Chapter 15: Chemical Equilibrium

1. The equilibrium between carbon dioxide gas and carbonic acid is very important in biology and environmental science.
   $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$

   Which one of the following is the correct equilibrium constant expression (K_c) for this reaction?

   A) $K_c = \dfrac{[H_2CO_3]}{[CO_2][H_2O]}$

   B) $K_c = \dfrac{[CO_2][H_2O]}{[H_2CO_3]}$

   C) $K_c = \dfrac{[H_2CO_3]}{[CO_2]}$

   D) $K_c = \dfrac{[CO_2]}{[H_2CO_3]}$

   E) $K_c = \dfrac{1}{[H_2CO_3]}$

3. The equilibrium constant expression for the reaction $2BrF_5(g) \rightleftharpoons Br_2(g) + 5F_2(g)$ is

   A) $K_c = [Br_2]\,[F_2]\,/\,[BrF_5]$

   B) $K_c = [Br_2]\,[F_2]^5\,/\,[BrF_5]^2$

   C) $K_c = [Br_2]\,[F_2]^2\,/\,[BrF_5]^5$

   D) $K_c = [BrF_5]^2\,/\,[Br_2][F_2]^5$

   E) $K_c = 2[BrF_5]^2\,/\,([Br_2] \times 5[F_2]^5)$

5. Consider the two gaseous equilibria:
   $SO_2(g) + {}^1/_2O_2(g) \rightleftharpoons SO_3(g)$ K_1

   $2SO_3(g) \rightleftharpoons SO_2(g) + O_2(g)$ K_2

   The values of the equilibrium constants K_1 and K_2 are related by

   A) $K_2 = K_1^2$ B) $K_2^2 = K_1$ C) $K_2 = 1/K_1^2$ D) $K_2 = 1/K_1$ E) none of these.

7. The equilibrium constant for the reaction $Ni(s) + 4CO(g) \rightarrow Ni(CO)_4(g)$ is 5.0×10^4 at 25°C. What is the equilibrium constant for the reaction
   $Ni(CO)_4(g) \rightleftharpoons Ni(s) + 4CO(g)$?

   A) 2.0×10^{-5} B) 2.5×10^9 C) 5.0×10^4 D) 5.0×10^{-4} E) 2.0×10^{-3}

9. When the following reaction is at equilibrium, which of these relationships is *always* true?
$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$

A) $[NO]\,[Cl_2] = [NOCl]$
B) $[NO]^2\,[Cl_2] = [NOCl]^2$
C) $[NOCl] = [NO]$
D) $2[NO] = [Cl_2]$
E) $[NO]^2\,[Cl_2] = K_c[NOCl]^2$

11. On analysis, an equilibrium mixture for the reaction $2H_2S(g) \rightleftharpoons 2H_2(g) + S_2(g)$ was found to contain 1.0 mol H_2S, 4.0 mol H_2, and 0.80 mol S_2 in a 4.0 L vessel. Calculate the equilibrium constant, K_c, for this reaction.
A) 1.6 B) 3.2 C) 12.8 D) 0.64 E) 0.8

13. 1.25 moles of NOCl were placed in a 2.50 L reaction chamber at 427°C. After equilibrium was reached, 1.10 moles of NOCl remained. Calculate the equilibrium constant, K_c, for the reaction $2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$.

A) 3.0×10^{-4} B) 1.8×10^{3} C) 1.4×10^{-3} D) 5.6×10^{-4} E) 4.1×10^{-3}

15. The brown gas NO_2 and the colorless gas N_2O_4 exist in equilibrium, $2NO_2 \rightleftharpoons N_2O_4$. In an experiment, 0.625 mole of N_2O_4 was introduced into a 5.00 L vessel and was allowed to decompose until equilibrium was reached. The concentration of N_2O_4 at equilibrium was 0.0750 M. Calculate K_c for the reaction.
A) 7.5 B) 0.125 C) 0.0750 D) 0.10 E) 0.050

17. Phosgene, $COCl_2$, a poisonous gas, decomposes according to the equation $COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g)$. Calculate K_p for this reaction if $K_c = 0.083$ at 900°C.

A) 0.125 B) 8.0 C) 6.1 D) 0.16 E) 0.083

19. If one starts with pure $NO_2(g)$ at a pressure of 0.500 atm, the total pressure inside the reaction vessel when $2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$ reaches equilibrium is 0.674 atm. Calculate the equilibrium partial pressure of NO_2.
A) 0.152 atm
B) 0.174 atm
C) 0.200 atm
D) 0.326 atm
E) The total pressure cannot be calculated because K_p is not given

21. At 250°C, the equilibrium constant K_p for the reaction $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ is 1.80. Sufficient PCl_5 is put into a reaction vessel to give an initial pressure of 2.74 atm at 250°C. Calculate the pressure of PCl_5 after the system has reached equilibrium.
A) 1.50 atm B) 1.24 atm C) 4.24 atm D) 0.94 atm E) 1.12 atm

23. For the reaction $SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$, the equilibrium constant is 18.0 at 1,200°C. If 1.0 mole of SO_2 and 2.0 moles of NO_2 are placed in a 20. L container, what concentration of SO_3 will be present at equilibrium?
A) 0.48 mol/L B) 0.11 mol/L C) 0.95 mol/L D) 2.22 mol/L E) 18 mol/L

25. Hydrogen iodide decomposes according to the equation $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$, for which $K_c = 0.0156$ at 400°C. 0.550 mol HI was injected into a 2.00 L reaction vessel at 400°C. Calculate the concentration of HI at equilibrium.
A) 0.138 M B) 0.220 M C) 0.550 M D) 0.275 M E) 0.0275 M

27. At 400°C, $K_c = 64$ for the equilibrium $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$. If 3.00 mol H_2 and 3.00 mol I_2 are introduced into an empty 4.0 L vessel, find the equilibrium concentration of HI at 400°C.
A) 0.15 M B) 1.2 M C) 2.4 M D) 4.8 M E) 5.8 M

29. At 340 K, $K_p = 69$ for the reaction $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$. 50.0 g of HI is injected into an evacuated 5.00-L rigid cylinder at 340 K. What is the total pressure inside the cylinder when the system comes to equilibrium?
A) 2.60 atm B) 1.76 atm C) 0.424 atm D) 2.18 atm E) 10.9 atm

31. For the nitrogen fixation reaction $3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)$, $K_c = 6.0 \times 10^{-2}$ at 500°C. If 0.250 M H_2 and 0.050 M NH_3 are present at equilibrium, what is the equilibrium concentration of N_2?
A) 0.750 M B) 2.7 M C) 0.250 M D) 0.025 M E) 1.85 M

33. Consider the following equilibria:
$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$ $K_c = 2.3 \times 10^{-7}$

$2NO_3(g) \rightleftharpoons 2NO_2(g) + O_2(g)$ $K_c = 1.4 \times 10^{-3}$

Calculate the equilibrium constant for the reaction
$SO_2(g) + NO_3(g) \rightarrow SO_3(g) + NO_2(g)$
A) 78 B) 1.3×10^{-2} C) 1.6×10^{-4} D) 3.2×10^{-10} E) 6.1×10^{3}

35. At 700 K, the reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ has the equilibrium constant $K_c = 4.3 \times 10^{6}$, and the following concentrations are present: $[SO_2] = 0.010$ M; $[SO_3] = 10.$ M; $[O_2] = 0.010$ M. Is the mixture at equilibrium? If not at equilibrium, in which direction (as the equation is written), *left to right* or *right to left*, will the reaction proceed to reach equilibrium?
A) Yes, the mixture is at equilibrium.
B) No, *left to right*
C) No, *right to left*
D) There is not enough information to be able to predict the direction.

37. For the reaction $PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$ at a particular temperature, $K_c = 24.3$.

Suppose a system at that temperature is prepared with $[PCl_3] = 0.10$ M, $[Cl_2] = 0.15$ M, and $[PCl_5] = 0.60$ M. Which of these statements is *true*?
A) The reaction is at equilibrium.
B) The reaction will proceed in the direction of forming more PCl_5 until equilibrium is reached.
C) The reaction will proceed in the direction of forming more PCl_3 and Cl_2 until equilibrium is reached.
D) None of the above statements is true.

39. For the following reaction at equilibrium, which one of the changes below would cause the equilibrium to shift to the *left*?
$2NOBr(g) \rightleftharpoons 2NO(g) + Br_2(g)$, $\Delta H^\circ_{rxn} = 30$ kJ/mol

A) Increase the container volume.
B) Remove some NO.
C) Remove some Br_2.
D) Add more NOBr.
E) Decrease the temperature.

41. For the following reaction at equilibrium in a reaction vessel, which one of these changes would cause the Br_2 concentration to *increase*?
$2NOBr(g) \rightleftharpoons 2NO(g) + Br_2(g)$, $\Delta H^\circ_{rxn} = 30$ kJ/mol

A) Lower the temperature.
B) Remove some NO.
C) Remove some NOBr.
D) Compress the gas mixture into a smaller volume.

43. The reaction $2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$ is endothermic. If the temperature is increased,

A) more SO_3 will be produced.
B) K_c will decrease.
C) no change will occur in K_c .
D) K_c will increase.
E) the pressure will decrease.

45. Which of these situations will result if some $CH_4(g)$ is removed from the reaction $CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$ at equilibrium?

A) H_2O will be consumed.
B) More CH_4 and H_2O will be produced.
C) K_p will decrease.
D) More CO will be produced.
E) No change will occur.

47. In which of these gas-phase equilibria is the yield of products increased by increasing the total pressure on the reaction mixture?

A) $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$

B) $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$

C) $2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$

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

49. The reaction $2NO(g) \rightleftharpoons N_2(g) + O_2(g)$ is exothermic, $\Delta H^\circ_{rxn} = -180$ kJ/mol.

Which one of these statements is *true*?

A) K_p at 1,000 K is less than K_p at 2,000 K.
B) K_p at 1,000 K is larger than K_p at 2,000 K.
C) The K_p's at 1000 K and 2000 K are the same.
D) K_p depends on total pressure as well as temperature.

51. Consider this reaction at equilibrium at a total pressure P_1:
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

Suppose the volume of this system is compressed to one-half its initial volume and then equilibrium is reestablished. The new equilibrium total pressure will be

A) twice P_1.
B) three times P_1.
C) 3.5 P_1.
D) less than twice P_1.
E) unchanged.

53. The equilibrium constants for the chemical reaction
$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$ are $K_P = 1.1 \times 10^{-3}$ and 3.6×10^{-3} at 2,200 K and 2,500 K, respectively. Which one of these statements is *true*?

A) The reaction is exothermic, $\Delta H^\circ < 0$.
B) The partial pressure of NO(g) is less at 2,200 K than at 2,500 K.
C) K_P is less than K_c by a factor of (RT).
D) The total pressure at 2,200 K is the same as at 2,500 K.
E) Higher total pressure shifts the equilibrium to the left.

55. 50.0 g of N_2O_4 is introduced into an evacuated 2.00 L vessel and allowed to come to equilibrium with its decomposition product, $N_2O_4(g) \rightleftharpoons 2NO_2(g)$. For this reaction $K_c = 0.133$. Once the system has reached equilibrium, 5.00 g of NO_2 is injected into the vessel, and the system is allowed to equilibrate once again. Calculate the mass of NO_2 in the final equilibrium mixture.

A) 17.8 g B) 12.4 g C) 14.7 g D) 19.7 g E) 15.5 g

57. 75.0 g of $PCl_5(g)$ is introduced into an evacuated 3.00 L vessel and allowed to reach equilibrium at 250°C.
$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$

If $K_p = 1.80$ for this reaction, what is the total pressure inside the vessel at equilibrium?

A) 2.88 atm B) 2.27 atm C) 4.54 atm D) 7.42 atm E) 9.69 atm

59. 25.0 g of HI(g) is injected into a 4.00 L reaction vessel that contains 20.0 g of $I_2(g)$. When the system comes to equilibrium at 400°C, what will be the total pressure inside the reaction vessel?
$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$, $K_c = 0.0156$ at 400°C

A) 2.70 atm B) 13.0 atm C) 2.43 atm D) 0.815 atm E) 3.24 atm

61. When the reaction $2H_2S(g) \rightleftharpoons 2H_2(g) + S_2(g)$ is carried out at 1065°C, $K_p = 0.012$.

    Starting with pure H_2S at 1065°, what must the initial pressure of H_2S be if the equilibrated mixture at this temperature is to contain 0.250 atm of $H_2(g)$?

    A) 1.06 atm B) 1.86 atm C) 0.94 atm D) 0.90 atm E) 1.52 atm

63. A quantity of liquid methanol, CH_3OH, is introduced into a rigid 3.00-L vessel, the vessel is sealed, and the temperature is raised to 500K. At this temperature, the methanol vaporizes and decomposes according to the reaction

    $CH_3OH(g) \rightleftharpoons CO(g) + 2\ H_2(g)$, $K_c = 6.90 \times 10^{-2}$.

    If the concentration of H_2 in the equilibrium mixture is 0.426M, what mass of methanol was initially introduced into the vessel?

    A) 147 g B) 74.3 g C) 33.9 g D) 49.0 g E) 24.8 g