1. An equilibrium is established in which both the forward (fwd) and the reverse (rev) reactions are elementary. If the equilibrium constant $K_c = 1.6 \times 10^{-2}$ and the rate constant $k_{fwd} = 8.0 \times 10^7 \text{ s}^{-1}$ what is the value of $k_{rev}$?

A) $1.3 \times 10^{-8} \text{ s}^{-1}$
B) $7.8 \times 10^7 \text{ s}^{-1}$
C) $2 \times 10^4 \text{ s}^{-1}$
D) $5.0 \times 10^{-5} \text{ s}^{-1}$
E) none of the above

2. Consider the equilibrium reaction shown below.

$\text{B}_2(g) \rightleftharpoons 2\text{B}(g)$

If the rate constants are: $k_{fwd} = 7.00 \times 10^{-1} \text{ s}^{-1}$ and $k_{rev} = 2.00 \times 10^{-3} \text{ L mol}^{-1} \text{ s}^{-1}$, what is the value of $K_c$ under these conditions?

A) $1.75 \times 10^5$
B) $3.50$
C) $0.286$
D) $5.71 \times 10^{-6}$
E) $1.40 \times 10^{-10}$

3. The reaction quotient, $Q_c$, for a reaction has a value of 75 while the equilibrium constant, $K_c$, has a value of 195. Which of the following statements is accurate?

A) The reaction must proceed to the left to establish equilibrium.
B) The reaction must proceed to the right to establish equilibrium.
C) The concentrations of the products will be much smaller than the concentrations of the reactants when the system is at equilibrium.
D) The concentrations of the products will be about the same as the concentrations of the reactants when the system is at equilibrium.
E) None of the above statements is accurate.
4. Carbon monoxide and chlorine combine in an equilibrium reaction to produce the highly toxic product, phosgene (COCl₂)

\[ \text{CO}(g) + \text{Cl}_2(g) \rightleftharpoons \text{COCl}_2(g) \]

If the equilibrium constant for this reaction is \( K_e = 248 \), predict, if possible, what will happen when the reactants and product are combined with the concentrations shown.
\[ [\text{CO}] = [\text{Cl}_2] = 0.0200 \text{ M}; [\text{COCl}_2] = 0.0992 \text{ M} \]
A) The reaction will proceed to the right.
B) The reaction will proceed to the left.
C) The reaction is at equilibrium, and no change in concentrations will occur.
D) The container volume needs to be specified before a prediction can be made.
E) The temperature needs to be specified before a prediction can be made.

5. Consider the reactions of cadmium with the thiosulfate anion.

\[ \text{Cd}^{2+}(aq) + \text{S}_2\text{O}_3^{2-}(aq) \rightleftharpoons \text{Cd}(	ext{S}_2\text{O}_3)(aq) \quad K_1 = 8.3 \times 10^3 \]
\[ \text{Cd}(	ext{S}_2\text{O}_3)(aq) + \text{S}_2\text{O}_3^{2-}(aq) \rightleftharpoons \text{Cd}(	ext{S}_2\text{O}_3)_2^{2-}(aq) \quad K_2 = 2.5 \times 10^2 \]

What is the value for the equilibrium constant for the following reaction?

\[ \text{Cd}^{2+}(aq) + 2\text{S}_2\text{O}_3^{2-}(aq) \rightleftharpoons \text{Cd}(	ext{S}_2\text{O}_3)_2^{2-}(aq) \]
A) 0.030
B) 33
C) \( 8.1 \times 10^3 \)
D) \( 8.6 \times 10^3 \)
E) \( 2.1 \times 10^6 \)

6. \( \text{N}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}(g) \quad K_e = 4.8 \times 10^{-11} \)
\( 2\text{NOBr}(g) \rightleftharpoons 2\text{NO}(g) + \text{Br}_2(g) \quad K_e = 0.50 \)

Given the above equilibrium constant data at 25 °C, what is the value of \( K_e \) at this temperature for the reaction

\( 2\text{NOBr}(g) \rightleftharpoons \text{N}_2(g) + \text{O}_2(g) + \text{Br}_2(g) \)?
A) \( 2.4 \times 10^{-31} \)
B) \( 9.6 \times 10^{-31} \)
C) \( 1.0 \times 10^{26} \)
D) \( 4.2 \times 10^{16} \)
E) none of the above
7. The equilibrium constant, $K_e$, for the decomposition of COBr₂

$$\text{COBr}_2(g) \rightleftharpoons \text{CO}(g) + \text{Br}_2(g)$$

is 0.190. What is $K_e$ for the following reaction?

$$2\text{CO}(g) + 2\text{Br}_2(g) \rightleftharpoons 2\text{COBr}_2(g)$$

A) 0.0361
B) 2.63
C) 5.62
D) 10.5
E) 27.7

8. Consider the following two equilibria and their respective equilibrium constants:

1. \( \text{NO}(g) + \frac{1}{2} \text{O}_2(g) \rightleftharpoons \text{NO}_2(g) \)

2. \( 2\text{NO}_2(g) \rightleftharpoons 2\text{NO}(g) + \text{O}_2(g) \)

Which one of the following is the correct relationship between the equilibrium constants \( K_1 \) and \( K_2 \)?

A) \( K_2 = 2/K_1 \)
B) \( K_2 = (1/K_1)^2 \)
C) \( K_2 = -K_1/2 \)
D) \( K_2 = 1/(2K_1) \)
E) \( K_2 = 1/(2K_1)^2 \)

9. The reaction of nitrogen with oxygen to form nitrogen monoxide can be represented by the following equation.

$$\text{N}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}(g)$$

At 2000°C, the equilibrium constant, $K_e$, has a value of $4.10 \times 10^{-4}$. What is the value of $K_p$?

A) $2.17 \times 10^{-8}$
B) $4.10 \times 10^{-4}$
C) $7.65 \times 10^{-2}$
D) 7.75
E) none of the above

10. Nitric oxide and bromine were allowed to react in a sealed container. When equilibrium was reached, $P_{\text{NO}} = 0.526 \text{ atm}$, $P_{\text{Br}_2} = 1.59 \text{ atm}$, and $P_{\text{NOBr}} = 7.68 \text{ atm}$. Calculate $K_p$ for the reaction.

$$2\text{NO}(g) + \text{Br}_2(g) \rightleftharpoons 2\text{NOBr}(g)$$

A) $7.45 \times 10^{-3}$
B) 0.109
C) 9.18
D) 91.8
E) 134
11. Compounds A, B, and C react according to the following equation.
\[ 3A(g) + 2B(g) \rightleftharpoons 2C(g) \]
At 100°C a mixture of these gases at equilibrium showed that [A] = 0.855 M, [B] = 1.23 M, and [C] = 1.75 M. What is the value of \( K_c \) for this reaction?
A) 0.309
B) 0.601
C) 1.66
D) 3.24
E) > 10

12. Consider the reversible reaction: \[ 2\text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g) \]
If the concentrations of both NO\(_2\) and N\(_2\)O\(_4\) are 0.016 mol L\(^{-1}\), what is the value of \( Q_c \)?
A) 0.016
B) 0.50
C) 1.0
D) 2.0
E) 63

13. At high temperatures, carbon reacts with O\(_2\) to produce CO as follows:
\[ \text{C(s)} + \text{O}_2(g) \rightleftharpoons 2\text{CO(g)} \]
When 0.350 mol of O\(_2\) and excess carbon were placed in a 5.00-L container and heated, the equilibrium concentration of CO was found to be 0.060 M. What is the equilibrium constant, \( K_c \), for this reaction?
A) 0.010
B) 0.072
C) 0.090
D) 0.17
E) 1.2

14. A mixture 0.500 mole of carbon monoxide and 0.400 mole of bromine was placed into a rigid 1.00-L container and the system was allowed to come to equilibrium. The equilibrium concentration of COBr\(_2\) was 0.233 M. What is the value of \( K_c \) for this reaction?
\[ \text{CO}(g) + \text{Br}_2(g) \rightleftharpoons \text{COBr}_2(g) \]
A) 5.23
B) 1.22
C) 1.165
D) 0.858
E) 0.191
15. A mixture of 0.600 mol of bromine and 1.600 mol of iodine is placed into a rigid 1.000-L container at 350°C.

\[ \text{Br}_2(g) + I_2(g) \rightleftharpoons 2 \text{BrI}(g) \]

When the mixture has come to equilibrium, the concentration of iodine monobromide is 1.190 M. What is the equilibrium constant for this reaction at 350°C?

A) $3.55 \times 10^{-3}$  
B) 1.24  
C) 1.47  
D) 282  
E) 325

16. The equilibrium constant $K_c$ for the reaction

\[ \text{PCl}_3(g) + \text{Cl}_2(g) \rightleftharpoons \text{PCl}_5(g) \]

is 49 at 230°C. If 0.70 mol of PCl3 is added to 0.70 mol of Cl2 in a 1.00-L reaction vessel at 230°C, what is the concentration of PCl3 when equilibrium has been established?

A) 0.049 M  
B) 0.11 M  
C) 0.30 M  
D) 0.59 M  
E) 0.83 M

17. The equilibrium constant $K_c$ for the reaction

\[ \text{A}(g) + \text{B}(g) \rightleftharpoons \text{C}(g) \]

is 0.76 at 150°C. If 0.800 mol of A is added to 0.600 mol of B in a 1.00-L container at 150°C, what will be the equilibrium concentration of C?

A) 0.19 M  
B) 0.29 M  
C) 0.36 M  
D) 0.41 M  
E) 0.51 M

18. At a certain temperature the reaction

\[ \text{CO}_2(g) + \text{H}_2(g) \rightleftharpoons \text{CO}(g) + \text{H}_2\text{O}(g) \]

has $K_c = 2.50$. If 2.00 mol of carbon dioxide and 1.5 mol of hydrogen are placed in a 5.00 L vessel and equilibrium is established, what will be the concentration of carbon monoxide?

A) 0.091 M  
B) 0.191 M  
C) 0.209 M  
D) 0.913 M  
E) 1.05 M
19. When a chemical system is at equilibrium,
   A) the concentrations of the reactants are equal to the concentrations of the products.
   B) the concentrations of the reactants and products have reached constant values.
   C) the forward and reverse reactions have stopped.
   D) the reaction quotient, \( Q \), has reached a maximum.
   E) the reaction quotient, \( Q \), has reached a minimum.

20. Which of the following has an effect on the magnitude of the equilibrium constant?
   A) removing products as they are formed
   B) adding more of a reactant
   C) adding a catalyst
   D) increasing the pressure, in a gas-phase reaction
   E) change in temperature

21. Write the mass-action expression, \( Q_e \), for the following chemical reaction equation.
    \[ 2C_6H_6(g) + 15O_2(g) \rightleftharpoons 12CO_2(g) + 6H_2O(g) \]
   A) \[ \frac{[CO_2]^{12}}{[C_6H_6]^2 [H_2O]^6} \]
   B) \[ \frac{[CO_2]^{12} [H_2O]^6}{[C_6H_6]^2 [O_2]^{15}} \]
   C) \[ \frac{[C_6H_6] [O_2]}{[CO_2] [H_2O]} \]
   D) \[ \frac{[C_6H_6]^2 [O_2]^{15}}{[CO_2]^{12} [H_2O]^6} \]
   E) \[ \frac{[12CO_2] [6H_2O]}{[2C_6H_6] [15O_2]} \]
22. Write the mass-action expression, $Q_c$, for the following chemical reaction.

$$\text{Fe}^{3+}(aq) + 3\text{OH}^-(aq) \rightleftharpoons \text{Fe(OH)}_3(s)$$

A) $\frac{[\text{Fe}^{3+}][\text{OH}^-]^3}{[\text{Fe(OH)}_3]}$

B) $\frac{[\text{Fe}^{3+}][\text{OH}^-]^3}{[\text{Fe(OH)}_3]}$

C) $\frac{1}{[\text{Fe}^{3+}][\text{OH}^-]^3}$

D) $[\text{Fe}^{3+}][\text{OH}^-]^3$

E) $\frac{1}{[\text{Fe}^{3+}]^3[\text{OH}^-]}$

23. What is the mass-action expression, $Q_e$, for the following chemical reaction?

$$\text{PbO}(s) + \text{CO}(g) \rightleftharpoons \text{Pb}(l) + \text{CO}_2(g)$$

A) $\frac{[\text{CO}_2]}{[\text{CO}]}$

B) $\frac{[\text{CO}]}{[\text{CO}_2]}$

C) $\frac{[\text{Pb}][\text{CO}_2]}{[\text{PbO}][\text{CO}]}$

D) $\frac{[\text{Pb}][\text{CO}_2]}{[\text{CO}]}$

E) None of the above expressions is correct.

24. What is the mass-action expression, $Q_e$, for the following chemical reaction?

$$4\text{H}_2\text{O}^+(aq) + 2\text{Cl}^-(aq) + \text{MnO}_2(s) \rightleftharpoons \text{Mn}^{2+}(aq) + 6\text{H}_2\text{O}(l) + \text{Cl}_2(g)$$

A) $\frac{[\text{H}_2\text{O}^+]^4[\text{Cl}^-]^2[\text{MnO}_2]}{[\text{Mn}^{2+}][\text{H}_2\text{O}]^4[\text{Cl}_2]}$

B) $\frac{[\text{Mn}^{2+}][\text{H}_2\text{O}]^4[\text{Cl}_2]}{[\text{H}_2\text{O}^+]^4[\text{Cl}^-]^2[\text{MnO}_2]}$

C) $\frac{[\text{H}_2\text{O}^+]^4[\text{Cl}^-]^2}{[\text{Mn}^{2+}][\text{H}_2\text{O}]^4[\text{Cl}_2]}$

D) $\frac{[\text{Mn}^{2+}][\text{Cl}_2]}{[\text{H}_2\text{O}^+]^4[\text{Cl}^-]^2}$

E) None of the above expressions is correct.
25. The reaction system

\[ \text{POCl}_3(g) \rightleftharpoons \text{POCl}(g) + \text{Cl}_2(g) \]

is at equilibrium. Which of the following statements describes the behavior of the system if POCl is added to the container?

A) The forward reaction will proceed to establish equilibrium.
B) The reverse reaction will proceed to establish equilibrium.
C) The partial pressures of POCl and POCl will remain steady while the partial pressure of chlorine increases.
D) The partial pressure of chlorine remains steady while the partial pressures of POCl and POCl increase.
E) The partial pressure of chlorine will increase while the partial pressure of POCl decreases.

26. The reaction system

\[ \text{CS}_2(g) + 4\text{H}_2(g) \rightleftharpoons \text{CH}_4(g) + 2\text{H}_2\text{S}(g) \]

is at equilibrium. Which of the following statements describes the behavior of the system if the partial pressure of hydrogen is doubled?

A) As equilibrium is reestablished, the partial pressure of carbon disulfide increases.
B) As equilibrium is reestablished, the partial pressure of methane, CH₄, decreases.
C) As equilibrium is reestablished, the partial pressure of hydrogen decreases.
D) As equilibrium is reestablished, the partial pressure of hydrogen sulfide decreases.
E) As equilibrium is reestablished, all the partial pressures will decrease.

27. A container was charged with hydrogen, nitrogen, and ammonia gases at 120°C and the system was allowed to reach equilibrium. What will happen if the volume of the container is increased at constant temperature?

\[ 3\text{H}_2(g) + \text{N}_2(g) \rightleftharpoons 2\text{NH}_3(g) \]

A) There will be no effect.
B) More ammonia will be produced at the expense of hydrogen and nitrogen.
C) Hydrogen and nitrogen will be produced at the expense of ammonia.
D) The equilibrium constant will increase.
E) The equilibrium constant will decrease.

28. The reaction of nitric oxide to form dinitrogen oxide and nitrogen dioxide is exothermic.

\[ 3\text{NO}(g) \rightleftharpoons \text{N}_2\text{O}(g) + \text{NO}_2(g) + \text{heat} \]

What effect will be seen if the temperature of the system at equilibrium is raised by 25°C?

A) The partial pressure of NO will increase.
B) The partial pressure of NO will decrease.
C) The partial pressure of NO₂ will increase.
D) The partial pressures of NO and N₂O will increase.
E) All three partial pressures will increase.
29. Methanol can be synthesized by combining carbon monoxide and hydrogen.

\[ \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) \quad \Delta H^\circ_{\text{rxn}} = -90.7 \text{ kJ} \]

A reaction vessel contains these compounds at equilibrium. What effect will be seen when equilibrium is re-established after decreasing the temperature by 45°C?

A) All the partial pressures will decrease.
B) The partial pressure of methanol will decrease.
C) The partial pressures of hydrogen and methanol will decrease.
D) The partial pressure of hydrogen will increase.
E) The partial pressure of carbon monoxide will decrease.

30. Nitrogen dioxide can dissociate to nitric oxide and oxygen.

\[ 2\text{NO}_2(g) \rightleftharpoons 2\text{NO}(g) + \text{O}_2(g) \quad \Delta H^\circ_{\text{rxn}} = +114 \text{ kJ} \]

Under which reaction conditions would you expect to produce the largest amount of oxygen?

A) high temperature, high pressure
B) low temperature, high pressure
C) high temperature, low pressure
D) low temperature, low pressure
E) none of the above, unless a catalyst is present