

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 = 6.022×10^{23} units/mol

$32.00^\circ\text{F} = 0.000^\circ\text{C} = 273.15\text{K}$

Density of Water = $1.000^{\text{g}}/\text{mL}$

$R = 0.08206 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K} = 8.314 \text{ J}/\text{mol}\cdot\text{K}$

$1\text{atm} = 760\text{torr} = 760\text{mmHg} = 101.325\text{kPa}$

$PV = nRT$

$\Delta T_{\text{fp/bp}} = k_{\text{fp/bp}} \cdot m \cdot i$

For water: $k_{\text{fp}} = -1.86^\circ\text{C}/m$
 $k_{\text{bp}} = 0.512^\circ\text{C}/m$

$P_1 = X_1 P_1^\circ$

$\Pi = MRTi$

$C_1 V_1 = C_2 V_2$

$E = C_s \cdot g \cdot \Delta T$

Quadratic formula:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Integrated Rate Laws:

0th $[A]_t = -kt + [A]_o$

1st $\ln[A]_t = -kt + \ln[A]_o$

2nd $1/[A]_t = kt + 1/[A]_o$

$k = Ae^{-E_a/RT}$

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

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

$$\text{pH} = \text{pK}_a + \log\left(\frac{[\text{conjugate base}]}{[\text{conjugate acid}]} \right)$$

$E_{\text{cell}} = E_{\text{cell}}^\circ - \frac{RT}{nF} \ln Q$

$E_{\text{cell}}^\circ = \frac{RT}{nF} \ln K^\circ$

$K^\circ = e^{(nF/RT) E_{\text{cell}}^\circ}$

$F = 96485 \text{ J}/\text{V}\cdot\text{mol of electrons}$

$\Delta G^\circ = \Delta H^\circ_{\text{system}} - T\Delta S^\circ_{\text{system}}$

$\Delta G^\circ = -nFE_{\text{cell}}^\circ = -RT \ln K^\circ$

$\Delta G = \Delta G^\circ + RT \ln Q$

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

$1A = 1 \text{ C} / \text{sec}$

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							

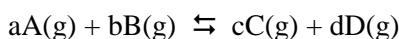
58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.94	70 Yb 173.04	71 Lu 174.97
90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)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

Multiple Choice: Circle the letter of the most correct response. (5pts per question)

1. For a reaction at equilibrium:
- The reactants and products must be in the gas phase.
 - The concentration of reactants is equal to the concentration of products.
 - The reaction has stopped.
 - The mass of reactants is equal to the mass of products.
 - The rate of the forward reaction is equal to the rate of the reverse reaction.**

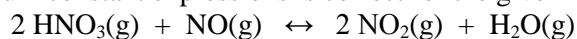
2. Which of the following is **true** regarding equilibrium constants?
- If $K = 1$, the reaction has stopped.
 - If $K < 0$, the reaction reaches equilibrium very quickly.
 - If $K > 1$, the reaction is reactant-favored.
 - If $K < 1$, the reaction is product-favored.
 - If K is very large, the limiting reactant is very nearly used up.**

3. For the generic equation



The value of the equilibrium constant, K_c :

- Is not affected by temperature
 - Is equal to $([A]^a[B]^b)/([C]^c[D]^d)$
 - Is equal to $k[A]^a[B]^b$
 - Is equal to $([C]^c[D]^d)/([A]^a[B]^b)$**
 - Must be measured, it cannot be derived from the balanced equation
4. Which of the following is **false** regarding equilibrium?
- Equilibrium can usually be shifted by changing pressure or temperature
 - The rates of the forward and reverse reactions are equal
 - Equilibrium concentrations do not depend upon whether you approach equilibrium from the left or the right
 - The forward and reverse reactions stop when a system reaches equilibrium**
 - The concentrations of products and reactants does not change once the reaction has reached equilibrium
5. Which of the following equilibrium constant expressions is correct for the given reaction:



a. $K_c = \frac{2[\text{NO}_2]_{\text{eq}} [\text{H}_2\text{O}]_{\text{eq}}}{2[\text{HNO}_3]_{\text{eq}} [\text{NO}]_{\text{eq}}}$

b. $K_c = \frac{[\text{NO}_2]_{\text{eq}}^2 + [\text{H}_2\text{O}]_{\text{eq}}}{[\text{HNO}_3]_{\text{eq}}^2 + [\text{NO}]_{\text{eq}}}$

c. $K_c = \frac{[\text{NO}_2]_{\text{eq}}^2 [\text{H}_2\text{O}]_{\text{eq}}}{[\text{HNO}_3]_{\text{eq}}^2 [\text{NO}]_{\text{eq}}}$

d. $K_c = \frac{[\text{HNO}_3]_{\text{eq}}^2 [\text{NO}]_{\text{eq}}}{[\text{NO}_2]_{\text{eq}}^2 [\text{H}_2\text{O}]_{\text{eq}}}$

e. $K_c = \frac{[\text{NO}_2]_{\text{eq}}^2}{[\text{HNO}_3]_{\text{eq}}^2 [\text{NO}]_{\text{eq}}}$

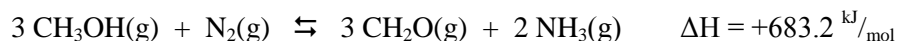
6. All of the following can be explained by LeChatelier's Principle except:
- Removing a gaseous product will shift the equilibrium right.
 - Adding more of an aqueous reactant will shift the equilibrium right.
 - Increasing the temperature of an endothermic reaction will shift the equilibrium right.
 - Increasing the pressure will shift an equilibrium toward the side that has more gas particles.**
 - Removing a gaseous reactant will shift the equilibrium left.
7. Considering the reaction given, all of the following stresses will shift the equilibrium to the left except:
- $$\text{CO(g)} + \text{H}_2\text{O(g)} \leftrightarrow \text{CO}_2\text{(g)} + \text{H}_2\text{(g)} \quad \Delta H_{\text{rxn}} = 131 \text{ kJ/mol}$$
- Decreasing the pressure on the system**
 - Adding carbon dioxide to the system
 - Adding hydrogen to the system
 - Decreasing the temperature of the system
 - Removing carbon monoxide from the system
8. The reaction quotient for a reaction:
- Tells you how fast the reaction happens
 - Is usually a negative number
 - Is a constant
 - Tells you what direction the reaction must shift to reach equilibrium**
 - Is the concentration of reactants divided by the concentration of products
9. Which of the following statements is *false* regarding the reaction quotient, Q ?
- It tells the direction that the reaction must shift to reach equilibrium
 - If $Q < K_c$, the system needs to shift toward the products to reach equilibrium
 - If $Q = K_c$, the system is at equilibrium
 - If $Q > K_c$, the system needs to shift toward the products to reach equilibrium**
 - It has the same mathematical form as the equilibrium constant

True/False: For each of the following statements, circle T for true and F for false. For all false statements, give a brief explanation of *why* the statement is false. (5pts each row)

		Statement	If false, explain why (briefly)
10.	T F	The presence of a catalyst changes the equilibrium constant for a reaction	Equilibrium is thermodynamics, catalysts affect kinetics
11.	T F	Equilibrium can often be shifted by changing pressure or temperature	
12.	T F	At equilibrium, the concentration of reactants and products are equal	@Equilibrium the rates of the forward and reverse rxns are equal, the concentrations rarely are.
13.	T F	If $K > 1$, the reaction is reactant-favored.	If $K > 1$, rxn is product-favored
14.	T F	The reaction quotient indicates the direction that the reaction must shift to reach equilibrium	
15.	T F	If $Q < K_c$, the system needs to shift toward the products to reach equilibrium	

Problems: Show your work.

16. For the reaction:



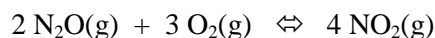
The following equilibrium concentrations are observed: $[\text{CH}_3\text{OH}]_{\text{eq}} = 3.48 \times 10^{-2} \text{ M}$, $[\text{N}_2]_{\text{eq}} = 0.281 \text{ M}$, $[\text{CH}_2\text{O}]_{\text{eq}} = 0.186 \text{ M}$, $[\text{NH}_3]_{\text{eq}} = 7.29 \times 10^{-5} \text{ M}$. What is the equilibrium constant value for this reaction? (10pts)

$$K = \frac{[\text{CH}_2\text{O}]_{\text{eq}}^3 [\text{NH}_3]_{\text{eq}}^2}{[\text{CH}_3\text{OH}]_{\text{eq}}^3 [\text{N}_2]_{\text{eq}}^1}$$

$$K = \frac{(0.186)^3 (7.29 \times 10^{-5})^2}{(3.48 \times 10^{-2})^3 (0.281)^1} = 2.89 \times 10^{-6}$$

Answer 16:

17. You have been studying the reaction of $\text{N}_2\text{O}(\text{g})$ with $\text{O}_2(\text{g})$ to form $\text{NO}_2(\text{g})$. After your system has reached equilibrium, you find that the concentrations of all species are: $[\text{N}_2\text{O}]_{\text{eq}} = 0.391 \text{ M}$, $[\text{O}_2]_{\text{eq}} = 0.106 \text{ M}$, $[\text{NO}_2]_{\text{eq}} = 0.442 \text{ M}$. What is the value of the equilibrium constant for this reaction? (12pts)



$$K = \frac{[\text{NO}_2]_{\text{eq}}^4}{[\text{N}_2\text{O}]_{\text{eq}}^2 [\text{O}_2]_{\text{eq}}^3} = \frac{(0.442)^4}{(0.391)^2 (0.106)^3} = 210.$$

Answer 17:

18. What are the concentrations of lead(II) ions {Atomic # = 82} and bromide ions {Atomic # = 35} in a saturated solution of lead(II) bromide? $\{K_{\text{sp}} = 6.60 \times 10^{-6}\}$ (15pts)

Table time...

	$\text{PbBr}_2(\text{s}) \rightleftharpoons$	$\text{Pb}^{+2}(\text{aq}) +$	$2 \text{Br}^{-1}(\text{aq})$
[] _{initial}	XXXX	0 M	0 M
Δ []	XXXX	+ x	+ 2x
[] _{equilibrium}	XXXX	x M	2x M

$$K_{\text{sp}} = [\text{Pb}^{+2}]_{\text{eq}} [\text{Br}^{-1}]_{\text{eq}}^2 = (x)(2x)^2 = 6.60 \times 10^{-6}$$

$$4x^3 = 6.60 \times 10^{-6}$$

$$x = 0.0118$$

$$[\text{Pb}^{+2}]_{\text{eq}} = x \text{ M} = 0.0118 \text{ M}$$

$$[\text{Br}^{-1}]_{\text{eq}} = 2x \text{ M} = 2(0.0118) \text{ M} = 0.0236 \text{ M}$$

19. When 0.191mols of nitrogen dioxide {NO₂(g)} and 0.235mols of hydrogen gas {H₂(g)} are sealed together in a 1.500L vessel, they reach equilibrium with ammonia {NH₃(g)} and oxygen {O₂(g)}. The equilibrium concentration of NO₂(g) is found to be 0.0584 M. (18pts)
- What are the equilibrium concentrations of all products and reactants?
 - What is the value of K_c?
 - Is the reaction product-favored or reactant-favored?

Setting everything up in a table:

	2 NO ₂ (g) +	3 H ₂ (g) ⇌	2 NH ₃ (g) +	2 O ₂ (g)
Initial	(0.191mol NO ₂)/(1.500L) = 0.12733 M	(0.235mol H ₂)/(1.500L) = 0.15667M	0M	0M
Δ	-2x	-3x	+2x	+2x
@Equil	(0.12733-2x) M	(0.15667-3x) M	2x M	2x M

The problems gives [NO₂]_{eq} = 0.0584 M, so
 $0.12733 - 2x = 0.0584 \text{ M}$
 $x = 0.03447$

Plugging in to get all of the concentrations,

$$[\text{NO}_2]_{\text{eq}} = 0.05584 \text{ M}; [\text{H}_2]_{\text{eq}} = 0.05327\text{M}; [\text{NH}_3]_{\text{eq}} = 0.06893 \text{ M}; [\text{O}_2]_{\text{eq}} = 0.06893 \text{ M}$$

Plugging in to the equilibrium constant expression:

$$K_c = \frac{[\text{NH}_3]_{\text{eq}}^2 [\text{O}_2]_{\text{eq}}^2}{[\text{NO}_2]_{\text{eq}}^2 [\text{H}_2]_{\text{eq}}^3} = \frac{(0.06893)^2 (0.06893)^2}{(0.0584)^2 (0.05327)^3} = 43.8$$

Since K < 1, the equilibrium is product-favored.

20. NH₃(g) reacts with ClO(g) to form NO₃(g) and HCl(g) with an equilibrium constant of 5.72x10⁻⁸. In a 2.00L reaction vessel, you have combined 2.09g of NH₃ with 6.85g of ClO. What are the concentrations of all reactants and products when this reaction reaches equilibrium? (20pts)

Setting everything up in a table:

	NH ₃ (g) +	3 ClO(g) ⇌	NO ₃ (g) +	3 HCl(g)
Initial	(2.09g NH ₃ / 17.031 ^{g/mol}) / (2.00L) = 0.06136 M	(6.85g ClO / 51.452 ^{g/mol}) / (2.00L) = 0.06657 M	0M	0M
Δ	-x	-3x	+x	+3x
@Equil	(0.06136-x)M	(0.06657-3x)M	xM	3xM

Plugging in to the equilibrium constant expression:

$$K_c = \frac{[\text{NO}_3]_{\text{eq}} [\text{HCl}]_{\text{eq}}^3}{[\text{NH}_3]_{\text{eq}} [\text{ClO}]_{\text{eq}}^3} = \frac{(x)(3x)^3}{(0.06136-x)(0.06657-3x)^3} = 5.72 \times 10^{-8}$$

This would be an ugly polynomial expression, BUT since the equilibrium constant is rather reactant-favored we can try an assumption. The amount of reactant that is lost during this reaction should be quite small, so let's assume $3x \ll 0.06657$ {and $x \ll 0.06136$ }. The equilibrium constant expression then simplifies to:

$$\frac{(27x^4)}{(0.06136)(0.06657)^3} = 5.72 \times 10^{-8}$$

$$\text{Solving, } x = 4.425 \times 10^{-4}$$

CHECK YOUR ASSUMPTION!! $3x$ is less than 2% of 0.06657, so our assumption is valid. Hooray!!

Plugging in to get all of the reactant and product concentrations:

$$[\text{NH}_3]_{\text{eq}} = 0.0609\text{M}; [\text{ClO}]_{\text{eq}} = 0.0652\text{M}; [\text{NO}_3]_{\text{eq}} = 4.43 \times 10^{-4}\text{M}; [\text{HCl}]_{\text{eq}} = 1.33 \times 10^{-3}\text{M}$$