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TNCF MODEL –A PHENOMENOLOGICAL APPROACH

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Abstract

The TNCF model for the cold fusion phenomenon (CFP) is explained as an example of the phenomenological approach with a single adjustable parameter for this complicated phenomenon composed of various events occurring in complex systems. Applied to many selected data sets, the model has given satisfactory explanations and therefore the Premises of the model may be taken as reflections of some phases of physics in the materials where occurred CFP. Selection of more than 60 data sets has a statistical meaning even if each data set may include some faults in it. Physical bases of the Premises are suggested upon physics of neutrons in solids.

1. Introduction

The cold fusion phenomenon (CFP), more precisely "nuclear reactions and accompanied events in solids with high density hydrogen isotopes", is an extremely complicated phenomenon occurring in complex systems composed of composite solids including hydrogen isotopes covered by surface layers of metals or oxides in ambient background radiations, especially neutrons.

After the discovery of some phases of its events in 1989,[1] there have been explored its various phases of the phenomenon, or events, ranging from the excess heat production, tritium and helium-4 generations, neutron and photon emissions with energies up to about 10 MeV and generation of transmuted nuclei with atomic numbers larger than 3. These events seems to have listed up all by now and are divided into two categories, direct or indirect, by their relation to assumed nuclear reactions to explain them: *the direct evidence* of nuclear reactions includes spatial distribution of transmuted nuclei and energy spectra of neutron and gamma photon, and *the indirect evidence* includes the excess heat unexplainable by chemical processes and amounts of generated tritium, helium-4, and transmuted nuclei.

Other remarkable characteristics of the phenomenon are its sporadic occurrence and qualitative reproducibility, characteristics of chaotic systems. These phases of CFP together with its various products should be explained finally by a theory.

There is a pile of these complicated experimental data in CFP accumulated in these eleven years waiting to be explained by one or other theories. As a working hypothesis, it is possible, of course, to consider these events in CFP be caused by several different mechanisms working in the same system. On the other hand, it is possible to seek a single cause as a fundamental mechanism for all events in CFP. Which viewpoint one takes in the research is a matter of one's aesthetics. A trial given in this paper belongs to the latter with phenomenological manner.

It should be explained briefly a characteristic of *the phenomenological approach* contrasted to the *fundamental approach* to avoid unnecessary confusion. In the fundamental approach, the logic to explain a phenomenon starts from established Principles and ends up with a

Mechanism (or a single functioned model) assumed to explain a phase of the phenomenon even if there appear several appropriate assumptions to proceed the logic or mathematics.

On the other hand in the *phenomenological approach*, the logic starts from Premises assumed in the Model to explain the phenomenon. The value of the Premises assumed irrespective of justification by principles are evaluated by the degree of success accomplished by the model in the explanation of the phenomenon. If the reality of the assumed Premises is established, then the Premises, are tried to justify on the bases of the Principles or the Principles are overthrown by the phenomenon, as illustrated by many famous examples in the history of science.

Next step to present the TNCF (trapped neutron catalyzed fusion) model, therefore, is the explanation of its Premises in terms of experimental facts.

2. Premises of the TNCF Model suggested by Experimental Facts

The cold fusion phenomenon (CFP) occurs in solids where a distance between particles is about 10^{-8} cm and an average energy of a particle is about 25 meV. On the other hand, nuclear reactions between charged particles which is realized at a mutual distance of 10^{-13} cm can only effectively occur when the mutual energy of reacting particles is above about 1 MeV. Therefore, a nuclear reaction in solids if it occurs in reality is not easily catalyzed by constituent charged particles in solids.

The TNCF model is a phenomenological one using a neutral particle, neutron, as a catalyst of nuclear reactions in solids and the basic Premises (assumptions) extracted from experimental data sets are summarized as follows in terms of relevant experimental facts:[2,3]

First, there are very many experimental data showing effects of the background neutron from the beginning of the discussion about reality of CFP. There have been no positive data without the background neutron. All attempts to verify or check the reality in ambient with almost no background neutron failed without exception. On the other hand, there are several data showing positive effects of thermal neutrons in CFP. These experimental facts result in the first Premise of the TNCF model:

Premise 1. We assume a priori existence of the quasi-stable trapped thermal neutrons with a density n_n in pertinent solids, to which the neutron is supplied essentially from the ambient neutron at first and then by breeding processes (explained below) in the sample.

The density n_n is a single adjustable parameter in the TNCF model which will be determined by an experimental data set using the supplementary premises which will be explained below concerning reactions between the trapped neutron and other particles in the solids. The quasi-stability of the trapped neutron means that the neutron trapped in the crystal does not decay until a strong perturbation destroys the stability while a free neutron decays with a time constant of 886.7 ± 1.9 s.

It is anticipated from this nature of CFP that the "inverse correlation of solar activity with a period of 11 years and neutron flux on the Earth" should reflect in an annual change of probability of success in experiments of CFP.

Second, there are experimental data showing localization of nuclear reactions responsible to CFP at crystal boundary or surface region, especially NT.[4] To explain this phase of CFP, it is necessary to assume localization of effective reactions between the trapped quasi-stable neutron and nuclei in the crystal lattice (lattice nuclei) which results in the Premise 2:

Premise 2. The trapped neutron in a solid reacts with another nucleus in the surface layer of the solid, where it suffers a strong perturbation. We express this property by taking the parameter (the instability parameter) ξ, defined in the relation (1) written down below, as $\xi = 1$, which means the interaction is the same as it is in vacuum.

We have to mention here that the instability parameter ξ in the surface layer is not known at all and it can be, as noticed recently, more than one ($1 \leq \xi$) making the determined

with perturbing nuclei, proposed in the TNCF model.

3. Reaction between the Trapped Neutron and Lattice Nuclei and its Effects

If the stability of the trapped thermal neutron is lost by a large perturbation in the surface layer or in volume, the number of reactions between the trapped neutron and lattice nuclei ${}^{A}_{Z}\mathrm{M}$ (trigger reactions) in a time τ may be calculated by the same formula as the usual collision process in vacuum but an instability parameter ξ:

$$P_f = 0.35 n_n v_n n_M V \sigma_{nM} \tau \xi, \tag{1}$$

where $0.35 n_n v_n$ is the flow density of the trapped thermal neutron per unit area and time, n_M is the density of the nucleus ${}^{A}_{Z}\mathrm{M}$, V is the volume where the reaction occurs, σ_{nM} is the cross section of the reaction determined in vacuum. The instability parameter ξ as taken into the relation (1) expresses an order of the stability of the trapped neutron in the region as explained in premises 2 and 3, and also in the next paragraph.

If a fusion reaction occurs between a trapped thermal neutron and one of lattice nuclei ${}^{A}_{Z}\mathrm{M}$ with a mass number A and an atomic number Z, there appears an excess energy Q and nuclear products as follows:

$$n + {}^{A}_{Z}\mathrm{M} = {}^{A+1-b}_{Z-a}\mathrm{M}' + {}^{b}_{a}\mathrm{M}'' + Q, \tag{2}$$

where ${}^{0}_{0}\mathrm{M} \equiv \gamma$, ${}^{1}_{0}\mathrm{M} \equiv n$, ${}^{1}_{1}\mathrm{M} \equiv p$, ${}^{2}_{1}\mathrm{M} \equiv d$, ${}^{3}_{1}\mathrm{M} \equiv t$, ${}^{4}_{2}\mathrm{M} \equiv {}^{4}\mathrm{He}$, etc.

The liberated energy Q may be measured as the excess heat by the attenuation of the nuclear products, γ and charged particles, as generated in the nuclear reaction. Otherwise, the nuclear products may be observed outside with an energy (we assume it as the original one, hereafter) or may induce succeeding nuclear reactions (breeding reactions) with one of other nuclei in the sample.

4. Explanation of Several Events in a Data Set with a Single Parameter n_n

In general, the number of events (reactions) N_{nM} in time τ between the trapped neutron and the lattice nuclei ${}^{A}_{Z}\mathrm{M}$ in a volume V of a reaction region is given by the similar relation as (1);

$$N_{nM} = 0.35 n_n v_n n_M V \sigma_{nM} \tau \xi, \tag{3}$$

where n_M is the density of the nucleus M, σ_{nM} is the cross section of the reaction and ξ is the instability parameter defined in Premises 2 and 3.

In cases where is a surface layer of Li metal on the cathode, the numbers of tritium N_t and helium-4 atoms N_{He} in n - ${}^{6}_{3}\mathrm{Li}$ reaction (2) are determined by the relation (3) and is also number of the events N_Q generating the excess heat of 4.8 MeV per a reaction:

$$N_t = N_{He} = N_Q \cong Q\ (\mathrm{MeV})/4.8\ (\mathrm{MeV}). \tag{4}$$

A relation between N_n and N_t in D/Li system with the surface layer of Li metal is, then, given as follows; when the n $-{}^{6}\mathrm{Li}$ reaction is predominant in an electrolytic system with D_2O, a neutron with an energy 14.1 MeV is generated by the reaction between a deuteron and a triton with an energy 2.7 MeV generated in the $n$$-{}^{6}_{3}\mathrm{Li}$ reaction:

$$t + d = {}^{4}_{2}\mathrm{He}\ (3.5\ \mathrm{MeV}) + n\ (14.1\ \mathrm{MeV}). \tag{5}$$

Number of this reaction is calculated by a relation (6) given below which determines a relation between N_n and N_t assuming half of the generated triton contribute the reaction (5),

$$N_n \sim N_t \ell_t n_d \sigma_{t-d}, \tag{6}$$

where $\ell_t \sim 1\ \mu$m, $n_d = 6.8 \times 10^{22}\ x$ cm^{-3} (x = D/Pd) and $\sigma_{t\ d} \sim 1.4 \times 10^{-4}$ b. For x = 1, we obtain a relation

$$N_n/N_t = 9.5 \times 10^{-7} \sim 10^{-6}, \qquad (7)$$

$$\text{or}\quad N_t/N_n = 1.1 \times 10^{6} \sim 10^{6}. \qquad (8)$$

These quantitative results (4) and (8) on the numbers of events are compared with the lucky experimental data where observed several events in a sample simultaneously. Some of the results are shown in Table 1. In the case where the solid occluding hydrogen isotopes has no surface layers, we have to consider a trigger reaction between a trapped neutron and a deuteron (or a proton) in addition to those between a trapped neutron and one of lattice nuclei:

Table 1: Neutron Density n_n and Relations between the Numbers N_X of Event X Obtained by Theoretical Analysis of Experimental Data by TNCF Model ($N_Q \equiv Q$ (MeV)/5 (MeV)). Typical value of the surface vs. volume ratio S/V(cm^{-1}) of the sample is tabulated, also.

Authors	System	S/V cm^{-1}	Measured Quantities	n_n cm^{-3}	Other Results (Remarks)
Fleischmann et al.	Pd/D/Li	6 $\sim$ 40	Q, t, n $N_t/N_n \sim 4 \times 10^7$ $N_Q/N_t \sim 0.25$	$\sim 10^9$	(Q =10W/cm^3) $N_t/N_n \sim 10^6$ $N_Q/N_t = 1.0$
Morrey et al.	Pd/D/Li	20	Q,^{4}He ^{4}He in $\ell \leq 25\mu$m	4.8×10^8	N_Q/N_{He}~5.4 (If 3% ^{4}He in Pd)
Chien et al.	Pd/D/Li	4	^{4}He in surf. layer and t , no ^{3}He	1.8×10^6	$N_t/N_{He} \sim$ 1(If few%^{4}He in Pd)
Takahashi et al.	Pd/D/Li	2.7	t, n $N_t/N_n \sim 6.7 \times 10^4$	3×10^5	$N_t/N_n \sim$ 5.3×10^5
Miles et al.	Pd/D/Li	5	Q, ^{4}He (N_Q/N_{He}=1$\sim$ 10)	$\sim 10^{10}$	$N_Q/N_{He} \sim 5$
Okamoto et al.	Pd/D/Li	23	Q, NT$_D$ $\ell_0 \sim 1\ \mu$m	$\sim 10^{10}$	N_Q/N_{NT}~1.4 (^{27}Al $\rightarrow$ ^{28}Si)
Bockris et al.	Pd/D/Li	5.3	t,^{4}He;$N_t/N_{He} \sim 240$	3.2×10^6	$N_t/N_{He} \sim 8$
Cellucci et al.	Pd/D/Li	40	Q, ^{4}He N_Q/N_{He}=1$\sim$ 5	2.2×10^9	(IfQ =5W) N_Q/N_{He}=1
Iwamura et al.	PdD$_x$ and Pd/ CaOPd$_x$/Pd	20	$Q\sim$ 1W,$N_{NT}/N_Q \sim 1$ NT$_F$(Ti, Fe, Cu etc.)	3.1×10^{10}	$N_{NT}/N_Q)_{th}$=1 $\sim$ 3

$$n + d = t\ (6.98\ \text{keV}) + \gamma\ (6.25\ \text{MeV}), \qquad (9)$$

$$n + p = d\ (1.33\ \text{keV}) + \gamma\ (2.22\ \text{MeV}). \qquad (10)$$

5. Conclusion –Values of n_n, Sporadic Occurrence and Qualitative Reproducibility of Events in CFP

Typical values of the adjustable parameter n_n determined by experimental data sets where observed several events in the same sample are shown in Table 1. Generally speaking, the values of n_n determined using experimental data sets more than 60 are between 10^8 and 10^{12} cm^{-3}. This is rather large value and its meaning assumed at first as a density of the trapped thermal neutrons in solids has to be reconsidered. This problem with others concerned with Premises will be discussed in relation with the evolution of the model in another paper presented in this Conference.[5]

It should be given here qualitative explanations of the two remarkable characteristics of CFP, sporadic occurrence and poor reproducibility of its events. In the following, we confine our discussion to electrolytic systems with electrolytes of alkali metals.

In the process of a CF experiment, there are many atomic processes with stochastic property: distribution of impurity atoms in the matrix metal, diffusion of hydrogen isotopes in it, deposition and diffusion of the electrolyte on and into the cathode, and so on. As a due result, the microscopic structure of the cathode becomes different from one to another even if the macroscopic condition of the electrolysis is the same. It should also be noticed the chaotic nature of CFP occurring in complex systems which induces inevitably the qualitative reproducibility.

In view of the TNCF model, the microscopic difference of the sample influences sensitively on the trapping of thermal neutrons in the cathode and also on the trigger and breeding reactions between the trapped neutron and one of lattice nuclei. Occurrence of a trigger reaction in the surface layer formed on the cathode is governed by statistical law and is characterized by a statistical reproducibility, or *qualitative reproducibility*. Even if there are enough background neutrons in ambiance, there occurs a situation with a various number of trapped neutrons from zero to the maximum value tolerated by the condition not to start the trigger reaction; these values correspond to from a null result to a positive result with maximum gain of products.

Thus, the reactions relevant to CFP are divided into trigger and breeding reactions in the TNCF model. When a trigger reaction is induced by one of trapped neutrons piled up in the sample, which may be in the form of neutron drops in a boundary region, the start of the succeeding breeding reaction multiplying trapped neutrons is governed by statistical law and also resulting products of CFP are. Occurrence of an events with a large yield is not frequent and is observed sporadically.

The qualitative reproducibility, sometimes called irreproducibility by mistake, and sporadic nature of events in CFP are explained consistently as above from TNCF point of view. We would like to notice again that the experimental trials done in large Laboratories in 1989 to confirm and prove reality of CFP are destined to fail due to elimination of background neutrons, among others, to improve S/N ratio in terms of conventional consideration in physics.

As a result of our investigation of CFP by the TNCF model, it is obligatory to measure and describe the background neutron density as one of experimental conditions in this field.

The TNCF model has shown its usefulness as explained in this paper using a neutral particle, neutron, as a agent which catalyzes nuclear reactions in solids and giving a systematic explanation of CFP even if the Premises assumed in the model is not verified yet.

References

[1] M. Fleischmann, S. Pons and M. Hawkins, *J. Electroanal. Chem.* **261**, 301 (1989).

[2] H. Kozima, *Discovery of the Cold Fusion Phenomenon –Evolution of the Solid State - Nuclear Physics and the Energy Crisis in 21st Century*, Ohtake Co. Inc., Tokyo, Japan, 1998.

[3]H. Kozima, K. Kaki and M. Ohta, "Anomalous Phenomenon in Solids Described by the TNCF Model", *Fusion Technology* **33**, 52 (1998).

[4] H. Kozima, M. Ohta, K. Arai, M. Fujii, H. Kudoh and K. Yoshimoto, "Nuclear Transmutation in Solids explained by TNCF Model" *Proc. ICCF8* (to be published)

[5] H. Kozima, "The Cold Fusion Phenomenon and Physics of Neutrons in Solids", *Proc. ICCF8* (to be published).