

Given The General Equation A + B → C A.) Write A Rate Law For A First Order Reaction. B.) Write A Rate

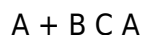
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Introduction

Understanding the kinetics of chemical reactions is fundamental in chemistry, especially when analyzing how reactions proceed and at what speed. The rate law describes the relationship between the reaction rate and the concentration of reactants, providing critical insights into the reaction mechanism. In this article, we will explore the process of deriving a rate law from a general equation, specifically focusing on first-order reactions. We will also examine how to write the rate expression based on given reaction conditions, enhancing your understanding of reaction kinetics.

The General Reaction Equation: A + B → C

Before diving into specific rate laws, let's understand the general reaction equation:



This notation indicates a reaction involving reactants A and B, and possibly other components such as C, leading to certain products. Although the notation may seem abstract, it serves as a foundation for deriving rate laws based on known or assumed mechanisms.

Part A: Writing a Rate Law for a First-Order Reaction

Understanding First-Order Reactions

A first-order reaction is characterized by a rate that depends linearly on the concentration of a single reactant. Such reactions follow the general form:

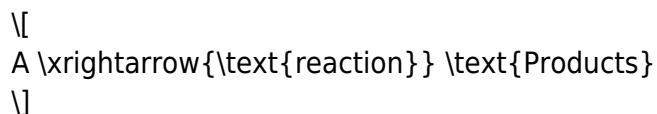
$$\text{Rate} = k [\text{Reactant}]$$

Where:

- k is the rate constant (units vary depending on order)
- $[\text{Reactant}]$ is the concentration of the reactant

Deriving the Rate Law from the General Equation

Suppose the reaction involving A follows a simple mechanism where A undergoes transformation in a single elementary step. For a first-order process:



The rate law is:

$$\boxed{\text{Rate} = k [\text{A}]}$$

This indicates that the rate is directly proportional to the concentration of A.

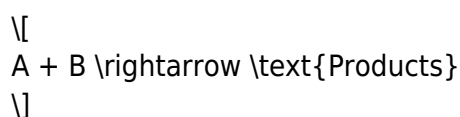
Assumptions for First-Order Rate Laws

- The reaction occurs via a single elementary step.
- The concentration of other reactants remains constant or their effect is incorporated into the rate constant.
- The reaction mechanism is straightforward, with no complex intermediates affecting the overall rate.

Part B: Writing a Rate Expression Based on the General Equation

Formulating the Rate Law

Given a reaction involving multiple reactants, the rate law can be written based on the overall reaction mechanism. For example:



The general rate law could be expressed as:

$$\text{Rate} = k [\text{A}]^m [\text{B}]^n$$

where:

- (m, n) are the reaction orders with respect to A and B, respectively
- (k) is the rate constant

Determining the Reaction Order

Reaction orders are typically determined experimentally through methods such as:

- Initial rate method
- Concentration variation experiments
- Integrated rate laws

Example: First-Order Reaction Rate Expression

If the reaction is known to be first order with respect to A and zero order with respect to B, the rate law simplifies to:

$$\boxed{\text{Rate} = k [A]}$$

Alternatively, if the reaction involves the complex equation $A + B \rightleftharpoons C$, and assuming the rate depends only on A's concentration, the rate law remains:

$$\text{Rate} = k [A]$$

Practical Steps to Write the Rate Law

1. Identify the reaction mechanism: Determine the elementary steps involved.
2. Determine the rate-determining step: The slowest step influences the overall rate.
3. Express the rate law based on the slow step: Use the molecularity of the step to write the rate.
4. Include concentrations of reactants involved in the rate-determining step: Adjust exponents based on reaction order.

Additional Considerations in Reaction Kinetics

Factors Affecting Reaction Rates

- Temperature: Increasing temperature generally increases reaction rate (Arrhenius equation).
- Catalysts: Catalysts alter the mechanism, often increasing the rate without being consumed.
- Concentration of Reactants: Higher concentrations typically increase the rate for reactions where reactant concentration influences the rate law.
- Surface Area: For heterogeneous reactions, larger surface areas accelerate reactions.

Experimental Determination of Rate Laws

- Method of Initial Rates: Measure initial reaction rates at different concentrations.
- Integrated Rate Laws: Use concentration vs. time data to determine reaction order.
- Half-life Analysis: Useful for first-order reactions, where half-life is independent of initial concentration.

Summary and Key Takeaways

- The general equation $A + B \rightarrow C + D$ serves as a basis for understanding complex reactions, but the rate law depends on the reaction mechanism.
- First-order reactions are characterized by a rate proportional to a single reactant's concentration, expressed as $\text{Rate} = k[A]$.
- Writing the rate law involves understanding the mechanism, identifying the rate-determining step, and determining the reaction order experimentally.
- Complex reactions may involve multiple reactants and steps, with the overall rate law being a product of individual contributions.
- Experimental methods are crucial for accurately determining reaction orders and rate constants.

Conclusion

Mastering the derivation and application of rate laws is essential for analyzing chemical kinetics comprehensively. Whether dealing with simple first-order reactions or complex mechanisms, understanding how to write and interpret rate laws enables chemists to predict reaction behavior, optimize conditions, and develop new reactions. Always consider the reaction mechanism, experimental data, and the influence of various factors when working with reaction kinetics.

References

- Atkins, P., & de Paula, J. (2014). Physical Chemistry (10th ed.). Oxford University Press.
- Laidler, K. J. (1987). Chemical Kinetics (3rd ed.). Harper & Row.
- House, J. E. (2007). Principles of Chemical Kinetics. Dover Publications.

Note: The concepts discussed can be extended to reactions of higher orders and more complex mechanisms, providing a solid foundation for advanced study in chemical kinetics.

Frequently Asked Questions

What is the general form of the rate law for a first-order reaction?

The rate law for a first-order reaction is expressed as $\text{Rate} = k[A]$, where k is the rate constant and $[A]$ is the concentration of reactant A.

How do you determine the rate constant (k) for a first-order

reaction?

The rate constant k can be determined from the slope of a plot of $\ln[A]$ versus time or using the half-life formula $t_{1/2} = 0.693 / k$.

What does the term 'rate law' signify in chemical kinetics?

The rate law expresses how the rate of a reaction depends on the concentration(s) of reactant(s) and the rate constant, providing insight into the reaction mechanism.

In the context of the general equation $A + B \rightarrow C$, how is the overall rate law typically expressed?

The overall rate law depends on the rate-determining step but is often expressed as $\text{Rate} = k[A]^m[B]^n$, where m and n are the reaction orders with respect to A and B .

What is the significance of reaction order in rate laws?

Reaction order indicates how the rate is affected by changes in reactant concentrations, helping to elucidate the reaction mechanism.

Can the rate law be determined experimentally for a reaction like $A + B \rightarrow C$?

Yes, the rate law is typically determined experimentally by measuring initial reaction rates at various concentrations of A and B .

What is the relation between the rate constant k and the reaction order?

The rate constant k 's units depend on the overall order of the reaction; for a first-order reaction, k has units of s^{-1} , while for higher orders, units vary accordingly.

Why is it important to write a rate law for a reaction?

Writing the rate law helps predict how changes in concentration affect the reaction rate and aids in understanding the reaction mechanism and designing chemical processes.

How does the rate law change for a reaction that is not first order?

For reactions that are second order or higher, the rate law includes higher powers of concentration, e.g., $\text{Rate} = k[A]^2$ or $\text{Rate} = k[A][B]$, reflecting different dependencies.

Additional Resources

Given The General Equation $A + B \rightarrow C$ A.) Write A Rate Law For A First Order Reaction. B.) Write A Rate

In the realm of chemical kinetics, understanding how reactant concentrations influence the rate at which reactions proceed is fundamental. The formulation of rate laws serves as a bridge connecting the observable reaction rates with the underlying molecular dynamics. Today, we'll delve into a specific scenario: starting from a general chemical equation, how can we derive a rate law assuming a first-order reaction? Furthermore, how do we express the reaction rate explicitly? These questions are essential for chemists aiming to predict reaction behavior, optimize conditions, or develop new chemical processes.

This article provides a comprehensive, reader-friendly exploration of these topics. We will examine the principles behind rate laws, walk through the derivation process from the given general equation, and clarify how to write the rate expression. Whether you're a student, a researcher, or an enthusiast, this guide aims to clarify complex concepts with clarity and depth.

Understanding the Foundations: What Is a Rate Law?

Before diving into the derivation, it's crucial to understand what a rate law is and why it matters.

Definition of a Rate Law

A rate law expresses the relationship between the rate of a chemical reaction and the concentrations of reactants (and sometimes products) involved. It typically has the form:

$$\text{Rate} = k [A]^m [B]^n \dots$$

where:

- k is the rate constant, specific to a particular reaction at a given temperature.
- $[A]$, $[B]$, ... are the molar concentrations of reactants.
- m , n , ... are the reaction orders with respect to each reactant, indicating how the rate depends on concentration.

The overall order of the reaction is the sum of individual orders: $m + n + \dots$

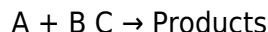
Importance of Rate Laws

Rate laws are pivotal because they:

- Enable prediction of reaction rate under different conditions.
- Help determine the mechanism of the reaction.
- Allow calculation of the rate constant, which is essential for scaling up reactions in industrial processes.
- Provide insight into how changes in concentration or temperature influence the reaction.

From the General Equation to the Rate Law: The Starting Point

Suppose we're given a general chemical equation involving reactants A, B, and C. The form of the general equation might be:



This notation indicates:

- Reactant A reacts with B and C.
- The reaction may involve multiple steps or a complex mechanism.

However, to develop a rate law, we need more specific information about the reaction order and mechanism. Let's assume, based on experimental data or theoretical considerations, that the overall reaction is first order with respect to A.

What Does First-Order Mean?

A first-order reaction with respect to A implies that the rate of the reaction depends linearly on the concentration of A:

$$\text{Rate} \propto [A]^1$$

This relationship indicates that doubling [A] will double the reaction rate, assuming other conditions remain the same.

Assumptions for Derivation

- The reaction is elementary or the rate-determining step involves only A.
- The concentrations of B and C are either constant (e.g., in excess) or their influence is incorporated into the rate constant.
- The temperature remains constant, and the reaction follows the basic principles of kinetics.

With these assumptions, we can now proceed to derive the specific rate law.

Part A: Writing the Rate Law for a First-Order Reaction

Given the general reaction and the assumption of first-order dependence on A, the rate law simplifies to a manageable form.

Deriving the Rate Law

1. Identify the Reactant of Interest: Since the reaction is first order in A, the rate law must include [A] to the first power.

2. Incorporate Other Reactants: If B and C are involved but are present in large excess or their influence is captured in the rate constant, they might not appear explicitly in the rate law. Alternatively, if B and C influence the rate, their concentrations must be included.

3. Express the Rate Law:

- Case 1 (A is the sole reactant controlling the rate):

$$\text{Rate} = k [A]$$

- Case 2 (A, B, and C all influence the rate):

$$\text{Rate} = k [A]^m [B]^n [C]^p$$

Since the focus is on a first-order reaction with respect to A, and if B and C are either in excess or their effects are ignored for simplicity, the rate law reduces to:

$$\text{Rate} = k [A]$$

This simple form allows for straightforward calculations and predictions.

Summary of the Rate Law for a First-Order Reaction

- The rate is directly proportional to the concentration of A.
- The rate constant, k , encapsulates the influence of temperature and other factors.
- The order with respect to A is 1 by definition.

Part B: Writing the Rate Expression

The second part of the question asks explicitly for the rate expression. Based on the above derivation:

$$\text{Rate} = k [A]$$

This formula succinctly captures the kinetics of the reaction, provided the assumptions hold true.

Expanding the Concept: How to Determine the Rate Law Experimentally

In real-world scenarios, chemists often determine the rate law experimentally rather than assuming it. Here's how they typically proceed:

Experimental Approach to Determine Reaction Order

- Vary the concentration of A: Keep other concentrations constant and measure the initial reaction

rate.

- Plot the data: Use methods such as:
- Initial rate method: Plotting rate vs. [A] on a log-log scale to determine the order.
- Integrated rate laws: Comparing concentrations over time to theoretical models.
- Determine the order: The slope of the $\log(\text{rate})$ vs. $\log([A])$ plot indicates the order with respect to A.

Role of Temperature and Rate Constant

The rate constant, k , depends on temperature via the Arrhenius equation:

$$k = A e^{(-E_a/RT)}$$

where:

- A is the frequency factor,
- E_a is the activation energy,
- R is the gas constant,
- T is the temperature in Kelvin.

Understanding this relationship helps in predicting how the rate changes with temperature.

Practical Implications and Applications

Understanding the rate law and the rate expression isn't merely academic; it has tangible applications across various industries and research domains.

Industrial Synthesis

Manufacturers optimize reaction conditions—concentration, temperature, catalysts—based on knowledge of the rate law to maximize yield and efficiency.

Pharmaceutical Development

Drug stability and shelf-life depend on kinetic data, including the reaction order and rate constants.

Environmental Chemistry

Pollution control relies on understanding how pollutants degrade over time, which involves rate laws.

Conclusion: From General Equations to Predictive Power

Deriving a rate law from a general chemical equation, especially under the assumption of a first-order

reaction, provides valuable insights into reaction dynamics. By focusing on the dependence of the reaction rate on the concentration of reactants, chemists can predict how reactions proceed under varying conditions. The explicit rate expression, $\text{Rate} = k [A]$, exemplifies the elegance and utility of kinetic principles.

Understanding these concepts enhances our ability to design, control, and optimize chemical processes across scientific and industrial landscapes. As with all scientific tools, experimental validation remains key, but the theoretical framework offers a solid foundation for further exploration and application.

Whether you're analyzing a simple laboratory reaction or designing complex industrial syntheses, mastering the derivation and application of rate laws remains an essential skill in the chemist's toolkit.

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