In A First Order Decomposition In Which The Rate Constant Is 0.0620sec1, How Long Will It Take (in Minutes)

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Understanding reaction kinetics is fundamental to chemistry, especially when predicting how long a chemical process will take under certain conditions. When dealing with first-order decomposition reactions, the rate constant (k) plays a crucial role in determining the reaction's duration. In this article, we explore how to calculate the time required for a first-order decomposition, given a rate constant of 0.0620 sec1. We will break down the concepts involved, provide step-by-step calculations, and illustrate how to convert the time from seconds to minutes for practical understanding.

Basics of First-Order Reactions

What Is a First-Order Reaction?

A first-order reaction is a type of kinetic process where the rate of reaction depends linearly on the concentration of a single reactant. The general form is:

- Rate = k [A]

where:

- k = rate constant (units: sec_{-1})
- [A] = concentration of reactant A

Integrated Rate Law for First-Order Reactions

The key to calculating reaction times is the integrated rate law:

- **$\ln([A]_0 / [A]) = kt$**

where:

- $[A]_0$ = initial concentration
- [A] = concentration at time t

- k = rate constant
- t = time elapsed

When the goal is to find out how long it takes for a certain fraction of the reactant to decompose, this law is invaluable.

Calculating the Time for a First-Order Decomposition

Determining Reaction Time Based on Concentration

Suppose we are interested in calculating how long it takes for a certain percentage of the reactant to decompose. For example, if 99% of the reactant has decomposed, the remaining concentration is 1% of the initial concentration.

The general steps are:

1. Identify the initial concentration, $[A]_0$.
2. Determine the remaining concentration, $[A]$.
3. Use the integrated rate law to solve for t.

Case Study: 99% Decomposition

Let's consider a scenario where 99% of the reactant decomposes, leaving only 1% remaining:

- $[A] = 0.01\ [A]_0$

Applying the integrated rate law:

- $\ln([A]_0 / [A]) = kt$
- $\ln([A]_0 / 0.01\ [A]_0) = kt$
- $\ln(1 / 0.01) = kt$
- $\ln(100) = kt$

Calculating:

- $\ln(100) \approx 4.6052$

Given:

- $k = 0.0620\ sec^{-1}$

We can now solve for t:

- $t = \ln(100) / k = 4.6052 / 0.0620 \approx 74.24$ seconds

Therefore, it takes approximately 74.24 seconds for 99% of the reactant to decompose.

Converting Seconds to Minutes

Why Convert Seconds to Minutes?

In practical applications, especially in industrial or laboratory settings, expressing time in minutes is often more intuitive than seconds. To convert seconds to minutes, simply divide by 60:

- t (minutes) = t (seconds) / 60

Applying this to our previous result:

- 74.24 seconds / 60 ≈ 1.237 minutes

Hence, it will take approximately 1.24 minutes for 99% decomposition at a rate constant of 0.0620 sec-1.

General Formula for Reaction Time in First-Order Reactions

Time for a Specific Fraction to React

If you want to find the time for a certain fraction of reactant to decompose (say, x%), use:

- **$t = (1/k) \ln([A]_0 / [A])$**

Given the percentage remaining:

- $[A] = (\text{remaining fraction}) [A]_0$

Thus, the formula becomes:

- $t = (1/k) \ln(1 / \text{remaining fraction})$

Example: For 90% decomposition (remaining 10%)

- remaining fraction = 0.10
- $t = (1/0.0620) \ln(1/0.10) \approx 16.13\ 2.3026 \approx 37.14$ seconds
- In minutes: $37.14 / 60 \approx 0.62$ minutes

This approach can be used for any percentage of decomposition.

Practical Applications of Decomposition Time Calculations

Industrial Processes

In manufacturing, understanding how long a decomposition process takes helps in designing reactors and ensuring safety. For instance, in the production of pharmaceuticals or polymers, precise timing ensures product quality.

Environmental Chemistry

Predicting the breakdown time of pollutants or hazardous chemicals in the environment relies on these calculations, informing cleanup strategies and safety protocols.

Laboratory Experiments

Chemists often need to determine reaction durations for experiments involving decomposition or decay, ensuring accurate timing for observations and data collection.

Summary and Key Takeaways

- First-order reactions follow the integrated rate law: $\ln([A]_0 / [A]) = kt$.
- Given a rate constant (k), you can calculate the time (t) for a particular degree of decomposition using: $t = (1/k) \ln([A]_0 / [A])$.
- For 99% decomposition, the time is approximately 74.24 seconds or about 1.24 minutes when $k = 0.0620\ sec^{-1}$.
- The same principles apply for other percentages, with the formula t = (1/k) ln(1 / remaining fraction).
- Converting seconds to minutes makes these calculations more accessible for practical purposes.

By mastering these calculations, chemists and engineers can effectively predict reaction durations and optimize processes involving first-order decompositions.

Final Thoughts

Understanding reaction kinetics and the role of the rate constant is essential for controlling and predicting chemical processes. Whether for safety, efficiency, or environmental reasons, being able to determine how long a reaction will take based on the rate constant is invaluable. With a rate constant of 0.0620 sec-1, it takes approximately 1.24 minutes for 99% of a first-order reactant to decompose, providing a clear example of how kinetic data translates into practical timing estimates.

Always remember: Precise calculations depend on initial conditions and the specific extent of reaction you are interested in. Adjust the equations accordingly, and you'll be well-equipped to analyze similar kinetic problems.

Frequently Asked Questions

What is the general formula for first-order

decomposition kinetics?

The rate law for first-order decomposition is expressed as $\ln([A]_0/[A]) = kt$, where $[A]_0$ is the initial concentration, [A] is the concentration at time t, and k is the rate constant.

How do you calculate the time required for a first-order reaction to decompose a certain amount?

Use the formula $t = (1/k) \ln([A]_0/[A])$ to find the time, where k is the rate constant and $[A]_0$ and [A] are the initial and remaining concentrations.

Given a rate constant of 0.0620 sec^{-1}, how long will it take for 50% of the substance to decompose?

For 50% decomposition, $[A] = 0.5\ [A]_0$. Then, $t = (1/0.0620) \ln(2) \approx 11.18$ seconds, which is approximately 0.186 minutes.

How long does it take for 90% decomposition at a rate constant of 0.0620 sec^{-1}?

For 90% decomposition, $[A] = 0.1\ [A]_0$. Therefore, $t = (1/0.0620) \ln(10) \approx 36.86$ seconds, or about 0.615 minutes.

What is the time required for complete decomposition in a first-order reaction with a rate constant of 0.0620 sec^{-1}?

Theoretically, complete decomposition takes infinite time. Practically, it is considered complete after about 5 half-lives, which is $t_{1/2} = 0.693 / 0.0620 \approx 11.17$ seconds.

How do I convert the reaction time from seconds to minutes for this rate constant?

Divide the time in seconds by 60 to convert it to minutes. For example, 11.18 seconds is $11.18 / 60 \approx 0.186$ minutes.

If the initial concentration is known, how can I determine the time for a specific percentage of decomposition using the rate constant 0.0620 sec^{-1}?

Use $t = (1/k) \ln([A]_0/[A])$ where [A] is the concentration after the desired decomposition percentage. For example, for 75% decomposition, $[A] = 0.25\ [A]_0$, so $t = (1/0.0620) \ln(1/0.25) \approx 17.72$ seconds or approximately 0.295 minutes.

Additional Resources

Understanding First-Order Decomposition and Its Significance in Chemical Kinetics

Chemical reactions are the cornerstone of countless processes in nature and industry, from metabolic pathways in biology to manufacturing of pharmaceuticals and materials. Among various types of reactions, first-order decomposition reactions are especially fundamental due to their simplicity and widespread occurrence. Understanding how long such reactions take under specific conditions is essential for designing safe, efficient, and predictable chemical processes. This review delves into the detailed calculation of reaction time in a first-order decomposition with a given rate constant, specifically focusing on how to determine the duration necessary for a specified degree of decomposition.

Fundamentals of First-Order Reactions

Definition and Characteristics

A first-order reaction is characterized by a rate that depends linearly on the concentration of a single reactant:

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

where:
- k is the rate constant (units: sec^{-1})
- $[A]$ is the concentration of reactant A

Key features:
- The reaction rate decreases exponentially over time as the reactant is consumed.
- The integrated rate law is straightforward:

$$ [A](t) = [A]_0 e^{-kt} $$

where:
- $[A]_0$ is the initial concentration at $t=0$
- t is time elapsed

Decomposition Reactions

Decomposition reactions involve the breakdown of a compound into simpler substances, often via thermal, catalytic, or chemical means. When such a reaction follows first-order kinetics, the rate at which the original compound diminishes is directly proportional to its current concentration.

Determining the Time for a Given Degree of Decomposition

Problem Restatement

Given:
- Rate constant, $k = 0.0620$ sec^{-1}
- The goal: Find the time required for a certain percentage of the reactant to decompose, expressed in minutes.

To proceed, we need to specify the extent of decomposition, which is usually expressed as a fraction or percentage of the original amount remaining or reacted.

Understanding the Relationship Between Time and Concentration

The integrated first-order rate law relates the initial concentration, the concentration at time t, and the rate constant:

$$ [A](t) = [A]_0 e^{-kt} $$

Alternatively, for decomposition, the fraction remaining (f) or fraction reacted (r) is more convenient:
- Fraction remaining: $f = \frac{[A](t)}{[A]_0}$
- Fraction reacted: $1 - f$

Expressed as:

$$ f = e^{-kt} $$

or equivalently:

$$ t = -\frac{1}{k} \ln f $$

This formula allows calculation of the reaction time for any desired extent of decomposition, given the rate constant.

Calculating Time for Specific Decomposition Extents

Example 1: 50% Decomposition

Suppose we want to determine the time it takes for 50% of the reactant to decompose:

- Fraction remaining, $f = 0.5$

Applying the formula:

$$ t = -\frac{1}{k} \ln 0.5 $$

$$ t = -\frac{1}{0.0620} \times (-0.6931) $$ (since $\ln 0.5 \approx -0.6931$)

$$ t \approx \frac{0.6931}{0.0620} $$

$$ t \approx 11.17\, \text{seconds} $$

To convert seconds to minutes:

$$ t \approx \frac{11.17}{60} \approx 0.186\, \text{minutes} $$

Thus, it takes approximately 0.186 minutes (or about 11 seconds) for 50% of the reactant to decompose.

Example 2: 90% Decomposition

For 90% decomposition, the fraction remaining:

$$ f = 0.10 $$

Applying the same formula:

$$ t = -\frac{1}{0.0620} \ln 0.10 $$

$$ t \approx \frac{2.3026}{0.0620} $$

$$ t \approx 37.16\, \text{seconds} $$

In minutes:

$$ t \approx \frac{37.16}{60} \approx 0.619\, \text{minutes} $$

Hence, about 0.62 minutes (roughly 37 seconds) are needed for 90% decomposition.

General Formula and Its Application

The general approach to determine the time for any degree of decomposition involves:

$$ t = -\frac{1}{k} \ln f $$

where:
- f = fraction remaining (from 1 for no reaction to 0 for complete reaction)
- k = rate constant (in sec^{-1})
- t = time in seconds

Once the value of t is obtained in seconds, converting to minutes involves dividing by 60.

Impact of Rate Constant on Reaction Time

The rate constant k fundamentally influences how quickly a reaction proceeds:

- Higher k: Faster reaction; less time needed for a given extent of decomposition.
- Lower k: Slower reaction; more time is required.

In this particular case, with $k = 0.0620\, \text{sec}^{-1}$, the reaction is relatively rapid; for example, half of the reactant decomposes in approximately 11 seconds.

Implication: Small changes in k can significantly affect reaction times, especially for reactions near complete decomposition.

Practical Considerations and Applications

Industrial and Laboratory Settings

Knowing how long a reaction takes to reach a certain extent of decomposition is vital in:

- Designing reactors: Ensuring sufficient residence time.
- Safety protocols: Preventing accumulation of unstable intermediates.

- Process optimization: Balancing reaction speed with energy and resource consumption.

Example Applications:

- Pharmaceutical stability testing: Assessing how long a drug decomposes under certain conditions.
- Thermal decomposition of materials: Determining processing times for materials subjected to high temperatures.
- Food preservation: Estimating spoilage times based on reaction kinetics.

Advanced Topics and Considerations

Temperature Dependence of k

- The rate constant k is highly temperature-dependent, following the Arrhenius equation:

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

where:
- A = frequency factor
- E_a = activation energy
- R = universal gas constant
- T = temperature in Kelvin

- An increase in temperature exponentially increases k, shortening the reaction time.

Reaction Conditions and Their Effects

- Pressure: Can influence reaction kinetics if gaseous reactants or products are involved.
- Catalysts: Can lower activation energy, increasing k.
- Solvent effects: Can alter reaction pathways and rates.

Limitations of First-Order Assumption

- Real reactions may deviate from ideal first-order kinetics due to:
- Reversibility
- Side reactions
- Changes in reaction conditions over time

- When deviations occur, more complex kinetic models are necessary.

Summary and Key Takeaways

- The rate constant $k=0.0620\, \text{sec}^{-1}$ indicates a relatively fast first-order decomposition reaction.
- The time t for a specific fraction of the reactant to decompose is calculated using:

$$t = -\frac{1}{k} \ln f$$

- For common decomposition extents:
- 50% decomposition: approximately 11 seconds (~0.186 minutes).
- 90% decomposition: approximately 37 seconds (~0.62 minutes).

- Understanding these times is crucial for process control, safety, and efficiency.

- The reaction time is inversely proportional to the rate constant; small increases in k significantly reduce the required reaction time.

- Temperature and other reaction conditions can drastically modify the rate constant, and thus, the reaction time.

Conclusion

Calculating the duration of a first-order decomposition process with a known rate constant is straightforward once the extent of decomposition is specified. The key is understanding the exponential nature of first-order kinetics, applying the integrated rate law, and performing the necessary logarithmic calculations. With $k=0.0620\, \text{sec}^{-1}$, the reaction proceeds rapidly, reaching significant decomposition levels within seconds. This knowledge enables chemists and engineers to design processes with precision, ensuring optimal reaction times, safety, and product quality. Whether for laboratory experiments or industrial operations, mastery of these calculations is fundamental to effective chemical management and innovation.

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