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Understanding chemical equilibrium and the relationship between the equilibrium constants Kp and Kc is fundamental in chemistry, especially when analyzing gaseous reactions. The given reaction involves gases and a solid, with a known equilibrium constant Kp at a specific temperature. The core objective is to determine the value of Kc, the equilibrium constant expressed in terms of molar concentrations. This process involves understanding the concepts of partial pressures, mole ratios, and their interrelation through thermodynamic principles.

In this article, we will explore the principles behind equilibrium constants, delve into the relationship between Kp and Kc, and provide a step-by-step method to compute Kc from the given data. Additionally, we will discuss common pitfalls, assumptions, and the significance of these constants in chemical analysis.

Understanding Equilibrium Constants: Kp and Kc

Before tackling the specific problem, it's essential to grasp what Kp and Kc represent and how they are related.

What Is Kp?

Kp is the equilibrium constant expressed in terms of partial pressures of gaseous species. It is defined as:

$$K_p = \frac{(P_{c})^{\nu_c} (P_{d})^{\nu_d}}{(P_{a})^{\nu_a} (P_{b})^{\nu_b}}$$

where P_i are the partial pressures of gases and ν_i are the stoichiometric coefficients.

What Is Kc?

Kc is the equilibrium constant expressed in molar concentrations:

$$K_c = \frac{[C]^{\nu_c} [D]^{\nu_d}}{[A]^{\nu_a} [B]^{\nu_b}}$$

where [X] denotes molarity (mol/L).

The Relationship Between Kp and Kc

The two constants are related through the ideal gas law. The general relation is:

$$ K_p = K_c \times (RT)^{\Delta n} $$

where:
- $ R $ is the universal gas constant (8.314 J/(mol·K))
- $ T $ is the temperature in Kelvin
- $ \Delta n = (\text{moles of gaseous products}) - (\text{moles of gaseous reactants}) $

This relation allows us to convert between Kp and Kc, provided we know the temperature and the change in moles of gas.

Analyzing the Given Reaction

Let's restate the reaction:

$$ 2a (g) + 3b (g) \rightleftharpoons 4c (g) + 5d (s) $$

- Gaseous species: a, b, c
- Solid species: d

Given:
- $ K_p = 184 $ at 25°C (which is 298 K)
- Temperature: 25°C = 298 K

Our goal:
- Find $ K_c $

Step-by-Step Calculation of Kc

Step 1: Determine $ \Delta n $

The change in moles of gaseous species during the reaction:

$$\Delta n = (\text{moles of gases in products}) - (\text{moles of gases in reactants})$$

- Reactants: $2a + 3b$ → total moles of gases: $2 + 3 = 5$
- Products: $4c$ → total moles of gases: 4

Note: d is a solid; solids are omitted in equilibrium expressions involving partial pressures or concentrations.

Thus:

$$\Delta n = 4 - 5 = -1$$

Step 2: Use the relation between K_p and K_c

$$K_p = K_c \times (RT)^{\Delta n}$$

Rearranged:

$$K_c = \frac{K_p}{(RT)^{\Delta n}}$$

Given that $\Delta n = -1$:

$$K_c = \frac{K_p}{(RT)^{-1}} = K_p \times (RT)^{1}$$

Step 3: Calculate RT

Using $R = 8.314 \, \text{J/(mol·K)}$ and $T = 298\, \text{K}$:

$$RT = 8.314 \times 298 \approx 2478.7 \, \text{J/mol}$$

Step 4: Compute K_c

$$K_c = 184 \times 2478.7 \approx 456,855.8$$

So,

$$\boxed{
K_c \approx 4.57 \times 10^{5}
}$$

Interpretation and Significance

The calculated value of K_c indicates a highly favorable formation of products (c) at equilibrium under the given conditions. A large K_c (much greater than 1) suggests that, at equilibrium, the reaction heavily favors the formation of products.

The relationship between K_p and K_c provides insight into how pressure and concentration influence equilibrium. In this case, because the change in moles of gases is negative, increasing pressure would shift the equilibrium toward the reactants, whereas decreasing pressure favors products.

Additional Considerations and Assumptions

While the calculation above provides a straightforward approach, several assumptions underpin it:

- The ideal gas behavior: The gases involved behave ideally, which is a good approximation at standard conditions.
- Temperature constant: The reaction occurs at 25°C, and temperature effects are negligible outside this context.
- Solid activity: Solids like d are omitted in the equilibrium expression since their activity is constant and taken as 1.

Practical Applications of Kp and Kc Calculations

Understanding and calculating equilibrium constants are crucial in various fields:

- Chemical Manufacturing: Optimizing reaction conditions for maximum yield.
- Environmental Science: Modeling pollutant formation and removal.
- Pharmaceuticals: Designing reactions for drug synthesis.
- Research and Development: Determining reaction feasibility and pathways.

Conclusion

The calculation of K_c from K_p involves understanding the fundamental relationships between partial pressures, molar concentrations, and the change in moles of gases during a reaction. For the given reaction:

$$ 2a (g) + 3b (g) \rightleftharpoons 4c (g) + 5d (s) $$

with $K_p = 184$ at 25°C, the value of K_c is approximately 4.57×10^5. This high value indicates a reaction strongly favoring product formation under equilibrium conditions. Recognizing these relationships enables chemists to predict reaction behavior, optimize conditions, and interpret experimental data effectively.

References:

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Frequently Asked Questions

What is the given reaction and its equilibrium constant Kp?

The reaction is $2a(g) + 3b(g) \rightleftharpoons 4c(g) + 5d(s)$, with Kp = 184 at 25°C.

How is the equilibrium constant Kc related to Kp?

Kc and Kp are related by the equation $Kp = Kc(RT)^{\Delta n}$, where Δn is the change in moles of gas, R is the gas constant, and T is temperature in Kelvin.

What is the value of Δn for the given reaction?

Δn = moles of gaseous products - moles of gaseous reactants = (4) - (2 + 3) = 4 - 5 = -1.

What is the temperature in Kelvin for the reaction?

The temperature is 25°C, which is 298 K.

What is the value of R (gas constant) in appropriate units?

Using R = 0.0821 L·atm/(mol·K).

How do you calculate Kc from Kp for this reaction?

Use the relation $Kp = Kc(RT)^{\Delta n}$; rearranged as $Kc = Kp / (RT)^{\Delta n}$.

What is the calculation of $(RT)^{\Delta n}$ at 25°C?

Calculate $(RT)^{\Delta n} = (0.0821 \times 298)^{-1} \approx (24.45)^{-1} \approx 0.0409$.

What is the final value of Kc for the reaction at 25°C?

$Kc = 184 / 0.0409 \approx 4494.6$.

What is the significance of the calculated Kc value?

A high Kc (~4495) indicates the reaction favors the formation of products at equilibrium at 25°C.

Additional Resources

Consider The Following Reaction: 2a (g) 3b (g) 4c (g) 5d (s) Kp = 184 At 25. What Is The Value Of Kc?

In the realm of chemical equilibrium, understanding the relationship between different equilibrium constants is fundamental. The problem statement, "Consider the following reaction: 2a (g) + 3b (g) ⇌ 4c (g) + 5d (s) with Kp = 184 at 25°C," presents a classic scenario where the task involves calculating the equilibrium constant in terms of concentration, Kc, given the partial pressure-based constant, Kp. This problem exemplifies the critical nature of translating between different forms of equilibrium constants, a core concept in chemical thermodynamics and kinetics.

This article provides an in-depth analysis of this calculation, exploring the principles underpinning the relationship between Kp and Kc, examining the specific reaction details, and delineating the step-by-step methodology to derive Kc from Kp at 25°C. We will explore the theoretical background, assumptions, and potential pitfalls, culminating in a comprehensive understanding suitable for students, educators, and practicing chemists.

Understanding Equilibrium Constants: Kp and Kc

Before delving into calculations, it’s essential to clarify what Kp and Kc represent.

Definition of Kp

Kp is the equilibrium constant expressed in terms of partial pressures of gaseous reactants and products. It is defined as:

$$ K_p = \frac{\prod_{i} P_i^{\nu_i}} $$

where P_i is the partial pressure of species i, and ν_i is its stoichiometric coefficient (positive for products, negative for reactants).

Definition of Kc

Kc is the equilibrium constant expressed in terms of molar concentrations:

$$ K_c = \frac{\prod_{i} [C_i]^{\nu_i}} $$

where $[C_i]$ is the molar concentration of species i.

Relationship Between Kp and Kc

The two constants are related by the following key equation:

$$ K_p = K_c \times (RT)^{\Delta n} $$

where:

- R is the universal gas constant (8.314 J·mol^{-1}·K^{-1})
- T is the temperature in Kelvin
- Δn is the change in moles of gas during the reaction, calculated as:

$$ \Delta n = \sum \nu_{products} - \sum \nu_{reactants} $$

This relationship assumes ideal gas behavior and that the reaction occurs at constant temperature.

Analyzing the Given Reaction

The reaction provided is:

\[2a (g) + 3b (g) \rightleftharpoons 4c (g) + 5d (s) \]

Key points:
- The reaction involves gaseous reactants and products, with one solid species, \(d (s) \).
- The equilibrium constant \(K_p = 184 \) at 25°C (which is 298.15 K).

Calculating Δn

Since solids do not appear in the equilibrium expression in terms of pressure or concentration, their activities are considered to be unity and do not influence the equilibrium constant for the gas phase.

The change in moles of gas:

\[\Delta n = (4 + 0) - (2 + 3) = 4 - 5 = -1 \]

Note: The solid \(d \) is excluded from this calculation because activities of pure solids are taken as 1.

Calculating Kc from Kp: Step-by-Step

Given the relationship:

\[K_p = K_c \times (RT)^{\Delta n} \]

Rearranged to solve for \(K_c \):

\[K_c = \frac{K_p}{(RT)^{\Delta n}} \]

Step 1: Convert Temperature to Kelvin

\[T = 25°C = 25 + 273.15 = 298.15\, \text{K} \]

Step 2: Use the Gas Constant in Correct Units

Since \(R \) is in J·mol\(^{-1}\)·K\(^{-1}\), and pressure in atm or bar, ensure unit consistency. For calculations involving pressure in atmospheres, the ideal gas constant is:

$$R = 0.082057\, \text{L·atm·mol}^{-1}\text{·K}^{-1}$$

Step 3: Calculate $(RT)^{\Delta n}$

$$(RT)^{\Delta n} = (0.082057 \times 298.15)^{-1}$$

First, calculate RT:

$$RT = 0.082057 \times 298.15 \approx 24.45\, \text{L·atm·mol}^{-1}$$

Since $\Delta n = -1$:

$$(RT)^{\Delta n} = (24.45)^{-1} = \frac{1}{24.45} \approx 0.0409$$

Step 4: Compute K_c

$$K_c = \frac{K_p}{(RT)^{\Delta n}} = \frac{184}{0.0409} \approx 4492.9$$

Thus,

$$\boxed{K_c \approx 4.49 \times 10^{3}}$$

Implications and Assumptions

This calculation hinges on several assumptions that are standard in thermodynamic calculations:

- Ideal gas behavior: All gases behave ideally, which is reasonable at moderate pressures and temperatures.
- Pure solids activity: The activity of the solid d is unity and does not influence the equilibrium constant calculation.
- Constant temperature: The temperature is maintained at 25°C during the process.

Significance of the Result

The calculated K_c (~4.49×10^3) indicates a reaction that heavily favors the formation of products at equilibrium under the specified conditions. The magnitude of K_c suggests that, at equilibrium, the concentration of gaseous products c and reactants a, b will be significantly skewed toward the products, consistent with the high value of K_p.

Understanding the linkage between K_p and K_c allows chemists to predict concentrations in different contexts—pressure versus concentration—enabling more precise control in industrial processes, laboratory experiments, and theoretical modeling.

Broader Context and Applications

The ability to convert between different equilibrium constants is vital across various fields:

- Chemical engineering: Designing reactors where pressure and concentration conditions vary.
- Environmental chemistry: Modeling atmospheric reactions involving gases.
- Pharmaceuticals: Optimizing reaction conditions for synthesis.
- Academic research: Validating thermodynamic data and models.

Furthermore, the approach outlined here demonstrates a systematic methodology applicable to a broad spectrum of reactions involving gases, solid phases, and complex stoichiometries.

Conclusion

The calculation of Kc from Kp is a fundamental skill in thermodynamics, bridging the gap between pressure-based and concentration-based perspectives of equilibrium. For the reaction:

$$2a (g) + 3b (g) \rightleftharpoons 4c (g) + 5d (s)$$

with $Kp = 184$ at 25°C, the derived value of:

$$\boxed{K_c \approx 4.49 \times 10^3}$$

reflects a strong tendency toward product formation in the gaseous phase, reinforcing the importance of thermodynamic principles in predicting and controlling chemical behavior.

This example underscores the critical importance of understanding the relationship between different forms of equilibrium constants, enabling chemists and engineers to interpret and manipulate reactions under diverse conditions effectively.

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