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The Cold Fusion Phenomenon as a Complexity (2) – Parameters Characterizing the System where occurs the CFP –

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Abstract

The cold fusion phenomenon (CFP) was investigated from the point of view developed in nonlinear dynamics. It was shown that the recursion relations are applicable to events in the CFP to explain their characteristics using the density of the trapped neutrons in the TNCF model as a parameter of the recursion function.

1. Introduction

The cold fusion phenomenon (CFP) contains events related with nuclear reactions accompanying excess energy production. In these events, we have determined experimentally parameters governing the occurrence of the CFP such as the loading ratio η (=D/Pd, H/Ni, etc.), temperature T, current density i to the cathode in electrolytic and discharge systems, etc. The events also show a characteristic of the recursion relations

$$x_{n+1} = \lambda f(x_n), \tag{1}$$

well investigated in nonlinear dynamics [1].

It is interesting to notice that a large class of recursion relations (1) exhibiting infinite bifurcation possesses a rich quantitative structure essentially independent of the recursion functions $f(x)$ when they have a unique differentiable maximum $\underline{x}$. With $f(\underline{x}) - f(x) \sim |x - \underline{x}|^z$ (for $|x - \underline{x}|$ sufficiently small) and $z > 1$, the universal details depend only upon z.

In particular, the local structure of high-order stability sets is shown to approach universality rescaling in successive bifurcations, asymptotically by the ratio α ($\alpha = 2.5029078750957\ldots$ for $z = 2$) [1].

We investigate the CFP from the point of view described by the recursion relations (1).

2. Structure of the Population (Density) Equation

The recursion equations (1) provide a description for a variety of problems. For example, a discrete population (density) satisfies the formula

$p_{n+1} = f(p_n)$,

determining the population (density) at one time in terms of its previous value [1].

The events we observe in the CFP seem to belong this type of quantities obeying the relations (1) as we have partly shown in recent works [2 – 5]. We confine our investigation in this paper to the discrete population (density) relations and make the result show its validity.

If the population (or density) referred to is such that of a dilute group of organisms (or agents e.g. density of trapped neutrons n_n in the CFP), then the population (density) equations

$$p_{n+1} = b\, p_n \tag{2}$$

accurately describe the population (density) growth with a growth rate b so long as it remains dilute, with the solution

$$p_n = p_0\, b^n. \tag{3}$$

For a given species of organism (agent) in a fixed milieu, b is a constant – the static birth rate for the configuration.

As the population grows, the dilute approximation will ultimately fail: sufficient organisms (agents) are present and mutually interfere. At this point, the next value of the population (density) will be determined by a dynamic or effective birth rate b_{eff}:

$$p_{n+1} = b_{eff}\, p_n \tag{4}$$

with $b_{eff} < b$. Clearly, b_{eff} is a function of p, with

$$\lim_{p\to 0} b_{eff}(p) = b, \tag{5}$$

the only model-independent quantitative feature of b_{eff}. It is also clear that

$$\lim_{p\to \infty} b_{eff}(p) = 0. \tag{6}$$

Accordingly, the simplest form of b_{eff} to reproduce the qualitative dynamics of such a population (density) should resemble Fig. 1, where $b_{eff}(0) = b$ is an adjustable parameter.

A simple specific form of $b_{eff}(p)$ is written with a constant a;

$$b_{eff}(p) = b - ap, \tag{7}$$

so that

$$p_{n+1} = b_{eff}\, p_n - a\, p_n^2.$$

By defining $p_n \equiv (b/a)x_n$, we obtain the standard form of logistic difference equations (l.d.e.)

$$x_{n+1} = bx_n\,(1 - x_n). \tag{8}$$

In (8), the adjustable parameter b is purely multiplicative. With a different choice of b_{eff}, x_{n+1} would not in general depend upon b in so simple a fashion [1]. Nevertheless, the internal b dependence may be (and often is) sufficiently mild in comparison to the multiplicative dependence that at least for qualitative purposes the internal dependence can be ignored. Thus, with $f(p) = p\, b_{\mathrm{eff}}(p)$, any function like Fig. 1,

$$p_{\mathrm{n+1}} = bf(p_n) \tag{9}$$

is compatible and representative of the population (density) discussed [1].

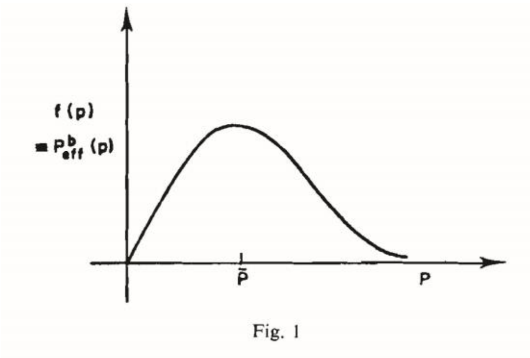

Fig. 1. Dependence of $f(p) = p\, b_{\mathrm{eff}}(p)$ on p after Feigenbaum [1].

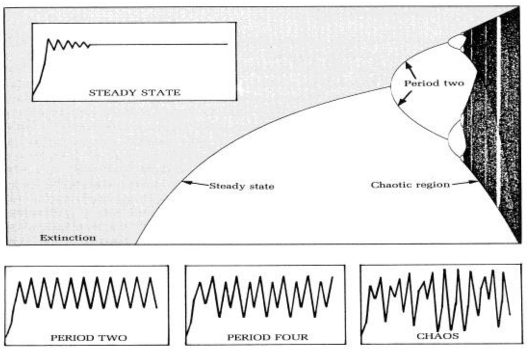

Fig. 2. Bifurcation diagram to show period-doubling and chaos (From "Chaos" by J. Gleick [6]. p.71). The main figure depicts x_∞ on the ordinate (x_∞ is x_{n} at $n = \infty$) vs. the parameter λ on the abscissa of the logistic difference equation, i.e. l.d.e., $x_{\mathrm{n+1}} = \lambda\, x_{\mathrm{n}}(1 - x_{\mathrm{n}})$ ($0 < x_0 < 1$). 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.

To investigate the structure of the population (density) equation (8), we study the l.d.e. after J. Gleick [6]. Figure 2 is a bifurcation diagram showing period-doubling and chaos [6, p. 71].

3. Parameters of the l.d.e. in the CFP

We investigate complexity of the cold fusion phenomenon (CFP) assuming that the density (or population) of agents for the CFP obey the recursion equations (1) or rather the simplified equation, the l.d.e. (8).

In accordance with the quantum mechanical explanation of mechanisms of the CFP, we may take the trapped neutron (the quasi-free neutron in the CF materials) as an agent for the CFP and its density n_n as the variable x_n in the l.d.e.

The number of reactions N_{nX} (per unit time) between trapped thermal neutrons and a nucleus $^{A}{}_{Z}X$ is assumed to be calculated by the same formula as the usual collision process in a vacuum [3]:

$$N_{nX} = 0.35\, n_n\, v_n\, n_X V \sigma_{nX}, \qquad (10)$$

where $0.35\, n_n\, v_n$ is the flow density of the trapped thermal neutrons per unit area and time, n_X is the density of the nucleus $^{A}{}_{Z}X$, V is the volume where the reaction occurs, σ_{nX} is the cross section of the reaction.

Then, the equations (8) applied to the CFP describes evolution of the adjustable parameter n_n (density of the trapped neutrons at an active region) due to variations of the CF material accompanied with such nuclear reactions in CF materials as

$$n + p = d\,(1.33 \text{ keV}) + \varphi\text{'s}\,(2.22 \text{ MeV}), \qquad (11)$$

$$n + d = t\,(6.98 \text{ keV}) + \varphi\text{'s}\,(6.25 \text{ MeV}), \qquad (12)$$

$$t + d = {}^{4}{}_{2}\text{He}\,(3.5 \text{ MeV}) + n\,(14.1 \text{ MeV}), \qquad (13)$$

where φ's mean phonons generated at the reaction in the CF material instead of a photon in the case of these reactions occurred in the free space.

The evolutions of nuclear products and/or excess energy due to $n - p$ and $n - d$ reactions are proportional to n_n and Eq. (10) is rewritten as follows;

$$N_{np} = 0.35\, n_n\, v_n n_p V \sigma_{np} \tau, \qquad (14)$$

$$N_{nd} = 0.35\, n_n\, v_n n_d V \sigma_{nd} \tau, \qquad (15)$$

where n_p and n_d are the densities of protons and deuterons, $\sigma_{np} = 3.32 \times 10^{-1}$ b and $\sigma_{nd} = 5.5 \times 10^{-4}$ b (1 b = 10^{-24} cm^2) are the cross sections of the $n - p$ and $n - d$ reactions for a thermal neutron, respectively.

There are several data sets which were obtained in systems with temperature variation. In these cases, such variables as n_n , v_n, σ_{nX} (σ_{np}, σ_{nd}) in Eqs. (10), (14) and (15) are temperature dependent and therefore the number of reactions N depends on the temperature T.;

$$N = N(T). \quad (16)$$

Furthermore, it should be noticed that the number N expressed as Eq. (16) shows also a temporal evolution of the nuclear products (including also the excess heat) when the parameter n_n depends on the time variable τ even if other quantities are not;

$$N(\tau) = Cn_n(\tau), \quad (17)$$

where C is a constant independent of time.

The parameter b in the l.d.e. (8) specifies evolution of the population (or density) x_n as we see in Fig. 2. The larger the constant (parameter) b is, the more complex the evolution (and bifurcation) becomes.

In the CFP, the parameters governing the events are experimentally figured out as follows; The most evident parameter is the loading ratio η of hydrogen isotopes to host metals (η = D/Pd, D/Ti, H/Ni, etc.). The other less definitely specified parameters are the temperature T, current density i to the cathode, homogeneity of composition in the active region of alloys (transition-metal hydrides and deuterides), a distance from equilibrium state, density of trapped neutrons n_n , etc.

Leaving comprehensive discussion about the parameters governing the CFP to the next paper, we show here only an example obtained by De Ninno et al. [7]. In their experiment, a titanium (Ti) sample in the shape of shavings was put in contact with a deuterium (D_2) gas with pressures up to 5 MPa at varying temperatures between 77K and room temperature. The samples were, thus, put in a dynamical condition for the process of absorption/desorption of deuterium in titanium.

Using a BF_3 neutron counter with high sensitivity (efficiency $\simeq 5 \times 10^{-5}$), they could observe neutron emissions in two runs up to 320 counts/10 min under a low background condition with an average value of 2.3 counts/10 min The results were shown in Figs. 3 and 4.

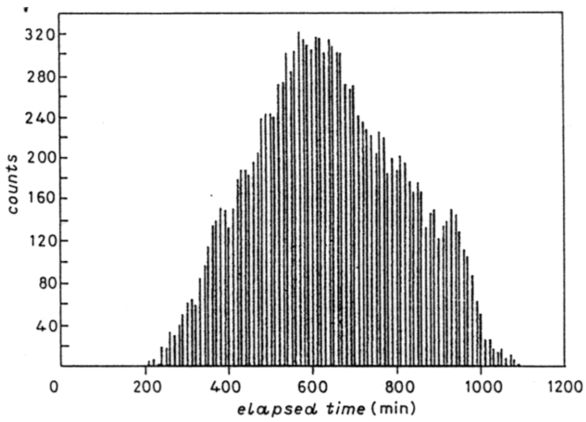

Fig. 3. Diagram showing the time evolution of the neutron emission from TiD_x sample during the run A (April 15-16, 1989). The values indicated are integral counts over periods of ten minutes (Fig.3 of [7]).

Figure 3 is a diagram showing the temporal evolution of the neutron emission during the run A (April 15 – 16, 1989). In this run, the system was put in the desorption phase; the deuterium gas was evacuated and the liquid-nitrogen Dewar was removed from the initial situation where deuterium pressure was 5 MPa at 77 K. Thus, the temperature of the system increases from 77 K at time 0 to room temperature about time 61 h accompanying desorption (and therefore decrease of the loading ratio η = D/Ti). From our point of view, this process can be interpreted as an increase of the parameter n_n (density of trapped neutrons) with increase of temperature despite of the decrease of η at first and then a decrease of n_n due to the decrease of η.

This variation of the parameter n is qualitatively described in Fig. 1 simulating an envelope of Fig. 3. This behavior suggests that neutron emission in this case is determined by a nuclear reaction such as Eq. (12) (followed by Eq. (13) to emit neutrons) where the reaction rate is proportional to the density n_n of the trapped neutrons assumed in the TNCF model.

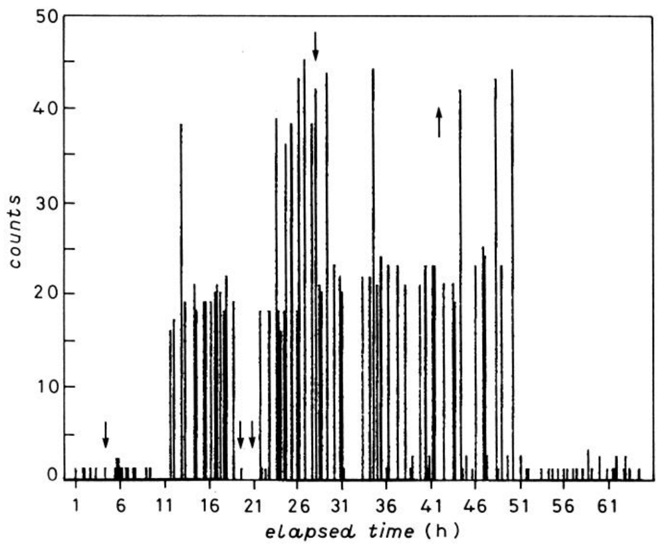

Fig. 4. Diagram showing the time evolution of the neutron emission counts (ordinate) during the run B (7-10 April, 1989) by De Ninno et al. [7]. The values indicated are integral counts over periods of 10 minutes.

Fig. 4 is a diagram showing the temporal evolution the neutron emission during the run B (April 7 – 10, 1989). In this run, D_2 gas was admitted to the cell in steps of increasing pressure after degassing the Ti sample. A pressure around 5 MPa was reached and then the temperature was lowered to 77 K by immersing the cell in a Dewar full of liquid nitrogen. At this point, the system was left to itself, at constant pressure, with the aim of obtaining changes of temperature both in time and space while the level of liquid nitrogen in the Dewar was going down.

In Fig. 4, the down directed arrows indicate liquid-nitrogen fillings. The up-directed arrow shows the time when the Dewar was taken away and the system was thus allowed to rise to room temperature. Thus, the abscissa of this diagram is not necessarily represents temperature of the system as in the case of Fig. 3.

We notice a characteristic of time pattern of neutron emission appeared in Fig. 4 that there are two levels of emission as if they are "quantized." We can give a possible explanation for this behavior by the bifurcation as appeared in Fig. 2.The inserted diagram "period two" shows an appearance of two stable states by bifurcation according to the increase of the parameter λ (b in Eq. (8)). We may identify two levels appeared in Fig.4 as the two states shown in the "period two" diagram.

4. Conclusion

We have shown that the recursion relations (1) studied in nonlinear dynamics may be applicable to dynamics of nuclear reactions in the CFP. Experimentally, observations of neutron emission illustrated characteristics of the l.d.e. suggesting the applicability of the nonlinear dynamics to the CFP..

Further investigation of the CFP as a complexity will be given in the following paper [8].

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