Equilibrium Constant

15.1. Use the following reaction to answer

$$H_2(g) + Br_2(l) \rightleftharpoons 2HBr(g)$$

Which one of the following is the equilibrium constant expression for the reaction in Figure 15.1?

a. $k = \frac{[HBr]^2}{[H_2][Br_2]}$

b. $k = \frac{[HBr]^2}{[H_2]}$

c. $k = \frac{[HBr]}{[H_2]}$

d. None of the above

15.2. Use the following reaction to answer

$$H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$$

What is the equilibrium concentration of HBr if H_2 and Br_2 are both 0.800M, and K=8.00 at 60°C.

15.3. Why is Br_2 a liquid in question 15.1 and a gas in 15.2 when the pressure is constant?

15.4. Use the following reaction to answer

$$H_2(g) + Br_2(l) \rightleftharpoons 2HBr(g)$$

Calculate K_p at 25° for a system at equilibrium if: $P_{H2} = 2.500 \times 10^{-2}$atm, and $P_{HBr} = 1.500$atm?

15.5. Use the following reaction to answer

$$H_2(g) + Br_2(l) \rightleftharpoons 2HBr(g)$$

What is K_c for the system in question 15.4?

Figure 15.1: Use this reaction for question 6-8:

$$(1)\ 2NO(g) \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} N_2O_2(g) \qquad k_1 = 4.8\times10^{-3} M^{-1}s^{-1}, k_{-1} = 3.6\times10^{-4} s^{-1}$$

$$(2)\ N_2O_2(g) + O_2(g) \longrightarrow 2NO_2(g) \qquad K_2 = 6.4\times10^{3}$$

$$(3)\ 2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

15.6. What is the value of K_c for reaction (1) in Figure 15.2?

15.7. What is the value of K_c for step (3) of question 15.6?

15.8. Does step 1 in question 15.6 favor reactants or products?

Calculations of Equilibrium Constant

Figure 15.2: Questions 9-14 deal with the following reaction:

$$H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$$

15.9. In what direction will the reaction at 440°C proceed if:
[HBr]= 1.0×10^{-2}M, [H_2]=5.0×10^{-3}M, [Br_2]=1.5×10^{-2}M and K_{eq}=50 at 440°C.

15.10. What is the equilibrium concentration of Bromine at 440°C if:
[H_2]= 0.60M, [HBr]=1.25M and [Br_2]=0

15.11. What is [HBr] after equilibrium is reached for the problem described in question 15.10?

15.12. Determine K_{eq} at a certain temperature if 0.80 mol HBr is produced after 0.50 mol H_2 and Br_2 react in a 2 L container.

15.13. At a certain temperature, $K_{eq}=6.30 \times 10^2$. What is the equilibrium concentration of H_2 if 4.50mol of each of the three species were placed into a 3.00L flask?

15.14. What is [HBr] after equilibrium is reached for the problem described in question 15.123?

15.15. Determine K_{eq} for the following reaction if 0.0500M N_2O_4 is placed in a container and it decomposes to an equilibrium value of 0.0155M.

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

Le Chatelier's Principle

Figure 15.3: Questions 15-20 deal with the following reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H^0 = -99\, kJ/mol$$

15.16. If the temperature increases while the pressure is constant, the reaction will proceed towards which direction?

15.17. For the same reaction, if the temperature is held constant and the pressure is increased, which direction will the reaction proceed?

15.18. If more oxygen is added, which direction will the reaction proceed?

15.19. If the container in which the reaction occurs is enlarged, which direction will the reaction proceed?

15.20. The addition of catalyst will make the reaction shift towards which direction?

15.21. The addition of He gas will make the reaction shift towards which direction?

Equilibrium Constant

Figure 15.4: Questions 22-26 deal with the following reaction:

$$C_4H_{10}(g) \rightleftharpoons C_2H_6(g) + C_2H_4(g)$$

15.22. What is the concentration of C_4H_{10} at equilibrium if the concentrations of C_2H_6 and C_2H_4 are both 0.014M? $K_c = 0.07$

15.23. For the same reaction, if the initial concentration of C_4H_{10} is 0.035M, and there is no C_2H_6 C_2H_4 present initially. What is the equilibrium concentration of C_4H_{10}?

15.24. Following Q 15.23, what is the equilibrium concentration of C_2H_6?

15.25. If the initial concentration of C_4H_{10} is 0.030M, and the ones of C_2H_6 and C_2H_4 are both 0.023M. At equilibrium, the concentration of C_4H_{10} becomes 0.018M, what is the value of K_c of the reaction.

15.26. For the same reaction, if the 2.0L container was evacuated, then pumped in with gases at the following pressure, C_4H_{10} = 1.2atm, $C_2H_6$and C_2H_4 = 0.6 atm. What is the partial pressure (in atm) of C_4H_{10} at equilibrium? K_p =0.64.

Equilibria Calculations Through "Completing the Power"

Figure 15.5: Questions 27-28 deal with the following reaction:

$$H_2(g) + Br_2(l) \rightleftharpoons 2HBr(g)$$

15.27. For the reaction, what is the equilibrium concentration of Br_2 at 4400C if initially $[H_2]$= 0.60M [HBr]=1.25M $[Br_2]$=0.6 and k=50?

15.28. What is the equilibrium concentration of HBr?

Figure 15.6: Questions 29-30 deal with the following reaction:

$$Cl_2(g) + 2HBr(g) \rightleftarrows Br_2(g) + 2HCl(g)$$

15.29. For the reaction, what is the equilibrium concentration of HCl if the initial $[Cl_2]$=0.1M, [HBr]=0.20M, $[Br_2]$=[HCl]=0 and k=15?

15.30. What is the equilibrium concentration of HBr in Q 15.29?

15.31. For the reaction, What is $[O_2]$ at equilibrium if 0.050mol of N_2O_2, O_2, and NO_2 are mixed in a 1.0L container? k=25

$$N_2O_2(g) + O_2(g) \longrightarrow 2NO_2(g)$$

Relating K_p and K_c

15.32. What is the relationship between Kp and Kc?

a. $K_p = K_c(RT)^{\Delta n}$
b. $K_c = K_p(RT)^{\Delta n}$
c. $K_p = K_c$
d. None of the above

Figure 15.7: Use the following equation for questions 33-36

$$3A_2(g) + 2B_3(s) \longrightarrow 6A_3B_2(g)$$

15.33. What is the Δn for the equation above?

15.34. Solve for K_p, given $K_c = 2.3*20^4$ at 30°C for the equation above?

15.35. Solve for K_c, given $K_p = 2.3*10^4$ at 30°C for the equation above?

15.36. Solve for K_c, given $K_p = 3.1*10^4$ at 30°C for the equation above?

15.37. Solve for Kc, given $K_p = 3.2*10^4$ at 30°C for the following equation:

$$3A_2(s) + 4B_3(g) \longrightarrow 2A_3B_2(g)$$

15.38. What is the temperature, given $K_c = 3.5*10^8$, and $K_p = 5.8*10^5$ for the following equation?

$$A_2(g) + 3B_2(g) \longrightarrow 2AB_3(g)$$

General Questions

15.39. Which of the following is the relationship between the rate constants for the forward and reverse reactions and the equilibrium constant for a process?

a. $K = k_f + k_r$
b. $K = k_f k_r$
c. $K = k_f - k_r$
d. $K = {1}/{(k_f k_r)}$
e. $K = {k_f}/{k_r}$

15.40. A flask of an aqueous equilibrium mixture of $CoCl_4^{2-}$, $CoBr_4^{2-}$, Cl^-, and Br^- is at 25°C. Which of the following actions will change the value of the equilibrium constant from that which currently describes the concentration relationships of the four species above?

a. add more $CoBr_4^{2-}$ to the solution
b. add more $CoCl_4^{2-}$ to the solution
c. add more Br^- to the solution
d. add more Cl^- to the solution
e. put the flask into an 80°C water bath

15.41. What is the Kc for the following reaction?

$$CO + 3H_2 \rightleftharpoons CH_4 + H_2O$$

15.42. If the equilibrium constant for reaction (1) is $4.22*10^{-3}$, what is the value of the equilibrium constant for the reaction (2) in the following mechanism?

$$3A + 2B \rightleftharpoons 2D + E \quad (1)$$

$$2D + E \rightleftharpoons 3A + 2B \quad (2)$$

15.43. The reaction

$$A + B \rightleftharpoons X + Y$$

has K_c = 1977 at 472 K. At equilibrium, _____.

a. only products exist
b. only reactants exist
c. products predominate
d. reactants predominate
e. roughly equal molar amounts of products and reactants are present

15.44. The equilibrium constant for reaction (1) is K. What is the equilibrium constant for equation (2)?

$$(1) \quad SO_2\,(g) + \frac{1}{2}O_2\,(g) \rightleftharpoons SO_3(g)$$

$$(2) \quad 2SO_3\,(g) \rightleftharpoons 2SO_2\,(g) + O_2\,(g)$$

a. 1/2K
b. $1/K^2$
c. 2K
d. K^2
e. $-K^2$

15.45. If the equilibrium constant for reaction (1) is K, what is the equilibrium constant for (2)?

$$(1) \quad \frac{1}{3}N_2(g) + H_2(g) \rightleftharpoons \frac{2}{3}NH_3(g)$$

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

a. K^3
b. 3K
c. K/3
d. $1/K^3$
e. $-K^3$

15.46. If the value of K_c for the following reaction is 0.25:

$$SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$$

What is the value of K_c for the reaction below?

$$2SO_2(g) + 2NO_2(g) \rightleftharpoons 2SO_3(g) + 2NO(g)$$

15.47. What is K_p for the following reaction at 25°C, $K_c = 3.0*10^5$?

$$2H_2S(g) + 3O_2(g) \rightleftharpoons 2H_2O(g) + 2SO_2(g)$$

15.48. The value of K_c for the reaction below is $2.0*10^{-10}$ at 100°C.

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

What is the value of K_c for the reverse reaction at 100°C?

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

15.49. The value of K_c for the following reaction is 1.10 at 25.0°C. What is the value of K_p for this reaction?

$$4CuO(s) + CH_4(g) \rightleftharpoons CO_2(g) + 4Cu(s) + 2H_2O(g)$$

15.50. What is the value of K_c for a flask at equilibrium that contains 0.0114 M HCl, 0.0931 M Cl_2, and 0.0154 M H_2 at a certain temperature?

$$2HCl(g) \rightarrow Cl_2(g) + H_2(g)$$

15.51. Consider the gaseous equilibrium: $2A \rightarrow 2B + C$

Determine the value of the missing B concentration at equilibrium.

Exp #	[A] at equilibrium	[B] at equilibrium	[C] at equilibrium
1	0.10 M	0.10 M	0.20 M
2	0.20 M	0.50 M	0.032 M
3	0.35 M	?	0.15 M

15.52. Which of the following reactions at equilibrium has the following equilibrium constant expression?

$$\frac{[IBr]^2}{[I_2][Br_2]}$$

a. $I_2(g) + Br_2 \rightleftharpoons IBr(g)$
b. $I_2(g) + Br_2 \rightleftharpoons 2\,IBr(g)$
c. $2\,IBr(g) \rightleftharpoons I_2(g) + Br_2(g)$
d. $2\,I_2(g) + 2\,Br_2 \rightleftharpoons IBr(g)$
e. $IBr(g) \rightleftharpoons 2\,I(g) + 2\,Br(g)$

15.53. The value of Kc for the following reaction at equilibrium is 54.0 at 427C.

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

At this temperature, what is the value of Kc for:

$HI(g) \rightleftharpoons {}^1/_2\,H_2(g) + {}^1/_2\,I_2(g)$

15.54. What is the equilibrium constant expression for the following reaction?

$$Al_2(SO_3)_3(s) + 6HCl(g) \rightleftharpoons 2AlCl_3(s) + 3H_2O(l) + 3SO_2(g)$$

15.55. What is the equilibrium constant expression for the following reaction?

$$3SO_2(g) \rightleftharpoons 2SO_3(g) + S(s)$$

15.56. Consider the following chemical reaction:

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

At equilibrium, the concentrations of H_2, I_2, and HI were 0.15M, 0.033 M, and 0.55 M, respectively. What is the K_c for this reaction?

Figure 15.8: Use the following reaction to solve questions 57-58

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

15.57. From Figure 15.8: Initially, 1.26 mol of PCl_5(g) was placed in a 1.0 L flask. At equilibrium, 1.08 mol of PCl_5(g) was present. What is the value of K_c for this reaction at this temperature?

15.58. What is the equilibrium partial pressure of PCl_3? If in a 3.00 L vessel that was charged with 0.123 atm of PCl_5 has a K_p of 0.0121?

15.59. The value of K_c for the following reaction is 0.070. What is the equilibrium concentration (M) of C_4H_{10} if the equilibrium concentrations of C_2H_6 and C_2H_4 are both 0.035M?

$$C_4H_{10}(g) \rightleftharpoons C_2H_6(g) + C_2H_4(g)$$

15.60. Nitrosyl bromide decomposes according to the following equation:

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

A sample of NOBr (0.64 mol) was placed in a 1.00 L flask containing no NO or Br_2. At equilibrium, the flask contained 0.46 mol of NOBr. How many moles of NO and Br_2 are in the flask at equilibrium?

15.61. Which of the following will shift to the left in response to a decrease in volume?

a. $H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$
b. $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
c. $2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$
d. $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$
e. $4Fe(s) + 3O_2(g) \rightleftharpoons 2Fe_2O_3(s)$

15.62. For the endothermic reaction

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$$

only _____ would favor shifting the equilibrium position to form more CO_2 gas.

a. both decreasing the system temperature and increasing the system pressure
b. decreasing the system temperature
c. increasing both the system temperature and the system pressure
d. increasing the system pressure
e. increasing the system temperature

15.63. Which of the following reactions would increase pressure at constant temperature not change the concentration of reactants and products?

a. $2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g)$
b. $N_2(g) + 2O_2(g) \rightleftharpoons 2NO_2(g)$
c. $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
d. $N_2O_4(g) \rightleftharpoons 2NO_2(g)$
e. $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$

15.64. Consider the following reaction at equilibrium

$$2CO_2(g) \rightleftharpoons 2CO(g) + O_2(g)$$

The yield of CO(g) in reaction can be maximized by carrying out the reaction _____.

a. at high temperature and high pressure
b. at high temperature and low pressure
c. at low temperature and high pressure
d. at low temperature and low pressure
e. in the presence of solid carbon

15.65. The effect of a catalyst on a chemical reaction is to _____.

a. accelerate the forward reaction only
b. increase the entropy change associated with a reaction
c. lower the energy of the transition state
d. make reactions more exothermic
e. react with product, effectively removing it and shifting the equilibrium to the right