Chapter 14

1. Which is the correct equilibrium constant expression for the following reaction?
\[ \text{Fe}_2\text{O}_3(s) + 3\text{H}_2(g) \rightleftharpoons 2\text{Fe(s)} + 3\text{H}_2\text{O(g)} \]

A. \( K_c = [\text{Fe}_2\text{O}_3] [\text{H}_2]^3/[\text{Fe}]^2[\text{H}_2\text{O}]^3 \)
B. \( K_c = [\text{H}_2]/[\text{H}_2\text{O}] \)
C. \( K_c = [\text{H}_2\text{O}]^3/[\text{H}_2]^3 \)
D. \( K_c = [\text{Fe}]^2[\text{H}_2\text{O}]^3/[\text{Fe}_2\text{O}_3] [\text{H}_2]^3 \)
E. \( K_c = [\text{Fe}] [\text{H}_2\text{O}]/[\text{Fe}_2\text{O}_3] [\text{H}_2]^3 \)

2. Consider the two gaseous equilibria
\[ \text{SO}_2(g) + (1/2)\text{O}_2(g) \rightleftharpoons \text{SO}_3(g) \quad K_1 \]
\[ 2\text{SO}_3(g) \rightleftharpoons \text{SO}_2(g) + \text{O}_2(g) \quad K_2 \]

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

3. Carbon tetrachloride reacts at high temperatures with oxygen to produce two toxic gases, phosgene and chlorine.
\[ \text{CCl}_4(g) + (1/2)\text{O}_2(g) \rightleftharpoons \text{COCl}_2(g) + \text{Cl}_2(g), \quad K_c = 4.4 \times 10^9 \text{ at } 1,000 \text{ K} \]

Calculate \( K_c \) for the reaction \( 2\text{CCl}_4(g) + \text{O}_2(g) \rightleftharpoons 2\text{COCl}_2(g) + 2\text{Cl}_2(g) \).

A. \( 4.4 \times 10^9 \)
B. \( 8.8 \times 10^9 \)
C. \( 1.9 \times 10^{10} \)
D. \( 1.9 \times 10^{19} \)
E. \( 2.3 \times 10^{-10} \)
4. Which of these statements is true about chemical equilibria in general?

A. At equilibrium the total concentration of products equals the total concentration of reactants, that is, \([\text{products}] = [\text{reactants}]\).
B. Equilibrium is the result of the cessation of all chemical change.
C. There is only one set of equilibrium concentrations that equals the \(K_c\) value.
D. At equilibrium, the rate constant of the forward reaction is equal to the rate constant for the reverse reaction.
E. At equilibrium, the rate of the forward reaction is equal to the rate of the reverse reaction.

5. The following reactions occur at 500 K. Arrange them in order of increasing tendency to proceed to completion (least completion \(\to\) greatest completion).

1) \(2\text{NOCl} \rightleftharpoons 2\text{NO} + \text{Cl}_2\) \(K_p = 1.7 \times 10^{-2}\)
2) \(\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2\) \(K_p = 1.5 \times 10^3\)
3) \(2\text{SO}_3 \rightleftharpoons 2\text{SO}_2 + \text{O}_2\) \(K_p = 1.3 \times 10^{-5}\)
4) \(2\text{NO}_2 \rightleftharpoons 2\text{NO} + \text{O}_2\) \(K_p = 5.9 \times 10^{-5}\)

A. \(2 < 1 < 3 < 4\)
B. \(3 < 1 < 4 < 2\)
C. \(3 < 4 < 1 < 2\)
D. \(4 < 3 < 2 < 1\)
E. \(4 < 3 < 1 < 2\)

6. Calculate \(K_p\) for the reaction \(2\text{NOCl}(g) \rightleftharpoons 2\text{NO}(g) + \text{Cl}_2(g)\) at 400°C if \(K_c\) at 400°C for this reaction is \(2.1 \times 10^{-2}\).

A. \(2.1 \times 10^{-2}\)
B. \(1.7 \times 10^{-3}\)
C. 0.70
D. 1.2
E. \(3.8 \times 10^{-4}\)
7. On analysis, an equilibrium mixture for the reaction $2\text{H}_2\text{S}(g) \rightleftharpoons 2\text{H}_2(g) + \text{S}_2(g)$ was found to contain 1.0 mol $\text{H}_2\text{S}$, 4.0 mol $\text{H}_2$, and 0.80 mol $\text{S}_2$ 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

8. 2.50 mol NOCl was placed in a 2.50 L reaction vessel at 400ºC. After equilibrium was established, it was found that 28% of the NOCl had dissociated according to the equation $2\text{NOCl}(g) \rightleftharpoons 2\text{NO}(g) + \text{Cl}_2(g)$.

Calculate the equilibrium constant, $K_c$, for the reaction.

A. 0.021  
B. 0.039  
C. 0.169  
D. 26  
E. 47

9. 1.25 moles of NOCl were placed in a 2.50 L reaction chamber at 427ºC. After equilibrium was reached, 1.10 moles of NOCl remained. Calculate the equilibrium constant, $K_c$, for the reaction $2\text{NOCl}(g) \rightleftharpoons 2\text{NO}(g) + \text{Cl}_2(g)$.

A. $3.0 \times 10^{-4}$  
B. $1.8 \times 10^{3}$  
C. $1.4 \times 10^{-3}$  
D. $5.6 \times 10^{-4}$  
E. $4.1 \times 10^{-3}$

10. The reaction $\text{A}(g) + 2\text{B}(g) \rightleftharpoons \text{C}(g)$ was allowed to come to equilibrium. The initial amounts of reactants placed into a 5.00 L vessel were 1.0 mol A and 1.8 mol B. After the reaction reached equilibrium, 1.0 mol of B was found. Calculate $K_c$ for this reaction.

A. 0.060  
B. 5.1  
C. 17  
D. 19  
E. 25
11. $K_p$ for the reaction of $\text{SO}_2(g)$ with $\text{O}_2$ to produce $\text{SO}_3(g)$ is $3 \times 10^{24}$. Calculate $K_c$ for this equilibrium at 25°C. (The relevant reaction is $2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g)$.)

A. $3 \times 10^{24}$  
B. $5 \times 10^{21}$  
C. $2 \times 10^{20}$  
D. $5 \times 10^{22}$  
E. $7 \times 10^{25}$

12. If one starts with pure $\text{NO}_2(g)$ at a pressure of 0.500 atm, the total pressure inside the reaction vessel when $2\text{NO}_2(g) \rightleftharpoons 2\text{NO}(g) + \text{O}_2(g)$ reaches equilibrium is 0.674 atm. Calculate the equilibrium partial pressure of $\text{NO}_2$.

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.

13. Hydrogen iodide decomposes according to the equation $2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g)$, 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

14. At 400°C, $K_c = 64$ for the equilibrium $\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g)$. If 3.00 mol $\text{H}_2$ and 3.00 mol $\text{I}_2$ 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
15. Sodium carbonate, \( \text{Na}_2\text{CO}_3(s) \), can be prepared by heating sodium bicarbonate, \( \text{NaHCO}_3(s) \).

\[
2\text{NaHCO}_3(s) \rightleftharpoons \text{Na}_2\text{CO}_3(s) + \text{CO}_2(g) + \text{H}_2\text{O}(g) \quad K_p = 0.23 \text{ at } 100^\circ\text{C}
\]

If a sample of \( \text{NaHCO}_3 \) is placed in an evacuated flask and allowed to achieve equilibrium at 100°C, what will the total gas pressure be?

A. 0.46 atm  
B. 0.96 atm  
C. 0.23 atm  
D. 0.48 atm  
E. 0.11 atm

16. 15.00 g of solid ammonium hydrogen sulfide is introduced into a 500.-mL flask at 25°C, the flask is sealed, and the system is allowed to reach equilibrium. What is the partial pressure of ammonia in this flask if \( K_p = 0.108 \) at 25°C for \( \text{NH}_4\text{HS}(s) \rightleftharpoons \text{NH}_3(g) + \text{H}_2\text{S} \quad (g) \)?

A. 0.657 atm  
B. 1.25 atm  
C. 0.329 atm  
D. 14.4 atm  
E. 2.50 atm

17. Consider the following reactions and their associated equilibrium constants:

\[
\begin{align*}
\text{A} + 2\text{B} & \rightleftharpoons \text{C} \quad K_1 \\
\text{C} & \rightleftharpoons \text{D} + \text{E} \quad K_2
\end{align*}
\]

For the reaction \( \text{A} + 2\text{B} \rightleftharpoons \text{D} + \text{E} \), having equilibrium constant \( K_c \).

A. \( K_c = K_1 + K_2 \)  
B. \( K_c = \frac{K_1}{K_2} \)  
C. \( K_c = K_1 \, K_2 \)  
D. \( K_c = (K_1)(K_2) \)  
E. \( K_c = \frac{K_2}{K_1} \)
18. At 700 K, the reaction \( 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \) has the equilibrium constant \( K_c = 4.3 \times 10^6 \), and the following concentrations are present: \([\text{SO}_2] = 0.10 \text{ M}; [\text{SO}_3] = 10. \text{ M}; [\text{O}_2] = 0.10 \text{ M}.\)

Is the mixture at equilibrium? If not at equilibrium, in which direction (as the equation is written), \textit{left to right} or \textit{right to left}, will the reaction proceed to reach equilibrium?

A. Yes, the mixture is at equilibrium.
B. No, \textit{left to right}.
C. No, \textit{right to left}.
D. There is not enough information to be able to predict the direction.

19. For the following reaction at equilibrium, which choice gives a change that will shift the position of equilibrium to favor formation of more products?

\[ 2\text{NOBr}(g) \rightleftharpoons 2\text{NO}(g) + \text{Br}_2(g), \Delta H_{\text{rxn}}^\circ = 30 \text{ kJ/mol} \]

A. Increase the total pressure by decreasing the volume.
B. Add more NO.
C. Remove \( \text{Br}_2 \).
D. Lower the temperature.
E. Remove NOBr selectively.

20. For the following reaction at equilibrium, which one of the changes below would cause the equilibrium to shift to the \textit{left}?

\[ 2\text{NOBr}(g) \rightleftharpoons 2\text{NO}(g) + \text{Br}_2(g), \Delta H_{\text{rxn}}^\circ = 30 \text{ kJ/mol} \]

A. Increase the container volume.
B. Remove some NO.
C. Remove some \( \text{Br}_2 \).
D. Add more NOBr.
E. Decrease the temperature.
21. For the following reaction at equilibrium in a reaction vessel, which one of these changes would cause the Br\(_2\) concentration to decrease?

\[
2\text{NOBr(g)} \rightleftharpoons 2\text{NO(g)} + \text{Br}_2\text{(g)}, \Delta H_{\text{rxn}}^\circ = 30 \text{ kJ/mol}
\]

A. Increase the temperature.
B. Remove some NO.
C. Add more NOBr.
D. Compress the gas mixture into a smaller volume.

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

A. \(\text{CO(g)} + \text{H}_2\text{O(g)} \rightleftharpoons \text{CO}_2\text{(g)} + \text{H}_2\text{(g)}\)
B. \(2\text{NO(g)} + \text{Cl}_2\text{(g)} \rightleftharpoons 2\text{NOCl(g)}\)
C. \(2\text{SO}_3\text{(g)} \rightleftharpoons 2\text{SO}_2\text{(g)} + \text{O}_2\text{(g)}\)
D. \(\text{PCl}_5\text{(g)} \rightleftharpoons \text{PCl}_3\text{(g)} + \text{Cl}_2\text{(g)}\)

23. Consider this gas phase equilibrium system:

\[
\text{PCl}_5\text{(g)} \rightleftharpoons \text{PCl}_3\text{(g)} + \text{Cl}_2\text{(g)}, \Delta H_{\text{rxn}}^\circ = +87.8 \text{ kJ/mol.}
\]

Which of these statements is false?

A. Increasing the system volume shifts the equilibrium to the right.
B. Increasing the temperature shifts the equilibrium to the right.
C. A catalyst speeds up the approach to equilibrium and shifts the position of equilibrium to the right.
D. Decreasing the total pressure of the system shifts the equilibrium to the right.
E. Increasing the temperature causes the equilibrium constant to increase.

24. The reaction \(2\text{NO(g)} \rightleftharpoons \text{N}_2\text{(g)} + \text{O}_2\text{(g)}\) is exothermic, \(\Delta H_{\text{rxn}}^\circ = -180 \text{ kJ/mol.}\)

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.
25. Consider this reaction at equilibrium:

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g), \quad \Delta H_{\text{rxn}}^\circ = -198 \text{ kJ/mol} \]

If the volume of the system is compressed at constant temperature, what change will occur in the position of the equilibrium?

A. a shift to produce more \( \text{SO}_2 \)
B. a shift to produce more \( \text{O}_2 \)
C. no change
D. a shift to produce more \( \text{SO}_3 \)
Chapter 14 Key

1. C
2. C
3. D
4. E
5. C
6. D
7. B
8. A
9. D
10. C
11. E
12. A
13. B
14. B
15. B
16. C
17. D
18. B
19. C
20. E
21. D
22. B
23. C
24. B