Neutron Energy Spectrum Measured by Bressani et al. Analyzed Using the TNCF Model

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Abstract

The energy spectra of neutrons in the cold fusion phenomenon measured by Bressani et al. in a Ti/D gas loading system were analyzed using the TNCF model proposed by us. The result shows that the data are interpreted consistently with the value of the adjustable parameter n_n, the density of the trapped neutron in the model supposed to be supplied from the ambient neutron, of a value $10^5 \sim 10^6$ cm^{-3}. The value of n_n is in the smallest range of values determined hitherto in more than 40 various materials used in the cold fusion research where positive results were obtained. A possible cause of the small value of the parameter n_n is discussed, taking into consideration the characteristics of the sample.

1. Introduction

Precise measurements of the energy spectrum of neutrons emitted from a cold fusion system have been performed by Bressani et al.[1,2] soon after the discovery[3] and confirmation[4~6] of the cold fusion phenomenon. Though the TNCF model[7~10] proposed by one of present authors (H.K.) at ICCF4 has been applied successfully during the last four years to various events of the cold fusion phenomenon in which it provided an explanation for the large ratio of numbers of tritium and neutrons N_t/N_n, up to 10^7 in experiments by a theoretical value of 1.1 x 10^6. It was, however, postponed to apply the model for the energy spectrum of neutrons observed in several cold fusion systems until the model was finally completed last year. The model was applied[12,13] recently to the first measurement of the energy spectrum of neutrons and a null result in electrolytic systems, and we analyze the precise measurements of the spectrum in Ti/D systems with gas loading in this paper.

From the trigger reactions to the energy spectrum of neutrons in the TNCF model is a long reaction chain process and the result of the analysis becomes rather ambiguous compared to those analyses applied for more than 40 events in experimental results hitherto and given in the previous papers[7~10].

Even so, the analysis given in this paper will show the reality of the cold fusion phenomenon through the appropriate consistent explanation of the precise measurement with many other data and also will show the effectiveness of a phenomenological model.

2. Experimental Results of Bressani et al.

Bressani et al.[1,2] made precise measurements of the energy spectra of neutrons emitted from gas loaded Ti/D systems. Their measurements were done with the time-of-flight method with a double scattering technique to measure the neutron energy and consisted of two sets of metals with Ti shavings and Ti sponge.

Set A. Experiment with Ti shaving sample[1]

In the first set of their experiment, hydrogen isotope gas with a pressure up to 1.5 x 10^3 Torr was used to load deuterium or protium into Ti metal (3g) with a shaving shape. Neutron emission was measured in thermocycles between 25 and 540 °C.

A small enhancement of the events around 2.45 MeV with D_2 gas was observed but not with H_2 gas. The background in the neutron energy spectra was due totally to noise inherent to the technique, i.e. the photomultipliers' noise.

An energy spectrum of neutrons observed in this Ti/D system is reproduced in Fig. 1 (from Fig. 1 of Reference 1). A clear peak centered at ~ 2.5 MeV was visible with a satisfactory background subtraction around the peak compatible with that expected by a Monte Carlo simulation.

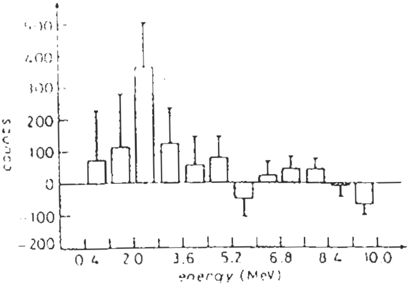

Fig. 1. Difference of the neutron energy spectrum measured in the runs 'down' and that measured in the runs 'up', normalized to the same time. The errors are the statistical ones. (Fig. 1 of Bressani et al.[1])

The neutron emission with energies between 2 and 3 MeV measured in this experiment was 4.0 +/- 1.5 *n*/s corresponding to 1.3 +/- 0.5 *n*/s·gTi without burst-type emission. The statistical significance of the 2.45 MeV neutron emission was ~ 2.5 σ.

Set B. Experiment with Ti sponge[2]

The second set of their experiment with Ti and Pd metal used a better control of the pressure and temperature of both the metal and the gas, which made the statistical significance larger. For the Ti experiment, 20 g of high purity Ti sponge was used. During the repeated cycles between 25 and 540 °C, the morphology of the Ti sample gradually changed from sponge to a powder due to the large strains associated with the hydrides formation and phase transformation. As a background measurement, several cycles were performed by filling the cell with protium instead of deuterium.

An energy spectrum of neutrons observed in this Ti/D system with Ti sponge is reproduced in Fig. 2 (from

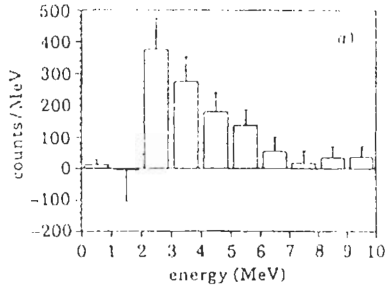

Fig. 2. Energy spectrum of neutrons emitted from the Ti/D system calculated by their use of Ti/H system as background as described in the paper by Botta et al.[2] (Fig. 5a) of the paper.

Fig. 5a of Reference 2). An estimate of the neutron emission between 2 and 3 MeV per unit mass and time was made assuming that the neutron production rate was independent of time and gave 0.11 +/- 0.03 *n*/s·gTi. There was no neutron burst at all. The statistical significance was 5 σ.

For Pd/D instead of Ti/D system, they observed 2.45 MeV neutron emission rate of 0.02 +/- 0.01 *n*/s·gPd without any burst.

Comparison of two sets of measurements A (with Ti shaving) and B (with Ti sponge) with the Ti/D system has given following facts: 2.5 MeV neutrons are emitted from a Ti/D system with the statistical significance of 2.5 σ, (A) and 5 σ, (B). The shape of the neutron spectrum was slightly different in two sets. The mass emission rate in two sets was different by one order of magnitude; 1.3 +/- 0.5 *n*/s·gTi (A) and 0.11 $\pm$ 0.03 *n*/s·gTi (B).

The difference of neutron emissions in the two sets was interpreted by the authors to indicate that the cold fusion phenomenon in this system is essentially a bulk and not a surface process because the surface-to-volume ratio *S*/*V* is larger for Ti sponge (B) than for Ti shaving (A).

We analyze above data using the TNCF model in the next section.

3. Analysis of the Data using the TNCF Model

In the cold fusion system with gas loading of hydrogen isotopes, there is no metal layer on the surface of the solid sample and the important role of trigger reactions played in the metal layer in electrolytic systems[8] is missing. The relevant reactions in this case using the TNCF model are written down as follows with cross sections given by data books[14,15]. The trigger reaction in the Ti/D system is that between a trapped neutron and the occluded deuteron;

$$n + d = t\,(6.98\ \text{keV}) + \gamma(6.25\ \text{MeV}).(1)$$

The cross section of this reaction is 5.5 x 10^{-4} barn.

The triton with $\varepsilon = 6.98$ keV generated in this trigger reaction can induce a succeeding breeding reaction with a deuteron, the cross section of which is 3.0 x 10^{-6} barn in a path of a length ~ 1 μm:

$$t(\varepsilon)+d={}^4\text{He}(3.5\ \text{MeV})+n(14.1\ \text{MeV}).(2)$$

The photon with an energy 6.25 MeV generated in the trigger reaction can induce photodisintegration of a deuteron (the threshold energy ~ 2.2 MeV) giving the neutron with an energy about 2 MeV:

$$\gamma(6.25\ \text{MeV}) + d = n + p. \qquad (3)$$

The cross section of this reaction is about 2 mbarn (2 x 10^{-3} barn) and the neutron generated in this reaction has an energy of – 2 MeV.

Neutrons with 14.1 MeV generated in the reaction (3) can accelerate or dissociate deuterons to generate neutrons:

$$n\,(14.1\,\mathrm{MeV}) + d = n' + d, \qquad (4)$$
$$n\,(14.1\,\mathrm{MeV}) + d = n + p + n. \qquad (5)$$

The cross sections of the elastic collision (4) and the disintegration (5) are 0.62 and 0.18 barn, respectively.

The accelerated deuteron up to an energy ε (the maximum value is 12.5 MeV) in the reaction (5) can induce direct d-d reactions:

$$d(\varepsilon\,\mathrm{MeV}) + d = {}^3\mathrm{He} + n\,(2.45\,\mathrm{MeV}) + \varepsilon, \quad (6)$$
$$= t + p. \qquad (7)$$

The cross sections of the reactions (6) and (7) for a deuteron with 12.5 MeV are 8.9×10^{-3} and 3.1×10^{-3} barn, respectively.

Thus, the neutrons with energies of between 2 and 3 MeV can be generated in several reactions in the chain from (2) to (6) in the TNCF model. From our point of view, therefore, to analyze the energy spectrum of neutrons, it is necessary to calculate number of neutrons generated in reactions (3), (5) and (6).

The rate P_f of the reaction (1) per unit time is expressed by the following relation:

$$P_f = 0.35 n_n v_n n_d V s_{nd} \xi, \qquad (8)$$

where $0.35 n_n v_n$ is the flow density of the thermal neutrons per unit area and time, n_d is the density of the deuteron in the reaction region with volume V and σ_{nd} is the cross section of the reaction. The factor ξ expresses an order of stability of the trapped neutron in the trapping region; we take $\xi = 0.01$ for reactions which occur in volume (and $\xi = 1$ for reactions in surface layer) according to the recipe of the TNCF model[9,10].

The energetic particles generated by the trigger reactions react with particles in the lattice and cause breeding reactions (2) to (7). The rate per unit time of a reaction between an energetic particle with an energy ε and one of stable nuclei in the solid is given by a similar formula as that in vacuum:

$$P_\tau = N_\varepsilon n_N \sigma_N l, \qquad (9)$$

where N_ε is the number of the particle with an energy e generated in the sample per unit time, l is the path length of the energetic particle, n_N is the density of the nucleus, σ_N is the cross section of the reaction.

Applying these relations (with $\xi = 0.01$) to the experimental data explained in Section 2 as done in a previous paper[11], we obtain the following values of n_n for the sets A and B;

$$n_n\,(\mathrm{A}) = 1.2 \times 10^6\ \mathrm{cm}^{-3}, \qquad (10)$$
$$n_n\,(\mathrm{B}) = 5.5 \times 10^4\ \mathrm{cm}^{-3}. \qquad (11)$$

In this calculation, the experimental value of neutron with energies between 2 and 3 MeV was assumed as the number of neutrons generated in the overwhelmingly predominant reaction (3) (because contribution of the reactions (5) and (6) is negligible).

These values of n_n determined with those assumptions explained above are in the range of experimental values and not inconsistent with them[9,10].

A result of numerical calculation[13] of energy spectrum of neutrons generated in Pd/D/Li system is shown in Fig. 3 for an illustration. Essentially the same figure is obtained for Ti/D system with a larger value of n_n than that used

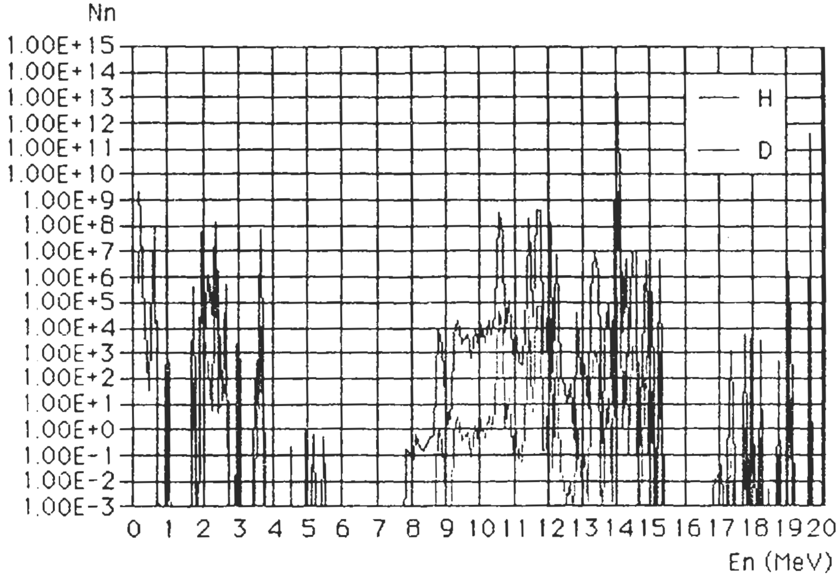

Fig. 3. Numerical result of the energy spectrum of neutrons generated in PdD/Li (PdH/Li) layers (1 μm thick each) on a Pd metal surface, including trapped neutrons of $n_n = 10^{10}$ cm^{-3} using the TNCF model.

in this calculation. This figure reproduces clearly a characteristic of the spectrum observed in the experiments[1,2] in Ti/D system as shown in Figs. 1 and 2. The comparison is effective because the two systems are essentially the same in the TNCF model except the trigger reactions which influence the value of n_n.

4. Discussion

The parameters n_n determined above for the data sets A and B are rather small compared with those determined before of $10^8 \sim 10^{12}$ cm^{-3}. As a cause of this difference, it is possible to consider that the parameter ξ is smaller in TiD$_x$ system than 0.01 assumed in this calculation determined according to a result of analysis of data obtained in an Ni/H/K system. The small number of data analysis for samples without surface layer of alkali metal makes some uncertainty in the value of C and the final determination of its value and its dependence upon the material should be considered as pending.

The formation of necessary conditions for neutron trapping by stochastic atomic processes in the sample is related with the problem of the poor reproducibility of the cold fusion phenomenon. In the paper[2] by Bressani et al., the authors cited a paper reporting a null result in a similar Ti/D system to theirs and commented the probable origin of the difference due to the difference of the thermal cycles used in one and other experiments. From our point of view, the differences of shape and quality of sample and of experimental processes (temperature range and temporal period of thermal cycles, and so on) influence the condition for neutron trapping and trigger and breeding reaction rates through the difference in deuteron distribution and surface structure. In the gas loading system, these processes surely influence on the distribution of hydrogen isotopes in the metal which is sensitive to the trapping of neutrons and the reactions between particles in the sample.

One of fundamental questions about possibility of $d-d$ reactions in a solid is overcome by the existence of energetic deuterons accelerated by energetic particles generated in trigger and breeding reactions in the TNCF model. A numerical estimation of the energy spectrum of neutrons to be observed outside has been shown in Fig. 3 by a computer simulation with a simplified structure of deuterium distribution and continuum approximation of lattice structure. This result compared with the experimental results Figs. 1 and 2 shows strong resemblance and effectiveness of the phenomenological approach.

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