Frequency of external influences as a source of biological system negentropy

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Abstract. This paper provides a qualitative analysis of one of the possible channels of negative entropy (negentropy) to ensure the evolution of biological systems. In particular, it is shown for the first time that a periodically changing flow of equilibrium radiation carries a reduced entropy content in comparison with a constant flow of the same power. This conclusion is made based on the analysis of the Shannon entropy time dependence graph for the model under consideration. The study relevance is due to the well-known contradiction between the statement of the second principle of thermodynamics about the tendency of closed systems to a state with maximum entropy (chaos) and Darwin's evolutionary theory describing the complexity of biological systems. This problem is worked out in many aspects and devoid of the status of an inexplicable paradox. However, a number of important questions, including the sources of negative entropy, remain open. As a function describing the frequency of incident radiation, a simple harmonic is chosen, which does not quite correspond to the daily change in illumination observed on the Earth, but allows us to draw conclusions about the qualitative nature of its influence. The result obtained can be of great importance for evaluating the equilibrium parameters and stability of open thermodynamic systems.

1. Introduction

The physics of biological systems, such as forests, is one of the most complex areas of modern science. First of all, it is due to the colossal complexity of even the simplest life units, surpassing all inanimate and artificially created systems. Another important feature is the openness property – the interaction of living systems, both with each other and the outside world of non-living nature. Moreover, this interaction is complex and multi-level.

However, nowadays, there are detailed theories as to the origin of life-abiogenesis, and its evolution. Despite the apparent success of theories of terrestrial abiogenesis, based on the ideas of the life origin from quartz drops in reservoirs [1], or at the bases of underwater volcanic sources, or directly in the atmosphere [2], a number of questions remain open. The most important is the transition from individual complex molecules to self-reproducing structures, which represents a qualitative leap in the system complexity. This is partly why theories are very popular in which the basic building blocks of life
originated outside the Earth [3], where it has already passed prebiological evolution, and getting into earth conditions served only as a catalyst for abiogenesis.

However, from the point of view of physics, the main problem of the life origin and its subsequent evolution is the elimination of the contradiction between the second law of thermodynamics and the high degree of organization of the world around us [4]. The fact is that living beings must maintain its form and all internal structures, constantly fighting the general tendency to dispersion and chaos [5]. The quantitative description of this trend is introduced by the mathematical formulation of the second law of thermodynamics

$$\delta Q \leq T dS,$$

where $\delta Q$ is the amount of heat entering the system, $T$ is thermodynamic temperature and $S$ is entropy – a new state function whose physical meaning can be interpreted as a measure of chaos (uncertainty) in the system [6]. Thus, thermodynamics predicts an increase in entropy and, consequently, disorder in a closed system. Darwin's theory of evolution postulates that the principle of selection is based on increasing the degree of biological system organization.

Of course, the key point in this thesis is the words “in a closed system”. The surface of our planet is an open system. Every second, and for billions of years, the Sun delivers energy to the Earth in the radiation form, more than sufficient to maintain life on it. But it is not only energy that is needed for life to exist. More precisely, we need not any energy, but a structured one with a low entropy content. The radiation of the Sun is thermal radiation with small deviations from the spectrum of an absolutely black body. In other words, the entropy of this radiation is close to the maximum value [7]. To characterize the deviation of the entropy content in the incoming energy from the maximum, E. Schrodinger proposed the term “negentropy” (negative entropy). This value has since been considered as a measure of information – the value of entropy inverse in its meaning. Calculating the value of the negentropy coming from the Sun is one of the most urgent tasks that lies in the research of the physical aspects of the theories of abiogenesis and evolution [8, 9]. At the same time, the spectral composition of the solar radiation [10, 11] and the nature of its absorption in the atmosphere are mainly studied [12]. In accordance with the physical picture of the world today, the value of this variable should directly correlate with the speed of evolution on our planet, which determines the relevance of these studies. In other words, an increase in the flow of negative entropy should lead to the appearance of more complex structures in nature, and its decrease – to a slowdown in the rate of evolution and, as a result, the extinction of highly organized organisms.

In this paper, we study the effect of the periodicity of the radiation flux on the entropy content in it. It is shown that the periodicity of even absolutely black (equilibrium) radiation caused, for example, by the rotation of the Earth, leads to an increase in its negentropy.

2. Materials and research methods

The presented research is purely theoretical. The starting points of the study are the classical ideas about entropy as a measure of chaos and the idea of the legitimacy of applying fundamental physical principles to biological systems. The method we use has something in common with the used one in the work [13] for analyzing astronomical signals for latent periodicity.

In the work “Mathematical Theory of Communication” (1984) investigating the transmission of signals along noisy lines K Shannon [14] suggested to use the formula

$$H = - \sum_i p_i \ln p_i$$  \hspace{1cm} (1)

as a measure of the transmitted signal distortion. Here $p_i$ is the $i$-state probability (the probability of $i$ symbol appearing in the transmitted message). Since then, this formula has become the basis of quantitative information theory. Shannon, at the suggestion of Von Neumann, called the value $H$ as entropy, due to the explicit analogy (1) with the formula for Boltzmann's specific entropy [15]

$$S = - k \rho \ln \rho d \Gamma,$$
where the function $\rho$ describes the probability distribution of thermodynamic states on the phase space $\Gamma$ and $k = 1.38 \cdot 10^{-23} \text{J/K}$ is the Boltzmann constant. This formula follows from the fundamental relationship between the entropy and the thermodynamic state probability $S = k \log P$ early proposed by Boltzmann.

In evaluating the non-entropic content of periodic radiation, we will rely on the formula (1), which is the most frequently used formula in information theory. Under the state, we will understand the fall on the surface of a photon of a certain frequency $i$ in a given time interval $t\Delta$. We will denote the function of the probability distribution of photons over frequencies as $\rho(\nu)$. Thus, $\rho(\nu)\Delta \nu$ is a probability that the frequency of a randomly selected photon lies in the interval $[\nu, \nu + \Delta \nu]$. The probability distribution in time is denoted as $\rho(t)\Delta t$. We note that the function $\rho(\nu)$ is assumed to be independent of time. That is, the radiation spectrum is taken unchanged over time. If we talk specifically about the Sun, then taking into account the high degree of stability of solar radiation during the whole life of the Earth, this simplification is considered acceptable.

Thus, neglecting the possible correlations between the quantities $\rho(\nu)$ and $\tau(t)$, we can write the probability of an event - a photon falling on the surface with a frequency $\nu \in [\nu, \nu + \Delta \nu]$, at a moment $t \in [t, t + \Delta t]$ – in the form

$$\Delta W = \rho(\nu)\tau(t)\Delta \nu \Delta t.$$  

Using this expression in formula (1) as $p_i$, we get

$$H = -\sum_{i} (\rho\tau\Delta \nu\Delta t) \ln (\rho\tau\Delta \nu\Delta t). \quad (2)$$

Here, when summing, we encounter a certain difficulty due to the divergence of the sum at $\Delta t \to 0$ or $\Delta \nu \to 0$. For physical systems, the existence of a lower limit is postulated by the third principle of thermodynamics, which reflects the quantum nature of our world. In particular, the Heisenberg uncertainty principle for the canonical conjugated energy-time pair $\Delta E\Delta t \geq \hbar$, where $\hbar$ is Planck's constant, is explicitly related to the limit that has arisen above. Indeed, taking into account that the photon energy is proportional to the frequency $E = h\nu$, we can put $\Delta \nu\Delta t = \hbar$ in the formula under the logarithm in (1), as the minimum possible value.

On the other hand, to be able to move from summation to integration, the first $\Delta \nu\Delta t$ in the formula (2) are simply replaced with $d\nu dt$. This approach does not harm the qualitative problem analysis. Thus, the formula (1) for the Shannon entropy, in our particular case, is converted to the form

$$H = -\int \rho(\nu)\ln (\rho(\nu)) d\nu dt.$$

The independence of the functions $\rho(\nu)$ and $\tau(t)$ allows you to separate the variables and split the double integral into single ones:

$$H = -\left(\int \rho(\nu)\ln (\rho(\nu)) d\nu\right)\tau(t) dt - \int \rho(\nu)\tau(t)\ln (\tau(t)) dt.$$

Since our goal is to compare the amount of negentropy entering the system depending on the time periodicity, we will not specify the spectral characteristics of the radiation and assume that the limits of integration cover all possible frequencies $\nu \in [0, \infty]$. Taking into account the standard condition of the probability density normalization $\int_{0}^{\infty} \rho d\nu = 1$, instead of the last expression we get

$$H = -\int_{0}^{\infty} \rho(\nu)\ln (\rho(\nu)) d\nu \tau(t) - \int_{0}^{\infty} \tau(t)\ln (\tau(t)) dt. \quad (3)$$
Let the radiation be characterized by some strict periodicity, characterized by the interval $T$. Taking into account the freedom to choose the units of time, we can put $T = 1$. The value $\tau$, in this case, should be normalized as $\int_0^1 \tau \, dt = 1$.

Consider first the case when the radiation is constant in time. That is, for a fixed period of time $T$, the radiation does not change either in intensity or in spectral distribution. In nature, this may be the case for old planetary systems, whose rotation around the axis is aligned with the angular velocity of the orbital motion (as is the case for the moon and the Earth). Thus, if the energy flow is constant in time, then we can put $\tau = 1$. In this case

$$H_0 = -\int_0^\infty \rho \ln(\rho) \, dv.$$

Taking into account all the above conditions, the formula (3) can be represented as

$$H = H_0 - \int_0^1 \tau \ln(\tau) \, dt.$$

Let’s get $\Delta H = H_0 - H(t)$ as a measure of negentropy. The positive definiteness of $\Delta H$ will indicate a reduced entropy content in the considered signal. From the last formula we have

$$H = \int_0^1 \tau \ln(\tau) \, dt. \quad (4)$$

As an example of a periodic function $\tau(t)$, it is natural to choose a harmonic function as the one that best meets the requirements of convenience and compliance with the observed natural conditions. So let’s take

$$\tau(t) = 1 + k \sin \omega t, \quad (5)$$

where the value $k$ characterizes the difference between the maximum and minimum of illumination (day and night), and the frequency $\omega$ corresponding to the period $T$. It is easy to see that this choice meets the normalization condition $\int_0^1 \tau \, dt = 1$ introduced above. Of course, the nature of the illumination of the planet’s surface differs from the law (5), but this does not matter in principle, as long as we are limited to the question of the principal existence of the effect. However, if we are talking about calculating specific values of the negentropy increment, the algorithm in question will not differ significantly.

Thus, from the formula (4) we have

$$H = \int_0^1 (1 + k \sin \omega t) \ln(1 + k \sin \omega t) \, dt. \quad (6)$$

3. Results and discussion

Calculating the integral (6) in analytical form meets a number of difficulties and, generally speaking, does not make much sense in the framework of the task. All we need to find out is the sign of $\Delta H$. To do this, it turns out that it is enough to consider the graph of the integrand function. The condition $k = 1$ corresponds to the illumination changes from maximum to full zero. The position of the corresponding function

$$f(x) = (1 + k \sin \omega t) \ln(1 + k \sin \omega t),$$

presented in the following figure 1.

The integral of the function is numerically equal to the area bounded by the function and the $X$-axis. It is easy to see that the area under the graph of $f(x)$ in the positive half-plane clearly exceeds the area
bounded by the graph in the lower, negative half-plane. That is, the integral $\int_0^{2\pi} f(x) \, dx$ is explicitly positive definite. Taking this result into account when analyzing expression (6), directly leads to the conclusion that the value $\Delta H$ is positive definite for sufficiently large values of the upper limit of integration. Thus, the increment of negentropy (6) has a positive value.

Thus, it can be unambiguously concluded that the periodicity of radiation is a factor that increases the volume of transferred negentropy. We believe that this result can be useful for a qualitative analysis of the impact of external conditions on self-organizing structures. A particular but the most important, in our opinion, case of such systems is living systems.

Indeed, as noted above, a purely thermodynamic approach to living evolving systems leads to an apparent seeming violation of the second law of thermodynamics. We say “apparent violation” because there are no reliable methods for assessing the change in the complexity of living systems during evolutionary leaps. However, assessing such a change as a whole, for the entire depth of the existence of life on our planet, we have to admit that it is colossal. In this regard, it seems that the source of the increment of negentropy indicated by us may be one of the key factors of abiogenesis.

It is easy to see that the above reasoning for radiation incident on the system can naturally be generalized to cases of temperature fluctuations and periodic mechanical effects (for example, ordinary coastal waves, tidal waves, etc. [16]). Especially considering that the Sun is the main governing force for most natural processes.

We see one of the areas of application of the result in possible experiments on artificial creation of elementary building blocks of life. In such experiments, it may be important not only to reproduce static conditions (chemical compounds of the initial system, temperature regime) but also periodical changes of them simulating daily temperature fluctuations, irradiation, concentration changes, etc.

![Figure 1](image)

**Figure 1.** The dependence graph $\tau(x) = 1 + \sin x$ (in blue), varying from 0 to 2 and the function graph $f(x) = (1 + k \sin \omega t) \ln(1 + k \sin \omega t)$ (in red), which determines the negentropy intensity.
We also assume that the proposed source of negentropy should be taken into account when assessing the likelihood of the emergence and existence of life on exoplanets. The basic principles for solving this interesting problem and the general equations of the balance of entropy and information on the example of planetary systems can be found in [17].

4. Conclusion
The presented work aimed to study the possibility of the influence of the Earth's rotation, and the resulting periodicity of the solar radiation incident on the surface, on the processes of the origin of life. The initial assumption of the study was the following. Let us assume that the original system is inanimate, but contains the same components as the living system, and is in the corresponding external physical conditions. The process of restructuring the components of the system into a fundamentally more complex structure, without outside influence, is impossible, in accordance with the second law of thermodynamics. Moreover, this influence cannot have a chaotic (equilibrium) character. In other words, for a qualitative transition, the system requires “pumping” with negentropy.

In our work it is shown that the source of negentropy for systems on the Earth's surface can be the solar radiation itself, whose entry into the system is modulated by the rotation of the planet.

In the chosen model, two simplifications are made: the solar radiation is taken as equilibrium and the daily modulation of the incident radiation is described by a simple harmonic. The measure of the increment of negentropy in the irradiated system was estimated using the formula for Shannon's entropy.

At the present stage of the study, no numerical estimates were made. We limited ourselves to a qualitative consideration of the problem. The conclusion about the influence of the Earth's rotation on the entropy balance was made based on the analysis of the negentropy versus time graph.

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