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Self-organization as physical basis of the hysteresis phenomena

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For explaining the genuine origin of the hysteresis phenomena we consider a new mechanism by which, exploiting quantum processes, matter concomitant with thermal energy is extracted from the surroundings for creating order from disorder. This mechanism, essentially based on self-organization, implies production of "negative" entropy. Since hysteresis is one of the basic qualities of advanced materials the presented new information offers a new insight concerning a problem not yet conclusively elucidated.

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1. Introduction

Hysteresis is a phenomenon revealed by advanced materials when, subjected to an external constraint, they spontaneously transit (for a critical value of this constraint) into a new state that qualitative differs from the former state. The new state is characterized by certain "robustness" with respect to the external causes that have produced the transition. Hysteresis manifests as the ability of the material to "survive" in the new state also when the "intensity" of the external constraint becomes smaller than the intensity required for initiating the transition. In the vocabulary of the Science of Complex Systems this means that, after the transition, the material is endowed with a special kind of memory by which it is able to "remind" a phenomenon produced at a certain moment of its past history [1].

Perhaps the most studied hysteresis phenomenon is that observed when a piece of material potentially able to be magnetized is subjected to an external magnetic field. For explaining this phenomenon the presence of spins in the material is considered. Before the external magnetic field acts, each spin has a particular orientation corresponding to the direction of its own magnetic field. Generally, the spins point in different directions, so that their magnetic fields cancel each other out. The higher the temperature, the stronger the random movements affecting the spins and the more difficult it will be to fix any ordered arrangement. When the temperature decreases, the spins will spontaneously align themselves, so that they all point in the same direction. Instead of canceling each other, the different magnetic fields add up, producing a strong overall field. Although magnetization is a clear case of self-organization the genuine cause of the spontaneous ordered orientation of the spins and the actual mechanism that maintains this orientation also when the intensity of the external magnetic field is decreased below the critical value for which this appears remains up to the present date an open problem of nonlinear physics. Strong similarities recently revealed between the hysteresis phenomenon emphasized by magnetic materials and gaseous conductors (plasma) suggested the consideration the same self-organization process at their genuine origin [2].

Based on a phenomenological model of self-organization revealed by plasma experiments [3-9] we explain in this paper the hysteresis phenomena observed in gaseous conductors. Potentially, this model is able to offer a paradigmatic new insight into the mechanism at the origin of the hysteresis phenomena in general.

2. Experimental device and results

The used experimental device is shown in Fig. 1. It schematically represents a diode whose cathode works as a source of plasma. The anode is a metal plate immersed in the plasma. Plasma arrives at anode surface after diffusion from the cathode. In experimental investigations whose results were already published [3-9] we used as control parameter the voltage applied on the diode.

In this paper we present experimental results obtained by using as control parameter the density D of the plasma *i.e.*, the concentration of the electrons in the plasma. This means that for proving the presence of the hysteresis phenomenon we plotted, instead of the usual current-voltage characteristic, the curve that reveals the relationship between the current I transported by the gaseous conductor (when the voltage delivered by the external dc power supply is maintained constant) and the concentration D of the electrons in the plasma. For changing the electron concentration D we varied the temperature of the tungsten filament F placed in the plasma source. The plasma was obtained by ionizations produced by the electrons emitted by F placed inside the metal cylinder M. The electrons emitted by the filament F are accelerated to the inner surface of M whose positive potential was maintained constant at a value for which inelastic electron-atom collisions (excitations and ionizations) take place.

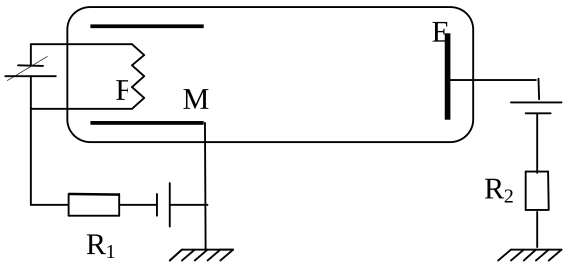

Fig. 1. Experimental device (R_1, R_2- current limiting resistors).

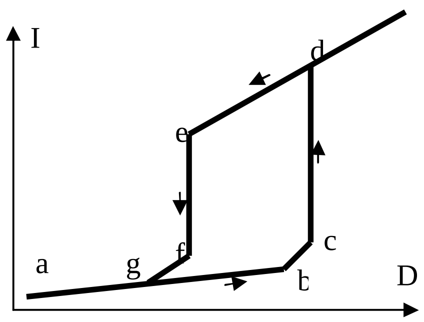

Fig. 2. Typical characteristic of a plasma diode when instead of the voltage is varied the concentration of the plasma electrons.

The typical *I-D* characteristic shown in Fig. 2 reveals the presence of critical values of *D* for which the current *I* varies drastically. Thus, gradually increasing *D* there is a threshold value for which *I* abruptly increases (jump *c-d*). As already shown [7] such abrupt variations of *I* are related to an instability process in which a self-enhancement of the production of positive ions takes place. Once started, the instability evolves independently from the cause that has initiated its appearance. During the instability, spatial order emerges by self-organization in the plasma diode. This spatial order appears in the form of a complex space charge configuration (CSCC) attached to the anode. The internal ordered space charge arrangement of the CSCC was already described [2-9]. After the spontaneous self-assemblage process of the CSCC the plasma diode is in a mettastable state. That is a state whose maintenance requires work performed by an external dc power supply. The actual mechanism that explains this state is the ability of the CSCC to “survive” performing all the operations “learned” during its emergence by self-organization [9]. These operations involve continuous extraction of matter concomitant with thermal energy from the plasma. Thus, this takes place by a mechanism exploiting quantum processes [9]. For working this mechanism the thermal energy extracted from the plasma is entirely expelled out in the surroundings in the form of incoherent radiation energy (light) [9]. Because, at last, the emitted incoherent radiation energy appears in the surroundings as thermal energy during the surviving process of the CSCC, the thermal energy extracted from the plasma entirely appears also as thermal energy in the surroundings. With other words, the surviving mechanism of the CSCC includes a process during of which the total entropy remains constant [9]. For creating the conditions required to determine the emergence of the CSCC but also for its survival the external dc power supply performs work. This work include a part that,, in agreement with the second low of thermodynamic, is dissipated increasing the entropy in the surrounding .

When an Ohmic resistance is inserted between the external dc power supply and the plasma diode, the abrupt increase of *I* produced when *D* reaches a critical value determines the decrease of the voltage supported by the gaseous conductor so that the plasma diode reveals the presence of a negative differential resistance. In this case, the appearance of the negative differential resistance is controlled by the concentration of the plasma electrons *D*. The negative differential resistance appears because the used dc instrument does not indicate the lost of energy caused by the emission of incoherent radiation during the surviving process of the CSCC [9]. Indicating only the diminution of the internal resistance of the gaseous conductor that accompanies the self-enhancement of the production of positive ions and the surviving process of the CSCC, the instrument used for plotting the current-voltage characteristic emphasizes the presence of an S-shaped negative differential resistance. Apparently, the plasma diode produces and does not consume energy.

The presence of the critical values of *D* for which the instability starts proves that the concentration of the electrons in the plasma is one of the parameters that essentially control the appearance of the aforementioned self-enhancement of the production of positive ions. This becomes easily explainable knowing that the factor that controls the appearance of the instability is a critical value of the ionization rate [7, 9]. When the voltage delivered by the dc power supply is maintained constant and the density *D* of the plasma is varied, the critical ionization rate for which the instability develops is evidently controlled by the electron concentration *D*.

For proving the presence of hysteresis we gradually decreased the concentration *D* of electrons. Under such conditions, the relative high value of *I* related to the described instability is maintained in a *D*-interval that depends on the other parameters of the plasma in the diode. Such parameters are: the gas pressure, the voltage of the dc power supply, the distance between the cathode and anode, the dimensions and shape of the anode, etc. The actual cause of the hysteresis revealed in Fig. 2 by the branch *d-e* is the ability of the CSCC to survive also under the conditions that the concentration of electrons *D* becomes smaller than the threshold value for which it emerged by self-organization. Evidently, for surviving, the CSCC must continue the operations learned during its emergence by self-organizations. This means that the CSCC exists by performing operations based on a mechanism by which matter concomitant with thermal energy is extracted from the plasma. Since this mechanism is related to the maxwellian distribution of the kinetic energy of the plasma electrons [9], the temperature of the plasma can also control the appearance of order in the form of a CSCC and, implicitly, the appearance of the hysteresis phenomenon emphasized by the plasma diode.

As known, in certain experimental conditions, many CSCCc that form a framework characterized by ordered spatial distributions of the CSCCs self-assemble at the surface of the anode [10]. For surviving, every of the CSCC extracts matter concomitant with thermal energy from the plasma. This means that the maintenance of spatial order in the form of a framework of CSCCs also bases on a mechanism by which matter concomitant with thermal energy is continuously extracted from the plasma. Simultaneously, exploiting quantum processes, this energy is emitted in the surroundings in the form of incoherent radiation energy. The spontaneous emission of incoherent radiant energy in the surroundings by the CSCC and implicitly by a framework of CSCCs apparently corresponds to the production of negative entropy.

In this context it is interesting to mention that "negative entropy" is a term introduced by Schrödinger in his book "*The origin of life*" [11]. As known, living organism operates with functional elements that actually exploit quantum processes by a mechanism extracting thermal energy from the surroundings. This means that the living organisms produce negative entropy for surviving. Evidently, referring to the phenomena observed in the plasma diode we can tell only about a system, emerged after self-organization, whose "life" is artificially maintained.

For avoiding the physical limits imposed by quantum and thermal fluctuations phenomena when new miniaturized components that manifest hysteresis are created the computer scientists seek inspiration from biology. Using the term negative entropy for explaining the physical basis of the hysteresis phenomenon described in this paper we point out that "materials" endowed with memory actually behaves in a "quasi-living" state. Thus, for revealing hysteresis, the material, in our case the plasma, must be subjected to an external constraint that surpasses a critical value. When this value is reached, spatial order in the form of quasi-autonomous entities appears by self-organization. Every of them are able to "survive" extracting matter concomitant with thermal energy by a mechanism apparently similar to that emphasized by living systems

Considering all the above said, it results that important for understanding the hysteresis phenomenon is the fact that the sample revealing this phenomenon is not in static state but in a state in which entities placed in its structure perform a proper activity learned during their emergence by self-organization. This activity is performed under the conditions that the total entropy remains constant, *i.e.*, the thermal energy extracted from the sample is entirely expelled in the surroundings in the form of incoherent radiant energy.

3. Conclusions

Based on a phenomenological model of self-organization already published we explain the hysteresis phenomena revealed by a plasma diode by a new mechanism that involves continuous extraction of matter concomitant with thermal energy. Since the extracted thermal energy is emitted in the surroundings in the form of incoherent radiation, the total entropy of the system remains constant.

If the information presented in this paper concerning the actual origin of hysteresis offers also a new insight about the hysteresis phenomenon emphasized by material potentially able to be magnetized is a problem of the future. The fact that ordered orientation of the spins in such materials critically depends on the temperature is a hint that thermal energy plays an important role also in the mechanism at the origin of the hysteresis revealed by such materials.

Considering that for the spontaneous transition of the matter from a disordered state into an ordered state the Nature "appeals" to a self-organization mechanism, that in principle is the same, it results that the genuine origin of the hysteresis phenomena is very probably also the same.

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