[Frontiers in Bioscience 6, 208-224, January 1, 2014]

Emergence of biological organization through thermodynamic inversion

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1. ABSTRACT

Biological organization arises under thermodynamic inversion in prebiotic systems that provide the prevalence of free energy and information contribution over the entropy contribution. The inversion might occur under specific far-from-equilibrium conditions in prebiotic systems oscillating around the bifurcation point. At the inversion moment, (physical) information characteristic of non-biological systems acquires the new features: functionality, purposefulness, and control over the life processes, which transform it into biological information. Random sequences of amino acids and nucleotides, spontaneously synthesized in the prebiotic microsystem, in the primary living unit (probiont) re-assemble into functional sequences, involved into bioinformation circulation through nucleoprotein interaction, resulted in the genetic code emergence. According to the proposed concept, oscillating three-dimensional prebiotic microsystems transformed into probionts in the changeable hydrothermal medium of the early Earth. The inversion concept states that spontaneous (accidental, random) transformations in prebiotic systems cannot produce life; it is only non-spontaneous (perspective, purposeful) transformations, which are the result of thermodynamic inversion, that lead to the negentropy conversion of prebiotic systems into initial living units.

2. INTRODUCTION

This article represents the review of the author's main research results in the origin-of-life field, based on his publications for the period of 2002-2013. The research includes two successive steps. The first one is the initial *systemic* approach to the origin of life, in which the unique properties of biological systems were formulated because of their all-round comparison with other types of natural systems (1-5). In the framework of the above mentioned approach, it was substantiated in what way a non-living prebiotic system might acquire the unique biological properties in the process of its transformation into a primary living unit (probiont). The second step is the origin of life *inversion* concept representing thermodynamic inversion in prebiotic systems as the key transformation, resulted in the emergence of biological organization on the Earth and other space bodies in the Universe (6-7).

3. BIOLOGICAL AND NON-BIOLOGICAL NATURAL SYSTEMS

3.1. Key terms: entropy, free energy and information

Entropy (S), free energy (F) and information (I) are the key characteristics determining the macro-state of a natural system and its evolution trend. Entropy (S) is an *integrated* characteristic: it doesn't reduce to the sum of the system's constituents, which can be described by strict equations only. When describing self-organization in open systems, the entropy notion serves as both the measure of energy value (the more entropy, the less useable energy value) and the measure of disorganization (the more entropy, the higher disorganization) (8-9). High-value energy can be defined in terms of free energy. Free energy is a part of the system's entire internal energy, which can be converted into any kind of work (mechanical, chemical, etc.). It is implied that the term *free energy* used in this paper corresponds to Gibbs energy. Nevertheless, the author uses this term in a rather general way, allowing him to compare thermodynamic processes in biological and non-biological systems. For this reason, free energy is denoted as F (not G). The remaining internal low-value energy (bound energy) cannot be converted into work.

A smaller part of entropy transmission is connected with informational processes. The entry of information (I) reduces disorganization in a system. From a physical point of view, information can be understood as the value which reduces uncertainty in the state of a system. The transfer of information in systems is always related to a corresponding transfer of entropy and free energy. The information flow represents a special case of entropy transfer between two systems. Informational entropy is the form of entropy directly connected with informational processes (8, 10). So, entropy, free energy and information are interrelated values. Generally, contributions of free energy and information decrease entropy and vice versa.

3.2. **Thermodynamic trend of biological evolution**

According to current opinion, free energy and information accumulate in the course of the biosphere evolution (6, 11-12). The entropy change, in the course of biological evolution, takes place in the field of negative values, as the export of entropy from biological systems prevails over its internal production. In this way, negative entropy (negentropy) increases and positive entropy (i.e. proper entropy) decreases (8, 13-14). This thermodynamic trend corresponds to the living systems' ability to concentrate free energy and information, which is considered to be one of the fundamental biological properties by many scientists, mentioned in the article by Kompanichenko (2008) (4). This ability allows biological systems to have an excess of free energy and information with respect to the environment maintaining their positive gradients. A thermodynamic trend of biological evolution is the phenomenon not characteristic of any non-biological natural system. Therefore, the beginning of biological evolution requires an inversion in the tendency to a change of free energy in the prebiotic system from dissipation to a continuous increase, as well as the inversion in the tendency to a change of information (from spontaneous loss to enduring accumulation) and entropy (from positive to negative values). On the whole, thermodynamic inversion can be understood as the inversion of entropy, when a natural system transits into the state characterized by a continuous entropy deficit due to excessive contributions and re-organization of free energy and information (6).

The processes in the Universe may proceed in the direction of either a more or a less probable state. The entropy rise corresponds to the transition of a natural system to a more probable state, due to the universal *spontaneous*, or *basic*, processes. Heat conductivity and diffusion represent examples of basic processes: they are flows of heat or chemical components along the corresponding gradients. In the long run, spontaneous processes resulted in the disappearance of gradients in a system, now characterized by maximum entropy and chaos. On the contrary, universal *non-spontaneous*, or *coupled*, processes are responsible for the system transition to a less probable state. An active transport in a biological organism represents a coupled process, resulted in the transference of a chemical component against the gradient – from its low content locations to higher ones (in defiance of the 2nd Law of thermodynamics). Non-spontaneous processes cannot proceed without the expenditure of energy and/or information. The negentropy trend of biological evolution is characterized by the prevalence of non-spontaneous processes over spontaneous ones in living systems (4, 6).

3.3. **Fundamental properties of biological systems**

The initial systemic approach to the origin of life was elaborated by the author on the basis of his systematization and analysis of the fundamental properties of biological systems and their all-round comparison with the properties of non-biological natural systems (1-3). The primary set of 230 biological properties was the result of summarizing the works by 73 scientists, including the author, published in the book (15). Integration of the properties has allowed the author to formulate 31 fundamental biological properties (3-4). They are subdivided into two groups. According to the elaborated generalization, 19 properties can be considered as the unique fundamental properties of biological systems. They are not common to any other natural systems. They can be narrowed down to the following four key integrated biological properties:

- ability to concentrate and reorganize free energy and information;
- ability to exhibit an intensified counteraction to external influences;
- expedient behavior (the ability to choose the most beneficial way of interaction with the environment);
- regular self-renovation at various levels, including self-reproduction.

A combination of intensified and expedient actions means the living being's "growing ability to control the environment and lessening dependence on it", recognized by Huxley (1942) as the most important criterion in the progressive biological evolution (16). The remaining 12 out of 31 properties are attributed to the non-unique fundamental biological properties. The same or similar features are also characteristic of some non-biological systems, devoid of any biological specificity.

3.4. **Principal difference between non-biological (physical) and biological information**

The broadest classification of information was offered by Shannon (1948) in his information theory (17). "Information" by Shannon is inversely related to uncertainty; the highest possible uncertainty characterizes a random sequence. Informational systems operate only in nonequilibrium states (18-19). Therefore, the exchange of information takes place in both self-organizing physical/chemical systems and living systems.

In both physical (non-biological) and biological worlds, the information inflow decreases entropy in systems. However, information in cosmic or geological systems ("physical" information) principally differs from information in biological systems (bioinformation). Their methods of organization are thermodynamically different: non-biological systems develop in accordance with the 2nd law of thermodynamics (entropy rises in them), while the biological evolution has the anti-entropy, or negentropy, direction (in biological systems entropy may rise as well, but it is immediately compensated - with excess - by free energy and information). Both physicists and biologists recognize the difference between physical and biological information. Quoting Feistel and Ebeling (2011, p.27)," We underline that biological just as socio-economic processes can be investigated with the help of the theory of self-organization because they obey the valid physical and chemical laws. However, processes which include real life (biological and socio-economic systems) also obey additional rules and laws that are not determined by physics alone" (10). In the co-evolution theory of the genetic code origin, Wong argued that bioinformation in heteropolymeric sequences (nucleic acids and proteins) is similar to alphabetic, non-alphabetic and computer languages (20-21).

These are the most essential features of biological information, formulated by the author, which are not characteristic of non-biological systems.

1. Functionality. Functional bioinformation is considered as "an encoded network of functions in living organisms - from molecular signaling pathways to an organism's behavior" (22), or as a measure of a biological system complexity (23). Functional information has meaning (such as in coded information). In a living organism, a sequence (gene or protein) is functional and meaningful, unlike a polynucleotide or polyamino acid chain, spontaneously synthesized *in vitro*. A semiotic system is necessarily made of three distinct entities: signs, meanings and code; signs (set of symbols) and meaning are connected by the conventional rules of a code (24-26). A code is a precise mapping from a set of symbols to specified meanings, actions, and objects. The best-known biological code is the codon-to-amino acid translation during protein construction that uses tRNAs to translate one codon from the 64-codon alphabet (a sign) into one amino acid in the 20 amino acid alphabet (meaning). There is no chemical or other deterministic link between the opposite ends of a tRNA that causes a particular amino acid to be associated with a particular codon. They are associated by an arbitrary rule determined by a code (26-27). Shortly, a semiotic system can be expressed as follows:

"Signs → Code → Function" (Scheme 1)

The values of functional bioinformation can be obtained with the method, developed and applied to 35 protein families (28), allowing to measure the functional sequence complexity.

2. Purposefulness (i.e. bioinformation is goal-oriented, aimed to perspective). Bioinformation is not only functional/meaningful, but also prescriptive and algorithmic - that is substantiated in the framework of the "prescriptive information" concept (25, 28-30). Prescriptive information is *purposeful* and it includes any form of programming, either instructing or directly producing a nontrivial function at its destination. Thus, the prescriptive information in a DNA sequence is a recipe or algorithm *to accomplish a desired task*. A biological system produces prescriptive information by means of some purposeful (perspective) choices at *bona fide* decision nodes. It is emphasized that purposeful choices can be produced neither by chance nor by necessity (26, 30).

The considered feature of bioinformation allows expanding the succession (Scheme 1) in the previous paragraph:

Purpose → ["Signs → Code → Function"] → Action, the achieved result (Scheme 2)

The general succession (2) can be interpreted as follows: a living organism or community sets a goal and achieves it through the biosemiotic system that includes signs, functions and a code.

3. Control over life's processes. Life's hardware and software systems control the chemistry and physics of all of life's processes, including metabolism, manufacturing, control, and feedback. These systems use digital processing of information to control, integrate, and maintain life's processes. A prescriptive algorithm can be implemented in either hardware or software (26). Life is basically the result of the information "software" process. Our genetic code is our software (31). For the last several years, the significant experimental confirmations of the fact that life has "hardware/software" organization have been published (26-27, 31-33). One proof is a computer-generated artificial genome. Venter's team placed life-synthesized pieces of the target DNA into yeast where they were assembled into the target genome. The assembled genome was transplanted into a different organism and 'booted up' to create a new synthetic version of the target. The "operating systems" and the interacting "computers" in the cell with the replaced genome remained intact, and they were able to function by using the replacement "software'. This research evidently demonstrates (at least for the two organisms involved) that life can use general "operating systems" "programming languages" and "devices" (31, 33).

In the sections 3.3, 4.2 the commencement of biological information from non-biological (physical) information, including the appearance of most essential features of bioinformation such as functionality, purposefulness and control over the life's processes, is considered

3.5. **Negentropy barrier**

It is only a biological system that is able to extract free energy and information from the environment and re-organize it. Some natural systems, for instance, volcanoes or stars, can accumulate free energy and preserve its excess. However, these two types of natural systems enrich the surroundings with energy, while a biological system extracts energy out of the medium (2). It follows that biological evolution proceeds in the thermodynamic direction opposite to the evolution of non-biological natural systems, i.e. opposite to the spontaneous entropy increase. As entropy serves the measure for both energy value and disorganization, thermodynamic inversion can be itemized through a change of the balances "free energy contribution / entropy contribution (F_c / S_c)", and "contribution of information / contribution of informational entropy (I_c / S_{ic})". A change in these balances determines the new quality of informational and energetic processes in a biological system. So, the origin of life principal question is how the thermodynamic inversion might occur during the prebiotic microsystems transition into primary living units. Such a transformation needs specific conditions owing to negentropy barrier.

Thermodynamic negentropy barrier is an obstacle for the non-living prebiotic system transformation into a primary living unit. The coupled (non-spontaneous) process develops using only a part of the related basic (spontaneous) process energy. For this reason, the coupled process energy cannot exceed the energy of corresponding basic process. For example, a downhill skier (spontaneous process along the gravity gradient) cannot rise up to the same altitude level of the next identical hill (non-spontaneous process against the gravity gradient) without his additional efforts, the reached hypsometric mark always being lower, due to friction and air resistance. An analogy between this situation and the processes in a living organism shows that the latter, in a paradoxical way, would allow the skier's final hypsometric mark to be higher than starting point. Life develops against the energy and informational gradients due to the predominance of non-spontaneous processes - from a certain starting point, which can be defined as the initial negentropy impulse in a prebiotic system. It follows that processes in living units are, energy-wise, uncompensated. To exist, a living unit must extract a missing quantity of free energy from the environment and remove entropy.

Therefore, the basic process of energy prevalence over the coupled process energy in the non-living world (including all types of prebiotic microsystems) forms a thermodynamic barrier on the way to the living world. It is the energy prevalence of coupled processes, and negentropy organization that can provide its emergence. Besides, to overcome the negentropy barrier the availability of special conditions is necessary. One of the conditions is a loss of the negentropy barrier, possible in the far from equilibrium medium. The peculiarity of the negentropy barrier is the entropy notion of duality, as a measure of both energy value and disorganization. The biological evolution negentropy trend is connected with a positive balance $F_c + I_c / S_c$ (contribution of free energy and information / contribution of entropy). Nevertheless, the balance $F_c + I_c / S_c$ is relative: absolute equality in this ratio is unattainable, free energy and information being measured in different units. It follows that there is a field of indeterminacy close to the inversion point $F_c + I_c \approx S_c$. This field admits producing of prevalent entropy in one part (high-entropy structures) of the non-equilibrium heterogeneous system, and the prevalence of free energy and information in its other part (low-entropy structures). In fact, negentropy barrier mitigates in such a heterogeneous system.

The negentropy barrier may display itself in multiple forms. Thus, Strazewski (2007) wrote about a high entropy penalty for the formation of the ordered association of polynucleic acids (34). The penalty can be considered as one of this barrier's constituents. At the inversion point, the formation of biopolymers functional sequences (based on programming) instead of spontaneous self-assembled associations of nucleic and amino acids needs additional negentropy. One more constituent is the entropy pump within the organic microsystem appearing at the inversion point. To start it, it is necessary that the export of entropy from the microsystem would exceed a certain critical value. Thus, overcoming the negentropy barrier implies an extra-high contribution of negentropy into a prebiotic chemical system, along with the free energy input and transformation of informational processes.

4. THERMODYNAMIC INVERSION: EMERGENCE OF PRIMARY BIOLOGICAL SYSTEMS

4.1. **Pre-inversion nonequilibrium state of prebiotic microsystems: a decrease of negentropy barrier**

The behavior of a system under far from equilibrium conditions is considered in the framework of the theory of dissipative structures by I. Prigogine and later in synergetics (its founder - H. Haken). A wide class of dissipative structures embraces all biological systems and some nonequilibrium chemical systems, like oscillating chemical reactions. Dissipative structures continuously lose energy; nevertheless, they maintain their existence, because of a continuous exchange by matter and energy with the outside world. A key notion of nonequilibrium thermodynamics is bifurcation of a system under the conditions far from equilibrium. Bifurcation occurs, when a system, due to its external or internal changes, must transfer into a new stable state through the unstable point of bifurcation. The system bifurcation universal scheme is as follows:

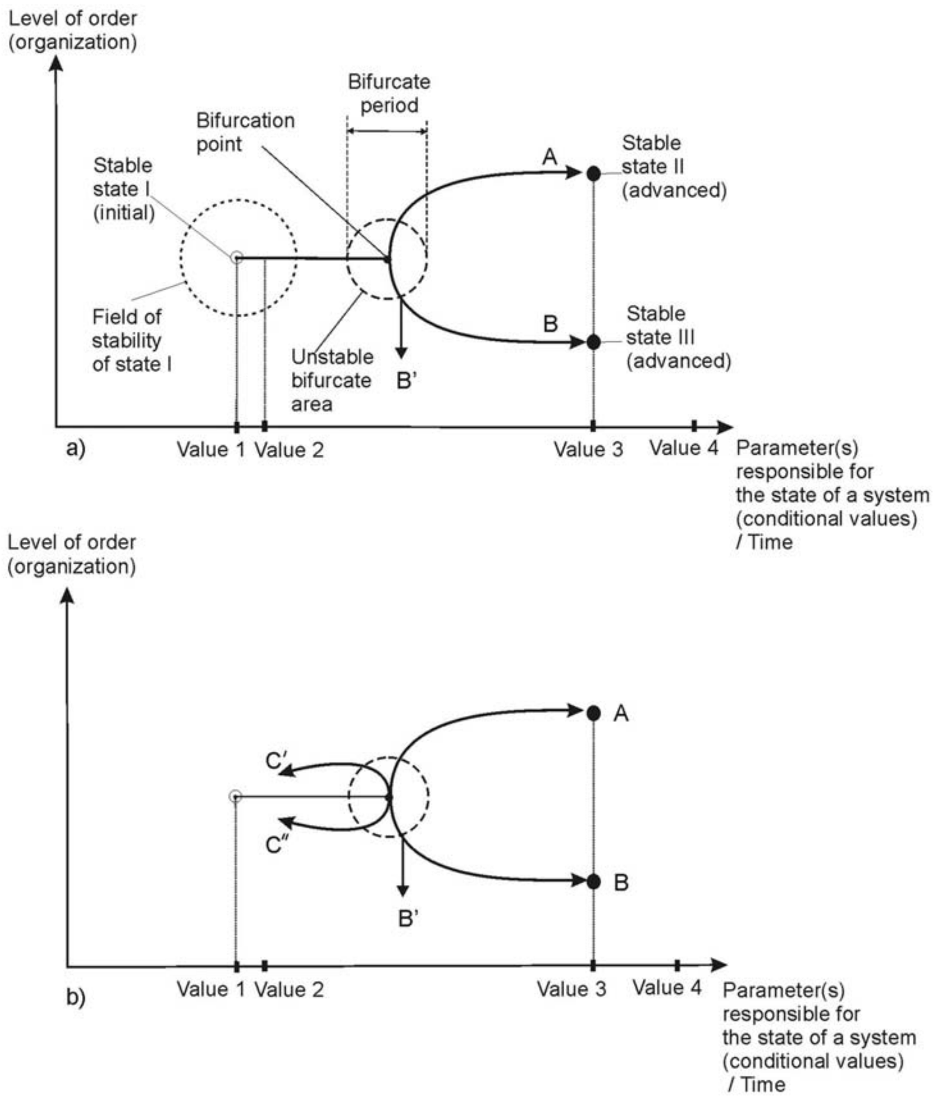

Figure 1. Principal scheme of bifurcation in a natural system under far-from-equilibrium conditions. ‘a’ – direct transition from the initial stable state into one of possible advanced stable states, due to a change of conditions in the outside world; ‘b’ – direct and reverse transitions (under oscillating conditions in the outside world). A – trend to an advanced higher-organized state; B – trend to an advanced lower-organized state; B’ – trend to complete destruction; C’ and C” - reverse trend to close to the initial state

stable existence of a system
↓
rise of instability through powerful fluctuations
↓
the highest point of instability (point of bifurcation, or critical point), radical change of the system’s structure
↓
choice of a new path of the development
↓
subsequent stage of its stable existence
(8, 35-37).

At the bifurcation point a system undergoes numerous accidental changes affecting its further development (Figure 1 a). This is the reason why the system’s potential paths of development bifurcate at the moment of its highest instability. Finally, the system follows one of many possible ways that can be united into two principal trends:

1) complication through self-organization (Trend A)
2) simplification and degradation (Trend B), up to full destruction (Trend B’).

The reverse of external conditions brings a system close to the initial state, in accordance with Trend C (Figure 1 b). Physicists understand self-organization as “an irreversible process, i.e., a process away from

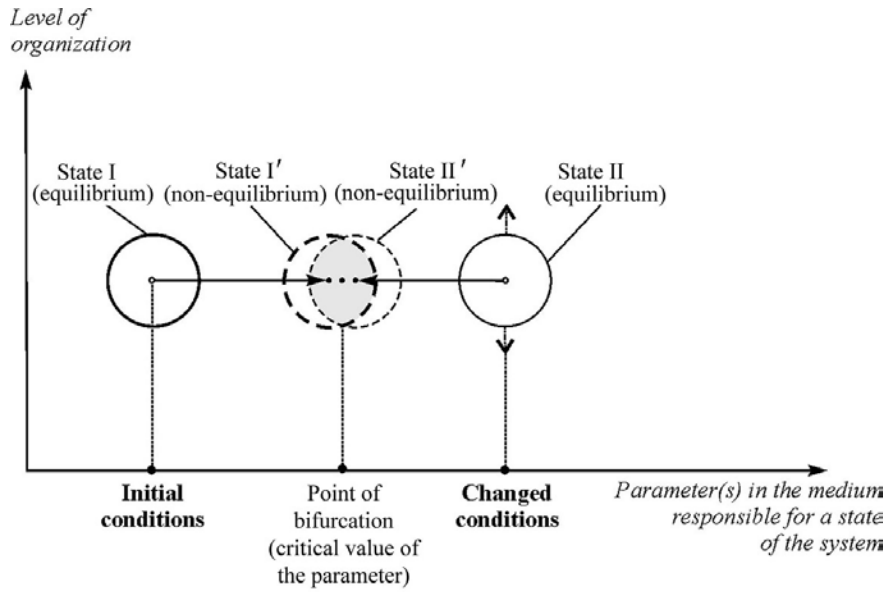

Figure 2. Attraction of the initial equilibrium state I and the advanced equilibrium state II to the point of bifurcation. Dotted circles – areas of relative stability of the nonequilibrium states I' and II' that are in a balance. The grey field is the area of 'interpenetrating' of the nonequilibrium states I' and II' around the point of bifurcation

thermodynamic equilibrium which through the cooperative effects of subsystems leads to higher complexity in spatial structures and temporal behavior of the system as a whole. Self-organization is the elementary step of evolution, while evolution consists of many such steps" (10, p.13). Some researchers in the field of biosemiotics and biocybernetics propose to employ the term "self-ordering", instead of "self-organization", having in mind non-equilibrium non-living systems, and to use the term "organization" for biological processes only (29).

The author has developed the theory of dissipative structures in the context of the origin-of-life problem (3-6). On basis of the bifurcate transition, described in detail in the literature (8, 35-37), several principal characteristics of the chemical system in the state of bifurcation were formulated (3-4). These are the most essential bifurcate or critical properties:

1) Sharp heterogeneity with intensive processes along and against gradients (i.e. counter spontaneous and non-spontaneous processes)
2) Continuous fluctuations (waves) and re-arrangement of molecules
3) Integrity through cooperative processes
4) Incessant exchange by matter and energy with the surroundings.

Although these properties do not express the unique essence of life, the loss of even one of them would make life impossible. Meanwhile, the critical properties are temporal, characteristic of a chemical system: they appear since the beginning of the bifurcate transformation and disappear with its completed transition to new stable state. Therefore, the bifurcate state of prebiotic organic systems is a starting point of their transformation into living units on the early Earth.

Non-spontaneous processes in biological systems are predominant. The first intensive non-spontaneous processes in chemical systems appear under far from equilibrium conditions (the first bifurcate property). At that stage, they do not yet dominate over spontaneous processes but counteract them. In this way, the emergence of an intensive counteraction between spontaneous and non-spontaneous processes decreases the difference between non-biological and biological worlds and, therefore, leads to a decrease in negentropy barrier. A further decrease in negentropy barrier is possible for the system existing in the oscillating regime around the bifurcation point, its internal structure bifurcated (Figure 2). This theoretically substantiated type was called "*bi-state* system" (3-4). A bistate system can be considered as a specific type of bistable system. It is characterized by its paradoxical tendencies to simultaneous separation and integration, because of balanced oscillations between two equal attractors (the initial and new stable states). The oscillations prolong the microsystem's existence around the point of bifurcation and preserve its bifurcate properties. Due to the bistate microsystem's oscillating character of existence, the contribution of free energy might, from time to time, prevail over the contribution of entropy, bringing it into the initial life thermodynamic niche that facilitates further loss of the negentropy barrier (Figure 3). In this way, the initial sparks of life may appear in such systems.

4.2. **Reconstruction of the inversion mechanism in oscillating prebiotic microsystems**

The reconstruction of the oscillating prebiotic microsystem transition into the primary living unit ("probiont") is represented in Figure 4. The individual

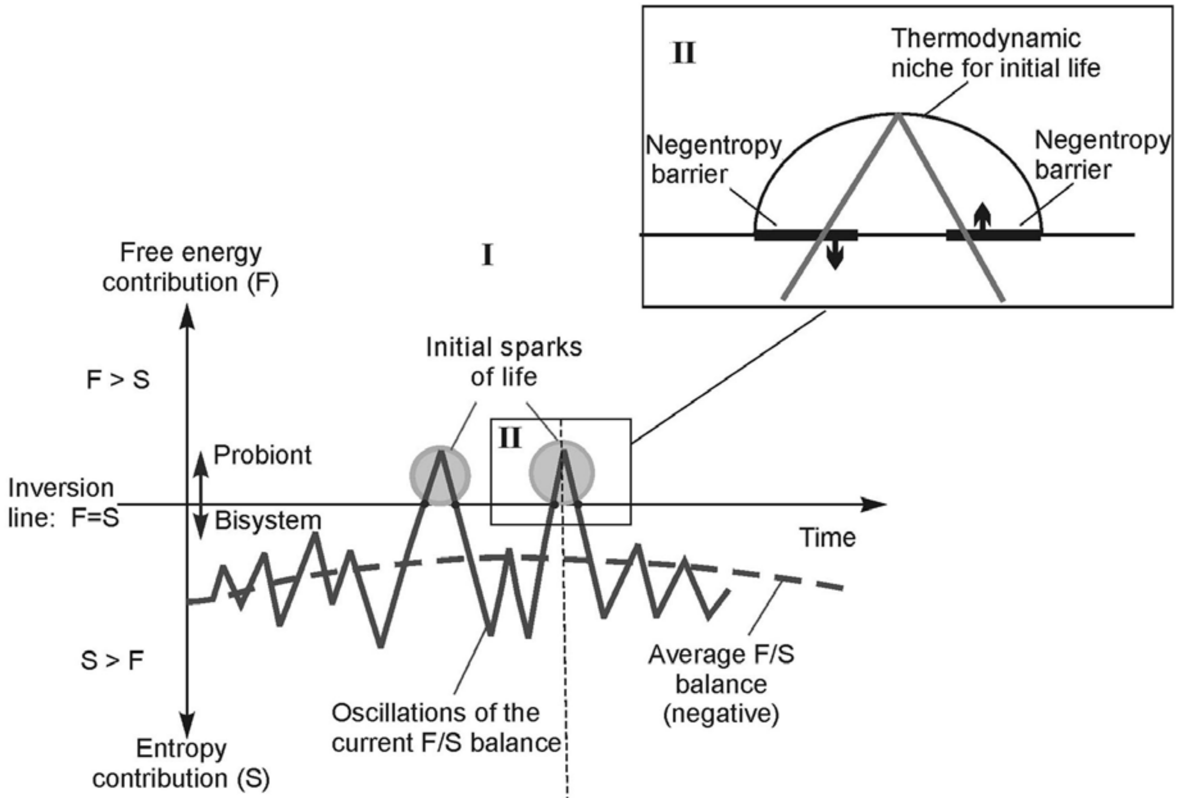

Figure 3. Oscillation of the balance "free energy contribution / entropy contribution" in a bistate prebiotic microsystem (I) and a thermodynamic niche for initial life (II, incut). A similar figure can be drawn for the balance "information contribution / informational entropy contribution".

figures show that the transition consists of the inversion of the balance "contribution of free energy / contribution of entropy"; the same illustrations could be made for the inversion of the balance "contribution of information / contribution of informational entropy". The oscillating prebiotic microsystem properties on the threshold of thermodynamic inversion have been considered in detail (4, 6). Such a microsystem is characterized by an exchange of energy and matter with the outside world, a tendency to dichotomy and continuous reactions that will result in free energy accumulation and preservation (Figure 4 A). Negentropy barrier is very low, because oscillations around the bifurcation point allow the microsystem to leap it at times (Figure 3). A further transformation of the oscillating prebiotic microsystem into probiont may proceed in the fluctuating medium only. Changes in the outside world stress the microsystem, provoking a release of preserved free energy. As a result, the total of internal and external energy contributions prevails over dissipation (Figure 4 B). The resultant direction of free energy flow reverses from the external to internal one (Figure 4 C). In this way, the microsystem undergoes thermodynamic inversion, importing free energy and exporting entropy (Figure 4 D).

Thermodynamic inversion can be expressed as follows (6):

$$(n\text{-}bs) \quad F^+ < F^- \rightarrow (F^+ \approx F^-, \text{ inversion moment}) \rightarrow F^+ > F^- \quad (bs) \qquad (1),$$

where F^+ is contribution of free energy into a system, both at the expense of its internal producing and extracting energy from the outside world, F^- represents loss of free energy in a non-biological or biological system, both at the expense of internal devaluation and dissipation in the outside world, *n-bs* – non-biological systems and *bs* represents biological systems;

$$(n\text{-}bs) \quad I^+ < I^- \rightarrow (I^+ \approx I^-, \text{ inversion moment}) \rightarrow I^+ > I^- \quad (bs) \qquad (2),$$

where I^+ is the input of information into a system and I^- is the loss of information in a system;

$$(n\text{-}bs) \quad S > 0 \rightarrow (S \approx 0, \text{ inversion moment}) \rightarrow S < 0 \quad (bs) \qquad (3),$$

$$\text{or: } (n\text{-}bs) \quad S^+ \rightarrow (S^+ \approx S^-, \text{ inversion moment}) \rightarrow S^- \quad (bs),$$

where S is entropy, S^+ is contribution of (positive) entropy into a system, S^- is contribution of negentropy into a system (both at the expense of internal production and extraction from the outside world).

Thermodynamic inversion simultaneously leads to the balance change of spontaneous and non-spontaneous processes, the latter predominant. Low entropy structures integrate the entire system: this process results in the formation of biological organization (Figure 5). The

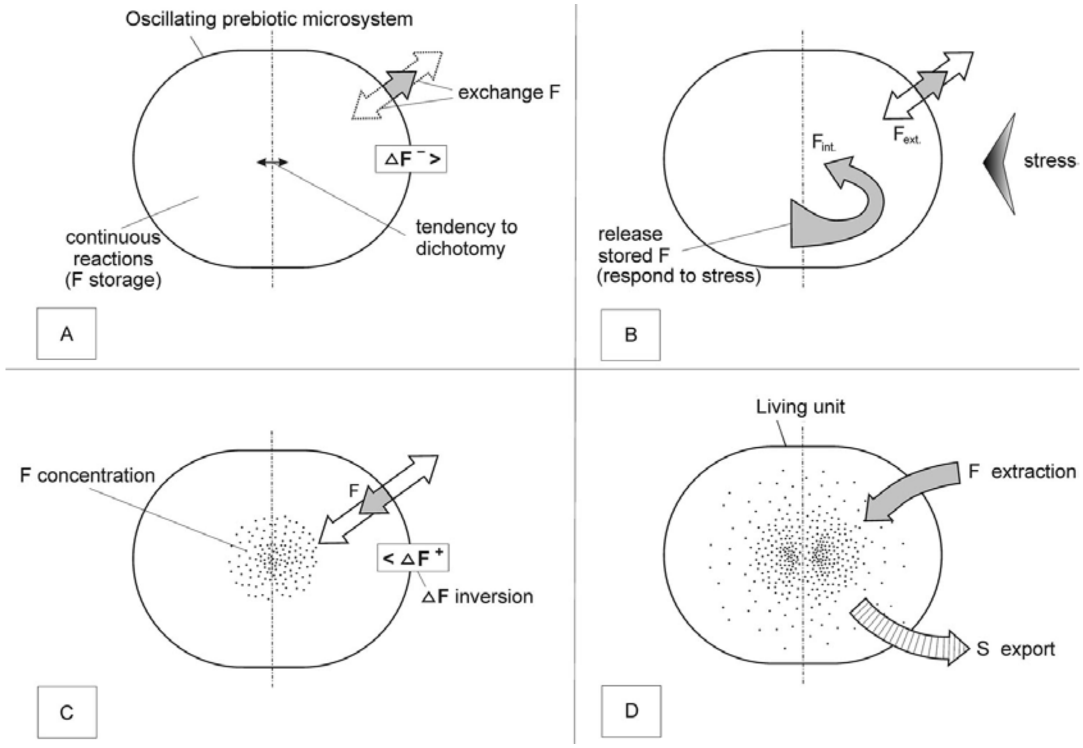

Figure 4. Reconstruction of a prebiotic microsystem transition into living unit. F_{int} (internal) and F_{ext} (external) free energy contributions into a prebiotic system; ΔF^+ (positive) and ΔF^- (negative) free energy gradients of the system with respect to the surroundings; arrows – directions of free energy and entropy flows

bifurcate structure of the oscillating prebiotic microsystem transforms into biological dichotomy.

4.3. After the thermodynamic inversion: the biological world

Thermodynamic inversion reverses a position of the chemical system from passive to active with respect to the environment. At the inversion point, the gradients of free energy and information between a prebiotic organic microsystem and its surroundings change from negative to positive (Figures 4 and 5). The actual initial biotic units (probionts) arise as "centers of activity" in the environment. By means of positive free energy gradient, a viable living system is able to transform the environment more efficiently than the environment does it. Unlike information in non-biological systems, bioinformation in a living being is based on purposefulness and programming, providing a positive information gradient with respect to the environment. In this way, the transformed microsystems acquire the previously listed key biological properties (the ability to concentrate and reorganize free energy and information; the ability to exhibit an intensified counteraction to external influences; expedient behavior; regular self-renovation).

After thermodynamic inversion, entropy production in the probiont is compensated by only a part of the internal free energy and information. The excess free energy and information provide the negentropy method of organization of a biological system. The entire system is arranged by predominant non-spontaneous processes and maintains an optimal balance between them and spontaneous processes. This balance results in the support of the biological system's functional parameters within optimal limits, by means of regulation and control. As non-spontaneous processes are directed against gradients, biological regulation functions on the basis of differentiation and specialization of structural-functional elements.

The change of predominant processes at the inversion point inverts interactions in the pair of systems "prebiotic system/probiont – environment". Before the inversion, a prebiotic chemical system reacts to external influences in accordance with Le Chatelier's principle just like any normal chemical system - it partially compensates the influence effect. The chemical system reaction is weakened (energetic effect of the external influence prevails over the effect of the system's response) and retarded (the external influence first, and later – the reaction). After inversion, a living probiont becomes an active component in the pair system "probiont – environment" (4). Correspondingly, its response to external influences becomes intensified (the second key biological property) and anticipatory, based on foresight (a constituent of the expedient behavior, the third key biological property). To be consistent with this method of organization, the probiont's structure, function and its behavior in the environment are to be formed on basis of purposefulness and programming. The appearance of

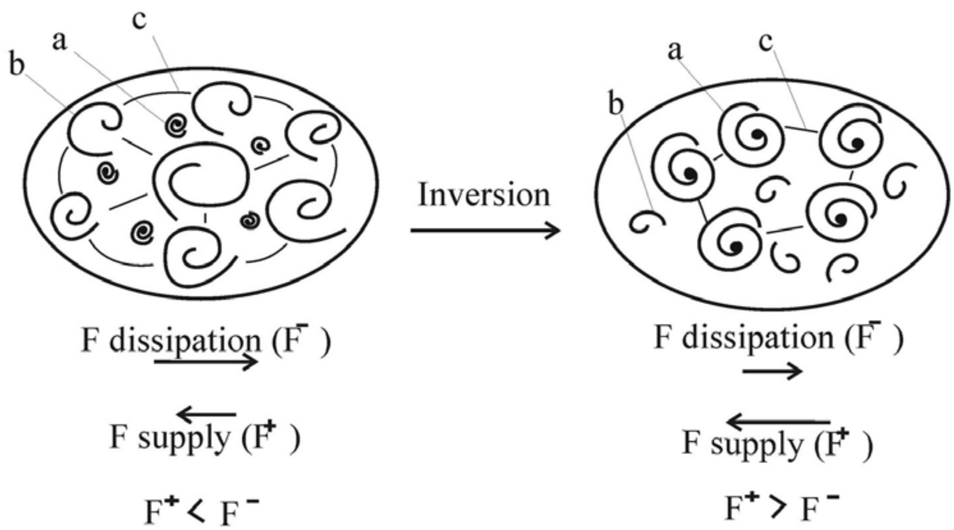

Figure 5. Inversion of the balance between the contributions of spontaneous and non-spontaneous processes in a chemical system. Left – a system with prevalence of spontaneous processes, right – one with prevalence of non-spontaneous processes. 'a' – areas with prevalence of non-spontaneous processes containing low entropy structures that produce free energy (and the initial biological information); 'b' – areas with prevalence of spontaneous processes containing high entropy structures; 'c' associative links between high entropy structures and low entropy structures. F – free energy, F^+ - input of free energy, F^- - loss (dissipation) of free energy

purposefulness and programming allows the probiont to become an active constituent in the pair system.

5. EMERGENCE OF BIOINFORMATION

5.1. Information exchange in a self-organizing chemical system

Extraordinary sensitivity to external changes is one of the most essential properties of a self-organizing chemical system, when it is in the state of bifurcate transition (4, 35-37). This property appears, on the one hand, to be the result of incessant fluctuations in such a system, and, on the other hand, a continuous exchange of matter, energy and information with the outside world. The information inflow into a self-organizing chemical system increases its level of order and decreases the uncertainty level, while the informational entropy inflow, on the contrary, decreases order and increases uncertainty. The informational exchange in this type of natural system is characteristic of the non-biological world ("physical" information).

Various physico-chemical processes may influence the balance "(physical) information / informational entropy", resulted in the information increase or decrease in a self-organizing chemical system under far from equilibrium conditions. Thus, for the transition of chemical compounds of different complexity, both inwardly and outwardly, the system changes its internal structure. The system becomes of higher- or lower-order, depending on the flows of information that change its structure ("structural" information). Besides, any change in the external conditions (for instance, a rise of temperature) exerts a certain influence (stress) upon the system, deforming its structure and associated chemical reactions network. The deformation may display itself in the modification of organic molecules, the appearance of new pathways of chemical reactions, etc.; it alters the chemical system's internal structure and the level of its order. In fact, this deformation is an imprint of a change in the surroundings. Figure 6 demonstrates the introduction of external information into the system. However, this structural information is depreciated by the informational entropy input, as a self-organizing chemical system does not have the mechanism for concentrating and re-organizing of information, unlike a living being.

It is important to emphasize another principal phenomenon peculiar to a self-organizing chemical system under far from equilibrium conditions: the presence of **choice** of a further development path at the bifurcation point. As the system undergoes numerous accidental changes at the bifurcation point, its further way of development cannot be precisely determined or predicted. In other words, each of the main trends A, B, B', C' and C'' (Figure 1) has a possibility (even extremely small) of being realized. Consequently, the probability of every trend cannot be equal to both 100% and 0%, after it has passed the bifurcation point. In fact, this opens boundless potential ways for the natural system development.

5.2. Exchange of information in a bistate prebiotic microsystem

Unlike a simple self-organizing chemical system, a bistate prebiotic system is characterized by accidental choices of its further way of development, due to its frequent transitions through the bifurcation point. The accidental choice allows the bistate prebiotic system to

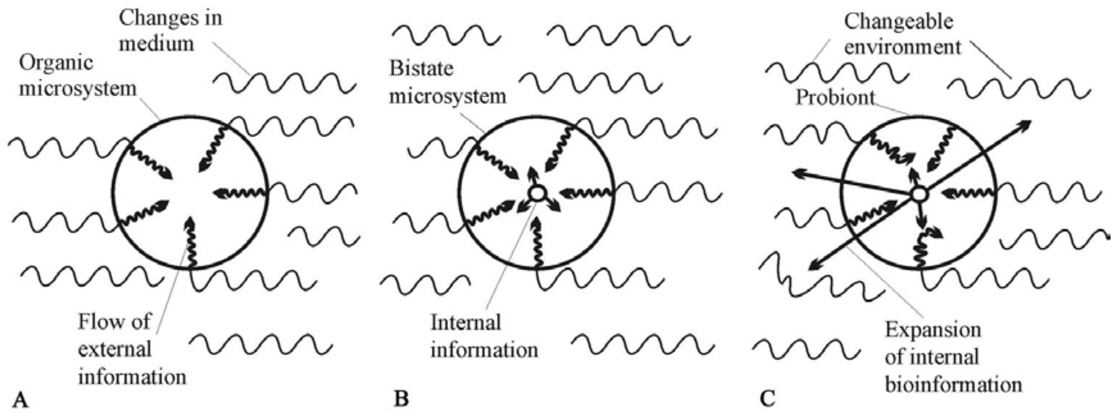

Figure 6. Arising of internal information in a bistate prebiotic microsystem and its transformation into bioinformation of living probiont. A – flow of external non-biological information into a prebiotic microsystem from the changeable medium; B – emergence of internal information in a bistate prebiotic microsystem; C – transformation of internal information into bioinformation and its expansion into the environment.

spontaneously obtain a higher order level (in accordance with the trend A, Figures 1 and 5) compensated by its fall to a much lower level (trend B, Figures 1 and 5) with time. However, heterogeneity of a bistate system admits a continuous existence of high-ordered (low-entropy) structures in its local parts.

As a bistate system tends to simultaneously develop in opposite directions from the central point of bifurcation, its real state is changeable dependent on a current balance between different potential states (A, B, and C, Figure 1). This peculiarity implies the internal information production by this type of systems. This thesis has corroborated by Ebeling *et al* (2001, p. 257): "Information may occur only in the system, characterized by several potential (possible) states and a certain indetermination with regard to its real state" (19).

Oscillations of a bistate prebiotic microsystem around the bifurcation point are not symmetrical: the onward transition through the bifurcation point brings about a further new accidental change that provides an expanding spectrum of potential advanced states (Figure 7 Right). In fact, a transition to a higher-order state (in accordance with the trend A) implies the input of (physical) information produced inside the system - while its move to a lower-order state (trend B) correlates with the input of informational entropy leading to disorganization. The reverse transition is characterized by a contracting spectrum of potential states. The system cannot return exactly to the initial state because of the internal irreversible changes it has undergone, but it tends to return close to the initial state, within the contracting spectrum (Figure 7 Left). The tendency towards contraction limits the opportunities for new transformations in the system and provides conservation of its current state. As a result, such an oscillating prebiotic microsystem obtains two simultaneous opposite tendencies to conservation and modification (7). Continuous oscillations lead to an incessant generation of new changes in the microsystem, due to the expanding spectrum of onward transitions conserved in congruence with the contracting spectrum of reverse transitions (Figure 8). In this way, the bistate prebiotic microsystem can produce and accumulate (physical) information.

Summarizing, in the course of its existence the bistate prebiotic system irreversibly transforms, due to accidental choices of trends for its further development. There are two counter information flows in the system. The flow of external information, initiated by changes in the outside world (imprint of events), makes its way to the center of the bistate system as it does in a usual self-organizing chemical system. Oscillations around the bifurcation point allow the generation of internal information, directed to the outside world, in the bistate system (Figure 6 B). An accidental adjustment of this system to a higher order state at the bifurcation point leads to the input of (physical) information that decreases the negentropy barrier, and to its negotiation, if the contribution of information is very high. This accident, being highly improbable in a *usual* self-organizing chemical system, becomes highly probable in a *bistate* prebiotic microsystem, because its negentropy barrier is very low, due to the irreversible accumulation of internal (physical) information, availability of local low-entropy structures and oscillating character of its existence.

5.3. General aspects of bioinformation rise

As it was considered in the section 4.2, thermodynamic inversion is the major transformation leading to the transition of a bistate prebiotic system into a living probiont. In the inversion course the tendency to concentration of free energy and information, characteristic of the living unit (Figure 9 B), starts prevailing over the tendency to their dissipation in the bistate system (Figure 9 A). In a probiont the gradients of free energy (F) and information (I) become positive with respect to the environment. A living system is now able to transform the environment and preserve free energy and information, concentrated in the probiont center (Figure 9 B). Their circulating flows embrace many cyclic chemical reactions.

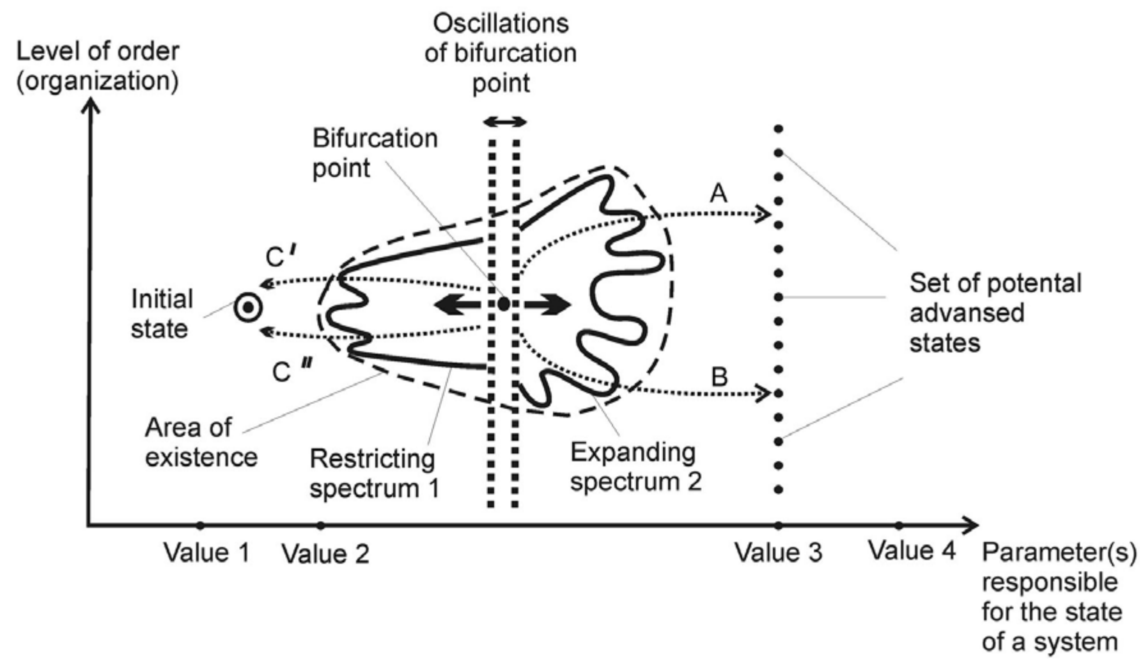

Figure 7. Spectra of potential states of a chemical system oscillating around the bifurcation point. A – trend to an advanced higher-ordered state; B – trend to advanced lower-ordered state; C' and C" - reverse trends to close to the initial state. On the left (from the bifurcation point) – contracting spectrum 1 focused on the initial state, on the right – expanding spectrum 2 corresponding to a set of potential advanced states.

Accumulation of free energy and information takes place within the limited space that leads to a continuous concentration of free energy and a compression of information. Because of oscillations within a probiont, free energy alternately concentrates and is released. Internal information is compressed and expands, all forming a continuous biological circulation.

The inversion moment inverts interactions in the pair system "prebiotic system/probiont – environment". Before the inversion, a prebiotic chemical system responds to external influences in accordance with Le Chatelier's principle, partially compensating the influence effect – the energetic effect of the external influence prevails over the system's response and the system's reaction is retarded (first external influence, and later – the reaction). After the inversion, a living probiont becomes an active constituent in the paired system "probiont – environment". The paired system's response to external influences is intensified (2nd key biological property) and anticipatory, based on the foresight (determining the expedient behavior, the 3rd key biological property) (4). To be consistent with this method of organization, the probiont's structures, functions and behavior in the environment must form on the basis of *purposefulness* and *programming* (the second feature of bioinformation listed in section 3.4).

Purposefulness begins when the values of positive and negative entropy are approximately equal ($S^+ \approx S^-$, $\Delta S \approx 0$), in the absence of any thermodynamic trends and thermodynamic limitations, as long as the contributions of constructive (trend A, Figures 1 and 5) and destructive (trend B, Figures 1 and 5) transformations compensate each other. Such a thermodynamic freedom provided boundless opportunities for the re-combination of nucleotide and amino acid monomers, necessary for the genetic code emergence in the Earth biosphere. Abel emphasizes that freedom from determinism is necessary for re-combinations of meaningful nucleotide syntax and the prescription of biofunction: "…each nucleotide can be freely "chosen" at each locus, not militated by law or polymerized by chance" (Abel D.L., personal communication, 2012). Starting from "thermodynamic zero", the negentropy trend had been running the probiont building on the principle of perspective choice and resulted in the appearance of biological programming in initial living units.

This adjustment means the reorganization of "physical" information into bioinformation. In a living probiont, information can be subdivided into two parts: (1) compensating informational entropy and (2) the excessive one, forming the "super-entropy informational structure" (the "super-entropy informational space," which soon becomes the "bioinformational superstructure") . The super-entropy informational structure, brought to life by the radical *thermodynamic* transformation determines the entire living system macro-state. It is maintained through the circulation of both internal and external (reflection of the outside world) information, involving the network of chemical reactions and compounds. The bioinformational superstructure, based on the interaction between external and internal bioinformation, provides the anticipatory reaction to changes in the environment, forming informational images of perspective actions:

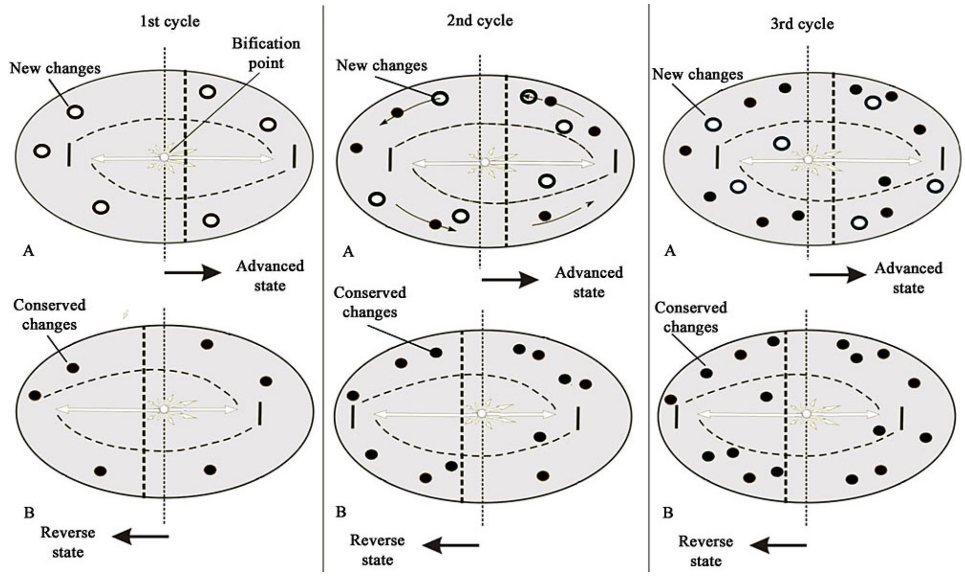

Figure 8. Irreversible accumulation of changes in a bistate prebiotic microsystem in the course of its oscillations around the bifurcation point. The 1st cycle of oscillations (left) is the transition to the advanced state, the appearance of new changes (A), with the following reverse transition and conservation of these changes (B). The 2nd (center) and 3rd (right) cycles are the same transitions, along with the appearance and conservation of additional changes.

Purpose → Action, the achieved result

The super-entropy information and free energy launch plenty of constructive transformations in a probiont (consistent with the trend A, Figures 1 and 5) that prevail over high-entropy destructive transformations (trend B, Figures 1 and 5). Nevertheless, destructive events inevitably disturb the circulation of bioinformation at various hierarchical levels. For this reason, both repetitions (for instance, tandem repeats) and mutations (misincorporations, errors) are peculiar to a living system. This thesis correlates with the expression "self-reproduction with variations", proposed by Trifonov (2011) as the minimalistic definition of life (38).

As bioinformation tends to compression, the bioinformational superstructure (the life's software) inevitably builds into the network of chemical reactions and organic molecules (life's hardware), purposefully reorganizing and directing it. In this way, circulating bioinformation controls the life's processes (its third feature: section 3.4). The interacting software/hardware systems organize all life's processes in the probiont, including metabolism, manufacturing, control, and feedback. The super-entropy information allows the *perspective choice* (or *choice with perspective*) of the development trend by a probiont in the course of its latent oscillations around the bifurcation point (instead of the *accidental choice* in a bistate prebiotic microsystem). Abel (2009) introduced the similar term *purposeful choice,* or *choice with intent* (principally different from *chance choice*) required for biological programming (25). In this way, a probiont is able to choose and execute the purposeful (expedient) behavior, allowing the bioinformation flow expand to the environment (Figure 3 **C**). A continuous accumulation and (algorithmic) compression of bioinformation in the course of the probiont's existence implies the appearance of rudimentary "mind" (conserved information of previous events), as a basis for the perspective choice and purposeful behavior.

The informational software basis and the substantial/energetic hardware basis in a living system are quite different. Therefore, perspective images from the probiont software (bioinformational superstructure) can be transferred into a corresponding action in the hardware (and later in the environment) only by means of a special converter - the code that integrates a set of signs (software) and corresponding function (hardware). The block – sign, code, function – is a biosemiotic system, with which a living system maintains its existence aimed at the perspective:

Purpose → ["Signs → Code → Function"] → Action, the achieved result

It follows that bioinformation is necessarily functional (its first feature listed in section 3.4).

6. ARISING OF BIOLOGICAL SYSTEMS ON THE EARLY EARTH

6.1 Physico-chemical aspects of the origin of probionts and their communities on the early Earth

When building the inversion model of life emergence on the Earth, a lot of data from terrestrial geology and biochemistry. According to the proposed concept, a three-dimensional organic microsystem, composed of hydrocarbons, lipids and amino acids, in combination with minor quantities of other biologically

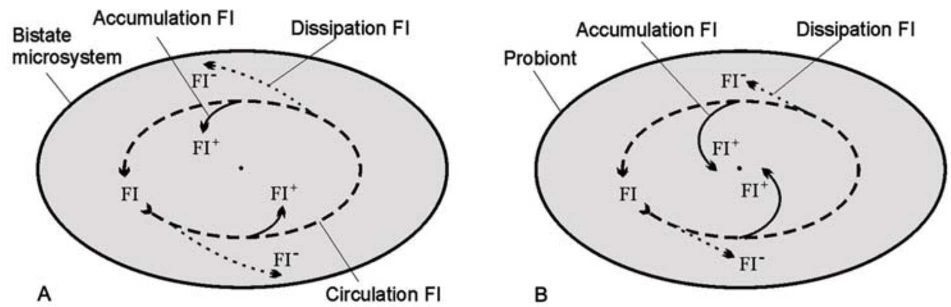

Figure 9. Resultant trends of free energy and information transference in a bistate prebiotic microsystem (A) and probiont (B). A. Bistate prebiotic microsystem: the trend to dissipation of free energy and information (FI^-) from the system prevails over the trend to their accumulation (FI^+). B. Probiont: accumulation of free energy and information (FI^+) in the system predominates over their dissipation (FI^-).

important organic molecules, was the most appropriate prebiotic system for the transformation into a primary living unit on the early Earth (6). The microsystem could also contain minor quantities of nucleotides, or they could be extracted from the outside world through the lipid bilayer membrane (39), or appear as co-products of (bio) chemical reactions (40). The transformation occurred in a hydrothermal medium, where macro- and microoscillations of thermodynamic and physico-chemical parameters (T, P, pH, Eh, $C_{comp.}$) took place. Simple and complex compounds detected in present hydrothermal systems contain all the biologically important atoms (C, H, N, O, P, S). The optimal temperature range for the transition of prebiotic microsystems into primary living units (probionts) is estimated to be from 70-80 to 100-120ºC. The origin-of-life process on the early Earth took place in the fluctuating hydrothermal medium. The process involved two successive stages: a) spontaneous self-assembly of initial three-dimensional prebiotic microsystems composed mainly of hydrocarbons, lipids and simple amino acids (or their precursors) within the temperature interval of 100-300ºC (prebiotic stage); b) non-spontaneous synthesis of proteins, sugars, ATP and nucleic acids which started at the inversion moment within the temperature interval of 70-100ºC (biotic stage). Macro- and microfluctuations of thermodynamic and physico-chemical parameters are able to sustain these chemical conversions. Such conversions have been detected in several contemporary hydrothermal systems in Kamchatka (41) and many other regions.

Thermodynamically and chemically coupled reactions were the most appropriate for the prebiotic microsystems to overcome the negentropy barrier, because they minimize the internal entropy production. ATP hydrolysis and condensation reactions to form biopolymers seem most relevant for this case, as they are in the foundation of biochemical processes. ATP hydrolysis (to ADP and AMP) proceeds with a release of energy and adsorption of water; on the contrary, the condensation reactions to form biopolymers (peptides, oligo/polysaccharides, oligo/polynucleotides) proceed with a release of water and utilization of energy. The high energy of ATP energy results from the phosphorylation of AMP and ADP:

$$ADP + P_i (+ E) \rightarrow ATP.$$

Reactions of phosphates provided the energetic basis for oligomerization and polymerization of amino acids and nucleotides (6, 42).

6.2. Emergence of bioinformation on the Earth

In this section, the reconstruction of bioinformation emergence in primary forms of life on the Earth is substantiated, based on the above-proposed general aspects of bioinformation. The inversion concept's major thesis, which differentiates it from other concepts, comprises, on the one hand, spontaneous (accidental, random) transformations in prebiotic systems. These alone cannot lead to life. On the other hand, non-spontaneous (purposeful) transformations – the result of thermodynamic inversion - are responsible for the *negentropy conversion* of prebiotic systems into initial living units.

Powered by the initial negentropy impulse, the ATP hydrolysis and biopolymers condensation contributed prebiotic bistate microsystems to launch specific circulations of both free energy and bioinformation. Living probionts inherited the bistate microsystem's oscillating character of existence. Thus, in all earthly forms of life oscillations of free energy and bioinformation are obvious: a) free energy first conserve in high energy compounds (ATP), and then release; b) bioinformation first stores in sequences of nucleic acids (DNA), and then releases in the active functional form of proteins. Such reorganization in the system substantial/energetic basis (life's hardware) was guided by the super-entropy informational structure (software) that provided its purposeful choices of constructive transformations and expedient behavior. Thus, the most appropriate building blocks for storage and activation of bioinformation were selected at the probiont stage. From both chemical and bioinformational points of view, only nucleotide chains are suitable for the compression, accumulation and preservation of bioinformation. Besides, the polynucleotide sequence of DNA or RNA is an ideal information storage structure since each nucleotide has no dependence on preceding or following nucleotides and can be arbitrarily set to the functional value desired from the four possible values (26).

In the probiont building process, random sequences of amino acids and nucleotides, which had been spontaneously synthesized in the former prebiotic microsystem, were re-assembled into functional sequences and became involved in a general circulation of bioinformation that proceeded as repetitions with variations. Plenty of experiments on thermal abiotic synthesis of polyamino acids made by Fox with co-workers demonstrated a principal difference between functional protein sequences synthesized *in vivo* (i.e. through *prescriptive* instructions), and random (non-functional) proteinoid sequences synthesized *in vitro*: the latter were devoid of some important properties peculiar to functional proteins (in particular, the tertiary structure) (40, 43).

Nucleotides and amino acids are linked together in heteropolymeric sequences, rich in bioinformation (20). The genetic code analysis suggests that an incessant search for enhanced performance is guided by an inherent logic of self-perfection (21); and it is in agreement with the "choice with perspective" principle and inevitable tendency to compression of bioinformation allowing the advancement of life. According to the theory of early molecular evolution, the very first genes may have been simple tandem repeats (44). They were complementary RNA chains, GCCn and GGCn; the codons GCC and GGC correspond to the first line of the Evolutionary Chart of Codons – the earliest step in the origin of life at its triplet stage. The following stages of the evolution of codons include point mutations of the initial GCC and GGC codons. In the framework of the inversion concept developed in this article, the emergence of these complementary RNA chains should be re-interpreted in the following way: they appeared not by chance as separate structures in the medium, but as sub-structures within thermodynamically inverse microsystems (original probionts), through their interaction with primary proteins. This thesis can be corroborated by the Seaman and Sanford's recent study, who presented the evidence that executable computer programs and human genomes contain similar patterns of repetitive code (27, 32). These researchers used the Skittle Genome Visualizer (a new sequence visualization suite of tools) developed to analyze DNA sequences and repeat patterns in any type of sequence, including RNA, protein, a written text, music, or a computer code. Examples of similarities between genomes and executable code were found at every scale: (1) homopolymers, (2) tandem repeats, (3) distributed repeats, (4) isochores, (5) and entire chromosome/file organization. The authors came to the conclusion that "…the patterns of variation visible within genomic [tandem] repeats do not appear to be random…, it is reasonable to consider the possibility that such variation may not be the result of an entirely random mutation process" (27, p 390). In general, Seaman and Sanford explain the similarities between genomes and executable code by universal constraints in efficient (bio)information (32). The availability of super-entropy information (see section 5.3) in both biological and social worlds may cause the universality of constraints.

The circulation of bioinformation on a purposeful basis needs the highest level of organization, because every message in a biological system has its destination and produces a function in the right place, on the right time. It follows of the reason that primary living units purposefully selected L-amino acids and D-sugars to interact in the sequences of functional proteins and nucleic acids, instead of the spontaneous D- and L-forms alternation in prebiotic microsystems. As it was emphasized by Galimov (2006), in the case of amino acids' racemic mixtures, they could not form complementary pairs and recognize each other within a polypeptide spiral (42).

A biosemiotic system, being a converter between life's software (purpose, signs) and hardware (function, action), evolves due to the inevitable tendency to bioinformation algorithmic compression, predetermined by a continuous complication of information processing. A functional sequence (gene or protein) became meaningful in the course of algorithmic optimization (selection of a symbol in the sequence to specify function) (25). Various codes convert signs and functions in primary and contemporary living beings. There is evidence of the bioinformation system-wide organization in living systems due to the existence of super-entropy informational structure. For instance, codon code, binding site code, and splicing code are separate yet interdependent on each other to make the right protein product at the right time (27).

6.3. **Further evolution of probionts to progenotes and prokaryotes**

The hydrothermal medium is usually anisotropic, and it is characterized by variable gradients of temperature, pressure, electric potentials, concentrations of chemical components, etc. The evolution of probionts in such wildly heterogeneous conditions had led to the formation of heterogeneous communities of various probionts and their groups occupying different ecological niches. Because of the expansion of bioinformation and free energy beyond the bounds of probionts (Figure 6 **C**), there appeared a circulation of bioinformation and free energy, uniting the entire community. In this way, geochemical cycles were converted into biogeochemical ones, and primary communities started their active transformation of the environment. The interaction between different complementary groups of probionts resulted in the emergence of the community functioning as a stable self-sufficient unit of life (6). According to the concept by Zavarzin (2006), biogeochemical cycles of the biosphere might be launched only by different obverse groups of microorganisms (45).

The progenote, theoretically reconstructed by Woese (1987), is considered as an intermediate form of life between probionts and prokaryotes (46). It is correlated with the Last Common Universal Ancestor (LUCA) in a structure of the extinct part of the Phylogenetic Tree. Organisms of this type could have had a genotype and phenotype (i.e., bioinformation stored in a quiescent [replicative] form in one class of molecules, that was also manifested in an active [functional] form in another), but their genes would for the most part have been physically separate units; they would not be organized into large contiguous linear arrays. Proteins would have been small or non-unique sequences or both. It follows that proteins of normal size could not have been synthesized without introducing (many) errors. As a consequence, enzymes would not be as accurate and specific as their modern counterparts. The progenote reasonably had error rates two or three orders of magnitude greater than found in cells today. To maintain the existence of minimally functional cells, genes should be disjoint, and they could have existed in large copy numbers. Probably, the informational macromolecule at this stage was RNA, the functional form of nucleic acid today, not DNA.

Evolution of progenotes into prokaryotic cells proceeded through a significant rise of the level of the translation accuracy, elongation of strings of both classes of biopolymers, the formation of DNA and a genome (46). This process led to an extraordinary rise of structural-functional complexity of living beings and their communities. In the ecosystemic aspect, process was characterized by the emergence of new species and parallel ways in the earliest biological evolution. Existence of manifold cross branches in the Phylogenetic Tree of prokaryotes was emphasized, in particular, by Doolittle (2000) (47). In the opinion of some microbial ecologists, thermophilic (or even hyperthermophilic) Archaea and Bacteria are at the root of the Phylogenetic Tree (46, 48-49). The emergence of species had led to the initial communities of probionts and progenotes ("embryos" of ecosystems) conversion into real ecological systems, hierarchically organized different microbial species. Due to their expansion, life had spread over the entire Earth surface. And it was a starting point of the microbial biosphere development (50).

7. METHODS OF THE INVERSION CONCEPT VERIFICATION

This theoretically elaborated concept can be verified in different ways. One of them is laboratory experiments on prebiotic chemistry under *oscillating* conditions modeling fluctuating hydrothermal environments. Currently, almost all experiments in prebiotic chemistry have been conducted under stable conditions. However, as it follows from the inversion approach, the experimental chamber conditions should be oscillating (in particular, for simulations of natural fluctuating hydrothermal environments). A few conducted experiments and computational models demonstrated a facilitation of synthesis and oligomerization of biologically important organic molecules under oscillating conditions (51-56). The next step would be experimental research of prebiotic (macro)molecules, microsystems and their associations in the state of bifurcate transition, including bi-state systems; this type of experiment has not yet been carried out. These experiments could form the basis for experimental attempts to obtain probionts (6).

One more way consists in estimations of probability of functional protein getting by chance, and its comparison with the probability of functional protein formation through the thermodynamic inversion. Thus, Axe (2004) estimated the probability of a spontaneous functional protein fold performing (from a prebiotic soup) as extraordinary low - one in 10^{77} (57). It is implied that the non-spontaneous process at thermodynamic inversion may increase the probability for many more orders, but these evaluations have not been made yet. Some actual probability estimates for one or two universal proteins could be done by using Hazen and colleagues' equation for 'functional information' and using Durston and colleagues' values for functional sequence complexity, plugging them into Hazen's 'functional information' variable and then solving for M(ex)/N. (23, 28). That should give a rough probability of obtaining a given universal protein in a single recombination. From there, one can evaluate the number of recombinations probable: (1) in the proposed scenario with the thermodynamic inversion leading to a salutary rise of the biosemiotic "signs-code-function" system due to availability of super-entropy information, and (2) in other scenario without the thermodynamic inversion that implies gradual random re-assembling of biopolymers into their functional form. Then it can be evaluated how plausible both scenarios are for re-assembling biopolymers into their functional form.

Strict physico-mathematical descriptions of the distinguished bistate type of systems could also be helpful in further elaboration of the inversion concept. They can be developed in the framework of irreversible thermodynamics, basing on the present descriptions of bifurcate transitions and dissipative structures.

8. CONCLUSION

The proposed inversion concept draws a dividing line between Physical (non-living) and Biological (living) Worlds in the Universe. A biological system (a living being/community and its environment) has the negentropy organization. Biotic systems (living beings and their associations) build into a physical spatio-temporal continuum (subjected to the second law of thermodynamics), transforming it into a negentropy spatio-temporal continuum. The prevalence of coupled processes over basic ones provides a further advancement of the constructive transformations in the negentropy continuum and its renovation. Being energy-wise uncompensated, negentropy systems can exist only in the conditions of their non-equilibrium exchange with the environment, their specific organization allowing them to extract free energy and information, and export entropy. A possible definition of a living system, having integrated the four above-mentioned key biotic properties, may be as follows: A living system is a negentropy self-renovation structure, characterized by the intensified counteraction against spontaneous destructive processes and an expedient interaction with the environment. The beginnings of life anywhere in the Universe represent the emergence of a primary negentropy impulse, due to thermodynamic inversion in prebiotic systems, their bifurcate state being retained by optimal fluctuations in the medium.

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Key words: Origin of Life; Biological information; Entropy and Free Energy; Nonequilibrium Conditions; Bifurcation; Properties of Biological Systems; Biosemiosis; Functional Sequences, Review

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