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Three Laws in the Cold Fusion Phenomenon and Their Physical Meaning

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Abstract

There have been discovered three empirical laws in the CFP; (1) The First Law: the stability effect for nuclear transmutation products, (2) the Second Law; the inverse power dependence of the frequency on the intensity of the excess heat production, and (3) the Third Law: bifurcation of the intensity of events (neutron emission and excess heat production) in time. There are two corollaries of the first law: Corollary 1-1: Production of a nuclide ${}^{A'}{}_{Z+1}X'$ from a nuclide ${}^{A}{}_{Z}X$ in the system. Corollary 1-2: Decay time shortening of unstable nuclei in the system. These laws and the necessary conditions for the CFP tell us that the cold fusion phenomenon is a phenomenon belonging to complexity induced by nonlinear interactions between agents in the open and nonequilibrium CF systems as far as we assume a common cause for various events in the CFP, i.e. excess heat production, neutron emission, and nuclear transmutation. The characteristics of the CF materials for the CFP are investigated using our knowledge of the microscopic structure of the CF materials consulting to the complexity in relation to the three laws explained above. A computer simulation is proposed to reproduce an essential feature of the CFP using a simplified model system (a super-lattice) composed of two interlaced sublattices; one sublattice of host nuclei with extended neutron wavefunctions and another of proton/deuterons with non-localized wavefunctions.

1. Introduction

The science of complexity has developed in the last half of 20th century to give a rather complete perspective of nature not only inorganic but also organic systems including human beings extending mathematical treatment from the physical science of simple systems developed since the birth of modern science in 16the century to social and human sciences.

Now, our understanding of nature is not confined to the traditional area of natural science described by differential equations but extends to the events determined by nonlinear dynamics without quantitative reproducibility.

As we know from the beginning of the research in the cold fusion phenomenon (CFP), there is no quantitative reproducibility and this is sometimes used to denounce the value of the investigation of the CFP. This situation is unreasonable if we recollect the fact that the qualitative reproducibility or probabilistic laws are popular in nuclear physics. One of these examples is the α-decay of $^{226}_{88}$Ra nucleus; We can not predict when a nucleus $^{226}_{88}$Ra under investigation will decay to $^{222}_{86}$Rn by emission of $^{4}_{2}$He but we know the constant of the decay, $\tau_{1/2} = 1.6 \times 10^3$ y, which describes a statistical law for temporal variation of the number of nuclei of $^{226}_{88}$Ra in a system.

It is interesting to find out several empirical laws or regularities between physical quantities observed in the CFP [1.1 – 1.3] from experimental data sets summarized in books [1.4, 1.5]. These laws suggest statistical nature of the events in this field. The laws or regularities can be divided into three; (1) the stability effect for nuclear transmutation products, (2) the inverse power dependence of frequency on intensity of the excess heat production, and (3) the bifurcation of intensity of events (neutron emission and excess heat production) in time. There are two corollaries to the first law: Corollary 1-1: A nuclide $^{A'}_{Z+1}$X' is generated from a nuclide $^{A}_{Z}$X in the system. Corollary 1-2: Shortening of decay time of unstable nuclei.

Recognizing the existence of these laws in this research field, we might be able to take a correct point of view for the science of the cold fusion phenomenon (CFP).

2. Three Empirical Laws deduced from Experimental Data and Their Explanation by Nonlinear Dynamics [2.1 – 2.3]

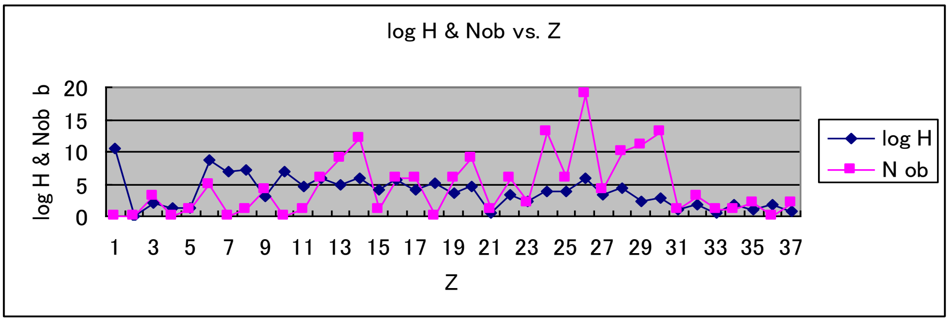
In the vast amount of information we have obtained in these more than 20 years since 1989, we can recognize several regularities or laws between observables in the CFP. The three laws we have figured out are specified as follows [1.1 – 1.3]; (1) First Law, the stability effect for nuclear transmutation products and two corollaries, (2) Second Law, the inverse power dependence of frequency on intensity of the excess heat production, and (3) Third Law, the bifurcation of intensity of events (neutron emission and excess heat production) in time. We give an explanation for them in this section.

2.1 The First Law; Stability Effect for Nuclear Transmutation Products

([1.1] Sec. 2.11, [2.1 – 2.3])

If we survey numbers of elements produced by the nuclear transmutation in the CFP, we notice the frequency obtaining an element has a positive correlation with the amount of the element in the universe (e.g. [2.4]). Plotting out (i) the number of experiments where observed an elements X together with (ii) that of the amount in the universe compiled by Suess and Urey [2.4] against its proton number *Z*, we obtain a diagram shown in Fig. 2.1.1. The coincidence of the peaks of numbers (i) and (ii), gives the stability effect for nuclear transmutation products [1.1]. We may call this regularity the "stability law" for nuclear transmutation in the CFP.

(a)



(b)

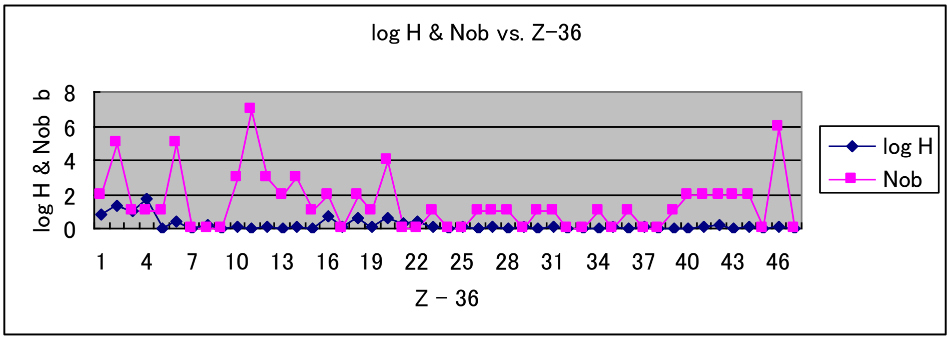


Fig. 2.1.1. Correspondence between the frequency N_{ob} observing elements in the CFP and the relative abundances $\log_{10}H$ of elements [2.4] in the universe: (a) Z = 3 – 38 and (b) Z = 39 – 83 [1.1].

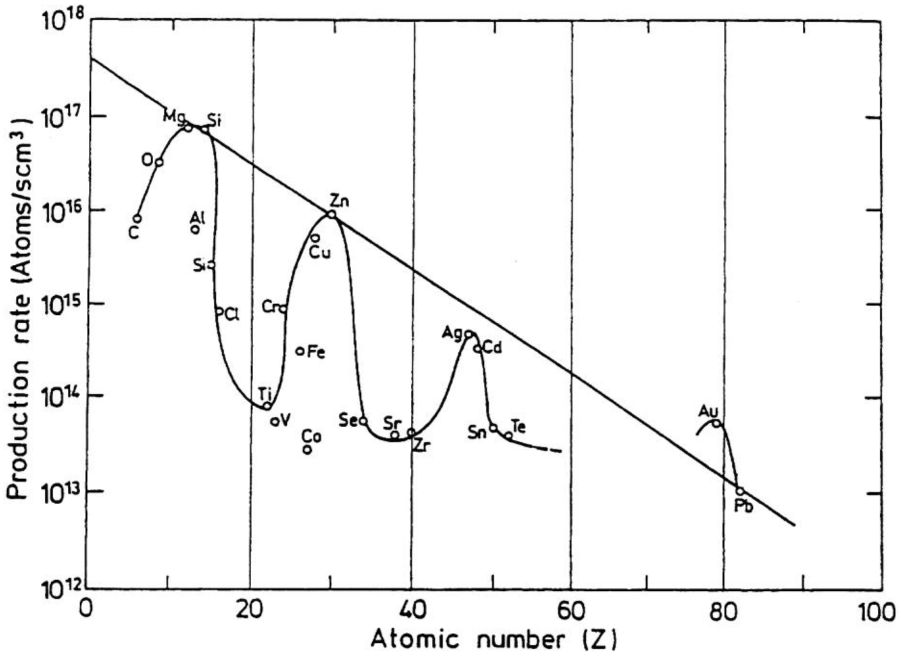


Fig. 2.1.2. Measured production rate $N(Z)$ for the nuclear transmutation on the atomic number Z for protons in palladium where and exponential decay of the maxima on Z follows a relation of a equation $N(Z) = N'\exp(-Z/7.86)$ and $N' = 3.56 \times 10^{17}$ atoms/cm^{3}s ([2.5] Fig. 1).

In addition, the maxima of measured production rate $N(Z)$ in many experimental data sets including the data by Hora et al. [2.5] shown in Fig. 2.1.2 rather agree with the magic numbers with exception of the magic number 20 where a clear minimum of $N(Z)$ was observed in all cases. This coincidence of the maxima of $N(Z)$ and the magic numbers is another example of the stability effect on the nuclear transmutation in the CFP.

This law shows that the stability of a nucleus keeps its nature in the cf-matter composed of high density neutrons in the neutron valence band [1.1, Sec. 2.4.2] and spring out as a nucleus just as in the case of nuclear transformation in stars. This characteristic appears also in somewhat different form in the following corollaries.

2.1.1 Corollary 1-1 (to the First Law); A nuclide $^{A'}_{Z+1}X'$ is generated from a nuclide $^{A}_{Z}X$ in the system.

The First Law explained above tells us that the nuclear transmutations occurring in the stars occur also in the CF materials in an appropriate condition where a nuclear transmutation occurs by transformation as classified before [1.3, Sec. 2.4.5]. However, there are situations where experimental conditions of the CFP reflect in the results of the nuclear transmutation. The most important of the experimental conditions different from nuclear reactions in free space is the existence of lattice nuclei immersed in the cf-matter [1.1]. The lattice nucleus $^{A}_{Z}X$ can absorb one neutron to be a new unstable nucleus $^{A+1}_{Z}X^{*}$ which becomes finally another stable nucleus $^{A-3}_{Z-2}X'$, $^{A+1}_{Z+1}X''$ or $^{A+1}_{Z}X$ by alpha, beta or gamma decay. This type of nuclear transmutations classified as the nuclear transmutations by decay [1.1, Sec. 2.4.5] can be picked up as a Corollary 1 to the First Law.

There are many examples showing this law in electrolytic and discharge experiments [1.4, Section 11.11]. The clearest example is obtained in electrolytic [2.6] and discharge [2.7] experiments where Pd transmuted into Ag.

Another example obtained in a different system is that in carbon arc in water where used several metal anodes and a carbon cathode [2.8]. In the cases of metal anodes of Ti, Co or Ni, a small amount of elements with atomic numbers increased by one, i.e. V, Ni, or Cu, was observed.

2.1.2 Corollary 1-2 (to the First law); Shortening of decay time of unstable nuclei.

The second situation characteristic to the CF material different from the free space is coexistence of the cf-matter and unstable radioactive nuclei in a crystal lattice. In the free space, a radioactive nucleus is governed by a statistical law in its stabilization by some decay processes. In the case of its coexistence with the cf-matter, the interaction between the nucleus and the trapped neutrons give another branch of stabilization giving the surplus energy to the lattice effectively without radiation outward.

There are several examples of drastic shortening of decay time of unstable nuclei including natural radioactive nuclei of uranium $^{232}_{90}{}^{Th}$, $^{235}_{92}U$ and $^{238}_{92}U$ and of $^{40}_{19}K$ and $^{107}_{46}Pd$ supposed to be generated in reactions of the CFP [1.1, Section 2.5.1.1].

The data show very fast nuclear transmutation in the laboratory time scale of following decay reactions (with decay types and times in free space);

$^{107}_{46}Pd^{*} \rightarrow {}^{107}_{47}Ag$, (β, $\tau_d = 1.3\times10^{9}$ y) [2.7]

$^{40}_{19}K^{*} \rightarrow {}^{40}_{20}Ca$, (β, $\tau_d = 6.5\times10^{6}$ y) [2.9]

$^{232}_{90}Th \rightarrow {}^{228}_{88}Ra$, (α, $\tau_d = 1.4\times10^{10}$ y) [2.10]

$^{235}_{92}U^{*} \rightarrow {}^{231}_{90}Th^{*}$, (α, $\tau_d = 1.0\times10^{9}$ y) [2.11, 2.12]

$^{238}_{92}U^{*} \rightarrow {}^{234}_{90}Th^{*}$. (α, $\tau_d = 6.5\times10^{9}$ y) [2.11, 2.12]

2.2 The Second Law; Inverse-Power Dependence of Frequency on Intensity of Excess Heat Production ([1.1] Sec. 2.12, [2.1])

In several experimental data sets, we are able to count numbers N_Q of an event (excess heat) with a specific amount Q (or an excess power P) and plot them as a function of Q (or P) obtaining N_Q vs. Q (or P) plot. The first plot was obtained for the data by McKubre et al. [2.13] as shown in Fig. 2.2.1 [1.1]. This plot clearly shows that there is a relation of frequency vs. intensity with an exponent of 1 famous in complexity. This regularity may be called the inverse-power dependence of frequency on intensity of the excess heat production.

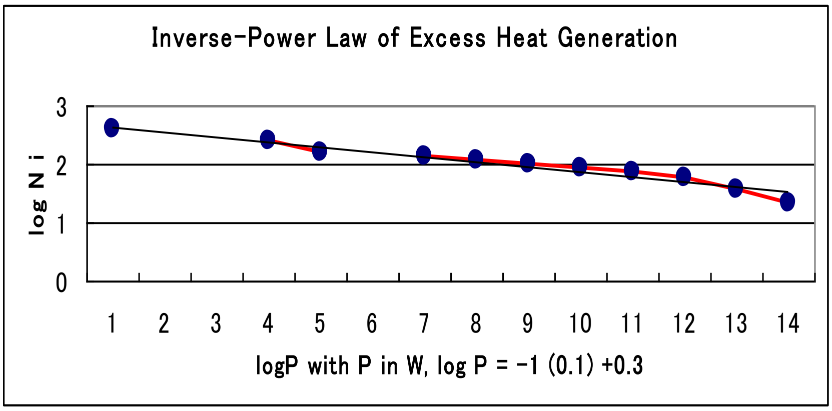


Fig. 2.2.1. Inverse power law revealed by excess power generation measured by McKubre et al. [2.13]

Another example of this law is obtained for the data of Kozima et al. [2.14] as depicted in Fig. 2.2.2. In this case, the exponent of the dependence is 2.

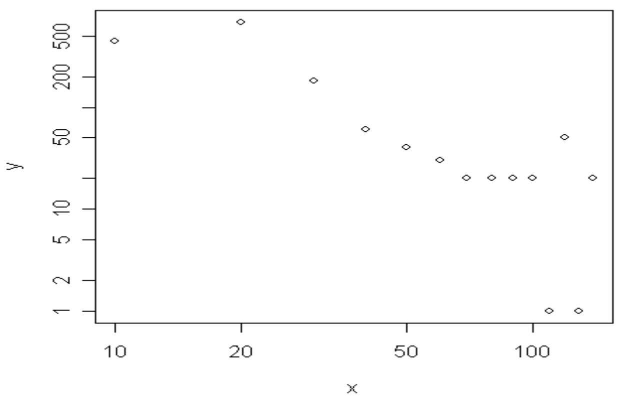


Fig. 2.2.2. Distribution of the frequency N_p (= y) producing excess power P_{ex} (= x). To depict log-log curve, values of N_p and P_{ex} were arbitrarily multiplied by 10^n. (x = 100 in this figure corresponds to P_{ex} = 1 W). [2.14]

In addition to these formulations, H. Lietz [2.15] tried to check the inverse-power law using the data accumulated by E. Storms [1.5]. The resulting plot by H. Lietz is given in Fig. 2.2.3 which shows the exponent of 1.0.

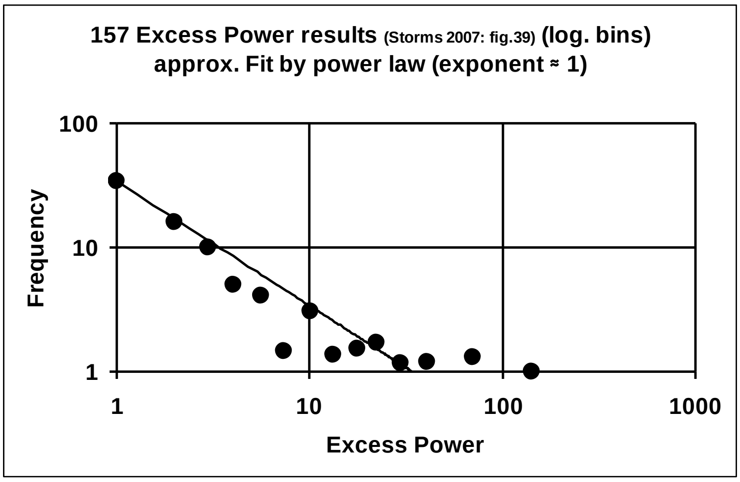


Fig. 2.2.3. Distribution of 157 excess heat results summarized by Storms [1.5]. Values have been stored in bins of size 10. The line shows a power-law fit to the binned data with an exponent of 1.0 (r^2 = 90%). (Fig. 3 of [2.15])

Therefore, we may conclude that the excess heat generation in the CFP is governed by a statistical law popular in complexity.

2.3 The Third Law; Bifurcation of Intensity of Events (Neutron Emission and Excess Heat Production) in Time

The third law in the CFP is a little subtle statistically compared with the former two.

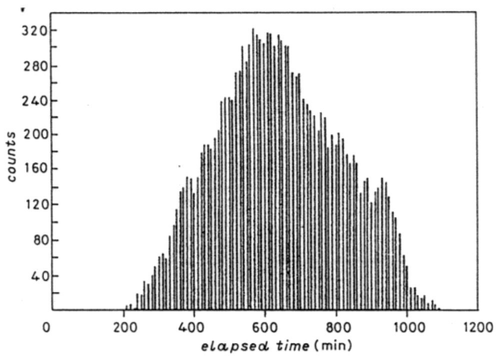


Fig. 2.3.1. Diagram showing the time evolution of the neutron emission from TiD_x sample during the run *A* (April 15-16, 1989). The values indicated are integral counts over periods of ten minutes [2.16].

Even if the number of examples is scarce, we have several fortunate data sets of temporal evolution of effects in the CFP. The first one is that of neutron emission from TiD_x by De Ninno et al. [2.17] published in 1989. The data are shown in Figs. 2.3.1 and 2.3.2.

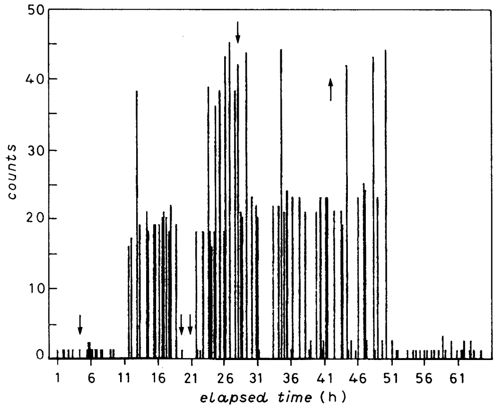


Fig. 2.3.2. Diagram showing the time evolution of the neutron emission counts (ordinate) during the run *B* (7-10 April, 1989). The values indicated are integral counts over periods of 10 minutes [2.16].

Another data set is the excess heat generation observed by McKubre et al. [2.13] as shown in Fig. 2.3.3.

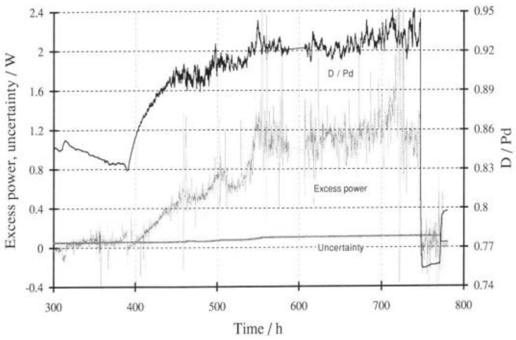


Fig. 2.3.3. Variation of Excess Power, Uncertainty and Loading ratio [2.13].

Furthermore, we can cite another example of the temporal evolution of excess heat generation measured by Kozima et al. [2.14] in Fig. 2.3.4.

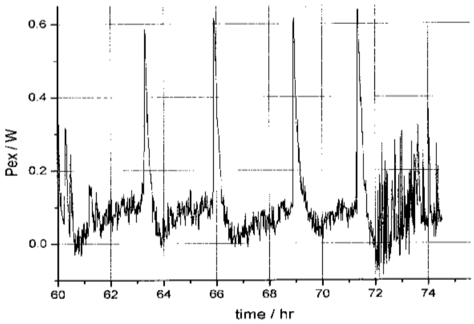


Fig. 2.3.4. Excess power pulses during a 14 hour period of an experiment (070108) which lasted 12 days as a whole [2.14].

By the nature of events in complexity, we can give only qualitative explanation of experimental result in analogy to the mathematical results of numerical simulations using the logistic difference equation [2.17]. The analogical explanations of the laws observed in the CFP have been given using the nature of an equation of nonlinear dynamics, Feigenbaum's theorem [2.18], in the previous paper [2.1].

We cite hear a bifurcation diagram from J. Gleick's book [2.17] in Fig. 2.3.5. The main figure depicts x_∞ on the ordinate (x_∞ is x_n at $n = \infty$) vs. the parameter λ on the abscissa of the logistic difference equation (l.d.e.)

$$x_{n+1} = \lambda\, x_n(1 - x_n), \quad (0 < x_0 < 1) \qquad (1)$$

The inserted figures, a) Steady state, b) Period two, c) Period four, and d) Chaos, depict variations of x_n with increase of suffix n (temporal variation if n increases with time) for four values of λ; a) $1 < \lambda < 3$, b) $3 < \lambda < 3.4$, c) $\lambda \simeq 3.7$, d) $4 < \lambda$. The region a), b) and d) correspond to "Steady state", "Period two" and "Chaotic region" in the main figure, respectively.

As we have shown in the previous paper [2.3], we may take our parameter n_n in the TNCF model as λ in the l.d.e. (1)

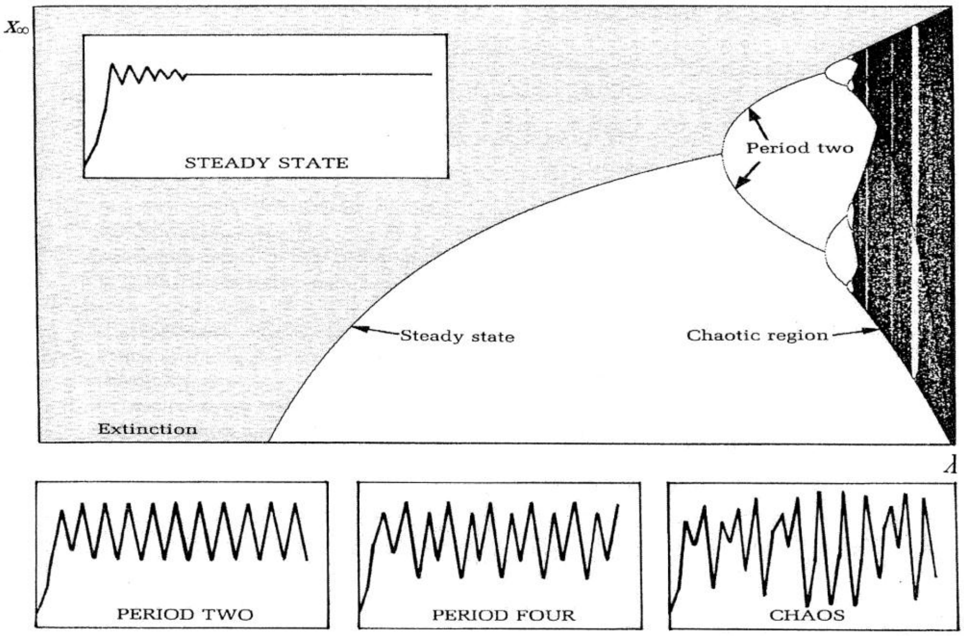


Fig. 2.3.5. Bifurcation diagrams ([2.17], page 71).

3. Physical Meaning of the Three Laws

The characteristics of the CFP have been revealed in the three empirical laws and two corollaries introduced in the previous section. The contents of these regularities exposed in the experimental results have given us important hints to investigate physics of the nuclear reactions occurring in the CF materials resulting in various events in the CFP.

3.1 The First Law and the Nature of Nuclear Reactions in the CFP

First of all, the first law and its corollaries disclose the nature of nuclear reactions in the CF materials. The first law tells us that the nuclear reactions in the CFP expressed in the stability effect in the nuclear transmutation are quite similar to those occurring in stars.

However, there is a little modification by the existence of lattice nuclei resulting in the two corollaries. The existence of appropriate nuclides in contact with the cf-matter formed at boundary regions of the CF material [1.1, Sec. 3.7] induces nuclear reactions expressed in the two corollaries. A nucleus ${}^{A}_{Z}X$ which can absorb a neutron to form a new nucleus ${}^{A+1}_{Z}X^{*}$ and stabilize by a disintegration gives rise to the corollary (1-1). When the nucleus ${}^{A}_{Z}X$ is a radioactive one, the result is drastic acceleration of the decay process of the nucleus resulting in the corollary (1-2).

3.2 The Second Law and the Structure of CF-Materials

The inverse-power law is ubiquitous everywhere in nature when the agents of a system are complex and interacting with nonlinear forces. One of the most familiar examples is the Gutenberg-Richter law of earthquake [3.1, 3.2]. The inverse-power law appears where there is a mechanism to cause an effect triggered by a subtle stimulation caused by any fluctuation of a parameter in the system. The appearance of 1/*f* fluctuations in every systems composed of many-body agents [3.3] suggest us a close relationship between the inverse-power law and the 1/*f* fluctuation even the relation is not solved yet.

Therefore, the existence of the second law in the CFP as explained in Sec. 2.2 tells us that the nuclear reaction resulting in the excess energy production, and also in the nuclear transmutations in the CFP, is induced by a subtle fluctuation of any parameter in the system which is essentially uncontrollable.

3.3 The Third Law and Complexity

The similarity between patterns of temporal variation of events in the CFP and those in nonlinear dynamics found by a numerical simulation suggests us existence of similar dynamical processes in CF materials to those assumed in the simulation that gave the bifurcation diagram from the period doubling to the chaos as shown in Fig. 2.3.5.

4. Discussion

The fluctuation known as 1/*f* fluctuation [3.3] is ubiquitous in all world from microscopic to macroscopic scale. Even if its origin is not confirmed yet [4.1], the existence is universal. So, if a phenomenon is caused by a fluctuation, the phenomenon is inherited the nature of the fluctuation and inevitably exhibit its characteristics. The inverse-power law in the CFP explained in Sec. 2.2 may be an evidence of its close relation to the 1/*f* fluctuation; the self-organization resulting in the formation of cf-matter or the nuclear reactions in the CFP may be triggered by the fluctuation in microscopic system.

Existence of the third law in the CFP explained in Sec. 2.3 suggests directly the statistical nature of the CFP while we do not know the mechanism of nuclear reactions in CF materials. Similarity between the bifurcation in the CFP and the bifurcation behavior exhibited by simulation of nonlinear dynamical systems may be an indirect evidence showing complexity in the CFP.

Once the cf-matter is formed in a CF material, the elementary particles, neutrons, protons and electrons, participating in the nuclear reactions in the CFP seem to behave as if they are in hot plasmas as in the stars if we consider the first law in the CFP as explained in Sec. 3.1. This is an amazing situation because the CF materials are in fairly low temperatures at most 10^3 K compared to about 10^6 K in the star. This difference may be related to the existence of lattice nuclei in the CF materials while there is no stable lattice of nuclei in the star. The stable state of cf-matter in the CF material facilitates the same nuclear transmutations as in stars in rather quiet manner than those in the latter.

As we have already discussed [1.1, 4.2], experimental data sets obtained in really various experimental systems [1.4, 1.5] suggest peculiarity of the CFP that asked new quantum mechanical states not noticed until now. The quantum mechanical investigation of the CF material [1.1, 4.2, 4.3] has given evidence or a hint to explain the basis of the TNCF model fairly successful to give a consistent explanation of the experimental results as a whole [1.1, 1.4].

It is desirable to investigate a possibility to form the new state of neutrons suggested by the TNCF model so successful to explain several characteristics of the CFP. The most promising method in this direction will be a computer simulation of the neutron bands in the superlattice made of two sublattices of host nuclei (e.g. Ni or Pd) with simplified but realistic neutron wavefunctions and of protons (or deuterons) with nonlocal wavefunctions.

The Corollary 2 to the First Law may be applicable to the remediation of hazardous nuclear waste in atomic piles.

Investigation of the relation between the three empirical laws discussed in this paper and the science of complexity should be taking up in near future.

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