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# Methodological Aspects of the Subject and Tasks of Biophysics

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**Abstract:** The article deals with the formation of basic competencies when teaching a biophysics course. The types, functions, pedagogical and psychological qualities of the basic competencies on which they are based are substantiated.

**Keywords:** formation of competencies, profession, pedagogical qualities, practical context, degree of universality, key competencies, educational practice, learning activities.

Biophysics as a medical-biological science that studies the mechanisms of physical and physico-chemical processes in biological systems. The place of biophysics among fundamental biological and medical disciplines, its connection with biological and medical sciences. A brief historical overview of the development of biophysics. Methods and directions of modern biophysics.

The subject of biophysics is the study of the physical and physico-chemical processes that underlie life. There are also more comprehensive definitions of biophysics. For instance, Nobel laureate A. Szent-Györgyi claimed that biophysics is "everything that is interesting." The term "biophysics" became established in scientific literature in 1892, when Karl Pearson, the author of the book "The Grammar of Science," stated on its pages: "...the science which attempts to show that the facts of biology—morphology, embryology and physiology—form particular cases of the application of general physical laws, has been named etiology... Perhaps it would be better to call it Biophysics." A. Fick and, following him, other German scientists called this field of knowledge medical physics, but the French physiologist J. A. d'Arsonval, even before K. Pearson's suggestion, preferred the term "biological physics" to "medical physics."

Modern biophysics investigates the mechanisms of physical and physico-chemical processes in biological systems at submolecular, molecular, supramolecular, cellular, tissue, organ, and organismal levels.

By the nature of its objects of study, biophysics is a typical biological science. By the methods of studying biological objects and analyzing research results, biophysics is a unique branch of physics (according to M.V. Volkenstein, "biophysics is the physics of life phenomena"). It is at the forefront of those areas of biology that are transforming this ancient field of human knowledge from a humanities discipline into an exact science. The introduction of physical principles for analyzing biological phenomena into medicine allows it to become not only an art but also a science. This is the special role of biophysics among other medical theoretical disciplines.

Often, biophysics is spoken of as a new, young science. For example, on November 9, 1934, P.L. Kapitsa wrote: "Biophysics is a completely new field; it came along with biochemistry to replace the old classical physiology. Instead of studying physiological processes as a whole... biophysics and biochemistry study the individual elements of a living being and try to explain its function through the laws of physics and chemistry." Indeed, biophysics became a separate scientific discipline relatively recently, but the beginnings of biophysics arose as soon as work in the field of experimental physics appeared. Thus, some of Galileo's investigations (measuring body temperature, determining the work performed by a person, etc.) can be classified as biophysical research.

The desire to explain the life processes of humans and animals by physical laws was very characteristic of the work of many scientists of the 17th and 18th centuries (R. Boyle, R. Hooke, I. Newton, P.S. Laplace, A.L. Lavoisier, M.V. Lomonosov, and many others). The 19th century became the century of the triumph of analytical methods in the study of biological phenomena. These methods received the greatest development in physiology, within which modern biophysics originated. Many physiological processes, up to and including nervous activity, were attempted to be explained on the basis of physical laws. Unlike similar attempts by predecessors, such explanations were largely confirmed experimentally. Hermann Helmholtz measured the speed of nerve impulse propagation. Emil du Bois-Reymond studied bioelectrogenesis in almost all organs and tissues of the body. Ernst Weber explained some properties of hemodynamics based on physical laws. Outstanding discoveries were made in the field of biophysics of sensory organs—it is enough to mention at least the Weber-Fechner law.

At the same time, the 19th century determined a very characteristic trend in the subsequent development of biophysics. One of the first scientists to notice and affirm this trend was Ivan Mikhailovich Sechenov—the father of Russian physiology. With no less justification, he can be called the founder of domestic biophysics. He used methods of mathematics and physical chemistry to study respiration and established quantitative patterns of gas dissolution in biological fluids. In the works of I.M. Sechenov, the most promising path for the development of physiology and biophysics, associated primarily with physical chemistry, can be traced. In his doctoral dissertation (1860), I.M. Sechenov asserted: "A physiologist is a physico-chemist dealing with the phenomena of the animal organism."

However, only in the 20th century did biophysics become an independent science. Since then, it has begun to study the fundamental problems of biology: heredity and variability, ontogeny and phylogeny, metabolism and bioenergetics.

Most researchers (biophysicists) of the 17th–19th centuries considered a living organism as a physical system, and the main method of such study of biological phenomena was the search for external analogies. Note that even now such a technique is not without success used in biophysics. For example, muscle contraction can be modeled by the inverse piezoelectric effect, amoeboid movement of cells—by the movement of a mercury drop in an acid solution, nerve impulse conduction—by the migration of a scratch along an iron wire treated with nitric acid (the Lillie model), etc.

The cognitive value of such models is quite limited. Often, when modeling the same biological phenomenon, they replace one another following the appearance of new technical devices. For example, reflex activity in the times of R. Descartes was considered by analogy with the work of a steam engine, at the beginning of the last century—with a telephone exchange, now—with a computer. However, such (phenomenological) models are also needed. They allow for the refinement of some details of already fundamentally understood phenomena, and the creation of bionic systems that use patterns of biological organization to build complex technical devices, such as robots. Nevertheless, this useful direction of physical modeling is not the main one in solving cardinal biophysical problems.

The main goal of biophysical research is to elucidate the intimate (internal) mechanisms of biological processes, not to consider external analogies. It is generally accepted that living organisms are complex physico-chemical systems. Therefore, not physical, but physico-chemical modeling has proven to be the most fruitful. It has led to the creation of the ion theory of excitation, the revelation of the nature of bioelectrogenesis, the clarification of the properties of biological membranes, etc. The achievements of biophysics along this path have been especially significant in recent years.

In essence, modern biophysics is the physical chemistry and chemical physics of biological systems. This direction is the leading one in the work of the two largest biophysics institutes in the world of the Russian Academy of Sciences, located in Pushchino near Moscow. Many research institutions of the Academy of Sciences, the Academy of Medical Sciences, and the Ministry of Health of Russia are now engaged in biophysics problems. Among them are institutes of physical chemistry and chemical physics of the RAS, the Institute of Biophysics of the Ministry of Health of Russia. The development of biophysics in our country is also carried out by university departments of biological physics.

Biophysics is a borderline field of knowledge, and the boundaries between it and a number of other biological sciences are rather arbitrary. When drawing these boundaries, the very definition of the subject of biophysics is used—biophysical research includes studies that reveal the physical and physico-chemical mechanisms of biological processes. Biophysical research applies the basic principle of experimental study of nature—quantitative analysis of the organism's reactions to certain stimuli, with the construction of functional dependencies between them. Life processes receive strict interpretation in the form of quantitative patterns, which represent an abstract form of expressing the functional dependence of the reaction on the stimulus.

The functions of the organism have been studied by physiology since time immemorial. At different times, the content of physiology has changed. Now it considers function as a form of activity with a certain final result, the manifestation of which is physiological properties (Shidlovsky, 1981). It is impossible to penetrate into their internal mechanisms using traditional physiological approaches to studying functions. These mechanisms, since they have a physical and chemical nature, are studied by biophysics and biochemistry. The difference in the tasks of biophysics and physiology in studying the functions of the organism can be illustrated by this example. Studying biopotentials, a biophysicist is primarily interested in the mechanism of electromagnetic processes in living tissues, the physico-chemical foundations of this phenomenon, its energy supply, while for a physiologist, biopotentials are indicators of the organism's vital activity and serve as a quantitative characteristic of the most important physiological properties (primarily excitability). Thus, from an electrocardiogram, a physiologist judges the properties of the heart muscle (automaticity, excitability, conductivity). He is less concerned with the physico-chemical nature of electrogenesis in the myocardium; this constitutes the main task of biophysical research of electrical processes in the heart.

Biochemistry, like biophysics, also strives to penetrate the mechanisms of physiological phenomena but studies their chemical nature. The difficulties in delineating biophysical and biochemical research are understandable, but it is necessary to do so. "There is no doubt," asserted Academician G.M. Frank (1974), "that any manifestations of life and living organisms as a whole are ultimately 'chemical machines.' However, despite the primacy of chemistry, the chemical language and chemical concepts are insufficient to reveal the material essence of life phenomena. This primarily applies to the pathways of energy transformation, the nature of interaction forces, and various physical processes, such as, for example, the generation of electrical potentials, the emergence of mechanical energy, and the mechanisms of control and regulation."

Biophysical methods are created based on physical and physico-chemical methods of studying nature. They must combine difficult-to-combine properties: high sensitivity and great accuracy. This condition is met primarily by the achievements of modern electronics. The use of optical methods is very fruitful. Various spectroscopy methods are widely used, including radio spectroscopy (electron paramagnetic resonance—EPR and nuclear magnetic resonance—NMR methods). Radioisotope techniques have long been in use.

Any research requires that recording instruments do not introduce distortions into the process under study. For a biophysical experiment, adherence to this requirement is especially relevant. The well-known Soviet biophysicist B.N. Tarusov believed that this requirement contains the most important feature of biophysical methods, distinguishing them from the application of similar methodological techniques in other areas of physics. This somewhat exaggerated formulation of the specificity of biophysical methods has certain grounds. It is difficult to compare any physical system with a living organism in terms of the latter's extraordinarily high sensitivity to any impacts on it. They do not simply disrupt the normal course of biological processes but cause complex adaptive reactions, diverse in different organs and under different conditions. The distortion of the meaning of true phenomena can be so significant that it becomes impossible to make corrections for artifacts (phenomena not inherent to the object under study under natural conditions and arising during its investigation), since correction methods used successfully in physics and technology are often fruitless in biophysics.

To better understand the areas of application of biophysical methods, let's consider the main directions of scientific inquiry in biophysics. According to the decision of the International Association of General and Applied Biophysics, these include research at the molecular and cellular levels, as well as the biophysical study of sensory organs and complex systems.

**Methods and Directions of Modern Biophysics -** Molecular biophysics studies the functional structure and physico-chemical properties of biologically important (biologically functional) molecules, as well as the physical processes that ensure their functioning, investigates the thermodynamics of biological systems, energy and charge transfer through biomolecules, quantum-mechanical features of their organization. This part of molecular biophysics is gradually distinguished into a new section called quantum biophysics. In general, the task of molecular biophysics is to reveal the physico-chemical mechanisms of the biological functionality of molecules.

Works on cell biophysics are devoted to the physical and physico-chemical properties of cellular and subcellular structures, patterns of cell division and differentiation, features of their metabolism, as well as biophysical mechanisms of specialized cell functions (muscle contraction, secretion, nerve impulse transmission, etc.).

Biophysics of sensory organs reveals the physical and physico-chemical mechanisms of perception of specific stimuli by the receptor apparatus of sensory systems (analyzers) of humans and animals (at quantum, molecular, cellular levels).

The task of biophysics of complex systems is to resolve general physico-biological problems (origin of life, heredity, variability, etc.) based on physico-mathematical modeling of the most important biological processes.

Many biophysicists insist on distinguishing another direction of biophysical research—the biophysical foundations of ecology. Its content is to clarify the mechanisms of the impact of physical and chemical environmental factors on the organism. There is a tendency to equate all biophysics with molecular biophysics, which is reflected in the textbook "Biophysics" by M.V. Volkenstein, published for students of biological and physical faculties of universities. Such a limitation can be allowed to define the area of the most relevant scientific inquiries of modern biophysics, although not everyone agrees with this. For instance, Academician G.M. Frank as early as 1974 argued that "the center of gravity of the physico-chemical consideration of the basis of life phenomena is now shifting to the field of cell biology," since "life phenomena arise only in a system called a cell," and, according to E.B. Wilson (1925), "the key to every biological problem must be sought in the cell," and modern biophysics has come to possess methods allowing the cell to become an object of precise physical experiment. This does not mean that other directions of biophysical research are assigned an auxiliary role. According to
G.M. Frank, in the development of biophysics, "…the continuity of the research line from the

section we have designated as 'molecular biophysics,' further through cell biophysics to the biophysics of complex processes" should be observed.

Biophysics is a science that studies the physical and physico-chemical processes occurring in biosystems at different levels of organization and constituting the basis of physiological acts. The emergence of biophysics occurred as progress in physics, with contributions from mathematics, chemistry, and biology.

Living organisms are open, self-regulating, self-reproducing, and developing heterogeneous systems, the most important functional substances of which are biopolymers: proteins and nucleic acids of complex atomic-molecular structure.

**Tasks of Biophysics:**

1. Revealing the general patterns of behavior of open nonequilibrium systems. Theoretical substantiation of the thermodynamic foundations of life.
2. Scientific interpretation of the phenomena of individual and evolutionary development, self-regulation, and self-reproduction.
3. Clarifying the connections between the structure and functional properties of biopolymers and other biologically active substances.
4. Creating and theoretically substantiating physico-chemical methods for studying biological objects.
5. Physical interpretation of an extensive complex of functional phenomena (generation and distribution of nerve impulses, muscle contraction, reception, photosynthesis, etc.)

**Sections of Biophysics:** Molecular – studies the structure, physico-chemical properties, and biophysics of molecules. The main objects of molecular biophysics research are functionally active substances, among which proteins and nucleic acids are prominent. Cell Biophysics – studies the features of the structure and functioning of cellular and tissue systems. Cell biophysics deals with supramolecular structures of the living cell, among which membrane structures of cells and subcellular structures occupy a special place. Biophysics of Complex Systems – studies the kinetics of biological processes, the behavior over time of diverse processes inherent in living matter, and the thermodynamics of biosystems. Biophysics of complex systems considers living organisms of various levels of organization from the standpoint of physico-mathematical modeling. Objects of research in this case are communities of cells, living tissues, physiological systems, populations of organisms. Model building is one of the main stages of biophysical research. A living organism is a very complex system, not always accessible for precise physical experiment. In this case, the use of physical, analog, and mathematical models becomes fruitful. Any major discovery in biophysics has been obtained through the use of models.

Representing biomacromolecules as crystals made it possible to establish the molecular structure of hemoglobin and myoglobin. The analog electrical model of the excitable membrane played an important role in the research of Hodgkin and Huxley. Physical models of membranes in the form of mono- and bimolecular lipid films have found wide application in membrane biophysics. With the development and improvement of computer technology, modeling is receiving new development.

Sciences such as biology, medicine, and agricultural sciences are becoming more and more precise. In this case, it is difficult to overestimate the role of biophysics, which is called upon to investigate life phenomena using physical concepts and methods.

**History of Biophysics Development.** Mathematical models describe a whole class of processes or phenomena that have similar properties or are isomorphic. The science of the late 20th century—synergetics—has shown that processes of self-organization of very different natures are described by similar equations: from the formation of galaxy clusters to the formation of plankton patches in the ocean.

Despite the diversity of living systems, they all possess the following specific features that must be taken into account when building models.

All biological systems are complex, multicomponent, spatially structured, and their elements possess individuality. When modeling such systems, two approaches are possible. The first is aggregated, phenomenological. In accordance with this approach, the defining characteristics of the system are identified (for example, the total number of species), and the qualitative properties of the behavior of these quantities over time are considered (stability of a stationary state, presence of oscillations, existence of spatial inhomogeneity). This approach is historically the most ancient and is characteristic of the dynamic theory of populations.

The other approach is a detailed consideration of the elements of the system and their interactions. A simulation model does not allow for analytical research, but its parameters have a clear physical and biological meaning; with good experimental knowledge of the fragments of the system, it can give a quantitative forecast of its behavior under various external influences.

**Reproducing systems** (capable of autoreproduction). This most important property of living systems determines their ability to process inorganic and organic matter for the biosynthesis of biological macromolecules, cells, and organisms. In phenomenological models, this property is expressed in the presence in the equations of autocatalytic terms that determine the possibility of growth, the possibility of instability of a stationary state in local systems, and instability of a homogeneous stationary state in spatially distributed systems.

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