Part 1: Calculating Equilibrium Constants

1. A mixture of H\textsubscript{2} and I\textsubscript{2} is allowed to react at 448°C. When equilibrium is established, the concentrations of the participants are found to be [H\textsubscript{2}] = 0.46 mol/L, [I\textsubscript{2}] = 0.39 mol/L and [HI] = 3.0 mol/L. Calculate the value of Keq at 448°C from this data.
   a. Write a balanced chemical equation for this reaction
   b. Write the equilibrium expression, Keq
   c. Calculate the numerical value of Keq
   d. Assume that in the analysis of an equilibrium mixture of H\textsubscript{2} and I\textsubscript{2} at 448°C, the equilibrium concentrations of I\textsubscript{2} and H\textsubscript{2} are found to be 0.50 mol/L. What is the equilibrium concentration of HI?

2. Gaseous hydrogen iodide is placed in a closed container at 425°C, where it partially decomposes to hydrogen and iodine: 2 HI\textsubscript{(g)} ⇌ H\textsubscript{2}\textsubscript{(g)} + I\textsubscript{2}\textsubscript{(g)}
   At equilibrium it was found that [HI] = 3.53 x 10\textsuperscript{-3} M; [H\textsubscript{2}] = 4.79 x 10\textsuperscript{-4} M; [I\textsubscript{2}] = 4.79 x 10\textsuperscript{-4} M. What is the value of Keq at this temperature?

3. At temperatures near 800°C, steam passed over hot coke (a form of carbon obtained from coal) reacts to form CO and H\textsubscript{2}: C\textsubscript{(s)} + H\textsubscript{2}O\textsubscript{(g)} ⇌ CO\textsubscript{(g)} + H\textsubscript{2}\textsubscript{(g)}
   The mixture of gases that results is an important industrial fuel called water gas. When equilibrium is achieved at 800°C, [H\textsubscript{2}] = 4.0 x 10\textsuperscript{-2} M; [CO] = 4.0 x 10\textsuperscript{-2} M and [H\textsubscript{2}O] = 1.0 x 10\textsuperscript{-2} M. Calculate Keq at this temperature.

4. A sample of nitrosyl bromide, NOBr, decomposes according to the following equation:
   2 NOBr\textsubscript{(g)} ⇌ 2 NO\textsubscript{(g)} + Br\textsubscript{2}\textsubscript{(g)}
   An equilibrium mixture in a 5.0 L vessel at 100°C contains 3.22 g NOBr, 3.08 g of NO, and 4.19 g of Br\textsubscript{2}. Calculate Keq at this temperature.

Answers

1. c. Keq = 5.0 x 10\textsuperscript{1}
   d. [HI] = 3.5 M
2. Keq = 0.0184
3. Keq = 0.16
4. Keq = 0.064
Part 2: Predict the Direction of Equilibrium

1. At 448°C, Keq = 50.5 for the reaction of hydrogen gas with iodine gas to form hydrogen iodide gas. Predict how the reaction will proceed if the concentrations are as given below:

\[
[H_2] = 0.150 \text{ M} \quad [I_2] = 0.175 \text{ M} \quad [HI] = 0.950 \text{ M}
\]

2. At 100°C, the equilibrium constant for the reaction \( \text{COCl}_2(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + \text{Cl}_2(\text{g}) \) has the value of Keq = \(2.19 \times 10^{-10}\). Are the following mixtures of COCl\(_2\), CO, and Cl\(_2\) at equilibrium? If not, indicate the direction that the reaction must proceed to achieve equilibrium

a. \([\text{COCl}_2] = 5.00 \times 10^{-2} \text{ M} \quad [\text{CO}] = 3.31 \times 10^{-2} \text{ M} \quad [\text{Cl}_2] = 3.31 \times 10^{-2} \text{ M}\)

b. \([\text{COCl}_2] = 3.50 \times 10^{-3} \text{ M} \quad [\text{CO}] = 1.11 \times 10^{-5} \text{ M} \quad [\text{Cl}_2] = 3.25 \times 10^{-6} \text{ M}\)

c. \([\text{COCl}_2] = 1.45 \text{ M} \quad [\text{CO}] = 1.56 \times 10^{-6} \text{ M} \quad [\text{Cl}_2] = 1.56 \times 10^{-6} \text{ M}\)

3. At 900°C, Keq = 0.0108 for the reaction

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

A mixture of CaCO\(_3\), CaO and CO\(_2\) is placed in a 10.0 L vessel at 900°C. For the following mixtures, will the amount of CaCO\(_3\) increase, decrease or remain the same as the system approached equilibrium?

a. 25.0 g CaCO\(_3\) 25.0 g CaO and 15.0 g CO\(_2\)

b. 1.5 g CaCO\(_3\) 15.0 g CaO and 4.75 g CO\(_2\)

c. 35.0 g CaCO\(_3\) 20.5 g CaO and 2.50 g CO\(_2\)

4. At a certain temperature Keq = 4 for the reaction

\( 2 \text{HF(}g) \rightleftharpoons \text{H}_2(\text{g}) + \text{F}_2(\text{g}) \)

Predict the direction in which the equilibrium will shift, if any, when the following systems are introduced into a 5.0 L bulb.

a. 3.0 mol HF 2.0 mol H\(_2\) 4.0 mol F\(_2\)

b. 0.20 mol HF 0.50 mol H\(_2\) 0.60 mol F\(_2\)

c. 0.30 mol HF 1.8 mol H\(_2\) 0.20 mol F\(_2\)

5. At a certain temperature, Keq = 125 for the reaction:

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

If 0.15 mol of HI, 0.034 mol of H\(_2\) and 0.096 mol of I\(_2\) are introduced into a 10 L vessel, will the reaction proceed to the reactant side or product side as the reaction attempts to reach equilibrium?

| Answers | 1. Q = 34.4 shifts to products/right | 2. a) Q = 0.022 Left b) Q = 1.03 x 10^{-8} Left c) Q = 1.68 x 10^{-12} Right | 3. a) mass increases b) remains the same c) mass decreases | 4. a) Q = 0.89 to right/products b) Q= 7.5 left/reactants c) Q = 4 no shift | 5. Q = 6.9 Eqm will shift to products |
Part 3: Calculating Equilibrium Constants
(from initial concentrations)

1. When 0.40 mol of PCl₅ is heated in a 1L container, and equilibrium is established in which 0.25 mol of Cl₂ is present. The equation for the reaction is:
   \[ \text{PCl}_5 (g) + 92.5 \text{ kJ} \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g) \]
   a. What are the equilibrium concentration of all three components? Make a RICE table.
   b. What is the equilibrium constant for the reaction?

2. A 1.0 L reaction vessel contained 0.750 mol of CO and 0.275 mol of H₂O. After 1 hour, equilibrium was reached according to the equation:
   \[ \text{CO}(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}_2(g) + \text{H}_2(g) \]
   Analysis showed that 0.250 mol of CO₂ was present at equilibrium. What is Keq for the reaction?

3. A 5.0 L reaction vessel was initially filled with 6.00 mol of SO₂, 2.5 mol of NO₂ and 1.0 mol of SO₃. After equilibrium was established according to the equation
   \[ \text{SO}_2(g) + \text{NO}_2(g) \rightleftharpoons \text{SO}_3(g) + \text{NO}(g) \]
   the vessel was found to contain 3.0 mol of SO₃. What is the Keq for the reaction?

4. Consider the equilibrium \( \text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2 \text{NO}_3(g) \)
   a. At a certain temperature 3.0 mol of N₂ and 2.0 mol of H₂ are introduced into a 5.0 L container. At equilibrium the concentration of NH₃ is 0.020 M. Calculate Keq for the reaction.
   b. At a different temperature, 6.0 mol of NH₃ was left. Calculate the Keq for the reaction at this temperature.

5. A mixture of 1.374 g of H₂ and 70.31 g of Br₂ is heated in a 2.00 L vessel at 700 K. These substances react as follows:
   \[ \text{H}_2(g) + \text{Br}_2(g) \rightleftharpoons 2 \text{HBr}(g) \]
   At equilibrium, the vessel is found to contain 0.566 g of H₂. Calculate the Keq.

Answers

1. Keq = 0.42
2. Keq = 5.0
3. Keq = 3.0
4. a) Keq = 0.013    b) keq is undefined, rxn must go to completion
5. Keq = 64
Part 4: Using Keq to Find Concentrations

1. \[2 \text{H}_2(g) + S_2(g) \rightleftharpoons 2 \text{H}_2S(g)\]  
   Keq = 7.5
   A certain amount of H\(_2\)S was added to a 2.0 L flask and allowed to come to equilibrium. At equilibrium, 0.072 mol of H\(_2\) was found. How many moles of H\(_2\)S were originally added to the flask?

2. At a certain temperature, Keq = 49.5 for the reaction: \[\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2 \text{HI}(g)\]
   If 0.250 mol of H\(_2\) and 0.250 mol of I\(_2\) are placed in a 10.0 L vessel and permitted to react, what will be the concentrations of each substance at equilibrium?

3. The equilibrium constant for the reaction: \[\text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2 \text{NH}_3(g)\]
   is 3.0 at a certain temperature. Enough NH\(_3\) was added to a 5.0 L container such that after equilibrium was established the container was found to contain 2.5 mol of N\(_2\). How many moles of NH\(_3\) were originally introduced into the container?

4. At a certain temperature, Keq = 1.00 for the reaction: \[\text{N}_2\text{O}_2(g) + \text{H}_2(g) \rightleftharpoons \text{N}_2\text{O}(g) + \text{H}_2\text{O}(g)\]
   If 0.150 mol of N\(_2\)O\(_2\) and 0.250 mol of H\(_2\)O were introduced into a 1.00 bulb and allowed to come to equilibrium, what concentration of N\(_2\)O\(_2\) was present at equilibrium?

5. Keq = 100 at a certain temperature for the reaction:
   \[\text{CH}_4(g) + 2 \text{H}_2\text{S}(g) \rightleftharpoons \text{CS}_2(g) + 4 \text{H}_2(g)\]
   Some CH\(_4\) and H\(_2\)S were introduced into a 1.0 L bulb and at equilibrium 0.10 mol of CH\(_4\) and 0.30 mol of H\(_2\)S were found. What was [CS\(_2\)] at equilibrium?

6. Keq = 5.0 at a certain temperature for the reaction: \[2 \text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{SO}_3(g)\]
   A certain amount of SO\(_3\) was placed in a 2.0 L reaction vessel. At equilibrium the vessel contained 0.30 mol of O\(_2\). What concentration of SO\(_3\) was originally placed in the vessel?

7. At 1285°C, the equilibrium constant for the reaction \[\text{Br}_2(g) \rightleftharpoons 2 \text{Br}(g)\]
   is \(1.04 \times 10^{-3}\). A 0.200 L vessel containing an equilibrium mixture of the gases has 0.245 g of Br\(_2\) in it. What is the mass of Br\(_2\) in the vessel?

8. At 21.8°C, the equilibrium constant Keq = 1.2 x 10\(^{-4}\) for the following reaction:
   \[\text{NH}_4\text{HS}(s) \rightleftharpoons \text{NH}_3(g) + \text{H}_2\text{S}(g)\]
   Calculate the equilibrium concentrations of NH\(_3\) and H\(_2\)S if a sample of solid NH\(_4\)HS is placed in a closed vessel and allowed to decompose until equilibrium is reached.

**Answers**

1. Moles H\(_2\)S = 0.098 mol
2. \([\text{HI}] = 0.039 \text{ M} \quad [\text{H}_2] = [\text{I}_2] = 5.5 \times 10^{-3} \text{ M}\)
3. \([\text{NH}_3] = 3.25 \text{ M} \quad : \quad 16 \text{ mol NH}_3\)
4. \([\text{N}_2\text{O}_2] = 0.0938 \text{ M}\)
5. \([\text{CS}_2] = 0.32 \text{ M}\)
6. \([\text{SO}_3] = 0.56 \text{ M}\)
7. 0.045 g Br
8. \([\text{NH}_3] = [\text{H}_2\text{S}] = 0.011 \text{ M}\)