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MECHANISMS OF ENZYME ACTION. STRUCTURE OF COENZYMES. ACTIVE SITES OF ENZYMES

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Abstract

This paper examines the mechanisms of enzyme action, the structure of their active sites, and the organization of coenzymes. The features of enzyme–substrate interactions, the stages of catalytic processes, and the role of coenzymes in enzymatic reactions are discussed. The biological significance of enzymes and their functions in metabolic processes are also analyzed.

Keywords: enzyme, coenzyme, active site, catalysis, substrate, enzyme–substrate complex, metabolism.

INTRODUCTION

Enzymes (Latin *fermentum* — leaven), or enzymes, are protein catalysts found in the living cells of animals, plants, and bacteria. Enzymes differ from ordinary catalysts by their high specificity and their ability to significantly accelerate chemical reactions. Like catalysts, they reduce the activation energy of chemical reactions.

In 1914, the Russian-German chemist G.S. Kirchhoff demonstrated that under the action of an extract from germinated barley, starch is broken down into sugar. In 1933, French chemists A. Payen and J. Perso first isolated the enzyme amylase from barley grains. In the mid-19th century, the founder of microbiology, L. Pasteur, proved that the fermentation process is caused by living microorganisms (yeasts) and is associated with their vital activity. In 1897, the German chemist E. Buchner isolated from yeast an enzyme that induces alcoholic fermentation. At the beginning of the 20th century, the German chemist R. Willstätter, together with his colleagues, widely used adsorption methods for the isolation and purification of enzymes. In the 1920s–1930s, J. Sumner first obtained a crystalline enzyme (urease), followed by pepsin and several other proteolytic enzymes in crystalline form.

By the middle of the 20th century, due to the development of physicochemical methods of analysis (in particular chromatography) and protein chemistry, the primary structures of many enzymes were determined. For example, it was shown that bovine pancreatic ribonuclease consists of 124 amino acid residues linked by four disulfide bonds. Subsequently, using X-ray structural analysis, the secondary and tertiary structures of many enzymes were determined. It was established that most enzymes possess a quaternary structure and consist of several protein subunits differing in composition and structure.

MAIN PART

Reactions catalyzed by enzymes follow the general laws of catalytic processes. Enzymatic reactions require significantly lower activation energy. According to the theory of catalysis, molecules must pass through a configuration known as the activated state in order to enter a reaction. Activation energy is required to overcome the energy barrier that prevents molecular interaction.

As an example, the hydrolysis of sucrose into glucose and fructose can be considered. Without a catalyst, this reaction requires 32,000 cal of energy; in the presence of hydrogen ions, 25,600 cal are required; whereas in the presence of the enzyme sucrase, only 9,400 cal are needed. This demonstrates the high energy efficiency of enzymatic reactions.

Enzymes weaken interatomic bonds in substrate molecules, causing deformation and increasing their reactivity. The mechanisms of action of simple and complex enzymes are similar, and their active sites perform comparable functions.

The study of enzyme action mechanisms began at the beginning of the 20th century. In 1902, the English chemist A. Brown suggested that an intermediate enzyme–substrate complex is formed during enzyme action. In 1913, L. Michaelis and M. Menten confirmed this hypothesis and presented the following scheme of enzymatic reactions:

$\mathbf{E + S \rightarrow ES \rightarrow ES' \rightarrow EP \rightarrow E + P}$,

where **E** is the enzyme, **S** is the substrate, and **P** is the product.

At the first stage, an enzyme–substrate complex is formed through ionic or covalent bonds. In the second stage, the substrate becomes activated, increasing its reactivity. In the third stage, a chemical reaction occurs on the enzyme surface, forming an enzyme–product complex, after which the product is released.

A clear example is the activity of aminotransferases that catalyze transamination reactions. These enzymes are holoenzymes, and their coenzyme, pyridoxal phosphate, is covalently bound to the apoenzyme.

Enzymes, like all proteins, are classified as simple and complex. Complex enzymes consist of an apoenzyme (protein part) and a non-protein component — a prosthetic group. When the prosthetic group is loosely bound, it is called a cofactor or coenzyme. Coenzymes include metal ions, carbohydrates, nucleotides, vitamins, and their derivatives. More than 150 enzymes containing vitamin-derived coenzymes are known. In cases of vitamin deficiency, the function of enzyme systems is impaired.

The concentration of enzymes in tissues is extremely low; therefore, their amount is determined by measuring activity. One unit of enzyme activity is defined as the amount of enzyme that catalyzes the conversion of a specific amount of substrate per minute.

Enzyme activity depends on temperature and pH. The optimal temperature for most enzymes ranges from 38–60 °C; at higher temperatures, enzymes usually denature. However, some enzymes (e.g., ribonuclease) are resistant to high temperatures. The optimal pH for most enzymes is close to neutral, except for pepsin and trypsin.

Enzyme activity is also influenced by activators and inhibitors. Metal ions often act as activators, whereas inhibitors form inactive complexes with enzymes.

Enzyme synthesis is controlled by the genetic code. Disorders of enzyme systems (enzymopathies) lead to the development of various diseases. Measurement of enzyme activity in blood serum is widely used in diagnostics and treatment (enzyme therapy).

Enzymes are widely used in the food, chemical, and light industries.

COENZYMES

Coenzymes are low-molecular-weight organic compounds of non-protein nature that are part of some enzymes. They participate in the transfer of hydrogen, electrons, or chemical groups. The most common coenzymes include NAD^+, $NADP^+$, FAD, coenzyme A, thiamine pyrophosphate, lipoic acid, and ATP.

Coenzymes are usually derived from B-group vitamins, for example:

Vitamin B_1 - thiamine pyrophosphate
Vitamin B_2 - FAD
Vitamin B_3 - NAD^+
Vitamin B_5 - coenzyme A
Vitamin B_6 - pyridoxal phosphate

ACTIVE SITES OF ENZYMES

The active site of an enzyme is the region of the molecule that directly binds the substrate and ensures the progress of the chemical reaction. It consists of 10–20 amino acid residues and includes:

A substrate-binding site that provides specificity;
A catalytic site where chemical transformation occurs.

The active site is characterized by high specificity and flexibility, which is explained by the “induced fit” model.

CONCLUSION

Enzymes are the main catalysts of all biochemical reactions occurring in living organisms. Their active sites and coenzymes ensure the high speed and accuracy of metabolic processes. The coordinated action of the enzyme, coenzyme, and active site underlies complex biological reactions. Studying their structure and mechanisms of action is of great importance for medicine, biotechnology, and the food industry.

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