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Self-Organization Scenario Relevant for the Formation of Prebiotic Complex Structures

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Abstract

A scenario in which the collective effects of quantum processes play an essential role in the physical basis of symmetry breaking and self-organization is presented. This scenario suggests a possible clue to the origin of life.

Keywords:
symmetry breaking, self-organization, entropy expulsion, self-consistent double layer, cell membranes

1. Introduction

Symmetry and symmetry breaking are key concepts of the modern physics. Such concepts govern the appearance of abrupt transitions, multiplicity of states, coherent structures or, generally speaking, the appearance of self-organization. Over the past few decades many examples of self-organized systems can be found in physics [1-3].

In biology, the symmetry breaking is a universally present phenomenon. Thus, Turing in his "Chemical Basis of Morphogenesis" [4] considered that a system of equations for chemical reactions, coupled with diffusion, would lead to solutions which could break the symmetry of the initial state of the system. An example of such a phenomenon is the self-assemblage process of spherical blastula.

The self-organization, related to symmetry breaking due to fluctuations in chemical systems with reactions and diffusion, is seen by Prigogine as a clue to the origin of life [5].

In this paper, we draw the attention to recent experimental results proving that the symmetry breaking is a complex process whose investigation in plasma offers new important information concerning the actual physical basis of self-organization.

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2. Symmetry Breaking and Self-Organization in Plasma

Recent investigations concerning the origin of coherent space charge configurations formed in plasma emphasized that the key processes related to self-organization are the symmetry breaking of both the excitation and ionizations cross section functions together with their spatial separation [6-10]. Because of the energy dependence of these functions, a double layer (DL) is generated. It appears after the accumulation of the electrons that lost their kinetic energy in the region where the excitation probability suddenly increases. The rest of the accelerated electrons, which have not produced excitations, obtain, when the accelerating electric field is sufficiently strong, kinetic energy for which the ionization cross section suddenly increases. As a result, a great number of positive ions are created in the region adjacent to the region where the net negative space charge is well located. Since the ionization take place in the region where an electric field is present, the electrons leave that region because of their higher mobility with respect to that of the positive ions. Under such conditions, a plasma enriched in positive ions appears. When the long range

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electrostatic forces, that act as correlations between the two net opposite space charges, exceed a certain critical value, the entire space charge arrangement spontaneously transits into a self-consistent DL. That is a localized double space charge configuration able to accelerate electrons at energies sufficient to ensure its existence conditions [6-10]. Usually, the electrons passing through the DL and, as a result, accelerated in its potential drop, are carried by the current. Therefore such a DL is only partial autonomous.

Evidently, the potential drop developed over the DL depends on the excitation and ionization rates and implicitly on the electric field intensity that accelerates the electrons. That electric field represents the external constraint, but a local acceleration inside the DL appears simultaneously with its self-assemblage. During the stationary state of the DL, the "equilibrium" between the adjacent net space charges placed at its two sides is statistically ensured, i.e. the particles lost by recombination, diffusion and so on are replaced continuously by the collective effects of the mentioned quantum processes. When the potential drop developed over the stationary DL reaches/exceeds values for which the production of positive ions at the positive side over-compensates the accumulation of electrons at its negative side, the DL transits into a non-stationary phase [11]. That is because the increase of the positive charge at the positive side of the DL determines the increase of its potential drop and consequently the growth of the ionization rate. At its turn, the increase of the net positive charge in that region determines a new increase of the DL potential drop and as a result the increase of the positive ion production, and so on. Acting as a gas anode whose potential continuously increases, the region where the electrons cumulate after excitations shifts into a direction contrary to that of the electron flux carried by the current. Therefore the DL self-assemblage process takes place in a region whose position becomes time dependent, i.e. the DL transits into a "moving" phase. Such a moving DL behaves as a soliton. The one-directional proper dynamics of the "moving" DL suggests an arrow of time, meaning that the temporal symmetry is broken [2].

We notice that the self-assemblage process of the DL during its moving state must be understood as a dynamical one, i.e. the self-assemblage takes place continuously. The cause that makes possible the continuous self-assemblage process of the DL is the acceleration of the electrons within its potential drop. This acceleration ensures the separation of the regions where the excitation and ionization cross section functions suddenly grow.

Because the DL "runs" through the plasma column, it is able to increase the electron flux that transverses it. Therefore, a moving DL can appear also in current-less plasma. This is evidently possible only if the amount of electrons, positive ions and neutrals in the region of the plasma where the DL is momentarily present can ensure the self-assemblage process.

Usually, the moving DL disrupts after passing a relatively small distance because its departure from the forming region creates there the conditions for of a new DL generation [11]. Since the new DL also transits into a moving state, the phenomenon becomes a periodical one.

The above described phenomenology, valid for one-dimensional DL, is also well based for a three-dimensional (nearly spherical or spherical) one [6-10]. That phenomenology explains the generation and the unstable state of the nearly spherical space charge configuration, bordered by a DL, observed as a fireball [6-8], a plasmoid [9], or a free floating ball of fire [10]. All mentioned complex structures contain a positive nucleus that acts as a gas anode able to accelerate the surrounding plasma electrons at energies for which the neutral excitation probability suddenly increases. That is the premise for the "creation", by a self-organization scenario recently called *intermittent* [12,13], of a complexity revealing some astonishing behaviors. Thus the complexity is protected from the environment by a cell membrane-like structure. That membrane has the form of an electrical DL that provides a selective enclosure of an environment that qualitatively differs from the surrounding. The complexity corresponds to a space charge configuration characterized by a local minimum of the free energy. Therefore, its formation takes place spontaneously and is accompanied by entropy expulsion. After the "birth" of the complexity, the spherical DL at its border sustains a trans-membranar electrical charge gradient that is also the source of energy for the inside processes required for its self-consistence. The complexity is able to develop a dynamics during of which a rhythmic matter and energy exchange with the surrounding environment (i.e. the plasma) ensures its "viability". Therefore such space charge configuration could be considered as a gaseous cell that satisfies the general criteria by which life can be recognized [6,7,10].

An additional argument that the DL at the border of the complex space charge configuration behaves as a cell membrane [14] is the power spectrum shown in Fig. 1. A similar spectrum is known as characteristic for the enzymatic processes at the interface of cells.

The self-assemblage of the DL involves a consecutive building process of well located net negative space charges related to the discrete energy values for which neutrals' excitations are produced, followed by a "sandpile"-like disruption mechanism, when the potential drop over the DL reaches a certain critical value.

We remark that the shape of the spectrum presented in Fig 1 suggests that the above-described phenomenology of the DL creation could be a new physical model for the "self-organization criticality" concept [15]. Based on these results, it becomes possible to explain the anomalous transport of particles and energy through cell membranes, but also in fusion devices [16], by the consecutive generation and disruption of DLs. In fusion devices the strong kinetic energy (temperature) gradient is the premise for a similar DL dynamics as those originating in a local electron acceleration [17].

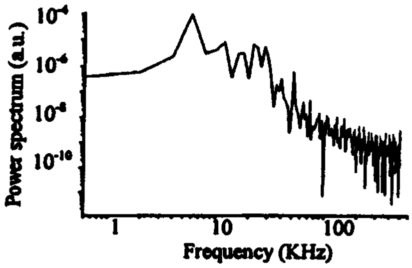

Fig. 1 Frequency spectrum of the DL dynamics.

The framework of the scenario of self-organization, briefly described in this paper, is schematically presented in Fig. 2.

3. Conclusions

As was shown, non-linear phenomena observed when matter and energy is gradually injected in the plasma can explain the genesis of a complexity by a self-organization mechanism taking place in an intermittent fashion. However, accepting that a sudden injection of matter and energy related to electrical activity (sparks) produced in the early earth's atmosphere is at the origin of life, a scenario, in principle similar to those known as *cascading self-organization* [12,13] is most probable in nature.

Thus the first phase of the new scenario [6,10] is

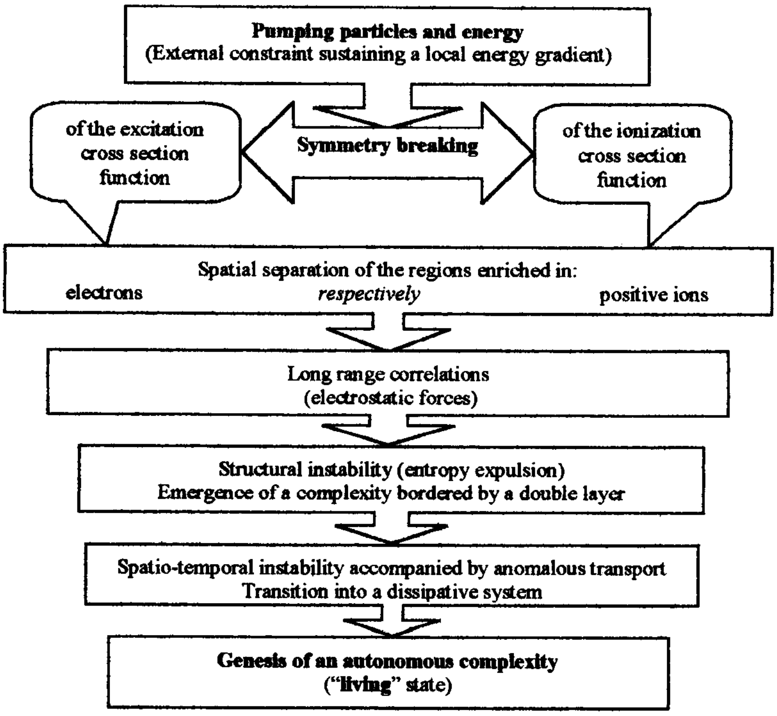

Fig. 2 Scenario of self-organization.

the *sudden injection* of particles and energy in a point where an electric spark strikes the earth's surface. In this way, an *unstable* hot plasma is generated. Owing to the difference between the diffusivity and mobility of electrons and positive ions, a nucleus enriched in positive ions appears. Acting as a gas anode, this nucleus is able to initiate all the key processes attributed to the intermittent self-organization scenario above described [6,10]. Owing to the developed electrostatic forces acting as long range correlations between the two adjacent opposite space charges, a *tensioned state* is realized. It determines the spontaneous appearance of a *structural instability* when the electrostatic correlation forces reach a certain critical value. This phenomenon is accompanied by *entropy expulsion*. As a result, a complexity, similar to that created by an intermittent scenario of self-organization, appears. Its genesis in a reactive plasma, as that presumed to exist in the early earth's atmosphere, could explain the further evolution to a more complex prebiotic structure. We notice that the spontaneous genesis of the complexity is governed by internal processes and takes place without any expenditure of energy. Such a phenomenon takes place against the second law of thermodynamics. However, after its "birth", the complexity becomes an open system whose existence requires the above-mentioned rhythmic matter and energy exchange with the surrounding. Under such conditions the complexity behaves as a dissipative system and consequently obeys to the second law of thermodynamics.

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