1. Find $K_c$ for the reaction: $2NH_3(g) + 3I_2(g) \rightleftharpoons 6HI(g) + N_2(g)$, given the information below.

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $K = 54$ — $\times 3$

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $K = 1.04 \times 10^{-4}$ — flip

$$\cancel{3H_2} + 3I_2 \rightleftharpoons 6HI \qquad K = (54)^3$$

$$2NH_3 \rightleftharpoons N_2 + \cancel{3H_2} \qquad K = (1.04 \times 10^{-4})^{-1}$$

$$2NH_3 + 3I_2 \rightleftharpoons 6HI + N_2 \qquad K = (54)^3(1/1.04 \times 10^{-4})$$

$$\therefore K = 1.5 \times 10^9$$

2. Write an expression for the equilibrium constant of each of the following reactions:

a. $2C_2H_4(g) + 2H_2O(g) \rightleftharpoons 2C_2H_6(g) + O_2(g)$ (Write $K_c$ and $K_p$)

$$K_c = \frac{[C_2H_6]^2[O_2]}{[C_2H_4]^2[H_2O]^2} \qquad K_p = \frac{(P_{C_2H_6})^2 P_{O_2}}{(P_{C_2H_4})^2 (P_{H_2O})^2}$$

b. $Mg(OH)_2(\cancel{s}) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$

ignore solids & liquids

$$K_c = [Mg^{2+}][OH^-]^2$$

c. $NH_3(aq) + H2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

$$K_c = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

d. $HCOOH\ (aq) \rightleftharpoons H^+\ (aq) + HCOO^-\ (aq)$

$$K_c = \frac{[H^+][HCOO^-]}{[HCOOH]}$$

e. $2HgO(s) \rightleftharpoons 2Hg(l) + O_2(g)$

$$K_c = [O_2]$$

3. The following equilibrium constants were determined at 1123 K:

$$C(s) + CO_2(g) \rightleftharpoons 2CO(g) \quad K_1 = 1.3 \times 10^{14}$$

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g) \quad K_2 = 6.0 \times 10^{-3}$$

Calculate the equilibrium constant for the following reaction at 1123 K:

$$C(s) + CO_2(g) + 2Cl_2(g) \rightleftharpoons 2COCl_2(g) \quad K_3 = ???$$

$$K_1 = \frac{[CO]^2}{[CO_2]} = 1.3 \times 10^{14}$$

$$K_2 = \frac{[COCl_2]}{[CO][Cl_2]} = 6.0 \times 10^{-3}$$

$$K_3 = \frac{[COCl_2]^2}{[CO_2][Cl_2]^2} = K_1(K_2)^2$$

$$\therefore K_3 = 4.7 \times 10^9$$

4. The equilibrium constant, $K_c$, for the reaction $H_2(g) + F_2(g) \rightleftharpoons 2HF(g)$ has the value $2.1 \times 10^3$ at a particular temperature. When the system is analyzed at equilibrium at this temperature, the concentrations of $H_2(g)$ and $F_2(g)$ are both found to be 0.0021 M. What is the concentration of HF(g) in the equilibrium system under these conditions?

$$K_c = \frac{[HF]^2}{[H_2][F_2]} \Rightarrow 2.1 \times 10^3 = \frac{[HF]^2}{(.0021)(0.0021)}$$

$$[HF] = 0.096\ M$$

5. At 25°C, $K_p = 5.3 \times 10^5$ for the reaction

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

When a certain partial pressure of $NH_3$ (g) is put into an otherwise empty rigid vessel at 25°C, equilibrium is reached when 50.0% of the original ammonia has decomposed. What was the original partial pressure of ammonia before any decomposition occurred?

$$K_p = \frac{(P_{NH_3})^2}{(P_{N_2})(P_{H_2})^3}$$

initial pressures:

$P_{NH_3} = x$

$P_{H_2} = 0$

$P_{N_2} = 0$

∴ reaction proceeds left

| | $N_2$ | $+3H_2$ | $\rightleftharpoons 2NH_3$ |
|---|---|---|---|
| I | 0 | 0 | $x$ |
| C | $+y$ | $+3y$ | $-2y$ |
| E | $y$ | $3y$ | $x-2y$ |
| | $0.25x$ | $0.75x$ | $0.5x$ |

$x - 2y = 0.5x$

$\therefore y = .25x$

$$5.3 \times 10^5 = \frac{(0.5x)^2}{(0.25x)(0.75x)^3}$$

$$5.3 \times 10^5 = 2.37037/x^2$$

$\therefore x = 2.1 \times 10^{-3}$ atm $= P_{NH_3}$ (initial)

6. For the following reaction:

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

the equilibrium constant, $K_C$, has been determined to be $6.0 \cdot 10^{-3}$ at 1123 K. If a mixture of 3.0 M CO, 2.0 M $Cl_2$ and 0.25 M $COCl_2$ is put in a vessel, which way will the reaction proceed to reach equilibrium?

$$Q = \frac{[COCl_2]_o}{[CO]_o[Cl_2]_o} = \frac{(0.25M)}{(3.0M)(2.0M)} = 0.0417$$

$Q > K$ ∴ reaction proceeds left

7. A mixture of 0.500 mol $H_2$ and 0.500 mol $I_2$ was placed in a 1.00 L steel container at 430°C. The equilibrium constant, $K_c$ for the reaction

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

is $5.43 \times 10^{-5}$. Calculate the equilibrium concentrations of all components.

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

initial conc:

$[HI]_0 = 0$

$[H_2]_0 = 0.5M$

$[I_2]_0 = 0.5M$

∴ reaction proceeds right

| | $H_2$ + | $I_2$ ⇌ | $2HI$ |
|---|---|---|---|
| I | 0.5 | 0.5 | 0 |
| C | $-x$ | $-x$ | $+2x$ |
| E | $.5-x$ | $.5-x$ | $2x$ |

$$5.43 \cdot 10^{-5} = \frac{(2x)^2}{(.5-x)(.5-x)}$$

* take square root of both sides

$$7.369 \cdot 10^{-3} = 2x/(0.5-x)$$

$$-7.369 \times 10^{-3}x + 3.684 \times 10^{-3} = 2x$$

$$x = 1.835 \times 10^{-3}$$

$[HI] = 3.67 \times 10^{-3} M$

$[H_2] = 0.498 M$

$[I_2] = 0.498 M$

8. The following equilibrium constants have been determined for oxalic acid at 25°C:

$H^+ (aq) + HC_2O_4^- (aq) \rightleftharpoons H_2C_2O_4 (aq)$ $K_1 = 15.384$

$3HC_2O_4^- (aq) \rightleftharpoons 3H^+ (aq) + 3C_2O_4^{2-} (aq)$ $K_2 = 2.27 \times 10^{-13}$

Calculate the equilibrium constant for the following reaction at the same temperature:

$H_2C_2O_4 (aq) \rightleftharpoons 2H^+ (aq) + C_2O_4^{2-} (aq)$ $K_3 = ???$

flip equation 1:

$$H_2C_2O_4 \rightleftharpoons H^+ + HC_2O_4^-$$

divide equation 2:

$$HC_2O_4^- \rightleftharpoons H^+ + C_2O_4^{2-}$$

$$K_c = (15.384)^{-1}(2.27 \times 10^{-13})^{1/3} = 3.965 \times 10^{-6}$$

9. For the following reaction:

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

The initial concentration of $PCl_5$ is 0.200 moles per liter and there are no products in the system when the reaction starts. If the equilibrium constant is 0.030, calculate all the concentrations at equilibrium.

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]}$$

$[PCl_5]_0 = 0.2M$

$[PCl_3]_0 = 0$

$[Cl_2] = 0$

$\therefore$ proceeds right

| | $PCl_5$ $\rightleftharpoons$ | $PCl_3$ + | $Cl_2$ |
|---|---|---|---|
| I | 0.2 | 0 | 0 |
| C | $-X$ | $+X$ | $+X$ |
| E | $0.2-X$ | $X$ | $X$ |

$$0.030 = \frac{x^2}{0.2-x}$$

$$0.006 - 0.03x = x^2$$

$$0 = x^2 + 0.03x - 0.006$$

using quadratic formula...

$x = 0.063899$ & $-\cancel{0.0939}$

$[PCl_5] = 0.136M$

$[PCl_3] = 0.0639M$

$[Cl_2] = 0.0639M$

10. Given this equation:

$$COCl_2 \rightleftharpoons CO + Cl_2$$

2.00 g of $COCl_2$ and 5.00 g of $Cl_2$ are placed in a 2.50 L flask. Calculate all three equilibrium partial pressures when $K_p$ = 0.680. at 25°C

$$K_p = \frac{P_{CO} \cdot P_{Cl_2}}{P_{COCl_2}}$$

Initial Pressures:

$P_{CO} = 0$ ∴ rxn proceeds right

$$P_{Cl_2} = \frac{nRT}{V} = 5.00g\left(\frac{mol}{70.5g}\right)\left(.08206\,\frac{L \cdot atm}{mol \cdot K}\right)(298.15K)/2.50L$$

$$= 0.694\,M$$

$$P_{COCl_2} = 2.00g\left(\frac{mol}{98.51g}\right)\left(.08206\,\frac{L \cdot atm}{mol \cdot K}\right)(298.15K)/(2.50L)$$

$$= 0.1987\,M$$

| | $COCl_2$ ⇌ | $CO$ + | $Cl_2$ |
|---|---|---|---|
| I | .1987 | 0 | .694 |
| C | −X | +X | +X |
| E | .1987−X | X | .694+x |

$[Cl_2] = 0.786M$

$[CO] = 0.0919M$

$[COCl_2] = 0.107M$

$$0.68 = \frac{x(.694+x)}{.1987-x}$$

$$.68(.1987-x) = x(0.694+x)$$

$$.1351 - .68x = .694x + x^2$$

$$0 = x^2 + 1.378x - 0.1351$$

$$x = 0.09191$$