HANDOUT SET

GENERAL CHEMISTRY II

Periodic Table of the Elements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 **H** 1.00794																	2 **He** 4.00262
2	3 **Li** 6.941	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984	10 **Ne** 20.179
3	11 **Na** 22.9898	12 **Mg** 24.305											13 **Al** 26.98154	14 **Si** 28.0855	15 **P** 30.97376	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.69	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.723	32 **Ge** 72.59	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
5	37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.710	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.29
6	55 **Cs** 132.9054	56 **Ba** 137.34	57 **La*** 138.91	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.9665	80 **Hg** 200.59	81 **Tl** 204.383	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** 226.0254	89 **Ac**** 227.0278	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (264)	108 **Hs** (265)	109 **Mt** (266)	110 (270)	111 (272)	112 ***** (277)						

*Lanthanides	58 **Ce** 140.12	59 **Pr** 140.9077	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.925	66 **Dy** 162.50	67 **Ho** 164.930	68 **Er** 167.26	69 **Tm** 168.9342	70 **Yb** 173.04	71 **Lu** 174.967
**Actinides	90 **Th** 232.038	91 **Pa** 231.0659	92 **U** 238.0289	93 **Np** 237.0482	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)	103 **Lr** (260)

Mass numbers in parenthesis are the mass numbers of the most stable isotopes. As of 1997 elements 110-112 have not been named.

***Peter Armbruster and Sigurd Hofman synthesized a single atom at the Heavy-Ion Research Center in Darmstadt, Germany in 1996. The atom survived for 280 μs after which it decayed to element 110 by loss of an α-particle

Chapter 15 – 17

Chemical Equilibrium

Equilibrium I: Basic Principles and Calculations

Remember the important associations about mass actions and equilibrium constant expressions:

- ✓**Reverse the direction the equation is written → invert *K***
- ✓**Add chemical equations → multiply the *K*'s for the reactions**
- ✓**Increase stoichiometric coefficients by a factor → raise *K* to the power of factor**

1. What is the calculated K_c for

$$2\,H_{2(g)} + O_{2(g)} \rightleftarrows 2\,H_2O_{(g)}$$

given the the following reactions:

$$CO_2(g) + H_2(g) \rightleftarrows CO(g) + H_2O(g) \quad K_c = 1.4$$
$$C(s) + \tfrac{1}{2}O_2(g) \rightleftarrows CO(g) \quad K_c = 1.0 \times 10^8$$
$$C(s) + CO_2(g) \rightleftarrows 2\,CO(g) \quad K_c = 0.64$$

2. For the reaction:

$$COCl_2(g) \rightleftarrows CO(g) + Cl_2(g) \quad K_c = 8.3 \times 10^{-4}\ (395°C)$$

a. What direction will the reaction proceed if 0.100 mol of $COCl_2$ is placed in a 2.0 L container and heated to 395°C?

b. What direction will the reaction proceed if 0.030 mol of each gas are placed in a 2.0 L vessel and heated?

c. For question a, what is the final concentration of each gas?

d. For question b, what is the final concentration of each gas?

3. A quantity of 0.10 mol of I_2 and 0.10 mol H_2 are placed in a 1.00-L reaction vessel at 430°C. Calculate the equilibrium concentration of all species after equilibrium has been established.

$$H_2(g) + I_2(g) \rightleftarrows 2\,HI(g) \qquad K_c = 54.3$$

4. The K_c for the reaction

$$N_2(g) + 3\,H_2(g) \rightleftarrows 2\,NH_3(g)$$

At 300°C is 0.45. Predict whether the reaction will proceed to the right, left, or is already at equilibrium when 0.10 mol N_2, 0.30 mol H_2, and 0.2 mol NH_3 are placed in a 2.00-L container and heated to 300°C. If a reaction occurs, what is the final concentration of each species?

5. The following quantities of reagents are introduced into a 1.00-L reaction vessel: 0.15 mol H_2, 0.23 mol I_2, and 0.015 mol HI. The reaction vessel is then thermostatted at 430°C. Convince yourself that the system is not at equilibrium and will shift right (to produce more product). What are the equilibrium concentrations of all species? (See problem 3 for additional information.)

6. For question 5, what will be the effect on the equilibrium concentrations if the volume of the container is reduced to 500.0 mL with no loss of reagents.

7. Consider the system at equilibrium in problem 4: what will be the new equilibrium concentrations if the volume of the container is reduced to 1.00 L with no loss of reactants or products?

8. Consider the system at equilibrium in problem 4: what will be the new equilibrium concentrations if the total pressure in the container is increased by adding 1.0 atm of helium gas?

Equilibrium Problems Using K_p

1. Nitrogen dioxide is a component of the brown smog seen over some industrialized cities. The brown nitrogen dioxide participates in an equilibrium with colorless dinitrogen tetraoxide according to the equation

$$2\ NO_2(g) \rightleftarrows N_2O_4(g)$$

The $K_{p,atm}$ for the reaction is 7.5 at 298K (25°C). What is the partial pressure of each gas (in atm) if 0.10 mol of N_2O_4 is placed in a 1.0 L container, sealed, and allowed to come to equilibrium at 298 K?

Unimportant information pertaining to the problem: The N_2O_4 is transferred as a solid at -100°C then the reaction vessel is sealed and the N_2O_4 allowed to vaporize at the experimental temperature.

2. Nitrogen dioxide is a component of the brown smog seen over some industrialized cities. The brown nitrogen dioxide participates in an equilibrium with colorless dinitrogen tetraoxide according to the equation

$$2\ NO_2(g) \rightleftarrows N_2O_4(g)$$

The $K_{p,atm}$ for the reaction is 7.5 at 298K. What is the partial pressure of each gas (in atm) if a NO_2/N_2O_4 mixture, already at equilibrium, is introduced into a container to a total pressure of 150 mmHg?

Equilibrium II: A Couple More Equilibrium Problems

1. A solution of 0.1 M acetic acid is about 1.4% ionized in water as measured by solution's electrical conductivity. What is K_c for

$$CH_3COOH(aq) \rightleftarrows CH_3COO^-(aq) + H^+(aq)$$

2. A quantity of 0.050 mol of SO_2 gas and 0.025 mol of Cl_2 gas are introduced into an evacuated 1.75 L flask and the following equilibrium is established at 303 K:

$$SO_2Cl_2(g) \rightleftarrows SO_2(g) + Cl_2(g) \qquad K_c = 1.2 \times 10^{-3}$$

   What are the final concentrations of each gas?

Some Relative Acid-Conjugate Base Strengths

Strong Acids		K_a	**Conjugate Bases**	
perchloric acid	$HClO_4$	large	perchlorate	ClO_4^-
hydroiodic acid	HI	large	iodide	I^-
hydrobromic acid	HBr	large	bromide	Br^-
hydrochloric acid	HCl	large	chloride	Cl^-
sulfuric acid	H_2SO_4	large	hydrogen sulfate	HSO_4^-
nitric acid	HNO_3	large	nitrate	NO_3^-

Weak Acids			**Conjugate Bases**	
hydrogen sulfate	HSO_4^-	1.1×10^{-2}	sulfate	SO_4^-
nitrous acid	HNO_2	7.2×10^{-4}	nitrite	NO_2^-
formic acid	HCO_2H	1.8×10^{-4}	formate	HCO_2^-
acetic acid	CH_3COOH	1.8×10^{-5}	acetate	CH_3COO^-
carbonic acid	H_2CO_3	4.4×10^{-7}	hydrogen carbonate	HCO_3^-
ammonium ion	NH_4^+	5.6×10^{-10}	ammonia	NH_3
hydrogen carbonate	HCO_3^-	4.8×10^{-11}	carbonate	CO_3^{2-}
ammonia	NH_3	very small	amide ion	NH_2^-

Equilibrium III: Basic Acid-Base Equilibrium

1. What are the species (equilibrium) concentrations of H_3O^+, OH^-, and Cl^- in 0.10 M hydrochloric acid?

2. What are the concentrations of each species in a solution prepared to be 0.10 M acetic acid (CH_3COOH)? $K_a = 1.75 \times 10^{-5}$

3. What is the approximate pH of 0.075 M formic acid? $K_a = 1.7 \times 10^{-4}$

4. What is the K_a of nitrous acid if a 0.050 M solution has a pH of 2.34?

5. What is the pH of 0.010 M ammonia? $K_b = 1.8 \times 10^{-5}$

6. Assuming that $K_a = 1.75 \times 10^{-5}$ for acetic acid, what is K_b for acetate ion? What is the pH of 0.010 M sodium acetate?

Equilibrium IV: Polyprotic Acid-Base Equilibrium

1. Calculate the approximate pH of a solution prepared to be 0.0010 M malonic acid ($H_2C_3H_2O_4$, $K_1 = 1.5 \times 10^{-3}$, $K_2 = 2.0 \times 10^{-6}$).

2. Calculate the concentration of all species in 0.10 M H_3PO_4.

   $K_1 = 7.5 \times 10^{-3}$ $K_2 = 6.2 \times 10^{-8}$ $K_3 = 4.8 \times 10^{-13}$

3. Calculate the pH of the solution prepared to be 0.015 M sodium malonate ($Na_2C_3H_2O_4$)

Equilibrium V: Acid-Base Buffers and Titrimetry

1. Calculate the pH of the solution which is prepared to be 0.10 M in nitrous acid and 0.15 M sodium nitrite.

2. What is the calculated pH of the buffer solution formed by dissolving 4.2 g of acetic acid and 9.0 g of sodium acetate in water and diluting to 500.0 mL?

3. A 10.0 mL quantity of 0.1 M HCl is mixed with 95 mL of 0.15 M sodium nitrite. What is the pH of the new solution?

4. What is the calculated pH of the solution formed by mixing 10.0 mL of 0.15 M NaOH with 85 mL of 0.10 M benzoic acid?

Titration Problems

1. In 1 or 2 sentences, explain back-titration.

2. Name and give the formulas for any 2 different substances used in common antacids.

3. Write the reaction of HCl with one of the two substances listed in question 2. If you cannot answer question 2, write the reaction of HCl with barium hydroxide.

4. To a 0.100 g sample of an antacid was added 50.00 mL of 0.100 M HCl. The antacid tablet dissolved and CO_2 gas was produced. The solution was boiled and cooled to remove the last of the CO_2. Phenolphthalein was added to the solution and the excess HCl titrated with standard 0.100 M NaOH to the phenolphthalein endpoint. It required 3.00 mL of the NaOH.

   a. What color is the phenolphthalein endpoint?

   b. What is the number of moles of HCl neutralized per gram of antacid?

   c. What is the percentage $CaCO_3$ in the antacid?

5. 25 mL of 0.1 M acetic acid is titrated with 0.1 M NaOH. Calculate the pH of the solution after the addition of the following amounts of base. What acid-base indicator would be best to indicate endpoint?

0 mL of NaOH

1 mL

5 mL

15 mL

25 mL

30 mL

For personal extra credit, calculate more points and plot the curve of pH vs Volume of base added. Then compare this curve to that obtained by titrating 25 mL of 0.1 M HCl with 0.1 M NaOH.