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Short communication

Comparative study of entropy and information change in closed and open thermodynamic systems

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ABSTRACT

In this paper we discuss the entropy and information aspects of closed and open systems. The information and entropy change of the system are discussed in the context of RNA synthesis.

1. Introduction

Von Bertalanffy suggested the theory of open systems in biology [1]. Organisms are open thermodynamic systems far from equilibrium. Boltzmann suggested that organisms (open systems) decrease their entropy during life [2]. Schrödinger followed his lead and suggested that organisms feed on negative entropy [3]. Schrödinger [3] argued "If D is a measure of disorder, its reciprocal, l/D, can be regarded as a direct measure of order. Since the logarithm of l/D is just minus the logarithm of D, we can write Boltzmann's equation[1] thus:

$$-(\text{entropy}) = k \log \left(\frac{1}{D}\right) \quad (1)$$

Hence the awkward expression 'negative entropy' can be he replaced by a better one: entropy, taken with the negative sign, is itself a measure of order" [3]. Mahulikar [20], Davis [15] and Ho [21,22] contribute to the concept of negentropy. Prigogine developed nonequilibrium thermodynamics and applied it on living organisms [4,5]. Balmer argued that "*living systems are uniquely characterized by decreasing their entropy over their life spans*" [6]. Davies predicts decrease of entropy of open thermodynamic systems in self-assembly processes [15]. In general, it was suggested [1–6,15,21,22] that open thermodynamic systems decrease their entropy and increase information during metabolic processes. "The two fundamental laws in a manner which is common in classical axiomatic thermodynamics [18], namely:

I) Energy is conserved in any real thermal process.
II) Caloric (heat) cannot be annihilated in any real thermal process".

"Theorem (II) can thus be reformulated in terms of information as Information (I) is destroyed in any real thermal process" [19].

Everyday experience that by "burning of newspapers in a stove or combusting petrol these materials are lost forever, together with the information involved, is a subject for discussion more than argument" [19]. "In the late 1990s the Dutch Nobel prize laureate Hooft argued that the salient difference between quantum and classical mechanics is the information loss. A classical system contains more information than a quantum system, because classical variables can take any value, whereas quantum ones are discrete. So far a classical system, to give rise to a quantum one, must lose information and that can happen naturally because of friction or other dissipative forces" [19].

Garby introduced "unsteadiness" of the open system [7]. Accumulation/deacumulation of substance and therefore, the entropy is the mechanism of unsteadiness. However, Hayflick [8–10] analyzed aging process and reported an increase of entropy during life. Silva [11] reported an increase of entropy during the

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[1] Notice that (1) is not Boltzmann equation. It is the result of mathematic manipulation of it. The proposed term −(entropy) has no physical sense according to the third law of thermodynamics/Nernst–Planck theorem.

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lifespan of average individuals to be 11.404 kJ/K/kg of body mass. Hansen [12] concluded that the entropy of an open thermodynamic system does not have to decrease. Gems and Doonan [13] reported that the entropy of the *Caenorhabditis elegans* pharynx tissues increases as the animal ages (and organizes itself). Popovic [14] suggested that organisms increase their entropy during and after life.

There are three types of thermodynamic systems:

a Isolated system is outlined by both rigid and isothermal border. It exchanges neither substance nor energy in any form with its surroundings.
b Closed system border allows exchange of energy and work, but not substance with its surroundings.
c Open system exchanges both, substance and energy with its surroundings.

In that case the number of particles inside closed and isolated systems is constant because there is no exchange of substances with the surroundings. In open systems the number of particles is variable. If open system exhibits growth, that is followed by import and accumulation of the substances. Thus, the number of particles inside the system increases. If open system loses substance then the number of particles decreases and organism exhibits atrophy.

In information theory, information is quantified through Shannon's formula [16,17]

$$i = \frac{I}{n} = -k\sum_{j=1}^{m} p_j \ln p_j \qquad (2)$$

where i is information per symbol in a message, I is information, n is the number of symbols in a message, k is a constant and p_j is the probability of occurrence of symbol j. In statistical thermodynamics, the most general expression for entropy is Gibbs entropy [16,17], defined as

$$S = -k\sum_{j=1}^{m} p_j \ln p_j \qquad (3)$$

where S is the entropy, k is the Boltzmann constant and p_j is the probability of a microstate. If we choose the constant in the Shannon's formula to be equal to the Boltzmann constant then both the information and the entropy can be expressed in same units. The connection between information and entropy is even deeper, since starting from Shannon's formula we can derive expressions for well known thermodynamic properties such as the Gibbs free energy and the Helmholtz energy [16].The aim of this research is to analyze the entropy and information change in closed and open systems that perform metabolic processes.

2. Theoretical analysis

Theorem (II) reformulated in terms of information says: "Information (I) is destroyed in any real thermal process" [19]. The question appears: can the Information be destroyed? Let us analyze, starting from: "We can assume now that there is no information "an sich" or in other words information needs in all cases a material carrier" [19]. We can conclude that as long as material carrier exists in thermodynamic system, the information should also exist in some form. Material carrier cannot be destroyed, but only removed. Even the complex molecule decompose itself, they are not destroyed but decomposed in its oligomer component. Those components also represent material carrier for information. If we cut chromosome into a million fragments, information from the chromosome is not destroyed but transited into its potential form contained in those fragments. Fragments containing information can be used to build same or different structured chromosome. Let us in our mind decompose a book into its pages. Information carried by book is not destroyed. It is still on the pages, fragmented but not destroyed. We can use this stored information (if we have all the pages) to restore this book. Indeed archeologist uses fragments of information from the past to rebuild information. If he is lucky, all the pieces (fragments, material carrier) are preserved then he can rebuild the exact information. Information can be destroyed only by destroying its carrier. However, it is not possible to destroy material carrier according to conservation law.

In that case there must be two forms of information. First form is potential (invisible) form, and the second is phenotypic (visible) form. So the information could be removed from the system only, and only, if carrier (substance) is removed from the system. Information is not destroyed in that case, but it is removed from the system and forwarded to the surroundings. So it seems the information cannot be destroyed nor created. The conservation law must hold for both matter (substance and energy) and information. Information can be removed from the system in its potential or phenotypic form. Information is therefore a property of the thermodynamic system. In Fig. 1 on the left picture there is no material carrier so there is no information; information in its potential (invisible) form is contained in the middle picture. Information in its phenotypic (visible) form is represented on the right picture.

So, just like potential and kinetic energy in classical physics, information can transit from its potential to manifest (visible) form and vice versa. Only in case we remove the material carrier, information can be lost (not destroyed) from the system. Otherwise it will be present in its "hidden form", in the form of potential information. The conservation law must be therefore valid for both matter (substance and energy) and informationI_p is potential information and I_v is "visible" manifest information.

Let us consider example of burning newspaper. It seems obvious that information in its phenotypic form is disappearing. But is it destroyed? No, because the carrier is not (and it could not be) destroyed according to the conservation law. Information transits into its potential form carried by new simpler carrier CO_2 and H_2O. This potential information will be used by plants to create new molecule (glucose, cellulose) in photosynthesis. In some way we can conclude that information recycle trough synthesis and decomposition of material carrier of information. We can assume that information is just like substance subject of composition/ decomposition process, and makes cycles in nature.

Since information and entropy are closely related properties, a conservation law for them (Eq. (4)) was established [16,17]. According to it the sum of information and entropy in a closed thermodynamic system is constant, so we can write

$$I + S = (\mathrm{c\ o\ n\ s\ tan\ t}) \qquad (4)$$

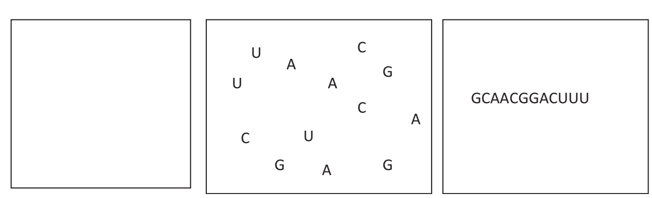

Fig. 1. Information content of the thermodynamic system. Left picture does not contain any substance (material carrier of information). It is not a thermodynamic system by definition. Consequently it contains no information. Each thermodynamic system contains some substance and consequently information in its potential form (middle) or phenotypic (visible) form (right). As long as thermodynamic system exists it contains some substance and information carried by it or its components in potential or manifest form.