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The essence of homeostasis and other properties of living organisms: stemming from thermodynamics of biological systems

Abstract

Homeostasis and its role in the functioning of living organisms as non-equilibrium thermodynamic systems have been carefully investigated. The author tends to prove that homeostasis remains as a desire of a living organism to be closer to an optimal equilibrium thermodynamic state, depending on the conditions of its functioning. Simultaneously, a few definitions are clarified, such as the principle of life activity of living organisms, a living organism, life, the purpose of life, as well as the property of loss and restoration of functions.

Keywords: thermodynamics, biological, system, homeostasis, living organism.

Introduction

Historically, research in the field of biology and physiology is based on methods of observation and experiments, according to which such terms as life, living organisms, homeostasis, adaptation, biorhythms, and some others were shaped. In this regard, explanations of the nature of these properties are mostly subjective, and therefore ambiguous, and sometimes even erroneous.

To date, the main properties and characteristics of living organisms have the following widely used definitions.

A living organism and life currently have more than a hundred of definitions [1, 2, 3].

Homeostasis is defined as the ability of living organisms to maintain dynamic constancy of the composition and properties of the internal environment [4, 5].

Adaptation is determined as the ability of an organism to adapt to external conditions [6].

Biorhythms look as periodic changes in the nature and intensity of biological processes [7].

As it can be seen from the above definitions, all terms, except for homeostasis, have corresponding logical explanations. Meanwhile, the latter do not reveal, except for adaptation, the role of these properties in the process of existence of living organisms.

As for the term of homeostasis, its formula contains a certain contradiction, such as dynamic constancy, which indicates on a lack of understanding of the nature of this property, being one of the main essences of living organisms.

Purpose and content of the study

The purpose of this study is to determine the actual content and role of homeostasis in the life of living organisms from the position of thermodynamics of biological systems.

The study performed has proved the following:

During a day the plants are consumed by photosynthesis and other biochemical reactions associated with it, which develops consumption of sunlight energy. This, in turn, is resulted in the synthesis of the most energetically consumed compound: substance-adenosine triphosphate (ATP) [8].

The energy supply of other organisms occurs through the use of plants as meal.

Thus, all living organisms are always present in a non-equilibrium thermodynamic state.

For the first time, this existence of living organisms was proclaimed by E. S. Bauer in 1935, who called it as “the Universal law of biology" [9]. He clearly noted that "only living systems are never in equilibrium and constantly work against the equilibrium required by the laws of physics and chemistry, under existing external conditions and due to their free energy."

However, this law was inaccurate. As B. S. Dobroborsky declared in 2010, there are two types of processes in thermodynamic systems in the material world [10]:

1. The processes of energy redistribution under which thermodynamic systems tend to get thermodynamic equilibrium (for example, by equalizing temperatures). Such systems are called "passive".

2. The processes that convert one type of energy into another (for example, electrical energy into mechanical one), under which thermodynamic systems tend to be in terms of the non-equilibrium state by changing the temperature. Such systems are called "active".

In living organisms, some types of energy are converted into others through various biochemical reactions. Therefore, they are observed as thermodynamic systems of the active type, tending to get the equilibrium thermodynamic state. Therefore, in this case there are no contradictions with the laws of physics.

The second Bauer’s inaccuracy concerning the "Universal law of biology" is that living systems constantly work against equilibrium.

The process of photosynthesis and biochemical reactions resulted in the synthesis of ATP is carried out during the day. Yet, at night ATP is split mainly to adenosine diphosphate (ADP) accompanied by the release of energy. Thus, the non-equilibrium thermodynamic state is provided by a continuous sequence of phases of biochemical reactions of synthesis and cleavage of ATP, as well as by other substances associated with these reactions.

As a result of the analysis of these processes, in 2006 B. S. Dobroborsky formulated the "Second law of thermodynamics of biological systems". The law explains how living organisms maintain their non-equilibrium thermodynamic state in the following wording [11]:

The stability of the non-equilibrium thermodynamic state of biological systems is provided by a continuous alternation of biochemical processes of energy consumption and release through controlled reactions of synthesis and splitting of ATP, respectively.

This law originates the following consequences:

1) Living organisms never stimulate the processes that occur continuously, and they alternate with the opposite direction: inhalation with exhalation, work with rest, wakefulness with sleep, synthesis of substances with splitting, etc.

2) The state of a living organism is never static, and all its physiological and energy parameters always circulate in a state of continuous fluctuations being relative to the average values, both in frequency and amplitude.

However, living organisms during the same process in its initial period of time have certain functions provided by the necessary amount and concentration of ingredients involved in biochemical reactions, and on the final stage they lose these functions due to decreasing a number and concentration of these ingredients on a minimum level. However, after the ingredients reach this level, the process stops, and another one begins, in which the amount and concentration of these ingredients are being restored, following, for example, continuous alternations of inhalation and exhalation.

The regularities of these processes ultimately correspondent with the law of active masses, despite the fact that they are, to a certain extent, controlled by inhibitors and catalysts of feedback systems that respond to the parameters of the external environment and internal state of the body [12].

An example of graphs of changes in the intensity of ATP synthesis and splitting and their energy processes is shown in figure 1, where C is the concentration of ATP and W is the energy [11].

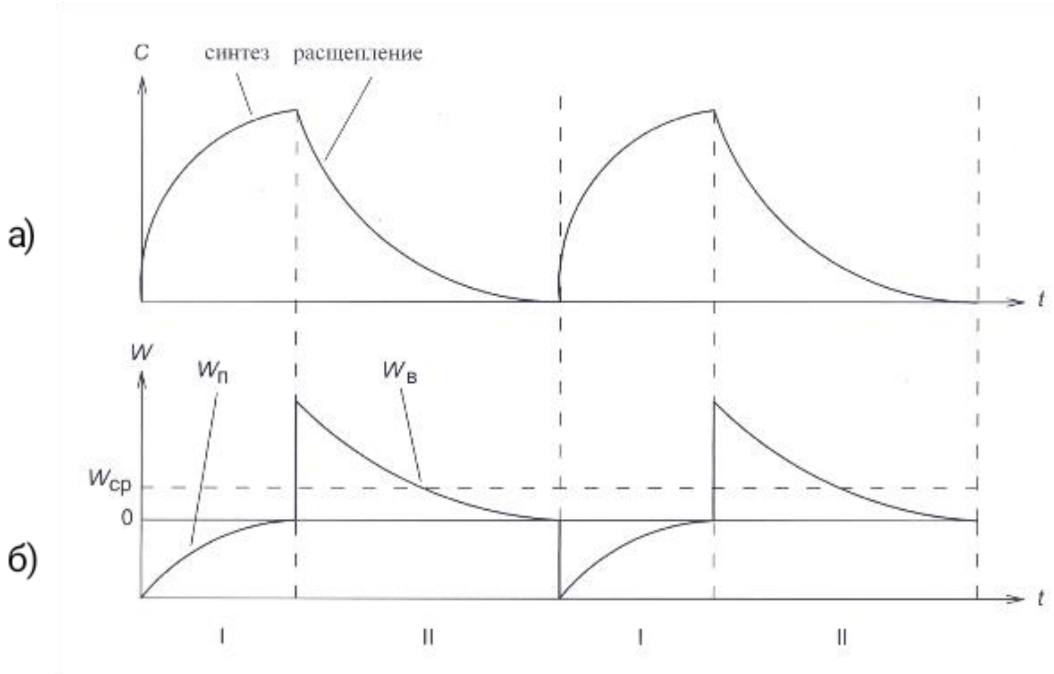


Figure 1: Graphs of ATP synthesis and cleavage processes and their energy processes

a) The schedule of alternating phases of synthesis and splitting of substances; b) the schedule of alternating phases of energy consumption and release; I is the phase of energy consumption; II is the phase of energy release; $W_{п}$ is the energy being consumed; $W_{в}$ is the energy being released; and $W_{ср}$ is the average value of the energy released.

As it can be visualized from the graphs in figure 1a), the changes in the intensity of synthesis reaction and ATP cleavage occur in accordance with the law of active masses.

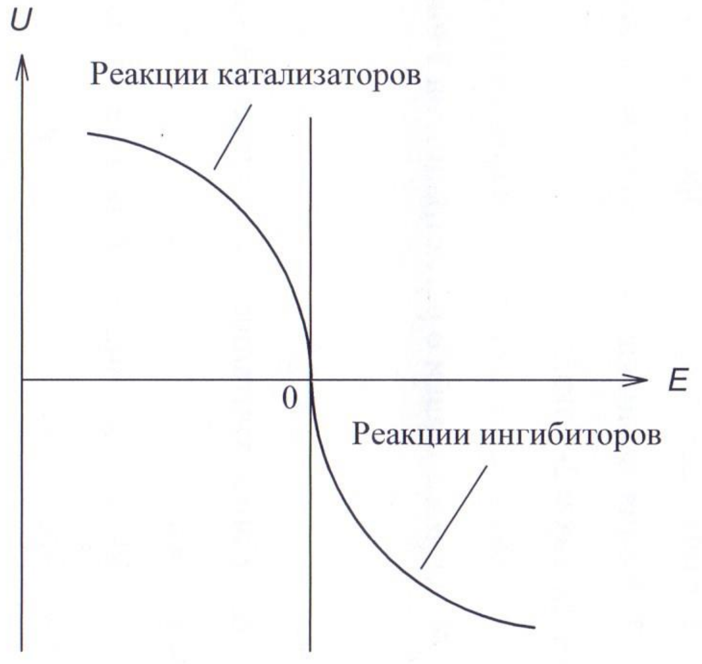
As it can be seen from the graphs in figure 1b), the synthesis and splitting of ATP in phase I, $W_{п}$ energy is leading to consumption of $W_{в}$ energy and its release in phase II, Moreover, $W_{в} > W_{п}$. Energy $W_{ср}$ provides vital activity of the body, and its value continuously changes, depending on the instantaneous state of the organism and the loadings it experiences, which ensures stability of its non-equilibrium thermodynamic state.

Due to the processes of photosynthesis, the period of alternating phases of synthesis and splitting of ATP that occur in plants is equal to one day around.

The animals have different priorities: a continuous sequence of alternating phases of synthesis and cleavage of ATP from food and other biochemical reactions in their bodies occurs automatically, with different frequency concerning numerous organs and systems.

At the same time, warm-blooded animals are thermally stabilized, which provides them with the best functioning conditions.

A typical graph regarding regulation of biochemical reactions with assistance of appropriate catalysts providing positive feedback and of inhibitors that provide negative feedback is shown in figure 2.



Реакции катализаторов - **Reactions of catalysts**,

Реакции ингибиторов - **Reactions of inhibitors**

Figure 2: Graph of functioning the system for maintaining stability of the non-equilibrium thermodynamic state of the organism

Here E is an acting factor, U is functional shift, 0 is the mode of optimal non-equilibrium thermodynamic state.

As we can see from figure 2, the functioning of this system fully correspondents to the conditions of M. A. Lyapunov's stability theory expressed by the formulas (1) and (2) [13]:

$$\Delta E > 0, \ \frac{dU}{dt} < 0, \tag{1}$$

$$\Delta E < 0, \ \frac{dU}{dt} > 0, \tag{2}$$

As formulas (1) and (2) demonstrate, if the influencing factor E increases, then the rate of change in the functional shift U decreases. Also, if the change in the influencing factor E decreases, the rate of change in the functional shift increases. In this case, the deviation of the thermodynamic state from the optimal one tends to 0, thus ensuring the stability of its non-equilibrium thermodynamic state.

Thus, the complex of biochemical reactions of a living organism aimed at ensuring maximum stability within its non-equilibrium thermodynamic state by continuous alternation of phases of synthesis and splitting of ATP is what biologists and physiologists call **homeostasis**.

The research conducted above has shown that thermodynamics of biological systems enables to give some other definitions concerning the nature of processes occurring in living organisms:

- **The principle of life activity of living organisms** consists in a continuous sequence of alternating phases of biochemical reactions, as a result of which their non-equilibrium thermodynamic state is continuously provided.
- **A living organism** is a biochemical machine that converts energy.
- **Life** is a complex of biochemical reactions that occur in a living organism, aimed at ensuring the stability of its non-equilibrium thermodynamic state.
- The **goal of life** is to increase the stability of the non-equilibrium thermodynamic state of a living organism, its offspring and the population as a whole.
- **Loss and restoration of functions** is the property of living organisms to perform functions for a limited time and then restore them.

To achieve this goal (along with the priorities listed above), the processes of self-organization of living organisms population are being activated and related, in particular, to a person, families, communities and associations based on national, political, religious, territorial and other priorities. Also, the states and their associations are involved in these processes which can affect the improvement of political systems, scientific, technical and economic progress in all trends of human activity.

Conclusion

As a result of the performed research from the point of view of thermodynamics of biological systems, the following priorities were proclaimed.

1. The analysis of the life activity of living organisms from the point of view of thermodynamics of biological systems allowed using a new approach to solve the problems of cognition of its functioning.
2. The nature, purpose and main properties of homeostasis are determined.
3. New definitions of living organisms and a number of their properties are proposed.
4. The goal of life and the ways of its realization are defined.

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