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The Main Tasks of Biophysics and the Physical Foundations of Biological Structures

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Annotation: This paper presents widely used biophysical methods and key research areas. It also examines key parameters of living organisms, the most important source of which is the chemical energy of the molecules within the system. Living organisms are known to produce energy by utilizing the chemical energy of the food they digest. Within a living cell, the concentration of ions and substances differs from the intercellular environment; that is, a concentration gradient exists across the cell membrane. Differences in ion and molecular concentrations are also caused by other gradients, such as osmotic , electrical, filtration, and others.

Keywords: Biophysics, organism, chemical energy, food products, living cell, ion concentration, intercellular environment, membrane, molecule.

INTRODUCTION

In recent years, scientific interest in various aspects of integration has grown significantly.

Biophysics is essential and important for the professional development of future medical specialists.

The subject of biophysics is the study of the physical and physicochemical processes underlying life. In terms of the nature of its objects of study, biophysics is a typical biological science, and in terms of its methods of studying and analyzing its results, it is a unique branch of physics. Biophysical methods are based on physical and physicochemical methods of studying nature. These methods must combine qualities that are difficult to combine:

1. High sensitivity.
2. High accuracy.

No method fully satisfies these requirements; however, the following methods have found the widest application in biophysical research:

- optical;
- radio spectroscopy
- ultrasound radioscopy;
- electron paramagnetic resonance spectroscopy (EPR);
- nuclear magnetic resonance spectroscopy.

It should be noted that any research requires that recording devices do not introduce distortions into the process being studied; however, it is difficult to compare any physical system with a living organism due to the organism's unusually high sensitivity to any influences on it.

These influences not only disrupt the normal course of biological processes but also trigger complex adaptive responses that vary across different organs and under different conditions. The distortion of the meaning of measurements can be so significant that it becomes impossible to correct for phenomena that are not characteristic of the object being studied.

Moreover, correction methods used successfully in physics and engineering are often useless in biophysics.

To better understand the scope of biophysical methods, let us consider the main areas of research in biophysics:

1) molecular and quantum biophysics study the physical structure and properties of biologically important molecules, the physical processes that ensure their functioning, and also investigate the thermodynamics of biological systems, the transfer of energy and charge through biomolecules , and the quantum-mechanical features of their structure;

2) cell biophysics is associated with the physical and physicochemical properties of cellular and subcellular structures, the patterns of their division, the features of their metabolism, as well as with the biophysical mechanisms of special cellular functions;

3) the biophysics of the sensory organs conceals the physical and physicochemical mechanisms of perception of stimuli by receptors of the sensory systems of humans and animals at the quantum, molecular or cellular levels;

4) biophysics of complex systems studies the problems of intercellular interaction, information transmission in biological communication channels and control of the functions of living organisms;

5) biophysics of external influences studies the mechanisms of influence of physical environmental factors (for example, fields) on the body.

Despite their diversity, life processes share common features. Specifically, every process requires energy expenditure. Therefore, an important area of biophysical research is the study of energy conversion in biological systems. The processes by which the body obtains energy from external energy resources are the subject of bioenergetics.

In bioenergetics, two approaches are distinguished:

1) the mechanisms of energy processes occurring in the body at the molecular and submolecular levels are studied;

2) the characteristics of biological processes are studied based on the general laws of energy transformation, without a detailed study of their molecular mechanisms. This constitutes the content of biological thermodynamics.

In thermodynamics, the object of study is a system, which is defined as a set of objects bounded to varying degrees by their environment. A distinction is made between isolated systems, which do not exchange energy, matter, or information with the environment, and open systems, where such exchange occurs. A living organism is considered an open system.

The state of any system is characterized by certain parameters. Some of these are independent of the mass or number of particles in the system, that is, their size, while others are proportional to these parameters. The former are called intensive thermodynamic parameters and include temperature, pressure, and so on. Parameters in the second group are called extensive thermodynamic parameters. Examples include volume, energy, entropy, and so on.

The energy of the system can be represented as consisting of two parts:

- the energy of the system as a whole;
- internal energy (atomic energy, etc.).

The first law of thermodynamics states that a change in a system's internal energy can only occur through energy exchange with its environment. Energy exchange between a system and its environment occurs in two ways: through heat transfer and/or through the performance of work.

- amount of heat;
- Job.
- the first law of thermodynamics.

The sign in the formula takes the following forms:

- the heat that the system receives from the environment is considered positive;
- work is considered positive when the system produces it on surrounding bodies.

Let's look at some ways to do the job:

- mechanical work.
- work at constant volume.
- work when moving a charge and potential difference.

$$dA = P_{oc}\frac{dm}{\rho}$$

- - osmotic pressure.
- change in the number of moles,
- chemical potential.

... - quantities that cause the causes of the work, intensive parameters.

- a generalizing force that causes work;
- generalizing coordinate.
- extensive parameters.

$$A = \int X dx,$$

$$A = \int \sum_i X_i dx_i \quad \Delta U = Q - \int \sum_i X_i dx_i \quad Q = \Delta U + \int \sum_i X_i dx_i$$

The amount of heat received by a system is determined by the change in the internal energy of the system, as well as the sum of all types of work performed by the system.

The motion of particles in any body can be ordered or disordered. For example, all molecules of a gas (or water) flowing through a pipe share a common velocity component, which determines the motion of the gas as a whole. Such motion is called ordered. Furthermore, gas molecules engage in continuous disordered thermal motion. Ordered motion is the electric current, while disordered motion is the thermal motion of the gas's electrons.

There is a fundamental difference between ordered and disordered movements: ordered movement can completely turn into disordered movement, but the transition from disordered movement to ordered movement is never complete.

The reason for the difference between these two movements is due to the different probability of each of them.

To ensure orderly motion, it is necessary that all particles have velocity components of the same magnitude and direction at a given moment, and coherent waves must have the same frequency and phase.

Such a state is less likely than one in which the particle velocities or wave phases are different.

The internal energy in an ideal gas is entirely, and in other bodies, partially, associated with the disordered thermal motion of molecules. At the same time, performing work always requires the transfer of matter, that is, ordered motion.

Therefore, it is fundamentally impossible to use all the internal energy of the body to perform work.

Only that part of the internal energy of a system that can in principle be used to perform work is called free energy - G. The rest of the internal energy cannot be converted into work and is called bound energy.

Therefore, the work done by a system in any process cannot be greater than the change in that system.

Those processes in which are called reversible, since by running such a process in the opposite direction and spending work, it is possible to return the system to its original state.

Such processes do not exist in nature. All real processes are irreversible.

In such a transformation, part of it is necessarily converted into heat. To achieve the maximum degree of reversibility of thermodynamic processes, it is necessary to achieve a minimum difference between and.

In both technology and biology, the primary interest is in the perfect system, so it is important to know not so much the complete system, but rather its system, as a function in which the system is located.

The most important parameters are:

- temperature;
- pressure;
- the number of moles of a substance;

and in the presence of an electric field, its intensity.

Then, in many systems, particularly in living organisms, the most important source is the chemical energy of the molecules that make up the system.

In this regard, the concept of chemical potential was introduced.

$$\mu_x = \frac{dG}{dv}$$

The chemical potential of a system with respect to a specific substance is equal to the increase in the system with an increase in the amount of this substance by one mole.

$$\Delta G = \sum_{i=1}^{k} \mu_{x_i} \Delta v_i$$

Application of the first law of thermodynamics to living organisms

Unlike heat engines, living organisms produce not through thermal energy, but by utilizing the chemical energy of the food they digest. Therefore, the equation for a system's change equaling its energy exchange with the environment is:

Animals have a constant temperature, and their chemical composition remains unchanged on average. Therefore, for such an organism, the change in temperature is constant, and the given equation then takes the form:

Since there are many types of work and heat exchange with the environment, the equation can be represented as:

$$W_{\text{пищи}} = \sum_i Q_i + \sum_j A_j$$

- the first law of thermodynamics as applied to living organisms.

It's worth noting that the primary source of energy is the sun. The solar radiation's power is approximately watts, but only a small portion, about watts, reaches the Earth's surface. Of this, 0.02% is absorbed by green plants and stored through photosynthesis.

Consequently, the energy flux extracted by green plants from sunlight is on the order of watts. This energy powers all heat engines and enables all life processes.

However, the methods for converting solar energy accumulated by green plants in the form of chemical energy into work are, in principle, not the same in heat engines and biological systems.

The differences in thermodynamic processes can be seen in the following diagram:

In a heat engine:

In a biological system:

As already noted, the sun is the source of all living things. Terrestrial plants (autotrophs) create approximately tons of nutrients annually through photosynthesis.

Heterotrophs cannot feed on light themselves; they obtain it by consuming each other or plants. Digestion is achieved by the entry of hydrolytic products of food into the cells—that is, carbohydrates, proteins, and fats, which contain sunlight.

The body's primary method of utilizing nutrients is through biological oxidation. This occurs primarily in the inner membrane of the mitochondria, where enzymes catalyzing biological oxidation (cellular respiration) are concentrated. Therefore, mitochondria are often called the cell's energy factory.

The energy extracted from the chemical bonds of nutrients during their biological oxidation can in some cases be directly used for life processes, but most of it goes to the synthesis of so-called macroenergetic compounds, among which the most important is ATP.

Energy stored in macroergs is used by the body to perform various types of work, although mechanical (muscular) work is not the most energy-intensive. In human life, enormous amounts of energy are expended on the synthesis of complex biomolecules .

Thus, the synthesis of one mole of protein requires between 12,000 and 200,000 kJ. The assembly of one protein molecule requires between 1,000 and 16,000 ATP molecules (with an efficiency of approximately 40%). The synthesis of an RNA molecule requires approximately

6,000 ATP molecules, and even more energy is required to form DNA; for example, the creation of one DNA molecule requires ATP molecules. However, the number of synthesized protein molecules is significantly greater than that of nucleic acids, due to the diversity of its functions and its constant, rapid renewal. As a result, protein synthesis in the body is the most energy-intensive, compared to other biosynthetic processes. For example, during each hour of life in mammals, cellular protein is renewed by approximately 1%, and protein enzymes by 10%. A human weighing 70 kg renews approximately 100 grams of protein hourly.

Within a living cell, the concentration of ions and substances differs from the intercellular environment, meaning a concentration gradient exists across the cell membrane. Differences in ion and molecule concentrations are also caused by other gradients: osmotic , electrical, filtration, and so on.

The presence of gradients causes the continuous movement of substances across cell membranes (passive transport). Passive transport should reduce the magnitude of the gradients, that is, equalize the concentration and other physicochemical parameters. However, under normal cellular conditions, membrane gradients are stably maintained at a certain level, due to the ability of the biological system to transport substances against the gradients. This type of transport is called active transport. Active transport requires energy, which in most cases is derived from ATP. Therefore, active transport is a form of biological system operation with an efficiency of approximately 20-25%. The efficiency of muscle contraction in the body does not exceed 20%.

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