The TNCF Model: Its Fundamentals

Hideo Kozima
Department of Physics
Faculty of Science
Shizuoka University
836 Oya, Shizuoka 422, Japan
e-mail sphkoji@sci.shizuoka.ac.jp

Abstract

Success in explaining the cold fusion phenomenon using the TNCF model requires a presentation of the model's fundamental points in its most recent version, with a particular emphasis on its physical concepts.

1. Introduction

In the recent issue of this journal, Chuck Bennett[1] cited the TNCF (Trapped Neutron Catalyzed Fusion) model for its broad consequences in explaining many of the cold fusion phenomena. Though the model is successful in explaining the experimental data obtained by cold fusion (CF) researchers, there are still some misunderstandings in the evaluation of the TNCF model as a phenomenological theory. This situation might be a result of the present status of physics becoming too microscopic to consider experimental facts in a frame of phenomenological thought. When old theories and new data conflict, it is the theories which should give way.

I would like to ask those who are unconfident of the phenomenology to remember a typical example of phenomenological theory, the Bohr's model of hydrogen atom proposed in 1913. Bohr had assumed stationary orbits for the electron around a nucleus. The stationary orbit was successful in explaining chemical properties and the energy spectrum of photon, but was in contradiction to the laws of classical electrodynamics, as was well known. This inconsistency of the Bohr's model was not resolved until 1926 when the quantum mechanics was constructed.

I will provide a purely phenomenological form of the TNCF model in this paper in order to avoid any unnecessary confusion in the evalation of a model which has been so successful in the interpretation of the often complex experimental facts.

2. The TNCF Model

The TNCF model had been proposed three years ago in its original form[2] evolving to fit experimental data into the present form[3-6]. The model has

assumed a common cause for the cold fusion phenomenon, including excess heat generation, nuclear product production and transmuted nuclei formation.

The TNCF model is a phenomenological model which explains the cold fusion phenomenon as a whole, assuming a stable existence of thermal neutrons in solids with characteristics to trap ambient neutrons and also to breed neutrons in them. The characteristics are necessarily determined by a combination of a matrix solid and additive factors-distribution of solute atoms, surface layer of electrolyte alkali metal, surface layer of compounds on the sample, and so on.

In the following treatment, I assume an a priori existence of trapped neutrons with a density N_n in pertinent solids. The density N_n is an adjustable parameter in the TNCF model which will be determined by experimental data using the supplementary assumptions which will be explained later concerning to reactions of the neutrons with other particles in the solids.

Premises on the reaction of the trapped neutron: The following properties are premised for the trapped neutron:

1) The trapped neutron reacts with another nucleus in the surface layer as if they are in vacuum. We express this property by taking the parameter defined below in the relation (1) as $xi = 1$.

2) The trapped neutron reacts with another nucleus in volume by the relation (1) with $xi = 0.01$ due to its stability in the volume.

Premises on the measured quantities: The following premises are used to calculate reaction rate, for simplicity:

1) Products of a reaction lose all their kinetic energy in the sample except they go out without energy loss.

2) A nuclear product observed outside of the sample has the same energy as its initial one.

This means that if gamma or neutron spectrum is observed outside, it directly reflects nuclear reactions in the solid sample. The same holds for the distribution of the transmuted nucleus in the sample. Those spectra and the distribution of the transmuted nuclei are the direct information of the individual events of the nuclear reaction in the sample.

3) The amount of the excess heat is the total liberated energy dissipated in the sample, except that brought out by nuclear products observed outside.

4) Tritium and helium measured in a system are accepted as all being generated in the sample.

The amounts of the excess heat, tritium and helium are accumulated quantities reflecting nuclear reactions in the sample indirectly and are the indirect information of the individual events.

Premises about structure of the sample:

1) In electrolytic experiments, the thickness of the alkali metal layer on the cathode surface will be taken as 1 μm.

2) The mean free path of the triton with an energy 6.98 MeV in any solid will be taken as 1 μm irrespective of material of the solid. Collision and fusion cross sections of the triton with nuclei in the sample will be taken as the same as those in vacuum.

3) The efficiency of detectors will be assumed as 100% except otherwise de-

scribed, i.e. the observed quantities are the same as that generated in the sample and to be observed by the detector.

These assumptions will introduce more uncertainty in the obtained numerical values than one order of magnitude which we have to always realize when we make comparison with experimental data.

The formation of the characteristic structure realizing cold fusion reactions as mentioned above is determined by stochastic processes in solid-diffusion of solute atoms, crystal growth, nuclear reaction of neutron breeding process, decay of an excited nuclear state, and so on — and therefore CF phenomenon has only qualitative reproducibility. Also, it is probable that the density of ambient thermal neutrons may depend on time and place of experiment and the breeding of neutrons by nuclear reactions and disintegrations in solids depends on the constituent of the sample.

3. Calculation of Events induced by the Trapped Neutron in Solid

Using those premises explained in the preceding section, we can calculate rates of nuclear reactions between the trapped neutron and a nucleus in a solid according to the following recipe.

If the stability of the trapped neutron is lost, the fusion probability may be calculated by the same formula as the usual collision process in vacuum between a thermal neutron and a nucleus with an additional factor ξ expressing degree of stability:

$$P_f = 0.35 n_n v_n n_N V \sigma_{nN} \xi, \qquad (1)$$

where $0.35 n_n v_n$ is the flow density of the neutron per unit area and time, n_N is the density of the nucleus, V is the volume where is the nucleus, σ_{nN} is the fusion cross section for the reaction. The factor x in the relation (1) expresses a degree of stability of the trapped neutron in a region where it is.

In the electrolytic experiments, we have taken as $\xi = 1$ in the surface layer and $\xi = 0$ in the volume except otherwise stated. As was justified experimentally by a gamma spectrum (Notoya et al.), it is reasonable to take $\xi = 0.01$ in the volume of a sample. This values of $\xi = 0.01$ instead of $\xi = 0$ will result in lower n_n determined from excess heat in the electrolytic data by a factor 2 than that determined with a value $\xi = 0$ as had been used. (We will cite in this paper previous data with $\xi = 0$ as they were.)

In the case of a sample with a definite boundary layer surrounding a trapping region where is the thermal neutron, the volume V should be that of the boundary region where is the nucleus to fuse with the thermal neutron. On the other hand, in a sample without definite boundary layer but disordered array of minor species of lattice nuclei in the sample, the volume should be the whole volume of the sample.

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

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

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

The excess energy Q may be measured as the excess heat by the attenuation of the nuclear products γ and charged particles in the reaction (2). Otherwise, the nuclear products may be

observed outside or may induce succeeding nuclear reactions with one of other nuclei in the sample.

Typical reactions related with TNCF model are written down as follows.

The trapped thermal neutron can fuse with ^{6}Li nucleus in the surface layer formed on the cathode by electrolysis of D_2O (H_2O) + LiOD (LiOH) with a large cross section ~ 1 x 10^3 barn (at 300°C): (3)

$n + {}^6\mathrm{Li} = {}^4\mathrm{He}$ (2.1 MeV) + t (2.7 MeV).

The thickness of the surface layer will be assumed as 1 μm throughout the following analysis (as explained above) though it has been determined as 1 \teido 10 μm in experiments (allowing one order of magnitude uncertainty in the determined value of N_n).

The triton with an energy of 2.7 MeV generated in this reaction can pass through the crystal along the channeling axis on which is an array of occluded deuterons or can proceed a finite path with a length ($l_t = \simeq 1 \sim 10$ μm) determined by the interaction with charged particles in the crystal. In these processes, the triton can fuse with a deuteron with a cross section ~ 1.4 x 10^{-1} barn:

t (2.7 MeV) + d =
^{4}He (3.5MeV) + n (14.1 MeV). (4)

One defect in experimental research has been in not trying to measure high energy neutrons up to 15 MeV. In the following analyses, we assume $l_t = 1$ μm throughout this paper, as explained above.

The neutrons with 14.1 MeV generated in this reaction can interact with particles, especially with deuterons in the crystal elastically giving a large amount of energy to the deuteron and inelastically dissociating it:

$$n + d = n' + d' \quad (5)$$
$$n + d = n' + p + n'' \quad (6)$$

In these reactions, the original high energy neutron will be thermalized or will generate another low energy neutron to be trapped in the sample.

When the neutron become thermal, it can fuse effectively with a deuteron or ^{7}Li nucleus: (7) (8)

$n + d = t + \gamma + 6.25$ MeV,
$n + {}^7\mathrm{Li} = {}^8\mathrm{Be} + \gamma = 2\,{}^4\mathrm{He} + e^- + \nu_e + 16.2$ MeV + γ.

The reaction (7) for thermal neutrons has a cross section 5.5 x 10^4 barn and the reaction (8) has 4 x 10^{-2} barn, which will be used in the estimation given in the following section.

The deuteron having an energy up to 12.5 MeV accelerated elastically in the scattering (5) by a neutron with 14.1 MeV can fuse with another deuteron in two modes with a fairly large cross section of the order of 0.1 barn: (9) (10)

$d + d = t$ (1.01MeV) + p (3.02MeV),
$= {}^3$He (0.82MeV) + n (2.45MeV).

Depending on the situation in the cold fusion system, the trapped thermal neutrons can induce trigger reactions like the reaction (3) and generate energetic particles which sustain a breeding chain reaction producing a lot of the excess heat and the nuclear products.

In the case of solids with hydrogen or deuterium, the following reaction should be taken into consideration in the analysis:

$n + p = d\,(1.33\text{keV}) + \gamma(2.22\text{MeV})$, (11)

$d + p = {}^3\text{He}\,(5.35\text{keV}) + \gamma(5.49\text{MeV})$. (12)

The fusion cross section of the reaction (11) for a thermal neutron is 3.5×10^{-1} barn.

The photons generated in the reactions (7), (8), (11) and (12) can induce photo-disintegration of deuterons and nuclei if they have more energy than the threshold energies of following reactions (for the reaction (13) it is 2.22 MeV):

$$\gamma + d = p + n, \quad (13)$$

$$\gamma + {}^{A}_{Z}\text{M} = {}^{A-1}_{Z}\text{M} + n. \quad (14)$$

In samples with deuterons, this reaction (13) with a cross section ~ 2.5×10^{-3} barn works effectively as a neutron breeder.

The results of analyses in these two years are summarized in Table 1 from papers[7,8].

4. Discussion

The success of the explanation of the cold fusion phenomenon using the TNCF model as given in the preceding section has confirmed the reality of the assumptions and will clarify the physics of the cold fusion processes occurring in materials. Several points will be surveyed below:

First of all, the supposed existence of the trapped thermal neutron should be investigated using our knowledge of solid state and nuclear physics. A treatment on this problem was given in the previous paper[4]. There are several causes to reflect thermal neutrons to trap them in a crystal; the difference of the neutron band structure, the Bragg reflection and the total reflection at a boundary.

The difference of the neutron band structure seems effective in larger samples and the total reflection in the case of special samples using a geometry like the Patterson's beads and Arata's Pd-black.

The conditions which facilitate the existence of trapped thermal neutrons explain the qualitative reproducibility of the phenomenon; The trapping conditions would be formed by stochastic processes and are not reproducible quantitatively by their nature. The cold fusion phenomenon induced by trapped thermal neutrons, therefore, have no quantitative reproducibility.

Though the experimental results had been supporting the idea of trapped neutrons, the idea has not attracted the attention of researchers in this field because the unconventional nature of thermal neutrons hasn't been noticed until now.

Second, the trapped thermal neutrons behave as a Bloch wave in the crystal and it is possible to become stable through the interactions with the lattice nuclei against the beta decay and also against the fusion with one of lattice nuclei. A trapped thermal neutron, though, can fuse with a nucleus in the surface layer or in the volume of the crystal if a perturbation is strong enough to destroy the stability of the neutron. From the results of the analyses, we can say that the instability of trapped neutrons occurs usually near the surface of the sample where the neutrons are reflected, i.e. where the stay longer. Otherwise, when the temperature of the sample is fairly high and the amplitude of light ions becomes large, it occurs even in the volume of the sample.

Table 1: Neutron Density n_n and Relations between the Numbers N_x of Event x Obtained by Theoretical Analysis of Experimental Data on TNCF Model ($N_Q \equiv Q(\mathrm{MeV})/5\ (\mathrm{MeV})$)

Authors	System	Measured Quantities	n_n (cm^{-3})	Other Results (Remarks)
M.Fleischmann et al.	Pd/D/Li	Q, t, n $N_t/N_n \sim 10^7$ $N_Q/N_n \sim 5.6 \times 10^7$	$\sim 10^9$	$N_t/N_n \sim 5.3 \times 10^5$ $N_Q/N_n \sim 8.6 \times 10^7$ $N_Q/N_t \sim 5.5$
T.Roulette et al.	Pd/D/Li	Q	$10^{11} \sim 10^{12}$	
A.Takahashi et al.	Pd/D/Li	t, n $N_t/N_n \sim 6.7 \times 10^4$	10^3	$N_t/N_n \sim 5.3 \times 10^5$
M.H.Miles et al.	Pd/D/Li	Q, ^{4}He ($N_Q/N_{He} = 1 \sim 10$)	$10^9 \sim 10^{10}$	$N_Q/N_{He} \sim 5$
R.Bush et al.	Ni/H/Rb	NT (^{85}Rb$\rightarrow$ ^{86}Sr)	1.6×10^7	$N_Q/N_{NT} \sim 3$
M.Okamoto et al.	Pd/D/Li	Q, NT(^{27}Al $\rightarrow$ ^{28}Si)	$\sim 10^{10}$	$N_Q/N_{NT} \sim 1.4$
Y.Oya et al.	Pd/D/Li	Q, γ spectrum	3.0×10^9	(with ^{252}Cf source)
Y.Arata et al.	Pd/D/Li	Q, ^{4}He ($10^{20} \sim 10^{21}$ cm^{-3})	$\sim 10^{12}$	$N_Q/N_{He} \sim 6$ (Assume t channeling in cathode wall)
M.C.H.McKubre	Pd/D/Li	Q (Formula)	$10^9 \sim 10^{10}$	Qualit. explanation
T.O.Passell	Pd/D/Li	NT (^{10}B$\rightarrow$ ^{7}Li + ^{4}He)	1.1×10^9	$N_{NT}/N_Q = 2$
D.Cravens (P.P.C.)	Pd/H/Li	Q (Q_{ost}/Q_{in}=3.8)	8.5×10^9	(If PdD exists)
J.O'M.Bockris et al.	Pd/D/Li	t ($\sim 3.8 \times 10^7$/cm^{2}s)	1.1×10^6	$N_t/N_{He} \sim 1$
A.G.Lipson et al.	Pd/PdO/D,Na	γ (E_γ=6.25 MeV)	4×10^5	(If efficiency = 1 %)
V.Romodanov et al.	Mo/D_2	t ($\sim 10^7$ /s)	1.8×10^7	(If sample is MoD)
I.Savvatimova	Pd/D_2	NT (^{106}Pd$\rightarrow$ ^{107}Ag)	9×10^{10}	
O.Reifenschweiler	$TiT_{0.0035}$	Reduction of β decay	1.1×10^9	(T = 0 ~ 450 °C)
J.Dufour (SS is for Stainless Steel)	Pd,SS/D_2 Pd,SS/H_2	Q, t, n	9.2×10^{11} 4.0×10^9	(D(H)/Pd ~ 1 is assumed)
T.N.Claytor et al.	Pd/D_2	t (0.15 nCi/h)	1.4×10^7	(If D/Pd ~ 1.)
F.G.Will et al.	Pd/D_2SO_4	t ($\sim 1.8 \times 10^5$/cm^{2}s)	3.5×10^7	(If $\ell_0 \sim 10\ \mu$m)
M.Srinivasan et al.	Ti/D_2	t ($t/d \sim 10^{-5}$)	1.9×10^8	
A.DeNinno et al.	Ti/D_2	t (5.4 Bq/g D_2)	1.2×10^6	(D/Ti=1, τ=1 week)
S.Focardi et al.	Ni/H_2	Q	3.0×10^{12}	($N_e = 10^{21}$ was used)
D. Gozzi et al.	Pd/D/Li	Q, ^{4}He $N_Q/N_{He} = 1 \sim 5$	2.2×10^9	(Assume Q= 5 W) $N_Q/N_{He} = 1$
F.Celani et al.	Pd/D/Li	Q(Q_{max}=7 W (200%))	1.0×10^{12}	(at Q_{max})
R.A. Oriani	$SrCeO_3/D_2$	Q~ 0.7 W (400 °C)	4.0×10^{10}	V=0.31 cm^3
R.Notoya et al.	Ni/H(D)/K	NT(^{39}K$\rightarrow$ ^{40}K)	1.4×10^9	

Third, the fusion reaction between the neutrons and nuclei becomes as a trigger inducing successive reactions, breeding more neutrons, the excess heat and other nuclear products. The particles generated by a trigger reaction such as the reaction (3) or (7) react with particles and nuclei in the sample. The triton reacts with a deuteron to generate ^{4}He and a neutron; the neutron with an energy 14.1 MeV can accelerate several deuterons to energies sufficient to fuse with another deuteron with a high probability. Furthermore, a photon can induce the reaction (14) to generate a neutron, the catalyst of the cold fusion in our model.

These breeding reactions can occur successively and then generate a gigantic amount of heat and particles in optimum situations. These processes would be the cause of some experimental data showing such an extraordinary result as explosions and neutron bursts. This phase of the cold fusion phenomenon has not been fully analyzed yet, though some possibilities were shown with model calculations[9,10].

Fourth, the variety of values of a trapped thermal neutron n_n from 10^3 to 10^{12} cm^{-3} as determined from experimental data, shows a variety of the trapping ability of materials which have been used in cold fusion experiments.

Also, the variety of events from the excess heat and several nuclear products, tritium, helium 4, neutrons and gamma, to the transmuted nuclei shows how the TNCF model is universally applicable in nuclear processes occurring in cold (~ room temperature) solids.

Though the values of n_0 are distributed rather widely to explain the various events, the variety of materials and events from which the values were obtained impress us with the effectiveness of the TNCF model.

Fifth, there were many reports showing the effect of sample aging to trigger the cold fusion phenomenon such as that shown in the experiment analyzed in this paper. The present author had a similar experience in which Pd plate bought many years ago gave a positive result[11], but a newly bought one did not (though this point was not reported in the paper). Such experiences are explained by the TNCF model if the aged Pd samples had the surface layer, for instance, by oxidation in the air to trap thermal neutrons and kept many of neutrons in them.

5. Conclusion

The above phenomenological analysis of typical experimental data obtained in many cold fusion experiments with electrolysis or discharge gives us a unified consistent concept of the physics of the cold fusion. The reliable data clearly showed several facets of truth in the solid state - nuclear physics. The facets provide an understanding of the physics of particles in a crystal with trapped thermal neutrons.

If we have no appropriate reference, phenomena appear as chaos, giving no perspective for understanding. It is true that the cold fusion phenomenon had appeared to some amateurs as only a confusion of the experimental results.

Though the analysis given above has been confined to the limited data in experiments with electrolysis and discharge, the result is remarkable. Assuming only the existence of the stable thermal neutrons in cold fusion materials with some properties for nuclear reaction, we could have a consistent understanding of events in the phenomenon with quantitative relationships among them.

The assumption of the existence of stable thermal neutrons in crystal itself has a theoretical verification[4,5] based on the neutron - lattice nuclei interaction, with a new concept "neutron affinity of lattice nuclei."

The success in the analysis of the cold fusion phenomenon using the TNCF model shows in reverse the reality of trapped thermal neutrons. This feature of the analysis will open a new science, solid state-nuclear physics, of low energy neutrons in solid interacting with lattice nuclei through the nuclear force. The existence of trapped neutrons in appropriate systems as Pd-black will be checked by the neutron magnetic resonance (nMR) like NMR or ESR used in the solid state physics and in the physical chemistry.

Other systems than the electrolytic and discharge ones have shown the characteristic cold fusion phenomenon. It will be fascinating to analyze various experimental data in various systems on the TNCF model as done above. If we have a hint to get rid of riddles disturbing our route to a goal, it is easy then to find other paths to reach the goal. The exploration of the cold fusion phenomenon as an answer to the energy crisis

will be accelerated by the new idea of unifying the abundant separate facts which have been obtained in experiments.

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