e) Both a and c

6) Consider the three substances H_2SO_4, H_2SeO_4, and H_2SeO_3. Of these three substances

a) H_2SeO_3 is the strongest acid and H_2SeO_4 is the weakest acid
b) H_2SeO_4 is the strongest acid and H_2SeO_3 is the weakest acid
D c) H_2SeO_4 is the strongest acid and H_2SO_4 is the weakest acid
d) H_2SO_4 is the strongest acid and H_2SeO_3 is the weakest acid
e) H_2SO_4 is the strongest acid and H_2SeO_4 is the weakest acid

7) The indicator methyl red has $pK_a = 5.1$ Methyl red would be a good choice for an indicator for

a) the titration of a strong acid with a strong base
b) the titration of a strong base with a strong acid
C c) the titration of a weak base with a strong acid
d) the titration of a weak acid with a strong base
e) Methyl red would be a good choice of indicator for all of the above titrations

8) In which of the following substances does phosphorus have the largest value for oxidation number?

a) $PF_3(g)$
b) $P_4(s)$
C c) $P_2O_5(s)$
d) $P_4O_6(s)$
e) $H_3PO_3(aq)$

9) Consider the following two half cell reduction potentials

$Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s)$ E° = 0.34 v $Zn^{2+}(aq) + 2\ e^- \rightarrow Zn(s)$ E° = - 0.76 v

Based on this information, which reaction is most likely to occur for standard conditions

a) $Zn(s) \rightarrow Zn^{2+}(aq) + 2\ e^-$
b) $Zn^{2+}(aq) + 2\ e^- \rightarrow Zn(s)$
A c) $Cu(s) \rightarrow Cu^{2+}(aq) + 2\ e^-$
d) $Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s)$
e) All of these reactions are equally likely to occur for standard conditions

10) The stoichiometric equation for the reaction of hydrogen with oxygen to form water may be written as

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$$

This reaction is

a) 2^{nd} order with respect to $H_2(g)$
b) 2^{nd} order with respect to $O_2(g)$
E c) 2^{nd} order with respect to $H_2O(l)$
d) Both a and c
e) Cannot tell from the information given

Part 2. Short answer questions.

1) A 1.358 mol/L solution of glycerol ($C_3H_8O_3$, MW = 92.09 g/mol) in water (H_2O, MW = 18.02 g/mol) has a density D = 1.029 g/mL. What is the percent by mass glycerol in the solution? [10 points]

Assume 1.000 L solution. Then

$$\text{grams glycerol} = 1.000\ \text{L soln}\ \frac{1.358\ \text{mol glycerol}}{\text{L soln}}\ \frac{92.09\ \text{g}}{1\ \text{mol}} = 125.1\ \text{g glycerol}$$

$$\text{grams solution} = 1.000\ \text{L soln}\ \frac{1000.\ \text{mL}}{\text{L soln}}\ \frac{1.029\ \text{g}}{\text{mL soln}} = 1029.\ \text{g solution}$$

$$\text{So percent by mass} = \frac{125.1\ \text{g}}{1029.\ \text{g}} \times 100\ \% = 12.2\ \%\ \text{by mass}$$

2) A solution is prepared by dissolving 0.0681 g of potassium bromide (KBr, MW = 119.0 g/mol), a soluble ionic compound, in water, at T = 30.0 °C. The final volume of the solution formed is V = 200.0 mL. What is the osmotic pressure of the solution (relative to pure water)? Give your final answer in units of torr. [12 points]

$$[\text{KBr}] = \frac{0.0681 \text{ g KBr}}{0.2000 \text{ L}} \; \frac{1 \text{ mol}}{119.0 \text{ g}} = 2.61 \times 10^{-3} \text{ mol/L KBr}$$

$$[\text{particle}] = \frac{2.61 \times 10^{-3} \text{ mol}}{\text{L}} \; \frac{2 \text{ mol particle}}{1 \text{ mo KBr}} = 5.22 \times 10^{-3} \text{ mol/L particles}$$

$$\Pi = [\text{B}]\,\text{RT} = (5.22 \times 10^{-3} \text{ mol/L})\,(0.08206 \text{ L}\bullet\text{atm/mol}\bullet\text{K})\,(303.\text{ K}) = 0.142 \text{ atm} \; \frac{760 \text{ torr}}{1 \text{ atm}} = 108.\text{ torr}$$

3) Define the following terms [5 points each]

a) amphoteric

A substance that can act as either a Bronsted acid or a Bronsted base (H_2O, for example).

b) buffer

A solution that is resistant to changes in pH. Buffers usually contain weak acid/conjugate base or weak base/conjugate acid pairs.

c) electrode

The site of an oxidation or reduction reaction in an electrochemical cell.

4) Balance the following oxidation-reduction reaction for acid conditions [12 points]

$As_2O_3(s) + NO_3^-(aq) \rightarrow H_3AsO_4(aq) + NO(g)$

oxidation $As_2O_3(s) + 5\ H_2O(l) \rightarrow 2\ H_3AsO_4(aq) + 4\ e^- + 4\ H^+(aq)$ x 3

reduction $NO_3^-(aq) + 3\ e^- + 4\ H^+(aq) \rightarrow NO(g) + 2\ H_2O(l)$ x 4

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net $3\ As_2O_3(s) + 4\ NO_3^-(aq) + 7\ H_2O(l) + 4\ H^+(aq)$

$\rightarrow 6\ H_3AsO_4(aq) + 4\ NO(g)$

5) Pure magnesium metal (Mg, MW = 24.31 g/mol) does not occur in nature, but can be produced by electrolysis of molten magnesium chloride ($MgCl_2$, MW = 95.22 g/mol). The half-cell reaction corresponding to the production of magnesium metal is

$Mg^{2+} + 2\ e^- \rightarrow Mg$

In a particular experiment, molten magnesium chloride undergoes electrolysis for a period t = 6.00 hours, at a current i = 35.0 amp = 35.0 Coulomb/s. How many grams of magnesium metal are produced? [10 points]

$$\text{moles electrons} = 6\text{ hours}\ \frac{60\text{ min}}{1\text{ hr}}\ \frac{60\text{ sec}}{1\text{ min}}\ \frac{35.0\text{ Coulomb}}{\text{sec}}\ \frac{1\text{ mol }e^-}{96485.\text{ Coulomb}} = 7.84\text{ mol }e^-$$

$$\text{grams Mg} = 7.84\text{ mol }e^-\ \frac{1\text{ mol Mg}}{2\text{ mol }e^-}\ \frac{24.31\text{ g Mg}}{\text{mol}} = 95.24\text{ g}$$

Part 3. Problems

1) Thermochemistry is often useful in determining properties for substances that cannot be measured directly.

Consider the following reaction

$In(OH)_3(s) \leftrightarrows In^{3+}(aq) + 3\ OH^-(aq)$

Thermochemical data for the substances involved in the above reaction are given below.

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	S° (J/mol•K)
$In^{3+}(aq)$	- 14.2	- 133.9	259.4
$In(OH)_3(s)$	- 895.4	- 761.5	104.6
$OH^-(aq)$	- 230.0	- 157.3	- 10.7

a) What are the values for $\Delta S°_{rxn}$ and $\Delta G°_{rxn}$ for the above reaction? [10 points]

$\Delta S°_{rxn} = [\ S°(In^{3+}(aq)) + 3\ S°(OH^-(aq))\ ] – [\ S°(In(OH)_3(s))\ ]$

$= [\ (259.4) + 3\ (-10.7)\ ] – [\ 104.6\ ] = + 122.7$ J/mol•K

$\Delta G°_{rxn} = [\ \Delta G°_f(In^{3+}(aq)) + 3\ \Delta G°_f(OH^-(aq))\ ] - [\ \Delta G°_f(In(OH)_3(s))\ ]$

$= [\ (-133.9) + 3\ (-157.3)\ ] – [\ -761.5\ ] = + 155.7$ kJ/mol

b) Give the expression for K (the equilibrium constant) for the above reaction, in terms of reactant and product concentrations. [5 points]

$K = [In^{3+}]\ [OH^-]^3$

c) What is the numerical value for K, the equilibrium constant for the above reaction. [8 points]

$$\ln K = -\frac{\Delta G°_{rxn}}{RT} = -\frac{(-155700.\ \text{J/mol})}{(8.314\ \text{J/mol•K})\ (298.\ \text{K})} = -62.84$$

$K = e^{-62.84} = 5.1 \times 10^{-28}$

2) Find the values for pH for the following two solutions.

a) A 0.0409 M solution of pivalic acid ($C_5H_{10}O_2$, MW = 102.1 g/mol), a weak monoprotic acid with K_a = 9.3 x 10^{-6}. [10 points]

Reaction is $C_5H_{10}O_2(aq) + H_2O(l) \leftrightarrows H_3O^+(aq) + C_5H_9O_2^-(aq)$

$$K_a = \frac{[H_3O^+][C_5H_9O_2^-]}{[C_5H_{10}O_2]}$$

	Initial	Change	Equilibrium
H_3O^+	0	x	x
$C_5H_9O_2^-$	0	x	x
$C_5H_{10}O_2$	0.0409	- x	0.0409 - x

$\frac{(x)(x)}{(0.0409 - x)} = 9.3 \times 10^{-6}$ If we assume x << 0.0409, then

$\frac{x^2}{0.0409} = 9.3 \times 10^{-6}$ $x^2 = (9.3 \times 10^{-6})(0.0409) = 3.8 \times 10^{-7}$

$x = (3.8 \times 10^{-7})^{1/2} = 6.2 \times 10^{-4}$ So assumption was good.

$pH = -\log_{10}(6.2 \times 10^{-4}) = 3.21$

b) A solution that contains 0.0521 M of acetic acid (CH_3COOH, MW = 60.1 g/mol), a weak monoprotic acid with K_a = 1.8 x 10^{-5}, and 0.0338 M sodium hydroxide (NaOH, MW = 40.0 g/mol), a strong soluble base.
[15 points]

The neutralization reaction with NaOH is

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COO^-(aq) + Na^+(aq) + H_2O(l)$$

	CH_3COOH	NaOH	CH_3COO^-
Initial	0.0521	0.0338	
After neutralization	0.0183	0	0.0338

Since there are appreciable amounts of a weak acid and its conjugate base present, we can use the Henderson equation

$pH = pK_a + \log_{10}\{[base]/[acid]\} = -\log_{10}(1.8 \times 10^{-5}) + \log_{10}\{(0.0338)/(0.0183)\}$

$= 4.475 + 0.266 = 5.01$

Note: This problem can also be done by making an ICE table, using the concentrations present after the neutralization reaction is complete.

3) Several reduction reactions and their half-cell potentials for standard conditions are given below

$Br_2(l) + 2\ e^- \rightarrow 2\ Br^-(aq)$	E° = + 1.06 v
$Ag^+(aq) + e^- \rightarrow Ag(s)$	E° = + 0.80 v
$I_2(s) + 2\ e^- \rightarrow 2\ I^-(aq)$	E° = + 0.54 v
$Ni^{2+}(aq) + 2\ e^- \rightarrow Ni(s)$	E° = - 0.28 v
$Fe^{2+}(aq) + 2\ e^- \rightarrow Fe(s)$	E° = - 0.44 v
$Al^{3+}(aq) + 3\ e^- \rightarrow Al(s)$	E° = - 1.66 v

a) Which of the following metals is easiest to oxidize (circle the correct answer)? [5 points]

Ag(s) **Al(s)** Fe(s) Ni(s)

b) Consider the following galvanic cell

$Ni(s)\ |\ Ni^{2+}(0.400\ M)\ ||\ I^-(6.2 \times 10^{-4}\ M)\ |\ I_2(s)\ |Pt(s)$

For the above galvanic cell, give the half-cell oxidation reaction, the half-cell reduction reaction, and the net cell reaction. Also find the values for $E°_{cell}$ and E_{cell} for the galvanic cell. [15 points]

oxidation	$Ni(s) \rightarrow Ni^{2+}(aq) + 2\ e^-$	E° = + 0.28 v
reduction	$I_2(s) + 2\ e^- \rightarrow 2\ I^-(aq)$	E° = + 0.54 v
net	$Ni(s) + I_2(s) \rightarrow Ni^{2+}(aq) + 2\ I^-(aq)$	$E°_{cell}$ = + 0.82 v

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

$$Q = [Ni^{2+}]\ [I-]^2 = (0.400)\ (6.2 \times 10^{-4})^2 = 1.5 \times 10^{-7}$$

$$E_{cell} = 0.82\ v - \frac{(8.314\ J/mol\cdot K)\ (298.\ K)}{(2)\ (96485\ Coulomb/mol)} \ln(1.5 \times 10^{-7}) = 0.82\ v + 0.20\ v = 1.02\ v$$

4) In the gas phase, dinitrogen pentoxide (N_2O_5, MW = 108.0 g/mol) decomposes to form nitrogen dioxide (NO_2, MW = 46.0 g/mol) and nitrogen trioxide (NO_3, MW = 62.0 g/mol). The balanced chemical equation for the reaction is

$$N_2O_5(g) \rightarrow NO_2(g) + NO_3(g)$$

The reaction follows first order kinetics, with

$$\text{rate} = k\,[N_2O_5]$$

Experimentally, it is found that $k = 3.4 \times 10^{-5}\ s^{-1}$ at T = 30.0 °C, and $k = 7.5 \times 10^{-4}\ s^{-1}$ at T = 75.0 °C.

a) A system at T = 30.0 °C initially contains 4.55×10^{-2} mol/L of N_2O_5. After 100.0 minutes, what will be the concentration of N_2O_5 in the system? [8 points]

For first order kinetics, $[A]_t = [A]_0\, e^{-kt}$

T = 100.0 min (60 s/min) = 6000. s

So $[N_2O_5]_t = (4.55 \times 10^{-2}\ \text{mol/L}) \exp(-(3.4 \times 10^{-5}\ s^{-1})(6000.\ s))$

$= (4.55 \times 10^{-2}\ \text{mol/L})(0.8155) = 3.71 \times 10^{-2}\ \text{mol/L}$

b) Assuming the rate constant for this reaction obeys the Arrhenius equation, find the values for A and E_a (including correct units). [15 points]

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

So $$E_a = -\frac{R \ln(k_2/k_1)}{[\,(1/T_2) - (1/T_1)\,]} = -\frac{(8.314\ \text{J/mol}\cdot\text{K}) \ln(7.5 \times 10^{-4}/3.4 \times 10^{-5})}{[\,(1/348.\text{K}) - (1/303.\ \text{K})\,]}$$

$= 60270.$ J/mol $= 60.27$ kJ/mol

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

$A = k\, e^{+Ea/RT}$. We can use either value for k. If we use the value at T = 30. °C, then

$A = (3.4 \times 10^{-5}\ s^{-1}) \exp[\,(60270.\ \text{J/mol})/(8.314\ \text{J/mol}\cdot\text{K})(303.\ \text{K})]$

$= (3.4 \times 10^{-5}\ s^{-1}) \exp(23.92) = 8.4 \times 10^{5}\ s^{-1}$