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THERMODYNAMIC THEORY OF ORIGIN OF LIFE, BIOLOGICAL EVOLUTION AND AGING OF LIVING SYSTEMS

«There is one thing stronger than all the armies in the world, and that is an idea whose time has come.»
Victor Hugo

The author of this article believes that the time of thermodynamic theory of biological evolution, aging and origin of life has come now.

1. Introduction

It is well known that the thermodynamics (thermostatics or quasi-thermostatics) is a key theory of physics, chemistry, biology, and all natural sciences. This statement would generally be accepted as a fact **[1, 2]**.

However, for many decades, the opinion was widespread that natural open biological systems are far from an equilibrium state. It was also believed that far from equilibrium processes take place in these systems. Indeed, if this is true, then thermodynamics –thermostatics (or the thermodynamics of quasi-equilibrium systems and processes) – cannot be applied.

Recently, the law of temporal hierarchies was formulated [**3–12**]. This law substantiates the possibility of identifying (discerning) quasi-closed monohierarchical systems (subsystems) within open polyhierarchical biological systems. It was also established that, as a rule, the processes of evolution in living natural systems are quasi-equilibrium processes. It was shown that models of living systems are analogues of models of equilibrium (quasi-equilibrium) chromatographic columns [**3**].

These facts allowed creation of the quasi-equilibrium thermodynamics of near to equilibrium quasi-closed systems. This thermodynamics is based on the statement that the functions of state (with a good approximation) at any moment of time in quasi-closed monohierarchical systems have a real physical meaning (sense).

Thus, classical thermodynamics in a linear approximation (the thermodynamics of near to equilibrium systems) at the phenomenological level can be used for the investigation of the origin of life, biological evolution, and the development and aging of organisms. The investigations are carried out in terms of kinetic (dynamical) linear thermodynamics.

It has been shown that the variation of the chemical composition of living beings in the course of ontogenesis and phylogenesis is a consequence of change in the mean specific value of the Gibbs function for supramolecular (intermolecular) interaction in formation of supramolecular structures of an organism's tissues, which tends to a minimum. More strictly speaking, this variation is connected with the trend of mean specific values of the Gibbs function related to a unit of volume or mass at all hierarchical levels to a minimum.

The principle of the substance stability – feedback has been formulated. It is applicable to any biological systems (belonging to different hierarchies). For instance, this principle explains the accumulation of a substance with a chemically high energy capacity by biological systems in the course of evolution and aging of living beings. This substance forces water out of these systems.

The arguments presented in the author’s works (in my view, well-substantiated) indicate that practically all concrete (detailed) recommendations relating to nutrition (and physical activity, etc.) are individual. They should be formulated on the basis of general and anti-aging medicine (gerontology) and should take into account the findings of physicochemical dietetics. Nevertheless, the thermodynamic theory of biological evolution and the aging of living organisms (built on the foundation of classical science) provides an opportunity to formulate general concepts pertaining to nutrition and helping prolong healthy human life.

This article is a short review of last author's works in the field of hierarchical thermodynamics theory, which is the classical thermodynamic study of hierarchy dynamics in evolutionary timescales. With this theory, we are able to develop dynamical models of equilibrium analysis of hierarchical structures such as atomic hierarchies, molecular hierarchies, nutritional hierarchies, and social hierarchies. Thermodynamically, we are able to predict and study their course of evolution as they approach equilibrium points of stability and to study energetic transitions that occur between adjoined hierarchies.

We also include, here, new explanations of some statements of theory. Note that only the classical work of Willard Gibbs is used as the fundament of this theory. There are practically no new publications in this area of science. I know only of the important work of Libb Thims' in the field of human thermodynamics [**13**]. It is possible to find much useful information on this new science at the Institute of Human Thermodynamics websites [**14**].

2. The law of temporal hierarchies

The law of temporal hierarchies, which some researchers have begun to call Gladyshev’s law, can be presented as a series of strong inequalities [**6, 7, 12, 15, 16**]. The direction of this series is towards increasing average life-spans of structures on going from lower to higher structures. In the simplest case, this law can be presented as:

$$\ldots \ll t^{m} \ll t^{im} \ll t^{organism} \ll t^{pop} \ll \ldots, \qquad (2.1)$$

where t^{m} is the average life-span, or duration of existence, of the organism’s molecules (or chemical compounds) taking part in metabolism; t^{im} is the average life-span of any intermolecular (or supramolecular) structures of the organism’s tissues renovated in the process of its growth and development; $t^{organism}$ is the average life-span of organisms in the population; and t^{pop} is the average life-span of the populations. For the sake of simplicity and clarity, in the series of strong inequalities (2.1) the life-span of cells and some other complex supramolecular structures are omitted. Needless to say, this series, as determined by the presence of metabolism in the world of living matter, accords well with reality, and reflects the existence of temporal hierarchies in living systems. This rigorously substantiates the possibility of identifying, i. e. separating, monohierarchical quasi-closed systems (or subsystems) belonging to different temporal or structural polyhierarchies in open biological systems. Note that each type or species of organism is characterized by its own average life-span value for each respective hierarchy. However, series (2.1) is observed for each species of organism.

The series of times of imagined relaxation of different-hierarchy structures postulated by the author in 1976 had a reverse direction as compared to series (2.1), as in its originally form it was based relaxation times of dissociation and thermalisation rather than component life-spans in its current form [**3**]. Nevertheless, both of these series give reason to make a conclusion on the possibility of identifying quasi-closed systems in open biological spheres and structures. There is a profound link between the direction of these series of the times of imagined relaxation and the life-spans of different-hierarchy structures. The sources of this link can be identified on a statistical basis for an ideal structural hierarchical model. In any case, there is a simple route towards comprehending the existence of this link.

Thus, the law of temporal hierarchies *makes it possible to identify, in open biological systems, quasi-closed thermodynamic systems*, i. e. subsystems, and to study their development (ontogenesis) and evolution (phylogenesis) by measuring the *change in the specific (per unit of volume or mass) value of the Gibbs function of formation of the given higher hierarchical structure from structures of a lower level.*

It was established, in the process of ontogenesis as well as phylogenesis and evolution generally, that the specific value of the Gibbs function of formation of supramolecular structures of the tissues of an *i*th organism $\bar{\tilde{G}}_i^{im}$ tends toward a minimum. First, this tendency is defined by the variation of chemical composition of the system during its evolutionary development. This tendency towards a minimum can be pressed in the form:

$$\bar{\tilde{G}}_i^{im} = \frac{1}{V}\int_0^V \frac{\partial \tilde{G}_i^{im}}{\partial m}(x, y, z)dxdydz \to \min_2 \qquad (2.2)$$

For the phase of supramolecular structures of varying composition (for the times of ontogenesis, phylogenies, etc.)

Here, V is the volume of the investigated system; m is the mass of the identified microvolumes; x, y, and z are coordinates; the symbol «‒» means that value $\bar{\tilde{G}}_i^{im}$ is specific, i. e. relating to the macrovolume; and the symbol «~» stresses the heterogeneous character of the system. The subscript « i » of G is related to the systems of different of chemical composition.

Note, once again, that the value $\bar{\tilde{G}}_i^{im}$ tends toward a minimum as a result of the system's tendency to seek the equilibrium state; i. e., the tendency of the «the investigated system within the constant temperature constant pressure environment» to evolve towards a stable potential energy well, as defined by a minimum of free energy. In this case, the environment is the physical thermostat, i. e. the medium of higher hierarchical structures (e. g. the hierarchy of organisms within a population) which evolves gradually.

From another perspective, as a consequence of the quick attainment of supramolecular equilibrium at each moment of time (t = 1, 2, 3, …), in the investigated system, $\bar{\tilde{G}}_i^{im}$, where subscript « i » corresponds a system of constant chemical composition, attaches or reconfigures molecularly to a minimum that corresponds to the resultant stable supramolecular structure.

Thus, we have:

$$\tilde{G}_i^{im} = \frac{1}{V}\int_0^V \frac{\partial \tilde{G}_i^{im}}{\partial m}(x, y, z)\,dxdydz \to \min_1 \qquad (2.3)$$

For the phase of supramolecular structures with constant composition (at times of relaxation to local equilibrium)

It is important to note that correlations, i. e. the schematic tendencies, (2.2) and (2.3) imply taking into account the intermolecular interactions in all supramolecular structures of the biological tissue, both intracellular and extracellular. This is fully justified since structural hierarchy does not always coincide with temporal hierarchy. Thus, some types of cells do not divide (according to current views) and, like organs, age along with the organism. However, for any supramolecular hierarchy ($j - 1$) there exists some higher ($j + x$) hierarchy, such that:

$$t^{j-1} \ll t^{j+x},$$

where t^{j-1} and t^{j+x} are the average life-spans (lifetimes) of elementary structures of the corresponding structural hierarchies in a living system, $x = 0, 1, 2, \ldots$, etc.

The presented detailed explanations given here characterize the «principle of substance stability».

3. On the Principle of Substance Stability

The principle of substance stability describes the tendency (trend) of natural systems to local and general equilibria at all temporal and structural levels of the organization of matter [**5, 6, 15–18**]. It corresponds to the second law of the Clausius–Gibbs thermodynamics (thermostatics) and the Le Chatelier–Braun principle. The principle of substance stability is determined by the limited energetic potential (the Gibbs potential energy) of associated (interacting) elementary structures of every hierarchy. This principle appears at all hierarchical levels (temporal and structural) of living matter. It is connected with the fact that we can observe its action at time scales corresponding to our capabilities.

The principle applied to molecular and supramolecular structures was named the principle of the stability of a chemical substance. Subsequently this principle was applied by the author to various hierarchies as a part of the theory of the evolution of life. It has been named the principle of stability of matter or the principle of substance stability – the feedback (Gladyshev's) principle.

It boils down to the following: 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.

I would like to present an illustration. The supramolecular structures of the tissues (a higher level of structure j, compared to the molecular level, j-1) in the course of ontogenesis and phylogenesis accumulate relatively unstable molecules (substances with a relatively high chemical energy capacity), for instance, fats, which force water out of these tissues. Similar phenomena occur in some molecular chromatographic columns (as a rule, in hydrophobic cells and columns) [**3, 4, 11-12**]. All chemists know about it. These columns accumulate substance with a high energy capacity. These facts do not surprise us, although open heterogeneous *adsorbent (absorbent) – adsorbate* systems, **approaching supramolecular equilibria**, on the whole, **move away from chemical equilibrium with the environment.**

In this environment there are precisely those chemical substances that penetrate the column. The removal from chemical equilibrium with the environment is the consequence of the trend toward a minimum of the specific supramolecular component of the Gibbs function – the Gibbs free energy (e. g., for biological tissue), $\bar{\tilde{G}}^{im}$.

The author applied the principle of substance stability to the structural hierarchies that function inside any temporal hierarchy. These structural hierarchies have been named «understructure hierarchies.» An illustration of the principle is provided by the selection of a sequence of nucleic acids including AU pairs in evolution, although these pairs are less stable from the standpoint of supramolecular thermodynamics than GC pairs. Hence, the selection of natural (AUGC) sequences takes into account not only the stability of the lower understructure supramolecular hierarchy, as was sometimes previously believed, but also the stability of the highest understructure supramolecular hierarchy, as well as tertiary, quaternary, and the highest supramolecular structures – nucleic acid–protein complexes.

There are some facts that call for application of the principle of substance stability to the hierarchy of cells. Thus, tumor cells have a lower ability for aggregation. As a result, they easily move in the body, which leads to the appearance of metastases. The cell membranes of tumor cells are, apparently, formed from supramolecular structures of increased stability. Hence, the supramolecular stability of cell aggregates formed with the participation of tumor cells should be lowered according to the principle in question. In order to increase the adhesive ability of the cells, the structure of membranes should be «diluted» and made less thermodynamically stable. Hence, it is clear why experimental anticancer diets propose the use of plant oils, fats of animals from cold seas, and other products containing residues of unsaturated low-melting-point fatty acids. The anti-tumor effect of aspirin can also be explained on the basis of such statements. These ideas agree with the recommendations made using the thermodynamic theory of aging [**15–18**].

The principle of substance stability facilitates our understanding of the effect of the influence of some chemical substances on the supramolecular structures of nucleic acids. As a result of the action of such substances, dormant ancient genes, accumulated during the evolution of living beings, may be activated. These genes can stimulate some types of cancer.

A well-known fact in the sphere of sociology concerning family ties illustrates the relationship between the principle of substance stability and a social hierarchy. Here, we have in mind the substance (elemental structures) of any inside social hierarchy («understructure hierarchy»), such as a hierarchy of organisms, groups of organisms, etc. The stronger the love and mutual understanding between a couple, the less time they spend «outside the family.» Such spouses do not have the desire, power, or time for this. This seems surprising. Hierarchical thermodynamics can be applied here as well. These conclusions of hierarchical thermodynamic are excellent correspond to the conception of Libb Thims about the thermodynamics of human molecules [**13–14**].

The principle of substance stability corresponds with the well-known rules of maintenance of stability of parties, unions, states, and nations. Furthermore, one can comprehend in this way age-old social management methods such as «divide and rule.»

Professor L. Gumilev's and Professor A. Akhiezer's dynamic models of the development of communities (nations) can be also confirmed using the quantitative basis of hierarchical thermodynamics [**15**]. Here it is useful to make an apposite remark concerning the possibility of prediction of the history of mankind. This history can be predicted on the basis of the principles of hierarchical thermodynamics. In these examples, the quantitative thermodynamics of social hierarchy and the concept of sociological potential can be used [**3**].

Some facts confirm the author's point of view that feedback between all hierarchical levels of the biological world is based on hierarchical thermodynamics. These feedbacks can be schematically presented as a sequence: *biosphere → ecosystems → populations → organisms' → cells → supramolecular structures → proteins and some other macromolecules → DNA (RNA)* **[9, 15-17**]. Hence, the principle in question is applicable to all hierarchies (and understructure hierarchies), including the molecular and supramolecular structures for which it was first formulated.

Now some remarks on thermodynamics and politics.

From the viewpoint of the principle of substance stability, it is clear why people who, as a rule, are distinguished by their independence and audacity seek power (and often achieve it). These individuals use techniques and methods known only to them and unavailable (due to moral considerations) to the average cultured person. However, having achieved a high position, these members of society begin, under favorable conditions, to come into confrontation with similar members of society. To achieve great power requires not only a combination of favorable factors but also a person's intelligence, which, however, usually shows itself in various peculiar (particular) aspects. To create an algorithm of the coming of a particular person to power is without a doubt practically impossible. In such cases, we deal with a varying algorithm, which is constantly transforming (changing) under the effect of change in the environment. Here the situation, in my view, calls to mind the hopelessness of the creation of artificial intelligence [**17**], as well as the search for a rigorous genetic program of aging predicting the life span of a person and, perhaps, synonymous with his fate. In such cases, we can speak of averaged thermodynamic tendencies determined by the blurred «fan of thermodynamics."

The possibility of applying the principle to reveal the evolutionary trend of human society should especially be noted.

The rapid development of humanity in our time is associated with the preferential selection of energy-consuming systems and devices. These systems and devices, making life easier for people owning them and for society as a whole, increase its thermodynamic (sociological) potential. However, in accordance with the principle of substance stability, humanity together with its technical environment, as a single system, is becoming with time too unstable. This must lead, sooner or later, to the partial degradation of this system and, in the end, to its complete degradation or even to its destruction. However, hierarchical thermodynamics does not deny the possibility of the rebirth of humanity in a new, less perfect (from the point of view of modern morality) form. This is all that we, the inhabitants of the planet, can count on in the future. The laws of thermodynamics are relentless. I have no doubt that they are in effect everywhere in our universe.

I am certain that the principle of substance stability in various forms can be extended to all hierarchies of matter [**17**].

4. The anti-aging quality of foodstuff

It follows from the thermodynamic theory [**6, 9, 10, 15–22**], that the changes in the Gibbs specific function when supramolecular structures of a foodstuff (a substance) are formed, as well as the value of gerontological (anti-aging) quality of foodstuff, i. e. the GPG_i index, connected with it can be easily assessed from the approximated Gibbs–Helmholtz–Gladyshev equation [**23**], which is an **analogue** of the classical Gibbs–Helmholtz approximated equation. As applied to natural fats and oils, it can be written down as:

$$\Delta\bar{\tilde{G}}_i^{im} = (\Delta\bar{\tilde{H}}_m^{im} / T_m)(T_m - T_0) = \Delta\bar{\tilde{S}}_m^{im}\Delta T , \qquad (4.3)$$

where $\Delta\bar{\tilde{G}}_i^{im}$ is the Gibbs specific function or Gibbs specific free energy of the supramolecular or intermolecular formation of the condensed phase *i*, $\Delta\bar{\tilde{H}}_m^{im}$; $\Delta\bar{\tilde{S}}_m^{im}$ is the change of specific enthalpy and entropy during the solidification of natural fat (oil); T_m is the pour or melting point; and T_0 is the standard temperature (e. g., 25, 0, – 25, – 50 °C) at which values $\Delta\bar{\tilde{G}}_i^{im}$, and consequently GPG_i, are compared. Value T_0 must be lower than value T_m. When the gerontological value of a food is assessed, the choice of T_0 is determined by the melting point of the lowest melting-point substance in the series of compared products. It is assumed that the low melting-point substances take part in the formation of corresponding low melting-point supramolecular structures in an organism's tissues.

Let me note that the Gibbs–Helmholtz equation is correct for an individual substance in a closed system in which chemical, phase or other transformations may take place. **The analogue** of this equation, often with a good approximation, can be applied to various substances of the same type and for variable composition systems. The Gibbs–Helmholtz equation and its **analogue** (4.3) were used, with good results, by the author when determining the thermodynamic direction of evolutionary processes. Such relationships, by default, are widely used in the study of synthetic copolymers, biological polymers, and other variable composition systems [**6**] It follows from equation (4.3) that a correlation between $\Delta\bar{\tilde{G}}_i^{im}$ calculated for standard temperature and the pour or melting point of fats or oils, T_m should often be observed, with acceptable approximation [**6, 15–18**]. Such a correlation should of course, be also observed between the indicator of the anti-aging (gerontological) value of the food in question, GPG_i and T_m [**6, 20**]. Indeed, such a correlation does exist [**6, 9, 10**].

Now some words on the mechanisms of rejuvenation of organism's tissues.

I wish to model the human organism as complex chromatograph column [6, 18], such that upon digestion of food-stuffs, in which sustenance first reacts with hydrochloric acid and enzymes to break-down in the stomach, the nutritive particle molecules will then each migrate to different parts of the human molecular structure based on their relative thermodynamic stability and their relative chemical affinities for different intra-molecular attachment sites within the human molecule – the body.

Hence, by way of correlating these theories and subsequent data sets to longevity statistics I which to assign gerontological values to food-stuffs based on enthalpy or heats (Gibbs function) of supramolecular interaction measurements. So, essentially, I patented the idea that all items of food intake can be assigned an anti-aging value based on thermodynamic parameters.

Graphic examples of the accord between theory and observations are connected with the well-known medical recommendation to include vegetable oil and seafood (cold seas) into one's diet. These products add «young chemical matter» to the biotissues, «building material» that corresponds to the composition of a young organism. In thermodynamic terms (and in the light of known facts), this rejuvenates the organism's tissues.

All conclusions of the theory are fully conformed to the experience of medicine and dietetics. Hear we can only delighted by the efficiency of thermodynamic methods.

5. The general concepts pertaining to nutrition

Thus, the thermodynamic theory of biological evolution and aging of living organisms, as built on the foundation of classical science, provides an opportunity to formulate general concepts pertaining to nutrition [**9**]. These formulations and concepts will encourage and stimulate behavioral and dietary changes thermodynamically-favored towards the development of long and healthy human lives.

Diets promoting a healthy life style should, of course, comprise only ecologically clean foods. They should be balanced as to composition and caloric value. It is extremely important for a diet to include foods from cold, i. e. deep, regions of the sea and foods made from plants and animals inhabiting cold and Alpine regions. It is also desirable that the biomass used should be that of young plants and animals; being that this biomass has a higher anti-aging value. Moreover, food stuffs should be prepared from the biomass of ancient species, i. e., living organisms with a low phylogenetic development level, being those situated at the early stages of phylogenesis. Food for which young, ontogenetically and phylogenetically, plants and animals are used is not only gerontologically valuable but also, for obvious reasons, has a low caloric value. These steps are known to prolong life in a healthy manner and certain to increase general longevity. Pure, practically salt-free drinking water, as unadulterated glacial water, should be used in the maximal quantity acceptable for every patient. Medicinal mineral waters should be specifically indicated.

Generally, it is advisable to use foods and water that meet general up-to-date standards developed on a strictly scientific basis. It is also desirable that these foods and water intake recommendations, according to well-known patents, should be recognized to have high anti-aging value and that the water should be «gerontologically pure.» Specific recommendations, which are an object of current research, are also available.

Lastly, it is important to take into account, from the viewpoint of hierarchical thermodynamics, that anti-aging diets and many drugs can be used for the prophylaxis and treatment of cardiovascular diseases, cancer, and for numerous other illnesses.

6. Conclusion

Some colleagues, it is possible, will call attention to the fact that much of what the author is writing about is already known! Much, but not all! Some very important statements of the hierarchic thermodynamics theory are motivated.

The thermodynamic hierarchical theory of biological evolution and aging applied to the living world should not only explain all that is reliably known but also predict new knowledge.

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