# CHAPTER 16

# GENERAL ASPECTS OF EQUILIBRIUM

16-1. Which of the following is true about a chemical system at equilibrium?
- (a) no reactions take place
- (b) temperature increases will no longer increase reaction rates
- (c) the rates of forward and reverse reactions are equal
- (d) all reaction products will be solids

16-2. Which of the following is *not* true about a chemical system at equilibrium?
- (a) no reactions take place
- (b) the rates of forward and reverse reactions are equal
- (c) temperature changes can affect concentrations
- (d) concentrations are stable as long as temperature and pressure are stable

16-3. Which of the following is true about a chemical system at equilibrium?
- (a) addition of added reactants can have no effect on concentrations
- (b) no reactions take place
- (c) temperature changes can have no effect on concentrations
- (d) concentrations are stable as long as temperature and pressure are stable

16-4. Which is true about the equilibrium constant expression?
- (a) it determines the activation energy needed to perform a reaction
- (b) it relates reactant and product concentrations
- (c) it relates concentrations to rates
- (d) it tells which reactant is highest in concentration

16-5. Which of the following is the correct form of the equilibrium constant expression for the following reaction?

$A(aq) + B(aq) \rightleftharpoons C(aq) + D(aq)$

- (a) $K = [A][B] / [C][D]$
- (b) $K = [C][D] / [A][B]$
- (c) rate = $k[A][B]$
- (d) $k = [A][B] / [C][D]$

16-6. Which of the following is the correct form of the equilibrium constant expression for the reaction below?

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

- (a) $K = [SO_2][O_2] / [SO_3]$
- (b) $K = [SO_3]^2 / [SO_2]^2[O_2]$
- (c) $K = [SO_2]^2[O_2] / [SO_3]^2$
- (d) $K = [SO_2][O_2]^2$

16-7. Which of the following is the correct form of the equilibrium constant expression for the reaction below?

$Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2\ OH^-(aq)$

- (a) $K = [Zn^{2+}][OH^-]^2$
- (b) $K = [Zn^{2+}][OH^-]$
- (c) $K = [Zn^{2+}][OH^-]^2 / [Zn(OH)_2]$
- (d) $K = [Zn^{2+}][OH^-] / [Zn(OH)_2]$

16-8. Which of the following is the correct form of the equilibrium constant expression for the reaction below?

$Fe^{2+}$(aq) + Sn(s) ¸ $Sn^{2+}$(aq) + Fe(s)

(a) K = $[Sn^{2+}][Fe] / [Fe^{2+}][Sn]$
(b) K = $[Fe^{2+}][Sn] / [Sn^{2+}][Fe]$
(c) K = [Fe] / [Sn]
(d) K = $[Sn^{2+}] / [Fe^{2+}]$

16-9. Which of the following is the correct form of the equilibrium constant expression for the reaction below?

$NH_3$(aq) + $H_2O$(ℓ) ¸ $NH_4^+$(aq) + $OH^-$(aq)

(a) K = $[NH_4^+][OH^-] / [NH_3][H_2O]$
(b) K = $[NH_3]$
(c) K = $[NH_4^+][OH^-]$
(d) K = $[NH_4^+][OH^-] / [NH_3]$

16-10. Which of the following correctly relates the two equilibrium constants for the two reactions shown?

A + B ¸ 2 C $K_1$

2 A + 2 B ¸ 4 C $K_2$

(a) $K_2 = 2 \times K_1$
(b) $K_2 = K_1^2$
(c) $K_2 = 1/K_1$
(d) $K_2 = 1/K_1^2$

16-11. Which of the following correctly relates the two equilibrium constants for the two reactions shown?

A + B ¸ 2 C $K_1$

C ¸ 1/2 A + 1/2 B $K_2$

(a) $K_2 = 1/(K_1)^{1/2}$
(b) $K_2 = 1/K_1$
(c) $K_2 = K_1^2$
(d) $K_2 = -K_1^{1/2}$

16-12. Which of the following correctly relates the two equilibrium constants for the two reactions shown?

NOCl(g) ¸ NO(g) + 1/2 $Cl_2$(g) $K_1$

2 NO(g) + $Cl_2$(g) ¸ 2 NOCl(g) $K_2$

(a) $K_2 = -K_1^2$
(b) $K_2 = 1/(K_1)^{1/2}$
(c) $K_2 = 1/K_1^2$
(d) $K_2 = 2 K_1$

16-13. The equilibrium for conversion of *iso*-butane and *n*-butane is,

*n*-butane ¸ *iso*-butane $K_1 = 2.5$

What is the value of the equilibrium constant for the following reaction ( = $K_2$)?

*iso*-butane ¸ *n*-butane $K_2$ = ?

(a) 2.5
(b) -2.5
(c) 1.58
(d) 0.40

16-14. The equilibrium for the following reaction at 700 K is,

$H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g)$ $K_1 = 55.17$

What is the value of the equilibrium constant for the following reaction ( = $K_2$)?

$HI(g) \rightleftharpoons 1/2\ H_2(g) + 1/2\ I_2(g)$ $K_2 = ?$

(a) $3.29 \times 10^{-5}$ (b) -55.17
(c) 0.0181 (d) 0.135

16-15. Given the equilibrium constant, $K_c$, for the following reaction at 25 $^oC$,

$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g)$ $K_c = 3.6 \times 10^8$

calculate the equilibrium constant, $K_p$, for the same reaction at the same temperature.

(R = 0.08206 L • atm/K • mol)

(a) $2.8 \times 10^{-9}$ (b) $6.0 \times 10^5$
(c) $2.2 \times 10^{11}$ (d) $1.5 \times 10^9$

16-16. Given the equilibrium constant, $K_p$, for the following reaction at 25 $^oC$,

$N_2O_4(g) \rightleftharpoons 2\ NO_2(g)$ $K_p = 0.15$

calculate the equilibrium constant, $K_c$, for the same reaction at the same temperature.

(R = 0.08206 L • atm/K • mol)

(a) 3.7 (b) $6.1 \times 10^{-3}$
(c) 5.5 (d) 0.30

16-17. Given the following two equilibria,

$NiCO_3(s) \rightleftharpoons Ni^{2+}(aq) + CO_3^{2-}(aq)$ $K_1 = 6.6 \times 10^{-9}$

$HCO_3^-(aq) + H_2O(\ell) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$ $K_2 = 4.8 \times 10^{-11}$

calculate the equilibrium constant for the following reaction.

$NiCO_3(s) + H_3O^+(aq) \rightleftharpoons Ni^{2+}(aq) + HCO_3^-(aq) + H_2O(\ell)$ $K_3 = ?$

(a) $7.3 \times 10^{-3}$ (b) $3.2 \times 10^{-19}$
(c) 140 (d) $1.8 \times 10^{-9}$

16-18. Given the following two equilibria,

$PbI_2(s) \rightleftharpoons Pb^{2+}(aq) + 2I^-(aq)$ $K_1 = 8.7 \times 10^{-9}$

$PbSO_4(s) \rightleftharpoons Pb^{2+}(aq) + SO_4^{2-}(aq)$ $K_2 = 1.8 \times 10^{-8}$

calculate the equilibrium constant for the following reaction.

$PbSO_4(s) + 2\ I^-(aq) \rightleftharpoons PbI_2(s) + SO_4^{2-}(aq)$ $K_3 = ?$

(a) 0.48 (b) $6.4 \times 10^{15}$
(c) 2.1 (d) $1.6 \times 10^{-16}$

16-19. We have the following equilibrium: $2\ A(aq) \rightleftharpoons B(aq)$. At equilibrium we measure [A] = 0.056 M and [B] = 0.21 M. Calculate the equilibrium constant for the reaction as written.

(a) 67 (b) 0.015
(c) 3.8 (d) 14

16-20. We examine the following reaction at 250 $^oC$: $PCl_5(g)$ ¸ $PCl_3(g) + Cl_2(g)$. At equilibrium we find $[PCl_5] = 3.4 \times 10^{-5}$ M, $[PCl_3] = 1.3 \times 10^{-2}$ M, and $[Cl_2] = 1.0 \times 10^{-4}$ M. Calculate the equilibrium constant, $K_c$, for the reaction.

(a) 26 (b) 5.1
(c) $2.8 \times 10^{-4}$ (d) 0.038

16-21. We examine the following reaction at 690 $^oC$: $CO_2(g) + H_2(g)$ ¸ $CO(g) + H_2O(g)$. At equilibrium we find $[CO_2] = 1.5 \times 10^{-4}$ M, $[H_2] = 2.2 \times 10^{-4}$ M, $[H_2O] = 3.3 \times 10^{-4}$ M, and $[CO] = 1.6 \times 10^{-4}$ M. Calculate $K_c$ for this equilibrium.

(a) 0.62 (b) 1.6
(c) 3.8 (d) $4.2 \times 10^{-4}$

16-22. We place an excess (more than can dissolve) of $PbCl_2(s)$ into 100.mL of water and find that at equilibrium, $[Cl^-] = 0.032$ M. Calculate K for the following reaction:
$PbCl_2(s)$ ¸ $Pb^{2+}(aq) + 2\ Cl^-(aq)$

(a) $5.1 \times 10^{-4}$ (b) $3.9 \times 10^{-5}$
(c) $4.8 \times 10^{-3}$ (d) $1.6 \times 10^{-5}$

16-23. We place 1.00 g of $[Ni(NH_3)_6]Cl_2$ into 100. mL of water and find that at equilibrium, $[NH_3] = 0.0452$ M. Calculate K for the following reaction:
$[Ni(NH_3)_6]^{2+}$ ¸ $Ni^{2+}(aq) + 6\ NH_3(aq)$

(a) $1.79 \times 10^{-9}$ (b) $2.23 \times 10^{-4}$
(c) $1.60 \times 10^{-9}$ (d) $7.32 \times 10^{-18}$

16-24. We place 0.010 mol of $N_2O_4(g)$ in a 2.0 L flask at 200 $^oC$. After reaching equilibrium, $[N_2O_4] = 0.0042$ M. What is $K_c$ for the following reaction?
$N_2O_4(g)$ ¸ $2\ NO_2(g)$

(a) 1640 (b) $3.1 \times 10^{-4}$
(c) $6.1 \times 10^{-4}$ (d) $8.8 \times 10^{-6}$

16-25. We place 1.00 g of NaF in 1.00 L of water and find that at equilibrium $[OH^-] = 5.77 \times 10^{-7}$ M. What is the equilibrium constant for $F^-(aq) + H_2O(\ell)$ ¸ $HF(aq) + OH^-(aq)$?

(a) $7.2 \times 10^{10}$ (b) $1.4 \times 10^{-11}$
(c) $1.4 \times 10^{-8}$ (d) $4.4 \times 10^{-8}$

16-26. If we have AgBr(s), $Ag^+(aq)$ and $Br^-(aq)$ in equilibrium and we know that $[Br^-] = 0.50$ M, what is $[Ag^+]$ in the solution?
AgBr(s) ¸ $Ag^+(aq) + Br^-(aq)$ $K = 3.3 \times 10^{-13}$

(a) $6.6 \times 10^{-13}$ M (b) $1.5 \times 10^{12}$ M
(c) $3.3 \times 10^{-13}$ M (d) $1.7 \times 10^{-13}$ M

16-27. If we have $Fe(OH)_2(s)$, $Fe^{2+}(aq)$, and $OH^-(aq)$ in equilibrium, and we know that $[OH^-] = 0.0010$ M, what is $[Fe^{2+}]$ in the solution?

$Fe(OH)_2(s) \rightleftharpoons Fe^{2+}(aq) + 2\ OH^-(aq)$ K = $7.9 \times 10^{-15}$

(a) $7.9 \times 10^{-12}$ M (b) $7.9 \times 10^{-15}$ M
(c) $7.9 \times 10^{-9}$ M (d) $7.9 \times 10^{-18}$ M

16-28. We have a solution where $Ag(CN)_2^-(aq)$, $CN^-(aq)$, and $Ag^+(aq)$ are at equilibrium. If we know that $[Ag(CN)_2^-] = 0.030$ M and that $[CN^-] = 0.10$ M, what is $[Ag^+]$ in the solution?

$Ag(CN)_2^-(aq) \rightleftharpoons Ag^+(aq) + 2\ CN^-(aq)$ K = $1.8 \times 10^{-19}$

(a) $5.4 \times 10^{-20}$ M (b) $5.4 \times 10^{-10}$ M
(c) $5.4 \times 10^{-19}$ M (d) $3.0 \times 10^{-12}$ M

16-29. We have a gaseous sample where $NO_2$ and $N_2O_4$ are in equilibrium. If we know that $[N_2O_4] = 4.6 \times 10^{-5}$ M, what is $[NO_2]$?

$2\ NO_2(g) \rightleftharpoons N_2O_4(g)$ K = 180

(a) 2000 M (b) $4.6 \times 10^{-5}$ M
(c) $2.6 \times 10^{-7}$ M (d) $5.1 \times 10^{-4}$ M

16-30. We have a gaseous sample where *iso*-butane and *n*-butane are in equilibrium at 300 K. If we know that [*iso*-butane] = 0.040 M, what is [*n*-butane]?

*n*-butane $\rightleftharpoons$ *iso*-butane K= 2.5

(a) 2.5 M (b) 0.016 M
(c) 62.5 M (d) 0.13 M

16-31. Determine if the following system is at equilibrium, the reactant concentrations are too high, the product concentrations are too high, or if one simply cannot determine which with the information given.

*n*-butane $\rightleftharpoons$ *iso*-butane K = 2.5

[*iso*-butane] = 0.030 M and [*n*-butane] = 0.020 M

(a) at equilibrium (b) product concentrations too high
(c) reactant concentrations too high (d) cannot be determined

16-32. Determine if the following system is at equilibrium, the reactant concentrations are too high, the product concentrations are too high, or if one simply cannot determine which with the information given.

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ $K_p = 11.5$

$P(PCl_5) = 1.15$ atm $P(PCl_3) = 5.30$ atm $P(Cl_2) = 2.80$ atm

(a) at equilibrium (b) product concentrations too high
(c) reactant concentrations too high (d) cannot be determined

16-33. Determine if the following system is at equilibrium, the reactant concentrations are too high, the product concentrations are too high, or if one simply cannot determine which with the information given.

$BaSO_4(s)$ ¸ $Ba^{2+}(aq) + SO_4^{2-}(aq)$ $K = 1.0 \times 10^{-10}$

$[Ba^{2+}] = 1.0 \times 10^{-5}$ M $[SO_4^{2-}] = 1.0 \times 10^{-5}$ M

(a) at equilibrium (b) product concentrations too high
(c) reactant concentrations too high (d) cannot be determined

16-34. Determine if the following system is at equilibrium, the reactant concentrations are too high, the product concentrations are too high, or if one simply can not determine which with the information given.

$N_2(g) + O_2(g)$ ¸ $2\ NO(g)$ Temperature = 570 K

$P(N_2) = 1.22$ atm$P(O_2) = 0.31$ atm$P(NO) = 3.38$ atm

(a) at equilibrium (b) product concentrations too high
(c) reactant concentrations too high (d) cannot be determined

16-35. We place 2.0 mol of $PCl_5$ in a 5.0 L flask and let the system come to equilibrium. What will the final concentration of $Cl_2$ be?

$PCl_5(g)$ ¸ $PCl_3(g) + Cl_2(g)$ $K_c = 0.47$

(a) 0.40 M (b) 0.26 M
(c) 0.33 M (d) 0.023 M

16-36. An important reaction in the formation of acid rain is,

$2\ SO_2(g) + O_2(g)$ ¸ $2\ SO_3(g)$ $K = 6.41 \times 10^3$

If we add 3.00 g of $SO_2$ and 5.00 g of $O_2$ to a 1.0 L flask, approximately how many grams of $SO_3$ will be in the flask once reactants and the product reach equilibrium? (NOTE: Do not try to solve this problem exactly. It is a cubic equation. The idea is to decide which of the answers below is most reasonable.)

(a) 2.21 g (b) 4.56 g
(c) 3.61 g (d) 8.00 g

16-37. We place 0.100 mol of pure *iso*-butane in a 3.00 L flask at low temperature and then raise the temperature to 25 $^oC$, where the following equilibrium exists,

*n*-butane ¸ *iso*-butane; K = 2.50

What will the equilibrium concentration of [*iso*-butane] be?

(a) 0.0335 M (b) 0.0238 M
(c) $9.52 \times 10^{-3}$ M (d) 0.100 M

16-38. We add 50.0 mL of 0.200 M $NH_3$(aq) to 50.0 mL of 0.010 M $CuCl_2$(aq). What will $[Cu^{2+}]$ be when equilibrium is reached? (NOTE: Do not solve this problem exactly. Decide which of the answers is the most reasonable based on the principles of chemical equilibria.)

$Cu^{2+}$(aq) + 4 $NH_3$(aq) ¸ $[Cu(NH_3)_4]^{2+}$(aq) K= 6.8 x $10^{12}$

(a) 1.79 x $10^{-11}$ M (b) 4.42 x $10^{-3}$ M
(c) 5.00 x $10^{-3}$ M (d) 2.24 x $10^{-12}$ M

16-39. We place 0.100 mol of a diatomic gas, X—X, in a 1.00 L high temperature vessel and heat it to 2000 K. What will the concentration of free X, [X], be when equilibrium is reached?
X—X(g) ¸ X(g) + X(g) K = 0.393
(a) 0.200 M (b) 0.123 M
(c) 0.0815 M (d) 2.88 x $10^{-4}$ M

16-40. Ammonium hydrogen sulfide decomposes on heating,
$NH_4HS$(s) ¸ $NH_3$(g) + $H_2S$(g) $K_p$= 0.11 at 25°C
If we have a 1.00 L flask which already contains gaseous $NH_3$ at a pressure of 0.25 atm and heat up some $NH_4HS$, what will the equilibrium pressure of $NH_3$ be?
(a) 0.23 atm (b) 0.11 atm
(c) 0.48 atm (d) 0.18 atm

16-41. We have the following equilibrium,
$PbCl_2$(s) ¸ $Pb^{2+}$(aq) + 2 $Cl^-$(aq)
What will happen to $[Pb^{2+}]$ if some solid NaCl is added to the flask?
(a) it will increase (b) it will decrease
(c) it will not change (d) cannot tell

16-42. We have the following equilibrium,
$PCl_5$(g) ¸ $PCl_3$(g) + $Cl_2$(g) $K_c$= 0.47
What will happen to $[Cl_2]$ if additional $PCl_5$(g) is added to the flask?
(a) it will increase (b) it will decrease
(c) it will not change (d) cannot tell with the information provided

16-43. We have the following equilibrium,
$BaSO_4$(s) ¸ $Ba^{2+}$(aq) + $SO_4^{2-}$(aq)
What will happen to $[Ba^{2+}]$ if additional solid $BaSO_4$ is added to the flask?
(a) it will increase (b) it will decrease
(c) it will not change (d) cannot tell with the information provided

16-44. We have the following equilibrium,

$N_2O_4(g)$ ¸ $2\ NO_2(g)$ $\Delta H^o_{rxn} = +150kJ$

What will happen to $[N_2O_4]$ if the temperature is increased?

(a) it will increase (b) it will decrease
(c) it will not change (d) cannot tell with the information provided

16-45. We have the following equilibrium: $2\ SO_3(g)$ ¸ $2\ SO_2(g) + O_2(g)$. What will happen to $[SO_3]$ if the temperature is increased?

(a) it will increase (b) it will decrease
(c) it will not change (d) cannot tell

16-46. We add 1.00 mol each of *iso*-butane and *n*-butane to a 1.00 L flask. What is [*iso*-butane] when the system reaches equilibrium?

*n*-butane ¸ *iso*-butane K=2.50

(a) 0.429 M (b) 1.429 M
(c) 0.571 M (d) 0.238 M

16-47. We have the following equilibrium: $PCl_5(g)$ ¸ $PCl_3(g) + Cl_2(g)$ where $K_c = 0.470$. We have a 1.00 L flask where $[PCl_5] = 0.150$ M, $[PCl_3] = 0.280$ M, and $[Cl_2] = 0.252$ M. If we add 0.20 mol of $Cl_2(g)$ to the flask, what will $[PCl_3]$ be when equilibrium is reached?

(a) 0.231 M (b) 0.290 M
(c) 0.329 M (d) 0.0486 M

*Questions 48-50 removed. (They cover kinetics and mechanisms)*

16-51. The hydrocarbon $C_4H_{10}$ can exist in two forms, *n*-butane and *iso*-butane. The value of $K_c$ for the interconversion of the two forms is 2.50 at a given temperature.

*n*-butane ¸ *iso*-butane $K_c = 2.50$

You mix 1.75 moles of *n*-butane and 1.25 moles of *iso*-butane in a 0.50-L flask. What are the concentrations of the two forms at equilibrium?

(a) [*n*-butane] = 3.50 M and [*iso*-butane] = 2.50 M
(b) [*n*-butane] = 1.71 M and [*iso*-butane] = 4.29 M
(c) [*n*-butane] = 4.29 M and [*iso*-butane] = 1.71 M
(d) [*n*-butane] = 1.79 M and [*iso*-butane] = 1.79 M

16-52. The formation of $ClF_3(g)$ is exothermic.

$Cl_2(g) + 3\ F_2(g)$ ¸ $2\ ClF_3(g)$ + heat

Predict the effect on the equilibrium of each change listed below. Answer by choosing (a) no change, (b) shifts left, or (c) shifts right.

(i) add $Cl_2$
(ii) add $ClF_3$
(iii) raise the temperature
(iv) decrease the volume of the flask containing the reaction

16-53. Heating a metal carbonate leads to decomposition.

heat + $BaCO_3(s) \rightleftharpoons BaO(s) + CO_2(g)$

Predict the effect on the equilibrium of each change listed below. Answer by choosing (a) no change, (b) shifts left, or (c) shifts right.

(i) add $BaCO_3$

(ii) add $CO_2$

(iii) add BaO

(iv) raise the temperature

(v) increase the volume of the flask containing the reaction

16-54. $H_2$ gas, $H_2S$ gas, and solid sulfur are placed in a flask and heated to 90 $^{o}$C. K at this temperature is 0.068.

$H_2(g) + S(s) \rightleftharpoons H_2S(g)$

You mix 17.5 moles of $H_2$ and 1.25 moles of $H_2S$ in a 0.50-L flask at 25 ˚C. Is the system at equilibrium? If not, in which direction does the reaction shift in order to establish equilibrium?

(a) The concentrations given are equilibrium concentrations

(b) The reaction is not at equilibrium, and so shifts left to achieve equilibrium.

(c) The reaction is not at equilibrium, and so shifts right to achieve equilibrium.

16-55. Cyclohexane, $C_6H_{12}$, a hydrocarbon, can isomerize or change into methylcyclopentane, a compound of the same formula but with a different molecular structure.

$C_6H_{12}(g) \rightleftharpoons C_5H_9CH_3(g)$

cyclohexane methylcyclopentane

The equilibrium constant has been estimated to be 0.12 at 25 °C. If you had originally placed 3.79 grams of cyclohexane in a 2.80 L flask, how many grams of cyclohexane are present when equilibrium is established?

(a) 0.401 g (b) 1.13 g

(c) 3.30 g (d) 3.77 g

## ANSWERS — CHAPTER 16

| | | | | | |
|---|---|---|---|---|---|
| 1. | c | 11. | a | 21. | b |
| 2. | a | 12. | c | 22. | d |
| 3. | d | 13. | d | 23. | a |
| 4. | b | 14. | d | 24. | c |
| 5. | b | 15. | b | 25. | b |
| 6. | c | 16. | a | 26. | a |
| 7. | a | 17. | c | 27. | c |
| 8. | d | 18. | c | 28. | c |
| 9. | d | 19. | a | 29. | d |
| 10. | b | 20. | d | 30. | b |
| 31. | c | 41. | b | 51. | b |
| 32. | b | 42. | a | 52. | c, b, b, c |
| 33. | a | 43. | c | 53. | a, b, a, c, c |
| 34. | d | 44. | b | 54. | b |
| 35. | b | 45. | d | 55. | c |
| 36. | c | 46. | b | | |
| 37. | b | 47. | a | | |
| 38. | a | 48. | d | | |
| 39. | b | 49. | c | | |
| 40. | c | 50. | d | | |