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Minimal-cell system created in laboratory by self-organization

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Abstract

Essentially based on nonlinear effects of quantum processes a self-organization scenario able to explain the emergence in laboratory of a complex gaseous space charge configuration displaying features like of a primitive organism is described. Possible also under primitive earth conditions the emergence of a similar complexity could be the prerequisite physical phenomenon needed for a further biochemical evolution. Governed by an intrinsic self-assembling mechanism involving local self-enhancement complemented by long-range inhibition, this scenario of self-organization offers a new insight into a phenomenology potentially able to explain the origin of life.
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1. Introduction

In this paper, we would like to inform on the possibility to create in laboratory a gaseous complex space charge configuration (CSCC) by self-organization that could be the simplest possible system able to reveal behaviors usually attributed to a biological cell. In spite of its gaseous nature, such a CSCC satisfies, to a large extent, the criteria usually required for recognizing it as a potential precursor of a living being. Thus, similar to biological cells, the boundary of a self-assembled gaseous cell provides a selective enclosure of an environment that qualitatively differs from the surrounding medium. The boundary appears as a spherical self-consistent electrical double layer (DL) able to sustain and control operations such as: (i) capture and transformation of energy, (ii) preferential and rhythmic exchange of matter across the system boundary and (iii) internal transformation of matter by means of a continuous ‘‘synthesis’’ of all components of the system. After its emergence, the CSCC is able to replicate, by division, and to emit and receive information. Such a CSCC spontaneously emerges when an electrical spark creates a well localized nonequilibrium plasma at the surface of a positively biased electrode immersed into a gaseous medium which contains free electrons and atoms in ground, excited and ionized states (low temperature plasma).

The hypothesis that primitive organisms have emerged in primordial chemical reacting gases has already been considered by [1]. Generally, it is postulated a long chemical evolution extending over million years.This evolution includes essential steeps from a mixture of chemical reacting gases towards amino acids, primitive proteins and, as a final product, a primitive organized structure. As known, one of the challenging problems concerning the biochemical evolution is the question if there existed a prerequisite initial condition beginning from which this evolution would start. As we will show in this paper, a possible answer to this question is the consideration of a scenario of self-organization produced under primitive earth conditions similar to those that explain the emergence of the CSCC in laboratory. This scenario of self-organization describes a nonlinear phenomenon that evolves, once started by a spark, very quickly. This seems to prove that the condition for a biochemical evolution is created by the Nature spontaneously. Performing activities that simulate those of living beings, the CSCC self-assembled under primitive earth conditions could be the precursor, at present missed in the biochemical evolution theory, the evolution of which into a living cell, respectively into a multicellular organism, was produced over million years and under external selection mechanism.

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As proved by simulation studies [2,3], self-organization can occurs in an intermittent fashion (intermittent self-organization), or in a stepwise fashion (cascading self-organization). Intermittent self-organization occurs when the system is gradually driven away from equilibrium by continuous injection of matter and energy, while cascading self-organization occurs when matter and energy is suddenly injected into the system so that it relaxes stepwise towards a minimum energy state. The presence of the aforementioned two kinds of self-organization scenarios in collisional plasma was revealed by experiments already described [4,5]. Because under primitive earth conditions electrical sparks have generated in the impact point with the positive Earth a nonequilibrium plasma, the cascading scenario of self-organization is the most suitable for explaining the emergence of a CSCC.

Owing to the fact that the succession of physical processes involved in the intrinsic nonlinear mechanism at the origin of the cascading scenario of self-organization is very fast, their identification was not possible until now. However, it was possible to obtain information on this mechanism starting from the experimentally proved fact that the CSCC, created by a cascading scenario of self-organization, strictly reveals the same features as those of a CSCC, created by an intermittent scenario of self-organization [4,5]. Based on these experimental results we will explain the creation of a CSCC by an electrical spark, considering the well-identified physical processes, the successive development of which explains the generation of a CSCC by an intermittent scenario of self-organization. These physical processes naturally evolve when an electrical spark locally creates a nonequilibrium plasma.

2. Potential precursors of biological complex structures emerged in plasma after self-organization

Since life necessarily exists in the form of cells, the self-accumulation of charged particles in the form of a membraneous boundary is the first structural requirement for the emergence of a minimal prebiotic system. As mentioned above, in a cold laboratory plasma in thermodynamic equilibrium, the premise for the formation of a gaseous membrane is the generation of a well localized nonequilibrium plasma in a point where an electrical spark strikes the surface of a positively biased electrode [4]. Because of the differences in the mobility and thermal diffusivity of electrons and positive ions, the former are quickly collected by the positive electrode, so that a positive "nucleus" in the form of an ion-rich plasma appears. Acting as a gas anode, the potential of which depends on the positive electrode potential, the nucleus attracts the electrons from the surrounding cold plasma. When the potential of the positive electrode, and implicitly of the gas anode, is so high that the attracted electrons obtain kinetic energies sufficient to produce excitations and ionizations of the neutrals, the conditions for the self-assembling of a CSCC by an intermittent scenario of self-organization are fulfilled [6–15]. Thus, it is well known that the excitation and ionization cross sections depend on the kinetic energy of the electrons in such a way that the former suddenly increases for kinetic energies lower than the latter. Consequently, a net negative space charge populated with electrons that have lost their kinetic energy by excitation of neutrals at the specific energy levels is formed. This appears in agreement with the equation $A + e_{fast} \rightarrow A^* + e_{slow}$ where A^* is an excited—but still neutral—atom, which, after about 10^{-8} s, returns into the ground state by emitting a photon $h\nu$. Therefore the region where the net negative space charge is located appears as a luminous sheet that surrounds the positive nucleus. Its extension depends on the scheme of the excitation levels of the respective gas atoms. The concentration of the electrons in the net negative space charge is dynamically maintained since the part of electrons lost by recombination, diffusion and so on is replaced by those electrons that have lost their momentum after neutral excitations.

The appearance of a well-located net negative space charge represents the first phase in the pattern formation mechanism. Thus, the net negative space charge determines the location of the electric field in a relatively small region at the border of the positive nucleus. This creates the premise for the following evolution sequence of the space charge into a CSCC. It is related to the electrons that have not produced excitations and, as a consequence of the acceleration in the electric field, obtain kinetic energies sufficient to produce ionization in the nucleus according to the process $A + e_{fast} \rightarrow A^+ + 2e_{slow}$. Here A^+ is a single-ionized positive ion. Since the electrons that have produced ionizations and those resulting from these processes have low kinetic energies and are located in a relatively high electric field, formed between the net negative space charge and the positive electrode, the electrode quickly collects them. The ions produced in the ionization processes have also low kinetic energy and form, after accumulation in the vicinity of the net negative space charge, a layer of positive charge. As a consequence, in this initial phase of the CSCC self-assembling process, there are two adjacent space charge layers of opposite signs in front of the positive electrode a positive one located in the nucleus and a negative one in the form of a sheet surrounding the nucleus. Between them the electrostatic forces act as long-range correlations. As a result the adjacent space charge layers naturally associate in the form of a DL. So, a well-located electric field appears. Within it the electrons are accelerated, obtaining additional kinetic energy. The strength of this field depends on the densities of the two adjacent opposite net space charges, which in turn depend on the excitation and ionization rates and, implicitly, on the potential of the positive electrode. However, such a space charge configuration is unstable because any small increase of the density of the positive ions in the nucleus induces a further increase of this density [14,15]. Thus, an instability starts to grow when the potential drop over the DL surpasses a certain critical value because a higher ion density causes an increase of the local electric field. As a consequence, the kinetic energy of the electrons accelerated towards the nucleus increases so that the ionization rate also grows. The result is an additional amount of positive ions that is added to the previous one so that the local electric field further increases. In turn, the increase of the ionization rate produces a further increase of the positive ion density and consequently a further growth of the electric field, and so on. As a result of this positive feedback mechanism the density of positive ions quickly grows in the region where the ionization cross-section suddenly increases (i.e. adjacent to the well-localized net negative space charge). In this way a *self-enhancing* mechanism for the production of positive ions at the border of the nucleus is created [14,15].

Once started at a given position, the sudden increase of the production rate of positive ions leads to an overall "activation" of this process. Therefore the self-enhancement of the production of positive ions alone is not sufficient to generate stable patterns in plasma. Their generation becomes, however, possible if the positive ion production is complemented by a mechanism able to act as "*long-range inhibitor*" without impeding the incipient self-enhancing mechanism of the production of positive ions. The appearance of the long-range inhibitor is related to the creation of a negative space charge by accumulation of those electrons that have lost their momentum by neutral excitations. This net negative space charge acts as an "antagonist" to the positive one. Since the excitation rate of neutrals also depends on the kinetic energy of electrons, the increase of the electric field intensity, related to the self-enhancement of the production of positive ions, also determines the growth of the density of the adjacent negative space charge.

Simultaneously with the self-enhancement of the positive ion density the local electric field increases so that the region, where the negative space charge forms by accumulation of those electrons that have lost their kinetic energy by neutrals excitations, is shifted away from the positive electrode. This "expansion" phase of the space charge configuration ceases because the production rate of positive ions cannot increase above a certain value when the neutral gas pressure is maintained constant. In the final phase of the CSCC evolution the negative space charge "balances" the positive space charge situated between it and the positive electrode. After this evolution the space charge configuration appears as a stable (static) self-confined luminous, nearly spherical, gaseous body attached to the anode [4,6,9,12]. Its self-assembling process does not require additional energy since the transition occurs into a state characterized by a local minimum of the potential energy. Measurements performed by using electrical probes reveal the presence of a spatial pattern in the form of a well-located positive nucleus surrounded by a nearly spherical DL [4–6]. The geometrical dimension of the CSCC is self-adjusted in such a way that the above-mentioned balance between the negative space charge, located at the low potential side of the DL, and the positive space charge, located at its high potential side and in the nucleus, is realized. This balance works in a dynamical way because the charged particles lost by recombination, diffusion and so on are continuously replaced by new charged particles. These opposite net space charges appear by accumulation in the regions where the excitation and the ionization cross-sections suddenly increase. For ensuring the stability of the CSCC, the DL at its boundary must be able to sustain a potential drop sufficient to maintain the spatial separation of the regions where the excitation and ionization cross-sections suddenly increase. This becomes possible only when the thermalized plasma electrons are transported by the external dc power supply to the region where the DL self-assembling process takes place.Therefore the DL self-consistency is only partial because its existence requires work performed by the external dc power supply. The stable CSCC, the self-assembling process of which requires a continuous "feeding" with electrons corresponds to a first stage of self-organization, revealed by the presence of a spatial pattern located in a region where a local acting constraint maintains the plasma away from the thermodynamic equilibrium.

Very interesting is the experimental emphasized fact observed in a plasma diode when the voltage of the anode is gradually decreased [5,9,14]. In that case the CSCC reveals a new quality emphasized in the current voltage characteristic by a hysteresis loop. The appearance of such a phenomenon is usually attributed to a special kind of memory by which a self-organized structure "reminds" its early history [16]. In our case this memory is experimentally emphasized by the fact that the CSCC is able, after its emergence to "survive" when the voltage of the anode is smaller than the critical value necessary to initiate its spontaneous emergence. This is an intriguing behavior revealing that, after its emergence, the potential-drop over the DL at the boundary of the CSCC is maintained by operations performed by the system itself. These operations involve quantum processes as excitations and ionizations related to the acceleration of thermalized plasma electrons in the DL that protects the CSCC like a membrane [9]. In this way all operations required for the continuous self-assembling of the CSCC are performed by the DL itself. However, to ensure the existence of the CSCC the external dc power supply must perform a work related with its "nutriment", i.e. transport of matter and energy towards it. Since the "effort" required from the external dc power supply for initiating the emergence of the CSCC is greater than that required for ensuring its existence, it result, that the CSCC performs, after its emergence, a part of the operations required for its survival in a "metastable" state [12]. These operations involve local acceleration of electrons during which the kinetic energy of the thermalized plasma electrons (placed at the high-energy side of their Maxwellian distribution) is conversed into energy stored in the electric field of the DL. Performing the operations required for its existence when the work done by the external dc power supply is smaller than that required for initiating its birth, the CSCC apparently transforms thermal energy in electric field energy.

The CSCC being after its emergence in a metastable state, i.e. a state possible only as long as the external dc power supply performs work, it reveals only a first phase of self-organization. During this state the survival of the CSCC is ensured by the help of the external dc power supply that transports the matter and the energy necessary for the operations required for the self-assembling process of the CSCC.

A higher degree of self-organization appears when the distance from the thermodynamic equilibrium is further increased, by increasing the voltage of the positive electrode so that, through a new instability, the CSCC spontaneously transits from the static state into an open steady (regular in behavior) state. The presence of this steady-state is emphasized by the periodic limitation of the current collected by the anode [17]. Electrical and optical measurements have proved that the periodical current limitations are produced by successive detachment and re-assembling of the nearly spherical DLs at the boundary of the CSCC. The detachment process starts for a voltage of the dc power supply for which the potential drop over the DL becomes so high that the electrons accelerated there create an amount of positive ions able to balance the adjacent net negative space charge. Under such conditions the self-assembling process of the DL can be realized independent of the electric field created by the positive electrode. This new state of the DL is unstable because its self-assembling process can be easily maintained when the DL transits into a moving phase. This happens since, self-adjusting its velocity, the DL is able to ensure itself a part of the flux of electrons required to sustain the excitation and ionization rates needed for replacing all its components by collisional events within the system. In this way the ‘‘effort’’ required from the external dc power supply to maintain this new stage of self-organization attains a second (lower) local minimal value. During this new ‘‘meta-stable’’ state of the gaseous conductor the flux of electrons traversing the DL consists of two parts. The first part contains the electrons transported by the current, driven by the external dc power supply. The second part represents electrons that cross the DL because of its propagation through the plasma.

The periodicity of the DL detachment process in a current carrying plasma appears because, after the detachment of a DL from the CSCC border, a new DL is self-assembled in the region where the previous one was generated. Since the negative space charge at the low potential side of the new DL acts as a barrier for the current, its development determines a decrease of the current transported by the plasma to a value for which the existence conditions for the moving DL are no longer fulfilled. So, the moving DL vanishes and, consequently, the electrons initially bounded at the DL become free and move, as a bunch, towards the positive nucleus where a new DL is in the forming phase [5–7,17,18]. The current increase when the bunch of electrons passes through the new DL causes a sudden increase of the excitation and ionization rates, so that this new DL starts its detachment process. This mechanism acts as an internal feedback by which DLs are successively detaching and self-assembling at the border of the CSCC. In this open steady-state, the periodical exchange of matter and energy with the surrounding environment by the agency of DLs ensures the existence of the CSCC.

We mention that, under special conditions, also in a currentless plasma, the DL can sustain its existence in a moving phase. This happens when the amount of material (neutrals, electrons and positive ions) in the plasma is so large that the flux of electrons needed for ensuring its existence can be attained by self-adjusting of the DL velocity. In this case the moving DL reveals soliton-like behavior.

After the transition from a stable static state into an open steady-state, the CSCC displays a higher level of self-organization emphasized by the decreasing to a new minimum of the ‘‘effort’’ required from the external dc power supply to maintain the new conductive state of the gaseous conductor. This means that, with respect to the ‘‘effort’’ performed by the dc power supply to determine the emergence of the CSCC in a stable static state, the ‘‘effort’’ to maintain the CSCC in an open steady-state becomes smaller. This reveals a new quality of the steady CSCC very alike to the specific features of a living being before its ‘‘birth’’ namely to undertake a part of the work required for ensuring its viable state. This is realized by a proper rhythmic exchange of matter and energy between the CSCC and the medium in which its emergence was produced. In this ‘‘pre-natal’’ phase of the CSCC existence, it is intermittently ‘‘nourished’’ with matter and energy supplied by the external source.

It is perhaps interesting to remark that the two stages of self-organization observed in a plasma diode marked by critical points in the static current voltage characteristic can be related to modern concepts of nonlinear dynamics. Thus, a subcritical Hopf bifurcation appears when the voltage of the external dc power supply (that acts as a control parameter) reaches the critical value for which the ‘‘birth’’ of the stable CSCC takes place. In the current–voltage characteristic the emergence of the CSCC is marked by the appearance of an S-shaped bistability, i.e. of an S-shaped negative differential resistance accompanied in certain conditions by the appearance of large current oscillations [12,14]. When the voltage of the dc power supply is additionally increased the gaseous conductor reaches another critical state for which the CSCC transits, through a supercritical Hopf bifurcation, into an open steady-state. This transition is experimentally proved in the static current–voltage characteristic by the appearance of a Z-shaped bistability (N-shaped negative differential resistance) and the simultaneous appearance of current oscillations, the amplitude of which softly increases [15].

We point out that the described evolution sequences (the result of which is an open steady CSCC) are based on phenomena such as nonequilibrium, symmetry breaking, instability, bifurcation and long range order, usually considered as key processes of self-organization [16].

The most interesting phenomenon observed in physical plasmas appears when the CSCC is created in low voltage arcs [19]. In that case, for a critical value of the anode potential, the CSCC detaches from the anode surface transiting into a free-floating state. Simultaneously with the emergence of the free-floating state of the CSCC the current–voltage characteristic proves the appearance of a Z-shaped bistability accompanied by a periodic limitation of the current. An investigation of the causes of this periodic current limitation showed that, in this state of the free-floating CSCC, the DL at its border is subjected to successive detachment and reformation processes. These phenomena reveal striking similarities with those observed when a CSCC in a steady-state is attached to the positive electrode [5,6,9] or is created in an hf electric field [20]. Surprising is the fact that, in this free-floating steady-state, the mean potential of the nucleus exceeds the ionization potential of the gas also when the anode potential is much smaller than this. The mechanism, by which the steady free-floating CSCC is able to self-maintain its mean potential equal/greater than the ionization potential of the gas, also when the anode potential is much smaller than this, is a problem not conclusively solved as yet. Since, by the detachment of a DL, a part of the positive ions initially located at the boundary of the CSCC are transported towards the surrounding plasma the potential of the nucleus decreases.

We tentatively explain the periodical recharging of the nucleus with positive ions during the intrinsic self-sustained dynamics of the DL from the boundary of the free floating CSCC, by a mechanism involving direct conversion of thermal energy into electrical energy. For such a conversion to be possible it is necessary to consider the Maxwellian energy distribution of the plasma electrons and also the experimental emphasized fact that, simultaneously with the detachment of the CSCC from the anode, it suffers a peeling off process by which the DL at the CSCC boundary starts its own detachment process. In this state, the free-floating CSCC becomes able to perform operations by which the processes needed for maintaining its steady-state occur by transformation within the system. As aforementioned, in a usual plasma diode such operations compensate only a part of the work required from the external dc power supply to ensure the "survival" conditions of the CSCC. This situation is changed when a discharge is ignited in a thermionic diode because in that case the temperature of the plasma is much higher and the gas (cesium) in which the discharge is produced has a very small ionization potential.

The recharging process of the nucleus of the free floating CSCC self-assembled in a thermionic diode becomes potentially explainable in an open steady state where the DL from its boundary performs a proper dynamics controlled by internal processes. Thus, in the first phase of this dynamics, realized after the detachment of the DL from its boundary, the thermalized plasma electrons "feel" the action of two electric fields. One of them is the electric field of the expanding DL [21], whereas the other one is the electric field created by the net positive space charge that remains in the nucleus after the CSCC peeling off process. As a result the plasma electrons are accelerated towards the nucleus obtaining kinetic energies sufficient to produce direct or stepwise ionizations. During this process a part of the kinetic energy of the electrons is dissipated in the form of thermal energy. So, the nucleus is heated especially by those plasma electrons, the kinetic energy of which is placed in the high-energy tail of its Maxwellian energy distribution. After this heating process a part of the electrons are ejected by thermal diffusion so that the nucleus is recharged to a potential, for which the new DL is self-assembled at its boundary. To explain the peeling off process of the CSCC, we consider a feedback mechanism similar to that producing the periodic current limitation observed in a plasma diode when the CSCC is attached to the anode [5,8,17,18]. This mechanism involves the deaggregation of the DL after its detachment process. This deaggregation is caused by the diminution of the flux of electrons traversing it. This happens because the reassembling of a new DL at the boundary of the stationary CSCC annihilates the existence conditions for the spherical DL in an expanding phase. After the deaggregation of the expanding DL the electrons, bounded in its space charge configuration, become free and are accelerated, as a bunch, towards the positive nucleus. Reaching the boundary of the nucleus, where a new DL is self-assembling, the flux of electrons increases to the critical value for which the new DL starts its detachment process. So, a positive feedback mechanism, able to ensure the steady-state of the CSCC by periodical self-assembly, detachment and decay of DLs from its boundary, can also work when the potential of the anode is much smaller than the ionization potential of the gas.

By performing operations during which thermal energy is transformed in the electric field energy required for maintaining its self-organized state, the CSCC performs operations that apparently defy locally the second law of the thermodynamic. As known, this experimental result is interesting as it starts to relate to the central issue of Complexity science namely to the presumption that natural phenomena, like life, violate thermodynamics over quite a large "local" system.

The experiments on low voltage arcs prove that for performing the operations required for ensuring the existence of the free floating CSCC this must be placed in a medium the temperature of which is sustained by an external source over a critical value. In this context, we remind that a similar condition must be fulfilled for initiating the birth of a living being from an egg or for creating the conditions for the development of a plant from a seed.

For high gas pressure, the geometrical dimensions of the CSCC are very small so that the described DL detachment and reformation processes occur in a relatively thin region at its border. Conveniently, this region could be considered as playing the role of a "membrane" that protects the CSCC from the surrounding environment [8,9]. Since the detachment of the DL involves the extraction and transport of positive ions from the nucleus of the CSCC to the surrounding plasma, a pressure difference appears between the former and the latter. Thus the periodic detachment of DLs from the boundary of the CSCC border implies a rhythmic "inhalation" of fresh neutrals into the nucleus. So, a CSCC self-assembled in a plasma also mimics the breathing process proper to all living systems. By this breathing process the concentration of neutrals in the nucleus is periodically self-adjusted to a value for which the described rhythmic exchange of matter and energy ensures the autonomous state of the free-floating CSCC.

With respect to other laboratory experiments performed with the aim to create precursors of living systems, the essential news of our experiments consist in the fact that the CSCC is the result of cascading scenario of a self-organization that involves a succession of physical processes, the stepwise appearance of which evolves naturally. This means that once started by an external cause (spark) the spontaneously produced self-assembling process of the CSCC is governed only by a mechanism that intrinsically controls its evolution into a self-organized autonomous state. Showing the described characteristics the CSCC "created" in laboratory is, to the best of our knowledge, the first complexity that, after its spontaneous emergence, reveals a structure and perform operations usually proper to living being. Proving such new qualities the CSCC is potentially able to perform a further biochemical evolution into a "living" cell.

3. The self-assembling process and the dynamics of a gaseous cell potentially informative for the emergence and behavior of a biological system

For biologist it could be of interest that the self-organization scenario explaining the emergence of a CSCC is based on opposite space charge separation related to the symmetry breaking of specific quantum cross-sections functions. In plasma such phenomena appear when an external constraint produces a local gradient of the kinetic energy of electrons so that the regions where the excitation and ionization cross-sections suddenly increase are spatially separated. This facilitates the accumulation of charged particles in two adjacent regions and, implicitly, the formation of a pattern. If a mechanism that is in principle similar to one acting in plasma, could also continue in chemical media, in which autocatalytic processes sustain pattern formation [22], this would be a fascinating problem for further investigations. As known, this possibility is supported by the fact that the simulations of biological pattern generation are essentially based on nonlinear chemical reactions presumable related to a negative differential resistance. Since the nature of this negative differential resistance remained up yet not conclusively elucidated [23], the consideration of a self-organization scenario as described in this paper could be an alternative explanation. In this context we remember that, starting from the fact that symmetry breaking is a universally present phenomenon in biology, in his work "The Chemical Basis of Morphogenesis" [24] Turing proposed a mechanism for the generation of biological patterns. He considered a system of equations for chemical reactions, coupled by diffusion, which would deliver solutions that could break the symmetry of the initial state of a system. In the same context we remember that self-organization, related to symmetry breaking due to fluctuations in chemical systems with reaction and diffusion are regarded by Prigogine [25] as a clue to the origin of life.

Concerning the cell models hitherto proposed, based on electronic circuits, constructed in order to simulate the electric activity of a biological system, we point out that a CSCC created by a cascading self-organization, initiated by a spark, reveals a phenomenology which could also appear under natural conditions. A phenomenon that illustrates such a possibility is, in our opinion, the ball lightning, the occasional appearance of which proves the ability of Nature to create well localized ordered space charge configurations [4]. Its interpretation as a "giant" cell seems to be justified if the described cascading scenario of self-organization actually determines its emergence. Produced in a point where an electrical spark strikes the surface of the Earth that is positively charged and in an atmosphere that essentially differs from that presumably existent under prebiotic Earth conditions, the evolution of a ball lightning-like CSCC ceases after a relatively short lifetime. This was, very probably, not the case when a CSCC was created by a simple spark under the conditions that existed in the prebiotic Earth. Occurring in a medium, presumed to be a chemically reactive plasma, the possibility of a further evolution of a CSCC into the contemporary cell becomes a potentially possible alternative.

As revealed by Nature, the creation of a living cell requires the self-assembling of a framework in the form of the cell membrane mainly constituted of lipids and proteins. The most important parts of this framework are the channels that, by a specific electric activity, control the matter and energy exchange between the nucleus of the cell and the surrounding medium. The force that maintains the ionic current through a channel has its origin in the electric potential produced by the gradients of the concentration of the different ion species inside and outside the cell. In the steady-state of the cell, the local ionic influx compensates the ionic efflux. Why this gradient appears and acts, is today a challenging problem of biology. In this context new information offered by biological observations have proved the presence of pH modulations. These are accompanied by the appearance of spatio-temporal patterns originating from a hypothetical self-organization scenario presumably related to a symmetry breaking mechanism [26]. For explaining the periodic pattern in the diffusion currents, induced by concentration gradients, a theory of electrodynamic instabilities was proposed linked to the specific properties of the membrane [26].

An alternative explanation of the presence of spatio-temporal patterns in biological observations could be based on a self-organization mechanism as that one described in this paper. Such a mechanism becomes possible if a biological cell is the result of the evolution of a gaseous cell, formed by a cascading self-organization scenario in a chemical reactive medium, as that presumably present under the prebiotic Earth conditions. In that case, in order to ensure its viability, the membrane of the cell must contain channels able to maintain a local gradient of different ion species. This could be possible if at the ends of the channels micro-DLs with qualities remembering their early history are present. This means that the micro-DL preserves its initial ability to sustain and control an anomalous transport of matter and energy through the channel by a proper dynamics. It has obtained this ability during its emergence under prebiotic Earth conditions. In this way, the living state of a cell can be related to a mechanism able to explain the presence of periodic current patterns observed in the channels of its membrane [26]. This mechanism can also explain the manner by which the pumping process is sustained in the channels of the cell membrane.

The initiation of the self-assembling process of the CSCC requires energy sufficient to produce the spatial separation of electrons from the positive ions by thermal diffusion (plasma at relatively high temperature). However, its further development into a self-organized complexity takes place when the kinetic energy of the electrons is sufficient to excite and ionize neutrals in the ground state. This means that nonlinear chemical processes usually present in a mixture of chemical reacting gases in which the CSCC was created take place at temperatures suitable for a biochemical evolution.

It is worth to mention that CSCCs, created in plasma by self-organization, also reveal other interesting phenomena, such as self-multiplication by division and exchange of information [27]. The last mentioned behavior is realized by the emission of electromagnetic energy with an appropriate frequency by a CSCC in a steady state and its resonant absorption by another CSCC.

We remember that experiments performed in chemical reactive plasma created in hf electric field [28,29], where electrical sparks are present during nonstationary phases [30], have proved the emergence of micro-spheres bordered by an electrical DL. Acting as a membrane, the DL selectively retains biologically active compounds. Considered by the authors as a primitive structure able to potentially explain the origin of life, their spontaneous self-assembling process remained up yet not explained. Perhaps the new insight offered by the self-organization scenario described in this paper can gives more knowledge concerning the mechanism by which such complexities, potential precursors of living beings, emerge in a chemical active plasma.

4. Conclusions

In this paper, we pointed out that the identification of the physical processes at the origin of pattern formation in plasmas reveals the presence of a mechanism of self-organization that substantially advances the knowledge concerning the creation of complex systems in general.

Although the new knowledge about the succession of physical processes implied in the described scenario of self-organization was obtained from experimental investigation performed on a physical plasma, i.e. a gaseous medium at relatively small pressures, similar phenomena can be observed at relatively high pressures [11], as well as at normal atmospheric pressure [31]. For simple sparks where the involved energy is relatively small the dimensions of the CSCC are also small. We also mention that similar self-organization phenomena could potentially explain the emergence of spatial and spatio-temporal patterns in semiconductors [12,23,32] and also the appearance of flicker noise [33].

Based on phenomena such as local self-enhancement and long-range inhibition, the described scenario of self-organization shows striking similarities to those considered being at the heart of biological pattern formation [22]. Therefore for biologists the knowledge of the physical phenomena that explain the emergence of the steady CSCC in a physical plasma could be interesting, accepting that their understanding has paramount importance in various biological events, as for example the morphogenesis, the polarization, and the acquisition of nutrients [34]. Concerning the hypothetical origin of a self-organization process presumed by [26] to be present for explaining the generation of periodic patterns in the cell membrane, the phenomenology at the origin of the dynamical behavior of a CSCC described in this paper could potentially offer a new insight. Additionally new information in which electrical signals could eventually control the rhythm of the membrane dynamics is revealed.

The plasma experiments presented in this paper suggest that the premises for a biochemical evolution into a contemporary cell produced over millions of years comprise a first phase during which physical nonlinear phenomena, initiated in the early earth atmosphere by electrical sparks, determines the spontaneous self-assembling of a CSCC. Revealing an internal structure and performing operations specific to a living organism, the CSCC emerged under prebiotoc earth conditions potentially represents the most simple organism the further biochemical evolution of which can eventually explain the origin of the life.

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