Multiple Choice

Introduction to Equilibrium/General (No calculator)

1) At equilibrium, __________.

A) all chemical reactions have ceased
B) the rates of the forward and reverse reactions are equal
C) the rate constants of the forward and reverse reactions are equal
D) the value of the equilibrium constant is 1
E) the limiting reagent has been consumed

2) Which one of the following will change the value of an equilibrium constant?

A) changing temperature
B) adding other substances that do not react with any of the species involved in the equilibrium
C) varying the initial concentrations of reactants
D) varying the initial concentrations of products
E) changing the volume of the reaction vessel

3) The equilibrium-constant expression depends on the __________ of the reaction.

A) stoichiometry
B) mechanism
C) stoichiometry and mechanism
D) the quantities of reactants and products initially present
E) temperature

4) Consider the following equilibrium:

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \]

The equilibrium cannot be established when __________ is/are placed in a 1.0-L container.

A) 0.25 mol \text{SO}_2(g) and 0.25 mol \text{O}_2(g)
B) 0.75 mol \text{SO}_2(g)
C) 0.25 mol \text{SO}_2(g) and 0.25 mol \text{SO}_3(g)
D) 0.50 mol \text{O}_2(g) and 0.50 mol \text{SO}_3(g)
E) 1.0 mol \text{SO}_3(g)

5) Which of the following statements about chemical equilibrium are not true?

A) The equilibrium constant is dependent on temperature.
B) The equilibrium constant is independent of the concentrations of reactants or products at certain reaction conditions.
C) The initial concentrations of reactants and products will affect the equilibrium position.
D) When starting with only reactants, only the forward reaction will take place until equilibrium is reached.
E) When starting with only the products, the reverse reaction rate will exceed the forward reaction rate until equilibrium is reached
6) Which of the following expressions is the correct equilibrium-constant expression for the equilibrium between dinitrogen tetroxide and nitrogen dioxide?

\[ \text{N}_2\text{O}_4(g) \rightleftharpoons 2\text{NO}_2(g) \]

A) \([\text{NO}_2]/[\text{N}_2\text{O}_4]\)
B) \([\text{NO}_2]^2/[\text{N}_2\text{O}_4]^2\]
C) \([\text{NO}_2]/[\text{N}_2\text{O}_4]^2\)
D) \([\text{NO}_2] \cdot [\text{N}_2\text{O}_4]\)
E) \([\text{NO}_2]^2 \cdot [\text{N}_2\text{O}_4]\)

7) Which of the following expressions is the correct equilibrium-constant expression for the reaction below?

\[ (\text{NH}_4)\text{Se(s)} \rightleftharpoons 2\text{NH}_3(g) + \text{H}_2\text{Se(g)} \]

A) \([\text{NH}_3][\text{H}_2\text{Se}]/(\text{NH}_4)\text{Se} \]
B) \((\text{NH}_4)\text{Se}/[\text{NH}_3]^2[\text{H}_2\text{Se}] \)
C) \(1/(\text{NH}_4)\text{Se} \)
D) \([\text{NH}_3]^2[\text{H}_2\text{Se}] \)
E) \([\text{NH}_3]^2[\text{H}_2\text{Se}]/[(\text{NH}_4)\text{Se}] \)

8) Which of the following expressions is the correct equilibrium-constant expression for the reaction below?

\[ \text{HF(aq)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{F}^-(aq) \]

A) \([\text{HF}][\text{H}_2\text{O}]/[\text{H}_3\text{O}^+][\text{F}^-] \)
B) \(1/\text{HF} \)
C) \([\text{H}_3\text{O}^+][\text{F}^-]/[\text{HF}][\text{H}_2\text{O}] \)
D) \([\text{H}_3\text{O}^+][\text{F}^-]/[\text{HF}] \)
E) \([\text{F}^-]/[\text{HF}] \)

9) The equilibrium-constant expression for the reaction below is__________.

\[ \text{Ti(s)} + 2\text{Cl}_2(g) \rightleftharpoons \text{TiCl}_4(l) \]

A) \([\text{TiCl}_4]/[\text{Ti}][\text{Cl}_2] \)
B) \([\text{Ti}][\text{Cl}_2]^2/[\text{TiCl}_4] \)
C) \([\text{TiCl}_4]/[\text{Cl}_2]^2 \)
D) \([\text{Cl}_2]^2 \)
E) \([\text{TiCl}_4]/[\text{Ti}][\text{Cl}_2]^2 \)

10) What is the equilibrium expression for the following reaction?

\[ \text{CuSO}_4(s) + 5 \text{H}_2\text{O(g)} \rightleftharpoons \text{CuSO}_4\cdot5\text{H}_2\text{O(s)} \]

A) \(K = [\text{CuSO}_4][\text{H}_2\text{O}]^5/[\text{CuSO}_4][\text{H}_2\text{O}]^5 \)
B) \(K = [\text{H}_2\text{O}]^5 \)
C) \(K = 1/[\text{H}_2\text{O}]^5 \)
D) \(K = [\text{CuSO}_4]/[\text{H}_2\text{O}]^5 \)

11) Which of the following correctly equilibrium expressions uses the law of mass action correctly for the equation \(2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \)?

A) \(K = [\text{SO}_3]/[\text{SO}_2][\text{O}_2] \)
B) \(K = [\text{SO}_3]^2/[\text{SO}_2]^2[\text{O}_2] \)
C) \(K = [\text{SO}_2]^2[\text{O}_2]/[\text{SO}_3]^2 \)
D) \(K = [\text{SO}_3]^2/[\text{SO}_2]^2[\text{O}_2] \)
12) The equilibrium constant for the gas phase reaction \( \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \) is \( K_{eq} = 4.34 \times 10^{-3} \) at 300 °C. At equilibrium, __________.

A) products predominate
B) reactants predominate
C) roughly equal amounts of products and reactants are present
D) only products are present
E) only reactants are present

13) The equilibrium constant for the gas phase reaction \( 2\text{NH}_3(g) \rightleftharpoons \text{N}_2(g) + 3\text{H}_2(g) \) is \( K_{eq} = 230 \) at 300 °C. At equilibrium, __________.

A) products predominate
B) reactants predominate
C) roughly equal amounts of products and reactants are present
D) only products are present
E) only reactants are present

14) The reaction \( \text{A}(g) \rightleftharpoons \text{B}(g) \) has a \( K \) value of \( 4.1 \times 10^2 \). At equilibrium, which of the following would be true?

A) \([A] = [B]\)
B) \([A] > [B]\)
C) \([A] < [B]\)

15) Which of the following statements are true for a reaction with a very small equilibrium constant?

A) The equilibrium position lies far to the right.
B) The equilibrium position lies far to the left.
C) The reaction will proceed rapidly to the equilibrium position upon the combination of reactants.
D) The reaction will proceed slowly to the equilibrium position upon the combination of reactants.
E) Two of the above

16) For a reaction which has an equilibrium of constant (\( K \)) value of \( 2.3 \times 10^{12} \), which of the following statements are true?

A) At equilibrium the forward reaction is faster than the reverse reaction.
B) The reaction will proceed rapidly from the initial concentrations to equilibrium.
C) At equilibrium the concentrations of the products are greater than the concentration of the reactants.
D) The value of \( K \) would double if the concentrations of the products were doubled.
2. Calculation of K or [Reactant], [Product], or Pressure at Equilibrium
Use calculator

17) Consider the following chemical reaction: \( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \). At equilibrium in a particular experiment, the concentrations of \( \text{H}_2 \), \( \text{I}_2 \), and \( \text{HI} \) were 0.25M, 0.043M, and 0.65M respectively. The value of \( K_{eq} \) for this reaction is __________.

A) 60.46  
B) 111  
C) 9.0 \times 10^{-3}  
D) 3.93  
E) 39.30

18) Consider the equation: \( \text{HC}_2\text{H}_3\text{O}_2(\text{aq}) \rightleftharpoons \text{C}_2\text{H}_3\text{O}_2^-(\text{aq}) + \text{H}^+(\text{aq}) \). At equilibrium at 25 °C a 0.100 M solution of acetic acid has the following concentrations: \([\text{HC}_2\text{H}_3\text{O}_2]\) = 0.990M, \([\text{C}_2\text{H}_3\text{O}_2^-]\) = 1.33 \times 10^{-3}M and \([\text{H}^+]\) = 1.33 \times 10^{-3}M. The equilibrium constant, \( K_{eq} \), for the ionization of acetic acid at 25 °C is __________.

A) 5.71 \times 10^4  
B) 0.100  
C) 1.75 \times 10^{-7}  
D) 1.79 \times 10^{-6}  
E) 5.71 \times 10^6

19) The equilibrium constant \( (K_p) \) at 721 K for the reaction \( 2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \) is 0.0198. In a particular experiment, the partial pressures of \( \text{H}_2 \) and \( \text{I}_2 \) at equilibrium are 0.710 and 0.888 atm, respectively. The partial pressure of \( \text{HI} \) is __________ atm.

A) 7.87  
B) 1.98  
C) 5.64  
D) 0.125  
E) 0.389

20) The equilibrium concentrations for the reaction \( \text{N}_2\text{O}_4(g) \rightleftharpoons 2 \text{NO}_2 \) at a certain temperature are \([\text{N}_2\text{O}_4]\) = 3.50 \times 10^{-3} and \([\text{NO}_2]\) = 1.40 \times 10^{-3}. What is the value of \( K \) at this temperature?

A) 2.4x10^{-3} \text{ mol/L}  
B) 5.1x10^{-3} \text{ mol/L}  
C) 8.8x10^{-3} \text{ mol/L}  
D) 5.6x10^{-4} \text{ mol/L}  
E) 8.1 \times 10^{-4} \text{ mol/L}

21) The reaction \( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2 \text{HI}(g) \) has a \( K \) value of 240 at a certain temperature. If the concentration of \( \text{H}_2 \) is .060 M and \( \text{I}_2 \) is .030 M at equilibrium, what is the concentration of \( \text{HI} \) at equilibrium?

A) .85M  
B) .657M  
C) .432M  
D) .077M  
E) .035M
22) A reaction vessel is charged with hydrogen iodide, which partially decomposes to molecular hydrogen and iodine: 

\[ 2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \]

When the system comes to equilibrium at 425 °C, \( P_{\text{HI}} = 0.808 \text{atm} \), and \( P(\text{H}_2) = P(\text{I}_2) = 0.0860 \text{atm} \). The value of \( K_p \) at this temperature is __________.

A) \( 9.15 \times 10^{-3} \)
B) \( 1.30 \times 10^{-2} \)
C) \( K_p \) cannot be calculated for this gas reaction when the volume of the reaction vessel is not given.
D) 54.3
E) \( 1.13 \times 10^{-2} \)

23) Given the following reaction at equilibrium at 300.0 K:

\[ \text{NH}_4\text{HS(s)} \rightleftharpoons \text{NH}_3(g) + \text{H}_2\text{S(g)} \]

If \( p_{\text{NH}_3} = p_{\text{H}_2\text{S}} = 0.095 \text{ atm} \), \( K_p = \) __________.

A) \( 9.025 \times 10^{-3} \)
B) \( 5.990 \times 10^{-4} \)
C) \( 1.112 \times 10^{-1} \)
D) \( 3.222 \times 10^{-2} \)
E) \( 5.660 \times 10^{-3} \)

24) The \( K_{eq} \) for the equilibrium below is \( 6.5 \times 10^{-2} \) at 480.0 °C.

\[ 2\text{Cl}_2(g) + 2\text{H}_2\text{O(g)} \rightleftharpoons 4\text{HCl(g)} + \text{O}_2(g) \]

What is the value of \( K_{eq} \) at this temperature for the following reaction?

\[ 4\text{HCl(g)} + \text{O}_2(g) \rightleftharpoons 2\text{Cl}_2(g) + 2\text{H}_2\text{O(g)} \]

A) 0.0752
B) -0.0752
C) 15.32
D) \( 5.66 \times 10^{-3} \)
E) 0.150

25) Phosphorus trichloride and phosphorus pentachloride equilibrate in the presence of molecular chlorine according to the reaction:

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

An equilibrium mixture at 450 K contains: \( P(\text{PCl}_3) = 0.202 \text{ atm} \); \( P(\text{Cl}_2) = 0.256 \text{ atm} \), \( P(\text{PCl}_5) = 3.45 \text{ atm} \). What is the value of \( K_p \) at this temperature?

A) 66.7
B) \( 1.50 \times 10^{-2} \)
C) \( 1.78 \times 10^{-1} \)
D) 2.99
E) 7.54

26) The \( K_p \) for the reaction below is \( 1.60 \times 10^8 \) at 100.0 °C:

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

In an equilibrium mixture of the three gases: \( (\text{CO}) = P(\text{Cl}_2) = 7.5 \times 10^{-4} \). The partial pressure of the product, phosgene (\( \text{COCl}_2 \)), is __________ atm.

A) 90
B) \( 2.84 \times 10^{14} \)
C) \( 4.96 \times 10^{-15} \)
D) \( 6.26 \times 10^{-5} \)
E) \( 3.72 \times 10^{11} \)
27) At 900.0 K, the equilibrium constant \(K_p\) for the following reaction is 0.500.
\[
2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g)
\]
At equilibrium, the partial pressure of \(\text{SO}_2\) is 25.0 atm and that of \(\text{O}_2\) is 14.0 atm. The partial pressure of \(\text{SO}_3\) is __________ atm.
A) 66.1
B) 4.3x10^{-3}
C) 625
D) 5.20x10^{-4}
E) 60.2

28) The reaction \(A(g) + B(g) \rightleftharpoons 2C(g)\) has a \(K_P\) value of 62.0 at 800. K. At equilibrium in a 2.0 L vessel the partial pressure of \(C\) was found to be 3.20 atm and the partial pressure of \(A\) was .15 atm. What is the partial pressure of \(B\)?
A) .98 atm
B) 1.1 atm
C) 1.4 atm
D) 1.6 atm

29) A reaction has the equation \(2A(g) + 3B(g) \rightleftharpoons 2C(g)\) at equilibrium. which of the following is the correct expression for the relationship between \(K\) and \(K_P\)?
A) \(K = K_P\)
B) \(K_P = K(RT)^3\)
C) \(K_P = K(RT)^{-3}\)
D) \(K = K_P (RT)^{-3}\)

30) A certain reaction occurs by the equation \(2A(g) + B(g) \rightleftharpoons C(g) + 2D(g)\) has an equilibrium constant \(K\) of 2.3 x 10^{-3} at 300. K. What is the value of \(K_P\) for this reaction at 300. K?
A) less than 2.3 x 10^{-3}
B) greater than 2.3 x 10^{-3}
C) equal to 2.3 x 10^{-3}
D) not enough data

31) A certain reaction that has the equation \(A(g) + 2B(g) \rightleftharpoons 3C(g)\) has a \(K\) value of \(X\). What is the value of \(K_P\) at the same reaction conditions?
A) \(X\)
B) \(X^2\)
C) 2\(X\)
D) \(\sqrt{X}\)

32) Given the following reaction at equilibrium, if \(K_c = 6.44 \times 10^5\) at 230.0 °C, \(K_P = \) __________.
\[
2\text{NO}(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}_2(g)
\]
A) 3.67 x10^{-2}
B) 1.56 x10^4
C) 6.44 x10^5
D) 2.66 x10^6
E) 2.67 x10^7
33) Given the following reaction at equilibrium at 450.0 °C:

\[ \text{CaCO}_3(s) \rightleftharpoons \text{CaO(s)} + \text{CO}_2(g) \]

If \( p\text{CO}_2 = 0.0160 \text{ atm} \), \( K_c = \) __________.

A) 0.0160  
B) 0.0821  
C) 7.23  
D) 2.70x10^-4  
E) 723

34) Given the following reaction at equilibrium, if \( K_p = 1.05 \) at 250.0 °C, \( K_c = \) __________.

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

A) 3.90x10^-6  
B) 2.45x10^-2  
C) 1.05  
D) 42.9  
E) 45.0

35) A certain reaction occurs by the equation \( \text{A(g)} + \text{B(g)} \rightleftharpoons \text{2C(g)} + \text{2D(g)} \) has an equilibrium constant \( (K) \) of \( 4.3 \times 10^{-5} \text{ M}^2 \) at 200 K. What is the value of \( K_p \) for this reaction at 200 K?

A) 0.012 \text{ atm}^2  
B) 3.5 \times 10^{-3} \text{ atm}^2  
C) 7.1 \times 10^{-3} \text{ atm}^2  
D) 2.1 \times 10^{-4} \text{ atm}^2  
E) 0.112

3. Manipulating K: May use calculator

36) The \( K_{eq} \) for the equilibrium below is 0.135 at 700.0 °C.

\[ \text{SO}_2(g) + \frac{1}{2}\text{O}_2(g) \rightleftharpoons \text{SO}_3(g) \]

What is the value of \( K_{eq} \) at this temperature for the following reaction?

\[ \text{SO}_3(g) \rightleftharpoons \text{SO}_2(g) + \frac{1}{2}\text{O}_2(g) \]

A) 0.224  
B) 0.0185  
C) 0.112  
D) 7.40  
E) -0.112

37) At 1000.0 K, the equilibrium constant for the reaction \( 2\text{NO(g)} + \text{Br}_2(g) \rightleftharpoons 2\text{NOBr(g)} \) is \( K_p = 0.013 \). Calculate \( K_p \) for the reverse reaction, \( 2\text{NOBr(g)} \rightleftharpoons 2\text{NO(g)} + \text{Br}_2(g) \).

A) 0.013  
B) 1.6x10^{-4}  
C) 77  
D) 0.99  
E) 1.1

38) If the reaction \( 2\text{A(g)} + \text{B(g)} \rightleftharpoons 3\text{C(g)} \), \( K_p = X \) was changed to \( 3\text{C(g)} \rightleftharpoons 2\text{A(g)} + \text{B(g)} \) at the same conditions, what would the value of \( K_p \) be?

A) 2X  
B) \( X^2 \)  
C) \( 1/X \)  
D) \( \sqrt{X} \)
39) The value of \( K_{eq} \) for the equilibrium \( \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \leftrightarrow 2\text{HI}(\text{g}) \) is 890 at 25 °C. What is the value of \( K_{eq} \) for the equilibrium below?
\[
\frac{1}{2}\text{H}_2(\text{g}) + \frac{1}{2}\text{I}_2(\text{g}) \leftrightarrow \text{HI}(\text{g})
\]
A) 397
B) 0.035
C) 29.83
D) 1588
E) 0.0013

40) The value of \( K_{eq} \) for the following reaction is 0.20:
\[
\text{SO}_2(\text{g}) + \text{NO}_2(\text{g}) \leftrightarrow \text{SO}_3(\text{g}) + \text{NO}(\text{g}).
\]
The value of \( K_{eq} \) at the same temperature for the reaction below is ________.
\[
2\text{SO}_2(\text{g}) + 2\text{NO}_2(\text{g}) \leftrightarrow 2\text{SO}_3(\text{g}) + 2\text{NO}(\text{g})
\]
A) 0.50
B) 0.04
C) 0.12
D) 0.25
E) 16

41) The \( K_{eq} \) for the equilibrium below is 6.5x10^{-2} at 480.0 °C.
\[
2\text{Cl}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \leftrightarrow 4\text{HCl}(\text{g}) + \text{O}_2(\text{g}).
\]
What is the value of \( K_{eq} \) at this temperature for the following reaction?
\[
\text{Cl}_2(\text{g}) + \text{H}_2\text{O}(\text{g}) \leftrightarrow 2\text{HCl}(\text{g}) + \frac{1}{2}\text{O}_2(\text{g})
\]
A) 0.0255
B) 1.66 x10^{-3}
C) 0.255
D) 0.0287
E) 0.280

42) The \( K_{eq} \) for the equilibrium below is 0.135 at 700.0 °C.
\[
\text{SO}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \leftrightarrow \text{SO}_3(\text{g})
\]
What is the value of \( K_{eq} \) at this temperature for the following reaction?
\[
2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \leftrightarrow 2\text{SO}_3(\text{g})
\]
A) 0.224
B) 0.335
C) 0.0182
D) 0.0560
E) 0.112

43) The value of \( K_{eq} \) for the equilibrium \( \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \leftrightarrow 2\text{HI}(\text{g}) \) is 890 at 25 °C. At this temperature, what is the value of \( K_{eq} \) for the equilibrium below?
\[
\text{HI}(\text{g}) \leftrightarrow \frac{1}{2}\text{H}_2(\text{g}) + \frac{1}{2}\text{I}_2(\text{g})
\]
A) 1588
B) 28
C) 397
D) 0.034
E) 0.0013
The value of $K_{eq}$ for the equilibrium $\text{H}_2(g) + \text{I}_2(g) \leftrightarrow 2\text{HI}(g)$ is 54.0 at 427 °C. What is the value of $K_{eq}$ for the equilibrium below?

$$\text{HI}(g) \leftrightarrow \frac{1}{2}\text{H}_2(g) + \frac{1}{2}\text{I}_2(g)$$

A) 27  
B) 7.35  
C) 0.136  
D) 2.92 x 10^3  
E) 3.43 x 10^{-4}

The $K_{eq}$ for the equilibrium below is $6.5 \times 10^{-2}$ at 480.0 °C.

$$2\text{Cl}_2(g) + 2\text{H}_2\text{O}(g) \leftrightarrow 4\text{HCl}(g) + \text{O}_2(g)$$

What is the value of $K_{eq}$ at this temperature for the following reaction?

$$2\text{HCl}(g) + \frac{1}{2}\text{O}_2(g) \leftrightarrow \text{Cl}_2(g) + \text{H}_2\text{O}(g)$$

A) 39.2  
B) 3.92  
C) -0.0376  
D) 5.66 x 10^{-3}  
E) 0.274

The $K_{eq}$ for the equilibrium below is 0.135 at 700.0 °C.

$$\text{SO}_2(g) + \frac{1}{2}\text{O}_2(g) \leftrightarrow \text{SO}_3(g)$$

What is the value of $K_{eq}$ at this temperature for the following reaction?

$$2\text{SO}_3(g) \leftrightarrow 2\text{SO}_2(g) + \text{O}_2(g)$$

A) 54.86  
B) 5.49  
C) 7.86  
D) 15.46  
E) 8.93

The reaction $2\text{A}(g) \leftrightarrow \text{B}(g)$ has a $K$ value of 8. What is the value of $K$ for the reaction $\frac{1}{2}\text{B}(g) \leftrightarrow \text{A}(g)$?

A) 2  
B) 0.125  
C) 0.354  
D) 0.25  
E) 64

The equilibrium constant for reaction 1 is 2. The equilibrium constant for reaction 2 is

A) $2^2$  
B) 4  
C) 1  
D) 1/4  
E) $-2^2$
4. Calculation of K or [Reactant], [Product], or Pressure – Using an ICE Chart:

Use calculator

49) The reaction \(2A(g) \rightleftharpoons B(g)\) has a K value of 4.0 when 4.00 mol of A and 8.00 mol of B are added to a 2.0 L vessel. What is the value of K when 2.00 mol of A and 4.00 mol of B are added to a 1.0 L vessel at the same temperature?

A) 36  
B) 16  
C) 8  
D) 4  
E) 2

50) At high temperatures, molecular hydrogen and molecular bromine react to partially form hydrogen bromide: \(H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)\). A mixture of 0.682 mol of \(H_2\) and 0.440 mol of \(Br_2\) is combined in a reaction vessel with a volume of 2.00 L. At equilibrium at 700 K, there are 0.566 mol of \(H_2\) present. At equilibrium, there are __________ mol of \(Br_2\) present in the reaction vessel.

A) 0.200  
B) 0.480  
C) 0.500  
D) 0.400  
E) 0.324

51) Dinitrogentetraoxide partially decomposes according to the following equilibrium: \(N_2O_4(g) \rightleftharpoons 2NO_2(g)\). A 1.00-L flask is charged with 0.055 mol of \(N_2O_4\). At equilibrium at 373 K, 0.0065 mol of \(N_2O_4\) remains. \(K_{eq}\) for this reaction is __________.

A) 2.2 x10^{-4}  
B) 0.097  
C) 0.22  
D) 0.0485  
E) 1.45

52) Carbon monoxide is converted to carbon dioxide via the following reaction: \(CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)\). In an experiment, 0.45 mol of CO and 0.30 mol of \(H_2O\) were placed in a 1.00-L reaction vessel. At equilibrium, there were 0.19 mol of CO remaining. \(K_{eq}\) at the temperature of the experiment is __________.

A) 4.47  
B) 0.55  
C) 8.89  
D) 0.63  
E) 1.0

53) A sealed 1.0 L flask is charged with 0.600 mol of \(I_2\) and 0.600 mol of \(Br_2\). \(I_2(g) + Br_2(g) \rightleftharpoons 2IBr(g)\). When the contents achieve equilibrium, the flask contains 0.80 mol of \(IBr\). The value of \(K_{eq}\) is __________.

A) 6.4  
B) 4.0  
C) 16  
D) 7.1  
E) 3.5
54) Nitrosyl bromide decomposes according to the following equation.

\[ 2\text{NOBr}(g) \leftrightarrow 2\text{NO}(g) + \text{Br}_2(g) \]

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\(_2\), respectively, are in the flask at equilibrium?

A) 0.18, 0.18
B) 0.46, 0.23
C) 0.18, 0.090
D) 0.18, 0.360
E) 0.46, 0.46

55) Dinitrogen tetroxide partially decomposes according to the following equilibrium:

\[ \text{N}_2\text{O}_4(g) \leftrightarrow 2\text{NO}_2(g) \]

A 1.000-L flask is charged with 3x10\(^{-2}\) mol of \(\text{N}_2\text{O}_4\). At equilibrium, 2.36x10\(^{-2}\) mol of \(\text{N}_2\text{O}_4\) remains. \(K_{eq}\) for this reaction is __________.

A) 0.723
B) 0.391
C) 0.212
D) 6.94x10\(^{-3}\)
E) 1.92x10\(^{-4}\)

56) Two moles of gas A are placed in a one liter vessel and decompose into the gaseous products B and C according to the equation \(2\text{A}(g) \leftrightarrow \text{B}(g) + \text{C}(g)\). If it is 40.0\% dissociated at equilibrium, what is the value of the equilibrium constant?

A) .025
B) .011
C) .012
D) .111

57) At 22 °C, \(K_p = 0.070\) for the equilibrium: \(\text{NH}_3\text{HS(s)} \leftrightarrow \text{NH}_3(g) + \text{H}_2\text{S(g)}\)

A sample of solid NH\(_3\)HS is placed in a closed vessel and allowed to equilibrate. Calculate the equilibrium partial pressure (atm) of ammonia, assuming that some solid NH\(_3\)HS remains.

A) 0.26
B) 0.070
C) 0.52
D) 4.9 x10\(^{-3}\)
E) 3.8

58) The equilibrium constant (\(K_p\)) for the interconversion of PCl\(_5\) and PCl\(_3\) is 0.0121: \(\text{PCl}_5(g) \leftrightarrow \text{PCl}_3(g) + \text{Cl}_2(g)\). A vessel is charged with PCl\(_5\), giving an initial pressure of 0.123 atm. At equilibrium, the partial pressure of PCl\(_3\) is __________ atm.

A) 0.0782
B) 0.0455
C) 0.0908
D) 0.0330
E) 0.123
59) At 200 °C, the equilibrium constant \(K_p\) for the reaction below is \(2.40 \times 10^3\).
\[
2\text{NO(g)} \leftrightarrow \text{N}_2(g) + \text{O}_2(g)
\]
A closed vessel is charged with 36.1 atm of NO. At equilibrium, the partial pressure of \(\text{O}_2\) is __________ atm.

A) 294  
B) 35.7  
C) 17.9  
D) 6.00  
E) 1.50 \times 10^{-2}

5. **Comparing Reaction Quotient, \(Q\) and \(K\): No calculator**

60) At 400 K, the equilibrium constant for the reaction \(\text{Br}_2(g) + \text{Cl}_2(g) \leftrightarrow 2\text{BrCl(g)}\) is \(K_p = 7.0\). A closed vessel at 400 K is charged with 1.00 atm of \(\text{Br}_2\), 1.00 atm of \(\text{Cl}_2\), and 2.00 atm of \(\text{BrCl}\). Use \(Q\) to determine which of the statements below is true.

A) The equilibrium partial pressures of \(\text{Br}_2\), \(\text{Cl}_2\), and \(\text{BrCl}\) will be the same as the initial values.  
B) The equilibrium partial pressure of \(\text{Br}_2\) will be greater than 1.00 atm.  
C) At equilibrium, the total pressure in the vessel will be less than the initial total pressure.  
D) The equilibrium partial pressure of \(\text{BrCl}\) will be greater than 2.00 atm.  
E) The reaction will go to completion since there are equal amounts of \(\text{Br}_2\) and \(\text{Cl}_2\).

61) Which of the following statements is true?

A) \(Q\) does not change with temperature.  
B) \(K_{eq}\) does not change with temperature, whereas \(Q\) is temperature dependent.  
C) \(K\) does not depend on the concentrations or partial pressures of reaction components.  
D) \(Q\) does not depend on the concentrations or partial pressures of reaction components.  
E) \(Q\) is the same as \(K_{eq}\) when a reaction is at equilibrium.

62) How is the reaction quotient used to determine whether a system is at equilibrium?

A) The reaction quotient must be satisfied for equilibrium to be achieved.  
B) At equilibrium, the reaction quotient is undefined.  
C) The reaction is at equilibrium when \(Q < K_{eq}\).  
D) The reaction is at equilibrium when \(Q > K_{eq}\).  
E) The reaction is at equilibrium when \(Q = K_{eq}\).

6. **Le Chatelier's Principle: NO calculator**

63) Consider the following reaction at equilibrium:
\[
2\text{NH}_3(g) \leftrightarrow \text{N}_2(g) + 3\text{H}_2(g) \quad \Delta H^\circ = +92.4 \text{ kJ}
\]
Le Chatelier's principle predicts that adding \(\text{N}_2\) to the system at equilibrium will result in __________.

A) a decrease in the concentration of \(\text{NH}_3\)  
B) a decrease in the concentration of \(\text{H}_2\)  
C) an increase in the value of the equilibrium constant  
D) a lower partial pressure of \(\text{N}_2\)  
E) removal of all of the \(\text{H}_2\)
64) Consider the following reaction at equilibrium:

$$2\text{CO}_2(g) \leftrightarrow 2\text{CO}(g) + \text{O}_2(g) \quad \Delta H^\circ = -514 \text{ kJ}$$

Le Chatelier's principle predicts that adding $\text{O}_2$ (g) to the reaction container will __________.

A) increase the partial pressure of CO at equilibrium  
B) decrease the partial pressure of CO at equilibrium  
C) increase the value of the equilibrium constant  
D) increase the partial pressure of CO at equilibrium  
E) decrease the value of the equilibrium constant

65) Consider the following reaction at equilibrium:

$$2\text{CO}_2(g) \leftrightarrow 2\text{CO}(g) + \text{O}_2(g) \quad \Delta H^\circ = -514 \text{ kJ}$$

Le Chatelier's principle predicts that an increase in temperature will __________.

A) increase the partial pressure of $\text{O}_2$  
B) decrease the partial pressure of CO  
C) decrease the value of the equilibrium constant  
D) increase the value of the equilibrium constant  
E) increase the partial pressure of CO

66) Consider the following reaction at equilibrium:

$$2\text{SO}_2(g) + \text{O}_2(g) \leftrightarrow 2\text{SO}_3(g) \quad \Delta H^\circ = -99 \text{ kJ}$$

Le Chatelier's principle predicts that an increase in temperature will result in __________.

A) a decrease in the partial pressure of $\text{SO}_3$  
B) a decrease in the partial pressure of $\text{SO}_2$  
C) an increase in $K_{eq}$  
D) no changes in equilibrium partial pressures  
E) the partial pressure of $\text{O}_2$ will decrease

67) Of the following equilibria, only __________ will shift to the left in response to a decrease in volume.

A) $\text{H}_2(g) + \text{Cl}_2(g) \leftrightarrow 2\text{HCl}(g)$  
B) $2\text{SO}_3(g) \leftrightarrow 2\text{SO}_2(g) + \text{O}_2(g)$  
C) $\text{N}_2(g) + 3\text{H}_2(g) \leftrightarrow 2\text{NH}_3(g)$  
D) $4\text{Fe}(s) + 3\text{O}_2(g) \leftrightarrow 2\text{Fe}_2\text{O}_3(s)$  
E) $2\text{HI}(g) \leftrightarrow \text{H}_2(g) + \text{I}_2(g)$

68) In which of the following reactions would increasing pressure at constant temperature not change the concentrations of reactants and products, based on Le Chatelier's principle?

A) $\text{N}_2(g) + 3\text{H}_2(g) \leftrightarrow 2\text{NH}_3(g)$  
B) $\text{N}_2\text{O}_4(g) \leftrightarrow 2\text{NO}_2(g)$  
C) $\text{N}_2(g) + 2\text{O}_2(g) \leftrightarrow 2\text{NO}_2(g)$  
D) $2\text{N}_2(g) + \text{O}_2(g) \leftrightarrow 2\text{N}_2\text{O}(g)$  
E) $\text{N}_2(g) + \text{O}_2(g) \leftrightarrow 2\text{NO}(g)$

69) The reaction below is exothermic: $2\text{SO}_2(g) + \text{O}_2(g) \leftrightarrow 2\text{SO}_3(g)$

Le Chatelier's Principle predicts that __________ will result in an increase in the number of moles of $\text{SO}_3$ in the reaction container.

A) increasing the pressure  
B) decreasing the pressure  
C) increasing the temperature  
D) removing some oxygen  
E) increasing the volume of the container
70) For the endothermic reaction \( \text{CaCO}_3(s) \leftrightarrow \text{CaO}(s) + \text{CO}_2(g) \), Le Chatelier’s principle predicts that __________ will result in an increase in the number of moles of CO\(_2\).

A) increasing the temperature  
B) decreasing the temperature  
C) increasing the pressure  
D) removing some of the CaCO\(_3\)  
E) none of the above

71) Consider the following reaction at equilibrium:
\[
2\text{NH}_3(g) \leftrightarrow \text{N}_2(g) + 3\text{H}_2(g)
\]
Le Chatelier's principle predicts that the moles of H\(_2\) in the reaction container will increase with __________.

A) some removal of NH\(_3\) from the reaction vessel (V and T constant)  
B) a decrease in the total pressure (T constant)  
C) addition of some N\(_2\) to the reaction vessel (V and T constant)  
D) a decrease in the total volume of the reaction vessel (T constant)  
E) an increase in total pressure by the addition of helium gas (V and T constant)

72) Consider the following reaction at equilibrium:
\[
\text{C}(s) + \text{H}_2\text{O}(g) \leftrightarrow \text{CO}(g) + \text{H}_2(g)
\]
Which of the following conditions will increase the partial pressure of CO?

A) decreasing the partial pressure of H\(_2\)O  
B) removing H\(_2\)O from the system  
C) decreasing the volume of the reaction vessel  
D) decreasing the pressure in the reaction vessel  
E) increasing the amount of carbon in the system

73) Consider the following reaction at equilibrium.
\[
2\text{CO}_2(g) \leftrightarrow 2\text{CO}(g) + \text{O}_2(g) \quad \Delta H^\circ = -514 \text{ kJ}
\]
Le Chatelier’s principle predicts that the equilibrium partial pressure of CO (g) 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 low pressure  
D) at low temperature and high pressure  
E) in the presence of solid carbon

74) The effect of a catalyst on equilibrium is to __________.

A) increase the rate of the forward reaction only  
B) increase the equilibrium constant so that products are favored  
C) slow the reverse reaction only  
D) increase the rate at which equilibrium is achieved without changing the composition of the equilibrium mixture  
E) shift the equilibrium to the right
7. Conceptual questions – All sections included; No calculators

75) In which of the following systems would the number of moles of the substances present at equilibrium NOT be shifted by a change in the volume of the system at constant temperature?

A) CO(g) + NO(g) $\leftrightarrow$ CO$_2$(g) + 1/2 N$_2$(g)
B) N$_2$(g) + 3 H$_2$(g) $\leftrightarrow$ 2 NH$_3$(g)
C) N$_2$(g) + 2 O$_2$(g) $\leftrightarrow$ 2 NO$_2$(g)
D) N$_2$O$_4$(g) $\leftrightarrow$ 2 NO$_2$(g)
E) NO(g) + O$_3$(g) $\leftrightarrow$ NO$_2$(g) + O$_2$(g)

76) Which of the following is the correct equilibrium expression for the hydrolysis of CO$_3^{2-}$?

A) K = [HCO$_3^-$] / ([CO$_3^{2-}$] [H$_3$O$^+$])
B) K = ([HCO$_3^-$] [OH$^-$]) / [CO$_3^{2-}$]
C) K = ([CO$_3^{2-}$] [OH$^-$]) / [HCO$_3^-$]
D) K = [CO$_3^{2-}$] / ([CO$_2$] [OH$^-$]$^2$)
E) K = ( [CO$_3^{2-}$] [H$_3$O$^+$]) / [HCO$_3^-$]

77) CuO(s) + H$_2$(g) $\leftrightarrow$ Cu(s) + H$_2$O(g); $\Delta$H = - 2.0 kilojoules
When the substances in the equation above are at equilibrium at pressure P and temperature T, the equilibrium can be shifted to favor the products by

A) increasing the pressure by means of a moving piston at constant T
B) increasing the pressure by adding an inert gas such as nitrogen
C) decreasing the temperature
D) allowing some gases to escape at constant P and T
E) adding a catalyst

78) H$_2$C$_2$O$_4$ + 2 H$_2$O $\leftrightarrow$ 2 H$_3$O$^+$ + C$_2$O$_4^{2-}$

Oxalic acid, H$_2$C$_2$O$_4$, is a diprotic acid with $K_1 = 5.36 \times 10^{-2}$ and $K_2 = 5.3 \times 10^{-5}$. For reaction above, what is the equilibrium constant?

A) 5.36 x 10$^{-2}$
B) 5.3 x 10$^{-5}$
C) 2.8 x 10$^{-6}$
D) 1.9 x 10$^{-10}$
E) 1.9 x 10$^{-13}$
79) \( 4 \text{HCl}(g) + \text{O}_2(g) \leftrightarrow 2 \text{Cl}_2(g) + 2 \text{H}_2\text{O}(g) \)

Equal numbers of moles of HCl and O\(_2\) in a closed system are allowed to reach equilibrium as represented by the equation above. Which of the following must be true at equilibrium?

I. \([\text{HCl}]\) must be less than \([\text{Cl}_2]\).
II. \([\text{O}_2]\) must be greater than \([\text{HCl}]\).
III. \([\text{Cl}_2]\) must equal \([\text{H}_2\text{O}]\).

A) I only  
B) II only  
C) I and III only  
D) II and III only  
E) I, II, and III

80) \( \text{SO}_3 \text{(g)} \leftrightarrow 2 \text{SO}_2 \text{(g)} + \text{O}_2 \text{(g)} \)

After the equilibrium represented above is established, some pure \( \text{O}_2 \text{(g)} \) is injected into the reaction vessel at constant temperature. After equilibrium is reestablished, which of the following has a lower value compared to its value at the original equilibrium?

A) \( \text{Keq for the reaction} \)  
B) The total pressure in the reaction vessel.  
C) The amount of \( \text{SO}_3 \text{(g)} \) in the reaction vessel.  
D) The amount of \( \text{O}_2 \text{(g)} \) in the reaction vessel.  
E) The amount of \( \text{SO}_2 \text{(g)} \) in the reaction vessel.

81*) The reaction represented below has an equilibrium constant equal to \(3.7 \times 10^4\). Which of the following can be concluded from this information?

\[
\text{HC}_2\text{H}_3\text{O}_2\text{(aq)} + \text{CN}^-\text{(aq)} \leftrightarrow \text{HCN(aq)} + \text{C}_2\text{H}_3\text{O}_2^-\text{(aq)}
\]

A) \( \text{CN}^-\text{(aq)} \) is a stronger base than \( \text{C}_2\text{H}_3\text{O}_2^-\text{(aq)} \)  
B) \( \text{HCN(aq)} \) is a stronger acid than \( \text{C}_2\text{H}_3\text{O}_2^-\text{(aq)} \)  
C) The conjugate base of \( \text{CN}^-\text{(aq)} \) is \( \text{C}_2\text{H}_3\text{O}_2^-\text{(aq)} \)  
D) The equilibrium constant will increase with an increase in temperature.  
E) The pH of a solution containing equimolar amounts of \( \text{CN}^-\text{(aq)} \) and \( \text{C}_2\text{H}_3\text{O}_2^-\text{(aq)} \) is 7.0.
The energy diagram for the reaction $X + Y \leftrightarrow Z$ is shown above. The addition of a catalyst to this reaction would cause a change in which of the indicated energy differences?

A) I only  
B) II only  
C) III only  
D) I and II only  
E) I, II, and III

83) For the equilibrium system: $\text{CO(g)} + 2 \text{H}_2(\text{g}) \leftrightarrow \text{CH}_3\text{OH(l)}$
what is $K_c$ ?

A) $K_c = \frac{\text{CH}_3\text{OH}}{2\text{(CO)} \text{(H}_2)^2} $  
B) $K_c = \frac{\text{CH}_3\text{OH}}{\text{(CO)} \text{(H}_2)^2} $  
C) $K_c = \frac{1}{2\text{(CO)}\text{(H}_2)} $  
D) $K_c = \frac{1}{(\text{CO})(\text{H}_2)^2} $  

84) Consider the system at equilibrium: 
$2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \leftrightarrow 2\text{SO}_3(\text{g})$ for which $\Delta H < 0$. Which change(s) will increase the yield of $\text{SO}_3(\text{g})$?

I Increasing the temperature  
II Increasing the volume of the container

A) I only  
B) II only  
C) Both I and II  
D) Neither I nor II

85) $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \leftrightarrow 2\text{HI(g)}$ $\Delta H>0$
Which of the following changes to the equilibrium system represented above will increase the quantity of HI(g) in the equilibrium mixture?

I adding $\text{H}_2(\text{g})$  
II increasing the temperature  
II decreasing the pressure

A) I only  
B) III only  
C) I and II only  
D) II and III only  
E) I, II and III
86) \( \text{HCO}_3^- (aq) + \text{OH}^- (aq) \leftrightarrow \text{H}_2\text{O}(l) + \text{CO}_3^{2-} (aq) \quad \Delta H = -41.4 \text{kJ} \)

When the reaction above is at equilibrium at 1 atm and at 25\textdegree C, the ratio \([\text{CO}_3^{2-}] / [\text{HCO}_3^-]\) can be increased by doing which of the following?

A) Decreasing the temperature  
B) Adding acid  
C) Adding catalyst  
D) Diluting the solution with distilled water  
E) Bubbling neon gas through the solution

87) Which statement is correct about a system at equilibrium?

A) The forward and reverse reactions occur at identical rates.  
B) The concentrations of reactants must equal the concentrations of the products.  
C) The concentrations of reactants and products can be changed by adding a catalyst.  
D) The concentrations of reactants and products are not affected by a change in temperature

88) For which reaction at equilibrium will an decrease in volume at constant temperature cause a decrease in the amount of product?

(A) \( \text{N}_2 (g) + 3\text{H}_2 (g) \leftrightarrow 2\text{NH}_3(g) \)

(B) \( \text{HCl}(g) + \text{H}_2\text{O}(l) \leftrightarrow \text{H}_3\text{O}^+(aq) + \text{Cl}^-(aq) \)

(C) \( \text{Fe}_3\text{O}_4 (s) + 4\text{H}_2(g) \leftrightarrow 3\text{Fe}(s) + 4\text{H}_2\text{O}(g) \)

(D) \( \text{CaCO}_3(s) \leftrightarrow \text{CaO}(s) + \text{CO}_2(g) \)

89) \( \text{P}_4(s) + 5 \text{O}_2(g) \leftrightarrow \text{P}_4\text{O}_{10}(s) \) The equilibrium constant is

A) \( K_c = [\text{P}_4\text{O}_{10}] / [\text{P}_4][\text{O}_2]^5 \)

B) \( K_c = [\text{P}_4\text{O}_{10}] / 5 [\text{P}_4][\text{O}_2] \)

C) \( K_c = [\text{O}_2]^5 \)

D) \( K_c = 1 / [\text{O}_2]^5 \)

90) \( \text{Fe}_3\text{O}_4(s) + 4 \text{H}_2(g) \leftrightarrow 3 \text{Fe}(s) + 4 \text{H}_2\text{O}(g) \quad \Delta H > 0 \)

For this reaction at equilibrium, which changes will increase the quantity of \( \text{Fe}(s) \)?

1. increasing temperature  
2. decreasing temperature  
3. adding \( \text{Fe}_3\text{O}_4(s) \)

A) 1 only  
B) 1 and 2 only  
C) 2 and 3 only  
D) 1, 2, and 3
91) What is the relationship between the equilibrium constant ($K_c$) of a reaction and the rate constants for the forward ($k_f$) and backward ($k_b$) steps?

A) $K_c = k_f \times k_b$
B) $K_c = k_b / k_f$
C) $K_c = k_f / k_b$
D) $K_c = 1 / (k_f k_b)$

92) Which factors will affect both the position of equilibrium and the value of the equilibrium constant for this reaction? The $\Delta H = -92 \text{ kJ}$, $\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g}) \leftrightarrow 2 \text{NH}_3(\text{g})$

A) increasing the volume of the container
B) adding $\text{N}_2$
C) removing $\text{NH}_3$
D) lowering the temperature

93) For which reaction at equilibrium does a decrease in volume of the container cause a decrease in product(s) at constant temperature?

(A) $\text{CaCO}_3(\text{s}) \leftrightarrow \text{CaO(}\text{s}) + \text{CO}_2(\text{g})$
B) $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \leftrightarrow 2\text{SO}_3(\text{g})$
C) $\text{HCl}(\text{g}) + \text{H}_2\text{O(l)} \leftrightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq})$
D) $\text{SO}_2(\text{g}) + \text{NO}_2(\text{g}) \leftrightarrow \text{SO}_3(\text{g}) + \text{NO}(\text{g})$

94) $\text{N}_2\text{O}_4(\text{g}) \leftrightarrow 2\text{NO}_2(\text{g})$

The equilibrium reaction shown is endothermic as written. Which change will increase the amount of NO$_2$ at equilibrium?

A) adding a catalyst
B) decreasing the temperature
C) increasing the volume of the container
D) adding an inert gas to increase the pressure
95) \(2\text{SO}_2(g) + \text{O}_2(g) \leftrightarrow 2\text{SO}_3(g)\) \(\Delta H < 0\)

Which change(s) will increase the quantity of \(\text{SO}_3\) (g) at equilibrium?

I. increasing the temperature

II. reducing the volume of the container

III. adding He to increase the pressure

A) I only

B) II only

C) I and III only

D) II and III only
96) Use the diagram above to show/draw the answer to the question below.

\[ A + B \rightarrow 2C + D \]

The amount of C produced in this reaction is as shown on the graph. Draw the corresponding change for the reactant A on the graph if the reaction started with 9 moles of A.
97) \[2A + B \rightarrow C + 2D\]

The change in \([A]\) for the above reaction is given in the above graph. Indicate the change in \([C]\) on the graph.
## Answers - MC

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## Conceptual questions: all sections

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96)
Free Response

1) For the system \(2 \text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{SO}_3(g)\), \(\Delta H\) is negative for the production of \(\text{SO}_3\). Assume that one has an equilibrium mixture of these substances. Predict the effect of each of the following changes on the value of the equilibrium constant and on the number of moles of \(\text{SO}_3\) present in the mixture at equilibrium. Briefly account for each of your predictions. (Assume that in each case all other factors remain constant.)

(a) Decreasing the volume of the system.
(b) Adding oxygen to the equilibrium mixture.
(c) Raising the temperature of the system.

2) Suppose the substances in the reaction below are at equilibrium at 600K in volume \(V\) and at pressure \(P\). State whether the partial pressure of \(\text{NH}_3(g)\) will have increased, decreased, or remained the same when equilibrium is reestablished after each of the following disturbances of the original system. Some solid \(\text{NH}_4\text{Cl}\) remains in the flask at all times. Justify each answer with a one-or-two sentence explanation.

\[
\text{NH}_4\text{Cl}(s) \rightleftharpoons \text{NH}_3(g) + \text{HCl}(g) \quad \Delta H = +42.1 \text{ kilocalories}
\]

(a) A small quantity of \(\text{NH}_4\text{Cl}\) is added.
(b) The temperature of the system is increased.
(c) The volume of the system is increased.
(d) A quantity of gaseous \(\text{HCl}\) is added.
(e) A quantity of gaseous \(\text{NH}_3\) is added.

3) Ammonium hydrogen sulfide is a crystalline solid that decomposes as follows:

\[
\text{NH}_4\text{HS}(s) \rightleftharpoons \text{NH}_3(g) + \text{H}_2\text{S}(g)
\]

(a) Some solid \(\text{NH}_4\text{HS}\) is placed in an evacuated vessel at 25ºC. After equilibrium is attained, the total pressure inside the vessel is found to be 0.659 atmosphere. Some solid \(\text{NH}_4\text{HS}\) remains in the vessel at equilibrium. For this decomposition, write the expression for \(K_P\) and calculate its numerical value at 25ºC.

(b) Some extra \(\text{NH}_3\) gas is injected into the vessel containing the sample described in part (a). When equilibrium is reestablished at 25ºC, the partial pressure of \(\text{NH}_3\) in the vessel is twice the partial pressure of \(\text{H}_2\text{S}\). Calculate the numerical value of the partial pressure of \(\text{NH}_3\) and the partial pressure of \(\text{H}_2\text{S}\) in the vessel after the \(\text{NH}_3\) has been added and the equilibrium has been reestablished.

(c) In a different experiment, \(\text{NH}_3\) gas and \(\text{H}_2\text{S}\) gas are introduced into an empty 1.00 liter vessel at 25ºC. The initial partial pressure of each gas is 0.500 atmospheres. Calculate the number of moles of solid \(\text{NH}_4\text{HS}\) that is present when equilibrium is established.
4) Sulfuryl chloride, SO$_2$Cl$_2$, is a highly reactive gaseous compound. When heated, it decomposes as follows: SO$_2$Cl$_2$($g$) $\rightarrow$ SO$_2$($g$) + Cl$_2$($g$). This decomposition is endothermic. A sample of 3.509 grams of SO$_2$Cl$_2$ is placed in an evacuated 1.00 liter bulb and the temperature is raised to 375K.

(a) What would be the pressure in atmospheres in the bulb if no dissociation of the SO$_2$Cl$_2(g)$ occurred?

(b) When the system has come to equilibrium at 375K, the total pressure in the bulb is found to be 1.43 atmospheres. Calculate the partial pressures of SO$_2$, Cl$_2$, and SO$_2$Cl$_2$ at equilibrium at 375K.

(c) Give the expression for the equilibrium constant (either $K_p$ or $K_c$) for the decomposition of SO$_2$Cl$_2(g)$ at 375K. Calculate the value of the equilibrium constant you have given, and specify its units.

(d) If the temperature were raised to 500K, what effect would this have on the equilibrium constant? Explain briefly.

5) When H$_2$(g) is mixed with CO$_2$(g) at 2,000 K, equilibrium is achieved according to the equation below. In one experiment, the following equilibrium concentrations were measured.

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

\[
[H_2] = 0.20 \text{ mol/L} \\
[CO_2] = 0.30 \text{ mol/L} \\
[H_2O] = [CO] = 0.55 \text{ mol/L}
\]

(a) What is the mole fraction of CO(g) in the equilibrium mixture?

(b) Using the equilibrium concentrations given above, calculate the value of $K_c$, the equilibrium constant for the reaction.

(c) Determine $K_p$ in terms of $K_c$ for this system.

(d) When the system is cooled from 2,000 K to a lower temperature, 30.0 percent of the CO(g) is converted back to CO$_2$(g). Calculate the value of $K_c$ at this lower temperature.

(e) In a different experiment, 0.50 mole of H$_2$(g) is mixed with 0.50 mole of CO$_2$(g) in a 3.0-liter reaction vessel at 2,000 K. Calculate the equilibrium concentration, in moles per liter, of CO(g) at this temperature.

6) A rigid container holds a mixture of graphite pellets (C(s)), H$_2$O(g), CO(g), and H$_2$(g) at equilibrium. State whether the number of moles of CO(g) in the container will increase, decrease, or remain the same after each of the following disturbances is applied to the original mixture. For each case, assume that all other variables remain constant except for the given disturbance. Explain each answer with a short statement.

\[
\text{C(s)} + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}(g) + \text{H}_2(g) \quad \Delta H^\circ = +131 \text{kJ}
\]

(a) Additional H$_2$(g) is added to the equilibrium mixture at constant volume.

(b) The temperature of the equilibrium mixture is increased at constant volume.

(c) The volume of the container is decreased at constant temperature.

(d) The graphite pellets are pulverized.
7) At elevated temperatures, SbCl$_5$ gas decomposes into SbCl$_3$ gas and Cl$_2$ gas as shown by the following equation: SbCl$_5$(g) $\leftrightarrow$ SbCl$_3$(g) + Cl$_2$(g)

(a) An 89.7 gram sample of SbCl$_5$ (molecular weight 299.0) is placed in an evacuated 15.0 liter container at 182ºC.

1. What is the concentration in moles per liter of SbCl$_5$ in the container before any decomposition occurs?
2. What is the pressure in atmospheres of SbCl$_5$ in the container before any decomposition occurs?

(b) If the SbCl$_5$ is 29.2 percent decomposed when equilibrium is established at 182ºC, calculate the value for either equilibrium constant K$_p$ or K$_c$, for this decomposition reaction. Indicate whether you are calculating K$_p$ or K$_c$.

(c) In order to produce some SbCl$_5$, a 1.00 mole sample of SbCl$_3$ is first placed in an empty 2.00 liter container maintained at a temperature different from 182ºC. At this temperature, K$_c$ equals 0.117. How many moles of Cl$_2$ must be added to this container to reduce the number of moles of SbCl$_3$ to 0.700 moles at equilibrium?

8) Solid sodium hydrogen carbonate, NaHCO$_3$, decomposes on heating according to the equation below.

$$2 \text{NaHCO}_3(s) \leftrightarrow \text{Na}_2\text{CO}_3(s) + \text{H}_2\text{O}(g) + \text{CO}_2(g)$$

(a) A sample of 100. grams of solid NaHCO$_3$ was placed in a previously evacuated rigid 5.00-liter container and heated to 160ºC. Some of the original solid remained and the total pressure in the container was 7.76 atmospheres when equilibrium was reached. Calculate the number of moles of H$_2$O(g) present at equilibrium.

(b) How many grams of the original solid remain in the container under the conditions described in (a)?

(c) Write the equilibrium expression for the equilibrium constant, K$_p$, and calculate its value for the reaction under the conditions in (a).

(d) If 110. grams of solid NaHCO$_3$ had been placed in the 5.00-liter container and heated to 160ºC, what would the total pressure have been at equilibrium? Explain.

9) The equilibrium below is established by placing solid ammonium hydrosulfide in an evacuated container at 25ºC. At equilibrium, some solid NH$_4$HS remains in the container. Predict and explain each of the following.

$$\text{NH}_4\text{HS} (s) \leftrightarrow \text{NH}_3 (g) + \text{H}_2\text{S} (g) \quad \Delta H^\circ = +93\text{kJ}$$

(a) The effect on the equilibrium partial pressure of NH$_3$ gas when additional solid NH$_4$HS is introduced into the container.

(b) The effect on the equilibrium partial pressure of NH$_3$ gas when additional H$_2$S is introduced into the container.

(c) The effect on the mass of solid NH$_4$HS present when the volume of the container is decreased.

(d) The effect on the mass of solid NH$_4$HS present when the temperature is increased.
10) When the reaction below took place at a temperature of 570K, the following equilibrium concentrations were measured.

\[ \text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3 \quad \Delta H^\circ = -92.5\text{kJ} \]

\[ [\text{NH}_3] = 0.20\text{mol/L} ; \quad [\text{N}_2] = 0.50\text{ mol/L} ; \quad [\text{H}_2] = 0.20\text{ mol/L} \]

a) Write the expression for \( K_c \) and calculate the value.
b) What is the value for \( K_p \) for this reaction?
c) Describe how the concentration of \( \text{H}_2 \) will be affected by each of the following changes to the system at equilibrium.
   i. The temperature is increased
   ii. The volume of the reaction chamber is increased
   iii. \( \text{N}_2 \) gas is added to the reaction chamber
   iv. \( \text{H}_2 \) gas is added to the reaction chamber

11) When heated, hydrogen sulfide gas decomposes according to the equation below. A 3.40 g of the sample of \( \text{H}_2\text{S} \) (g) is introduced in to an evacuated rigid 1.25L container. The sealed container is heated to 483K, and 3.72x10\(^{-2}\) mol of \( \text{S}_2\) (g) is present at equilibrium.

\[ 2\text{H}_2\text{S}(g) \rightleftharpoons 2\text{H}_2 (g) + \text{S}_2(g) \]

a) Write the expression for the equilibrium constant \( K_c \) for the reaction.
b) Calculate the equilibrium concentration ( mol/L) of the following gases at 483K.
   1. \( \text{H}_2 \) (g)
   2. \( \text{H}_2\text{S} \) (g) at 483K
c) Calculate \( K_c \) for the reaction at 483K
d) Calculate the partial pressure of \( \text{S}_2\) (g) in the container at equilibrium at 483K.
e) Calculate the \( K_c \) value for the reaction below at 483K.

\[ \text{H}_2(g) + \frac{1}{2} \text{S}_2(g) \rightleftharpoons \text{H}_2\text{S}(g) \]

12) The value of the equilibrium constant \( K_p \) for the below reaction is 3.1 x10\(^{-4}\) at 700K.

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

a) Write down the expression for the equilibrium constant \( K_p \) for the reaction.
b) Given the initial partial pressures of the gases, \( p\text{N}_2 = 0.411 \text{ atm} \); \( p\text{H}_2 = 0.903 \text{ atm} \); \( p\text{NH}_3 = 0.224 \text{ atm} \), complete the following:
   1. Calculate the value of the reaction quotient, \( Q \) at these initial conditions.
   2. Predict the direction in which the reaction will proceed at 700K with the given pressure values as above. Justify your answer.
c) Calculate the value of equilibrium constant \( K_c \), if the \( K_p \) of the reaction at 700K is 3.1 x10\(^{-4}\).
d) The \( K_p \) for the reaction below is 8.3 x10\(^{-3}\) at 700K.

\[ \text{NH}_3 (g) + \text{H}_2\text{S}(g) \rightleftharpoons \text{NH}_4\text{HS} (g) \]

Calculate the value of \( K_p \) at 700K for each of the reactions represented below.
   1. \( \text{NH}_4\text{HS} (g) \rightleftharpoons \text{NH}_3 (g) + \text{H}_2\text{S} (g) \)
   2. \( 2\text{H}_2\text{S} (g) + \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_4\text{HS}(g) \)
Free response questions: Answers

1) 
   (a) As volume decreases, pressure increases and the reaction shifts in the direction of fewer molecules (less volume; more SO$_3$) to relieve the stress. Value of $K_{eq}$ does not change.
   (b) Additional O$_2$ disturbs the equilibrium and SO$_3$ is formed to relieve the stress. Value of $K_{eq}$ does not change.
   (c) Increase in temperature shifts the reaction to the left to "use up" some of the added heat. Less SO$_3$ remains. Value of $K_{eq}$ decreases due to the relative greater increase in the rate of the endothermic reaction (reaction to the left).

2) 
   (a) $P_{NH_3}$ does not change. Since NH$_4$Cl(s) has constant concentration ($a = 1$), equilibrium does not shift.
   (b) $P_{NH_3}$ increases. Since the reaction is endothermic, increasing the temperature shifts the equilibrium to the right and more NH$_3$ is present.
   (c) $P_{NH_3}$ does not change. As V increases, some solid NH$_4$Cl decomposes to produce more NH$_3$. But as the volume increases, $P_{NH_3}$ remains constant due to the additional decomposition.
   (d) $P_{NH_3}$ decreases. Some NH$_3$ reacts with the added HCl to relieve the stress from the HCl addition.
   (e) $P_{NH_3}$ increases. Some of the added NH$_3$ reacts with HCl to relieve the stress, but only a part of the added NH$_3$ reacts, so $P_{NH_3}$ increases.

3) 
   (a) $K_p = (P_{NH_3})(P_{H_2S})$
       $P_{NH_3} = P_{H_2S} = 0.659/2 \text{ atm} = 0.330 \text{ atm}$
       $K_p = (0.330)^2 = 0.109$
   (b) $P_{NH_3} = 2 P_{H_2S}$
       $(2x)(x) = 0.109 \implies x = 0.233 \text{ atm} = P_{H_2S}$
       $P_{NH_3} = 0.466 \text{ atm}$
   (c) Equilibrium pressures of NH$_3$ and H$_2$S are each 0.330 atm. Amounts of each NH$_3$ and H$_2$S that have reacted correspond to $(0.500 - 0.330) = 0.170 \text{ atm}$.
       $n = \text{mol of each reactant} = \text{mol of solid product}$
       $n = \frac{PV}{RT} = 0.170 \text{ atm} \times 1 \text{ L} / 0.0821 \text{ atm/mol K} \times 298 \text{ K} = 6.95 \times 10^{-3} \text{ mol}$
4) 

(a) \[ P = \frac{nRT}{V} = \frac{(3.509/135) \times 0.0821 \times 375}{1L} = 0.800 \text{ atm} \]

(b) \[ P_{SO_2Cl_2} = (0.800 - y) \text{ atm} \]
\[ P_{SO_2} = P_{Cl_2} = y \text{ atm} \]
\[ P_T = P_{SO_2Cl_2} + P_{SO_2} + P_{Cl_2} \]
\[ 1.43 \text{ atm} = (0.800 - y + y + y) \text{ atm} \]
\[ y = 0.63 \text{ atm} = P_{SO_2} = P_{Cl_2} \]
\[ P_{SO_2Cl_2} = (0.800 - 0.63) \text{ atm} = 0.17 \text{ atm} \]

(c) \[ K_p = \frac{[P_{SO_2} \times P_{Cl_2}]}{P_{SO_2Cl_2}} = 0.63^2/0.17 = 2.3 \text{ atm} \]

(d) Heat is absorbed during the dissociation and so \( K_{500} > K_{375} \). A stress is placed on the system and \( K \) increases, which reduces the stress associated with the higher temperature. The equilibrium will shift to the right favoring endothermic reaction. This will produce more products and \( K \) will increase.

5) 

(a) \[ \text{mole fraction}_{CO} = \frac{(0.55 \text{ mol}/1.6 \text{ mol})}{0.34} \]

(b) \[ K_c = \frac{[H_2O][CO]}{[H_2][CO_2]} = \frac{(0.55 \times 0.55)}{(0.20 \times 0.30)} = 5.04 \]

(c) since \( \Delta n = 0 \), \( K_c = K_p \)

(d) \[ [CO] = 0.55 - 30.0\% = 0.55 - 0.165 = 0.385 \text{ M} \]
\[ [H_2O] = 0.55 - 0.165 = 0.385 \text{ M} \]
\[ [H_2] = 0.20 + 0.165 = 0.365 \text{ M} \]
\[ [CO_2] = 0.30 + 0.165 = 0.465 \text{ M} \]
\[ K = \frac{(0.385)^2}{(0.365 \times 0.465)} = 0.87 \]

(e) \[ \text{let } x = \Delta[H_2] \text{ to reach equilibrium} \]
\[ [H_2] = 0.50 \text{ mol}/3.0L - X = 0.167 - X \]
\[ [CO] = +X; \quad [H_2O] = +X \]
\[ K = X^2/(0.167 - X)^2 = 5.04; \quad X = [CO] = 0.12 \text{ M} \]

6) 

(a) CO will decrease. An increase of hydrogen gas molecule will shift the equilibrium to the left and increase the rate of the reverse reaction which consumes CO. According to LeChatelier Principle the equilibrium shifts to the left.

(b) CO will increase. Since the forward reaction is endothermic (a \( \Delta H > 0 \)) an increase in temperature will cause the forward reaction to increase its rate and produce more CO. According to LeChatelier Principle the equilibrium shifts to the right.

(c) CO will decrease. A decrease in volume will result in an increase in pressure; the equilibrium will shift to the side with fewer gas molecules to decrease the pressure. Therefore the equilibrium will shift to the left.

(d) CO will remain the same. Once at equilibrium, the size of the solid will affect neither the reaction rates nor the equilibrium nor the concentrations of reactants or products.
7)

(a) \( 89.7 / 299 = 0.300 \text{ mol SbCl}_5 \)
1. \( [\text{SbCl}_5]_{\text{init}} = 0.300 \text{ mol/15L} = 0.0200 \text{M} \)
2. \( T = 182^\circ \text{C} + 273 = 455 \text{K} \)
   \[
P = \frac{nRT}{V} = 0.300 \times 0.0821 \times 455 / 15 \text{L} = 0.747 \text{ atm} \]

(b) \( [\text{SbCl}_5] = [\text{Cl}_2] = (0.0200 \text{ mol/L})(0.292) = 5.84 \times 10^{-3} \text{M} \)
    \( [\text{SbCl}_3] = (0.0200 \text{ mol/L})(0.708) = 1.42 \times 10^{-2} \text{M} \)
    \( K_c = [\text{SbCl}_3][\text{Cl}_2] / [\text{SbCl}_5] = (5.84 \times 10^{-3})^2 / 1.42 \times 10^{-2} = 2.0 \times 10^{-3} \)
    \( OR \)
    \( P_{\text{SbCl}_3} = P_{\text{Cl}_2} = (0.747 \text{ atm})(0.292) = 0.218 \text{ atm} \)
    \( P_{\text{SbCl}_5} = (0.747 \text{ atm})(0.708) = 0.529 \text{ atm} \)
    \( K_p = (P_{\text{SbCl}_3})(P_{\text{Cl}_2}) / (P_{\text{SbCl}_5}) = 0.218^2 / 0.529 = 8.98 \times 10^{-2} \)
    \( K = [\text{SbCl}_3][\text{Cl}_2] / [\text{SbCl}_5] = 0.117 \)

(c) \( [\text{SbCl}_5]_{\text{eqbm}} = (1.00 - 0.70) \text{mol} / 2.00 \text{L} = 0.15 \text{M} \)
    \( [\text{SbCl}_3]_{\text{eqbm}} = 0.7/2 = 0.35 \text{M} \)
    \( [\text{Cl}_2] = X = 0.05 \text{M} = 0.05 \text{M} \times 2 \text{L} = 0.1 \text{ mol at equilibrium} \)
    \( 0.1 + 0.3 \text{ (consumed)} = 0.4 \text{ mol minimum at initial} \)

8)

(a) \( n = \frac{PV}{RT} = 7.76 \times 5.00 \text{L} / 0.0821 \times 433 = 1.09 \text{ mol} \)
    \( \text{mol H}_2\text{O} = (\frac{1}{2})(1.09 \text{ mol}) = 0.545 \text{ mol H}_2\text{O}(g) \)

(b) \( 0.545 \times 2/1 \times 84.0 / 1 = 91.9 \text{ g NaHCO}_3 \text{ decomposed} \)
    \( \text{remaining} = 100. \text{ g} - 91.6 \text{ g} = 8.4 \text{ g} \)
    \( OR \)
    \( 100 - (0.545 \times 18/1 + 0.545 \text{ mol CO}_2 \times 44/1) \)
    \( 100 \text{ g} - 33.8 \text{ g} = 66 \text{ g} \text{ (or 66.2 g)} \) \([\text{includes Na}_2\text{CO}_3 \text{ solid in this mass}]\)

(c) \( K_p = (P_{\text{H}_2\text{O}})(P_{\text{CO}_2}) = (3.88)(3.88) \text{ atm}^2 = 15.1 \text{ atm}^2 \)

(d) Pressure would remain at 7.76 atm. Since some solid remained when 100. g was used (and there has been no temperature change), then using 110g will not affect the equilibrium.
9) (a) The equilibrium pressure of NH\textsubscript{3} gas would be unaffected. \( K_p = (P_{NH3})(P_{H2S}) \). Thus the amount of solid NH\textsubscript{4}HS present does not affect the equilibrium.

(b) The equilibrium pressure of NH\textsubscript{3} gas would decrease. In order for the equilibrium constant, \( K_p \), to remain constant, the equilibrium pressure of NH\textsubscript{3} must decrease when the pressure of H\textsubscript{2}S is increased. \( K_p = (P_{NH3})(P_{H2S}) \). (A complete explanation based on LeChatelier's principle is also acceptable.)

(c) The mass of NH\textsubscript{4}HS increases. A decrease in volume causes the pressure of each gas to increase. To maintain the value of the pressure equilibrium constant, \( K_p \), the pressure of each of the gases must decrease. The decrease is realized by the formation of more solid NH\textsubscript{4}HS. \( K_p = (P_{NH3})(P_{H2S}) \). (A complete explanation based on LeChatelier's principle is also acceptable.)

(d) The mass of NH\textsubscript{4}HS decreases because the endothermic reaction absorbs heat and goes nearer to completion (to the right) as the temperature increases.

10) (a) \( K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} \)

(b) \( K_p = \frac{0.20^2}{0.50 \times 0.20^3} = 10 \)

(c) \( K_p = K_c \frac{RT}{\Delta n} = 10 \times \frac{0.0821 \times 570 \times 2}{10} = 10 \times 46.7^2 = 4.7 \times 10^{-3} \)
   i. an increase of T favors the endothermic reaction (reverse reaction) and will produce more H\textsubscript{2}. The hydrogen concentration will increase.
   ii. An increase in volume (decrease in pressure) favors the direction that produces more molecules (increase in pressure) of the gas. The reverse reaction is more favorable and will increase the H\textsubscript{2} concentration.
   iii. adding N\textsubscript{2} will shift the reaction to the right so that the added amount is being consumed. This will decrease the concentration of H\textsubscript{2}.
   iv. The addition of He, an inert gas will have no effect on the concentration of H\textsubscript{2}.

11) (a) \( K_c = \frac{[H_2]^2[S_2]}{[H_2S]^2} \quad K_c = \frac{[H_2]^2[S_2]}{[H_2S]^2} \)

(b) \( [H_2] = 2[S_2] = 2 \times 3.72 \times 10^{-2}/1.25L = 5.95 \times 10^{-2} \text{ M} \)
\( [H_2S] = 0.10 \text{ mol} - \{2 \times 3.72 \times 10^{-2}/1.25L\} = 2.05 \times 10^{-2} \text{ M} \)
\( [H_2S] = 0.0800 - 0.0595 = 0.0205 \text{ M} \)
\( K_c = \frac{(5.95 \times 10^{-2})^2(3.72 \times 10^{-2}/1.25L)}{(2.05 \times 10^{-2})^2} = 0.250 \)

(c) \( P = \frac{nRT}{V} = \frac{(3.72 \times 10^{-2} \times 0.0821 \times 483)}{1.25} = 1.18 \text{ atm} \)

(d) \( K_c = \frac{1}{K_c^{1/2}} = \frac{1}{0.25^{1/2}} = 2.00 \)
\( K_c = \frac{[H_2S]}{[H_2][S_2]^{1/2}} \)
12)

(a) \( K_p = \frac{[P_{NH_3}]^2}{[P_{N_2}] \times [P_{H_2}]^3} \)

(b) 
1. \( Q = \frac{0.224^2}{0.411 \times 0.903^3} = 0.161 \)
2. since \( Q > K_p \), the equilibrium will proceed to the left to bring the value of \( Q \) down to \( 3.1 \times 10^{-4} \)

(c) \( K_c = \frac{K_p}{(RT)^{\Delta n}} = \frac{3.1 \times 10^{-4}}{(0.0821 \times 700)^2} = 1.023 \)

(d) 
1. \( K_{p1} = \frac{1}{K_p} = \frac{1}{8.3 \times 10^{-3}} = 120.48 \)
2. \( N_2 + 3H_2 \rightarrow 2NH_3 \quad 3.1 \times 10^{-4} \)
   \( 2NH_3 + 2H_2S \rightarrow 2NH_4HS \quad (8.3 \times 10^{-3})^2 \)
\( N_2 + 3H_2 + 2H_2S \rightarrow 2NH_4HS \quad 2.1 \times 10^{-8} \)