

FORMULA SHEET (tear off)

1A										8A									
1 H 1.01	2A										3A	4A	5A	6A	7A	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]						

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

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

$$1 \text{ atm} = 760 \text{ torr} = 760 \text{ mm Hg}$$

$$R = 0.08206 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K}$$

$$R = 8.314 \text{ J}/\text{mol}\cdot\text{K}$$

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

$$^{\circ}\text{C} = (5/9)(^{\circ}\text{F} - 32)$$

$$^{\circ}\text{C} = \text{K} - 273.15$$

$$1 \text{ atm} = 1.013 \text{ bar}$$

$$1 \text{ L}\cdot\text{atm} = 101.3 \text{ J}$$

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

$$^{\circ}\text{F} = (9/5)(^{\circ}\text{C}) + 32$$

$$\text{K} = ^{\circ}\text{C} + 273.15$$

$$pV = nRT$$

$$p_A = X_A p_A^{\circ}$$

$$\Delta T_b = K_b m_B$$

$$H = U + pV$$

$$\Delta G_{\text{rxn}} = \Delta G^{\circ}_{\text{rxn}} + RT \ln Q$$

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

$$K_a \cdot K_b = K_w$$

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

$$\Delta G = -nFE_{\text{cell}}$$

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

$$[A]_t = \frac{[A]_0}{(1 + kt[A]_0)}$$

$$k = A e^{-E_a/RT}$$

$$[B] = k p_B$$

$$\Delta T_f = K_f m_B$$

$$G = H - TS$$

$$\ln K = -\frac{\Delta G^{\circ}_{\text{rxn}}}{RT}$$

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

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

$$\frac{1}{[A]_t} = \frac{1}{[A]_0} + kt$$

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

$$\Delta p_A = X_B p_A^{\circ}$$

$$\Pi = M_B RT$$

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

$$\ln K = \frac{nFE^{\circ}_{\text{cell}}}{RT}$$

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

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

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

$$pH + pOH = pK_w$$

$$pH + pOH = 14.00 \text{ (at } T = 25. ^{\circ}\text{C)}$$

**GENERAL CHEMISTRY 2
FINAL EXAM
DECEMBER 6, 2021**

Name _____

Panthersoft ID _____

Signature _____

Part 1 _____ (45 points)

Part 2 _____ (87 points)

Part 3 _____ (68 points)

TOTAL _____ (100 points)

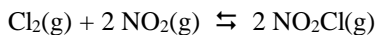
Do all of the following problems. Show your work.
Unless otherwise stated, you may assume T = 25. °C in all problems.

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]

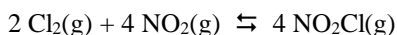
- 1) When a non-volatile solute is dissolved in a volatile liquid
- a) the boiling point temperature of the liquid increases
 - b) the freezing point temperature of the liquid increases
 - A** c) the vapor pressure of the liquid increases
 - d) both a and b
 - e) both a and b and c

- 2) For which of the following substances is $S^\circ = 0.00 \text{ J/mol}\cdot\text{K}$ at $T = 25.0 \text{ }^\circ\text{C}$?
- a) Cu(s)
 - b) O₂(g)
 - E** c) CuO(s)
 - d) Both a and b
 - e) None of the above

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



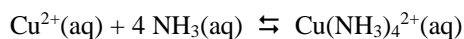
is $K_C = 3.8$ at a particular temperature. The equilibrium constant for the reaction



measured at the same temperature is

- a) 0.13
 - b) 3.8
 - D** c) 7.6
 - d) 14.4
 - e) Cannot be determined from the information given
- 4) For a spontaneous chemical reaction for standard conditions which of the following must be true?
- a) $\Delta G^\circ_{\text{rxn}} < 0$
 - b) $\Delta H^\circ_{\text{rxn}} < 0$
 - A** c) $\Delta S^\circ_{\text{rxn}} < 0$
 - d) Both a and c
 - e) Both a and b and c
- 5) A Bronsted base
- a) is a proton donor
 - b) is a proton acceptor
 - B** c) is an electron pair donor
 - d) is an electron pair acceptor
 - e) none of the above

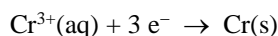
6) The reaction



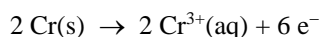
is an example of

- a) an Arrhenius acid-base reaction
- b) a Bronsted acid-base reaction
- C** c) a Lewis acid-base reaction
- d) Both b and c
- e) Both a and b and c

7) The half-cell potential for the reaction



is $E^\circ = -0.74 \text{ v}$. The half-cell potential for the reaction



is

- a) + 0.74 v
- b) - 0.74 v
- A** c) + 1.48 v
- d) - 1.48 v
- e) 0.00 v

8) A particular chemical reaction follows the rate law

$$\text{rate} = k [\text{A}] [\text{B}]^2$$

The concentration of A is doubled, and the concentration of B is tripled. The new rate of reaction will be

- a) the same as the old rate of reaction
- b) 2 times the old rate of reaction
- D** c) 6 times the old rate of reaction
- d) 18 times the old rate of reaction
- e) 36 times the old rate of reaction

9) According to collision theory, which of the following must occur for a chemical reaction to take place?

- a) There must be a collision between the two molecules that are reacting
- b) There must be sufficient energy in the collision to overcome the energy barrier separating reactants from products
- c) The collision must have a favorable orientation between the reactant molecules
- E** d) Both a and b
- e) Both a and b and c

Part 2. Short answer.

1) A solution is prepared by dissolving 0.1786 g of barium chloride (BaCl_2 , MW = 208.2 g/mol) in water. The final volume of the solution is $V = 200.0$ mL. What is the molarity of barium chloride in the solution? [12 points]

$$\text{moles BaCl}_2 = 0.1786 \text{ g} \frac{1 \text{ mol}}{208.2 \text{ g}} = 8.578 \times 10^{-4} \text{ mol}$$

$$\text{molarity} = \frac{\text{moles BaCl}_2}{\text{L solution}} = \frac{8.578 \times 10^{-4} \text{ mol}}{0.2000 \text{ L}} = 4.289 \times 10^{-3} \text{ M}$$

2) For a particular chemical reaction it is found that $\Delta S^\circ_{\text{rxn}} = -14.6 \text{ J/mol}\cdot\text{K}$. Is it possible that the reaction is spontaneous for standard conditions (yes or no, plus a brief justification of your answer)? [8 points]

Yes. For a chemical reaction at standard conditions, $\Delta S^\circ_{\text{rxn}} = \Delta S_{\text{sys}}$. The requirement from the second law of thermodynamics is

$$\Delta S_{\text{univ}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} \geq 0$$

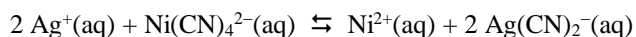
If $\Delta S_{\text{surr}} > +14.6 \text{ J/mol}\cdot\text{K}$, then $\Delta S_{\text{univ}} > 0$. In that case, the reaction will be spontaneous.

3) Give the conjugate acid and the conjugate base for the HPO_4^{2-} ion (correct formula and charge). [4 points each]

conjugate acid H_2PO_4^-

conjugate base PO_4^{3-}

4) Cyanide ion (CN⁻) will interact with a variety of different metal cations. One example of this is the following reaction:



A system initially contains 0.00240 M Ni(CN)₄²⁻, 0.0428 M Ni²⁺(aq), and 0.0138 M Ag(CN)₂⁻. There is initially no Ag⁺ present in the system. Set up an appropriate ICE table for the above system. NOTE: You are not given a numerical value for K_C, the equilibrium constant for the reaction, so only set up the ICE table. [12 points]

$$K_C = \frac{[\text{Ni}^{2+}][\text{Ag}(\text{CN})_2^-]^2}{[\text{Ag}^+]^2 [\text{Ni}(\text{CN})_4^{2-}]}$$

So we need to keep track of all the reactants and products

	Initial	Change	Equilibrium
Ag ⁺	0	2x	2x
Ni(CN) ₄ ²⁻	0.00240	x	0.00240 + x
Ni ²⁺	0.0428	- x	0.0428 - x
Ag(CN) ₂ ⁻	0.0138	- 2x	0.0138 - 2x

Note that there are other ways to define x that would also lead to a correct ICE table.

5) The concentration of magnesium ion in an aqueous solution is [Mg²⁺] = 4.6 x 10⁻⁴ M. At what value for pH will magnesium hydroxide first begin to precipitate from the solution? Note that the solubility product for magnesium hydroxide (Mg(OH)₂) is K_{sp} = 5.6 x 10⁻¹². [12 points]



$$K_{\text{sp}} = [\text{Mg}^{2+}] [\text{OH}^-]^2 = 5.6 \times 10^{-12}$$

We are told the value for [Mg²⁺], and so we need to find the value for [OH⁻] corresponding to the maximum amount of OH⁻ that can be present before Mg(OH)₂ begins to precipitate.

$$[\text{OH}^-]^2 = \frac{K_{\text{sp}}}{[\text{Mg}^{2+}]} = \frac{5.6 \times 10^{-12}}{4.6 \times 10^{-4}} = 1.22 \times 10^{-8}$$

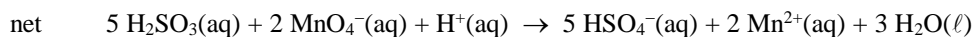
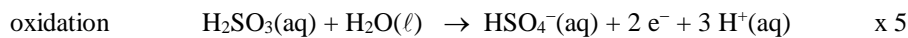
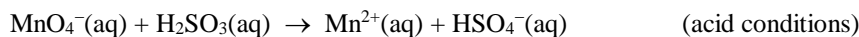
$$[\text{OH}^-] = (1.22 \times 10^{-8})^{1/2} = 1.10 \times 10^{-4} \text{ M}$$

$$\text{pOH} = -\log_{10}(1.10 \times 10^{-4}) = 3.96$$

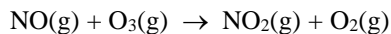
$$\text{pH} = 14.00 - 3.96 = 10.04$$

When the pH reaches 10.04, then Mg(OH)₂(s) will start to precipitate from the solution.

6) Balance the following unbalanced oxidation-reduction reaction for acid conditions. [15 points]



7) The activation energy and pre-exponential factor for the rate constant for the reaction



are $E_a = 12470. \text{ J/mol}$ and $A = 1.8 \times 10^9 \text{ L/mol}\cdot\text{s}$. Based on this, find the numerical value for k at $T = 240. \text{ K}$ (including correct units). [12 points]

$$k = A e^{-E_a/RT} = (1.8 \times 10^{12} \text{ L/mol}\cdot\text{s}) e^{-[(12470. \text{ J/mol})/(8.314 \text{ J/mol}\cdot\text{K})(240.0 \text{ K})]}$$

$$(1.8 \times 10^9 \text{ L/mol}\cdot\text{s}) (1.93 \times 10^{-3}) = 3.48 \times 10^6 \text{ L/mol}\cdot\text{s}$$

8) Define the word catalyst. [8 points]

A catalyst is a substance that when added to a system increases the rate of reaction without itself being produced or consumed.

Part 3. Problems.

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

Substance	ΔH_f° (kJ/mole)	ΔG_f° (kJ/mole)	S° (J/mole·K)
I ₂ (s)	0.0	0.0	116.1
IF(g)	- 95.7	- 118.5	236.2
IF ₅ (g)	- 822.5	- 751.7	327.7

a) What are $\Delta S^\circ_{\text{rxn}}$ and $\Delta G^\circ_{\text{rxn}}$ for the reaction



at T = 25. °C (including units)? [15 points]

$$\begin{aligned}\Delta S^\circ_{\text{rxn}} &= [S^\circ(\text{IF}_5\text{(g)}) + 2 S^\circ(\text{I}_2\text{(s)})] - [5 S^\circ(\text{IF(g)})] \\ &= [(327.7) + 2 (116.1)] - [5 (236.2)] = - 621.1 \text{ J/mol}\cdot\text{K}\end{aligned}$$

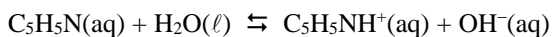
$$\begin{aligned}\Delta G^\circ_{\text{rxn}} &= [\Delta G_f^\circ(\text{IF}_5\text{(g)}) + 2 \Delta G_f^\circ(\text{I}_2\text{(s)})] - [5 \Delta G_f^\circ(\text{IF(g)})] \\ &= [(- 751.7) + 2 (0.0)] - [5 (- 118.5)] = - 159.0 \text{ kJ/mol}\end{aligned}$$

b) What is the numerical value for K, the equilibrium constant, for the above reaction? [12 points]

$$\ln K = - \frac{\Delta G^\circ_{\text{rxn}}}{RT} = - \frac{(- 159000. \text{ J/mol})}{(8.314 \text{ J/mol}\cdot\text{K}) (298. \text{ K})} = 64.18$$

$$K = e^{64.18} = 7.4 \times 10^{27}$$

2) Pyridine (C_5H_5N , MW = 79.10 g/mol) is a weak base. When added to water it reacts by the process



The base ionization constant for pyridine is $K_b = 1.8 \times 10^{-9}$

a) In the above reaction, is $H_2O(\ell)$ a Bronsted acid or a Bronsted base (circle the correct answer)?
[5 points]

Bronsted acid

Bronsted base

b) A chemist prepares a 0.0428 M solution of pyridine. What is the pH of the solution? [16 points]

$$K_b = \frac{[C_5H_5NH^+][OH^-]}{[C_5H_5N]} = 1.8 \times 10^{-9}$$

	Initial	Change	Equilibrium
C_5H_5N	0.0428	- x	0.0428 - x
$C_5H_5NH^+$	0	x	x
OH^-	0	x	x

So
$$\frac{(x)(x)}{(0.0428 - x)} = \frac{x^2}{(0.0428 - x)} = 1.8 \times 10^{-9}$$

Assume $x \ll 0.0428$. Then

$$\frac{x^2}{0.0428} = 1.8 \times 10^{-9} \quad x^2 = (1.8 \times 10^{-9})(0.0428) = 7.70 \times 10^{-11}$$

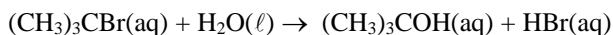
$$x = (7.70 \times 10^{-11})^{1/2} = 8.78 \times 10^{-6}$$

The assumption that $x \ll 0.0428$ was correct.

So $[OH^-] = x = 8.78 \times 10^{-6} \text{ M}$ $pOH = -\log_{10}(8.78 \times 10^{-6}) = 5.06$

$$pH = 14.00 - 5.06 = 8.94$$

3) The irreversible chemical reaction of tert-butyl bromide ((CH₃)₃CBr) in water



follows a first order rate law rate = k [(CH₃)₃CBr] ; with k = 5.2 x 10⁻⁴ s⁻¹ at T = 25.0 °C.

a) What is the value for t_{1/2}, the half-life for the above reaction? Give your final answer in units of minutes. [8 points]

For a first order irreversible reaction

$$t_{1/2} = \frac{\ln(2)}{k} = \frac{\ln(2)}{5.2 \times 10^{-4} \text{ s}^{-1}} = 1333. \text{ s} \frac{1 \text{ min}}{60 \text{ s}} = 22.2 \text{ min}$$

b) In a particular experiment at T = 25.0 °C, the initial concentration of tert-butyl bromide is [(CH₃)₃CBr]₀ = 3.66 x 10⁻³ M. What will be the concentration of tert-butyl bromide after 1 hour? [12 points]

For a first order reaction

$$[(\text{CH}_3)_3\text{CBr}]_t = [(\text{CH}_3)_3\text{CBr}]_0 e^{-kt}$$

$$t = 1 \text{ hr} \frac{60 \text{ min}}{1 \text{ hr}} \frac{60 \text{ s}}{1 \text{ min}} = 3600. \text{ s}$$

$$\text{At } t = 1 \text{ hour, } [(\text{CH}_3)_3\text{CBr}] = (3.66 \times 10^{-3} \text{ M}) e^{-(5.2 \times 10^{-4} \text{ s}^{-1})(3600. \text{ s})}$$

$$= (3.66 \times 10^{-3} \text{ M}) e^{-1.872} = 5.63 \times 10^{-4} \text{ M}$$