The rate of a chemical reaction is the *change* in concentration over the *change* in time.

**Introduction**

The rate of a chemical reaction is the *change* in concentration over the *change* in time and is a metric of the "speed" at which a chemical reactions occurs and can be defined in terms of two observables:

1. The Rate of Disappearance of Reactants \(-\frac{\Delta [\text{Reactants}]}{\Delta t}\) Note this is negative because it measures the rate of disappearance of the reactants.
2. The Rate of Formation of Products \(\frac{\Delta [\text{Products}]}{\Delta t}\) This is the rate at which the products are formed.

They both are linked via the balanced chemical reactions and can both be used to measure the reaction rate.

**Example**

For example, in the simple reaction \(A + B \rightarrow C + D\) The reaction rate can be defined thusly:

- rate of disappearance of A \(\frac{\text{rate}}{\Delta t} = \frac{\Delta [A]}{\Delta t}\)
- rate of disappearance of B \(\frac{\text{rate}}{\Delta t} = \frac{\Delta [B]}{\Delta t}\)
- rate of formation of C \(\frac{\text{rate}}{\Delta t} = \frac{\Delta [C]}{\Delta t}\)
- rate of formation of D \(\frac{\text{rate}}{\Delta t} = \frac{\Delta [D]}{\Delta t}\)

There are many factors that can either slow or speed up the rate of a chemical reaction such as temperature, pressure, concentration, and catalysts. The Rate of a Chemical Reaction is *always positive*. It can be confusing since the Rate of Disappearance is negative, however when you think about it, a rate should never be negative since the rate is describing how fast the concentration changes with time. The units for the rate is **Molarity per Seconds (M/s)**.

**Reaction Rates from Non-unity Stoichiometric Coefficients**

It does not matter whether an experimenter monitors the reagents or products. However, since reagents *decrease* during reaction, and products *increase*, there is a sign difference between the two rates. Reagent concentration decreases as the reaction proceeds, giving a negative number for the change in concentration. The products, on the other hand, increase concentration with time, giving a positive number. *Since the convention is to express the rate of reaction as a positive number*, to solve a problem, set the overall rate of the reaction equal to the *negative* of a reagent's disappearing rate.

The overall rate also depends on stoichiometric coefficients; consider the more general balanced equation

\((aA+bB \rightarrow cC + dD)\),

where the lower case letters represent the coefficients of the **balanced** equation and the upper case letters (i.e. A) represent the molecular concentration. As with the example above, the rate of reaction can be defined with respect to loss of reactants or gain of products:

- Rate of Disappearance of reactants: \(\frac{\text{rate}}{\Delta t} = \frac{1}{a}\frac{\Delta [A]}{\Delta t} = -\frac{1}{b}\frac{\Delta [B]}{\Delta t}\)
Rate of Formation of product: \[
\frac{\Delta [C]}{\Delta t} = \frac{\Delta [D]}{\Delta t}
\]

Since Rate of Disappearance and Rate of Formation are equal
\[
-\frac{\Delta [A]}{\Delta t} = -\frac{\Delta [B]}{\Delta t} = \frac{\Delta [C]}{\Delta t} = \frac{\Delta [D]}{\Delta t}
\]

It is worth noting that the process of measuring the concentration can be greatly simplified by taking advantage of the different physical or chemical properties (i.e.: phase difference, reduction potential, etc.) of the reagents or products involved in the reaction by using the above methods. We have emphasized the importance of taking the sign of the reaction into account in order to get a positive reaction rate. Now, we will turn our attention to the importance of stoichiometric coefficients.

Even though the concentrations of A, B, C and D may all change at different rates, there is only one average rate of reaction. To get this unique rate, choose any one rate and divide it by the stoichiometric coefficient. When the reaction has the formula:
\[
C_{R1}R_1 + \ldots + C_{Rn}R_n \rightarrow C_{P1}P_1 + \ldots + C_{Pn}P_n
\]

The general case of the unique average rate of reaction has the form:
\[
\text{rate of reaction} = \left(-\frac{1}{C_{R1}}\frac{\Delta [R_1]}{\Delta t}\right) = \ldots = \left(-\frac{1}{C_{Rn}}\frac{\Delta [R_n]}{\Delta t}\right) = \left(\frac{1}{C_{P1}}\frac{\Delta [P_1]}{\Delta t}\right) = \ldots = \left(\frac{1}{C_{Pn}}\frac{\Delta [P_n]}{\Delta t}\right)
\]

Example

For the reaction: \[2A+B \rightarrow 2C + D\]

a. find the reaction rate and

b. find the reaction rate given \(\Delta [A] = 0.002,M\) and \(\Delta t = 77, s\).

**SOLUTION**

a. rate of reaction = \[\left(-\frac{1}{2}\frac{\Delta [A]}{\Delta t}\right) = -\frac{\Delta [B]}{\Delta t} = \left(\frac{1}{2}\frac{\Delta [C]}{\Delta t}\right) = \frac{\Delta [D]}{\Delta t}\]

b. rate of disappearance of A = \[\left(-\frac{\Delta [A]}{\Delta t}\right) = \frac{-0.002M}{77 \text{ sec}}\] = -0.000026 M per sec

rate of reaction = \[\left(-\frac{1}{2}\right)\] (rate of disappearance of A) = \[\left(-\frac{1}{2}\right)\] (-0.000026 M per sec) = 0.000013 M per sec

**Average and Instantaneous Reaction Rate**

Reaction rates have the general form of (change of concentration / change of time). There are two types of reaction rates. One is called the average rate of reaction, often denoted by (\[\Delta[\text{conc.}] / \Delta t\]), while the other is referred to as the instantaneous rate of reaction, denoted as either:
\[
\lim_{\Delta t \rightarrow 0} \frac{\Delta [\text{concentration}]}{\Delta t}
\]
which is the definition of the derivative

\[
\frac{d [\text{concentration}]}{dt}
\]

The average rate of reaction, as the name suggests, is an average rate, obtained by taking the change in concentration over a time period, for example: -0.3 M / 15 minutes. This is an approximation of the reaction rate in the interval; it does not necessarily mean that the reaction has this specific rate throughout the time interval or even at any instant during that time. The instantaneous rate of reaction, on the other hand, depicts a more accurate value. The instantaneous rate of reaction is defined as the change in concentration of an infinitely small time interval, expressed as the limit or derivative expression above. Instantaneous rate can be obtained from the experimental data by first graphing the concentration of a system as function of time, and then finding the slope of the tangent line at a specific point which corresponds to a time of interest. Alternatively, experimenters can measure the change in concentration over a very small time period two or more times to get an average rate close to that of the instantaneous rate. The reaction rate for that time is determined from the slope of the tangent lines.

Outside links

- [http://www.chm.davidson.edu/vce/kinetics/ReactionRates.html](http://www.chm.davidson.edu/vce/kinetics/ReactionRates.html) (this website lets you play around with reaction rates and will help your understanding)
- [http://goldbook.iupac.org/R05156.html](http://goldbook.iupac.org/R05156.html)
- [http://www.youtube.com/watch?v=FfoQsZa8F1c](http://www.youtube.com/watch?v=FfoQsZa8F1c) YouTube video of a very fast exothermic reaction.

References


Problems

1. Consider the reaction \((2A + B \rightarrow C)\). The concentration of \([A]\) is 0.54321M and the rate of reaction is \((3.45 \times 10^{-6} \text{ M/s})\). What Concentration will \([A]\) be 3 minutes later?
2. Consider the reaction \((A + B \rightarrow C)\). The rate of reaction is \(1.23 \times 10^{-4}\). \([A]\) will go from a 0.4321 M to a 0.4444 M concentration in what length of time?
3. Write the rate of the chemical reaction with respect to the variables for the given equation. \([2A+3B \rightarrow C+2D]\)
4. True or False: The Average Rate and Instantaneous Rate are equal to each other.
5. How is the rate of formation of a product related to the rates of the disappearance of reactants.
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