Abstract: A brief historical review is given to the substantiation of the thermodynamic principle of substance stability that governs chemical and biological evolution. It is stated that this principle can be extended to all structural hierarchies in the Universe. The author believes that there is a variable thermodynamic code of life implemented through the principle of substance stability at a level of supramolecular and higher structures of living matter. It is felt that the principle of substance stability is a general physical principle of hierarchical organization and evolution of matter. The use of the principle for studying evolution processes requires correct separation of interacting hierarchical systems.

Key-words: thermodynamics, evolution, principle of substance stability, life, code of life, gas-liquid-crystalline objects, thermodynamic self-organization

Epigraphs—a guide to action
“…nothing at all takes place in the universe in which some rule of maximum or minimum does not appear …”
Leonhard Euler

1. INTRODUCTION

Hierarchical structure of our world has been known from the time immemorial. However, the main physical causes underlying occurrence of hierarchical structures became clearer from the standpoint of exact sciences only in the past century.

In 1977 the author showed [1] that there was a certain law of Nature that dictates separation of lifetimes of hierarchical structures in the living world. This law allowed methods of extended Gibbs thermodynamics [2] to be used for establishing physical causes for the origin of life and directionality of biological evolution. The preprint of the author’s above-mentioned work was sent to a number of leading American scientists in May–September 1977. Later a distinct formulation was proposed for that law which some authors began treating as a general law of Nature. It was given the name law of temporal hierarchies.

After the author’s first publication that presented the law of temporal hierarchies [1], new works of Prof. A. Iberall and colleagues appeared which dealt with the hierarchical structure of the Universe [3, 4]. From a certain point of view, those works resembled the approaches of the author of this paper. Professor A. Iberall and colleagues were acquainted with the preprint of the author’s pioneering work [1], but, probably deliberately, did not cite that investigation [4]. Later the author stressed many times that the law of temporal hierarchies and the principle of substance stability were applicable to all structural hierarchies of the real world.

2. GENERAL

The law of temporal hierarchies allows quasi-closed monohierarchical thermodynamic systems (subsystems) to be singled out within open polyhierarchical biological systems and their development (ontogenesis) and evolution (phylogenesis) to be studied by investigating variation in the specific (per unit volume or mass) Gibbs energy of the formation of this higher monohierarchical structure from lower-level structures [1, 5 - 14].

The law of temporal hierarchies reads as follows:
«Any living system of any temporal hierarchical level in a normal state has a thermostat—a surrounding medium that is characterized by slightly changing average values of the thermodynamic parameter».

Sometimes we use the law of temporal hierarchies in the form
\[ ... \ll t^m \ll t^{im} \ll t^{organism} \ll t^{pop} \ll ... \] (1)

Here \( t^m \) (\( t^{ch} \)) is the average lifetime of those molecules (chemical compounds) in the organism which participate in metabolism, \( t^{im} \) (\( t^{supra} \)) is the average lifetime of any intermolecular...
(supramolecular) organism tissue structures renewed as the organism grows and develops, $t^{\text{organism}}$ is the average lifetime of organisms in the population, and $t^{\text{pop}}$ is the average lifetime of the population (the gas–liquid crystal structure). Lifetimes of cells and a number of other complex supramolecular formations are deliberately omitted in series of strong inequalities (1). However, this series undoubtedly represents a general law of Nature that agrees with reality and reflects existence of temporal hierarchies in the living world.

The above (Gladyshev’s) law allows rigorously substantiating the possibility of selecting (singling out) quasi-closed monohierarchical systems (subsystems) in open polyhierarchical biological systems. Series (1) is a set of Bogoliubov’s overlapping unidirectional triads [15]. The latter indubitably allows one to investigate thermodynamic transformations in each particular hierarchy irrespective of the processes taking place in other hierarchical structures. These assertions substantiate hierarchical thermodynamics with its mathematical formalism entirely similar to that of classical thermodynamics. S. A. Eloshvili asserts that Gladyshev’s law is a quantitative law [16].

The work [1] laid the groundwork for linear dynamic quasi-equilibrium hierarchical thermodynamics on a strong basis of Gibbs’s thermodynamics. In the above work the author used for the first time the principle of substance stability, which was presented in the form of a figure [1]. It was postulated that changes occurring at certain times in structural stability of living beings in the process of biological evolution and aging are spontaneous and obey the second law of thermodynamics. In other words, it was asserted that the specific Gibbs energy of formation of supramolecular structures of living beings tends to a minimum in phylogenesis and ontogenesis. Later in [5] the above principle was called the principle of chemical substance stability. Later on, the principle was generalized to all levels of living matter (atoms, molecules, supramolecular structures, including organelles and cells, populations, ecological systems, etc.) and became known in the scientific literature as Gladyschev’s principle of substance stability. Now the principle is formulated with application to biological and chemical evolution as follows:

During the formation (self-assembly) of the most thermodynamically stable structures at the highest hierarchical level (j), e.g., the supramolecular level, Nature, in accordance with the second law, spontaneously uses predominantly the (available for the given local part of the biological system) least thermodynamically stable structures belonging to a lower level, for example, the molecular level (j-1). The justice of the principle is proved on a quantitative basis as applied to the molecular and supramolecular structural levels of biological tissues.

By now, a lot of evidence has been found to validate this principle with application to chemical substances and systems [17–23].

Physical substantiation of the principle stems from the known statement that Nature tends to Gibbs energy minima. The author of this work specified the statement and asserted that Nature tends to minima of specific Gibbs energies of formation of individual (allotted) structures at all hierarchical levels. This assertion means that Nature tends to maximum stability of locally individual structures at all hierarchical levels. This is the formulation of the principle of substance stability extended to all hierarchical structural levels of matter in the Universe.

The tendency for qualitative change in stability of chemical compounds as their nature changes during chemical and biological evolution can be revealed by comparing standard Gibbs energies of their formation [22]. However, this change cannot be exactly determined because we do not know absolute values of the Gibbs energy of formation of simple substances.

Studying evolution processes in dynamic quasi-closed systems, one should bear in mind that evolution of these systems does not involve only spontaneous processes inside the systems. Nonspontaneous processes initiated by the environment should also be taken into account. However, when the environment of the quasi-closed systems under study changes insignificantly, spontaneous processes inside the system dominate. In this case, we may speak about the decisive action of the second law of thermodynamics in complex quasi-closed systems or about the tendency of these systems to achieve the maximum stability [5, 6, 11-13].

As was already mentioned, the principle of substance stability extends its action to all structural and substructural hierarchies of living matter. This action can be substantiated on the physical basis for subhierarchies of the general supramolecular level (im level). The following model seems to be applicable.

In aqueous biological environments liquid-crystal structures are formed. They are transformed and successively condensed to higher substructures of the general im level. The author believes that this condensation proceeds in accordance with the thermodynamic variable architectural code of life (code of living matter development) implemented by the principle of substance stability at the level of supramolecular and higher structures of living
matter. As was already mentioned, the directional action of the principle results from that the specific Gibbs energy of formation of hierarchical structures tends to a minimum. It should be stressed again that this tendency also agrees with the statement that the above structures tend to maximum stability. This successive thermodynamic self-organization (condensation or self-assembly) at the im level is accompanied by chemical transformations and metabolism. These dynamic processes are very close to equilibrium. For example, these transformations are well known for ATP synthesis and metabolism in living systems [23]. The above transformations and restructuring are only possible in the presence of liquid water. In inanimate nature, e.g., during formation of minerals, polyhierarchical multistep thermodynamic self-assembly processes are impossible, because there is no necessary spatial (complementary) correspondence between the above-mentioned structures.

Thus, the physicochemical successive im self-assembly can be comprehended in view of existence of the thermodynamic variable architectural code of life, probably “inherent” in properties and structure of water molecules and other simple molecules—“building blocks” of life.

The variability of the code of life is connected, first of all, with the variability of the environment. Note once again that the principle applies to all higher hierarchies of the living world. In this case, the action of principle is connected with chemical and physical interactions in gas-liquid-crystalline objects of the living world. For example, such interactions take place between the organisms of populations and ecological systems. The structures of all hierarchies are thermodynamically self-organized according to the rule "similar to seek for similar."

A change in the Gibbs energy (or its specific value) can be estimated using the extended generalized Gibbs equation—the extended generalized equation of the first and second laws of thermodynamics.

This equation for the differential of the Gibbs function, which allows for all kinds of work that can be performed in a living system under the effect of internal and/or external forces, has the form [5-9, 11-13]

\[
dG^* = \sum_i dG_i^* - \sum_i s_i \delta \tau_i + \sum_i \sum_q x_{iq} \delta X_q + \sum_i \mu_i \delta m_i \\
\tag{2}
\]

Here \( T \) is the temperature; \( S \) is the entropy; \( U \) is the internal energy; \( V \) is the volume; \( p \) is the pressure; \( X \) is any generalized force except pressure; \( x \) is any generalized coordinate except the volume; \( \mu \) is the chemical (evolutionary) potential; \( m \) is the mass of the \( k \)th substance; the work performed by the system is negative. The subscript \( i \) is related to partial evolution, and the subscript \( k \) is related to the component of the \( i \)th evolution. The superscript * indicates that behavior of a complex system is considered. The above equation generalizes the first and second laws of thermodynamics [5, 11-13]. It simultaneously considers all types of energy (work): thermal, mechanical, acoustical, hydrodynamic, electromagnetic, chemical, gravitational, sociological, ecological, and others. Equation (2) reminds us that structural evolution of living bodies is connected with both internal spontaneous processes and external environmental effects that stimulate nonspontaneous transformation of these objects [7-9, 11-13]. Equation (2) is considered as “speculative” because it involves terms incomparable in magnitude. Clearly, rational calculations should assume separation of the equation terms that usually characterize tropisms [12] of each particular hierarchical level. Eclectic consideration of the overall variation of all terms of this equation (\( \Delta G^* \)) during evolution and aging of living beings can in no way be effective in the description of these processes. Note that the overall variation (production) of entropy in biological evolution and aging of living beings does not have a unique physical meaning either. This approach is also eclectic.

It is important to remember that the structure formation model under discussion can be close to reality only if we manage to separate correctly quasi-closed systems in particular hierarchical structures.

Interaction of chemical and biological hierarchies and their constituent subhierarchies involves forces of the “physicochemical and physical nature”. Biological evolution proceeds in parallel with geological evolution, and it tends over long periods to achieve, step by step, maximum stability of structures at all hierarchical levels. The tendency to maximum stability of structures in evolution can be represented as a spiral. This tendency can be comprehended on the basis of extended Darwinism, the general foundation of which is undoubtedly hierarchical thermodynamics [11-13]. Figure 1, borrowed from the Internet, shows the spiral of the geological and biological evolution on our planet.
Interactions of hierarchies of space objects (stars, galaxies, etc.) are related to gravitational interactions. Interactions between elementary particles of the “microworld” must be governed by the forces of the corresponding nature. For example, the author earlier called attention to the fact that such patterns are sometimes revealed through comparing the stability of sequences of monotypic atoms and their nuclei. It was mentioned [17] that the stability of atoms of inert gases gradually decreases in the sequence He, Ne, Ar, Kr, Xe, and Rn. At the same time, stability of nuclei (characterized by specific energy of nucleons, E/A, MeV) increases in the sequence He, Ne, and Ar, although upon transition to Ar, Kr, Xe, and Rn the value of E/A decreases, but not significantly. Thus, again, when considering the stability of monotypic structures of the nuclear (lower, j-th) and atomic (j-th) hierarchies, it is sometimes pertinent to speak, with some reservations, about the above-mentioned principle.

However, we know too little about structural hierarchies of space objects and microworld particles to study interactions of these structures from the standpoint of the principle of substance stability.

3. CONCLUSION

The author believes that the principle of substance stability is a general physical principle of hierarchical organization of matter and its evolution. This principle appears to determine the thermodynamic trend to directional development of the universe.

4. CITATION


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