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

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

R = 0.08206 L•atm/mol•K $\quad$ 1 L•atm = 101.3 J

R = 8.314 J/mol•K $\quad$ 1 J= 1 kg•m^2/s^2

F = 96485. C/mol $\quad$ (1 volt) • (1 Coulomb) = 1 Joule

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

$\Delta T_b = K_b\, m_B$ $\quad$ $\Delta T_f = K_f\, m_B$ $\quad$ $\Pi = M_B RT$

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

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

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

$K_a \cdot K_b = K_w$ $\quad$ $pH + pOH = pK_w$

$K_a \cdot K_b = 1.0 \times 10^{-14}$ (at T = 25. °C) $\quad$ pH + pOH = 14.00 (at T = 25. °C)

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

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

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

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

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

GENERAL CHEMISTRY 2
FINAL EXAM
APRIL 25, 2022

Name ____

Panthersoft ID ____

Signature ____

Part 1 ________________ **(50 points)**

Part 2 ________________ **(82 points)**

Part 3 ________________ **(68 points)**

TOTAL ________________ **(200 points)**

Do all of the following problems. <u>Show your work.</u>
Unless otherwise stated, you may assume T = 25. °C in all problems.

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) Consider a nonpolar liquid such as carbon tetrachloride (CCl_4). Which general types of solids would be expected to usually be soluble in such a liquid?

a) Polar molecular solid
b) Non-polar molecular solid
B c) Ionic solid
d) Both a and c
e) Both b and c

2) For a chemical reaction to be spontaneous for standard conditions which of the following must be true?

a) $\Delta S°_{syst} > 0$
b) $\Delta S°_{surr} > 0$
C c) $\Delta S°_{univ} > 0$
d) Both a and b
e) Both a and b and c

3) For which of the following reactions can an expression for K_p be written?

a) $CO_2(g) + H_2O(\ell) \leftrightarrows H_2CO_3(aq)$
b) $H_2(g) + I_2(s) \leftrightarrows 2\ HI(g)$
B c) $NH_3(aq) + H_2O(\ell) \leftrightarrows NH_4^+(aq) + OH^-(aq)$
d) Both a and b
e) None of the above

4) For the chemical reaction

$$H_2CO(g) \leftrightarrows H_2(g) + CO(g)$$

$K_C = 2.9 \times 10^4$ at T = 400. °C. In a closed system containing CH_2O, CO, and H_2 at 400. °C the value for the reaction quotient is $Q = 2.0 \times 10^6$ As the system approaches equilibrium, which of the following will occur?

a) The moles of H_2CO in the system will increase
b) The moles of CO in the system will increase
A c) The moles of H_2 in the system will increase
d) Both b and c
e) Both a and b and c

5) A Bronsted base is

a) an electron pair donor
b) a proton donor
D c) an electron pair acceptor
d) a proton acceptor
e) an amphoteric substance

6) For which type of titration will the pH at the equivalence point be expected to be less than 7.0?

a) The titration of a strong acid with a strong base
b) The titration of a weak acid with a strong base
E c) The titration of a strong base with a strong acid
d) Both a and b
e) None of the above

7) The solubility product for four slightly soluble ionic compounds containing hydroxide ion (OH^-) are given below

$Co(OH)_2$	$K_{sp} = 5.9 \times 10^{-15}$	$Ni(OH)_2$	$K_{sp} = 5.5 \times 10^{-16}$
$Pb(OH)_2$	$K_{sp} = 1.4 \times 10^{-20}$	$Zn(OH)_2$	$K_{sp} = 3.0 \times 10^{-17}$

Which of the above compounds would have the highest molar solubility when addd to a pH = 10.00 buffer?

a) $Co(OH)_2$
b) $Ni(OH)_2$
A c) $Pb(OH)_2$
d) $Zn(OH)_2$
e) All four compounds would have the same molar solubility when added to a pH = 10.00 buffer

8) In a galvanic cell

a) oxidation occurs at the anode
b) reduction occurs at the anode
A c) oxidation occurs at the cathode
d) Both a and c
e) Both b and c

9) A particular irreversible chemical reaction follows the following rate law: rate = k [A] [B]. The rate law is

a) first order in A
b) first order in B
D c) a homogeneous rate law
d) Both a and b
e) Both a and b and c

10) In the Arrhenius equation, the value for the pre-exponential factor A depends on

a) the collision frequency
b) the orientation of the reactant molecules when they collide
D c) the height of the energy barrier separating reactant and product molecules
d) Both a and b
e) Both a and b and c

Part 2. Short answer.

1) Short answer questions. For each of the following questions given the correct answer by filling in the blank. [5 points each]

a) The conjugate acid of methylamine (CH_3NH_2). ____$CH_3NH_3^+$__________

b) The oxidation number for an atom in an elemental form of a pure chemical substance. ____0_______

c) An expression for the average rate of reaction for the process $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$, in terms of formation of product.

$$\text{average rate} = \frac{1}{2}\frac{\Delta[H_2O]}{\Delta t} = \frac{1}{2}\frac{[H_2O]_2 - [H_2O]_1}{t_2 - t_1}$$

2) At room temperature, hydrogen and bromine gas exist in equilibrium with hydrogen bromide

$H_2(g) + Br_2(g) \rightleftarrows 2\ HBr(g)$ $\quad\quad K_C = 2.2 \times 10^9$

A system initially contains 0.0080 mol/L H_2 and 0.0260 mol/L HBr. There is no Br_2 initially present. Find $[Br_2]$, the concentration of bromine (in mol/L) when equilibrium is reached. [12 points]

$$K_C = \frac{[HBr]}{[H_2]\,[Br_2]}$$

	Initial	Change	Equilibrium
H_2	0.0080	x	0.0080 + x
Br_2	0	x	x
HBr	0.0260	- 2x	0.0260 – 2x

So $\frac{(0.0260 - 2x)^2}{(0.0080 + x)\,(x)} = 2.2 \times 10^9$ $\quad$ Assume x << 0.0080, then

$\frac{(0.0260)^2}{(0.0080)\,x} = 2.2 \times 10^9$ $\quad x = \frac{(0.0260)^2}{(0.0080)\,(2.2 \times 10^9)} = 3.8 \times 10^{-11}$ $\quad$ So x << 0.0080

Therefore, at equilibrium $[Br_2] = 3.8 \times 10^{-11}$ mol/L

3) Find the pH for each of the following solutions [10 points each]

a) A 0.0590 M solution of sodium hydroxide (NaOH), a strong soluble base.

$NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$

So $[OH^-] = 0.0590\ M\ NaOH \ \frac{1\ mol\ OH^-}{1\ mol\ NaOH} = 0.0590\ M\ OH^-$

$pOH = -\log_{10}[OH^-] = -\log_{10}(0.0590) = 1.23$ $\quad\quad pH = 14.00 - pOH = 14.00 - 1.23 = 12.77$

b) A 0.0860 M solution of propanoic acid ($C_3H_6O_2$), a weak acid, with $K_a = 1.35 \times 10^{-5}$

Reaction is $C_3H_6O_2(aq) + H_2O(\ell) \rightleftarrows H_3O^+(aq) + C_3H_5O_2^-(aq)$ $\quad K_a = \frac{[H_3O^+]\,[C_3H_5O_2^-]}{[C_3H_6O_2]}$

	Initial	Change	Equilibrium
H_3O^+	0	x	x
$C_3H_5O_2^-$	0	x	x
$C_3H_6O_2$	0.0860	– x	0.0860 – x

So $\frac{(x)\,(x)}{(0.0860 - x)} = 1.35 \times 10^{-5}$ $\quad$ Assume x << 0.0860, then

$\frac{x^2}{0.0860} = 1.35 \times 10^{-5}$ $\quad x^2 = (0.0860)\,(1.35 \times 10^{-5}) = 1.16 \times 10^{-6}$

$x = (1.16 \times 10^{-6})^{1/2} = 1.07 \times 10^{-3}$ $\quad$ So x << 0.0860

So $[H_3O^+] = x = 1.07 \times 10^{-3}$ $\quad pH = -\log_{10}[H_3O^+] = -\log_{10}(1.07 \times 10^{-3}) = 2.97$

4) A student prepares a buffer solution at pH = 4.80 The buffer uses acetic acid (CH_3COOH) as the weak acid, and acetate ion (CH_3COO^-) as the conjugate base of the weak acid.

a) What are pOH, $[H_3O^+]$, and $[OH^-]$ for the buffer solution? [10 points]

pOH = 14.00 – pH = 14.00 – 4.80 = 9.20

$[H_3O^+] = 10^{-pH} = 10^{-4.80} = 1.6 \times 10^{-5}$ M

$[OH^-] = 10^{-pOH} = 10^{-9.20} = 6.3 \times 10^{-10}$

b) Give the balanced chemical reaction that takes place when a small amount of KOH (a strong soluble base) is added to the buffer solution. [5 points]

$CH_3COOH(aq) + KOH(aq) \rightarrow K^+(aq) + CH_3COO^-(aq) + H_2O(\ell)$

5) Balance the following unbalanced oxidation-reduction reaction for acid conditions. [12 points]

$I_2(aq) + ClO^-(aq) \rightarrow IO_3^-(aq) + Cl^-(aq)$

oxidation $I_2(aq) + 6\ H_2O(\ell) \rightarrow 2\ IO_3^-(aq) + 10\ e^- + 12\ H^+(aq)$

reduction $ClO^-(aq) + 2\ e^- + 2\ H^+(aq) \rightarrow Cl^-(aq) + H_2O(\ell)$ x 5

net $I_2(aq) + 5\ ClO^-(aq) + H_2O(\ell) \rightarrow 2\ IO_3^-(aq) + 5\ Cl^-(aq) + 2\ H^+(aq)$

6) For a particular first order irreversible homogeneous reaction, the half-life of the reaction is found to be $t_{1/2}$ = 47.8 minutes. What is the value for k for the reaction (including correct units)? [8 points]

$t_{1/2} = \frac{\ln(2)}{k}$ $k = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{47.8\ \text{min}} = 0.0145\ \text{min}^{-1}$

Part 3. Problems.

1) Thermodynamic data are given below (at T = 25. °C) and may be of use in doing this problem.

Substance	$\Delta H°_f$(kJ/mole)	$\Delta G°_f$(kJ/mole)	S°(J/mole·K)
Br_2(g)	30.9	3.1	245.5
NO(g)	91.3	87.6	210.8
NOBr(g)	82.2	82.4	273.7

Nitrosyl bromide (NOBr) can be formed from the reaction of bromine gas with nitrogen monoxide. The balanced equation for the reaction is

$$2\ NO(g) + Br_2(g) \leftrightarrows 2\ NOBr(g)$$

a) Find the numerical values for $\Delta S°_{rxn}$, $\Delta G°_{rxn}$, and K (the thermodynamic equilibrium constant) for the above reaction. [18 points]

$$\Delta S°_{rxn} = [\ 2\ S°(NOBr(g))\ ] - [\ 2\ S°(NO(g)) + S°(Br_2(g))\ ]$$

$$= [\ 2\ (273.7)\ ] - [\ 2\ (210.8) + (245.5)\ ] = -\ 119.7\ J/mol\bullet K$$

$$\Delta G°_{rxn} = [\ 2\ \Delta G°_f(NOBr(g))\ ] - [\ 2\ \Delta G°_f(NO(g)) + \Delta G°_f(Br_2(g))\ ]$$

$$= [\ 2\ (82.4)\ ] - [\ 2\ (87.6) + (3.1)\ ] = -\ 13.5\ kJ/mol$$

$$\ln K = -\ \frac{\Delta G°_{rxn}}{RT} = -\ \frac{(-\ 13500.\ J/mol)}{(8.3145\ J/mol\bullet K)\ (298.2\ K)} = 5.44 \qquad K = e^{5.44} = 232.$$

b) Is the above reaction spontaneous for standard conditions (yes/no and a brief justification of your answer)? [6 points]

Yes, because $\Delta G°_{rxn} < 0$.

2) Cadmium II iodate ($Cd(IO_3)_2$, MW = 462.2 g/mol) is a slightly soluble ionic compound.

a) Give the correctly balanced equation for the solubility reaction for cadmium II iodate in water. Also give the expression for K_{sp}, the solubility product. [8 points]

$Cd(IO_3)_2(s) \leftrightarrows Cd^{2+}(aq) + 2\ IO_3^{-}(aq)$ $\qquad$ $K_{sp} = [Cd^{2+}]\ [IO_3^{-}]^2$

b) The osmotic pressure of a saturated solution of cadmium II iodate, measured at T = 25.0 °C, is Π = 104. torr. Based on this result, find the numerical value for K_{sp}, the solubility product of cadmium II iodate. [16 points]

$\Pi = M_BRT$, where M_B is the molarity of solute particles

$$M_B = \frac{\Pi}{RT} = \frac{104.\ \text{torr}\ (1\ \text{atm}/760.\ \text{torr})}{(0.08206\ \text{L}\bullet\text{atm/mol}\bullet\text{K})\ (298.2\ \text{K})} = 5.59 \times 10^{-3}\ \text{M}$$

If we call $[Cd^{2+}] = x$, then $[IO^{3-}] = 2x$

$M_B = [Cd^{2+}] + [IO_3^{-}] = x + 2x = 3x$ $\qquad$ $x = \frac{M_B}{3} = \frac{5.59 \times 10^{-3}}{3} = 1.86 \times 10^{-3}$ M

$K_{sp} = (x)\ (2x)^2 = 4x^3 = 4\ (1.86 \times 10^{-3})^3 = 2.6 \times 10^{-8}$

3) A particular irreversible chemical reaction obeys the rate law

rate = $k [A]^m [B]^n$

The initial rate of reaction is measured for a variety of initial conditions, and the data are given below. All experiments were carried out at the same temperature. Based on this information, find the values for m, n, and k (including correct units). [20 points]

experiment	[A] (mol/L)	[B] (mol/L)	initial rate (mol/L•s)
1	0.0200	0.0200	0.88×10^{-6}
2	0.0200	0.0500	5.54×10^{-6}
3	0.0100	0.0200	0.42×10^{-6}

For m, compare experiments 1 and 3

$$\frac{R_1}{R_3} = \frac{k [A]_1^m [B]_1^n}{k [A]_3^m [B]_3^n} = ([A]_1/[A]_3)^m$$

$(0.88/0.42) = (0.0200/0.0100)^m$ $\quad$ $2.10 = 2^m$ $\quad$ $m = 1$

For n, compare experiments 2 and 1

$$\frac{R_2}{R_1} = \frac{k [A]_2^m [B]_2^n}{k [A]_1^m [B]_1^n} = ([B]_2/[B]_1)^n$$

$(5.54/0.88) = (0.0500/0.0200)^n$ $\quad$ $6.30 = (2.5)^n$ $\quad$ $n = 2$

So the rate law is $\quad R = k [A] [B]^2$

$$k = \frac{R}{[A] [B]^2}$$

Using the data for experiment 1 $\quad k = \dfrac{0.88 \times 10^{-6} \text{ mol/L•s}}{(0.0200 \text{ mol/L}) (0.0200 \text{ mol/L})^2} = 0.110 \text{ L}^2/\text{mol}^2\text{•s}$