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PHENOMENOLOGY OF THE BALL LIGHTNING AND ITS RELEVANCE FOR OTHER ENIGMAS OF NATURE

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PREFACE

One of the most astonishing phenomena occasionally revealed by Nature is ball lightning. Observed during thunderstorms it appears as a free-floating spherical or nearly spherical luminous gaseous body the lifetime of which substantially surpasses the duration of its emergence. Each year, hundreds of eyewitness accounts of such strange events are reported to local journals, police and even military authorities. Appearing randomly, their scientific investigation is very difficult. So, the elucidation of its genuine origin remained one of the most intriguing and enduring challenges of the contemporary science.

The presence of lightning balls was well documented more than a hundred years ago in many journals and periodicals. At present the information concerning their aspects and behavior are mainly based on eyewitnesses and on the very rare performed photographs. For example, in the United States, lightning balls have been observed by about 5% of the adult population at some times in their lives [1]. Among the prominent individuals who have observed lightning balls are *Niels Bohr, Peter Kapitsa* and *Victor Weisskopf.*

The literature of ball lightning comprises a very great number of reports that appeared as letters, for example in *Nature* (see references), books entirely dedicated to this subject [2-4], review papers focussed on this topic [5-8], as well as data banks. Periodically, new aspects concerning the ball lightning appearance and behaviors are discussed at international conferences and symposiums. Essentially based on eyewitnesses, various theories have been published but none of them account for their emergence and proprieties completely satisfactory. All of them run into problems of their stability and relative long lifetime.

Potentially informative for the phenomenology of the ball lightning is the fact that most frequently the observers relate its appearance to effects produced by ordinary (linear) lightnings in points where these strike the surface of the Earth. So, starting from the premise that the hot plasma in non-equilibrium produced by vaporization of the matter in such points is at their origin, the emergence of the ball lightning can be related to information offered by plasma experiments. Containing large groups of electrons and positive ions (in certain cases also negative ions) able to interact electrically the plasma created in this way exhibits collective effects produced by electrons many of them not explainable in the frame of the contemporary Science. So, referring to the ball lightning phenomenon we remark that instead to transit into a state of thermal equilibrium, as required by the second law of thermodynamics, the hot plasma in non-equilibrium produced by the linear lightning evolves into a coherent, self-confined and relative stable luminous gaseous body. Owing to the fact that this evolution of the hot plasma takes place naturally, i.e., in absence of any driving forces up yet identified, the emergence of ball lightning was potentially explained considering self-organization at its origin [9,10].

In this book we describe in detail laboratory experiments concerning the mechanism by which self-organization intrinsically emerges. Based on these experimental results we offer a new paradigm for the perception, besides the ball lightning, also of other enigmatic phenomena observed in Nature and laboratory. Such phenomena appear in Nature at scales ranging from macroscopic to mesoscopic ones. So, for example, the appearance of the well-located giant luminous spheres occasionally observed in certain points at the surface of the Sun but also the emergence of the well-defined luminous filaments that connect together galaxies could be explained considering self-organization at their origin [11]. At mesoscopic scale, a scenario of self-organization similar to that at the origin of the ball lightning initiated by minuscule electric sparks under early Earth conditions potentially explains the emergence of the most simple living systems [12-14]. Emerged initially in a dusty plasma and in absence of organic matter [15] in an environment itself in evolution as that at the surface of the Earth, where water and organic matter appeared at a certain phase of its evolution, the appearance of the biochemical assemblies and implicitly of the organic life becomes potentially explainable [14,16].

The essential news revealed in this book refers to the fact that self-organization and implicitly the appearance of ball lightning are phenomena not explainable by classical processes. Once emerged, order is maintained in a dynamical state of self-organization activated by a mechanism by which the thermal energy extracted by electrons from the surroundings is directly converted into electric field energy.

In writing this book we have used many experimental results obtained and published in collaboration. We indebted, especially, to professors G. Popa, M. Toma, L. Biborosch, S. Popescu, D. Dimitriu, V. Pohoata and S. Gurlui from our University and professors R. Schrittwieser and C Ionita from the University of Innsbruck, Austria.

We thank Miss R. Aldea and Mr. G. Tibu for technical assistance.

We express also our thanks to the editorial board of Nova Science Publisher and in particular to Mr. Frank Columbus for the proposal to publish this book.

DEDICATION

We dedicate this book to Alexandru Ioan Cuza University, Iasi, Romania, that recently celebrated its 150 Years anniversary.

Chapter 1

BALL LIGHTNING MODELS: SHORT REVIEW

Starting from the very great number of papers describing the appearance and behavior of ball lightning, two essential questions prevail. First there is the question of what form of energy could be stored in a well-localized relatively small volume of air (of the order of 10^{-3} to 10^{5}J/cm^{3}) and second, what mechanism explains its occasionally observed long life (up to 100s). There are two essential distinct opinions. One of them starts form the hypothesis that the generation and lifetime of the ball lightning can be explained by considering the nature of the material located in it during its generation by the linear lightning. So, different reactions ranging from chemical to nuclear ones initiated by the energy injected by the linear lightning were considered to be at the origin of the ball lightning. The other opinion relates the appearance and lifetime of the ball lightning to a local concentration of high-frequency electric field energy. Such phenomena are possible after interference of electromagnetic waves generated by linear lightning or other electrical phenomena occurred during thunderstorm in the atmosphere of the Earth. This opinion is argued by measurements showing that lightning flashes generate damped electromagnetic waves the duration of which surpasses the time span of their occurrence.

Starting from the first hypothesis, *Kadomtsev* [17] considered the ball lightning as a gas accumulator, charged by ordinary lightning, where the accumulated chemical energy is released in the form of an electric discharge. *Turner* [18] considered the ball lightning to be a thermochemical heat pump powered by the electric field of a thunderstorm. A theory of the ball lightning based on the electric field associated with current filaments originating from a point where linear lightning strikes the surface of the Earth was proposed by *Lowke* [19]. A new kind of power source of the ball lightning, considered by *Hubler* [20] to be the most appropriate to elucidate the ball lightning phenomenon, was proposed by *Abrahamson* and *Dinniss* [21]. They consider at the origin of the ball lightning the chemical energy stored in pure silicon which is unstable to oxidation at high temperatures.

Starting from the second hypothesis, firstly proposed by *Kapitsa* [22], *Jennison* [23] suggested that ball lightning consists of electric field energy trapped in an air-evacuated cavity of approximately spherical shape with an ionized sheet separating it from the atmosphere. *Zheng* [24] considered ball lightning to be an enclosed plasma shell generated by short radio waves associated with ordinary lightning. In the same context, microwave experiments performed by *Othsuki and Ofuruton* [25] proved the possibility for producing fireballs in air by using microwaves. *Yasui* [26] proposed a model related to this experiment. Another model proposed by *Handel and Leitner* [27] explains ball lightning as a plasma caviton feed by a large atmospheric maser. The caviton is considered to be a non-linear quasi-stationary electric field localized in a plasma configuration in oscillation. *Ranada and Trueba* suggested that ball lightning could be formed from knots of the electric and magnetic components of an electromagnetic field [28]. In more detail, this model is described in [29]. For explaining the occasionally reported very high energy density delivered by some lightning balls during their disintegration, *Altschuler, House and Hilder* [30] suggest to consider the presence of nuclear reactions. Recently, *P. A. Torchigin and A. V. Torchigin* [31] showed that ball lightning can be a pure optical phenomenon where only intense light and compressed air interact. More recently, *Peer and Kendl* [32] consider that strong electromagnetic pulses are able to induce transcranial magnetic stimulation of phosphenes in the visual cortex that could eventually explain a large class of reports on luminous perception during thunderstorms. In their opinion lightning balls could by hallucinations. Considering the appearance of the ball lightning as a fractal process, *Mohorianu and Agop* [33] elaborated a theoretical model of the ball lightning by applying the Scale Relatively Theory.

The great interest concerning the possible implication of the phenomena at the origin of the ball lightning in fusion research, industrial plasma engineering, and military applications were emphasized in the comprehensive paper published by *Roth* [1]

Chapter 2

EXPERIMENTS POTENTIALLY INFORMATIVE FOR THE BALL LIGHTNING GENESIS

Luminous gaseous flaming globes bearing many resemblances to lightning balls were observed long time ago in laboratories where the transport of current in rare gases was experimentally investigated. Thus, as reported by *Wayne Strattman* [34], *Irving Langmuir*, a prominent American scientist, and his collaborators have published in *Scientific American,* beginning with the second decade of the 20^{th} century, photographs revealing that free floating flaming blobs with sizes in the order of centimeters emerge spontaneously in plasma devices. Briefly speaking, their device consisted of a glass tube, filled with argon at very low pressures. Two heated, i.e., electron emitting tungsten filaments were placed in opposite sides in the tube. Positively biasing one of the filaments with respect to the other one (250 V), a gaseous conductor namely the plasma was produced. The plasma located in the glass tube contains, besides electrons, free positive argon and tungsten ions but also neutral and excited argon atoms. Bringing the electric field generated by a terminal of a high frequency coil near the tube, a free-floating flaming globe spontaneously emerges in the glass tube. The globe consists, as authors reported, of a central red core, with a diameter about one centimeter, which bears positive charge. A thin dark space surrounds this region and, beyond this, a bright yellow negative sheath of glowing gas that gradually disappears. Instead of this negative sheath, an electric double layer that borders the flaming globe spontaneously appears. The authors explained the appearance and the visual aspect of the flaming globe observed in their experimental device considering the effects related to the implication of ionizations and excitations of the tungsten atoms.

In spite of the fact that the presence of beautifully colored flaming globs revealing many similarities with lightning balls continues to be reported in a great number of papers these experimental results are considered at the present date not able to offer sufficient information to explain the actual origin of ball lightning. This is due to its appearance in very rare gases and the relatively small energy involved in its emergence. This state of the art was changed recently by new laboratory experiments showing that, by very quick local injection of energy, it is possible to produce in air, under controllable laboratory conditions, free floating flaming globs, the lifetime of which substantially surpasses the time span in which they emerged.

In the following we will describe some of these experimental results but also other ones obtained in different devices were plasma is present. Thus, in a recently published paper, *V. Dikhtyar and E. Jerby* [35] showed that fireballs can be ejected from a molten hot spot in air by localized microwaves. The evolution from the molten hot spot created in this way into a microwave cavity comprises three phases emphasized in Figure 1 [36].

Thus, briefly speaking: (i) A well-located hot plasma is created by microwave drill by vaporization of the substrate material; (ii) A fire column is ejected from the well located hot plasma; (iii) The fireball detaches from the hot spot and floats near the cavity border. The fireball survives for another 30-40 ms after the microwave source is turned off. The emergence of the fireball is accompanied by strong absorption of microwave energy. The fireball consumes entirely the energy produced by the source of microwaves. In the conclusion of their paper, the authors consider the obtained experimental results to be a strong argument in favor of the model of ball lightning proposed by *Abrahamson and Dinniss* [21]. As aforementioned, this model considers at the origin of the ball lightning a slowing “burning” process of solid material particles of the substrate material initiated by very quick injection of energy by a linear lightning.

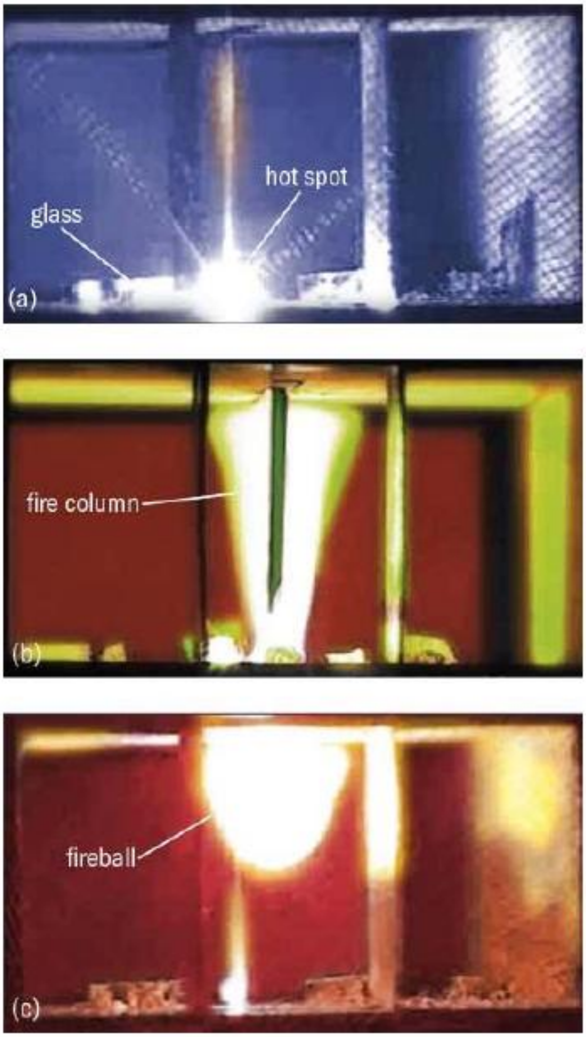


Figure 1.

Other experimental results, also frequently commented in the last time in the scientific literature in connection with the ball lightning phenomenon, were published by researches at the Humbold University, University Leipzig, Germany and Eindhoven University, The Netherlands [37]. In that experiment, fireballs of diameters between 10-20 cm were produced by very short high voltage discharges (up to 60 amperes) in water. The fireballs (Figure 2) continued to be visible about 300 milliseconds after the current has decayed and the energy input was thus turned off.

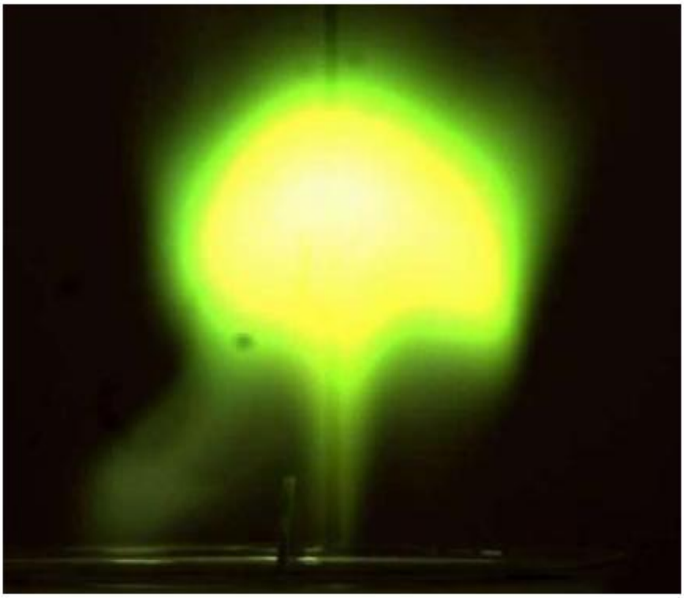


Figure 2.

The fireball glows very brightly although it appears to be rather cold. Thus, a sheet of paper placed above it does get lifted but it does not catch fire.

The two above briefly described experimental results obtained in air at normal pressures were related to the ball lightning phenomenon because the fireballs appear in an environment similar to that in which lightning balls usually appear. However, many characteristics of ball lightning as, for example, its motion against the wind and its penetration through windows without damaging them, many times reported by the observers, are events not explainable by the above described experiments. In this context there are reports that lightning balls are able to trail beside aircrafts. Occasionally, these penetrate the windows of aircraft mowing inside them before they disintegrate without producing important physical injuries. Nevertheless the above presented experimental results are important in connection with the phenomenology of the ball lightning because they prove that, under controllable laboratory conditions, it is possible to create in air free floating fireballs the lifetime of which substantially surpasses the duration of their emergence. The importance of these experimental results resides in the fact that these demonstrate that it is possible to initiate the emergence of confined plasma blobs by a very quick injection of energy in ambient air. However, referring to the opinion of *Dikhthyar and Jerby* that their experimental results could be arguments in favor of the ball lightning model proposed by *Abrahamson and Dinniss* the fact that the plasma blobs created by them survive as long as the micro-wave field is present reveals that at their actual origin is not a slowing burning process. Evidently, after the combusting material is finished, their further existence is based on another mechanism namely the absorption at resonance of microwave energy. As we will show in this book, the mechanism by which this actually works can be explained considering at the origin of the fireball a dynamical state of self-organization.

Chapter 3

CURRENT STATUS OF THE CONCEPT OF SELF-ORGANIZATION

Self-organization is a phenomenon observed in nature and laboratory that relates the presence of order formation in complex dynamic systems, i.e., systems the state of which in any moment of time is a function of their state in the previous moment of time and the input of energy. Included in the fields of *Cybernetics* and the so-called *"Gestalt Theory",* the identification of the physical processes involved in the emergence of self-organized (complex) systems could offer, as generally accepted, a new support for understanding enigmas observed in Nature but also in all branches of Science.

As known, the concept of self-organization was first introduced in the 1940 by cyberneticist *W. Rodd-Ashby* [38] and developed by *Heinz von Foerester* [39]. The idea was picked up by *Ilya Prigogine* [40], who received a Nobel Price for his investigation of self-organizing "disipative structures" and *Herman Haken* [41] who dubbed his approach as "synergetics". For arguing its theory Prigogine starts from the experimental results known as *"Bénard cells"* [42] and from the chemical patterns discovered by *Zhabotinsky* and *Belousov* [43] whereas *Haken* underground its theory considering the laser as a paradigm for self-organization of the first kind reduction of the degrees of freedom.

Paradoxically, self-organization is a phenomenon the presence of which was observed investigating chaotic processes emphasized by the so called non-linear systems the spontaneous transition of which into an ordered state is controlled by deterministic chaos. This means that these systems are characterized by extreme sensitivity to their initial conditions.

For modeling dynamical systems, many theories were proposed. So, cellular automata models of distributed dynamical processes, characterized by discrete space and time, have been used to study the behavior of the nonlinear systems and implicitly of self-organization. A mathematical model known as catastrophe theory, elaborated by *Rene Thom* [44], was also proposed to explain self-organization. More recently *Bar-Yam* [45] has developed the *"Science of Complexity"* essentially based on self-organization.

As remarked by *F. Heylighen* [46], in spite of intensive investigations, the science of complex self-organized systems taken as a whole is still little more than a collection of examples, methods and metaphors for modeling their emergence and behavior. So, at present, a phenomenological model and implicitly an integrated theoretical explanation of self-organization, describable in terms of mathematical equations, is missed. This lack in understanding self-organization, i.e., the emergence of order in the form of patterns was compensated by enouncing a principle as *"order from noise"* (Heinz von Foerster), *"order through fluctuations"* (Ilya Prigogine) and the so-called *"slaving principle"* (Herman Haken). These principles were inspired by experiments as afore mentioned. However only principles alone are not able, in our opinion, to answer the important questions for understanding how self-organization actually emerges. Such questions listed for example by *Gollub and Langer* [47], are:

- Which perturbations and parameters sensitively control pattern formation?
- What are the mechanisms by which those small effects govern the dynamics of pattern formation?
- What are the interrelations between physics at different length scales in pattern-forming systems?
- When and how do atomic-scale mechanisms control macroscopic phenomena ?

In this book we will try to answer all these questions.

In the following, we present experimental results proving that the "organizer" of the ordered state (not identified in all models elaborated up today) is a population of electrons driven at a critical distance from thermal equilibrium by an external constraint. So, in an environment where such a population of electrons is present, thermal fluctuations the appearance of which is controlled by deterministic chaos, are able to initiate a bifurcation-like instability. As a result, a complexity able to perform, in a dynamical state, all of the operations “learned” (encoded) during its emergence by self-organization, appears.

Referring to the technological applications of self-organization, its presence under special laboratory conditions provides, as generally accepted, the single route for “mastering” so called intelligent materials, i.e., materials endowed with memory. Acting as physical basis for the emergence of structures (including nanostructures) able to store information, the knowing of the actual origin of self-organization is essential for an advance of the technologies in all branches of the human activities.

Chapter 4

EXPERIMENTAL DEVICE AND RESULTS

For identifying the initial conditions and the mechanism by which complexities in a dynamical state of self-organization actually emerge, we investigate the formation of spatial and spatiotemporal patterns in devices known as plasma diodes. A scheme of such devices is presented in Figure 3.

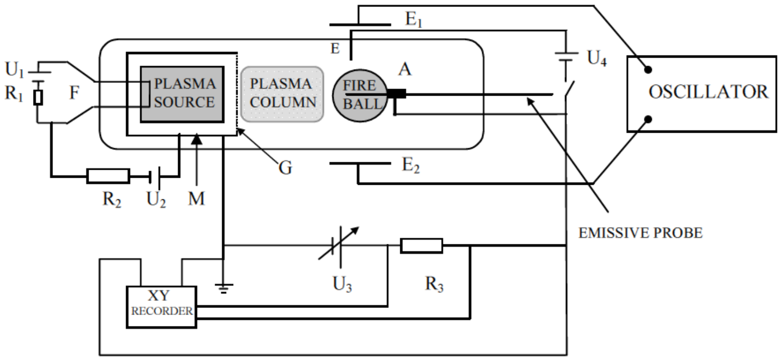


Figure 3.

Usually, such a device consists of a glass or an electrically insulated metal tube filled with gas at low pressure and a set of electrodes (marked by capital letters in Figure 3). The plasma is produced by direct current gas discharge ignited between a heated tungsten filament marked **F** and a metal cylinder **M** bordered at its open side by the grid **G.** The dc power source $\mathbf{U_1}$ connected through the resistor $\mathbf{R_1}$ at **F** produces the direct current for heating the filament. Using the dc power source $\mathbf{U_2}$, the negative pole of which is connected through the resistor $\mathbf{R_2}$ at **F** and its positive pole at **M**, it is created an electric field that accelerates the electrons emitted by **F** at energies sufficient to excite and ionize the gas atoms. The plasma created in this way penetrates the grid **G,** reaching by diffusion the surface of the anode **A**. For working as a diode, a dc power source PS, marked $\mathbf{U_3}$, the positive pole of which is connected to **A** through the resistor $\mathbf{R_3}$ and its negative pole is connected to **M** and, implicitly, to **G** is used**.** A movable electron-emitting probe (emissive probe) that penetrates **A** in axial direction is used to measure the potential in front of the anode. Another very fine filament electrode **E**, positively biased by $\mathbf{U_4}$, is used to produce, when certain investigations were performed, an electric spark at the surface of **A**. An auxiliary device consisting of an oscillator, which generates a high frequency electric field (about 100 MHz) between the plate electrodes $\mathbf{E_1}$ and $\mathbf{E_2}$, is used to investigate the phenomena that appear in the diode when the plasma is produced or it is subjected to the influence of this electric field.

Using the above briefly described experimental device it was possible [9,10] to prove that stable coherent luminous gaseous bodies, having strong similarities to that revealed by the ball lightning, emerge by a mechanism involving self-organization. For proving this we have identified the key processes as instability, bifurcation, symmetry breaking and long-range order, all of them considered essential for defining a system in a self-organization state [48]. However, only the identification of these key processes without elucidation of their genuine origin does not offer the informational content required today for elaborating a phenomenological (conceptual) model of self-organization eventually describable by mathematical equations.

In the following, we show that collective quantum effects produced by a population of electrons, driven at a critical distance from thermal equilibrium, are at the genuine origin of these key processes. For proving this we present in the following the experimental results previously published by us, many of them in collaboration. Such ordered patterns emerge in plasma diodes as that shown in Figure 3, under two different conditions: (i) A coherent, stable and luminous gaseous body known as fireball [49], spontaneously emerges attached to the anode when the population of electrons is driven at a critical distance from its initial thermal equilibrium by the electric field created by the dc power supply (PS); (ii) A free floating spherical luminous gaseous body known as plasmoid [50] emerges between the plates **E1** and **E2,** when the energy injected by the oscillator in the high frequency plasma is decreased at a critical value.

In the following we describe the physical processes at the origin of both phenomena considering a scenario of self-organization able to explain the actual origin of the key processes at its origin. Most of the experiments were performed in plasma where the background gas was argon. However similar phenomena were observed by us, but also by other investigators, in plasma the background gas of which was, for example, air, oxygen, hydrogen, nitrogen, vapors of alcohol or iodine and others.

(A) THE FIREBALL

The investigation of the fireball performed up yet has established the following [9,10,12,14,16,51-68]: (i) The fireball is bordered by a nearly spherical dipolar structure; (ii) The nearly spherical structure supports a positive anode fall in the order of the ionization potential of the gas and a negative anode fall in the order of some volts; (iii) The kinetic temperature of the electrons inside of the fireball is three times greater than in the surrounding plasma; (iv) The density of the current sustained by the fireball is two-times greater than the mean anode current density; (v) The light emitted by the fireball is not related to thermal excitation of the atoms; (vi) The fireball is able to stimulate oscillations; (vii) Once emerged by self-organization, the fireball transits stepwise into more advanced states of self-organization concomitant with the gradual increase of the PS-voltage.

The explanation of many of the above listed properties of the fireball, although experimentally well established, remained unsolved problems of the plasma science. Such a problem is, for example, the ability of the nearly spherical dipolar structure at the border of the fireball to sustain a negative anode fall, i.e., to sustain the potential at its positive side some volts greater than the potential of the anode. Referring to the positive anode fall, the aforementioned values are valid for pressures of the gas in the range of mTorr. These values increase substantially when the gas pressure is smaller. Other non-elucidated problems refer to the ability of plasma to generate different kinds of oscillations.

For identifying the phenomena that attribute to the fireball the afore-listed properties but also other hitherto not explained ones, we consider experimental results obtained in our laboratories but also in the Laboratory of plasma physics of the University of Innsbruck, Austria. These were obtained in the frame of a collaboration of many years. The plasma diode at the University of Innsbruck was a part of a double plasma (DP)-machine where the background gas was argon (density 10^8-10^9 cm^{-3}) at pressures 1-5 mTorr. Plotting the intensity of the current *I* collected by the anode versus the voltage delivered by the PS we obtained the static current *(I)*-voltage *(V)*-characteristic shown in Figure 4 when the load resistor was 10 Ω [64].

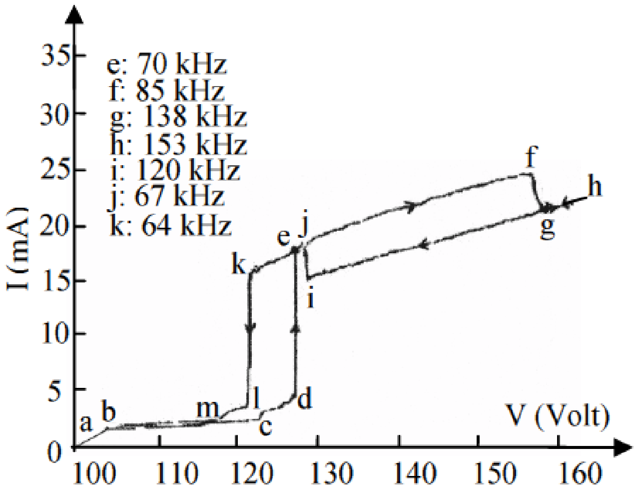


Figure 4.

Using a load resistor of 500 Ω, we obtained the static *I(V)* characteristic shown in Figure 5.

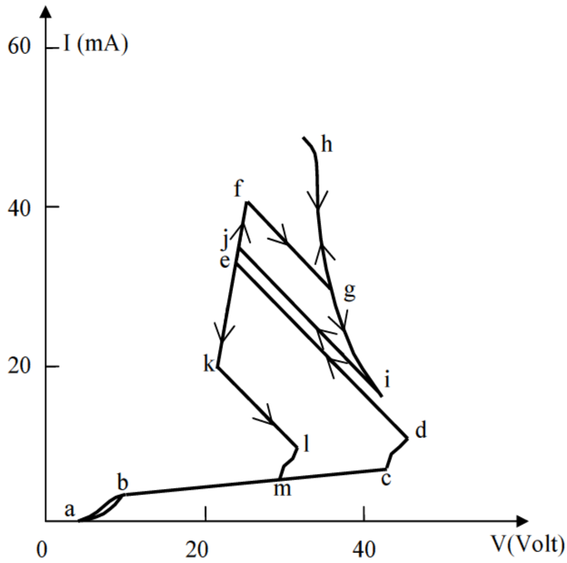


Figure 5.

In both cases the anode was a tungsten disc 3 mm in diameter laterally isolated by ceramics. Note that because of the presence of the load resistors the potential *V* of the anode differs from the PS-voltage.

Investigating the causes of the strongly non-linear phenomena (abrupt changes of the slopes of the branches marked in both figures by letters) revealed by these static *I(V)*-characteristics, we have identified the following causes. Increasing gradually the PS-voltage, the current *I* increases in proportion with the voltage *V* of the anode (branch **a-b**), i.e., Ohm's law is valid. Continuing to increase the PS-voltage (branch **b-c**) the first atom excitations appear in front of the anode, fact revealed by the appearance of a luminous sheet attached to the anode surface. The change of the slope is initiated, as proved by probe measurements, by the appearance of a net negative space charge after accumulation in front of the anode of those electrons that have lost their kinetic energy after atom excitations. Acting as a barrier for the current *I*, its development concomitant with the gradual increase of the PS-voltage explains the existence of the afore-mentioned branch. Further increasing the PS-voltage up to the value for which the first atom ionizations appear in front of the anode new free charges (positive ions and electrons) are produced. Their appearance explains the increase of the current *I* (branch **c-d**). Two essentially different phenomena appear in this voltage interval in front of the anode. The first is the accumulation of a net positive space charge at that distance from the anode where the ionization cross-section function begins to increase suddenly. This is because the electrons have mobility higher than the positive ions. Second, the concentration of positive ions is additionally increased at the same distance from the anode since the electrons increase their kinetic temperature concomitant with ionizations [58]. So, an additional number of positive ions are here located owing to the difference in the thermal diffusivities of the positive ions and the electrons. We explain the increase of the kinetic temperature of the electrons concomitant with ionization taking into account that the threshold energy for which an electron ionizes an atom consists of two parts. One part is the ordered kinetic energy obtained by acceleration of the electrons in the electric field sustained by the PS. The other part is related to the thermal energy initially achieved by the electron in the plasma. So, the part of electrons the momentum of which is so oriented that their thermal energy is added to their kinetic energy when the inelastic collision takes place, increase the kinetic energy available to produce ionizations. Because the ionization threshold energy has a very precise value, the electrons the kinetic energy of which has values greater but very close to the ionization energy produce ionizations and simultaneously a very small part of their kinetic energy becomes free. Since a very great number of electrons are involved in the ionization processes, a “rest” of kinetic energy, in the order of the thermal energy of the electrons, remains available for increasing their temperature. The increase of the kinetic temperature of the electrons, at the distance from the anode where the ionization cross-section suddenly increases was experimentally proved, but not explained, by *Chung Chan* and *Noah Hershkowitz* by measuring the kinetic temperature of electrons at the positive side of a dipolar structure (double layer), i.e., the region where the ionization cross section function suddenly increases. Comparing this temperature with that of the electrons located in the surrounding plasma they found a difference of some eV [69]. In their conclusions the authors remark: *“Experimental results from these areas all indicate an inhibition of electron thermal energy which may not be described by classical processes”.*

Considering the capacity of the electrons to increase their kinetic temperature concomitant with the increase of the ionization rate it is possible, as we will show in the following, to explain the nature of the nonlinear phenomena by which a complexity, i.e., the fireball, in a dynamic state of self-organization spontaneously emerges. Thus, increasing gradually the PS-voltage so that the potential of the anode surpasses the value marked **c**, the first ionizations are produced by that group of electrons the thermal energy of which is maximal. So, at the distance from the anode where the ionization cross-function suddenly increases, a net positive space charge appears owing to: (i) The difference between the mobility of the electrons and the positive ions (ii) The increase of electrons kinetic temperature concomitant with ionizations. Referring to the first cause, positive ions accumulate at the distance from the anode where the ionization cross section-function suddenly increases by work done by the PS for producing atom ionizsations. Owing to difference between the masses of the electrons and positive ions, the electrons that produced and those resulted after ionizations are quickly extracted by the anode. Referring to the second cause, an additional number of positive ions remain in excess in the same region, after thermal diffusion of the electrons. Taking into account the thermal energy distribution function of the electrons in the plasma of the diode, the first atom ionizations are produced when the PS-voltage is gradually increased by that group of electrons the thermal energy of which is maximal. Increasing their kinetic temperature concomitant with ionization, a part of the electrons leave this region. So, a net positive space charge appears in excess at the distance from the anode where the ionization cross-section suddenly increases. Placed in the next vicinity of the region where electrons accumulated after atom excitations, there exists the chance that electrons electrostatic couple to the positive ions appeared in excess. In this way a great number of elementary electric dipoles are self-assembling in front of the anode. Every of these elementary electric dipoles “sequester” an infinitesimal amount of electric field energy. Related only to the thermal energy extracted by the electrons from the plasma, this infinitesimal amount of electric field energy has its actual origin in a mechanism by which thermal energy is directly converted into electric field energy. Once self-assembled, the elementary electric dipoles form a dipolar space charge arrangement the shape of which is governed by the electric field sustained in front of the anode by the PS. The positive and negative sides of the dipolar structure are placed at that distance from the anode where the ionization and respectively excitation cross-section functions begin to increase quickly. Its existence is ensured in a dynamical state. This involves a balance between the rate at which new elementary electric dipoles self-assemble and the rate at which the previously self-assembled elementary electric dipoles disintegrate by recombination of their positive ions with electrons. During these disintegrations the thermal energy sequestered in the elementary electric dipoles is emitted as “quantified” electric field energy in the surroundings. Owing to the time span, very short, that exists between the self-assemblage of the elementary electric dipoles and their disintegration the dipolar structure sustains a proper drop of potential. Continuing to gradually increase the PS voltage the following ionizations are produced by those groups of electrons the thermal energy of which varies in concordance with the descendant branch of their thermal energy distribution function. This means that those electrons the decrease of the thermal energy of which is compensated by the increase of the PS-voltage successively produce new ionizations. Producing, concomitantly with atom ionization, also an increase of their kinetic temperature, an additional excess of positive ions appears at the distance from the anode where the ionization cross-section suddenly increases. Consequently, by electrostatic coupling of electrons at these positive ions, the number of elementary electric dipoles incorporated in the dipolar structure becomes greater simultaneously with the gradual increase of the PS-voltage. Since the ionization rate depends, besides on the energy of the electrons, also on their number, the evolution of the dipolar structure, i.e., the increase of its potential drop, depends on the slope in every point of the descendant branch of the thermal energy distribution function of the electrons. As long as by gradually increasing of the PS-voltage, the decreasing rate of the thermal energy of the electrons overcompensates the rate by which their number increases, the evolution of the dipolar structure, i.e., its potential drop, is controlled by this voltage. In the following we will mark G1E the electrons the thermal energy of which varies in agreement with this part of the descendant branch of their thermal energy distribution function. In this phase of evolution the increase of the potential drop sustained by the dipolar structure involves work done by two different sources. Thus: (i) The PS does work for sustaining constant the rates of atom ionizations and, implicitly, excitations at the two sides of the dipolar structure, but also to collect the electrons that produced and those resulted after ionizations; (ii) The plasma source does work to compensate the thermal energy extracted by the electrons from the plasma that, after direct conversion into electric field energy, sustains the potential drop proper to the dipolar structure. Collecting the electrons that produced and those resulted after ionizations, the voltage of the PS controls the evolution of the dipolar structure till the potential at its positive side equals the potential of the anode. In this state, which is a dynamical one, the existence of the dipolar structure is realized by the aforementioned balance between the rate by which new elementary electric dipoles self-assemble and the rate by which the previously self-assembled dipoles disintegrate by recombination of their positive ions with electrons. The shape of the dipolar structure, assembled in this way, depends on the symmetry of the electric field in the next vicinity of the anode. When the anode is a disk as that used by us, the symmetry of the electric field is an axial one. Consequently the dipolar structure has a nearly spherical shape. Its dimensions increase concomitant with the gradual increase of the PS-voltage by incorporation of new elementary electric dipoles in its structure.

Related to a mechanism that involves the collection by the anode of the electrons that produced and those resulted after ionizations the evolution of the nearly spherical dipolar structure ends when the potential at its positive side equals the potential of the anode. However, as experimentally proved, in this state the plasma in front of the anode becomes unstable with respect to local thermal fluctuations. These appear as minuscule well located hot plasma (visually observed as electric sparks) after vaporization of the anode material from the top of protuberances where the current is concentrated. Controlled by deterministic chaos, the density of the energy injected into the electric spark and implicitly its initial temperature could be different. So, two routes of evolution become possible. When the temperature of the well-located plasma surpasses a critical value, a nucleus enriched in positive ions surrounded by a plasma mantle enriched in electrons appears owing to the difference between the thermal diffusivity of the positive ions and of the electrons [14]. Acting as a gas anode, the nucleus accelerates towards it the surrounding electrons at energies sufficient to produce ionizations at its border. Consequently, the further evolution of the positive nucleus depends on the thermal energy distribution function of the population of electrons present in the plasma mantle. When the initial temperature of the well-located hot plasma surpassed a critical value, the electric field created by the positive nucleus changes drastically the thermal energy distribution function of the electrons located in the plasma mantle. So, the slopes in all points of the descendant branch of the thermal energy distribution function of the electrons located in the plasma mantle become so abrupt that the number of electrons increases at a rate that varies quasi-exponentially when the thermal energy of the electrons decreases at constant rate. In the following we will mark by G2E these groups of electrons. Accelerated in the electric field of the nucleus the first ionizations are produced by that group of the G2E the thermal energy of which is maximal. Producing, besides ionizations, also a local increase of the kinetic temperature of the electrons these leave this region by thermal diffusion. Consequently, an excess of positive ions appears at the border of the nucleus. By electrostatic coupling of electrons at these positive ions a primary nearly spherical dipolar structure (PNS) emerges at the border of the positive nucleus. In the potential drop of this first PNS the following G2E increase the ionization rate and implicitly the kinetic temperature of the electrons at its positive side. So, new elementary electric dipoles are incorporated in the PNS. Related only to the thermal energy extracted by the G2E from the plasma mantle, the potential drop sustained by the PNS at the border of the positive nucleus becomes greater. As a result, the following G2E become able to produce new ionizations and implicitly the increase of the kinetic temperature of the electrons at the positive side of the PNS. So, the potential drop sustained by the PNS increases again. By this mechanism the thermal energy successively extracted by the G2E from the plasma mantle acts as a “catalyst” for producing new elementary electric dipoles and, implicitly, to increase the potential drop of the PNS. Since the slopes in all points of the descendant branch of thermal energy distribution function of the electrons are very abrupt, the evolution of the PSN, i.e., the incorporation of new elementary electric dipoles in its structure, takes place very quickly. Incorporating new elementary dipoles the PNS expands till it completely replaces the previously formed nearly spherical structures “mastered” by the G1E. The expansion of the PNS ends when the rate at which new elementary electric dipoles are created by the G2E balances the rate at which the previously self-assembled elementary electric dipoles disrupt. Started for values of the PS-voltage for which the potential at the positive side of the nearly spherical dipole structures, mastered by the G1E, equals the potential of the anode, the potential at the positive side of the PNS in its final state of evolution surpasses the potential of the anode. The potential of the nearly spherical dipolar structure is maintained in a dynamical state by the dipolar structure. This means that at every moment of time the G2E ensure the existence of the complexity converting at a constant rate thermal energy extracted from the plasma mantle into electric field energy. Simultaneously, the same amount of thermal energy is emitted as quantified electric field energy after disintegrations of the previously assembled elementary electric dipoles.

The complexity survives as long as the ionization and, implicitly, the excitation rates in the two adjacent regions where the cross-section functions of these quantum processes suddenly increase is maintained constant by work done by the PS. Returning quickly in the ground state, the excited atoms located at the negative side of the nearly spherical dipolar structure emit photons (light). So, the complexity appears as a nearly spherical luminous gaseous body, namely the fireball (Figure 6).

Figure 6.

It maintains the electric contact with the anode through a channel fixed at one end at the point on the anode surface where the electrical spark has initiated its emergence. Through this channel the anode collects the electrons that produced and resulted after ionizations in the nucleus maintaining its potential very close to the potential of the anode.

The other evolution route of the well-located hot plasma occurs when its temperature did not reach the value for which the fireball emerged. Consequently, in agreement with the second law of thermodynamics, the well located hot plasma transits into a state of thermal equilibrium. This means that the emergence of the fireball is actually related to an event known as a bifurcation, i.e., an event that usually serves as a memory mark [15].

Involving an abrupt increase of the ionization rate for constant PS-voltage, the emergence of the fireball is accompanied by a very quick decrease of the internal resistance of the plasma diode. As a result, the current I increases in the same way. So, because of the presence of the load resistor the potential V of the anode decreases in the same way and in a degree that depends on the value of the load resistors. This is clearly emphasized in the Figure 4 and Figure 5. Such abrupt changes of the behavior of a sample (in our case the conductance of the plasma) in absence of further variation of the intensity of the external constraint (in our case the PS-voltage) are known as instabilities. Having at its origin a bifurcation like instability the emergence of the fireball, i.e., the creation of order from disorder, takes place locally and in such a short time span that the second law of thermodynamics ceases to work. This instability involves a positive feedback mechanism in which the thermal energy extracted by the G2E from the plasma mantle acts as “catalyst”. Consequently the lifetime of the fireball depends on the amount of the thermal energy initially located in the plasma mantle, but also on the initial potential of the positive nucleus. This potential must be able to accelerate G2E from the plasma mantle at energies sufficient to produce ionizations. In the plasma diode the survival of the fireball is provided by the plasma that surrounds the plasma mantle but also by the potential of the anode. Since the amount of thermal energy extracted by the G2E from the plasma mantle is immediately emitted as quantified electric energy in the surroundings it must be replaced by new thermal energy from the plasma mantle. This is possible because the thermal energy in the plasma mantle remains constant by diffusion into the plasma mantle of the electrons that surrounds it. So, by work done by the plasma source, the potential at the positive side of the nearly spherical dipolar structure, at the border of the fireball is maintained greater than the potential of the anode. This is possible owing to the work done by the PS for collecting electrons from the nucleus of the fireball so that the potential of the nucleus is maintained constant at the value for which the G1E produce ionizations at its border.

Involving phases as non-equilibrium, instability, bifurcation and long- range order, the emergence of the fireball satisfies all criteria to be considered a typical example of self-organization [70].

The electric field energy located in the nearly spherical dipolar structure at the border of the fireball has its origin in the work done by the PS as well as by the plasma source. Thus, the PS does work for sustaining the potential at the positive side of the nearly spherical dipolar structure equal with the anode potential, whereas the plasma source does work for increasing this value greater than the anode potential. So, the part of the G2E that traverse the dipolar structure without losing their energy by inelastic collisions with atoms are propelled into the nucleus. After atom ionizations these electrons increase the kinetic temperature of the population of electrons there present. We explain in this way the experimental results proving that the kinetic temperature of the electrons inside of the nucleus of the fireball surpasses the kinetic temperature of the electrons in the surrounding plasma. A part of the propelled electrons reaches the surface of the anode running through a decelerating electric field, i. e., in a direction in which electrons normally do not run through. Reaching the anode these electrons increase the current I that traverses the plasma diode. In this way the nearly spherical dipolar structure at the border of the fireball generates current by a mechanism by which the G2E convert at a constant rate their thermal energy into electric field energy. So, the nearly spherical dipolar structure behaves like a direct current Josephson junction.

For surviving in this way the fireball maintains its electric contact with the anode through a very small channel. We revealed experimentally this phenomenon by using a plate anode (0,5x5 cm^2) having one dimension much smaller than the sizes of the fireball (Figure 7). When the anode is a sphere (1cm in diameter) the fireball appears as shown in the photograph presented in Figure 8 [68]

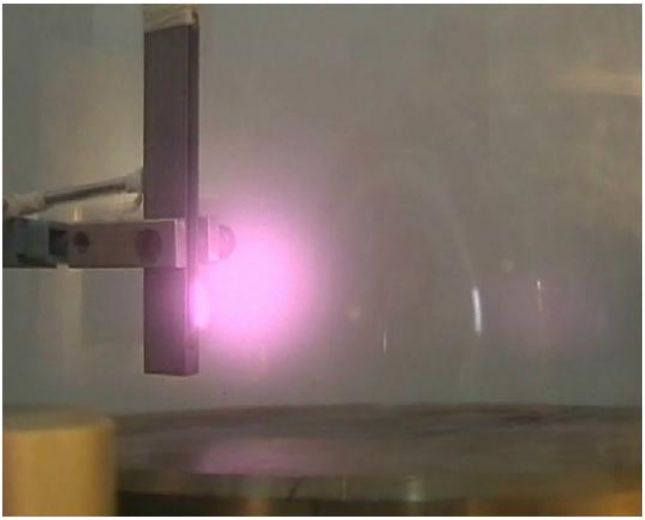


Figure 7.

Figure 8.

Measuring the ionic current by using a very fine electric probe that penetrates the center of a disk anode in axial direction, the aria of which is smaller than the size of the fireball we obtained the experimental results shown in Figure 9.

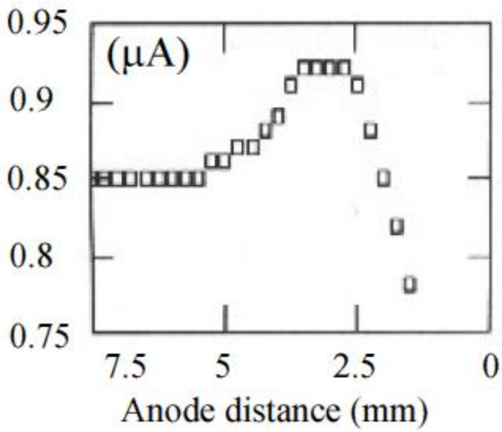


Figure 9.

These experimental results prove the presence of a nearly spherical dipolar structure at the border of the fireball the concentration of positive ions of which is greater than the concentration of positive ions at the anode surface. These and other measurements performed by us proved that the potential at the positive side of the nearly spherical dipotential structure is greater than the anode potential.

As experimentally proved the emergence of the fireball takes place after a so-called *"overshoot of the current "* [71]. Owing to the very short time span, in the order of some μs, in which this overshoot appears, the static *I(V)*-characteristics presented in Figure 4 and Figure 5, plotted with a usual mechanical *X-Y* plotter, do not reveal its presence. Its presence we will demonstrate later.

The news revealed by the information offered by the above described plasma experiments is the fact that once emerged, the fireball survives in a state the dynamics of which is permanently activated by conversion at a constant rate of thermal energy extracted from the plasma mantle by the G2E into electric field energy. Since the amount of thermal energy is continuously replaced by diffusion of electrons at the interface of the plasma mantle with the surrounding plasma, the dynamical state is only apparently a self-organized one. This information offers, in our opinion, a new paradigm for understanding how self-organization actually emerges. Thus, in an environment where the population of electrons is driven at a critical distance from thermal equilibrium, the appearance of well-located fluctuations of the thermal energy, controlled by deterministic chaos, can initiate the emergence of a complexity in a dynamical state of self-organization if the increase of the temperature produced by the fluctuations surpasses a critical value. Once emerged by a mechanism not explainable by classical processes, the dynamical state of the complexity is continuously activated by thermal energy extracted by the G2E from the surroundings. Emitted immediately after its conversion into electric field energy this thermal energy is not able to produce real work. Acting as reactive energy its presence is essentially for understanding self-organization.

Considering the population of the surrounding G2E as a “hot bath” and the nearly spherical dipolar structure as a “giant dipole”, the complexity, in our case the fireball, achieves macroscopic quantum coherence in a manner stipulated by H. Fröhlich [72].

(B) PROPRIETIES OF THE FIREBALL

Like all self-organized complex systems, the fireball reveals a certain degree of robustness [46]. This robustness manifests when the voltage of the PS-voltage is increased or decreased in certain limits around the value marked by **e**. Thus, decreasing the PS-voltage so that the current *I* runs through the branch **e-k**, the fireball continues to exist. This behavior of the plasma diode, known as a hysteretic one, reveals the presence of a certain kind of memory usually called electric memory. This memory, directly related to the dynamical state of the fireball, has its actual origin in the ability of the fireball to perform all operations “learned” during its emergence by self-organization also when the voltage of the PS becomes smaller than that for which it emerged. So, the fireball is able to store the information offered by the surrounding plasma in the moment when the self-organization process was produced. We explain this phenomenon considering that the fireball achieves the state of self-organization when only a part of the G2E has converted their thermal energy into electric field energy. So, the fireball survives when the potential of the anode becomes smaller than **e**, because there is a reserve of thermal energy

[58]. This reserve is proper to that part of G2E the thermal energy of witch corresponds to a part of the descendant branch placed immediately below the top of their thermal energy distribution function. Converting their thermal energy into electric field energy these G2E sustain the existence of the fireball when the branch **e-k** is run trough by the current *I*.

The succession of physical processes that act as premises for the emergence of the fireball, but also after its emergence, determines the appearance of the branches **b-c-d-e-f** in the static *I(V)*-characteristics when the PS-voltage is gradually increased. The succession of these branches corresponds to an S-shaped negative differential resistance.

As known, electronic devices emphasizing the behavior of an S-shaped negative differential resistance stimulate electric oscillations when they are suitably connected to a circuit able to oscillate naturally, i.e., a circuit that contains, reactive and active circuit elements. Adjusting the voltage of PS so that the potential of the anode corresponds to the value marked **d** in Figure 4 , the plasma diode generates oscillations [16]. As we will show in the following, the oscillations have the origin in a process during which, after the aforementioned overshoot of the current, i.e., the emergence of the fireball, all branches of the hysteresis cycle marked **d-e-k-l-m-c-d** are run through. As afore mentioned, inscribing the current with a mechanical plotter, the overshoot of the current that develops in a time span of some μs is not registered in Figure 4. The frequency and shape of the oscillations generated by the plasma diode depend on the capacitance of a condenser connected between the anode and the ground, on the inductance of an inductor present in the circuit (the nature of which we will discuss later), on the value of the load resistor and on the parameters of the plasma. For proving the presence of the overshoot of the current we present the experimental results shown in Figure 10

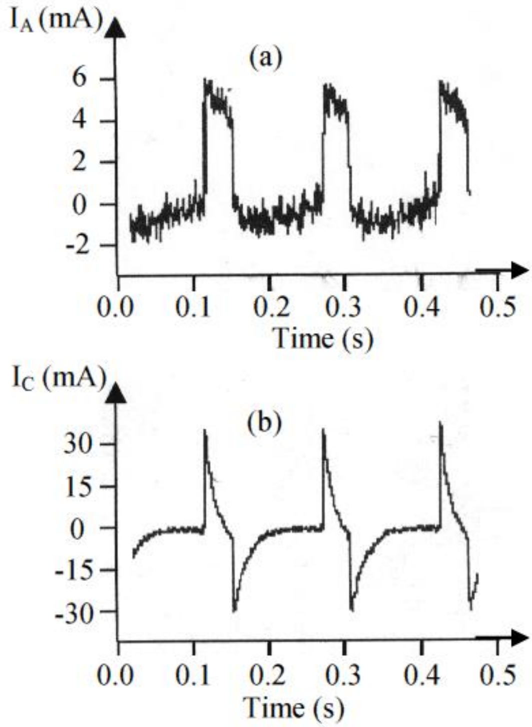


Figure 10.

These experimental results show the variation of the current I_A (registered by an oscilloscope) that flows from the anode through the load resistor toward the PS and of the current I_C that flows through the capacitor connected between the anode and the ground. Comparing the intensities of I_A and I_C, we remark that, concomitant with the emergence of the fireball, the current I_C shows a very sharp peak that substantially surpasses the current I_A that flows through the load resistor to the anode. In the same figure it is demonstrated the presence of chaotic, relative small variations of the current I_A, produced by the electric sparks on the surface of the anode.

In agreement with the above said, the survival of the fireball as a complexity in a dynamical self-organized state requires power delivered by two sources that work independently, namely the PS and the plasma source. Thus, the PS provides power for: (i) Acceleration of the electrons at energies sufficient to ionize and excite gas atoms, to collect the electrons that produced and resulted after atom ionizations, to heat the resistors present in the circuit and the electrodes and also to produce the electric sparks; (ii) For maintaining the population of electrons placed in the next vicinity of the anode, at a critical distance from thermal equilibrium, for which thermal fluctuations (electric sparks) are able to initiate the emergence of the fireball. The plasma source provides power for: (i) "Mastering", in collaboration with the PS, a first nearly spherical dipolar structure by directly converting thermal energy extracted by the G1E from the plasma into electric field energy till the potential at its positive side equals the potential of the anode; (ii) To replace the thermal energy extracted by the G2E from the plasma mantle that, converted directly into electric field energy, increases the potential at the positive side of the nearly spherical dipolar structure bordering the fireball at a value greater than the potential of the anode. The survival of the fireball in the dynamical state requires at every moment of time a balance between the rate by which thermal energy is directly converted into electric field energy and the rate by which quantified electric field energy is emitted in the surroundings after electric dipole disintegration. Since the thermal energy extracted at a constant rate by the G2E from the surrounding plasma appears at the same rate in the surroundings also as thermal energy after disintegration of the dipoles the entropy of the ensemble formed by the plasma source and its surroundings is not changed. By this mechanism the potential at the positive side of the nearly spherical dipolar structure is sustained greater than the potential of the anode. Because the converted thermal energy is immediately emitted in the surroundings as quantified electric field energy, the thermal energy of the G2E is not able to produce real work. In other words the thermal energy extracted by the G2E from the plasma plays the role of a sort of energy that, activating the dynamical state of self-organization of the fireball, provides its "living" state.

The fireball lives as a "machinery" which works in a reversed mode with respect to usual thermal machines. This means that instead to transfer a part of the thermal energy transported by the electrons into a cold "reservoir" this thermal energy is transported into a warmer "reservoir" (the positive side of the dipolar structure) where it is directly converted at a constant rate into electric field energy.

By this machinery the fireball attributes to the plasma diode the capacity to generate oscillations [16]. These results demonstrate that the frequency of the oscillations generated by a plasma diode is controlled by reactive and active circuit elements that are included in an oscillatory circuit proper to the diode. This oscillatory circuit contains a capacitor consisting of the external negative side of the nearly spherical dipolar structure at the border of the fireball and the surroundings (the ground). This capacitor is connected to the anode through the capacitors present in the PS. Considering also the capacitance proper to the nearly spherical dipolar structure at the border of the fireball [73] and the gaseous conductor located between its positive side and the anode (that works as an inductor) the plasma diode contains an enclosed circuit in which oscillations can be stimulated. The presence of an inductance is related to the fact that, in the region between the positive side of the nearly spherical dipolar structure and the anode, the electrons run through a decelerating electric field. So, there is a phase difference between the variation of the potential between the positive side of the nearly spherical dipolar structure and the variation of the current produced by electrons that run through this electric field. Owing to the presence of this oscillatory circuit, the plasma diode the static *I(V)* characteristic of which is shown in Figure 4, generates oscillations, the frequencies of which depend on the voltage of the PS. The oscillations generated by the plasma diode when the voltage of the PS reaches the critical value marked by **d** are shown in Figure 11a. The corresponding power spectrum is shown in Figure 11b.

Under such conditions, a deterministic chaos, related to the appearance of the electric sparks at the surface of the anode, controls the emergence of the fireball. Consequently, at every moment of time, there is the chance that a fireball to emerge in a self-organized dynamical state. Emerged concomitantly with an abrupt increase of the current *I* that includes also the current overshoot, the emergence of the fireball implies (because of the presence of the load resistor) an abrupt decrease of the anode potential. So, the premises for further emergence of new fireballs disappear. Once emerged in this way the fireball survives a time span in which the branch **e-k** is run through by the current *I*.

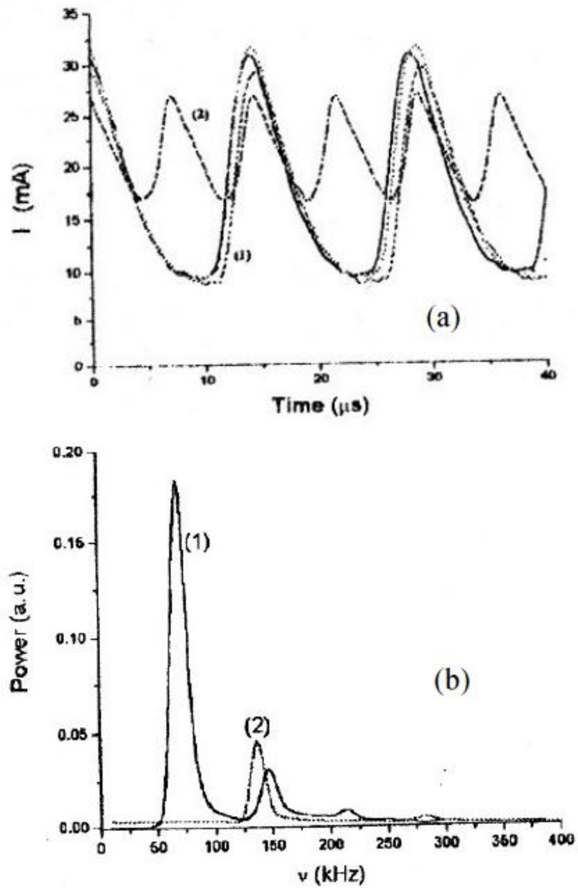


Figure 11a, b.

Reaching the value corresponding to the potential marked by **k**, the fireball disintegrates so that the current *I* decreases abruptly (branch **k-l-m**). Owing to the fact that the PS voltage is constant, the potential of the anode increases again at the value marked by **d**, for which a new electric spark generates the emergence of a new fireball. In this way fireballs emerge and disintegrate successively with a frequency related to the time span in which the hysteresis cycle **d-e-k-l-m-c-d** and the overshoot not revealed here are run through by the current *I*. Note that the area of this cycle and that corresponding to the overshoot of the current is a measure of the power corresponding to one period of the oscillations. A part of this power is provided by the PS for increasing, in “collaboration” with the plasma source, the potential at the positive side of the nearly spherical dipolar structure at a value that equals the potential of the anode. We remind that this phase of evolution involves work done by the PS for accelerating successive G1E at energies able to ionize and, implicitly, to excite the atoms and to collect a part of the electrons that produced ionization and those resulted after ionization, but also to convert the thermal energy of these electrons into electric field energy. So, the power delivered by the PS is consumed for increasing and sustaining the potential at the positive side of the nearly spherical dipolar structure, at the border of the fireball equal with the potential of the anode. The power delivered by the plasma source ensures the emergence of the fireball, i.e., the increase and the maintenance of the potential at the positive side of the nearly spherical dipolar structure at a value that surpasses the potential of the anode. This phase of evolution is provided by the G2E. Injected in the capacitor of the oscillatory circuit proper to the plasma diode this part of power delivered by the plasma source appears in the oscillatory circuit as reactive power. In this circuit oscillations are stimulated by successive emergence and disintegration of fireballs. Their amplitude increases till the real power delivered by the PS is consumed as heat by different mechanisms: emission of light after transition to the ground state of the exited atoms and of the free ions, thermal energy produced by the resistors present in the circuit and, when the circuit is open, as electromagnetic energy emitted as waves. The power delivered by the plasma source, i.e., the power that activates the dynamical state of self-organization of the fireball, plays a special role in the mechanism by which oscillations are stimulated. So, instead to be emitted as quantified electric energy after the disintegration of the elementary dipoles incorporated in the fireball it acts as reactive power. Injected into the circuit, during every disintegration of the fireball, this power grows the amplitude of the oscillations till the power delivered by the PS is entirely consumed by the mechanisms afore mentioned.

Remarkable is the fact that the oscillations above described are generated by the plasma diode also in the absence of a capacitor connected between the anode and the ground. This proves that the capacitance of the external side of the nearly spherical dipolar structure at the border of the fireball with respect to the ground, the inductance related to a part of the gaseous conductor where the electrons run in a decelerating electric field, the capacitance proper to the dipolar structure and the resistors present there form an oscillatory circuit able to control itself the frequency and shape of the oscillations. Surrounded by plasma subjected to the electric field sustained by the PS, the fireball survives in a dynamical state of self-organization by a mechanism by which thermal energy extracted by electrons from the plasma mantle and implicitly from the surrounding plasma is directly converted into electric field energy at a constant rate. Emitted, at the same rate, in the surroundings in the following moment of time as quantified electric field energy (by disintegration of elementary dipoles) the thermal energy extracted by the G2E is not able to produce real work. So, the power delivered by the plasma source to activate the dynamical state of the fireball appears in a theoretical model of these oscillations as an imaginary quantity.

When the voltage of PS is gradually increased so that the potential *V* of the anode increases above the value marked by **e**, the frequency of the oscillations increases also gradually concomitantly with the current *I*. So, in the interval **e-f** of the anode potential the frequency increases from 70 kHz to 85 kHz (Figure 4). Involving a time span where the potential of the positive side of the nearly spherical dipolar structure is greater than the potential of the anode the electrons extracted from the surrounding plasma are propelled partly inside of the fireball and partly to the anode surface. Reaching this surface after running through a decelerating electric field these electrons maintain the intensity of the current *I* at the values corresponding to all points of the branch **e-k**. This takes place by a mechanism that involves direct conversion of thermal energy extracted by the G2E from the plasma into electric field energy. Generating dc current in this way the nearly spherical dipolar structure at the border of the fireball behaves like a direct current Josephson junction.

When the voltage of the PS (the current *I*) is gradually increased the slopes of the descendant part of electrons thermal distribution function becomes more abrupt so that the branch **d-e** is quicker run through. This means that the time span in which the fireball emerges becomes smaller and implicitly the cycle **d-e-k-l-m-c-d** is quicker run through by the current *I*. So, gradually increasing the voltage of PS and in this way the slopes of the descendant branch of electrons thermal energy distribution function, the frequency of the oscillation increases also gradually. This behavior of the plasma diode reveals that during the dynamical state of self-organization the nearly spherical dipolar structure at the border of the fireball acts similar to an alternative current Josephson junction.

The gradual increase of the oscillation frequency generated by the plasma diode takes place up to a critical value of the anode potential *V*, marked by **f** in Figure 4. Reaching this value the frequency of the oscillations increases spontaneously at the twice and the amplitude decreases at the half with respect to the previous oscillations. This takes place concomitantly with an abrupt decrease of the current *I* (branch **f-g**) produced under constant value of the PS-voltage. Measurements of the light phenomena in front of the anode by using a photo-multiplier demonstrated [55, 56] that during these oscillations from the border of the fireball nearly spherical dipolar structures successively peel-off (Figure 12)

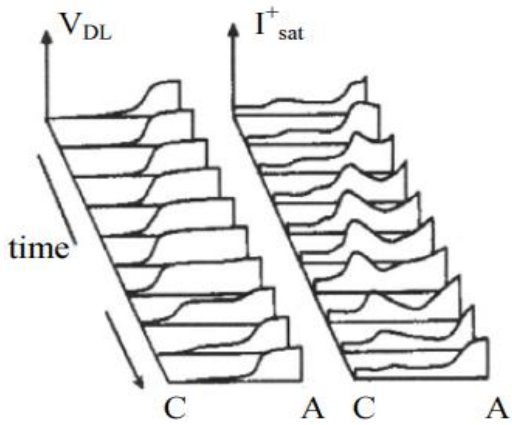


Figure 12.

After running through a certain distance these nearly spherical dipolar structures disintegrate. In the time span in which this distance is run through by the moving nearly spherical dipolar structure, a new nearly spherical dipolar structure appears in an evolution phase in the region where they emerged. Becoming free during the disintegration of the moving dipolar structure, the electrons reach the region where the new nearly spherical dipolar structure is in evolution phase. In this region the electrons are accelerated increasing in this way the ionization rate at the positive side of the new nearly spherical dipolar structure at the value for which this detaches from the fireball border. In this way, by an internal acting positive feedback mechanism the phenomenon becomes a periodical one. For transiting in this more advanced state of self-organization the nearly spherical dipolar structure that was peeled off must be able to survive in a dynamical state of self-organization during its departure from the anode. This means that, when by gradually increasing the PS-voltage the potential of the anode reaches the value **f**, the population of electrons reaches that critical state for which the relative small electric field created by the positive ions from the positive side of the nearly spherical dipolar structure at the border of the fireball is able to change this distribution so that the G2E appear in front of it. Consequently, the nearly spherical dipolar structure transits into a moving phase. In this phase it self-adjusts its velocity at the critical value for which the flux of electrons that traverses it determines an ionization rate that provides its dynamical state. This means that the temperature of the electrons is sufficient high to ensure the survival of the nearly spherical dipolar structure in this state by thermal diffusion of the electrons.

In the time span in which *I* runs through the hysteretic cycle **d-e-k-l-m-c-d,** both the self-assemblage of the dipolar structure at the border of the fireball and the displacement and disintegration of the peeled-off dipolar structure take place. Consequently the modulation of the current *I* is related to the development of two barriers. One is related to the accumulation of electrons during the emergence of the nearly spherical dipolar structure at the border of the fireball attached to the anode and the other one is related to the disruption of the barrier concomitant with the disintegration of the mowing dipolar structure. So, the modulation of the current transported by the plasma diode has a frequency that increases at the twice of the modulation produced by a single barrier that appears when the afore-mentioned hysteretic cycle is run through. Simultaneously, the amplitude of the oscillations decreases at the half of the previous oscillations. The generation of this kind of oscillations is related to a succession of processes during which the current *I* runs through the cycle marked **e-f-g-i-j** in Figure 4.

Increasing only gradually the PS so that the branch **e-f-g-h** is run through by the current *I* the shape of the static *I(V)*-characteristic of the plasma diode reveals an N-shaped negative differential resistance. The increase of the number of barriers in the unit of time diminishes the current *I* so that the frequency of oscillations is controlled predominantly by the PS-voltage (Figure 4).

(C) MULTIPLE FIREBALLS

Using a disc anode, the local conditions (electric sparks) required for initiating the emergence of a single fireball are present in many points of this surface. Owing to the presence of repulsive electrostatic forces that act between the negative (exterior) sides of every fireball their distribution at the surface of the anode becomes a symmetrical one. Examples of such distributions of fireballs that appear on the disk anode of a dc gas discharge are presented in Figure 13a,b and on a small plate anode in the plasma diode in Figure 13c,d. The number of the fireballs increases stepwise when the voltage of the PS-voltage is gradually increased.

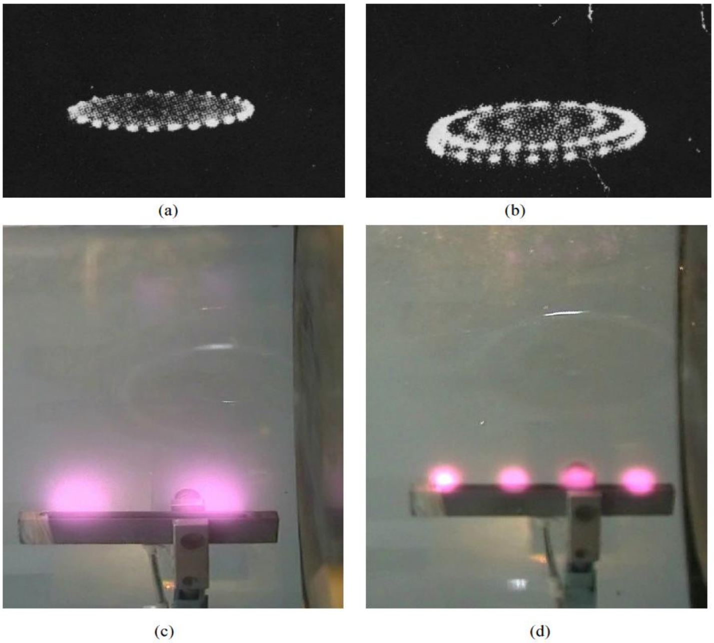


Figure 13a,b,c,d.

Different distributions of fireballs and complex combination of fireballs obtained in a gas discharge [74] are shown in Figure 14.

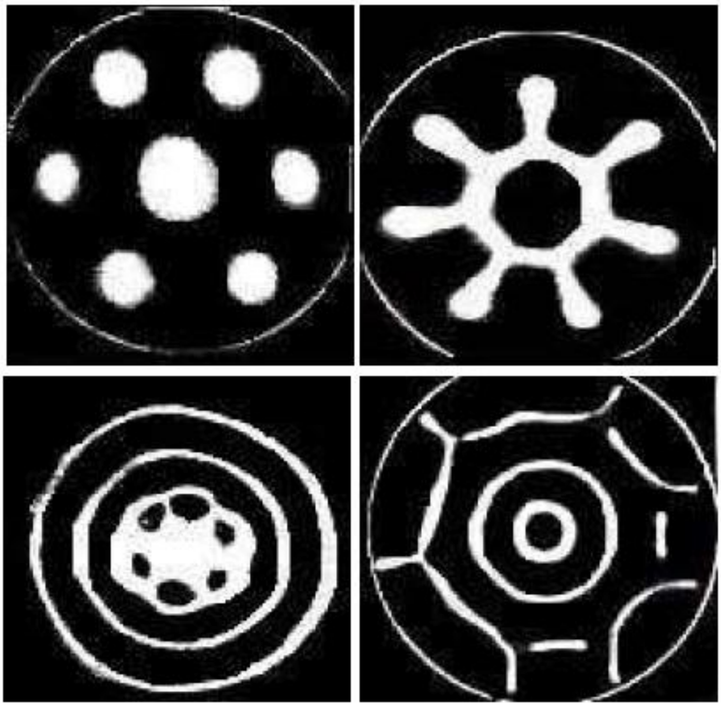


Figure 14.

Investigated long time ago in dc gas discharges ignited in different gases (oxygen, hydrogen, nitrogen or others) similar photographs were published in many papers.The authors invoke the principle of minimal value of the potential energy for explaining the emergence of such more complex space charge arrangements.

More recently, the problem of pattern formation was investigated in so- called micro-discharges. So, for example a framework consisting of luminous hexagonal patterns was observed in such a micro-discharge [75]. Important is the fact that every modification of the number or of the ordered space charge configuration (luminous pattern) involves a bifurcation-like instability, i.e., an event serving as memory mark. So, the framework survives in a dynamical state, performing the operations successively encoded in its dipolar space charge arrangement, realized by self-organization. This means that, with respect to a single nearly spherical fireball, such a framework is able to store an amount of information that substantially surpasses that stored by a single fireball. Taking into account the gaseous state of the plasma, the information encoded in its framework remains valid only as long as the dynamical state of self-organization is sustained by work done by the PS and by the plasma source, i.e., as long as the discharge is ignited. This situation drastically changes when, by a technology involving self-organization, i.e., the presence of G2E, patterns (dipolar structures) emerge in condensed matter. Once emerged in a dynamical state of self-organization these patterns remain imprinted in the condensed matter also when the causes that generated them are set away. So, the instructions offered by an environment that contains G2E remain encoded as flash memory, i.e., a memory that can be activated when the conditions for which these patterns emerged in a dynamical state of self-organization are again realized. So, placing the sample in an electric field the intensity of which surpasses a critical value, the G2E activate the dynamical state. So, the patterns perform the operations “memorized” in the moment when they emerged following the aforementioned technologies based on self-organization. In this context we remark that a recently published model for explaining elastic relaxation phenomena in condensed matter is based on such hexagonal space charge configurations [76]. A dynamical state of self-organization of these hexagonal structures, involving the presence of the G2E, could potentially elucidate their capacity to perform the operations encoded in their memory.

One of the most astonishing experimental results, revealed by micro-discharges, was reported by *Astrov and Purwins* [77]. The authors proved that the scattering of each other two plasma spots (in our opinion minuscule fireballs in a self-organized dynamical state) is sometimes accompanied by generation of an additional spot that is identical to the primary ones. These experimental results prove that under certain circumstances a new fireball in a dynamical state emerges after interaction of two independent fireballs, each of them being in a dynamical state of self-organization. Experiments performed in our laboratories proved also that fireballs are able to multiply by division (Figure 15).

Figure 15.

(D) THE PLASMOID

Using the experimental device, shown in Figure 3, we initiated the emergence of the plasmoid. It appears as a self-confined spherical luminous gaseous body (Figure 16) that floats freely in the high frequency plasma generated by the oscillator between the two plates marked **E1** and **E2** in Figure 3**.**

Figure 16.

For creating the premise required to generate the plasmoid we increased first the power generated by the oscillator at that critical value for which high frequency plasma was ignited in the tube. Plotting the power absorbed by the plasma as a function of the power generated by the oscillator by gradually decreasing the power of the oscillator we obtained the static characteristic shown in Figure 17

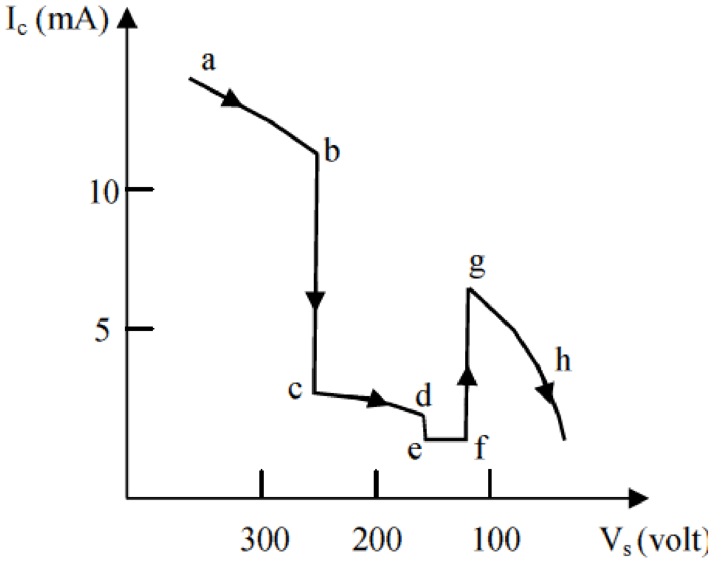


Figure 17.

The power generated by the oscillator was measured knowing that the screen grid voltage, marked V_S in this figure, controls the amount of this power. The power absorbed by the plasma was measured knowing that the current of the control grid marked I_C in the same figure decreases in proportion to the amount of energy absorbed by the plasma. This special kind of static characteristic reveals the presence of non-linear phenomena directly related to the spontaneous emergence of the plasmoid and also its property to transit into a pulsatory state [54]. Thus, decreasing gradually the power delivered by the oscillator, the energy absorbed by the plasma decreases firstly gradually (branch **a-b**). Reaching the value **b**, the power absorbed by the plasma increases abruptly (branch **b-c**), concomitantly with the spontaneous emergence of the plasmoid. Continuing to decrease gradually the high frequency power delivered by the oscillator, the plasmoid survives as a coherent spherical luminous gaseous body (branch **c-d**). When the power delivered by the oscillator corresponds to the value **d**, the plasmoid transits into pulsatory state in which the power delivered by the oscillator (at a frequency of the order of one hundred MHz) is modulated with a frequency in the order of ten kHz. The frequency of these modulations depends on the gas pressure. This is shown in Figure 18. for a plasmoid emerged in hydrogen at two values of the oscillatory power.

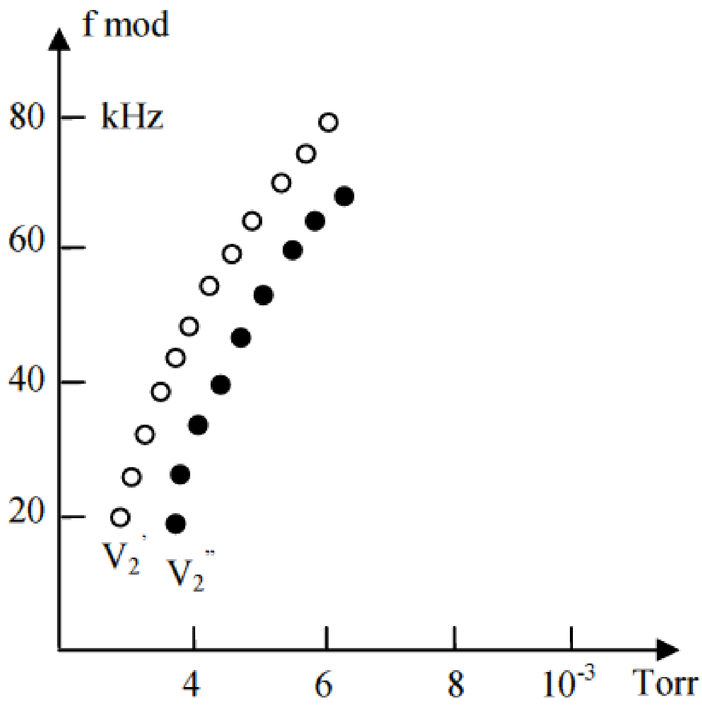


Figure 18.

Using movable electrical probe measurements we identified the presence at the border of the plasmoid of an enclosed (spherical) dipolar structure the potential at its positive side of wcich is greater than the positive potential inside of it. (Figure 19).

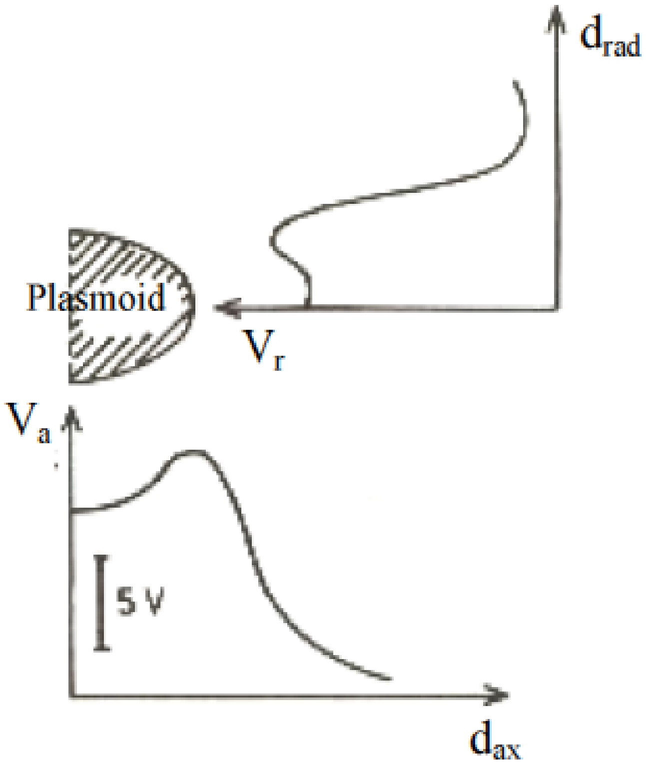


Figure 19.

Its presence proves that a mechanism similar to that at the origin of the fireball works in this case. Accelerating electrons extracted from the surrounding plasma at energies sufficient to produce atom ionizations and implicitly excitations, the plasmoid acts as a “machine” able to produce plasma. In this way the plasmoid maintains the plasma state in the diode also when the power delivered by the oscillator is below the value for which the high frequency plasma was ignited.

We proved the presence of a bipotential structure using two probes the distance between them being small with respect to the size of the plasmoid. Penetrating the plasmoid in axial direction, the probes collect a direct current the variation of which is shown in Figure 20.

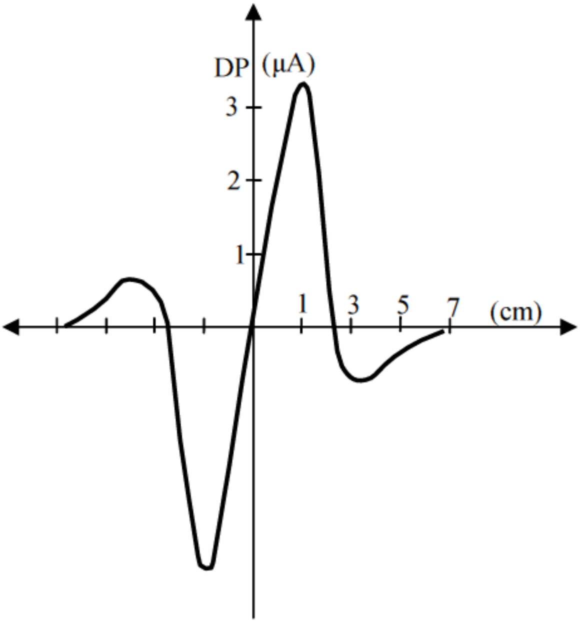


Figure 20.

Concerning the primary cause able to initiate the emergence of the plasmoid, we consider that the electric sparks, known as unipolar arcs, usually present in devices where high frequency plasma is produced are able to create a well-located hot plasma in non-equilibrium, as that at the origin of the fireball. Consequently, by a scenario of self-organization similar to that present in the plasma diode, this well located hot plasma detaches from the point where it appeared and transits into a free floating plasma globe, i.e., into a plasmoid. Once emerged, the spherical dipolar structure at the border of the plasmoid acts as a cavity able to absorb at resonance high frequency energy delivered by the oscillator. In this way the plasma located inside of the plasmoid is heated. As a result, a nucleus enriched in positive ions bordered by a plasma mantle enriched in electrons is maintained by a mechanism that involves thermal diffusion of the electrons in the surroundings. Subjected to the electric field created by the nucleus, the electrons in the surrounding plasma mantle behave as G2E. So, the conditions required for the survival of the plasmoid in a dynamical state of self-organization are realized.

Absorbing at resonance power delivered by the oscillator, the plasmoid acts as an additional source of plasma able to sustain the plasma state also when the power delivered by the oscillator is not sufficient for sustaining the presence of the required high frequency plasma in the tube. This possibility is related to a local heating process taking place concomitantly with resonant absorption of high frequency energy delivered by the oscillator. In this way, the survival of the plasmoid is conditioned by its capacity to sustain the positive potential of its nucleus at the critical value for which the electrons located in the plasma mantle are of type G2E. Consequently, by accelerating in the electric field created by the nucleus, these electrons are able to directly convert their thermal energy into electric field energy of the spherical dipolar structure that confines the plasmoid.

The plasmoid transits into the afore-mentioned pulsatory state when, by further decreasing the high frequency power delivered by the oscillator, the value marked by **d** in Figure 17 is reached. This is a state in which spherical dipolar structures are peeling off from its border. Running away from the region where they initially emerged, they disrupt at a certain distance. The periodicity of the peeling off process is ensured by an internal acting positive feedback mechanism, similar to that by which moving dipolar structures appear in the plasma diode [55]. The electrons liberated during the disintegration of the spherical dipolar structure obtain kinetic energies able to ionize atoms after acceleration toward the positive nucleus of the plasmoid. So, reaching the region where a new spherical dipolar structure was self-assembled these electrons increase the ionization rate at the value for which this new spherical bipotential structure starts its peeling off process. In this way the phenomenon becomes a periodical one. In the pulsatory state the plasmoid emits electrical and optical signals in the surroundings. Placing another plasmoid in its vicinity, these signals, which contain information concerning its internal structure and properties, are receipted at resonance by the other plasmoid. In this way plasmoids change information. When, by increasing V_S, the power value marked by **f** is reached, the plasmid disintegrates concomitantly with the abrupt decrease of the power absorbed from the oscillator (branch **f-g**).

When plasma generated by the plasma source was present in the tube the emergence of the plasmid can be initiated when the power of the oscillator was adjusted at a value smaller than that for which the high frequency plasma was ignited. Under such circumstances, an electric spark produced between the probe and the anode, marked **E** and **A** in Figure 3 initiates the emergence of a well located hot plasma and implicitly of a fireball that, detaching from the surface of the anode, transits into the plasmoid.

(E) FREE FLOATING FIREBALL EMERGED IN THE LOW-VOLTAGE-ARC

A gas discharge produced in a diode where the plasma is created by contact ionization at the surface of a heated cathode is known as low-voltage-arc. Most frequently, the plasma is produced by vaporization of solid cesium or sodium. The cathode is a tungsten plate the temperature of which is so high that plasma is created by contact ionization concomitantly with thermal emission of electrons. The plasma reaches the surface of the anode by dipolar diffusion. The anode is a tungsten plate placed at a distance of the order of ten millimeters from the plate cathode. Increasing gradually the voltage of the dc PS, connected through a load resistor to the diode, strong non-linear phenomena are revealed by the low voltage arc. Their presence can be demonstrated plotting the static $I(V)$-characteristic. Such a characteristic is shown in Figure 21 [78].

This characteristic presented in the left side of the figure shows branches the slopes of which abruptly change. Performing photographs of the light phenomena observed in front of the anode and inside of the diode, images as that presented in the right side of Figure 21 were obtained. The numbers indicate the relationship between the observed light phenomena and different points of the static $I(V)$-characteristic. The importance of these kinds of plasma experiments resides in the fact that it emphasizes the presence of phenomena still not fully explained at the present date. These phenomena listed for example by *G. Musa* [79] refer to the followings: (i) The density of the thermo-electronic current emitted by the cathode is much higher than that expected by Richardson law; (ii) The bright plasma appearing in the space between the electrodes is obtained by acceleration of electrons at energies lower than 1,2 eV in comparison with the ionization potential of the cesium atoms, which is 3,81 eV;. (iii) Some peculiar forms of the discharge including a ball of plasma, visually not connected to the electrodes, known as ball-of-fire appear when the energy injected in the plasma is gradually increased; (iv) After the ignition of the plasma no externally supplied voltage is necessary for maintaining the presence of the mentioned light phenomena, i.e., the low voltage burns only due to the thermal energy delivered by the cathode; (v) Strong oscillations of the current transported by the diode, some times more than 50% from the direct current value. are generated by the low-voltage. Photographs of four luminous structures (planar sheet, fireball attached to the anode, stable ball-of-fire, pulsating ball-of-fire) are shown in Figure 22. All these appear successively in a low–voltage arc when the voltage (kinetic temperature of the electrons) is gradually increased [80].

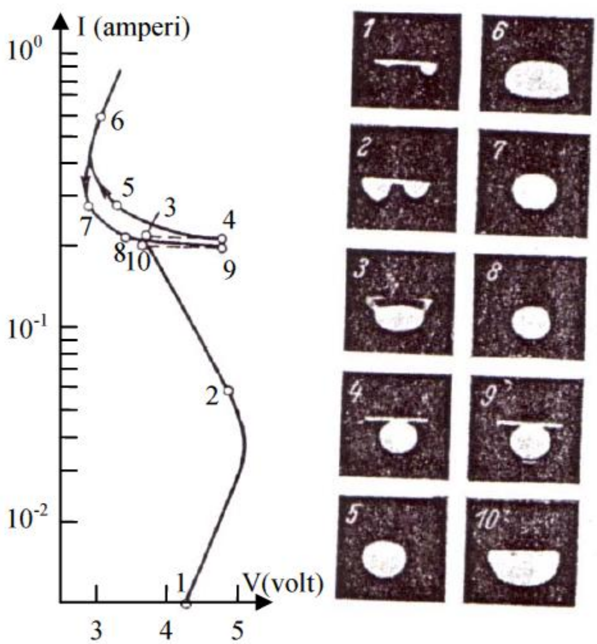


Figure 21.

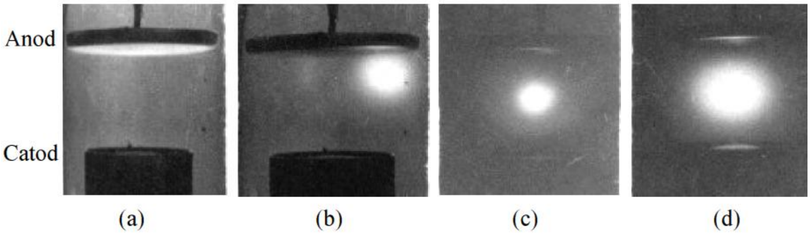


Figure 22.

From the above briefly mentioned phenomena we focus our attention to the emergence of the ball-of-fire, the generation of oscillations and the ability of the low-voltage arc to convert directly thermal energy into electric current, i.e., to act as a so-called thermionic energy converter. Comparing the luminous phenomena observed in the low voltage arc when the voltage of the PS is gradually increased with those observed in the plasma diode, we remark the presence of strong similarities. Thus, a single or more nearly spherical fireballs emerge at the surface of the anode of the low-voltage-arc through a succession of nonlinear phenomena revealed by its static *I(V)*-characteristic. Its (their) appearance can be explained by considering at their origin a scenario of self-organization similar to that at the origin of the fireball. The transition to this form of the discharge takes place, as proved by the photographs shown in Figure 21 when, gradually increasing the PS-voltage, the branch marked **3-4** is run through, i.e., in absence of an increase of the current. This phenomenon becomes explainable considering that in this voltage interval of the PS the fireball (photograph 4) stimulates oscillations in a manner similar to those stimulated by the fireball in the plasma diode, marked (a) in Figure 11. Their presence is confirmed experimentally [79]. The successive emergence and disintegration of the nearly spherical fireballs determines the appearance of barriers for the current in the low-voltage-arc. The modulation of the current appears as oscillations. Since the frequency of the oscillations increases gradually with the PS-voltage, the current measured with a direct current instrument remains constant.

The most peculiar phenomenon revealed by the low-voltage arc appears for the critical value of the PS-voltage when the nearly spherical fireball detaches from the anode surface transiting into the ball-of-fire. This special form of the low voltage arc is known in the literature as the ball-of-fire mode. Investigation performed with electrical probes demonstrates that the ball-of-fire consists of positive nucleus (plasma enriched in positive ions), bordered from the surrounding plasma by a spherical dipolar structure. By a mechanism not explained up yet, the potential of the nucleus surpasses the ionization potential of the gas in spite of the fact that the anode potential is much smaller than this potential. For explaining this phenomenon we consider at the origin of the ball-of-fire a more advanced state of self-organization possible under the circumstances as that present in the low-voltage-arc. Thus, we start from the fact that the ball-of-fire emerges in plasma the background of which is a gas with a very small ionization potential and the density and temperature of the plasma are much greater than in the plasma diode. Under such circumstances the detachment of the nearly spherical fireball and its transition into a spherical shape takes place when: (i) The G2E appear in the whole discharge by increasing the PS-voltage; (ii) The G2E appear in the whole discharge by increasing the temperature of the cathode. The transition takes place spontaneously because the spherical shape corresponds to a minimal value of the potential energy. Accelerated in the electric field of the positive nucleus the G2E produce besides atom ionizations also an increase of the electron kinetic temperature. As a result, a part of electrons leave the nucleus so that positive ions remain there in excess. In this way the nucleus of the ball-of-fire has a potential equal with the ionization potential of the gas, i.e., greater than the potential of the anode. So, a spherical dipolar structure able to support a drop of potential greater than the potential of the anode emerges by direct conversion of thermal energy extracted by the G2E from the plasma into electric field energy. The existence of the ball-of-fire is ensured by its transition into a dynamical state of self-organization. The ball-of-fire, emerged in this way, behaves as a complexity in a nearly autonomous state, i.e., a state that, once emerged, survives when the anode potential is smaller than the ionization potential of the gas. In context with this autonomy of the ball-of-fire, we remark that, in certain circumstances [79] related to the temperature of the cathode, the low-voltage-arc burns also when the PS is set away and the anode is directly connected to the cathode through a resistor. Burning under such conditions it results that the plasma in the low voltage arc is created only by work done by the source that heats the cathode. So, the survival of the ball-of-fire is an example of a dynamical self-organization the survival of which implies conversion with a constant rate of thermal energy into electric field energy and the entirely emission as quantified electric energy in the surroundings.

When the voltage of the PS (or the temperature of the cathode) is further gradually increased, the ball-of-fire transits into a special kind of dynamical state in which the low-voltage arc generates another kind of strong oscillations [79]. The frequency of these oscillations is the twice of the frequency of the aforementioned oscillations. Their appearance proves, in our opinion, that spherical dipolar structures from the border of the ball-of-fire are periodically peeled off and reformed. In this state of self-organization the ball-of-fire survives by a mechanism that involves a rhythmic exchange of thermal energy and matter (located in elementary dipoles) with the surrounding plasma.

The property of the low-voltage arc to convert directly thermal energy delivered by the cathode into electric current can be explained taking into account that the dipolar structure formed at the interface between the plasma and the electrodes is able to sustain the potential at its positive side greater than the potential of the anode in absence of the PS. So, propelling electrons extracted from the plasma to the surface of the anode, a direct current flows from the anode, through the resistor, to the cathode. Working as a direct current Josephson junction the low-voltage-arc generates direct current. In this way the low-voltage arc works as a thermionic converter.

(F) OTHER EXPERIMENTAL RESULTS INFORMATIVE FOR THE BALL LIGHTNING GENESIS

Using the experimental device described in [81], schematically shown in Figure 23, it is possible to produce well-located hot plasma in non-equilibrium in a metal vacuum chamber (pressure 10^{-8} Torr).

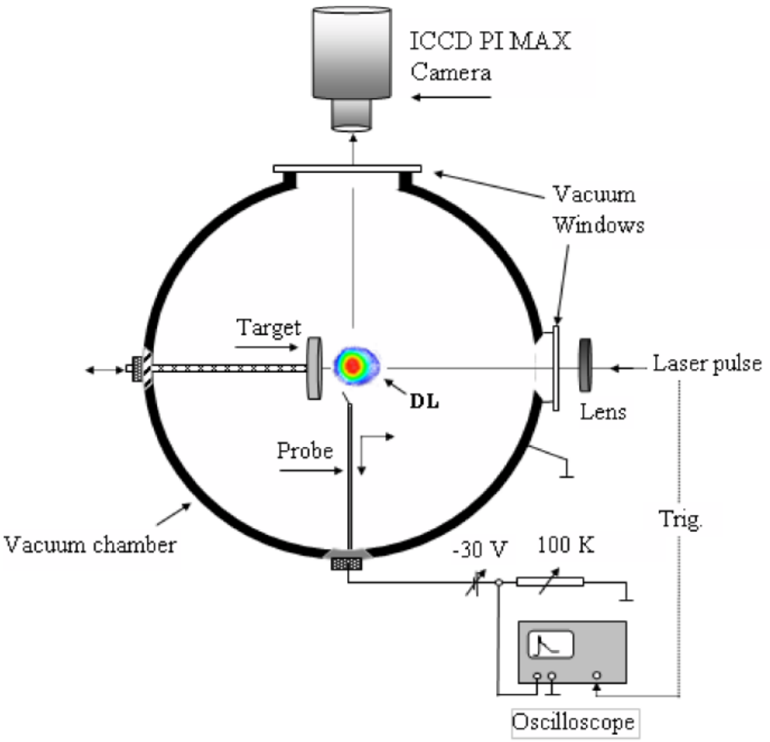
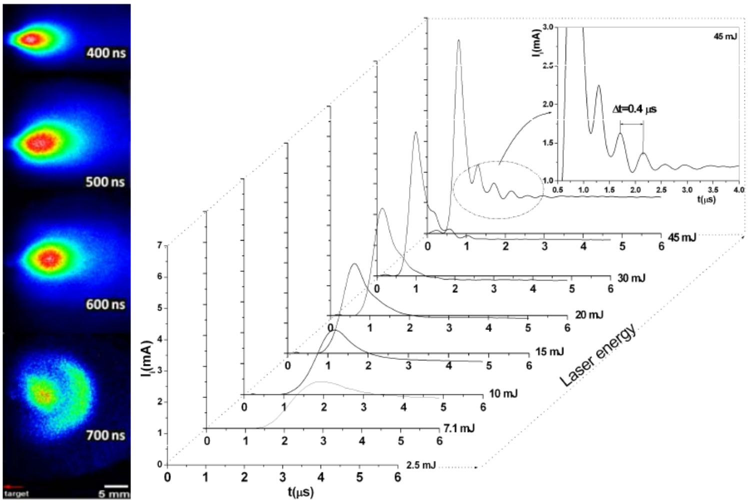


Figure 23.

In this experiment a Nd:Yag 10 ns pulsed laser beam has been focused on an aluminum target producing there a well localized hot plasma. A cylindrical electric probe negatively biased with respect to the grounded vacuum chamber was connected to an oscilloscope. The formation and dynamics of the hot plasma in nonequilibrium created by the laser pulse was studied by using an ultra rapid camera placed perpendicular to its expansion. The camera was gated 20 ns at different delay with respect to the laser pulse. When the energy of the laser pulse exceeds a certain value (30-40 mJ) the results presented in Figure 24a were obtained.



(a) (b)

Figure 24a,b.

These results reveal that well-located hot plasma in nonequilibrium is created by the laser pulse after local vaporization of aluminum target. Once emerged, the well-located hot plasma detaches from the surface of the target forming a nucleus surrounded by a plasma mantle. Beginning from a certain moment of time (700 ns) the fireball splits into two parts.

Plotting the variation of the ionic current collected by the probe for different energies of the laser pulse, the results shown in Figure 24b were obtained. These results prove that beginning from a critical value of the energy of the laser pulse (45 mJ) the ionic current collected by the probe reveals periodic variations. These variations are evidently related to the presence of moving nearly spherical dipolar structures that, during a limited time span, periodically peel-off from the border of the fireball. The aforementioned behavior of the fireballs emerged in this way reveals strong similarities with that of the fireball emerged by self-organization in the plasma diode. Thus, in the plasma diode the fireball emerges by self-organization in a stable state when the injected energy reaches a first critical value. After additional injection of energy in the diode, the fireball transits into a steady state in which nearly spherical bipotential structures are periodically peeling off from its border. Starting from these similarities, the above presented laser ablation experiments become explainable, in our opinion, by considering at their origin a scenario of self-organization as that revealed by plasma experiments. Additional information concerning the actual origin of fireballs created by laser ablation techniques was obtained by using a cooper target [82]. The obtained results presented in Figure 25 show more in detail the emergence of a fireball by laser ablation techniques. Similar plasma spheres considered synthetic lightning balls, that persist in air up to a half second after the power source was turned off, are obtained in electric arc [83].

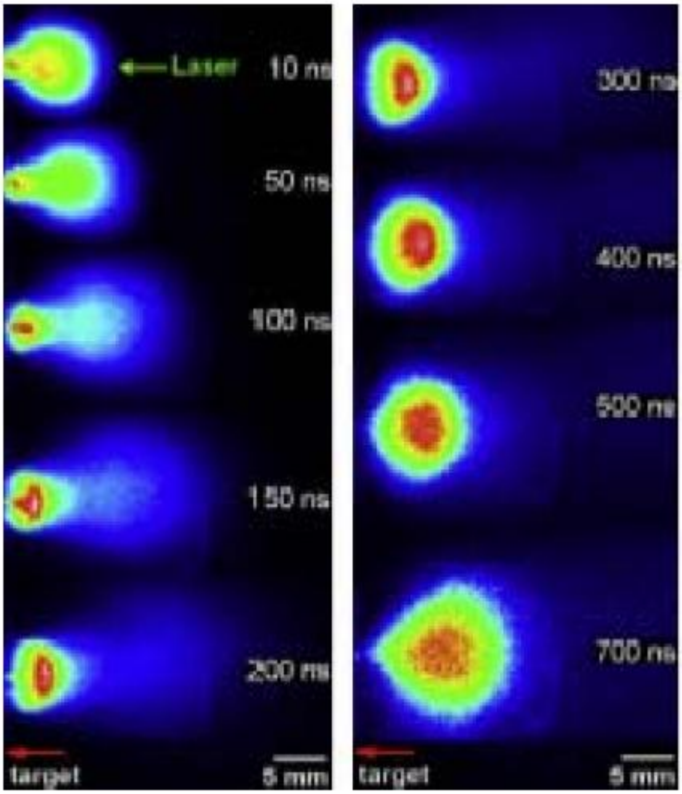


Figure 25.

A very interesting experimental result proving the emergence of fireballs under conditions very different from these presented up yet was obtained at the Heavy Ion Collider in New-York, US [84]. There, beams of gold nuclei were smashed together at nearly light speeds. So the nuclei are broken into particles called quarks and gluons. These particles form a ball of plasma about 300 times hotter than the surface of the Sun. The fireball (Figure 26) survives a time span that surpasses the duration of its emergence

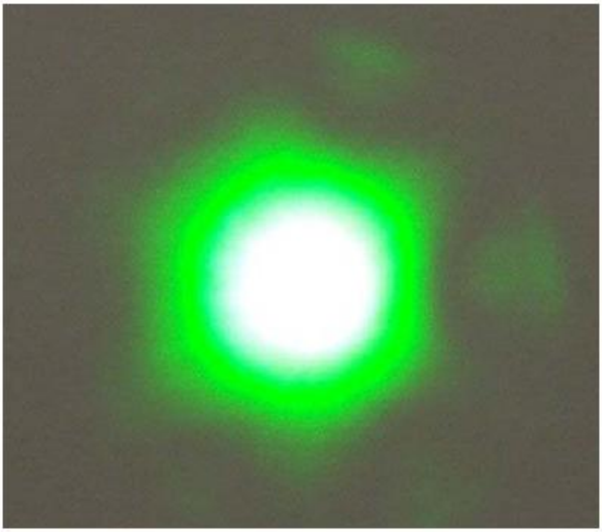


Figure 26.

This survival time of the fireball can be detected because it absorbs jet of particles produced by the beam collision. The model proposed to explain this experimental result considers that the particle are disappearing into the core of the fireball and reappearing as thermal radiation, just as matter is thought to fall into a black hole and come out as “Hawking” radiation.

Chapter 5

CONCEPTUAL MODEL OF THE BALL LIGHTNING

The above-described experimental results reveal that for initiating the emergence of a complexity in a dynamical state of self-organization it is necessary to create a well-located hot plasma in nonequilibrium by very quick injection of energy. It is important to mention the fact that decisive for the emergence of this complexity is not the amount of energy injected but rather its density and (implicitly) the temperature. So, a self-organization process is initiated when: (i) The temperature of the well-located plasma surpasses the critical value for which a nucleus bordered by a plasma mantle emerges by a mechanism driven only by thermal energy; (ii) The electric field created by the nucleus is so strong that the thermal distribution of the population of electrons in the plasma that surrounds it as a mantle has a descendant branch for which G2E are present. Under these initial conditions a complexity in a dynamical state of self-organization spontaneously emerges by a positive feedback mechanism by which G2E convert directly thermal energy into electric field energy located in a spherical dipolar structure. The dynamical state of the self-organized complexity remains "activated" by thermal energy extracted at a constant rate by electrons from the plasma mantle. In the plasma of the low voltage arc the thermal energy extracted by the electrons from the plasma mantle is continuously replaced by work done by the source that heats the cathode.

A similar process of self-organization can be initiated by a linear lighting under the conditions as that present in the atmosphere of the

Earth. So, as proved by photographs published in the literature, a ball lightning can emerge from the hot plasma generated by a linear lighting. Such a photograph presented in Figure 27 was, for example, taken by Sankt-Gallenkisch in Vorarlberg, Austria, in 1978 [20].

Figure 27.

It shows that well-located hot plasma, revealed by a whitish centre with a blue surrounding and a luminous tail, is produced in the point where the linear lightning strikes the surface of the Earth. This photograph, that represents objective information concerning the emergence of the ball lightning, proves that the premise for its emergence is the well located hot plasma (the whitish center) surrounded by a colder plasma mantle (the luminous tail). Produced by very quick injection of energy by the linear lightning, the hot well-located plasma in non-equilibrium evolves naturally, i.e., in the absence of an external driving force, into a manner that depends on its initial temperature. So, a plasma enriched in positive ions, surrounded by a plasma mantle enriched in electrons, emerges owing to the difference in thermal diffusivity of the electrons and of the positive ions. When the initial temperature of the whitish center surpasses a critical value its potential becomes greater than the ionization potential of the surrounding gas.

Simultaneously, the electric field created by the whitish centre is so strong that the thermal energy distribution function of the electrons located in the plasma mantle becomes similar to that for which fireballs emerge by self-organization under controllable laboratory conditions. This means that the descendant branch of the thermal energy distribution function of the electrons in the plasma mantle has slopes for which G2E are present. Under such circumstances, a self-enhancement of the number of positive ions is initiated, by a mechanism similar to that present in a plasma diode, at that distance from the positive whitish center where the electrons extracted from the plasma mantle produce ionizations. So, reproducing a scenario of self-organization as that revealed by plasma experiments, the emergence of the ball lightning can be explained starting from the fact that, concomitantly with atom ionizations, the electrons increase their kinetic temperature. As a result, at the distance from the whitish center, where the ionization cross-section function suddenly increases, positive ions are located owing to the difference between the thermal diffusivity of electrons and positive ions. The positive ions are located in the next vicinity of electrons that have lost their kinetic energy by atom excitations and, consequently, are thermalized. So, a part of these electrons electrostatic couple, at a certain moment of their thermal motion, to the positive ions in excess located in the region where the ionization cross-section suddenly increases. In this way, a scenario of self-organization similar to that emphasized by the plasma experiment is initiated. Thus, at the border of the whitish center, elementary electric dipoles are self-assembling, every of them sequestering a certain amount of electric field energy. Because the excess of positive ions that form the dipoles appears after thermal diffusion of electrons, the sequestered electric field energy has its actual origin in a mechanism by which thermal energy extracted by electrons from the plasma mantle is directly converted into electric field energy. Acting in a concerted way, the elementary electric dipoles initiate the formation of a dipolar structure having its positive side located at the distance from the whitish centre where the ionization-cross section suddenly increases and its negative side at the distance where the excitation cross-section function increases in the same way. So, the whitish centre is confined by an enclosed dipolar structure in a state of minimal value of the free energy. Acting as a “membrane”, the shape of the ball lightning is spherical. Having its origin in a self-enhancement of positive ions, i.e., a positive feedback mechanism by which the number of dipoles abruptly increases, the spherical dipolar structure expands. This expansion takes place till the rate by which new dipoles appear equals the rate by which previously dipoles disintegrate after recombination of positive ions with electrons existing at the positive side of the dipolar structure. The survival of the ball lightning in a dynamical state of self-organization is ensured by spherical bipotential structure. Acting as a relative small membrane (cavity) it ensures the stability of the ball lightning based on a balance between: (i) The rate by which new dipoles are created by direct conversion into electric field energy of thermal energy extracted by the G2E from the plasma mantle; (ii) The rate by which the previously self-assembled dipoles disintegrate. The very small time span that exists between the self-assemblage of the dipoles and their disintegration by recombination with electrons, located at their positive side, permanently ensures the presence of a constant number of elementary electric dipoles located in the spherical dipolar structure at the border of the ball lightning.

The lifetime of the ball lightning, emerged by a mechanism as above described, depends on the “reserve” of thermal energy located in the plasma mantle. Consequently, depending on the initial conditions related to the amount of thermal energy located in the plasma in nonequilibrium, created by the linear lightning, the lifetime of the ball lightning could be very different. Surviving in a dynamical state of self-organization, in which thermal energy is transported by electrons from a colder plasma (the mantle) to a warmer one (located at the positive side of the spherical dipolar structure) the “machinery” of the ball lightning works under the circumstances in which the second law of thermodynamics does not work locally and for a very short time span. Considering the plasma mantle as a hot “bath” and the spherical bipotential structure as a ‘”giant” dipole the ball lightning reveals a kind of macroscopic quantum coherence similar to that stipulated by Fröhlich for explaining the origin of the most simple living systems [85].

In the dynamical state of self-organization, the ball lightning achieves macroscopic quantum coherence as that stipulated by Fröhlich by a mechanism that involves: (i) Conversion at a constant rate of the thermal energy, extracted by electrons from the plasma mantle, into electric field energy sequestered in elementary electric dipoles; (ii) Emission at the same rate of electromagnetic energy after dipole disintegration by recombination of positive ions with electrons located at the positive side of the spherical bipotential structure. Formally, such a mechanism can be assimilated to that of a black hole that absorbs matter (electrons) concomitantly with their thermal energy achieved in the plasma mantle and then radiates this thermal energy in the form of electromagnetic energy in the surroundings.

Chapter 6

EXPLANATION OF BALL LIGHTNING OBSERVATIONAL CHARACTERISTICS

Considering the ball lightning as a self-organized complexity in a dynamical state, some (in our opinion all) of the observational characteristics listed in the literature become explainable. Thus:

- The very rare appearance of the ball lightning resides in the fact that the premises required for initiating its emergence by a scenario of self-organization, similar to that under which free floating fireball emerges in laboratory, are very strictly and consequently they can appear only under certain natural conditions.
- Its considerable stability is explainable considering the presence of a spherical bipotential structure the dynamical state of which is activated by a mechanism that involves extraction by electrons of thermal energy from the plasma mantle and its direct conversion into electric field energy. So, the life time of the ball lightning depends on the “reserve’ of thermal energy initially located in the plasma mantle.
- The spherical shape of the ball lightning is determined by the presence of a bipotential structure in dynamical state characterized by a local minimum of the free energy
- Its dimensions depend on the energy injected and the gas pressure in the region where the linear lightning creates the well-located hot plasma in nonequilibrium. Since the ionization rate

for which the expansion of the spherical bipotential structure at the border of the ball lightning stops depends on the gas pressure its sizes could be very different.

- Its color depends on the nature of the atoms located at the negative side of the spherical bipotential structure where the excitations occur. Since the nature of the atom can vary, the color of the emitted light changes during the existence of the ball lightning.
- Its smell is related to ozone produced by ultraviolet light emitted concomitantly with visible ones.
- The low temperature of certain lightning balls could be explained considering that, once emerged by self-organization, the collective quantum processes (ionizations and excitations at the two sides of the spherical bipotential structure) involved in sustaining its dynamical state are related to acceleration of electrons and only indirectly to their thermal energy.
- The frequently observed horizontal but occasionally erratic motion of the ball lightning could be explained considering that its existence is related to balance between: (i) The ascendant Archimedes force present because of the rare gas located in the hot plasma created by the linear lightning; (ii) The attractive force that acts between the negative side of the enclosed bipotential structure and the positive Earth. Although present, the gravitational force is much smaller than the electrostatic one. Owing to the erratic causes related, for example, to the distribution of the Earth potential this balance is not the same.
- The extremely different energy densities associated with lightning balls could be related to the nature of the materials confined inside of the spherical bipotential structure at their border. Consequently, there are possible different nonlinear reactions initiated by the hot whitish center at the origin of the ball lightning. Confined in an enclosed bipotential structure, these reactions produced in dusty plasma, i.e., plasma that contains material particles with sizes in the range of nano/micrometers, could be very different. So, a burning process initiated in the whitish center at the origin of the ball lightning can prolong its lifetime.

- The occasionally observed motion of the ball lightning against the wind can be explained taking into account that the ionization rate sustained by electrons extracted from the plasma mantle depends on the concentration of the atoms. It is possible that the increase of the concentration of the gas atoms at one side of the ball lightning increases the ionization rate at that side. So, the permanent re-formation of the spherical bipotential structure could be different depending on the direction of the wind.
- The property of the ball lightning to penetrate windows without damage them could be explained considering that, once emerged by self-organization, the spherical bipotential structure at its border acts as a cavity able to absorb at resonanc**e** energy transported by electromagnetic waves, originating in external sources. Such waves are emitted, for example, by other lightning flashes produced simultaneously or immediately after the emergence of the ball lightning. Working as a 'cavity", the spherical bipotential structure locates by interference energy in the form of strong electromagnetic oscillations. Reaching the surface of the window these "condensed" electromagnetic waves penetrates it. Consequently, a "knot" of electromagnetic waves appears at the other side of the window. It acts as the premise for the re-formation of the ball lightning at the other side of the window.
- The sound and radio interference occasionally associated with lightning ball becomes explainable considering its property to emit electromagnetic waves by transiting into a pulsating state similarly to fireball or plasmoid.
- The occasionally observed appearance of the ball lightning in higher regions of the Earth atmosphere can be potentially related to the electric activity in that region. Thus, an electrical discharge produced, for example, between clods could easily create a locally hot plasma in nonequilibrium capable to evolve by self-organization into a ball lightning.
- The occasionally observed simultaneous appearance of linearly ordered lightning balls can be explained considering that the "channel" through which the linear lightning propagates is bordered by a cylindrical bipotential structure. Acting similar to surface tension, this cylindrical bipotential structure

disintegrates in a set of “drops” under certain local conditions as for example sudden change of the speed or the direction of the wind.

- The very much energy release, occasionally observed during the disintegration of some lightning balls, attributed in the literature to nuclear reactions, could be explained by the capacity of the spherical bipotential structure to confine the matter of the whitish center the temperature of which could be very high at densities for which such phenomena become possible.

Chapter 7

SELF-ORGANIZATION AND THE ORIGIN OF UFOS

As known, extraordinary aerial ‘objects” known as ball plasma, earth light, plasma vortex, fireball and so on, all of them classified in the literature as *Unidentified Flying Objects* (UFOs) or *Crop Circles* were occasionally observed in the atmosphere of the Earth in absence of thunderstorms. Many photographs of such objects justify partially the occasionally expressed opinion that extra-terrestrial technology becomes sighting concomitant with their appearance [86].

In the following we will present arguments that the premises for the emergence by self-organization of objects as aforementioned exist in the atmosphere of the Earth in absence of intense electric activity during stormy weather or earth quarks. So, we start from the fact that in the atmosphere of the Earth there are rigid objects, one of them originating from the Cosmos, that, flying with very great speeds, produce by collision well-located hot plasma in non-equilibrium. Consequently, the appearance of certain types of UFOs becomes explainable by a mechanism as that at the origin of the ball lightning. The existence of the UFOs for durations that surpass substantially the very short time span in which it emerged in the dynamical state of self-organization is related to the presence of a plasma mantle that acts as a reservoir of thermal energy.

Because plasma exists naturally in the ionosphere, the most favourable conditions for the emergence of UFOs are present there. Placed between the atmosphere and the magnetosphere, the ionosphere, where the atmosphere is thin enough that the Sun's X-rays and UV rays can reach it, but thick enough that there are sufficient molecules able to absorb those rays. So, the concentration of free electrons in the ionosphere increases quickly beginning with a distance from the surface of the Earth of ~70 km owing to the ionizations produced by the mentioned rays. The maximum of electron concentration is reached at ~300 km from the surface of the Earth. At a distance greater than about 1000 km, the concentration of the electrons decreases very quickly at a mean value as that present in Cosmos. So, conditions similar to that present in plasma diodes exist in the ionosphere of the Earth. Under these circumstances, many natural phenomena as collisions between objects that fly with great speeds are able to produce well-located plasma in nonequilibrium. When the temperature of these plasmas surpasses a critical value, there exist the conditions that UFOs appear by a scenario of self-organization as that at the origin of the ball lightning.

Emerged in this way, the UFO consists of a nucleus surrounded by a plasma mantle. Consequently, its lifetime depends on the amount of thermal energy located there. Bordered by the plasma mantle, the UFO survives for a certain time span in regions nearer the surface of the Earth.

In context with the above, we remind that in frame of the project HAARP (High Frequency Active Auroral Research Program) it is stipulated to produce plasma balls in the ionosphere by locally heating the plasma. Thus, using as heater a high power, high frequency phases array radio transmitter with a set of 180 antennas, it is stipulated to energize a small portion of the ionosphere and to generate in this way giant plasma balls. For arguing this possibility, many patents were registered in the USA.

Starting from the fact that in plasma with parameters similar to those present in the ionosphere it is possible to initiate, under laboratory conditions, the emergence of plasmoids that survive in a dynamical state of self-organization we considers that, by a similar scenario of self-organization involving greater energies could take place also in the ionosphere. This is because the emergence of the plasmoid in a dynamical state of self-organization is not related to the amount of energy but rather to the density of this energy. Emerged by self-organization in the ionosphere, the size of the plasmoid depends on the amount of high frequency energy absorbed at resonance from the beam of high frequency energy. So, for the amount of energies used in the

HAARP-project the plasmoid has sizes much greater than those produced under usual laboratory conditions. Changing the direction of the beam, the plasmoid can be placed in different regions of the ionosphere. Bordered by a plasma mantle, the plasmoid can be transported by the beam into region nearer to the surface of the Earth where its disintegration can produce injuries that depend on the amount of energy located in them. At much smaller dimensions and energies, the phenomena afore mentioned can be proved by laboratory experiments.

Decreasing the energy absorbed at resonance from the beam of high frequency energy, the plasmoid transits into a pulsatory state. In this state, the plasmoid emits electromagnetic waves able, for example, to disrupt microwave transmission to satellites. A total disruption of communications of a large portion on the Earth can be realized by interference with waves emitted by the communication satellites. Other possibilities also presumed to be possible in the frame of the HAARP-project become, in our opinion, realizable considering that in the plasma of the ionosphere it is possible to initiate, under controllable conditions, the auto-assemblage of so-called “Ionospheric Research Instruments”, i.e., the emergence of giant plasmoids in a dynamical state of self-organization.

Chapter 8

Dynamical Self-Organization and the Origin of Life

For defining the nature of living systems, *Maturana* and *Varea,*[87] “invented” a so-called autopoietic machine. Such a machine performs ”a network of processes of production (transformation and destruction) of components which (i) through their interaction continuously regenerate and realize the network of processes that produced them: and (ii) constitute it (the machine) as a concrete unity in a space in which they (the components) exist by specifying the topological domain of its realization as such a network”.

Plasma experiments previously published by us [12] offered, as already remarked [13], a hint for explaining the origin of life. In the following we will describe a conceptual model that, based on hypotheses justifiable by the new experimental results presented in this book, could argue this presumption. We start from the premise that in certain well-located regions at the surface of the early Earth physical plasma, like that in a low-voltage arc, was present. Such kind of plasma the background of which could be different gases, have parameters that depend on the temperature of the plasma source. We presume that in the absence of organic matter at the surface of the early Earth such kind of plasma was present, for example, in craters of volcanoes or around them. Under such conditions, local thermal fluctuations as minuscule electric sparks initiate the emergence of a ball-of-fire in a dynamical state of self-organization. Appeared in an environment where the gas pressure did not differ essentially from that present at the surface of the contemporary Earth the sizes of the ball-of-fire are in the range of nano/micrometers. So, we presume that such a minuscule ball-of fire represents a complexity called minimal-cell [88], i.e., the simplest possible system capable of every operations required in its self-existence. Surviving in a dynamical state of self-organization, the minimal cell satisfies life's first structural requirement providing a selective enclosure of a microenvironment that differs electrically from the surroundings. Applying the general autopoietic criteria to the minimal cell, the following questions listed in [88] warrant an affirmative response: does matter self-assembles into a system boundary structure? does the boundary exhibit an electrical gradient? is the gradient sufficient to transport and transform matter through the system boundary? are all components produced by such transformations within the system? are all components replaced by transformations within the system? To a great extent, justifiable by the experimental results presented in this book, such a kind of minimal cell is in our opinion the most plausible candidate able to explain the genuine origin of life. This is in spite of the fact that the "living" state, i.e., the dynamical self-organization state of the minimal cell takes place in absence of water and organic matter. In this context, we remind that, recently, *Tsytovich et al,* [15] proved by simulation methods that in a dusty plasma (plasma that contains particles with sizes at microscopic scales) in the absence of organic matter, stable interacting helical structures that exhibit features attributed only to organic living matter emerge by self-organisation. In the abstract of their paper the authors stress that "each helical structure composed of solid microparticles is topologically and dynamically controlled by plasma flux leading to particle charging and over-screening, the later providing attraction even among helical structures of the same charge sign" and also that "These interacting complex structures exhibit thermodynamic and evolutionary features throughout to be peculiar only to living matter such as bifurcation that serves as *memory mark* self-duplication, metabolic rates in a thermodynamic open system and non-Hamiltonian dynamics".

Concerning the minimal cell, presumed by us to emerge in the absence of organic matter under early Earth conditions, its "living" state is possible accepting that plasma that surrounds the minimal cell has parameters similar to that of the plasma present in the low-voltage arc. This means that the minimal cell is bordered by a plasma mantle that contains a population of G2E. So, converting with a constant rate their thermal energy into electric field energy, the existence of the minimal cell in a dynamical state is provided by a functional spherical dipolar structure. This is a dipolar structure able to perform all operations “learned” during its emergence by self-organization in an environment where organic matter was absent.

For explaining the origin of the organic life, we start from the premise that initially a gaseous minimal cell emerged by a self-organization process that involves only physical phenomena. Endowed with a code of instructions offered by the environment that contains the G2E, the minimal cell acts as a “micocomputer” the program of which is activated by reactive energy, i.e., by thermal energy extracted at a constant rate by the G2E from the surroundings. By direct conversion this thermal energy appears as electric field energy located in the dipolar structure at the border of the minimal cell. Since this thermal energy is immediately emitted in the surroundings, it is not able to produce real work. Under such circumstance the dynamical (living) state of the minimal cell is possible in an environment that contains G2E. However, for surviving in this way the positive nucleus of the minimal cell has to sustain its potential at the value for which the surrounding G2E are accelerated at energies sufficient to produce ionizations. This is realized by that part of the G2E that, traversing the dipolar structure at the border of the minimal cell, are propelled into the nucleus. Producing there besides ionizations also an increase of their kinetic temperature, the electrons leave the nucleus. In this way an excess of positive ions remains in the nucleus, i.e., its potential remains constant. Once emerged in a dynamical state, the minimal cell lives apparently as a so-called dissipative structure [89]. This is a structure the machinery of which dissipates energy in agreement with the second law of thermodynamics. However, this sort of dissipative structure is of a special kind. Thus, for activating the dynamical state of the minimal cell, the surroundings must be driven by an external constraint at that distance from thermal equilibrium for which local fluctuations of the thermal energy have initiated its emergence, i.e., G2E must be present. Under such circumstances, the minimal cell lives by a mechanism by which the rate by which the G2E convert their thermal energy into electric field energy balances the rate by which the same energy is emitted in the surroundings as quantified electric energy after the disintegration of the elementary electric dipoles. Since the emitted quantified electric energy appears at last in the surroundings also as thermal energy, the entropy as a whole remains unchanged. Propelling into the nucleus the G2E the spherical dipolar structure at the border of the minimal cell acts as a Josephson junction.

This state of the minimal cell is modified when its nucleus is additionally heated by another mechanism. So, its further evolution becomes possible taking into consideration the capacity of the spherical dipolar structure at the border of the minimal cell to act as a cavity able to absorb at resonance electromagnetic energy (photons) emitted by the Sun. Capturing the energy of the photon, the nucleus increases abruptly its temperature so that its potential increases very quickly by thermal diffusion of the electrons. Consequently, the descendant branch of electrons thermal energy distribution function in the plasma mantle that surrounds it becomes more abrupt. So, the conversion of thermal energy delivered by the Sun into electric field energy by the G2E takes place instantaneously. Such a phenomenon produced when methane, CO2 and water vapors appeared at the surface of the early Earth potentially explains the efficiency of photosynthesis, i.e., the mechanism by which sunlight is directly converted by the G2E into electric field energy. In this way, the minimal cell is provided with that sort of energy that activates its dynamical (living) state. Reaching this advanced form of self-organization the living state of the minimal cell has achieved mesoscopic quantum coherence and in this way a certain degree of autonomy with respect to the environmental conditions existent outside of the plasma mantle. This means that the minimal cell is able to survive in an environment more appropriate to that present today at the surface of the Earth.

Concomitantly with the evolution of the environmental conditions at the surface of the early Earth the surroundings of the minimal cell become a so-called primordial soup after chemical reactions. Consequently, the further evolution of the minimal cell took place in an environment able to initiate a succession of steps related to bifurcation like nonlinear chemical reactions. Every of these nonlinear chemical reactions serves as memory mark [15]. Normally, the enzymes initiate such non-linear chemical reactions [72]. In this way the mechanism by which the minimal cell lives is stepwise improved. Emerged initially through a mechanism based only on physical processes the minimal cell acts as a mould on which a rigid spherical enclosure appears by further chemical reactions. The single possibility to provide the continuity of its living process, i.e., the activation of its dynamical state by the G2E, is the self-assemblage of channels in the rigid enclosure. This means that the initial gaseous dipolar structure divides into a great number of minuscule dipolar structures every of them located in a channel. Every of these tubular dipolar structures possesses a program encoded during their emergence by self-organization. In this more advanced state of self-organization the potential at the positive side of every minuscule dipolar structure located in the channels of the rigid enclosure is sustained by direct conversion of the thermal energy, extracted by G2E from the surrounding environment, into electric field energy. Arriving at this state of dynamical self-organization, fundamental problems as the appearance of biochemical assemblies (giant polymers self-assembled by proteins and nucleic acids synthesis) become explainable. Involving self-organization, many quantum states in protein and protein assemblies appear. So, for explaining such states, *H. Fröhlich* [85] proposed to consider a special configuration of dipoles emerged in hydrophobic regions of the proteins. Excited by continuous supply with thermal energy extracted from a so-called hot bath, these dipolar structures perform vibrations in a single longitudinal mode of minimal frequency. The common mode of vibration increases quickly the number of the spatially ordered dipoles in a reminiscent of Bose-Einstein condensation. So a “giant” enclosed dipolar structure appears. The frequency proposed by Fröhlich for such a phenomenon is in the order of microwave and corresponds to recognized protein conformational transitions. The origin of the hot bath and the manner by which this could supply the vibration of the dipoles remain not explained in this model. One of the possibilities advocated today starts from the zero point energy of quantum vacuum. Virtual particle/waves (photons) in the quantum vacuum “pop into and out of existence” giving rose to a description of space time as the “quantum foam” zero point vacuum energy [90]. As today accepted, zero point energy can be measured through the Casimir effect.

Instead to appeal to vacuum energy, we explain in the following the stimulation of “vibrations” by thermal energy extracted by the G2E from the surroundings when moving dipolar structures periodically peel off and reformed at the positive side of the minuscule dipolar structures located in the cannels. Initiated by local fluctuations of the thermal energy, the moving dipolar structures transport matter and energy through the channels. In this state the dipolar structure located in a channel acts as an alternative Josephson junction. Normally this dynamics is controlled by deterministic chaos.

The above briefly presented conceptual model of the minimal-cell potentially offers an answer to the question how the precursor of the eukaryotic nucleus appeared under early Earth conditions. Permanently positive charged by capture of photons, by chemical reactions under conditions that hydrogen and molecular oxygen is present but also by a mechanism like that revealed by a direct current Josephson junction, the positive nucleus sustains a proper electric field. This electric field is so strong that the population of electrons that surrounds it is of G2E type. So, an interface that separates the G2E from the surrounding electrons exists outside the eukaryotic nucleus. This creates the premise for the appearance of chemical reactions by which a new rigid enclosure that contains the eukaryotic nucleus appears. Once appeared, the enclosure separates an environment that contains the G2E from a population of electrons with another kind of thermal energy distribution function more nearer to a Maxwellian one. For maintaining the contact with the surroundings, this new enclosure must contain channels. Presuming that the nature of the ions that appear in the different aquatic environments separated by the enclosure depends on the thermal energy distribution function of the electrons, different kinds of ions are formed inside and outside of the membrane. So, a potential drop appears at the two ends of every channel. This potential drop sustains an ionic but also an electronic current which flows through the channels. Such a mechanism could potentially explain how matter and energy is pumped through the channels in the plasma that surrounds the eukaryotic nucleus. This plasma contains the G2E able to activate the living state of the eukaryotic nucleus. The presence of the G2E in this special kind of plasma creates the premise for the self-assemblage of groups of helical structures inside of the enclosure by a mechanism as that reported by *Taytovich et al*. In this way a complexity that contains a eukariotyic nucleus, but also the so-called organelles, emerged in an environment in evolution as that at the surface of the early Earth during its history. Such a complexity could explain the emergence of a protocell. Possessing a program encoded after a very great number of steps, related to new non-linear chemical reactions initiated by enzymes, the eukaryotic nucleus commands the living state of the protocell. Its further evolution is directly related to the change of the thermal energy distribution function of the G2E occurred simultaneously with the change of the local environmental conditions. So, different evolution routes of the eukariotic nucleus and, implicitly, of the protocell were possible at the surface of the early Earth. The evolution occurred stepwise, i.e., by events that involving bifurcation-like instabilities served as memory marks. Dubbed in the literature as *decision nodes* [91], every of these events improved the mechanism by which thermal energy could be directly converted into electric field energy. However, as shown [92], a succession of decision nodes, every of them leading to new functions, could not appear if deterministic cause-and-effect laws worked. This is because "decisions" are not possible under such deterministic conditions. Nevertheless, as we will show in the following, this restriction does not act when a self-organization process as that described in this book governs the living state of the cell. This is because between the cause, i.e., the self-assemblage of elementary electric dipoles by direct conversion of thermal energy into electric field energy and the effect, i.e., the emission of this energy as quantified electric energy by dipole disintegration, there is a very small time span. This time span separates temporally the cause from its effect. In this time span a new nonlinear process the duration of which is shorter than it can be intercalated. So, the evolution of the protocell is determined by the "chance" that in the above-mentioned time span, a nonlinear chemical process that optimizes its self-organization state is intercalated. Potentially, such nonlinear chemical processes are initiated when the concentration of a certain substance in the nucleus or at the border of the protocell reaches the critical value for which such non-linear phenomena develop owing to the appearance of enzymes. In this way, by selective exchange of information between the protocell and an environment itself in evolution, the "architecture" of the protocell and, implicitly, its "machinery" is optimized stepwise by adaptation. This takes place through a succession of instabilities initiated by instructions (information) offered by an environment itself in evolution, i.e., the thermal energy distribution function of the G2E is so changed that the dynamical state of self-organization becomes possible. The chain of decision nodes represents as a whole the algorithm by which an evolution from the protocell into the contemporary cell was possible.

Using for its survival also energy offered by oxidizable chemicals, the cell experiences an ageing process that ends with its death. So, for making possible such an evolution, the algorithm by which the protocell survives at a certain “moment” of its evolution must be transmitted, by inheritance, to a new daughter cell that could appear, for example, by replication. Because the transition from one organized into another better-organized state needs a certain time span, there exists the chance to change the arrow of evolution in the sense that the “replicant” daughter cell survives by a machinery quite different from that of the parent cell at the time of its own “conception”. In this context it is perhaps interesting to remind that there are plasma experiments proving that fireball is able to replicate by division or multiply after “collisions” between two fireballs [28-31].

Chapter 9

BIOPHOTON EMISSION AND INTERCELLULAR COMMUNICATION

Living cells emit in the surroundings electromagnetic energy in the form of photons. Discovered in 1920 by the Russian embryologist *Alexander Gurwitsch*, the magnitude of this emission is weaker than the well-known normal bioluminescence, but stronger than the black body radiation. After the discovery, *Gurwitsch* demonstrated that one plant separated by a quartz barrier from another one (for impeding chemicals messengers) stimulates the growth of the last one. For explaining this astonishing phenomenon, *Gurwitsch* suggested emission and reception of photons. Ignored by the scientific community, this phenomenon was rediscovered by Western, Australian and Japanese scientists. The common basis by which these scientists try to explain this phenomenon is the hypothesis that the photon emission is related to rare nonlinear oxidation processes.

Beginning from 1972, *Fritz-Albert Poop* and his research group [93] in Marburg, Germany, have shown that the spectrum of the emitted photons are in the wavelength range from 200 to 800 nm and a magnitude from a few up to several hundreds photons per second per square centimetres of surface aria of the emitting living matter. By using special techniques that include single photon counters, it was established that; (i) the radiations originate from an almost coherent photon field; (ii) essential sources of the radiations are DNA and compounding resonators in the cell; (iii) the mechanism involves photon storage in cavities and informational channels turned by Casimir forces; (iv) there is a close connection to delayed luminescence which corresponds to excited states of coherent photon field; (v) the occupation of the photons in the phase space is the same for all wavelengths and extends to the so-called hot radiation of the body; (vi) the radiation is the proper regulator and information carrier of life. For modelling the emission of biophotons, *Poop* and his collaborators start from the concept of quantum coherence, considering this as a mechanism that allows to consider the living cell as an open dissipative structure the metabolic activity of which holds them away from thermal equilibrium. The way by which this was theoretically modelled is that proposed by *H. Fröhlich*, which was briefly described by us in the former chapter. The self-organizing ability of the structures in the cell is related to a single oscillation mode, namely that which is the most strongly excited. The frequency of this so-called supra-thermal oscillation is that of the lowest frequency of the oscillators.

The above briefly described model of the biophoton emission starts from the hypothesis that a hot bath supplies the oscillations of an enclosed dipolar structure. The explanation of the actual origin of this hot bath is a problem not answered by this model.

Starting from the experimental results presented in this book, the hot bath could be assimilated to a population of G2E. Under such premises, the ability of the living cell to emit biophotons could be explained starting from the following model. The population of electrons located inside of the cell and, consequently surround the eukaryotic nucleus, is of G2E type. The living state of the eukaryotic nucleus, bordered by a dipolar structure in a dynamical state of self-organization, involves conversion at a constant rate of thermal energy extracted by the G2E from the surroundings and its emission at the same rate as quantified electric energy. So, the emission of biophotons and their properties afore listed can be explained considering that the biological plasma that surrounds the eukaryotic nucleus contains atoms in metastable states. Stimulated by the quantified electric (field) energy emitted by disintegration of the dipoles, the metastable atoms emit photons in the range of the mentioned amounts and frequencies. The so-called organelles and, implicitly, enclosed ordered structures (cavities) present in the cell absorb at resonance photons explaining in this way the intercommunication between living cells. .

The understanding the mechanisms by which living cells emit photons is of special interest taking into account the very large lots of possible applications in the health science, food science, environmental protections, living technology, artificial life and many others. For the complementary and alternative medicine, as for example laser treatments, the elucidation of the mechanism by which a living cell emits and absorbs photons argues the utility of these treatments.

Chapter 10

FINAL REMARKS

For explaining the mystery of how Nature creates complexities in a dynamical state of self-organization from matter in a disordered state we present plasma experiments. The essential news offered by these experiments refers to the fact that self-organization is a phenomenon only apparently controlled by internal causes. This is because "instructions" offered by the environment actually control the emergence and dynamical state of a complexity that survives in a dynamical state of self-organization. Involving a bifurcation-like instability, i.e., an event serving as memory mark, the complexity is able to encode an algorithm that enable it to perform all operations learned during the emergence, by self-organization, as long as the surrounding environment is driven by an external constraint at a critical distance from thermal equilibrium. Initiated by a well explainable cause, the self-organization is an event that evolves locally and in such a short time span that the second law of thermodynamics has not the time to work. Based on the capacity of electrons to convert directly their thermal energy achieved in the surroundings into electric field energy, the self-organization involves a new mechanism not explainable by classical processes. Phenomena like Bose-Einstein condensation, macroscopic quantum coherence, Josephson effects, the origin of the reactive energy, the negative differential resistance, the flash memory, the stimulation of oscillations but also other ones become explainable by considering this mechanism. Related only to the local concentration of the energy and, implicitly, to the initial temperature, complexities in a dynamical state of self-organization appear in Nature and laboratories at very different scales of energy and dimensions. In this way the ball lightning, the appearance of UFOs but also other enigmatic phenomena observed in Nature could be explained.

Starting from the new informational content offered by the experimental results presented in this book we are able to argue by a new conceptual model our already expressed hypothesis [12,14] that physical processes, as those specific to inorganic life, create the premises for the appearance of organic life.

These experimental results offer a new physical basis for elaborating a quantitative model of self-organization, eventually describable by mathematical equations. Thus, considering the elementary electric dipoles as fractals and implicitly springs, a fractal theory completed eventually by a spring theory seems to be the most adequate. However, for making credible such a theory it is necessary to abandon the concept of vacuum zero energy, replacing it by thermal energy of a population of electrons driven by an external constraint at a critical distance from thermal equilibrium. Since this energy is not able to produce real work it must be introduced in such a theory as reactive energy, i.e., as an imaginary quantity. The way by which this is possible could be very different.

Some unsolved problems of Science as that approached by the quantum consciousness theory or quantum mind theory, could obtain a new physical support by considering the capacity of electrons located in the biological plasma of cells to be of G2E type and consequently able to activate the dynamical (living) state of all living systems.

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