# TNCF Analysis of Tritium and Excess Heat Generation in a Pd/D/Li System

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## Synopsis

Experimental results of the tritium and the excess heat measurements in Pd/D/Li system conducted by Storms et al. were analyzed using the TNCF model. A consistent interpretation of the results, including time evolution of the excess heat generation, is demonstrated. The adjustable parameter in the model — the density of the trapped neutron was determined as $n_n \sim 10^7$ and $n_n)_{max} \sim 10^{10}$ cm$^{-3}$ in the experiments where tritium and excess heat were measured (the maximum value = 7W).

## 1. Introduction

The TNCF model for the cold fusion phenomenon has been used to explain various cold

fusion events measured in materials containing hydrogen isotopes with great success[1-3]. There have been, however, too many experimental data to treat in a short time since the model was developed only about two years ago. We are going to analyze the remaining excellent data obtained during the 8 years since the discovery of the cold fusion phenomenon using the TNCF model. In this paper, we have taken up data obtained by Storms et al.[4,5]

## 2. Experimental results

Storms and his collaborators have been working to measure the excess heat and tritium in Pd/D/Li electrolytic system. From their data we will take up one with tritium[4] and another with the excess heat[5,6] in this analysis.

### 2-1. Tritium

Storms and Talcott[4] had examined fifty-three electrolytic cells of various configuration and electrode compositions for tritium production during experiments running up to 100 days. A careful check of the distribution ratio of the excess tritium in the gas and electrolyte was performed; the average gas/liquid ratio based on 15 data sets was

0.91 ± 0.16. Significant tritium was found in 11 cells at levels between 1.5 and 80 times the starting concentration after enrichment corrections were made.

Although the amount of tritium made in this study was small, it was well outside of the uncertainty in the measurement based on a large and consistent data base. From their data we will take up cell 73 (Pd strip with an area S = 1.3 cm$^2$, 1 x 1.3 x 50 mm$^3$, D/Pd = 0.81) where a large excess of tritium was observed over ~ 70 days: The maximum tritium concentration was ~390 disintegration/min-ml. This number analyzed using the TNCF model will be given in the next section 3-1.

## 2-2. The excess heat

Storms[5,6] measured the excess heat from Pons-Fleischmann type electrolytic cells. In an experiment[5], one from two samples (S = 6.7 cm$^2$, D/Pd = 0.82) gave a maximum excess heat of 20% (7W) before the run was prematurely terminate about 60h after the onset of the heat production at 230h from the beginning of the electrolysis. In this case no tritium was detected.

In another experiment[6], additional evidence was presented to show that heat production had a positive temperature coefficient, had a critical onset current density, and originated at the palladium cathode.

These fine experimental data of the excess heat generation are analyzed by the TNCF model in the next section 3-2.

## 3. Analysis of the data using the TNCF Model

Using the recipe described in the preceding papers[1-3], we can explain the data of the too large excess heat to explain by chemical reaction obtained by Storms et al.[4-6]. The TNCF model assumes existence of the trapped thermal neutron with a density $n_n$ in a sample as an adjustable parameter.

The trapped thermal neutron can induce reactions with minor nuclei $^6$Li in the surface layer and $d$ in the volume (trigger reactions):

$$n + {}^6\mathrm{Li} = {}^4\mathrm{He}\ (2.1\ \mathrm{MeV}) + t\ (2.7\ \mathrm{MeV}), \qquad (1)$$

$$n + d = t\ (6.98\ \mathrm{keV}) + \gamma (6.25\ \mathrm{MeV}), \qquad (2)$$

The nuclear products generated in these trigger reactions can induce reactions (breeding reactions) with nuclei in the example:

$$\begin{aligned} &t\ (2.7\ \mathrm{MeV}) + d = \\ &\quad {}^4\mathrm{He}(3.5\ \mathrm{MeV}) + n(14.1\ \mathrm{MeV}), && (3)\\ &n\ (14.1\ \mathrm{MeV}) + d = n + p + n, && (4)\\ &\gamma(6.25\ \mathrm{MeV}) + d = p + n. && (5) \end{aligned}$$

Also, the 14.1 MeV neutron can accelerate deuterons by elastic collisions with them, making possible $d$-$d$ reactions:

$$\begin{aligned} &n + d = n' + d', && (6)\\ &d + d = t\ (1.01\ \mathrm{MeV}) + p\ (3.02\mathrm{MeV}), && (7)\\ &\quad = {}^3\mathrm{He}\ (0.82\ \mathrm{MeV}) + n\ (2.45\ \mathrm{MeV}). && (8) \end{aligned}$$

The number of the reactions (1) (generating $^4$He and $t$) and (2) (generating $t$ and $\gamma$) is calculated by the following relations, respectively:

$$N_{He} = 0.35 n_n v_n n_{Li} S l_o \sigma_{nLi} \qquad (9)$$

$$N_t = 0.35 n_n v_n n_d V \sigma_{nd} \xi, \qquad (10)$$

where $0.35 n_n v_n$ is the flow density of the neutron per unit area and time, $n_{Li}$ is the density of $^6$Li in the surface layer of Li metal with a thickness ( which we take as 1 μm unless otherwise stated), $S$ and $l_0$ are the surface area of the cathode and the thickness of the layer where the reaction occurs, $n_d$ is the density of deuterium in the volume, $\sigma_{nLi}$ and $\sigma_{nd}$ are the fusion cross section for the reaction (1) and (2) respectively, and are 9.4 x $10^2$ and 5.5 x $10^{-4}$ barn for the thermal neutron, respectively. The numerical factor $x$ related with stability of the trapped neutron in volume is taken as 1 in the surface layer and 0.01 in volume[7].

For $\xi = 0.01$, $N_{He}$ (Eq.(9)) is comparable with $N_t$(Eq.(10)) when S/V ~ $10^3$ $cm^{-1}$ or a volume with a linear dimension $l$ ~ $10^3$ cm ($l_0/l$ ~ $10^{-7}$). This relation for the equivalence of the two numbers realizes for $l$ ~ 10 cm when $\xi$ ~1 which will be in a high temperature sample (large amplitude of D vibration in a solid).

Using these relations between the observed quantities of the number of events $N$ and $n_n$, we can calculate $n_n$ for each event. In the analysis, we assume the excess heat inevitably accompanied with nuclear products according to the reactions given above though we assume all the liberated energy is thermalized in the system.

### 3-1. Tritium

The careful investigation of tritium generation in the electrolytic system Pd/D/Li with LiOD with a lowered composition of $^6$Li to 0.018%. In the case of the maximum tritium generation 1.8 x $10^2$ Bq/ml in 250 h with a electrolyte volume of 60 ml, the density of the trapped neutron was calculated as

$$n_n = 2.2 \times 10^7 \text{ cm}^{-3}.$$

The value of the density determined from the amount of tritium is about three orders of magnitude less than the value determined by the excess heat in the next subsection. This point is discussed in the next section.

### 3-2. The excess heat

From the data of the excess heat generation of 7W in the sample described above[5], we can calculate the arbitrary parameter $n_n$;

$$n_n = 5.5 \times 10^{10} \text{ cm}^{-3}.$$

The parameter $n_n$ calculated from another data[6] of the excess heat generation 2.3W is

$$n_n = 1.8 \times 10^{10} \text{ cm}^{-3}.$$

## 4.Conclusion

The discrepancy in the two values of $n_n$'s calculated above could be interpreted as showing that a large part of tritium generated in the sample remained in the sample and was not measured outside. There are also some reactions generating the excess heat, but it's tritium which makes the discrepancy large. Therefore, the discrepancy is understandable from our point of view.

Then, these values of $n_n$ 2.2 x $10^7$ and $10^{10}$ cm-3 in the tritium and the excess heat measurements, respectively, are consistent in themselves and also in the range of $n_n$ obtained hitherto for other similar experiments[1-3]. We have to remember an assumption in the calculation of $n_n$ that the liberated energy in the reaction (1) is entirely thermalized in the system.

We interpret that the above result

obtained in the analysis of the excess heat and tritium measurements shows a success of the model and that the cold fusion phenomenon is a probe suggesting the existence of the thermal neutron with a quasi-stability piled up in the solid[1] and also the existance of nuclear reactions between the trapped neutron and nuclei in and on the sample, another evidence of which is the nuclear transmutation[8-10].

Though the data of the excess heat and tritium in independent experiments can determine only the value of the adjustable parameter $n_n$ for each case, other events, if any, in the same sample can check the validity of the model comparing theoretical and experimental values of such ratios as $N_t/N_n$, or $N_Q/N_n$, which had been done before[11].

The value of $n_n$ determined in this analysis will increase by a factor with an order of one or two if the liberated energy in the reaction (1) is only partly thermalized in the system though contribution of other reactions than (1) decrease $n_n$. The remaining part to the liberated energy might be carried out from the system by the particles $t$, $n$ and $\gamma$ in reactions (1), (2) and (3), respectively.

In reality, the photon with an energy 6.25 MeV was observed in recent experiments[12-14]. Cold fusion experiments are not entirely free from radiation hazards.

### References

(1) H. Kozima, "On the Existence of the Trapped Thermal Neutron in Cold Fusion Materials," Progress in New Hydrogen Energy (*proc. ICCF6*), 332 (1996).; *Cold Fusion* 20, 5 (1996).

(2) H. Kozima, "The TNCF Model - Its Fundamentals," *Cold Fusion* 21, 19 (1997).

(3) H. Kozima, M. Ohta and K. Kaki, 'The Physics of the Cold Fusion Phenomenon," Cold Fusion 22 (1997).

(4) E. Storms and C. Talcott, "Electrolytic Tritium Production," *Fusion Technol.* 18, 680 (1990).

(5) E. Storms, "Measurement of Excess Heat from a Pons-Fleischmann Type Electrolytic Cell," Frontiers of Cold Fusion (*Proc. ICCF3*) p.21, ed. H.Ikegami, Universal Academy Press (Tokyo), 1993.

(6) E. Storms, "Some Characteristics of Heat Production using the 'Cold Fusion' Effect," Trans. Fusion Technol. (*Proc. ICCF4*) 26, 96 (1994).

(7) H. Kozinia, M. Nomura, K. Hiroe and M. Olita, "Nuclear Transmutations in Electrolysis with Porous Ni Cathode and $H_20 + K_2CO_3$ Electrolyte," *Cold Fusion* 21, 58 (1997).

(8) H. Kozima, M. Nomura, K. Hiroe and M. Ohta, "Nuclear Transmutation in Cold Fusion Experiments," Progress in New Hydrogen Energy (*Proc. ICCF6*), 660 (1996).; *Cold Fusion* 20, 16 (1996); *J. New Energy* 1-4, 21 (1996).

(9) H. Kozima, M. Ohta, and K. Kaki, "TNCF Model Explanation of Carbon Production in $D_2$ Gas Discharge," *Cold Fusion* 21, 48 (1997).

(10) H. Kozima, M. Nomura, K. Hiroe and M. Ohta, "Nuclear Transmutation in Electrolysis with Porous Ni Cathode and $H_20 + K_2CO_3$ Electrolyte," *Cold Fusion* 21, 58 (1997).

(11) H. Kozima, K. Hiroe, M. Nomura, and M. Ohta, "Analysis of the First Cold Fusion Experiment Using the TNCF Model," it *Cold Fusion* 21, 6 (1997).

(12) H. Kozima, "On the Absence of Photon with 6.25 MeV and Neutron with 14.1 MeV in Cold Fusion Experiment," it *Cold Fusion* 15, 12 (1996).

(13) A. G. Lipson, B.F. Lyakov, D. M. Sakov, V.A. Kuznetsov and T.S. Ivanova, "Heat Production, Nuclear Ashes and Electrophysical Processes in Heterostructure PdO/Pd/PdO saturated with Deuterium by Electrochemical Method," *Proc. RCCFNT4* (May 20 - 25, 1996, Sochi, Russia) (to be published); Progress in New Hydrogen Energy (*Proc. ICCF6*), 433 (1996)..

(14) Y. Oya, H. Ogawa, T. Ono, M. Aida and M. Okamoto, "Hydrogen Isotope Effect Induced by Neutron Irradiation in Pd-LiOD (H) Electrolysis," Progress in New Hydrogen Energy (*Proc, ICCF6*), 370 (1996).

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