More Equilibrium Problems

You should be able to do these problems without a calculator.

1) Solid compound A decomposes according to the endothermic reaction:

   $A(s) \rightleftharpoons 2B(g) + C(g) \quad K_p = 1.08 \times 10^{-4}$

   a) If 50.0 mmol of A(s) is placed in a 6.10-L sealed, evacuated flask at 25°C, calculate the total pressure in the flask at equilibrium. **(9.0 x 10^{-2} atm)**

   b) How many millimoles of A(s) will be left at equilibrium in the experiment described in part (a)? **(42.5)**

   c) If some A(s) is placed in a 6.10-L evacuated flask at 25°C and some C(g) added so that the partial pressure of C(g) at equilibrium is 1.00 atm, calculate the equilibrium partial pressure of B(g) in the system. **(about 1 x 10^{-2} atm)**

   d) What is the value of K_p for the equilibrium:

      $4B(g) + 2C(g) \rightleftharpoons 2A(s)$

      (about 9 x 10^{7})

   e) If the equilibrium $B(g) \rightleftharpoons D(g)$ has equilibrium constant $K_p = 5.0 \times 10^{-3}$, determine the equilibrium constant for the reaction

      $A(s) \rightleftharpoons C(g) + 2D(g)$

      (about 3 x 10^{-9})

2) The fastest growing use of methanol (CH_3OH) is to make the octane enhancer methyl tert-butyl ether. Today all methanol is produced (as a gas) by the reaction of carbon monoxide and hydrogen. The value of K_p for this reaction is (about) 2.0 x 10^{-4} at 327.°C.

   a) Write the equilibrium reaction for the production of methanol.
      ($2H_2(g) + CO(g) \rightleftharpoons CH_3OH(g)$)

   b) What is the value of K_c at 327.°C? **(about 0.5)**

   c) In which direction will this reaction shift if the temperature is raised, given that the $\Delta H^\circ_{rxn} = -90.7$ kJ? Explain! **(shifts to left because heat is a product when rxn. is exothermic, try to use up "excess" heat to re-establish equilibrium.)**

d) In the industrial process, the stoichiometric ratio of CO to H_2 is used. If the reaction is carried out at an initial total pressure of 300. atm, what are the initial partial pressures of CO and H_2? **(100. atm CO, 200. atm H_2)**

3) A flask initially contains only NOBr gas. Once heated to a temperature T, 20.0 % of the original gas decomposes via the following equation to give a total pressure of 0.33 atm at equilibrium:

$$2NOBr(g) \rightleftharpoons 2NO(g) + Br_2(g)$$

a) Determine the original pressure of NOBr in the flask. **(0.30 atm)**

b) What is the value of K_p at this temperature T? **(1.9 x 10^{-3} or 3/1600)**

c) If the value of K_c at this temperature T is 3.9 x 10^{-5}, determine the temperature T. **(600 K)**

4) For the equilibrium:

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

At some temperature T_1, $K_p = 2.25$. An unknown quantity of pure $PCl_5(g)$ is placed in an evacuated flask and heated to T_1. When equilibrium was established, the partial pressure of $PCl_5(g)$ was found to be 0.25 atm.

a) What were the partial pressures of PCl_3 and Cl_2 at equilibrium? **(0.75 atm)**

b) Determine the original pressure of PCl_5 (before any reaction) and the percent dissociation of PCl_5 at equilibrium. **(1.00 atm, 75 %)**

c) What is the value of K_c for the reaction if T_1 is 327°C? **(about 5 x 10^{-2})**

5) For the following system:

$$C(s) + CO_2(g) \rightleftharpoons 2CO(g)$$

At 700.°C in a 2.00 L flask there are 0.100 moles of CO, 0.200 moles of CO_2, and 0.400 moles of C at equilibrium. At 600.°C, an additional 0.0400 moles of C forms at equilibrium.

a) The process as written is: exothermic or **endothermic**

b) Determine the value of K_c at 600.°C and 700.°C. **(K_c = 0.0250 at 700.ºC, 8.3 x 10^{-4} at 600.ºC)**

c) An additional 0.200 moles of C is added to the flask at 600.°C. What will be the effect on:

i) K_c increase decrease **no effect**
ii) P_{CO} increase decrease **no effect**
iii) P_{CO2} increase decrease **no effect**

6) Consider the equilibrium:

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO_2(g) + 6H_2O(l) \quad \Delta H° = -1381 \text{ kJ}$$

Predict whether the equilibrium number of moles of NH_3 will increase or decrease and the direction that the reaction will shift in order to establish a new equilibrium if:

i) the volume of the system is decreased **(↓,shifts to right)**
ii) the temperature of the system is increased **(↑,shifts to left)**
iii) some O_2 is added to the container **(↓,shifts to right)**
iv) some He is added to the container **(no effect)**
v) some NH_3 is added to the container **(↑, shifts to right)**
vi) some H_2O is removed from the container **(no effect as long as some water remains)**

7) 0.50 moles of N_2O_4 were introduced into a 0.25 L flask. Determine the equilibrium concentrations of N_2O_4 and NO_2 if K_c for the equilibrium

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

is 5.0×10^{-7}. **(N_2O_4 = 2.0 M; NO_2 = 1.0×10^{-3} M)**

8) Some antimony sulfide and 500 mmol of H_2 were placed in a 500 mL flask and heated. What were the equilibrium concentrations of H_2 and H_2S once equilibrium had been reached?

$$Sb_2S_3(s) + 3H_2(g) \rightleftharpoons 2Sb(s) + 3H_2S(g) \quad K_c = 0.216$$

($[H_2]$ = 0.625 M; $[H_2S]$ = 0.375 M)

9) 0.100 mol of H_2 and 0.100 mol of HI were placed in a 1.00 L container and heated. Determine the equilibrium concentrations of all species.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad K_c = 5.0 \times 10^9$$

($[H_2]$ = [HI] = 0.100 M, $[I_2]$ = 2.0×10^{-11} M)