Equilibrium Problems (no calculator)

You can do these problems with or without a calculator. The answers here were calculated without a calculator.

1. For the equilibrium

   $A(g) \rightleftharpoons B(g) + \frac{1}{2}C(g)$

   $K_c = 4.0 \times 10^{-13}$ at 27°C.

   a) Evaluate K_P at 27°C. **[2.0 x 10^{-12}]**

   b) If a flask initially containing only 1.00 bar of A(g) is allowed to come to equilibrium, what will be the equilibrium pressure of each species?
   [P_A = 1 bar; $P_B = 2.0 \times 10^{-8}$ bar; $P_C = 1.0 \times 10^{-8}$ bar]

2. Bromine and chlorine both dissolve in carbon tetrachloride, whereupon they react (slowly) to form BrCl:

   $Br_2(CCl_4) + Cl_2(CCl_4) \rightleftharpoons 2BrCl(CCl_4)$

   Under equilibrium conditions at some temperature, $[Br_2] = [Cl_2]$ = 0.50 M, and [BrCl] = 0.10 M.

   a) Evaluate the equilibrium constant for this reaction at 25°C. **[0.040 or 1/25]**

   b) If 0.22 moles of BrCl were added to the equilibrium mixture you found in (a), what would be the new equilibrium concentrations of all species present? Assume 1 L of solution. **($[Br_2] = [Cl_2]$ = 0.60 M; [BrCl] = 0.12 M)**

3. Predict the effect each of the following would have on the reaction (initially at equilibrium):

   $CoCl_4^{-2}(aq) + 6H_2O(l) \rightleftharpoons Co(H_2O)_6^{+2}(aq) + 4Cl^{-1}(aq)$ $\Delta H° = -14$ kJ

   Indicate your choice by writing shift **R**ight, shift **L**eft, or **N**o change:

   a) Adding HCl gas ______
   b) Heating the reaction ______
   c) Adding $AgNO_3$ (AgCl is insoluble) ______
   d) Adding water ______

[L L R R]

4. The ionization of water is an equilibrium process for which $K_c = 1.0 \times 10^{-14}$ at 25°C:

   $H_2O(l) \rightleftharpoons H^+(aq) + OH^{-1}(aq)$ $\Delta H = +57$ kJ

   Should K_w be larger or smaller at 75 than at 25? How do you know?
   Determine the approximate K_w of water at 75°C. **[about 2 x 10^{-13}]**

5. The normal boiling point of a liquid is 67°C and its enthalpy of vaporization is 34 kJ/mol. What is its vapour pressure (in atmospheres) at 27°C? **[about 0.2]**

6. Solid compound A decomposes according to the endothermic reaction:

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

   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} bar)**

   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 bar, calculate the equilibrium partial pressure of B(g) in the system. **(about 1 x 10^{-2} bar)**

   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})

7. 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) 2.0×10^{-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 $\Delta H°_{rxn}$ = -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. bar, what are the initial partial pressures of CO and H_2? **(100. bar CO, 200. bar H_2)**

8. 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 bar at equilibrium:

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

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

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

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

9. 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 bar.

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

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

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

10. 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**

11. 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)**

12. 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 x 10^{-7}. **(N_2O_4 = 2.0 M; NO_2 = 1.0 x 10^{-3} M)**

13. 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?

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

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

14. 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.

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

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