



MODERN APPROACHES IN BIOMOLECULAR PHYSICS

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Abstract:

This article discusses modern approaches used in biomolecular physics, particularly the application of nanophysics, molecular dynamics modeling, artificial intelligence technologies, and the analysis of quantum behavior of molecules. These approaches expand the possibilities for deeper understanding of biological processes and the development of new biomedical technologies.

Keywords: Biomolecular physics, molecular dynamics, nanophysics, quantum mechanics, biophysical modeling, artificial intelligence.

Introduction

The study of biological systems from a physical perspective has led to the emergence of a new scientific discipline — biomolecular physics — since the late 20th century. This field investigates intermolecular interactions, energy exchange, quantum effects, and atomic-level movements within living organisms. Modern technologies, especially high-resolution spectroscopy, molecular modeling, and computational methods, have significantly advanced this area. Moreover, artificial intelligence, quantum computing, and nanotechnology are enabling the exploration of the physical properties of biomolecules at a new level. This, in turn, is opening up vast opportunities in fields such as medicine, pharmacology, bioinformatics, and environmental protection.

Molecular Dynamics (MD) is a method for predicting the physico-chemical properties of atoms and molecules by calculating their motion over time. This approach allows for the investigation of biomolecules' three-dimensional structures, mobility, thermodynamic stability, and kinetics in liquid environments under near-realistic conditions.

For example, molecular-level simulations are used to study the interactions between DNA or RNA molecules and enzymes, the binding kinetics of drug compounds with proteins, and ion transport across cell membranes. Software packages such as AMBER, GROMACS, and NAMD are among the most widely used tools for MD



simulations, allowing researchers to observe systems of hundreds of thousands of atoms over several microseconds.

Advantages:

- Enables real-time analysis of biological processes;
- Useful in the design of drug compounds;
- Facilitates the development of personalized therapeutic solutions;

Based on quantum mechanics, complex processes such as electron movement in biomolecules, orbital states, bonding energies, and interactions with photons can be precisely determined. This approach is particularly crucial for analyzing the photoactive behavior of small molecules, enzymatic reactivity, and electrical conductivity.

For instance, quantum analysis is used to study energy transfer through quantum coherence in the photosynthesis process, the light response mechanism of the rhodopsin molecule in the eye's retina, and the UV radiation resistance of DNA. These insights provide a deeper understanding of fundamental biological processes at the atomic level.

Nanophysics enables the study and manipulation of biomolecules at the atomic level. Using techniques such as Atomic Force Microscopy (AFM) and Scanning Tunneling Microscopy (STM), researchers can determine the actual shape, structure, mechanical, and electrical properties of molecules.

Through nanotechnological approaches:

Nanoarchitectures based on DNA and RNA are being developed;

Nanoscale drug delivery systems are being designed;

Nanosensors for protein identification are being produced;

Additionally, biochips, nanoimmunosensors, and nanobiomedical devices represent some of the most significant advancements in this field.

The amount of data related to biomolecules is increasing by millions each year. Artificial intelligence (AI) technologies are widely used to process, organize, and predict these data. In particular, through machine learning, deep learning, and AI-supported modeling methods, the structure, activity, energetic stability, and drug interactions of biomolecules are being automatically identified.

Modern approaches in biomolecular physics not only serve fundamental science, but also provide direct practical outcomes in the following fields:

Personalized medicine: Development of drugs tailored to each individual patient.

Pharmaceuticals: Drug design, testing, and ensuring safety.



Oncology: Early cancer diagnostics based on changes in protein structures.

Agricultural biology: Creation of stronger and more efficient crops through genetic engineering.

In addition, methods used in biomolecular physics are paving the way for emerging disciplines such as cosmobiology, neurophysiology, and environmental monitoring.

Modern biomolecular physics is a field that embodies multidisciplinary approaches and integrates the most advanced achievements of science. By applying theoretical models of physics to biological systems, the fundamental processes of life are being deeply analyzed. The advanced developments in this field will directly contribute to human health, environmental safety, and overall biotechnological progress in the future.

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