

# Reaction Mechanisms and Practical Applications of Activation Energy

Brit Long\*

Department of Chemistry, Valdosta State University, Valdosta, USA

## ABOUT THE STUDY

Chemical kinetics is a fundamental branch of chemistry that deals with the study of reaction rates and the mechanisms by which reactions occur. Central to this field is the concept of activation energy, a term that quantifies the minimum energy required for a chemical reaction to proceed. Understanding activation energy is important because it influences the rate at which reactions occur and thus has wide-ranging implications in fields ranging from industrial chemistry to biochemistry and environmental science.

### Understanding activation energy

Activation Energy ( $E_a$ ) can be envisioned as the energy barrier that reactants must overcome to transform into products. This concept was first introduced by Svante Arrhenius in 1889, who derived an empirical formula known as the Arrhenius equation.

The Arrhenius equation highlights that even a small change in activation energy can have a significant impact on the reaction rate, particularly because the relationship between the rate constant and activation energy is exponential.

### Role of activation energy in reaction rates

The rate of a chemical reaction depends on how frequently reactant molecules collide with sufficient energy to surpass the activation energy barrier. At lower temperatures, fewer molecules have the requisite energy, resulting in slower reaction rates. As temperature increases, a greater proportion of molecules possess the necessary energy, thus accelerating the reaction.

For example, consider the combustion of hydrogen gas. At room temperature, the reaction between hydrogen and oxygen to form water is extremely slow because only a few molecules have enough energy to overcome the activation energy barrier. However, if a spark is introduced, the temperature rises significantly, more molecules have sufficient energy, and the reaction proceeds rapidly, often explosively.

### Catalysts and activation energy

Catalysts play an important role in chemical kinetics by providing an alternative pathway for the reaction with a lower activation energy. This does not alter the overall thermodynamics of the reaction but significantly increases the rate at which equilibrium is reached. Enzymes, which are biological catalysts, are particularly efficient in lowering the activation energy of biochemical reactions, allowing them to proceed at the necessary rates to sustain life.

For instance, the decomposition of Hydrogen Peroxide ( $H_2O_2$ ) into water and oxygen is quite slow. However, when a catalyst such as Manganese Dioxide ( $MnO_2$ ) is introduced, the reaction rate increases dramatically. The catalyst lowers the activation energy required for the decomposition, thus making the process much faster.

### Factors influencing activation energy

Several factors can influence the activation energy of a reaction. These include the nature of the reactants, the presence of catalysts, and the solvent in which the reaction takes place. Molecular orientation and physical states of reactants also play significant roles. For example, reactions involving gaseous reactants generally have lower activation energies compared to those involving solids due to the higher mobility and collision frequency of gas molecules.

The structure of reactants can also impact activation energy. Reactions involving highly strained or reactive molecules typically have lower activation energies because these molecules are inherently unstable and require less additional energy to undergo transformation.

### Activation energy and reaction mechanisms

Understanding activation energy is integral to deciphering reaction mechanisms the step-by-step sequence of elementary reactions by which overall chemical change occurs. Each elementary step has its own activation energy, and the slowest step, known as the rate-determining step, dictates the overall reaction rate.

**Correspondence to:** Brit Long, Department of Chemistry, Valdosta State University, Valdosta, USA, E-mail: longritb12@yahoo.com

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For complex reactions, analyzing activation energies of intermediate steps can reveal important insights into how a reaction progresses. Techniques such as transition state theory provide a framework for understanding the energy changes that occur during these steps, helping chemists design better catalysts and optimize reaction conditions.

### **Practical applications**

The concept of activation energy is needed in a variety of practical applications. In industrial chemistry, controlling activation energy through temperature adjustments and catalysts is fundamental to optimizing production processes. For example, the Haber process for ammonia synthesis relies heavily on catalysts to lower activation energy, making the process economically viable.

In environmental science, understanding the activation energy of pollutant degradation can help in designing effective remediation strategies. In biochemistry, the study of enzyme kinetics hinges on activation energy, as it explains how enzymes lower energy barriers to facilitate biological reactions.

Activation energy is a fundamental concept in chemical kinetics, deeply influencing how and at what rate reactions proceed. From the basic principles outlined by the Arrhenius equation to practical applications in industry and biology, the role of activation energy is pervasive and profound. By mastering this concept, scientists and engineers can manipulate reaction conditions, design efficient catalysts, and innovate processes that drive advancements in technology and improve the quality of life.