1. At 450°C, 2.0 moles each of H₂(g), I₂(g), and HI(g) are combined in a 1.0 L rigid container. The value of K_c at 450°C is 50. Which of the following will occur as the system moves toward equilibrium?
   (A) More H₂(g) and I₂(g) will form.
   (B) More HI(g) will form.
   (C) The total pressure will decrease.
   (D) No net reaction will occur, because the number of molecules is the same on both sides of the equation.

Questions 2 – 6 refer to the following.

$$\text{PCl}_3(g) \rightleftharpoons \text{PCl}_4(g) + \text{Cl}_2(g)$$

PCl₃(g) decomposes into PCl₄(g) and Cl₂(g) according to the equation above. A pure sample of PCl₃(g) is placed in a rigid, evacuated 1.00 L container. The initial pressure of the PCl₃(g) is 1.00 atm. The temperature is held constant until the PCl₃(g) reaches equilibrium with its decomposition products. The figures show the initial and equilibrium conditions of the system.

2. Which is the most likely cause for the increase in pressure observed in the container as the reaction reaches equilibrium?
   (A) A decrease in the strength of intermolecular attractions among molecules in the flask
   (B) An increase in the strength of intermolecular attractions among molecules in the flask
   (C) An increase in the number of molecules, which increases the frequency of collisions with the walls of the container
   (D) An increase in the speed of the molecules that then collide with the walls of the container

3. As the reaction progresses toward equilibrium, the rate of the forward reaction (A) increases until it becomes the same as the reverse reaction rate at equilibrium (B) stays constant before and after equilibrium is reached (C) decreases to become a constant nonzero rate at equilibrium (D) decreases to become zero at equilibrium

4. If the decomposition reaction were to go to completion, the total pressure in the container would be
   (A) 1.4 atm
   (B) 2.0 atm
   (C) 2.8 atm
   (D) 3.0 atm

5. Which of the following statements about K_p, the equilibrium constant for the reaction, is correct?
   (A) K_p < 1
   (B) K_p = 1
   (C) K_p > 1
   (D) It cannot be determined whether K_p > 1, K_p < 1, or K_p = 1 without additional information.

6. Additional Cl₂(g) is injected into the system at equilibrium. Which of the following graphs best shows the rates of the reverse reaction as a function of time? (Assume that the time for injection and mixing of the additional Cl₂(g) is negligible.)

   (A) ![Graph A]
   (B) ![Graph B]
   (C) ![Graph C]
   (D) ![Graph D]

7. A sealed rigid vessel contains BaO₂(s) in equilibrium with BaO(s) and O₂(g) as represented by the equation below. Which of the following changes will increase the amount of BaO₂(s) in the vessel?
   (A) Removing a small amount of O₂(g)
   (B) Removing a small amount of BaO(s)
   (C) Adding He gas to the vessel
   (D) Lowering the temperature

8. Which of the systems in equilibrium represented below will exhibit a shift to the left (toward reactants) when the pressure on the system is increased by reducing the volume of the system? (Assume that temperature is constant.)
   (A) SF₆(g) + F₂(g) ⇌ SF₇(g)
   (B) H₂S(g) + Br₂(g) ⇌ 2 HBr(g)
   (C) CaF₂(s) ⇌ Ca²⁺(aq) + 2 F⁻(aq)
   (D) SO₂Cl₂(g) ⇌ SO₂(g) + Cl₂(g)

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

\[ 1-x + x + x = 1.4 \]

\[ x = 0.4 \text{ atm} \]

\[ K_p = \frac{(0.4)(0.4)}{(0.6)} < 1 \]
Questions 9 – 11 refer to the following information.

\[ \text{CO(g)} + 2 \text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH(g)} \quad \Delta H < 0 \]

The synthesis of CH\(_3\)OH(g) from CO(g) and H\(_2\)(g) is represented by the equation above. The value of \( K_c \) for the reaction at 483 K is 14.5

9. Which of the following explains the effect on the equilibrium constant, \( K_c \), when the temperature of the reaction system is increased to 650 K?

(A) \( K_c \) will increase because the activation energy of the forward reaction decreases more than that of the reverse reaction.

(B) \( K_c \) will increase because there are more reactant molecules than product molecules.

(C) \( K_c \) will decrease because the reaction is exothermic.

(D) \( K_c \) is constant and will not change.

10. A 1.0 mol sample of CO(g) and a 1.0 mol sample of H\(_2\)(g) are pumped into a rigid, previously evacuated 2.0 L reaction vessel at 483 K. Which of the following is true at equilibrium?

(A) [CO] = 2[CO] [H\(_2\)]

(B) [CO] < [CO] [H\(_2\)]

(C) [CO] = [CH\(_3\)OH] < [H\(_2\)]

(D) [CO] = [CH\(_3\)OH] = [H\(_2\)]

11. A mixture of CO(g) and H\(_2\)(g) is pumped into a previously evacuated 2.0 L reaction vessel. The total pressure of the reaction system is 1.2 atm at equilibrium. What will be the total pressure of the system if the volume of the reaction vessel is reduced to 1.0 L at constant temperature?

(A) Less than 1.2 atm

(B) Greater than 1.2 atm but less than 2.4 atm

(C) 2.4 atm

(D) Greater than 2.4 atm

PCl\(_3\)(g) + Cl\(_2\)(g) \rightleftharpoons PCl\(_5\)(g) \quad K_c = 6.5

12. At a certain point in time, a 1.00 L rigid reaction vessel contains 1.5 mol of PCl\(_3\)(g), 1.0 mol of Cl\(_2\)(g), and 2.5 mol of PCl\(_5\)(g). Which of the following describes how the measured pressure in the reaction vessel will change and why it will change that way as the reaction system approaches equilibrium at constant temperature?

(A) The pressure will increase because \( Q < K_c \).

(B) The pressure will increase because \( Q > K_c \).

(C) The pressure will decrease because \( Q < K_c \).

(D) The pressure will decrease because \( Q > K_c \).

\[ Q = \frac{1.5 \times 1}{1.5 \times 2} = \frac{6}{5} < K_c = 6.5 \]

\[ \therefore \text{ shift right} \]

Questions 13 – 14 refer to the following experiment:

H\(_2\) gas and N\(_2\) gas were placed in a rigid vessel and allowed to reach equilibrium in the presence of a catalyst according to the following equation.

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

The value of \( \Delta H^\circ \) for this reaction is equal to -92 kJ/mol. The diagram shows how the concentrations of H\(_2\), N\(_2\), and NH\(_3\) in this system changed over time.

13. Which of the following was true for the system between time \( t_1 \) and time \( t_2 \)?

(A) The rates of the forward and reverse reactions were equal.

(B) The temperature of the system decreased.

(C) The number of effective collisions between H\(_2\) and N\(_2\) was zero.

(D) The rate of formation of NH\(_3\) molecules was equal to the rate of disappearance of H\(_2\) molecules.

14. More NH\(_3\) gas is added to the system at time \( t_2 \). Which of the following will most likely occur as the system approaches equilibrium at constant temperature?

(A) [N\(_2\)] will increase, and \( K_c \) will decrease.

(B) [N\(_2\)] will decrease, and \( K_c \) will increase.

(C) [N\(_2\)] will decrease, but \( K_c \) will remain constant.

(D) [N\(_2\)] will increase, but \( K_c \) will remain constant.

Fe\(^{3+}\)(aq) + SCN\(^-\)(aq) \rightleftharpoons Fe(ScN)\(^{2+}\)(aq)

15. For the reaction represented above, the value of the equilibrium constant, \( K_c \), is 240 at 25°C. From this information, correct deductions about the reaction at 25°C include which of the following?

I. The reaction is quite rapid.
II. The product is favored over the reactants at equilibrium.
III. The reaction is endothermic.

(A) I. only

(B) II. only

(C) I. and II. only

(D) II. and III. only

16. At 25°C, the equilibrium constant for the reaction represented above has a value of 1.3. At 50°C, the value of the equilibrium constant is less than 1.3. Based on this information, which of the following must be correct?

(A) \( \Delta H^\circ \) for the reaction is positive.

(B) \( \Delta H^\circ \) for the reaction is negative.

(C) The reaction rate decreases as the temperature is increased.

(D) At 75°C, the value of the equilibrium constant will be greater than 1.3.

increased temp decreased \( K_c \), meaning rxn shifted left (\( \Delta H^\circ \) negative)
1. A 4.32 g sample of liquid SO₂Cl₂ is placed in a rigid, evacuated 1.50 L reaction vessel. As the container is heated to 400. K, the sample vaporizes completely and starts to decompose according to the equation above. The decomposition reaction is endothermic.

(a) If no decomposition occurred, what would be the pressure, in atm, of the SO₂Cl₂(g) in the vessel at 400. K?

\[
p = \frac{nRT}{V} = \frac{(4.32 \text{ g})(1 \text{ mol/L})(0.0821 \text{ L atm/mol K})(400 \text{ K})}{1.50 \text{ L}} = 1.680 \text{ atm}
\]

(b) When the system has reached equilibrium at 400. K, the total pressure in the container is 1.26 atm. Calculate the partial pressures, in atm, of SO₂Cl₂(g), SO₂(g), and Cl₂(g) in the container at 400. K.

\[
\begin{align*}
\text{SO}_2\text{Cl}_2 & \rightleftharpoons \text{SO}_2 + \text{Cl}_2 \\
\text{Partial Pressure} & = 1.26 \text{ atm} \\
\text{SO}_2 & = 0.7 + x + x = 1.26 \text{ atm} \\
\text{SO}_2 & = 0.56 \text{ atm} \\
\text{Cl}_2 & = 0.56 \text{ atm}
\end{align*}
\]

(c) For the decomposition reaction at 400. K,

(i) write the equilibrium-constant expression for \(K_p\) for the reaction

\[
K_p = \frac{P_{\text{SO}_2}(P_{\text{Cl}_2})}{P_{\text{SO}_2\text{Cl}_2}}
\]

(ii) calculate the value of the equilibrium constant, \(K_p\).

\[
K_p = \frac{(0.56)(0.56)}{0.14} = 2.24
\]

(iii) calculate the value of the equilibrium constant for the reverse reaction.

\[
K_{p,\text{rev}} = \frac{1}{2.24} = 0.446
\]

(d) The temperature of the equilibrium mixture is increased to 425 K. Will the value of \(K_p\) increase, decrease, or remain the same? Justify your prediction. Since the reaction is endothermic, increasing temperature will cause a shift towards the products, increasing \(K_p\).

(e) In another experiment, the original partial pressures of SO₂Cl₂(g), SO₂(g), and Cl₂(g) are 1.0 atm each at 400. K. Predict whether the amount of SO₂Cl₂(g) in the container will increase, decrease, or remain the same. Justify your prediction.

\[
Q = \frac{1 \times 1}{1} = 1 < 2.24
\]

reaction will shift towards the right to achieve equilibrium, so the amount of SO₂Cl₂ will decrease.

2. In a saturated solution of MgF₂ at 18°C, the concentration of Mg²⁺ is 1.21 x 10⁻⁴ molar. The equilibrium is represented by the equation above.

(a) Write the expression for the solubility-product constant, \(K_{sp}\), and calculate its value at 18°C.

\[
\text{Mgf}_2(s) \rightleftharpoons Mg^{2+}(aq) + 2 F^{-}(aq)
\]

\[
K_{sp} = [Mg^{2+}][F^-]^2
\]

\[
7.09 \times 10^{-9} = (x)(x)^2
\]

(b) Calculate the equilibrium concentration of Mg²⁺ in 1.00 liter of saturated MgF₂ solution at 18°C to which 0.100 mole of solid KF has been added (the value for Ksp is the same as in the previous part). The KF dissolves completely. Assume the volume change is negligible.

\[
\text{Mgf}_2(s) \rightleftharpoons Mg^{2+}(aq) + 2 F^{-}(aq)
\]

\[
[\text{Mg}^{2+}] = \frac{(0.100)(7.09 \times 10^{-9})}{(0.01)} = 7.09 \times 10^{-7}
\]

(c) Predict whether a precipitate of MgF₂ will form when 100.0 milliliters of a 3.00 x 10⁻³ molar Mg(NO₃)₂ solution is mixed with 200.0 milliliters of a 2.00 x 10⁻³ molar NaF solution at 18°C. Calculations to support your prediction must be shown.

\[
\frac{[\text{Mg}^{2+}]}{[\text{F}^-]} = \frac{(3 \times 10^{-3})(100)}{(2 \times 10^{-3})(200)} = 0.0013
\]

Q = (0.0013)(0.0013)² = 1.77 x 10⁻⁹ < 7.09 x 10⁻⁹ 

(d) At 27°C the concentration of Mg²⁺ in a saturated solution of MgF₂ is 1.17 x 10⁻³ molar. Is the dissolving of MgF₂ in water an endothermic or an exothermic process? Give an explanation to support your conclusion.

Ksp at 18°C = 7.09 x 10⁻⁷

Ksp at 27°C = (1.17 x 10⁻³)(2 x 1.17 x 10⁻³)² = 6.41 x 10⁻⁹

Ksp is smaller at a higher temperature, therefore dissolving MgF₂ in water must be an exothermic process.