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"TNCF Analysis of Excess Heat, Tritium and Helium-4 Generation in a Pd/B/Li System"

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Abstract
Experimental results of measurement of the excess heat, tritium and ^{4}He in Pd/D/Li electrolysis system were analyzed with the TNCF model. The remarkable result of the simultaneous observation of these quantities, which are decisive evidences of the nuclear reactions in solids, was interpreted consistently with one adjustable parameter of the model with a value $n_n \sim 10^{10}$ cm^{-3}.

1. Introduction

Since 1989, experimental results showing the excess heat and nuclear products unexplainable by chemical reactions in solid materials have been obtained by many researchers. It has been confirmed that the rates of generation of neutrons is several orders of magnitudes smaller than the value expected from excess heat generation in a conventional d-d reaction channel. To reconcile this contradiction, several mechanisms which were expected to happening in solids have been proposed with a hope that they would be verified by experimental facts and also by a solution of many-body problem in a lattice-deuterium system.

The TNCF model for the cold fusion phenomenon has been proposed[1] by one of authors (H.K.) and used to explain various events measured in materials containing hydrogen isotopes with a great success[2–4]. There has just been too much experimental data to cover in the short time since the proposal of the model about two years ago. Using the TNCF model, we are going to analyze remaining excellent data obtained in these 8 years after the discovery of this phenomenon[5]. The data[6] related to the pioneering work[5] and the data[7] which showed a definite evolution of ^{4}He have been explained by using the TNCF model.

It will be appropriate to summarize here the fundamental concepts of the TNCF model[1–4]. As a model, the TNCF model has its fundamental premise the quasi-stable existence of the trapped neutrons with thermal energy in some solids. The density of the trapped neutron n_n is a single adjustable parameter in this model. Further, several premises in the model are used in common for all experimental data and are not adjustable.

On the physical basis of the fundamental premise in the TNCF model, some thought should be given. As we know well, there are very many background neutrons with thermal energy in our environment which are an obstacle to measurements. One typical data of its existence was given in Fig. 2 of the paper by Jones et al., who made the first measurement of *2.45* MeV neutrons using an electrolytic system. On the other hand, they have obtained a null result[9] in an environment with almost zero background neutrons, which made them negative for the cold fusion phenomenon itself.

The ambient thermal neutron could be trapped in a crystal by several mechanisms. One of them is the Bragg reflection and its effect was demonstrated by Shuster et al.[10] showing trapping of neutrons in vacuum (but not in a crystal) surrounded by Si crystal. Another mechanism was by band structure effect[11], which has been proposed by one of the authors (H.K.). The possibility of this mechanism based on the neutron band formation in solids[12] has its support in an experimental observation[13] of the change of neutron mass reflected in a solid, consistent with the band structure in energy spectrum.

The thermal neutrons trapped in solids by these mechanisms can induce various reactions with particles in solids and can breed themselves if there are many hydrogen isotopes which work effectively to thermalize the bred energetic neutron. In situations where predominant events of the excess heat, tritium and helium generation were measured, the number of the trapped neutrons has attained some 10^9 — 10^{12} cm^{-3} in this model, the value of this order seems the threshold one to induce those events in detectable amounts.

In this paper, we have taken up one of excellent experimental data obtained by Gozzi et al.[14,15], where excess heat, tritium and ^4He in Pd + D_2O (LiOD) electrolysis system was observed. The analysis will show the consistency of the data and also with other data obtained hitherto by others.

2. Experimental Results

Gozzi et al.[14,15] tried to measure tritium and ^4He in the gas phase as well as the excess heat and neutrons, taking into consideration the practical difficulties involved in measuring both neutrons and radiation simultaneously and with comparable accuracy in their apparatus.

With better techniques they obtained fruitful results in the measurements of the excess heat, tritium and ^4He but not neutrons. Their experiment on neutron detection showed no statistically significant evidence of neutron emission from the cells[14].

From their data on the excess heat Q, tritium and ^4He, we take up data in the cells 2, 8 and 10, where some of these quantities were observed. The experimental results are tabulated in Table 1.

Cell No.	Q_{max} (W)	N_{max} ×10^{12}	Q_{av} (W)	N_{av} ×10^{12}	$^4He)_{max}$ (ppb)	N_{max} ×10^{12}	$^4He)_{av}$ (ppb)	N_{av} ×10^{12}	t_{av}	N_t ×10^3
# 2	10	13	2.0	2.5	—	—	—	—	yes	2.5
# 4	2	2.6	—	—	80	1.1	17	0.23	—	—
# 8	15	20	1.8	2.3	(15)	(0.21)	(0.4)	(0.06)	yes	2.3
# 10	19	25	2.5	3.3	540	7.6	65	0.92	—	—

Table 1: Experimental result Q_{max}(W), Q_{av}(W), $^4He)_{max}(s^{-1})$, $^4He)_{av}(s^{-1})$ and $t(s^{-1})$ obtained in cells 2,4,8 and 10. Numbers of these events $N(s^{-1})$ were calculated and listed in the next column of the corresponding event. The number of tritium events was calculated by a relation $N_t \sim 10^{-4} N_Q$ mentioned in the text[14].

They observed the excess heat in all runs tabulated in Table 1, but ^4He in only runs 4 and 10, and tritium in runs 2 and 8.

In the analysis of their data, Gozzi et al. assumed occurrence of following $d - d$ reactions in the cathodes:

$d + d = {}^4He$ + phonon (23.8 MeV), (1)

$d + d = t(1.01 MeV) + p(3.02 MeV)$. (2)

In the discussion of their result they reduced their data of ^4He and tritium to the excess heat assuming above reactions; one ^4He corresponds to the excess heat of 23.8 MeV (1 J= 6.24×10^{12} MeV) and one tritium corresponds to 4.03 MeV.

Their conclusion is as follows[14]:

(1) Their calorimetric results show an excess heat which is quite in line with the other positive results reported up to now.
(2) With regards to the nuclear products, in the present experiment a lack of neutrons and a low tritium excess on two out of four cells has been observed in contrast with what is expected on the bases of d -d reactions.
(3) If the tritium channel of the $d - d$ reactions of plasma fusion is invoked, we can calculate that the energy released throughout the experiment in the case of cell 2, for instance, is 115 J, whereas a rough estimation of the integrated heat excess measured by calorimetry in the same cell is more than four orders of magnitude greater.
(4) They are apparently left with the <u>dilemma</u> of one cell (cell 10) which shows a ^{4}He concentration in the gas phase of the correct order of magnitude (with respect to the beat excess), but two others (cells 2 and 8) which do not.
(5) The notable commensurate amounts of ^{4}He and heat excess found in the case of cell 10 cannot be ignored. The time pattern of the amount of ^{4}He recovered, which, although shifted in time, matches the power excess time pattern observed, is also quite striking.

Cell No.	Size ($\phi \times$h)	n_n (Q_{max})	n_n (Q_{av})	n_n (^{4}He)$_{max}$	n_n (^{4}He)$_{av}$	n_n (t_{av})
# 2	Pd, 2×25	3.2×10^{11}	6.3×10^{10}	—	—	6.3×10^{6}
# 4	Au+Pd, 6×23	2.1×10^{10}	—	9.0×10^{9}	1.9×10^{9}	—
# 8	Pd, 3×22	3.5×10^{11}	4.3×10^{10}	(3.8×10^{9})	(1.0×10^{9})	4.3×10^{6}
# 10	Pd, 3×23	4.4×10^{11}	5.9×10^{10}	1.4×10^{11}	1.7×10^{10}	—

Table 2: Cathode size (f (mm) ×h (mm)) and the density of the trapped thermal neutron n_n (cm^{-3}) determined by the data given in Table 1.

3. Analysis of the Data using the TNCF Model

Using the recipe described in the preceding papers[1–4], we can explain the data showing more excess heat than can be explained by chemical reaction and tritium and ^{4}He generations, in some cells together with the excess heat obtained by Gozzi et al.[14,15].
The TNCF model assumes existence of trapped thermal neutrons with a density n_n the only adjustable parameter in the model. In the electrolytic experiment, with heavy water with a lithium electrolyte, the following reactions (trigger reactions) are relevant and explained:

$$n + {}^6\text{Li} = {}^4\text{He}\ (2.1\ \text{MeV}) + t\ (2.7\ \text{MeV}), \quad (3)$$

$$n + d = \text{t}\ (6.98\ \text{keV}) + \gamma\ (6.25\ \text{MeV}), \quad (4)$$

$$t\ (2.7\ \text{MeV}) + d = {}^4\text{He}\ (3.5\ \text{MeV}) + \boldsymbol{n}\ (14.1\ \text{MeV}), \quad (5)$$

The reaction (3) and (4) are the trigger reactions induced by thermal neutrons trapped in the sample. The reaction (5) is a breeding reaction induced by tritium, a nuclear product of the reaction (3). The neutron and the γ generated in the above reactions (5) and (4), respectively, can induce following dissociation reactions (breeding reactions) to supply neutrons for the trigger reaction (3) and (4):

$$n\ (14.1\text{MeV}) + d = n + p + n, \quad (6)$$

$$\gamma\ (6.25\text{MeV}) + d = p + n. \quad (7)$$

Here we give the results of the calculation to determine n_n of the excess heat, tritium and ^{4}He from the experimental data using the above reactions. We use the number of events to specify the physical processes occurring in the solids: By the reaction (3), the excess heat measured in MeV gives a number of events N_Q generating the excess heat when divided by 5 (MeV) with an assumption that all the liberated energy is thermalized in the system. The number of events N_{He} and N_t generating ^{4}He and tritium, respectively, are naturally the same and equal to numbers of ^{4}He and tritium themselves, if we take only the reaction (3).

Then, N_{He} (and N_t) generated by the reaction (3) is related with n_n, the density of the trapped neutrons, by the following relation:

$$N_{He} = 0.35 n_n v_n n_{Li} S l_0 \sigma_{nLi}, \qquad (8)$$

where $0.35 n_n v_n$ is the flow density of the neutrons per unit area and time, v_n is the thermal velocity of neutron and is 2.2×10^5 cm/s at 300 K, n_{Li} is the density of ^{6}Li in the surface layer of Li metal with a thickness (which we take as 1 μm), S and l_0 are the surface area of the cathode and the thickness of the layer where the reaction occurs, $\sigma_{nLi,}$ is the fusion cross section for the reaction (3) and is 9.4×10^2 barn.
On the other hand, N_t *(and* N_γ*)* generated by the reaction (4) is given by the following relation in terms of n_n:

$$N_t = 035\ n_n v_n n_d V \sigma_{nd} \xi, \qquad (9)$$

The fusion cross section σ_{nd} is 5.5×10^{-4} barn for the thermal neutron, V is the volume of the cathode and n_d is the density of deuteron occluded in the cathode. The numerical factor ξ is related to the stability of the trapped neutron in volume and is taken as 0.01[16].
For $\xi = 0.01$, N_{He} (Eq. (3)) is comparable with N_t (Eq. (4)) for $S/V \sim 10^{-3}$ cm^{-1} or a volume sample with a linear dimension $l \sim 10^3$ cm ($l_0/l \sim 10^{-7}$). This relation for the equivalence of the two numbers works out for a sample with 1 ~10 cm when $\xi \sim 1$,which corresponds to a high temperature sample (large amplitude of D vibration in a solid).
For values of $l_0 \sim 10$ A (= 10^{-3} μm) and $\xi = 0.01$, the condition for the equivalence of the above two processes corresponds $l = 1$ cm. Therefore, for a very thin surface layer, N_t predominates over N_{He}, in our model.
Using the data given in Table 1, we could calculate n_n responsible to the reaction (3) and the result is shown in Table 2.
These values of n_n are consistent in themselves and also in the range of n_n obtained earlier for other similar experiments[1~4]. We have to remember an assumption in the calculation of n_n (Q)that the liberated energy in there-action (3) is entirely thermalized in the system.
From our point of view the excess energy (thermalized to heat in the sample or in the system) of 4.8 MeV, tritium and ^{4}He should be generated simultaneously by the reaction (3). It is the greatest riddle that there is a commensurate detection of the excess heat and ^{4}He only in the cell 10.
The lack of neutrons in the experimental results is reasonable because the reaction (3) does not generate any neutrons. Some neutrons could be generated in the breeding reactions with low energies which were difficult to detect outside of the sample.
The commensurate data of the excess heat and ^{4}He in the cell 10 is also understandable in our model where the heat generation per helium atom is 4.8/23.8 = 0.2 times that of the reaction (1) assumed by Gozzi et al.[14,15] From our experience of the data analysis[1–4], there might be several reactions generating excess heat but tritium and helium which give interpretation of the discrepancy between N_Q *and* N_{He}..

4. Conclusion

We think that the above result shows the success of the model and that the cold fusion phenomenon is a probe suggesting the existence of the thermal neutrons with a quasi-stability piled up in the solids and also the existence of nuclear reactions between the trapped neutrons and nuclei in and on the sample, another evidence of which is the nuclear transmutation[16–19].
The value of n_n determined in this analysis will increase by a factor one or two if the liberated energy in the reaction (3) is partly thermalized in the system though contribution of other reactions than (3) decrease n_n. The remaining part of the liberated energy might be carried out of the system by the particles t, γ and n generated in

reactions (3), (4) and (5), respectively.
In reality, photons with an energy 6.25 MeV were observed in recent cxperiments[20–22]. It should be noticed that cold fusion experiments are not entirely free from radiation hazard, as shown by these results.
The low tritium generation rate in this experiment might be a result of remaining existence of tritium in the cathode as mentioned by Gozzi et al.[14] which is sometimes the case as has been reported before[23].
Though the result given above shows fairly clearly the success of the model, there remains several unresolved features of the experimental data; disagreement of N_Q and N_t (and N_{He}) by a factor about 5; absence of simultaneous occurrence of events related with the excess heat, tritium and helium, rare observations of accompanied gammas expected in the reaction (4) in experimental data. These points should be solved by further experimental and theoretical researches.

References

(1) H. Kozima, *Trans. Fusion Technol. (Proc.ICCF4)* **26** (1994) 508.
(2) H. Kozima, *Progress in New Hydrogen Energy (Proc. ICCF6),* (1996) 332.; *Cold Fusion* **20** (1996) 5.
(3) H. Kozima, S. Watanabe, K. Hiroe, M. Nomura, M. Ohta and K. Kaki, J. *Electroanal. Chem.* **425** (1997) 173.
(4) H. Kozima, K. Kaki and M. Ohta, *Fusion Technol.* (1997) (to be published).
(5)M. Fleischmann, *S.* Pons and M. Hawkins, *J. Electroanal.* Chem. **261** (1989) 301.
(6) J.R. Money, M.R Caffee, H. Farrar, IV, N.J. Hoffman, G.B. Hudson, R.H. Jones, M.D. Kurz, J. Lupton, B.M. Oliver, B.V. Ruiz, J.F. Wacker and A. Van, *Fusion Technol.* **18** (1990) 659.
(7) M.H. Miles, R.A. Hollins, B.F. Bush and LI. Lagowski, *J. Electroanal. Chem.* **346** (1993)99.
(8) S.E. Jones, E.P. Palmer, J.B. Czirr, D.L. Decker, G.L Jensen, J.M. Thorne and S.E. Taylor, "Observation of Cold Nuclear Fusion in Condensed Matter," *Nature* **338** (1989) 737.
(9) S. E. Jones, D. E. Jones, D. S. Shelton and S. F. Taylor, "Search for Neutron, Gamma and X-ray Emission from Pd/LiOD Electrolytic Cells: A Null Results," *Trans. Fusion Technol.* **26** (1994) 143.
(10) Shuster, M., Ranch, H., Seidi, E., Jericha, E. and Carhie, *C.J., Phys. Letters* ***A*144** (1990) 297.
(11) H. Kozima, *J. New Energy* **2** (1997) (to be published).
(12) H. Kozima, *Proc. 3rd Russian Conf. Cold Fusion and Nuclear Transmutation* 1995, Sochi, RUSSIA) (to be published); *Cold Fusion* **16** (1996)4.
(13) Zeilinger, A., Shull, C. G., Horne, M.A. and Finkelstein, K. D., *Phys. Rev. Letters* **57**, (1986), 3089.,
(14) D. Gozzi, R. Caputo, P.L. Cignini, M. Tomelhni, G. Gigli, 0. Balducci, E. Cisbani, S. Fnillani, F. Garibaldi, M. Jodice and G.M. Urciuoli, J. *Electroanal. Chem.* **380** (1995) 91.
(15) D. Gozzi, R. Caputo, P.L. Cignini, M. Tosnellini, G. Gigli, G. Balducci, E Cisbani, S. Frullani, F. Garibaldi, M. Jodice and G.M. Urciuoli, *J. Electroanal. Chem.* **380** (1995) 109.
(16) H. Kozima, M. Nomura, K. Hiroe and M. Ohta, *Cold Fusion* **21** (1997) 58.
(17) H. Kozima, M. Nomura, K. Hiroe and M. Ohta, *Progress in New Hydrogen* Energy *(Proc. JCCF6),* (1996) 660.; *Cold Fusion* **20** (1996)16; *J. New Energy* **1-4** (1996) 21.
(18) H. Kozima, M. Ohta and K. Kaki, *Cold Fusion* **11**(1997) 48.
(19) H. Kozima, *Cold Fission* **15**(1996)12.
(20) A.G. Lipson, B.F. Lyakov, D. M. Sakov, V.A. Kuznetsov and T.S. Ivanova, *Proc. RCCFNT4 (1996,Sothi,Russia)(to be published); Pmg,zssinNew Hydrogen* Energy *(Proc.*

ICCF6), (1996) 433.
(21) Y. Oya, H. Ogawa, T. Ono, M. Aida and M. Okamoto, *Progress in New Hydrogen* Energy *(Proc. ICCF6),* (1996)370.
(22) R. Notoya, T. Ohnishi and Y. *Noya, Progress in New Hydrogen Energy (Proc. ICCF6),* (1996) 675.
(23) T.G. Will, K. Cedzynska and D.C. Linton, *Trans. Fusion Technol.(Proc. ICCF4)* **20**, (1994) 207.