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Self-Organization as a Possible Route to Fusion Energy

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Abstract

The generation of a ball lightning-like complex structure by sudden injection of matter and energy proves the presence of a cascading self-organization scenario in an experimental device containing a collisional plasma. Based on these results, we suggest the possibility to replicate, under controlled laboratory conditions, the ball lightning-like structures with potential fusion applications.

Keywords:

ball lightning, self-organization, double layer, energy trapping, fusion

1. Introduction

The interest of the plasma research community for clarifying the physical phenomena involved in the phenomenology of the **B**all **L**ightning (BL) is related to the occasionally observed high energy released during its explosive disaggregation. This energy can be greater than 2×10^{10}J/m^3. Such values of energies are well above the limit of chemical or other conventional energies.

Starting from this observational characteristic of the BL it was expressed the opinion that, besides the sun and the stars, the single natural phenomenon where fusion processes are present in the nature is the BL. Thus, in a recently published paper, Roth listed the characteristics that justify the opinion that BL can be a new kind of fusion reactor with very large industrial and military applications [1].

A physical process, very probable the single one, able to explain such a concentration of energy is, in our opinion, the space charge separation related in this case to the formation of a complex spherical structure bordered by an electrical **D**ouble **L**ayer (DL). Recent investigations, performed under controlled laboratory conditions, of the causes able to generate BL-like structures evidenced the presence of a succession of key processes that constitutes a new self-organization scenario based on collective effects of quantum processes [2-4]. The development of this intermittent self-organization scenario under controlled laboratory conditions is proved when matter and energy is continuously pumped into the plasma. Although unlikely in the earth atmosphere during thunderstorms, it is very informative to know this scenario for identification of the physical processes involved in the BL phenomenology.

More recently, T. Sato *et al.* [5] attested by simulations the possibility to create ordered structures in plasma devices by a cascading self-organization scenario produced by instantaneous energy pumping. Such a scenario is very probable present in the earth atmosphere during thunderstorms.

The purpose of this paper is to describe briefly an experiment able to prove the presence of a cascading self-organization scenario in a device in which the plasma is collisional. The informational content of this experiment can suggest a possible explanation of the BL phenomenology. In this context we notice that recently

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Kadomtsev [6] agreed the opinion already expressed [7] to consider the BL as a self-organization phenomenon. However, the consideration of the BL as an accumulator [6] charged with chemical energy by a lightning stroke does not present interest for further theoretical and experimental investigations concerning the possibility to replicate in laboratory a BL-like structure working as a new kind of fusion reactor.

2. Cascading Self-Organization at the Origin of the Ball Lightning

As already shown in laboratory plasma experiments space charge arrangements able to store energy can be produced after local acceleration of electrons towards a positively biased electrode immersed in a plasma in thermodynamic equilibrium and asymptotically stable [2-4]. Under such conditions the initially present symmetry of all the functions going in the system is broken. This is the initial condition for appearance of self-organization [8]. From these functions the most important are the excitation and ionization cross section functions whose symmetry breaking initiates the self-organization process. So, the sudden increase in different but adjacent regions of these functions determines the self-assemblage of a DL whose stability is assured by electrostatic forces acting as long range correlation between the two space charges [2-4]. The energy stored in the electric field located in the electrical DL structure evidently depends on the amount of the opposite net space charges and on their reciprocal position.

In agreement with Sato's simulation experiments [5] there are two self-organization scenarios (intermittent and cascading). The same scenarios can be observed in collisional plasma. These possibilities highly depend on the way of how energy is injected into the system. Thus, when energy is gradually injected, the system experiences intermittent order creation. By contrast, when energy is suddenly pumped, the system relaxes stepwise into a stable ordered structure. The final product of both self-organization physical scenarios is a complex space charge configuration whose genesis and behavior justify the opinion of considering it as a possible phenomenological replication of the BL.

Based on experimental investigations related to the appearance of ordered spatio-temporal structures known as fireballs observed in dc gas discharges [2], as well as plasmoids observed in hf gas discharges [9], we describe firstly the intermittent self-organization scenario. We consider its informational content elucidative for explaining the cascading self-organization scenario. Therefore such an experiment could be interesting for further investigations with the aim to replicate in laboratory BL able to work, eventually, as a new kind of fusion reactor.

3. Experimental Device and Results

The experimental device used to simulate in laboratory the phenomena presumptively involved in the intermittent self-organization scenario is schematically presented in Fig.1. It contains a dc discharge used as a plasma source placed in a glass tube filled with argon at low pressure (~1N/m^2). At the free end of the plasma column which diffuses from the plasma source is placed an electrode A whose potential can be gradually increased and decreased by changing the voltage of the external dc power supply. Under such conditions it is possible to generate in front of the electrode a fireball whose photograph is shown in Fig.2(a). The intermittent self-organization scenario involved in its generation was extensively described in already published papers [2-4].

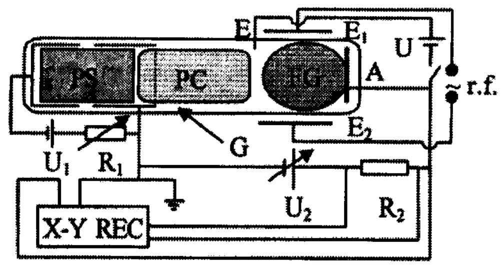
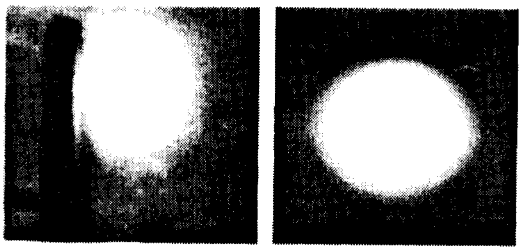


Fig. 1 Experimental device: PS – plasma source, PC – plasma column, FG – flaming globe, A – positive electrode, E – spark producing electrode, E_1, E_2 - electrodes connected to a radio frequency source.



a) b)

Fig. 2 (a) Flaming globe formed in front of A; (b) plasmoid formed between E_1 and E_2.

Each change of the plasma qualities related to this scenario is directly emphasized by the presence of critical points in the static current versus voltage characteristic of the gaseous conductor.

For proving the possibility to maintain the fireball in a free floating state by trapping only radiant energy we have used an external source of rf energy which creates an alternative electric field between the external electrodes E_1 and E_2. Its working frequency was in the range of 100MHz.

The experimental device above described allows to prove firstly the presence of an intermittent self-organization scenario by which a fireball can be created, (Such a scenario is not probable under natural conditions like those present during thunderstorms); and, secondly, a cascading self-organization scenario by which a ball lightning-like structure is formed after a cascading self-organization scenario (very probable in nature during thunderstorms).

Thus, gradually increasing and decreasing the voltage of the external power supply, we obtained the $I(V)$-characteristic shown in Fig.3. The key processes of the intermittent self-organization scenario related to the critical points emphasized in this characteristic were largely discussed already [2-4]. For initiating the cascading self-organization scenario it is necessary to bring the gaseous column in a bi-stable state obtained when V-value is between V_4 and V_1. When the current is situated in the low current branch of this $I(V)$-characteristic, the ignition of a point discharge (spark) between E and A spontaneously initiates the self-assemblage of a flaming globe attached at the A-surface accompanied by a sudden jump of the current. Its experimental investigation proved the presence of a complex space charge configuration whose self-consistence is ensured by a nearly spherical electrical DL [2]. The cascading self-organization scenario at its origin starts from a sudden injection of matter and energy in the hot plasma produced after material evaporation in the point where the spark strikes the A-surface. Because of the differences in diffusivities and mobilities of electrons and positive ions, the first ones are "collected" by the positive A so that a nucleus with positive ion excess is formed. Acting as a gaseous anode the nucleus attracts the electrons from the surrounding plasma initiating the known succession of key processes present in the intermittent self-organization scenario [2-4]. Taking into account the tendency of every physical system to transit into a stable state characterized by minimal free energy value, the flaming globe detaches

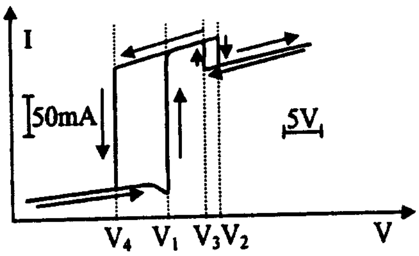


Fig. 3 I(V) characteristic of a plasma diode.

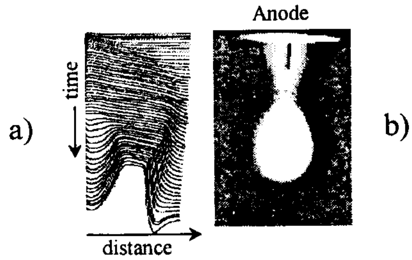


Fig. 4 (a) Space-time diagram of the light intensity proving the detachment process of the flaming globe (time step 2μs; detachment distance from A, 6cm); (b) Photograph of the detached flaming globe.

from the A surface transiting into a free floating state. The detachment process is evidenced in Fig.4(a), (b). The free floating flaming globe generated in this way is stable as long as the value of voltage V is between V_1 and V_2. When V is further increased the fireball becomes a pulsatory one [9].

For explaining the occasionally observed long lifetime of the BL we have set on the rf generator so that between the two plates E_1 and E_2 an electromagnetic field is created. Under such conditions, disconnecting the dc power supply, it is possible to maintain the flaming globe by resonant trapping of electromagnetic energy from an external rf generator. In this state the flaming globe behaves as a plasmoid (Fig.2(b)), i.e. a "cavity" bordered by a spherical DL whose properties were described in a previously published paper [9].

4. Conclusions

The above experiment proved the possibility to replicate in laboratory experiments a space charge configuration, formed as a result of a cascading self-organization scenario with relevance for the BL appearance. In this context it is interesting to mention experimental results performed in z-pinch and plasma focus device [10,11] by which the spontaneous generation of "plasmoids" was observed under conditions more appropriate to those existent in nature during thunderstorms. These experimental results seem to attest also the presence of a cascading self-organization scenario able to determine the self-assemblage process of a complex space charge configuration similar to that described in the test experiment. The self-assembled complex structure (plasmoid) observed in the last mentioned experiment proves very high electron concentrations ($2–5 \times 10^{24} m^{-3}$) as well implication of high energy processes. These are evidenced by x-ray radiation and by the presence of high energy ions [10,11]. Therefore the cascading self-organization scenario could be tentatively considered as a new possibility to create, under controlled laboratory conditions, ball lightning-like space charge configurations working, eventually, as fusion reactors.

For this end we suggest two essential succession of experiments:

i) generation by a sudden injection of matter and energy of a well localized hot plasma able to initiate a cascading self-organization scenario finished by the appearance of a space charge configuration bordered by a spherical double layer;

ii) sustenance of the self-organized space charge configuration by trapping at resonance radiant energy from a suitably working external source.

Clearly, some new investigations concerning the conditions as gas nature, amount of the injected energy, rf energy amount and rf frequency are necessary to reproduce in laboratory BLs as those which attracted the attention of the fusion research community (2nd Symposium on Current Trends in International Fusion Research. Review and Assessment, Washington, 1997).

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