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### **СИНГУЛЯРНЫЙ ПЕРЕХОД В БИОСИСТЕМЕ С НЕОГРАНИЧЕННЫМ ЧИСЛОМ КОНСЕРВАТИВНЫХ СВЯЗЕЙ**

**Аннотация.** Стадии натуральной эволюции, такие как биогенез и абиогенез, являются хорошо известными устоявшимися терминами для характеристики двух весьма различных фаз развития жизни на Земле. Традиционно, абиогенез, как ранняя стадия эволюции, является, главным образом, химической фазой, имеющей дело со взаимодействием между более или менее сложными цепями полимеров, когда возможные проявления жизни предполагают значительное включение коллективных эффектов. Абиогенез, как последующая фаза эволюции, — это время для доминирования законов Дарвина, проявляющихся, в частности, в состязании среди индивидуальных особей в форме игры между наследственностью и изменчивостью. В этой статье обсуждается возможная природа сингулярного перехода между стадиями эволюции как логичного последствия процессов обмена в открытой системе, моделируемым открытой системой с неограниченным числом консервативных связей. Таким образом, была исследована физическая окрестность точки перехода и обнаружен целый ряд резких, хотя и непрерывных, скачков в поведении ключевых параметров биосистемы. Показано, что биосистема в точке перехода испытывает глубокую перестройку в сложившейся картине энергообмена, что ведет к появлению более сложной и развитой стадии эволюции. При этом новизна в поведении системы проявляется прежде всего, как организованное взаимодействие энергетических взаимодействий. Автор приходит к выводу, что найденная точка перехода может рассматриваться как точка сингулярности в процессе системной эволюции. Со своей стороны, стадии эволюции, с, фактически, противоположным смыслом являются физической матрицей для стадий абиогенеза и биогенеза в натуральной эволюции, соответственно.

**Ключевые слова.** Эволюция системы, стадия эволюции, консервативная величина, уравнение непрерывности, абиогенез, биогенез.

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### **SINGULARITY TRANSITION IN BIOSYSTEM WITH INFINITE NUMBER OF CONSERVED LINKS WITH SURROUNDINGS**

**Abstract.** Stages of natural evolution such as biogenesis and abiogenesis are the well-recognized terms to characterize the very different phases of life development. Traditionally, an abiogenesis is believed as the early stage of evolution that is mainly the chemistry phase dealing with intercoupling between the complex polymer chains when manifestations of life assumes substantial participation of cooperative effects. It its turn, a biogenesis as the subsequent stage of evolution is the period for prevalence of Darwin's laws showing, in particular, in battle among separate species in the way of variability-heredity contest. In this

article, we discuss possible nature of the transition between above stages as a normal result of progress in an evolutionary system simulated by mathematical model of open system with infinite number of conserved links with system surroundings. It is shown that the biosystem, in transition point experiences the deep reconstruction in existing pattern of energy exchange which leads to emergence of the more complicated and advanced stage of evolution. Our study showed that the found transition point can be considered as a singularity point in system evolution. In its turn, the evolution stages with the dissimilar meaning are the physical placeholders for stage of abiogenesis and biogenesis in natural evolution, correspondingly.

**Keywords.** System evolution, evolution stage, conserved quantity, continuity equation, biogenesis, abiogenesis.

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## Introduction

At present, a commonly accepted physical and mathematical basis for a general philosophy of system evolution does not exist yet [1]. Nonetheless, likely conversion of non-living matter to complex life is usually divided into two successive stages. The first one (abiogenesis) contains transition of non-living material to plainest life forms, the second one (biogenesis) incorporates the range on which the Darwin's laws of evolution come to control [2]. Further, we will use this classification.

While scientific society has accepted above stage division a long time ago, we still do not have clear insight on actual meaning of abiogenesis and biogenesis. We do not know whether these parts are just different appearances of the same physical process, or they cover totally different physical mechanisms. Besides, what can be an essence of a connection between the mostly chemical nature of abiogenesis and the biological nature of the next stage? Is it a slow changing or a drastic quality jump?

Certainly, the early environment in which evolution began on the Earth is not known [3]. That is why, to describe evolution in the impartial way, in our opinion, we should pay attention to the most basic and universal physical relations which according to our existing knowledge could work for majority of environments on the early Earth. So, evolution needs an energy to develop. And what we know nearly for sure is that at the beginning Earth and its subsystems were under long-time permanent impact of energy flows of different nature where an energy conservation law (*ECL*) has ruled. Here, a concept of an open system (*OS*) to come.

So, the major objective of this paper is to apply the recent results in mathematical simulation of *OS* to an energy development of evolutionary unit (*EU*) to understand the context of a transition between the abiogenesis and biogenesis.

## Approach substantiation

In further text, an *EU* is the simplest possible *OS* which is able to evolve [4]. It is believed that *EU* is capable of a permanent energy exchange through available infrastructure as the set of bidirectional (in and out *EU*) energy currencies [5].

We will be simulating an energy evolution by the mathematical model described below [6; 7].

We take a differential form of *ECL*, *i.e.*, energy continuity equation (*ECE*), as a mathematical abstraction of a single energy link between *EU* and its surroundings and consider an infinite multitude of similar independent links as an energy image of *EU*. An external environment is simulated by a thermal bath of unlimited capacity and an energy exchange between bath and *EU* is assumed to last unlimited time.

Priority of the evolutionary contribution brought by the system's internal and external links over the essence of the system's elements was reported in [8; 9].

Though at any time, all energy links are available for an energy transfer inwards or outwards *EU*, however only one link will be picking up and this link will take a role of the instant energy source (energy transfer inwards) or the energy sink (energy transfer outwards). Random energy transfers  $\delta Q_{in}$  (inward *EU*) and  $\delta Q_{out}$  (outward *EU*) cannot coexist at the same time, *i.e.*, general energy flow  $\delta Q = \delta Q_{in} \oplus \delta Q_{out}$ , where  $\oplus$  signifies exclusive disjunction.

Write down *ECE* as

$$\frac{\partial \varepsilon}{\partial t} = -\text{Div} \mathbf{J}, \quad (1)$$

where  $\varepsilon$  is an energy volume density,  $t$  is time,  $\mathbf{J}$  is energy flux, *Div* is a divergence operator. It is thought that  $\mathbf{J}$  and  $\varepsilon$  are not attributed to any particular energy exchange process. Instead, as soon as any energy transport which affects *EU* energy balance upon arrival has happened, it falls under our consideration.

It is also thought a uniform probability distribution for affected random quantities.

For succinctness, we will call abiogenesis as the Phase 1, and biogenesis as the Phase 2.

### Mathematical formalism

So, mathematical model for energy evolution of *EU* is

$$\begin{cases} \frac{\partial \varepsilon_1}{\partial t} = -\text{Div} \mathbf{J}_1 \\ \frac{\partial \varepsilon_2}{\partial t} = -\text{Div} \mathbf{J}_2 \\ \dots \\ \frac{\partial \varepsilon_n}{\partial t} = -\text{Div} \mathbf{J}_n \\ \dots \end{cases} \quad (2)$$

which at  $n \rightarrow \infty$  converts to  $d$

$$\frac{dU}{Q} = -\frac{dy}{y}x \quad (3)$$

with the closed-form solution for the rate of total energy exchange

$$\Upsilon(y) = y - y \ln y \quad (4.a)$$

rate of low-structured thermal energy

$$W(y) = -y \ln y \quad (4.b)$$

and rate of structured energy

$$E(y) = y. \quad (4.c)$$

During evolution, the continuous spectrum in the  $y$ -range  $[0, 1/e]$  is swapped with the discrete one at  $[1/e, e]$

$$y_n = \exp\left[\pm \frac{1}{n}\right] \quad (5)$$

where  $e$  is Euler number. From (4.a) based on Gibbs' definition, statistical entropy is

$$\Delta S = \ln |d\Upsilon| = \ln |\ln y| \quad (6)$$

which yields probability density at  $\Delta S = 0$  as

$$f_i = W_L(f_o^{-f_o}) \quad (7)$$

so that at  $\Delta S \geq 0$

$$f_{in} \geq W_L(f_{out}^{-f_{out}}) \quad (8.a)$$

and at  $\Delta S \leq 0$

$$f_{in} \leq W_L(f_{out}^{-f_{out}}) \quad (8.b)$$

where  $x = \cos \beta$  continuous random quantity,  $y = J/J_0$  — unitless energy rate,  $U$  is internal system energy, normalizing constant  $J_0 > 0$ ,  $Q = J \cdot dS_A / dt$ ,  $S_A$  is area,  $d\beta = d\mathbf{J} \wedge \mathbf{n}$ ,  $\mathbf{n}$  is a unit normal oriented in the direction of incoming energy flux  $y_i$ ,  $D \subseteq \mathbf{R}^2$  — phase space for all microstates  $dU/Q$ , symbol  $|z|$  denotes absolute value of  $z$ ,  $f_i = f(y = y_i)$ ,  $f_o = f(y = y_o)$ ,  $W_L$  — Lambert function.

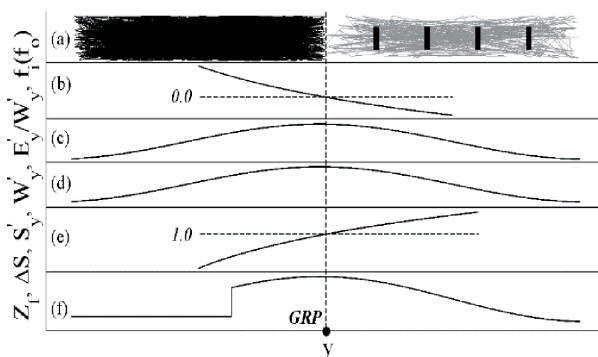
Solution (4–8) describes an energy evolution of *EU*. Our intention is to identify potential drastic change in *EU* parameters and track the reason of this change.

## Results

Although, solution has an unlimited number of the discrete modes, however we will be focusing in the first node  $y = 1/e$  (point *GRP*) only in which the most discerned changes of *EU* parameters happen.

Below we emphasize our findings and provide comment to them.

So, in *GRP*, the form of spectrum changes from continuous to discrete, Fig. 1 (a). Spectrum is continuous at  $y < \textit{GRP}$ , and discrete at  $y > \textit{GRP}$ . However, despite of the discrete harmonics, the spectrum in the right panel still keeps some noise-like background (marked in light grey), *i.e.*, actually it is a *quasi-discrete* one.



**Fig. 1. Schematic dependence of key parameters of *EU* at passing through *GRP* on energy exchange rate  $y$ . (a) Form of spectrum  $Z_f$ , continuous on the left panel and discrete on the right panel, discrete harmonics are shown as thick vertical segments; (b) change of entropy  $\Delta S$  from positive to negative; (c) rate of entropy production  $dS/dy$ ; (d) rate of unstructured thermal energy production  $dW/dy$ ; (e) ratio of  $dE/dy$  and  $dW/dy$ ; (f)  $f_i(f_o)$  — probability density  $f_i$  of energy flux inwards *EU* on density for flux  $f_o$  outwards *EU*. All quantities are unitless.**

**In the vertical axis, notation  $F'_y$  denotes  $dF/dy$ .**

The quasi-discrete form of spectrum in the Phase 2 means that the backstage physical mechanism dominating in the Phase 1 does not totally vanish, it is still there but its influence has decreased. So, Phase 1 and Phase 2 intersect in some extent, that is why they are most likely the different stages of the same physical process. In this sense, an evolutionary meaning of Phase 1 is to hoard up energy and history of random variations in an amount sufficient to supply the more sophisticated and complicate Phase 2 on the qualitatively distinct level of *EU* operation.

Another interesting point about Phase 2 is that a quasi-discrete nature of a spectrum assumes a co-existence of various energy modes of different level. The most discerned harmonics (thick vertical segments in Fig. 1 (a)) are the most appropriate for the current evolutionary conditions, whereas the weaker harmonics (light-grey background) cannot fully adapt to existing conditions and are finally suppressed. It means that in the Phase 2 we observe an actual competition between energy modes and the winners will compose the most visible portion of spectrum. In some approximation it looks as the precursor of the Darwin's competition between species as energy entities. Nothing like that is seen in the Phase 1.

In traditional thermodynamics, observed change in the sign of entropy  $\Delta S$  is typically attributed to passing through some state separating two qualitatively different regimes of *EU* operation, Fig. 1 (b). Accounting that the change is from positive to negative, it normally indicates to transition from the more chaotic regime to the more ordered one [4]. In the same way, the peaked profile of  $dS/dy$  tells us that the rate of energy dissipation experiences a qualitative change, Fig. 1 (c).

The rate of unstructured energy production  $dW/dy$  deals with the portion of exchange energy which converts to the noise and leaves *EU*. In the light of this, the profile of  $dW/dy$  (Fig. 1 (d)) finds the rational explanation. Indeed, if we associate  $dW/dy$  with the level of dissipation in *EU*, which is addressed by  $dS/dy$ , then the identical profile in Fig. 1 (c) and 1 (d) is fairly understandable.

In this model, the structured energy is a portion of exchange energy which can be used for reconfiguration of internal energy structure of *EU*. Then, ratio of  $dE/dy$  and  $dW/dy$  provides another important insight into *EU* evolution, Fig. 1 (e). While  $dW/dy$  surpasses  $dE/dy$ , it creates an insurmountable barrier for establishment of any long-living relationships between *EU* parameters due to predominance of the noise-like random processes. That is why neither discrete harmonics nor any other effects we observe during the Phase 2 do not occur in the Phase 1. And only after lowering of the level of the chaotic components ( $dW/dy < dE/dy$ ), the outstanding features of Phase 2 can come true.

As comes from (7, 8), in *GRP* we observe the beneficial conditions for the incoming flow  $y_i$  compared the outcoming one  $y_o$ . At  $y < GRP$ , the probability for realization of  $y_i$  against  $y_o$  increases, while at  $y > GRP$  it decreases. Then, prevalence of  $y_i$  means existence of the more noise-like environment suitable for the Phase 1. On the other hand, predominance of the  $y_o$  may signify that *EU* tries to rid of the redundant energy in order to optimize its internal energy structure in the form of a quasi-discrete spectrum which appears in the Phase 2. In above sense, our results support results [10] that system's native ability to adapt to changes in environment goes through dissipating abundant energy ( $y_o$  in this model).

## Discussion

It is worth to note that the aforesaid features in the Phase 2 come as an inseparable set due to existence of the connections between detectable factors of energy exchange. For example, preponderance of  $y_o$  is directly related to the emphasized above behavior of the unstructured  $dW/dy$  and the ratio  $(dE/dy):(dW/dy)$ , as well as the discrete nature of spectrum. Also, it is quite compliant with the changes in  $\Delta S$  and  $dS/dy$ . So, noted features in the Phase 2 come altogether as a whole or do not come at all, which can be described as advent of correlation in energy exchange processes. Again, we do not see any signs of correlation in the Phase 1. And this is a strong argument in favor of significance of distinctions between Phase 1 and Phase 2.

In the light of above, it is interesting to track a possible connection between the discussed features and the preferable form of an energy organization. So, to maintain an integrity of its energy structure and moreover to evolve in the Phase 1, *EU* should have the highly efficient energy-saving mechanisms since they do not have an energy immunity against small changes in its environment. In this scenario, the *collective* form of energy organization offers a solid advantage compared with an *individual* one.

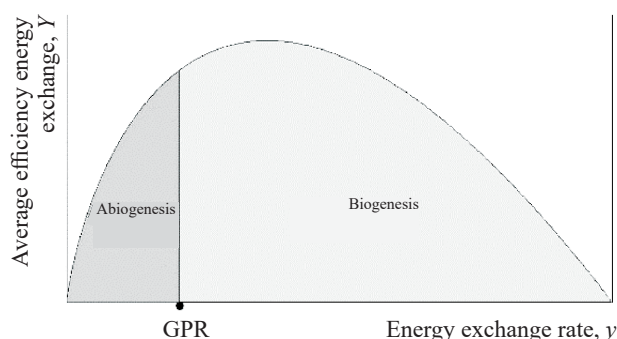
On the other hand, the discrete energy modes in the Part 2 benefit more freedom in energy maneuver as the loss of some energy (going away with  $y_o$ ) will not sweep these modes out the comfort energy zone around the most stable state (6). So, in the Phase 2 the *individuality* can be the winning solution for an energy organization compared the *collectivity*.

We see that Phase 2 is different from Phase 1, first of all, by emergence of the new qualities in *EU* operation that were not presented in the Phase 1. It is quite aligned with [11] where is stressed that qualitative changes in *OS'* operation come as a novelty of operation but not a novelty of the system parts and elements. Finally, such novelty appears as the ordered coupling of energetic interactions or as an evolution.

Summarizing, we investigated neighbourhood of *GRP* and discovered the number of radical changes in behavior for crucial factors of *EU*. It is shown that *EU* simulating as a evolving system, in *GRP* experiences the deep-rooted reconstruction in current configuration of energy exchange which leads to emergence of the more complicated and advanced Phase 2. This rebuilding comes as a consequence of thermodynamics laws within the same physical formalism and manifests as the concerted changes in behavior of parameters for energy exchange.

So, *GRP* can be considered as a singularity point in *EU* evolution. Then, Part 1 and Part 2 are the physical placeholders for stage of abiogenesis and biogenesis in natural evolution, correspondingly (Fig. 2).





**Fig. 2. Dependence of average efficiency for energy exchange  $Y$  on energy exchange rate  $y$  during EU evolution. GRP is the point where properties of solution are radically changed which leads to existence of two physically dissimilar phases. Character and depth of these changes provides arguments to think of GRP as a singularity point which separates abiogenesis and biogenesis in EU evolution. All quantities are unitless**

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