# Equilibrium Review

## Quantitative Review:

1) The following reactions occur at 500 K. Arrange them in order of increasing tendency to proceed to completion (i.e. least to greatest tendency):

   a. $2\ NOCl \leftrightarrow 2\ NO + Cl_2$ $\quad K_c = 1.7 * 10^{-2}$
   b. $2\ SO_3 \leftrightarrow 2\ SO_2 + O_2$ $\quad K_c = 1.3 * 10^{-5}$
   c. $2\ NO_2 \leftrightarrow 2\ NO + O_2$ $\quad K_c = 5.9 * 10^{-5}$

   **(Answer: b < c < a)**

2) The equilibrium constant for the reaction:

   $$Ni_{(s)} + 4CO_{(g)} \leftrightarrow Ni(CO)_{4\ (g)}$$

   Is $5.0 * 10^4$ at 25°C. What is the value of the equilibrium constant for the following reaction:

   $$Ni(CO)_{4\ (g)} \leftrightarrow Ni_{(s)} + 4CO_{(g)}$$

   **(Answer: $K_c = \frac{1}{K_c} = \frac{1}{5 * 10^4} = 2 * 10^{-5}$)**

3) For the following reactions the equilibrium constants are defined:

   a. $A + 2\ B \leftrightarrow C$ $\quad K_1$
   b. $C \leftrightarrow D + E$ $\quad K_2$
   c. $A + 2\ B \leftrightarrow D + E$ $\quad K_c$

   The final equilibrium constant is given by what expression?

   **(Answer: $K_c = K_1 * K_2$)**

4) Carbon tetrachloride reacts at high temperatures with oxygen to produce two toxic gases: phosgene, $COCl_2$ and chlorine, $Cl_2$:

   $$CCl_{4\ (g)} + \frac{1}{2} O_{2\ (g)} \leftrightarrow COCl_{2\ (g)} + Cl_{2\ (g)} \qquad K_c = 4.4 * 10^9$$

   Calculate the equilibrium constant for the following reaction:

   $$2\ CCl_{4\ (g)} + O_{2\ (g)} \leftrightarrow 2\ COCl_{2\ (g)} + 2\ Cl_{2\ (g)}$$

**(Answer: $K_c = (4.4 * 10^9)^2 = 1.9 * 10^{19}$)**

5) An equilibrium mixture for the reaction:

$$2\ H_2S_{(g)} \leftrightarrow 2\ H_{2\,(g)} + S_{2\,(g)}$$

On analysis was found to contain 1.0 mol of $H_2S$, 4.0 mol of $H_2$, and 0.80 mol of $S_2$ in a 4.0 $dm^3$ vessel. Calculate the equilibrium constant for this reaction.

**(Answer: 3.2 mol $dm^{-3}$)**

6) An aqueous solution is made by dissolving 1.00 mol of $AgNO_3$ and 1.00 mol of $FeSO_4$ in water and making up to 1.00 dm3:

$$Ag^{+}_{(aq)} + Fe^{2+}_{(aq)} \leftrightarrow Fe^{3+}_{(aq)} + Ag_{(s)}$$

When the equilibrium was established the following concentrations were obtained:

$[Ag^+] = [Fe^{2+}] = 0.44$ mol $dm^{-3}$
$[Fe^{3+}] = 0.56$ mol $dm^{-3}$

Find the equilibrium constant.

**(Answer: 2.89 $mol^{-1}$ $dm^3$)**

7) For the equilibrium:

$$2\ P_{(g)} + Q_{(g)} \leftrightarrow 2\ R_{(g)}$$

Kc is numerically equal to 6.0. Into a 1.00 $dm^3$ flask are introduced 3.0 mol of P, 3.0 mol of Q, and 3.0 mol of R.

a) State the units in which $K_c$ is expressed.
b) Is the mixture at equilibrium?
c) If not, what must the volume of the flask be in order for such a mixture to exist in equilibrium at the temperature for which $K_c$ was given?

**(Answer: a) $M^{-1}$; b) 0.33; c)** $K_c = 6 = \dfrac{(\frac{3}{V})^2}{(\frac{3}{V})^2(\frac{3}{V})} \rightarrow V = 18.0\ dm^3$**)**

8) 2.50 mol of NOCl was placed in a 2.50 $dm^3$ reaction vessel at 400°C. After equilibrium was established, it was found that 28% of NOCl has dissociated according to the following equation:

$$2\ NOCl_{(g)} \leftrightarrow 2NO_{(g)} + Cl_{2(g)}$$

Calculate the equilibrium constant for the reaction.

**(Answer: 0.021 mol $dm^{-3}$)**

9) The following reaction was allowed to come to equilibrium:

$$A_{(g)} + 2\ B_{(g)} \leftrightarrow C_{(g)}$$

The initial amounts of reactants placed into a 5.00 $dm^3$ container were 1.0 mol of A and 1.8 mol of B. After the reaction reached equilibrium, 1.0 mol of B was found. Calculate the value of $K_c$ for this reaction.

**(Answer: 17 $mol^{-2}$ $dm^6$)**

10) Consider the reaction:

$$N_{2(g)} + O_{2(g)} \leftrightarrow 2\ NO_{(g)}$$

Here the equilibrium constant is 0.10 at 2000°C. Starting with initial concentrations of 0.040 mol $dm^{-3}$ of $N_2$ and 0.040 mol $dm^{-3}$ of $O_2$, calculate the equilibrium constant concentration of NO.

**(Answer: 0.011 mol $dm^{-3}$)**

11) 4.21 moles of $S_2Cl_4$ are introduced into a 2.0 $dm^3$ vessel where the following reaction occurs:

$$S_2Cl_{4(g)} \leftrightarrow 2\ SCl_{2(g)}$$

It is allowed to come to equilibrium, and 1.25 moles of $S_2Cl_4$ are found in the container. Calculate the equilibrium constant for the reaction.

**(Answer: 14 mol $dm^{-3}$)**

12) The following question refers to the Haber process for the synthesis of ammonia. The equation which represents the reaction is given below:

$$N_{2(g)} + 3\ H_{2(g)} \leftrightarrow 2\ NH_{3(g)} \qquad \Delta H° = -92\ KJ\ mol^{-1}$$

a) Give one source each of nitrogen and hydrogen for this process. **(Answer: Air, water or natural gas)**

b) Write the expression for the equilibrium constant. **(Answer:** $K_p = \frac{P^2_{NH_3}}{P_{N_2} * P^3_{H_2}}$ **)**

c) What is the relationship between $K_c$ and $K_p$ for this reaction? **(Answer: $K_p = K_c(RT)^{-2}$)**

d) If the pressure is measured in kPa, what will be the units of $K_p$? **(Answer: $kPa^{-2}$)**

e) State and explain the effect on the equilibrium constant, and its numerical value, if:
   1. Pressure is increased? **(Answer: Shift to the right but $K_c$ is constant)**
   2. Temperature is increased? **(Answer: Shift to the left and $K_c$ will decrease)**

f) The numerical value of the equilibrium constant, $K_c$, is $6.0 * 10^{-2}$ $mol^{-2}$ $dm^6$ at 500°C. The following concentrations were determined in a mixture:

   $[NH_3] = 1.0 * 10^{-3}$ mol $dm^{-3}$
   $[N_2] = 1.0 * 10^{-5}$ mol $dm^{-3}$
   $[H_2] = 2.0 * 10^{-2}$ mol $dm^{-3}$

   1. Is the reaction at equilibrium? **(Answer: No)**
   2. Predict the direction that the system will shift to reach equilibrium. **(Answer: Left)**