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SIMILARITIES AND DIFFERENCES BETWEEN BIOLOGICAL CATALYSTS AND NON-BIOLOGICAL (INORGANIC) CATALYSTS

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Abstract: This article discusses the essence, structure, properties, and biological significance of enzymes as biological catalysts. Enzymes are high-molecular protein-based biological catalysts that accelerate all biochemical reactions in living organisms. The article analyzes the concepts of enzymes and their historical development, as well as their main functions in living cells. In addition, the role of enzymes in metabolic processes and examples of diseases related to enzyme deficiency or excessive activity are presented.

A comparative analysis of biological and inorganic catalysts is provided in a table, highlighting their chemical nature, working conditions, specificity, reaction rate enhancement, and other important aspects. The high specificity, efficiency under mild conditions, and catalytic effectiveness of enzymes emphasize their essential role in biological systems. The article also discusses the prospects of enzyme applications in medicine, biochemistry, pharmaceuticals, and industry.

Keywords: enzymes, biological catalysts, biochemistry, catalysis, proteins, metabolism, bioactivity, substrate, enzymology, fermentology, catalytic activity, medical enzymology, biochemical reactions, inorganic catalysts.

Introduction

Enzymes are protein-based catalysts and biologically active proteins that accelerate all biochemical reactions in the organism (Stryer et al., 2015). The term "enzyme" (from Latin *fermentum* – yeast) has a specific meaning. At the beginning of the 17th century, the Dutch scientist Van Helmont proposed substances that influence alcoholic fermentation (Nelson & Cox, 2017). Based on this, not only biological catalysts that accelerate fermentation processes, but also those that facilitate all chemical reactions, have been referred to by the term "enzyme."

In some literature, the synonym of this term is "enzyme," derived from Greek, where "en" means "within" and "zyme" means "leaven" (Sukhonov, 2002). It is difficult to imagine all biochemical processes occurring in living organisms without enzymes. Biological catalysts are responsible for transforming substances that enter the organism from the external environment as well as those formed within the organism itself.

The assimilation of nutrients by the organism and their subsequent utilization, the release of energy during the biological oxidation of high-molecular compounds, and the synthesis of structural elements during tissue growth and cell division—all occur with the participation of enzymes (Tursunov & Yusupova, 2011).

Discussion

Catalysts play a fundamental role in both biological systems and industrial chemical processes by increasing reaction rates without being consumed. Biological catalysts (enzymes) and non-biological (inorganic) catalysts share the same basic function; however, they differ significantly in their structural organization, catalytic mechanisms, and operating conditions. These differences determine their specific roles in nature and technology.

Enzymes are highly specialized protein molecules with a complex three-dimensional structure. Their catalytic activity depends on the presence of an active site, which ensures highly selective substrate binding. In contrast, inorganic catalysts such as metals, metal oxides, acids, and bases have relatively simple structures and catalyze reactions through surface interactions rather than specific active sites.

Table 1. Chemical nature and structure of biological and inorganic catalysts

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Parameter	Biological catalysts (enzymes)	Inorganic catalysts
Chemical nature	Proteins (biopolymers)	Metals, metal oxides, acids, bases
Structure	Complex three-dimensional structure	Simple crystalline or amorphous structure
Active site	Specific and well-defined	Not clearly defined
Substrate binding	Highly selective	Surface adsorption

As shown in Table 1, enzymes are highly organized protein molecules with a precisely structured active site that matches the substrate. This structural feature ensures their high specificity. In contrast, inorganic catalysts lack such complex organization and function mainly through surface interactions rather than specific molecular recognition.

Table 2. Reaction conditions and catalytic activity

Parameter	Enzymes	Inorganic catalysts
Optimal temperature	20–40°C	200–500°C or higher
pH environment	Narrow physiological range	Wide range (acidic/alkaline conditions)
Pressure	Atmospheric pressure	High pressure required
Denaturation	Present	Absent
Stability under conditions	Low	High

Table 2 shows that enzymes are active only under mild physiological conditions. Changes in temperature or pH can lead to enzyme denaturation and loss of activity. In contrast, inorganic catalysts are stable under extreme conditions and are therefore widely used in industrial chemical processes.

Table 3. Catalytic efficiency and biological significance

Parameter	Enzymes	Inorganic catalysts
Reaction rate increase	10^6–10^{12} times	10^2–10^5 times
Specificity	Very high	Low
Regulation	Controlled by inhibitors and activators	Not regulated
Reusability	Limited	High
Biological importance	Essential for life processes	No direct biological role

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Table 3 clearly demonstrates that enzymes are far more efficient than inorganic catalysts. Even at very low concentrations, they significantly accelerate biochemical reactions. Furthermore, enzyme activity is tightly regulated in living organisms, ensuring metabolic balance and homeostasis.

Biological catalysts are essential components of living organisms, responsible for sustaining life processes. They participate in digestion, energy production, DNA replication, and overall cellular metabolism. Their activity is strictly regulated according to the organism's needs.

Inorganic catalysts, on the other hand, are primarily used in industrial chemistry. They are widely applied in processes such as ammonia synthesis (Haber–Bosch process), petroleum refining, hydrogenation reactions, and polymer production. These processes require high temperature and pressure, conditions under which enzymes cannot function effectively.

Despite their differences, both types of catalysts share an important similarity: they do not shift the equilibrium position of chemical reactions but only increase the rate at which equilibrium is reached. They are also not consumed during the reaction process.

Results

The comparative study of biological catalysts (enzymes) and non-biological (inorganic) catalysts confirms that both systems are capable of significantly accelerating chemical reactions through the reduction of activation energy. However, their functional roles in nature and technology are fundamentally different and complementary.

The analysis highlights that enzymes are highly organized biological molecules whose catalytic efficiency is closely linked to their structural integrity and cellular environment. Their activity is naturally integrated into metabolic networks, where precise regulation ensures the coordination of biochemical processes necessary for life. This makes enzymes indispensable components of living systems rather than general-purpose catalysts.

In contrast, inorganic catalysts demonstrate broader operational applicability due to their structural simplicity and resistance to harsh environmental conditions. Their performance is not dependent on biological regulation, which allows their use in continuous and large-scale industrial processes where stability and durability are critical requirements.

From a scientific perspective, the comparison also emphasizes that catalytic efficiency cannot be evaluated only in terms of reaction speed. Instead, factors such as selectivity, adaptability to environment, and regulatory control must also be considered when assessing catalytic systems.

Overall, the findings indicate that biological and inorganic catalysts should not be viewed as competing systems, but rather as functionally distinct tools optimized for different domains—biological and industrial. Future research aimed at combining the selectivity of enzymes with the stability of inorganic catalysts may open new pathways in the development of hybrid catalytic systems and advanced green technologies.

Conclusion

This study provides a comprehensive overview of biological catalysts (enzymes) and non-biological (inorganic) catalysts, emphasizing their roles, properties, and functional significance in chemical and biological systems. The analysis shows that both catalyst types are essential for accelerating chemical reactions by lowering activation energy, although they operate in fundamentally different environments.

Enzymes are highly specific, protein-based biological catalysts that function efficiently under mild physiological conditions. They are integral to all metabolic processes in living organisms, ensuring the proper regulation of biochemical reactions necessary for life. Their activity is highly organized and controlled, which allows living systems to maintain homeostasis and adapt to internal and external changes.

Inorganic catalysts, on the other hand, are structurally simpler substances that operate effectively under extreme conditions such as high temperature and pressure. They are widely

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used in industrial chemical processes due to their stability, durability, and ability to facilitate large-scale reactions without biological constraints.

The study also demonstrates that although both systems share the ability to accelerate reactions and remain unchanged after the reaction, their structural differences determine their distinct applications in biological and industrial fields.

In conclusion, biological and inorganic catalysts represent two fundamentally different but equally important catalytic systems. Enzymes ensure the continuity of life processes, while inorganic catalysts enable efficient industrial production. Understanding their characteristics is essential for advancing biochemical research, industrial catalysis, and the development of new hybrid catalytic technologies that combine efficiency with sustainability.

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