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Two faces of entropy and information in biological systems

Yuriy Mitrokhin

The Institute of Problems of Chemical Physics of the Russian Academy of Sciences (RAS), 142432 Moscow region, Chernogolovka, Russian Federation

HIGHLIGHTS

- Thermodynamic and information entropy are considered as two forms of total entropic process in biosystems.
- The origination of complexity cannot be compensated only by thermodynamic entropy.
- When and where in the past the entropy has been produced that is a payment for biological organization at present?
- The idea is discussed that the genetic information is an instrument of entropy disproportioning in time.
- The Second Low realization today cannot be without taking into account the information entropy in past generations.

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ABSTRACT

The article attempts to overcome the well-known paradox of contradictions between the emerging biological organization and entropy production in biological systems. It is assumed that quality, speculative correlation between entropy and antientropy processes taking place both in the past and today in the metabolic and genetic cellular systems may be perfectly authorized for adequate description of the evolution of biological organization. So far as thermodynamic entropy itself cannot compensate for the high degree of organization which exists in the cell, we discuss the mode of conjunction of positive entropy events (mutations) in the genetic systems of the past generations and the formation of organized structures of current cells. We argue that only the information which is generated in the conditions of the information entropy production (mutations and other genome reorganization) in genetic systems of the past generations provides the physical conjunction of entropy and antientropy processes separated from each other in time generations. It is readily apparent from the requirements of the Second law of thermodynamics.

1. Introduction

Discussion about implementation of the Second law of thermodynamics in living systems has always been a collision of diverse points of view, especially when discussing the role of information processes in such fundamental biological phenomena as growth, embryogenesis, ontogenesis and evolution. The fact that genetic information is correlated with the entropy production was expressed in the question: "what is the entropy (and energy) payment for information…" (Romanovskiy et al., 1984). Blumenfeld (1977) wrote: "According to the thermodynamic criteria any biological system is not more ordered than a piece of rock the same weight". However, a few lines later he admitted formalism of his approach: "Orderliness of living matter and the information it contained *have a sense*".

Prigogine and his school developed thermodynamics of open nonequilibrium systems and formulated idea about the nonequilibrium stationary state which these systems tend to. It is characterized as a state with minimal and constant speed of entropy production in the system. At the same time the total entropy change (δS) for such open systems consists of d_eS—the inflow (outflow) of entropy due to the exchange of matter and energy between the system and the environment and d_iS—the entropy production within the system: $\delta S = d_eS + d_iS$.

It should be emphasized that the minimum entropy production is valid in close to equilibrium conditions. The authors extend the theory to growth and development, emphasizing that the processes in biological systems do not contradict the second law of thermodynamics. Ontogenesis is considered as a transition from the less probable state to the more probable (Nicolis and Prigogine, 1990). The last assertion hardly is justified. The more probable state is disorganization, not organization. Organization requires the prescriptive information to temporarily and locally outsmart the Second law of thermodynamics of progressive, relentless disorganization.

Interestingly, Prigogine and his colleagues speak exclusively about the thermodynamic entropy in their works and avoid

E-mail address: ymitrokhin@mail.ru

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discussion of rather evident for every biologist fact that both in a cell and multicellular organism there is a permanent creation of new structures, maintenance of organization. All the pathos of their works focuses on the emergence of structures in non equilibrium dissipative systems which prepared artificially as a rule. It all is true without any doubt, and, apparently, the contribution of this principle–organization out of chaos—was decisive at the very early stages of the prebiotic evolution. But it is not enough for adequate description of the modern biological systems in terms of physical laws. The put forward by Prigogine argument that the outflow of the entropy of the system into the environment d_eS can compensate for the production of entropy within the system (d_iS) seems very unconvincing for real cells. Hardly the outflow of heat and low-molecular components (H_2O, CO_2, etc.) from the cell, giving a contribution to the positive entropy balance, is sufficient, especially since this outflow is not related to the creation of complex macromolecular structures in the cell. Nonequilibrium structures of biopolymers are not dissipative, as their maintenance does not require any export of entropy and they are conservative structures (Ebeling et al., 2001).

In the same vein other attempts to explain the spontaneous generation of the organization in living organisms through the continuous entropy production which accompanies the flow of free energy through the system are made. However, doubts remain. So, Klimontovich (1997) in his work, devoted to the entropy production in open multilevel systems, answers to the question—can we expect that self-organization is the only result of biological evolution—not, as inner aspiration for self-organization is not inherent property of physical and biological systems. He supposes that since the state of full chaos, i.e. thermodynamic equilibrium has not been determined (and is not characteristic of) biological systems, and provided the absence of definition of full order, the systems can be described in terms of 'chaos norm' or a relative degree of chaos. The concept more adequately describes the state of genetic systems which are characterized by an acceptable ratio between determinism and randomness (freedom) for combining functional elements of the systems. It is seen that when interpreting specificity of living objects the author considers only thermodynamic entropy as a main factor defining the direction of their evolving.

The complexity of the correct interpretation of the efficiency of the Second Law of thermodynamics in biological systems continues to be relevant and sometimes elusive for understanding of the problem. This is reflected in the concluding sentences of the problem analysis which was made by Rubin (2004): "In the center of attention here is the main paradox that the increase in the orderliness of biological systems is accompanied with a spontaneous production of positive entropy". An important step in comprehending a specific role of biological information, its content and consideration for correct interpretation of the Second low of thermodynamics was made by Quastler (1964) who defined two principle moments for its generation: 1—random selection of one of possible versions, and 2—memorization of such selection . Later on, an essential condition was added, which consisted in that new information can be generated in the unsteady-state systems only (Chernavsky, 2001).

Among the present concepts of the essence of biological information, two principal viewpoints can be distinguished: in terms of physical reductionism, information is not considered as really existing substance (Wachtershauser, 1997; Boniolo, 2003). The opponents state that the thesis of physicalists about a *spontaneous* polymerization of information macromolecules in initial chemical (pre-biotic) systems is incorrect, that genes and proteins have *never* been generated spontaneously. They were synthesized by molecular machines, which physically combine monomers to polymeric chains in accordance with information matrixes and codes. Thus, proteins and genes are molecular 'artifacts' (Barbieri, 2012). We suppose that this statement opposes cause to effect and violates the principle of holism. A disputable is attribution of information to the class of physical essences, though the author states that specificity of biological sequences cannot be measured quantitatively. Therefore, it is not clear—is information a phenomenon of life or that of human consciousness. In other words, does this concept reflect objective reality or not?

An interesting information concept was proposed by Battail (2009) who considers it as one of the main essences of the physical world, along with the matter and energy. However, unlike them, the information exists only in the world of living beings where it can be generated and multiplied (where it can proliferate) and may at the same time be annihilated (lost). The author introduces the notion of potential information to denote the information which exists in the form of some immaterial essence in nonliving world. I the living world, potential information turns into symbolic one through materialization into the form of the base sequence of genomes. At the next stage of its passage it looks as structural information of functional macromolecules and structures of cell metabolism . I can agree with the notion of potential information, not in the prebiological world but rather in the world of ideas that exist in the person's head. It is no mere chance physicists find not place for information in the strict system of physical laws. One of such attempts was made in the well-known works by Haken (1988) in the new interdisciplinary filed called synergetics. Using several model systems the author found the appearance of information from observing the effects of ordering or even self-organization. When the known one-stage order emerges from chaos in laser or any other model system, it resembles crystallization at a moment of attaining required temperature rather than the appearance of organization.

The existence of special intangible essence in biological objects was comprehended by Schröedinger (1944) when 10 years prior to the discovery of DNA structure he attributed mutation effects transfer through generations with the effect of a certain non-physical law .

Barbiery justly supposes that now genetic information should be considered as new *observable physical* entity, which is present in living objects along with other fundamental physical entities. However, a more precise definition should be given. Information and human consciousness as a derivative of information processes in neuron networks appear as new *non-physical* realities emerging parallel to the germination of life and becoming of human being. They acquire sense only in the process of information transfer and reception by a receiver, subsequent re-coding and generation of a biological function or thought. The value of potential information equals zero similarly to rest mass of elementary particles. We suggest the following definition of the sense of information for natural biological systems, namely, *certain observed essence consisting in a sequence of monomers of genetic macromolecules, which provided carriers transfer to molecular recoding devices, unambiguously realizes one of multiple possible sequences of elements when building functional molecules of another nature in a genetic system*. Probability of such event out of an organized biological system is close to zero even in the presence of messenger. Thus, information is nonphysical essence, which *arises* inside a pre-biological physico-chemical system at a stage of life origin, evolves from generation to generation and is present in living systems as long as they are such.

These definitions are have been made to show that information is not coming to the system from without. It comes into existence, becomes a reality in a primary physical-chemical system when the succession of the following events spontaneously encloses to a cycle: minimal polynucleotide—primary recoding device—polypeptide showing presumably polymerase activity—replication of