The Equilibrium Constant Kp For The Reaction, 2SO2(g)+O2(g)2SO3(g), Is 900 Atm1 At 800 K. A Mixture Containing

The Equilibrium Constant Kp For The Reaction, 2SO2(g)+O2(g)→2SO3(g), Is 900 Atm1 At 800 K. A Mixture Containing

Understanding chemical equilibrium and the associated constants is fundamental in chemical thermodynamics and kinetics. In this article, we delve into the equilibrium constant K_p for the reaction:

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

which is given as 900 at a temperature of 800 K and a total pressure of 1 atm. We will explore what this constant signifies, how it is derived, and what implications it has for the behavior of the reaction mixture. Additionally, we will analyze various scenarios involving mixtures of reactants and products, the calculation of partial pressures, and the application of Le Châtelier’s principle.

Understanding the Equilibrium Constant K_p

Definition of K_p

The equilibrium constant K_p pertains to gaseous reactions and relates the partial pressures of the reactants and products at equilibrium. For a general reaction:

$$ aA + bB \rightleftharpoons cC + dD $$

the expression for K_p is:

$$ K_p = \frac{P_C^c \times P_D^d}{P_A^a \times P_B^b} $$

where P_X denotes the partial pressure of species X at equilibrium, measured in atmospheres (atm).

In the specific case of the formation of sulfur trioxide:

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

the equilibrium constant K_p is:

$$K_p = \frac{P_{\text{SO}_3}^2}{P_{\text{SO}_2}^2 \times P_{\text{O}_2}}$$

Given that $K_p = 900$ at 800 K, this indicates a strong tendency for the formation of SO_3 under these conditions.

Implications of a Large K_p Value

Significance of $K_p=900$

A K_p value much greater than 1 suggests the reaction heavily favors the formation of products—here, SO_3—at equilibrium. This means:

- The partial pressure of SO_3 at equilibrium is high relative to the reactants.
- The equilibrium mixture contains predominantly SO_3 under the given conditions.
- The forward reaction rate exceeds the reverse reaction rate significantly, leading to rapid conversion of SO_2 and O_2 into SO_3.

This information guides industrial processes such as the Contact Process for sulfuric acid production, where the conversion of SO_2 to SO_3 needs to be maximized.

Calculations Based on the Given Data

Total Pressure and Partial Pressures at Equilibrium

Given:
- Total pressure, $P_{total} = 1\,\text{atm}$
- Temperature, $T = 800\,K$
- Equilibrium constant, $K_p = 900$

Assuming the mixture contains only the gases involved (SO_2, O_2, SO_3), the sum of their partial pressures is:

$$P_{SO_2} + P_{O_2} + P_{SO_3} = P_{total} = 1\,\text{atm}$$

Let’s define:

- $x = P_{SO_3}$ (partial pressure of SO_3 at equilibrium)
- $a = P_{SO_2}$
- $b = P_{O_2}$

From the reaction stoichiometry:

$$ 2 \text{SO}_2 + \text{O}_2 \rightleftharpoons 2 \text{SO}_3 $$

The expression for K_p becomes:

$$ 900 = \frac{x^2}{a^2 \times b} $$

And the total pressure:

$$ a + b + x = 1 $$

To proceed, we need additional assumptions or data about initial concentrations, but for simplicity, consider a scenario where initially, the mixture contains only reactants, and the reaction proceeds toward products until equilibrium is established.

Estimating Partial Pressures at Equilibrium

Suppose initially, the mixture contains:

- $P_{SO_2, initial} = P_{SO_2}^0$
- $P_{O_2, initial} = P_{O_2}^0$
- $P_{SO_3, initial} = 0$

The extent of the reaction, ξ, leads to:

$$ P_{SO_2} = P_{SO_2}^0 - 2\xi $$
$$ P_{O_2} = P_{O_2}^0 - \xi $$
$$ P_{SO_3} = 2\xi $$

Applying these to the expression for K_p:

$$ 900 = \frac{(2\xi)^2}{(P_{SO_2}^0 - 2\xi)^2 \times (P_{O_2}^0 - \xi)} $$

And the total pressure:

$$ P_{total} = (P_{SO_2}^0 - 2\xi) + (P_{O_2}^0 - \xi) + 2\xi $$

which simplifies to:

$$ P_{total} = P_{SO_2}^0 + P_{O_2}^0 - \xi $$

Given the initial partial pressures, one could solve these equations for ξ. Alternatively, if initial partial pressures are unknown, one can analyze the equilibrium based on typical conditions or assume initial ratios.

Effect of Changing Conditions on Equilibrium

Le Châtelier's Principle

Since K_p is large and favors products, altering conditions will shift the equilibrium:

- **Increasing pressure:** Since the reaction reduces the total number of moles (from 3 moles of reactants to 2 moles of product), increasing pressure shifts the equilibrium toward SO_3 formation.

- **Changing temperature:** The reaction is exothermic (formation of SO_3 releases heat). Increasing temperature shifts the equilibrium toward reactants, decreasing K_p. Conversely, lowering temperature favors SO_3 formation.

Understanding these principles is critical in industrial settings, where temperature and pressure are optimized to maximize SO_3 yield.

Industrial Applications and Practical Considerations

Production of Sulfur Trioxide

The reaction:

$$ 2 \text{SO}_2 + \text{O}_2 \rightleftharpoons 2 \text{SO}_3 $$

is key in manufacturing sulfuric acid via the Contact Process. The high K_p value indicates that under optimal conditions, almost complete conversion can be achieved.

Operational Strategies:

1. **Temperature Control:** Operating at a temperature around 800–900 K balances the kinetics and equilibrium, maximizing SO_3 production while maintaining manageable reaction rates.

2. **Pressure Optimization:** Elevated pressures (around 1–2 atm) favor product formation due to the reduction in moles of gas during the reaction.

3. **Catalysis:** Use of vanadium pentoxide (V_2O_5) catalyzes the reaction, increasing the rate without affecting equilibrium position.

Conclusion

The equilibrium constant $K_p=900$ at 800 K for the reaction:

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

reflects a highly product-favored equilibrium under these conditions. The large value suggests that, at equilibrium, the mixture is predominantly SO_3, making the reaction ideal for industrial processes where high yields are desired. Understanding the interplay between temperature, pressure, and initial conditions allows chemical engineers to design optimal reactors and operational strategies, ensuring maximum efficiency and productivity.

The principles outlined here serve as a foundation for further exploration of chemical equilibria, kinetic considerations, and process optimization in industrial chemistry.

Frequently Asked Questions

What does the equilibrium constant Kp value of 900 indicate about the reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ at 800 K?

A Kp value of 900 suggests that at 800 K, the reaction strongly favors the formation of $SO_3(g)$, indicating the equilibrium lies significantly to the right.

How can the value of Kp (900 at 800 K) be used to determine the composition of a mixture containing the gases involved?

Knowing Kp allows calculation of the partial pressures or concentrations of SO_2, O_2, and SO_3 at equilibrium, helping to predict the proportion of each gas in the mixture at 800 K.

If a mixture contains equal initial moles of SO_2 and O_2, how will the composition change as the system reaches equilibrium with Kp = 900?

The system will shift toward producing more SO_3 until the partial pressures satisfy the equilibrium condition, resulting in a higher concentration of SO_3 compared to initial amounts.

What is the effect of increasing pressure on the equilibrium position in this reaction with a high Kp value?

Since the reaction produces fewer moles of gas ($2SO_3$) from more moles ($2SO_2 + O_2$), increasing pressure favors the formation of SO_3, reinforcing the equilibrium shift toward products.

How does temperature influence the value of Kp in this reaction, given that Kp is 900 at 800 K?

If temperature increases or decreases, the value of Kp may change depending on whether the reaction is exothermic or endothermic; knowing the enthalpy change helps predict how Kp varies with temperature.

What practical applications can be derived from understanding the Kp value of 900 for this reaction at 800 K?

This knowledge aids in optimizing industrial processes like sulfur trioxide production in the contact process, ensuring conditions favor maximum yield based on the equilibrium constant.

Additional Resources

Equilibrium Constant (Kp) and Its Significance in the Reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$: A Comprehensive Analysis

Understanding chemical equilibria is fundamental to mastering chemical reactions, especially in industrial processes like sulfur trioxide synthesis. Among the various parameters that characterize these equilibria, the equilibrium constant, particularly Kp (based on partial pressures), provides essential insights into the extent and direction of reactions under specific conditions. This article explores the significance of the equilibrium constant Kp for the reaction:

\[2 \mathrm{SO}_2(g) + \mathrm{O}_2(g) \leftrightarrow 2 \mathrm{SO}_3(g) \]

with a focus on the given value of $K_p = 900$ at 800 K and 1 atm pressure. We will analyze what this means for the reaction's position, how to interpret the value, and its implications for industrial and laboratory settings.

Understanding the Reaction and Its Equilibrium Constant

The Reaction in Focus

This reaction is a vital step in the Ostwald process, which is the industrial method for manufacturing sulfur trioxide, a precursor to sulfuric acid. It involves the oxidation of sulfur dioxide (SO_2) to produce sulfur trioxide (SO_3):

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

The reaction is exothermic, releasing heat as SO_2 is converted into SO_3. The equilibrium position of this reaction is sensitive to temperature, pressure, and the composition of the reactant mixture.

The Equilibrium Constant K_p

The equilibrium constant K_p is defined in terms of partial pressures of gases at equilibrium:

$$K_p = \frac{(P_{SO_3})^2}{(P_{SO_2})^2 \times P_{O_2}}$$

where:

- P_{SO_3}, P_{SO_2}, and P_{O_2} are the partial pressures of sulfur trioxide, sulfur dioxide, and oxygen, respectively.

A high K_p value indicates that, at equilibrium, the concentration (partial pressure) of products (SO_3) is much greater than that of reactants (SO_2 and O_2), favoring product formation. Conversely, a low K_p suggests the reaction favors reactants.

Interpreting $K_p = 900$ at 800 K and 1 atm

Magnitude of K_p

A K_p of 900 is considered very large, implying:

- The equilibrium heavily favors the formation of SO_3.
- The partial pressures of SO_3 at equilibrium are significantly higher relative to SO_2 and O_2.

This indicates that under the given conditions—800 K and 1 atm—the reaction proceeds predominantly toward SO_3 production.

Implications of the High K_p Value

- Reaction Extent: The high K_p suggests near-complete conversion of reactants to products at equilibrium.
- Industrial Efficiency: Conditions yielding such a large K_p are ideal for industrial settings where maximizing SO_3 output is desired.
- Temperature Dependence: Since the reaction is exothermic, decreasing temperature typically increases K_p, favoring product formation. The value at 800 K indicates an optimal or near-optimal temperature for the equilibrium position.

Calculating Partial Pressures in a Mixture

Suppose we have a mixture at equilibrium containing initial amounts of SO_2, O_2, and SO_3, and the total pressure is maintained at 1 atm. To understand the composition, we can analyze how the large K_p influences partial pressures.

Sample Approach:

1. Initial Conditions: Let's consider initial partial pressures—say, initial SO_2 and O_2 are supplied, and no SO_3 is present initially.
2. Reaction Progress: As the reaction proceeds, SO_2 and O_2 decrease, and SO_3 increases until equilibrium is established.
3. Equilibrium Conditions: Given $K_p = 900$, the partial pressures at equilibrium satisfy:

$$
900 = \frac{(P_{SO_3})^2}{(P_{SO_2})^2 \times P_{O_2}}
$$

4. Approximate Ratios: Because K_p is large, the equilibrium favors SO_3, so the partial

pressure of SO_3 will be close to the total pressure, while SO_2 and O_2 will be relatively low.

Factors Influencing K_p and Reaction Equilibrium

Temperature

- Since the reaction is exothermic, increasing temperature shifts equilibrium toward reactants, decreasing K_p.
- Conversely, lowering temperature favors SO_3 formation, increasing K_p.

Pressure

- Increasing total pressure generally favors the formation of fewer moles of gas.
- In this reaction, 3 moles of reactants produce 2 moles of product, so higher pressure shifts equilibrium toward SO_3.

Le Châtelier's Principle

- The reaction's equilibrium can be shifted by adjusting temperature and pressure to favor either reactants or products.
- Industrial processes exploit this principle to optimize SO_3 production.

Practical Applications and Industrial Significance

Optimizing Conditions for SO_3 Production

Given the high K_p at 800 K, industrial chemists aim to:

- Maintain a temperature around 800 K to maximize SO_3 yield.
- Use pressures higher than 1 atm, often in the range of 1-6 atm, to shift equilibrium further toward SO_3.
- Employ catalysts, such as vanadium pentoxide (V_2O_5), to accelerate reaction rates without affecting equilibrium positions.

Impact on Sulfuric Acid Manufacturing

- Since SO_3 is a key intermediate in sulfuric acid production, understanding and controlling K_p ensures efficient manufacturing.
- The high K_p indicates that under optimal conditions, the process can be highly productive with minimal waste.

Limitations and Considerations

- While a high K_p is desirable for maximal product formation, practical considerations such as catalyst activity, heat management, and equipment design also influence process efficiency.
- Temperature fluctuations can significantly alter K_p, so precise control is essential.
- The assumption of ideal gas behavior underpins the calculation of K_p. Deviations at high pressures or non-ideal conditions necessitate corrections.

Conclusion: The Significance of a Large K_p at 800 K

The equilibrium constant $K_p=900$ at 800 K and 1 atm for the reaction:

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

is a compelling indicator of the reaction's favorability toward SO_3 formation under these conditions. This large value underscores the efficiency of the process at this temperature and pressure, making it highly suitable for industrial applications where maximizing SO_3 yield is critical. Understanding this parameter empowers chemical engineers to optimize reaction conditions, enhance productivity, and ensure economic viability in sulfuric acid manufacturing and related processes.

In summary, the equilibrium constant $K_p=900$ at 800 K reflects a reaction strongly driven toward sulfur trioxide formation at standard conditions, offering valuable insights for both theoretical understanding and practical application in chemical industries.

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2so3 G Is 900 Atm1 At 800 K A Mixture Containing

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