Reaction Order 2

The reaction order is the relationship between the concentrations of species and the rate of a reaction.

Introduction

Once the rate law of a reaction has been determined, that same law can be used to understand more fully the composition of the reaction mixture. More specifically, the reaction order is the exponent to which the concentration of that species is raised, and it indicates to what extent the concentration of a species affects the rate of a reaction, as well as which species has the greatest effect.

Relation to Rate Law

For the reaction:

\[ aA + bB \rightarrow P \]

The rate law is as follows:

\[ \text{rate} = k[A]^x[B]^y \]

where

- \([A]\) is the concentration of species A,
- \(x\) is the order with respect to species A,
- \([B]\) is the concentration of species B,
- \(y\) is the order with respect to species B
- \(k\) is the rate constant.
- \(n\) is the reaction order for the whole chemical reaction. This can be found by adding the reaction orders with respect to the reactants. In this case, \(n = x + y\).
Simple Rules

The order of a reaction is not necessarily an integer. The following orders are possible:

- Zero: A zero order indicates that the concentration of that species does not affect the rate of a reaction
- Negative integer: A negative order indicates that the concentration of that species INVERSELY affects the rate of a reaction
- Positive integer: A positive order indicates that the concentration of that species DIRECTLY affects the rate of a reaction
- Non-integer: Non-integer orders, both positive and negative, represent more intricate relationships between concentrations and rate in more complex reactions.

Methods to Determining Reaction Order

For chemical reactions that require only one elementary step, the values of \( x \) and \( y \) are equal to the stoichiometric coefficients of each reactant. For chemical reactions that require more than one elementary step, this is not always the case. However, there are many simple ways of determining the order of a reaction. One very popular method is known as the differential method.

The Differential Method

The differential method, also known as the initial rates method, uses an experimental data table to determine the order of a reaction with respect to the reactants used. Below is an example of a table corresponding with the following chemical reaction:

\[
A + B \longrightarrow P
\]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>[A] M</th>
<th>[B] M</th>
<th>Rate M Min(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.100</td>
<td>0.100</td>
<td>1.0 x 10(^{-3})</td>
</tr>
<tr>
<td>2</td>
<td>0.200</td>
<td>0.100</td>
<td>1.0 X 10(^{-3})</td>
</tr>
<tr>
<td>3</td>
<td>0.100</td>
<td>0.200</td>
<td>2.0 x 10(^{-3})</td>
</tr>
</tbody>
</table>

When looking at the experiments in the table above, it is important to note factors that change between experiments. In order to determine the reaction order with respect to \( A \), one must note in which experiment \( A \) is changing; that is, between experiments 1 and 2. Write a rate law equation based on the chemical reaction above.

This is the rate law:

\[
\text{rate} = k[A]^x[B]^y
\]
Next, the rate law equation from experiment 2 must be divided by the rate law equation for experiment 1. Notice that the $[B]^y$ term cancels out, leaving "$x$" as the unknown variable. Simple algebra reveals that $x = 0$.

The same steps must be taken for determining the reaction order with respect to $B$. However, in this case experiments 1 and 3 are used. After working through the problem and canceling out $[A]^x$ from the equation, $y = 1$.

Finding the reaction order for the whole process is the easy addition of $x$ and $y$: $n = 0 + 1$. Therefore, $n = 1$.

After finding the reaction order, several pieces of information can be obtained, such as half-life.

**Other methods**

Other methods that can be used to solve for reaction order include the integration method, the half-life method, and the isolation method.

**Problems**

1. Define "reaction order."

Use the following information to solve questions 2 and 3:

Given the rate law equation:

$$ \text{rate} = k[A]^1[B]^2 $$

2. Determine: a) the reaction order with respect to $A$, b) the reaction order with respect to $B$, and c) the total reaction order for the equation.

3. Assuming the reaction occurs in one elementary step, propose a chemical equation using P as the symbol for your product.

Use the data table below to answer questions 4 and 5:

Use the data table below to answer questions 4 and 5:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>[A] M</th>
<th>[B] M</th>
<th>Rate M Min(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.100</td>
<td>0.100</td>
<td>$1.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>2</td>
<td>0.400</td>
<td>0.100</td>
<td>$2.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>3</td>
<td>0.100</td>
<td>0.150</td>
<td>$2.0 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
4. Use the differential method to determine the reaction order with respect to A (x) and B (y). What is the total reaction order (n)?

5. What is the rate constant, k?

---

**Answers**

1. The relationship between the concentrations of species and the rate of a reaction
2. a) x = 1, b) y = 2, and c) n = 3
3. \( \text{A + 2B} \rightarrow \text{P} \)
4. x = 0.5 and y = 1.7. n = 2.2
5. k = 0.10 M min\(^{-1}\)

---

**References**


---

**Contributors**

- Sevini Shahbaz, Andrew Iskandar (University of California, Davis)