Chemistry 210 Exam 2

Be sure to put your name on each page. This page can be removed from your exam so that you will have a Periodic Table handy throughout the exam, it does not need to be turned in. Show all your work for problems which require any sort of calculation, no credit will be given for answers without work shown. If you have shown a significant amount of work or multiple drawings for a problem, draw a box around what you consider your final answer.

Avogadro's Number = $6.022\text{x}10^{23}\ ^{\text{units}}/_{\text{mol}}$
R = $8.314\ ^{\text{J}}/_{\text{mol}\bullet\text{K}}$
$32.00^{o}\text{F} = 0.000^{o}\text{C} = 273.15\text{K}$
$k = Ae^{-Ea/RT}$
Integrated Rate Laws:
- $[A]_t = -kt + [A]_o$
- $ln[A]_t = -kt + ln[A]_o$
- $^1/_{[A]_t} = kt + {}^1/_{[A]_o}$

$$\ln(k) = \left(\frac{-E_{act}}{R}\right)\left(\frac{1}{T}\right) + \ln(A)$$

$$\ln\left(\frac{k_1}{k_2}\right) = \frac{E_{act}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

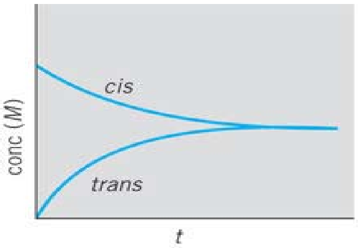
1 **H** 1.0079																	2 **He** 4.0026
3 **Li** 6.941	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
11 **Na** 22.990	12 **Mg** 24.305											13 **Al** 26.982	14 **Si** 28.086	15 **P** 30.974	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.078	21 **Sc** 44.956	22 **Ti** 47.88	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.847	27 **Co** 58.933	28 **Ni** 58.69	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.723	32 **Ge** 72.61	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.03	89 **Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 (269)	111 (272)	112 (277)		114		116		

58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.94	70 **Yb** 173.04	71 **Lu** 174.97
90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** 237.05	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (258)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

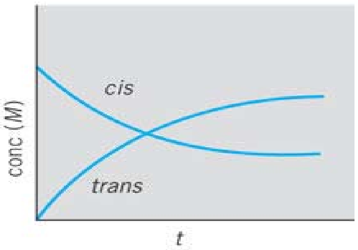
Multiple Choice (5pts each)

1. For a system at equilibrium:
   a. [reactants]/[products] is the equilibrium constant
   b. The forward rate constant ($k_{forward}$) is equal to the reverse rate constant ($k_{reverse}$)
   c. The concentration of products is equal to the concentration of reactants
   [✓ d.] The forward rate is equal to the reverse rate
   e. The reaction stops

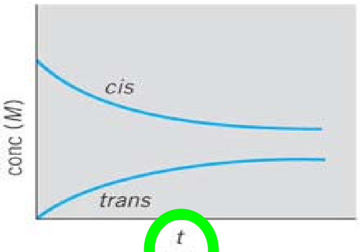
2. The reaction A(cis) ⇆ B(trans) is allowed to come to equilibrium, and the values of the forward and reverse rate constants are measured, $k_{for} = 7.39\text{x}10^{-6}\ \text{s}^{-1}$ and $k_{rev} = 2.88\text{x}10^{-2}\ \text{s}^{-1}$. Which of the following graphs is correct for this reaction?



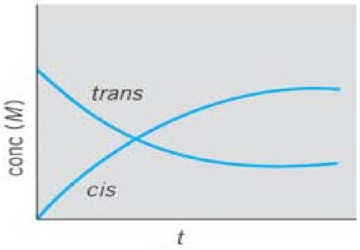
(a)



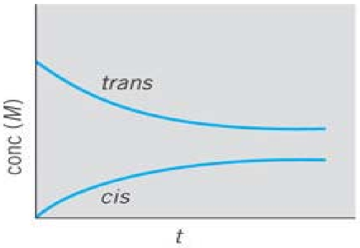
(b)



[✓ (c)]



(d)



(e)

3. For a system at equilibrium:
   a. The forward rate constant ($k_{forward}$) is equal to the reverse rate constant ($k_{reverse}$)
   b. [reactants]/[products] is the equilibrium constant
   c. The reaction stops
   [✓ d.] The forward rate is equal to the reverse rate
   e. The concentration of products is equal to the concentration of reactants

4. Which of the following is the correct equilibrium constant for the reaction?

$$2C_2H_6(g) + 7\,O_2(g) \leftrightarrows 4CO_2(g) + 6H_2O(g)$$

a. $K_c = \dfrac{[CO_2]^4 + [H_2O]^6}{[C_2H_6]^2 + [O_2]^7}$

b. $K_c = \dfrac{4[CO_2]\ + 6[H_2O]}{2[C_2H_6]\ + 7[O_2]}$

[✓ c.] $K_c = \dfrac{[CO_2]^4[H_2O]^6}{[C_2H_6]^2[O_2]^7}$

d. $K_c = \dfrac{[C_2H_6]^2[O_2]^7}{[CO_2]^4[H_2O]^6}$

e. $K_c = \dfrac{(4[CO_2])(6[H_2O])}{(2[C_2H_6])(7[O_2])}$

5. If the value of the equilibrium constant, K_c, is:
   a. Extremely large, no reaction occurs
   b. Equal to 1, the reaction has stopped
   c. Negative, the reaction is spontaneous
   d. Less than 1, the products and reactants are at the same concentration
   [✓ e.] Greater than 1, the equilibrium favors the products

6. For the equilibrium reaction:

$$CO(g) + 3\,H_2(g) \leftrightarrows CH_4(g) + H_2O(g) \qquad \Delta H = -206.2\ {}^{kJ}/_{mol}$$

   Which of the following is ***false***?
   a. Increasing the pressure will shift this equilibrium to the right
   b. Increasing the temperature will shift this equilibrium to the left
   c. Adding extra hydrogen {$H_2(g)$} will shift this equilibrium to the right
   [✓ d.] Removing carbon monoxide {$CO(g)$} will shift this equilibrium to the right
   e. The reaction is exothermic

7. The reaction quotient for a reaction:
   a. Tells you how fast the reaction happens
   b. Is a constant
   c. Is usually a negative number
   [✓ d.] Tells you what direction the reaction must shift to reach equilibrium
   e. Is the concentration of reactants divided by the concentration of products

8. Which of the following is ***true*** about perturbing a system at equilibrium?
   a. If there is more than 1 reactant, all of the reactants must be added to shift the reaction toward products
   b. If more products or reactants are added and all other conditions remain the same, the equilibrium constant will change
   [✓ c.] If more reactant is added, the reaction will shift toward products
   d. Removing products from the reaction will cause the reaction to shift toward reactants
   e. If one (or more) of the products is a solid (precipitate), the equilibrium constant will be exactly the same as if everything was in solution

9. Which of the following statements is ***false*** regarding the reaction quotient, Q?
   a. If $Q=K_c$, the system is at equilibrium
   b. It tells the direction that the reaction must shift to reach equilibrium
   c. If $Q<K_c$, the system needs to shift toward the products to reach equilibrium
   d. It has the same mathematical form as the equilibrium constant
   [✓ e.] If $Q>K_c$, the system needs to shift toward the products to reach equilibrium

10. Which of the following is ***false*** regarding the solubility product constant, K_{sp}?
   a. A large value for K_{sp} means that the substance is very soluble
   b. K_{sp} is just an equilibrium constant that applies to a specific system
   c. If K_{sp} is very small, the substance is insoluble
   d. The concentration of solids never appears in K_{sp}
   [✓ e.] For substances that are extremely insoluble, the value of K_{sp} can be negative

11. For the reaction:

$$CH_4(g) + H_2O(g) \leftrightarrows CO(g) + 3\,H_2(g) \quad \Delta H = 206.2\ {}^{kJ}/_{mol}$$

The equilibrium concentrations have been found to be $[CH_4]_{eq} = 5.34\text{x}10^{-6}$ M, $[H_2O]_{eq} = 1.16\text{x}10^{-8}$ M, $[CO]_{eq} = 3.35\text{x}10^{-5}$ M, $[H_2]_{eq} = 8.81\text{x}10^{-4}$ M.

a. What is the equilibrium constant *expression* for this reaction? (10pts)

$$K_c = \frac{[CO]_{eq}[H_2]^3_{eq}}{[CH_4]_{eq}[H_2O]_{eq}}$$

b. What is the *value* of the equilibrium constant for this reaction? (10pts)

$K_c = \{(3.35\text{x}10^{-5})(8.81\text{x}10^{-4})^3\} / \{(5.34\text{x}10^{-6})(1.16\text{x}10^{-8})\} = 0.370$

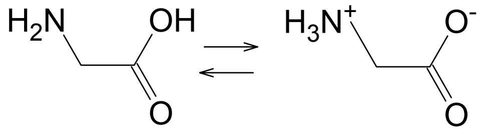
c. If the pressure on this system is changed and it is allowed to re-establish equilibrium, the "new" $[CO]_{eq}$ is $5.85\text{x}10^{-5}$ M. What are the new equilibrium concentrations of all species? (15pts)

Set up an equilibrium table and........ you get negative concentrations. Oops, there is no solution to this problem........

d. Was the pressure on the system increased or decreased in part c? Explain. (10pts)

When the pressure was changed, the concentration of CO increased. Since CO is a product, the equilibrium must have shifted toward products. There are 2 gas particles reacting to form 4 gas particles, so to form more products, the pressure of the system should have decreased.

12. Amino acids are the building blocks of proteins and can exist as either the "amino acid" form or the "zwitterion" form in aqueous solution. The simplest amino acid is glycine:



$C_2H_5O_2N$ Amino acid form

$C_2H_5O_2N$ Zwitterion form

After taking some careful measurements, it is found that the equilibrium constant for this reaction, K_c, is equal to 2.24×10^7.

a. What is the equilibrium constant expression for this reaction? (Use the abbreviation "gly(aa)" for the amino acid form and "gly(z)" for the zwitterions form.) (7pts)

$$K_c = \frac{[\text{gly(z)}]_{eq}}{[\text{gly(aa)}]_{eq}}$$

b. If 62.357g of gly(aa) is dissolved in water to make 500.0mL of solution and allowed to reach equilibrium, what are the equilibrium concentrations of products and reactants, $[\text{gly(z)}]_{eq}$ and $[\text{gly(aa)}]_{eq}$? (14pts)

Set up an equilibrium table, the initial concentration of gly(aa) is 1.66M

Given the size of K_c, this reaction is mostly products at equilibrium. We can say that $[\text{gly(z)}]_{eq}$ is approximately 1.66M, so plugging in to the equilibrium constant expression from above:

$$2.24\text{x}10^7 = 1.66 / x$$
$$x = 7.41\text{x}10^{-8}$$

Since $[\text{gly(aa)}]_{eq}$ is so small, the approximation that $[\text{gly(z)}]_{eq}=[\text{gly(aa)}]_{initial}$ is valid for this problem.

c. After the flask reaches equilibrium, as additional 16.113g of gly(aa) is added. When the system again reaches equilibrium, what are $[\text{gly(aa)}]_{eq}$ and $[\text{gly(z)}]_{eq}$? (Assume the total volume of the solution remains at 500.0mL.) (14pts)

This problem can be approached as an addition to the previous problem, or it can be viewed as the same as the previous problem but starting with (62.357g + 16.113g)=78.470g. Using the second approach, the "initial" concentration of gly(aa) is 2.091M. Using the same approximations as above, $[\text{gly(z)}]_{eq}$ is 2.091M. Plugging in:

$$2.24\text{x}10^7 = 2.091 / x$$
$$x = 9.33\text{x}10^{-8}$$

Since $[\text{gly(aa)}]_{eq}$ is so small, the approximation that $[\text{gly(z)}]_{eq}=[\text{gly(aa)}]_{initial}$ is still valid for this problem.

13. Strontium phosphate has $K_{sp}=3.67\text{x}10^{-43}$. What are the concentrations of strontium and phosphate ions in a saturated solution of strontium phosphate? (10pts)

This problem is essentially the same as the calcium iodate experiment we did in lab. Setting up a K_{sp} equation:

$$Sr_3(PO_4)_2(s) \leftrightarrows 3\ Sr^{2+}(aq) + 2\ PO_4^{3-}(aq)$$
$$K_{sp} = [Sr^{2+}]^3[PO_4^{3-}]^2$$
$$3.67\text{x}10^{-43} = (3x)^3(2x)^2 = (27x^3)(4x^2) = 108x^5$$
$$x = 1.277\text{x}10^{-9}$$
$$[Sr^{2+}]_{eq} = 3x = 3(1.277\text{x}10^{-9}) = 3.83\text{x}10^{-9}\ M$$
$$[PO_4^{3-}]_{eq} = 2x = 2(1.277\text{x}10^{-9}) = 2.55\text{x}10^{-9}\ M$$

14. You have set up two separate experiments:
Experiment #1: To a saturated solution of silver acetate ($AgC_2H_3O_2$, $K_{sp}=4.4\text{x}10^{-3}$) you have added 0.10 M sodium sulfide {$Na_2S(aq)$}.
Experiment #2: To a saturated solution of silver sulfide (Ag_2S, $K_{sp}=6.3\text{x}10^{-50}$) you have added 0.10 M sodium acetate {$NaC_2H_3O_2(aq)$}.
Will a precipitate form in either, neither or both experiments? Explain. (10pts)

In Expt#1, the saturated solution of silver acetate has $[Ag^+]_{eq} = 0.0663$ M. Plugging this into the Ag_2S expression for K_{sp} gives $(0.0663M)^2(0.10M) = 4.4\text{x}10^{-4}$. This is MUCH higher than K_{sp} for silver sulfide, so a precipitate will definitely form in Expt#1.

In Expt#2, the saturated solution of silver sulfide has $[Ag^+]_{eq} = 2.51\text{x}10^{-17}$ M. Plugging this into the silver acetate expression for K_{sp} gives $(2.51\text{x}10^{-17}M)(0.10M) = 2.51\text{x}10^{-18}$. This is much LOWER than K_{sp} for silver acetate, so a precipitate should not form in Expt#2

Bonus: Alanine is another amino acid, similar to the glycine shown in problem 12. If the equilibrium constant for ala(aa)⇆ala(z) is $5.13\text{x}10^5$, what *percentage* of alanine is in the amino acid form in a solution that is at equilibrium? (10pts)

There is no concentration information given in this problem, so let's think about it in terms of variables. If the percent in the amino acid form is "x", then the percent that is in the zwitterions form must be "100-x". (This only works because there is 1 reactant and 1 product in this reaction!) Setting up the K_c equation:

$$K_c = 5.13\text{x}10^5 = [ala(z)]_{eq} / [ala(aa)]_{eq} = (100-x) / x$$

We can probably assume that "x" is small compared to 100, so this can (probably) be simplified to:

$$5.13\text{x}10^5 = 100 / x$$
$$x = 1.95\text{x}10^{-4}$$

The assumption is valid and % ala(aa) at equilibrium is 0.000195%. That's small!!