

Under What Conditions Are The Values Of K_c And K_p For A Given Gas-phase Equilibrium The Same? A. If The

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Understanding the relationship between the equilibrium constants K_c and K_p is fundamental in chemical thermodynamics, especially when analyzing gaseous reactions. These constants provide insight into the extent of a chemical reaction at equilibrium, and knowing when they are equal simplifies calculations and interpretations. This article explores the specific conditions under which the values of K_c (equilibrium constant in terms of concentration) and K_p (equilibrium constant in terms of partial pressure) for a given gas-phase reaction are the same.

Introduction to Equilibrium Constants: K_c and K_p

Before delving into the conditions for equality, it is essential to understand what K_c and K_p represent and how they differ.

Definition of K_c

- The equilibrium constant K_c expresses the ratio of product concentrations to reactant concentrations, each raised to their stoichiometric powers, at equilibrium.
- Units are typically molarity (mol/L).
- For a general reaction:



$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

Definition of (K_p)

- The equilibrium constant (K_p) relates to the partial pressures of gases at equilibrium.
- For the same reaction as above:

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

where (P_i) is the partial pressure of species (i) .

Relationship Between (K_c) and (K_p)

The link between these two constants is established through the ideal gas law and the concept of reaction quotient.

Mathematical Relationship

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

Where:

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

$$\Delta n = \sum \text{moles of gaseous products} - \sum \text{moles of gaseous reactants}$$

This expression shows that (K_p) and (K_c) are directly related but generally differ unless specific conditions are met.

Conditions When $(K_c = K_p)$

The primary focus is on identifying the conditions where:

$$K_c = K_p$$

which simplifies the thermodynamic analysis of gas-phase reactions.

Key Condition: $(\Delta n = 0)$

- When the change in moles of gas during the reaction is zero $(\Delta n = 0)$, the relationship reduces to:

$$K_p = K_c \times (RT)^0 = K_c \times 1 = K_c$$

- Therefore, the fundamental condition for equality is:

The number of moles of gaseous reactants equals the number of moles of gaseous products.

Detailed Explanation of the Conditions

To understand why $(\Delta n = 0)$ leads to $(K_c = K_p)$, we need to analyze the thermodynamic principles and the mathematical derivation.

Role of the Change in Moles (Δn)

- (Δn) accounts for the change in the number of gas molecules, which affects the pressure-volume work and the partial pressures.

- When $(\Delta n \neq 0)$, the relationship between (K_c) and (K_p) involves the temperature and the gas constant, as seen in:

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

- If $(\Delta n > 0)$, then $(K_p > K_c)$ at a given temperature.

- Conversely, if $(\Delta n < 0)$, then $(K_p < K_c)$.

Implication of $(\Delta n = 0)$

- When $\Delta n = 0$, the expression simplifies to:

$$K_p = K_c$$

- This means the equilibrium constant in terms of pressure equals that in terms of concentration, regardless of temperature, provided the temperature remains constant.

Additional Conditions and Considerations

While the primary condition for $K_c = K_p$ is $\Delta n = 0$, some other factors may influence the relationship.

Temperature Independence

- The equality holds at a specific temperature, as both K_c and K_p are temperature-dependent.
- Changes in temperature can shift the equilibrium, affecting both constants.

Ideal Gas Behavior

- The derivation assumes gases behave ideally.
- Deviations from ideality can lead to discrepancies between K_c and K_p .

Reaction Stoichiometry and Gas Phases

- The reaction must involve only gaseous species, or at least the gaseous phase must be the dominant component influencing the equilibrium.

Practical Examples and Applications

Understanding when K_c equals K_p is vital in various industrial and laboratory processes.

Example 1: Homogeneous Gas Reactions with $\Delta n = 0$

- Consider the synthesis of ammonia:



- Moles of gaseous reactants: $1 + 3 = 4$
- Moles of gaseous products: 2
- $\Delta n = 2 - 4 = -2$
- Since $\Delta n \neq 0$, $K_p \neq K_c$.

Example 2: Reactions with $\Delta n = 0$

- Consider the following reaction:



- Reactants: 2 moles
- Products: 1 mole
- $\Delta n = 1 - 2 = -1$
- Again, $\Delta n \neq 0$, so $K_p \neq K_c$.
- Now, modify the reaction:



- Both sides have 1 mole of gas, so $\Delta n = 0$.
- In this case, $K_p = K_c$.

Summary and Key Takeaways

- The values of K_c and K_p for a given gas-phase equilibrium are equal when the reaction involves no net change in the number of moles of gas ($\Delta n = 0$).
- The relationship:

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

- When $(\Delta n = 0)$:

$$K_p = K_c$$

- This condition simplifies the thermodynamic analysis of gaseous reactions and is crucial for chemists working in industrial synthesis, environmental chemistry, and thermodynamic modeling.

Conclusion

Understanding the conditions under which (K_c) and (K_p) are equal enables chemists and chemical engineers to accurately interpret equilibrium data and optimize reaction conditions. The key takeaway is that the equality holds when the net change in moles of gaseous species during the reaction is zero $(\Delta n = 0)$. Recognizing this condition allows for easier calculations and better predictions of reaction behavior in gaseous systems, facilitating advancements in chemical manufacturing, environmental control, and research.

Meta Description: Discover the essential conditions under which the equilibrium constants (K_c) and (K_p) are equal for gas-phase reactions. Learn about the role of (Δn) , temperature, and ideal gas behavior in this comprehensive guide.

Frequently Asked Questions

Under what conditions are the values of K_c and K_p for a given gas-phase equilibrium the same? A. If the

reaction involves gases only and the temperature is constant, then K_c and K_p will be numerically equal when the ideal gas law applies without significant deviations.

Under what conditions are K_c and K_p equal for a gas-phase equilibrium? A. If the

reactants and products are all gases and the temperature remains constant, then K_c and K_p will have the same value.

When do K_c and K_p become equal in a gas-phase reaction? A. If the

reaction occurs at a constant temperature with gases only, then K_c equals K_p because the pressure-volume relationship remains consistent.

Under which scenario are the equilibrium constants K_c and K_p equal for a gaseous system? A. If the

reaction involves only gases and is measured at a fixed temperature, then K_c and K_p are numerically the same.

When are the values of K_c and K_p identical for a gas-phase equilibrium? A. If the

reaction is at constant temperature and involves only gases, then K_c and K_p will be equal because the ideal gas law relates concentration and pressure directly.

Under what specific conditions do K_c and K_p for a gas-phase equilibrium match? A. If the

reaction occurs at a fixed temperature with gases only, then the relationship between partial pressures and concentrations makes K_c equal to K_p .

Additional Resources

Under What Conditions Are The Values Of K_c And K_p For A Given Gas-phase Equilibrium The Same? A. If The

Understanding the relationship between K_c and K_p for a chemical equilibrium involving gases is fundamental in the field of chemical thermodynamics and reaction engineering. These equilibrium constants, while related, are defined differently and depend on various factors such as temperature, pressure, and the nature of the gases involved. Knowing under what conditions the values of K_c and K_p for a given gas-phase equilibrium are the same can significantly simplify calculations and deepen our understanding of reaction behavior. In this comprehensive guide, we will explore the definitions of K_c and K_p , their interrelation, the conditions under which they are equal, and practical implications for chemists and engineers.

Introduction to Equilibrium Constants: K_c and K_p

Before delving into the specific conditions that make K_c and K_p equal, it's essential to understand what these constants represent and how they are defined.

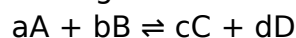
What is K_c ?

- K_c (Equilibrium Constant in terms of Concentration):

It is the ratio of the molar concentrations of products to reactants, each raised to the power of their respective coefficients in the balanced chemical equation, at equilibrium.

- Definition:

For a general reaction:



The equilibrium constant K_c is given by:

$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

- Units:

The units depend on the overall reaction and are often dimensionless when concentrations are expressed in molarity.

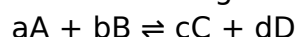
What is K_p ?

- K_p (Equilibrium Constant in terms of Partial Pressure):

It relates the partial pressures of gases at equilibrium, again raised to the power of their coefficients.

- Definition:

For the same general reaction:



The equilibrium constant K_p is:

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

- Units:

K_p is dimensionless if partial pressures are in atmospheres or other consistent units.

The Relationship Between K_c and K_p

The connection between K_c and K_p hinges on the ideal gas law and the reaction's stoichiometry, specifically the change in the number of moles of gases involved.

Fundamental Equation

The link between K_c and K_p is given by the equation:

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

where:

- R = ideal gas constant ($8.314 \text{ J mol}^{-1} \text{ K}^{-1}$)

- T = temperature in Kelvin

- Δn = change in moles of gases, calculated as:

$$\Delta n = (\text{sum of moles of gaseous products}) - (\text{sum of moles of gaseous reactants})$$

This equation indicates that K_p and K_c are equal when $\Delta n = 0$, provided the temperature remains constant.

When Are K_c and K_p Equal?

The Key Condition: $\Delta n = 0$

The most straightforward condition under which $K_c = K_p$ is when the change in the number of moles of gases (Δn) is zero.

In other words:

- For reactions where the total moles of gaseous reactants equal the total moles of gaseous products, K_c and K_p are equal at all temperatures.

Why Does Δn Matter?

Because the relation between K_p and K_c involves $(RT)^{\Delta n}$, if $\Delta n = 0$:

- $(RT)^0 = 1$
- Therefore, $K_p = K_c$

This simplifies calculations and interpretations in practical scenarios, especially in industrial chemical processes involving gases.

Additional Conditions and Considerations

While $\Delta n = 0$ is the primary condition, certain other factors influence the equivalence of K_c and K_p :

1. Temperature Independence

- Since the relation involves temperature explicitly, constant temperature is essential.
- Changes in temperature alter both K_c and K_p , but their equality at a specific temperature persists if $\Delta n = 0$.

2. Ideal Gas Behavior

- The relation assumes gases behave ideally.
- Deviations from ideality, especially at high pressures or low temperatures, can affect the relationship.

3. Pure Gases and Mixtures

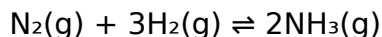
- The constants are defined for pure gases or ideal mixtures where partial pressures are proportional to molar quantities.

Practical Examples and Applications

Understanding the conditions where K_c and K_p are equal has real-world implications.

Example 1: Synthesis of Ammonia (Haber Process)

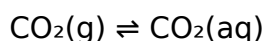
Reaction:



- $\Delta n = (2) - (1 + 3) = -2$
- Because $\Delta n \neq 0$, K_c and K_p are not equal, and their relationship involves $(RT)^{-2}$.

Example 2: Carbon Dioxide Dissolution

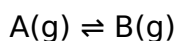
Reaction:



- No gaseous reactant or product on the product side, so $\Delta n = 1 - 0 = 1$, not zero.

Example 3: Isomerization Reactions

For certain isomerizations where the number of moles remains unchanged, such as:



- $\Delta n = 0 \rightarrow K_c = K_p$

Summary: The Conditions for K_c and K_p to be the Same

- Primary Condition:
 $\Delta n = 0$, meaning the total number of moles of gases does not change during the reaction.
- Additional Conditions:
 - Reaction occurs at constant temperature.
 - Gases behave ideally.
 - Measurements are taken under the same conditions (pressure, temperature).

Implications for Chemists and Engineers

Knowing when K_c and K_p are equal allows for:

- Simplification of calculations in gas reactions.
- Better prediction of reaction directions and yields.
- Easier control of industrial processes involving gases.

In practice:

- For reactions with $\Delta n = 0$, chemists can freely switch between concentration-based and

pressure-based equilibrium constants.

- For reactions with $\Delta n \neq 0$, adjustments involving $(RT)^{\Delta n}$ are necessary for conversions.

Final Thoughts

Understanding under what conditions the values of K_c and K_p for a given gas-phase equilibrium are the same is crucial in chemical thermodynamics. The key takeaway is that these constants are equal when the reaction involves no net change in moles of gases ($\Delta n=0$), at constant temperature, and assuming ideal gas behavior. Recognizing this simplifies many practical calculations and helps in designing efficient chemical processes. Whether you're a student, researcher, or engineer, grasping this fundamental concept enhances your ability to analyze and optimize gaseous reactions effectively.

References and Further Reading:

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