An Analysis of Tritium and Neutron Generation in a Pd + LiOD/D_2O System

Hideo Kozima, Masahiro Nomura
Katsuhiko Hiroe and Masayuki Ohta
Department of Physics
Faculty of Science
Shizuoka University
836 Oya, Shizuoka 422, Japan

Abstract

The trapped neutron catalyzed model for cold fusion (TNCF model) was used to analyze experimental data showing tritium and neutron generation in an electrolytic system composed of a Pd cylindrical cathode, a Pt anode and an LiOD + D_2O electrolytic solution. The density of the trapped thermal neutrons n_n was determined from the amount of tritium observed in the solution as 10^5 cm^{-3}. The density n_n was used to calculate the number of high energy neutrons to be observed in the experiment giving the t/n ratio 6×10^5 a result consistent with the observation 8.7×10^4.

Introduction

The experimental data piled up in these seven years after the report of an observation of the gigantic excess heat in an electrolytic system have shown us the wide-spread existence of conditions which result in the so-called cold fusion in solids. These data waiting explanation on a common base have been a target of eager scientists who have been excited by the interesting features of the cold fusion phenomenon. One of the present authors (K.H.) has been engaging in construction of a conceptual framework reconcilable with the abundant and complex data of cold fusion. A model named TNCF (trapped neutron catalyzed fusion) proposed by him has been applied for analyses of several typical experimental data and proved its ability to explain the phenomenon consistently. The data collectred until now include the excess heat Q and helium generation[3-5], Q and nuclear transmutation (NT)[6,7], Q, tritium and neutron generation[8] and the large excess heat with high qualitative reproducibility[9,10].

It is well known that tritium is one of main nuclear products together with helium and neutron. The amount of the tritium exceeded that of neutrons by a factor of five to eight, though the measurements were difficult to do simultaneously.

There were simultaneous and quantitative measurements[11] of tritium and neutron which were analyzed by TNCF model as will be reported.

Experimental results

In the experiment[11] with alternation of several modes of electrolysis, an on-line measurement of tritium and neutrons was conducted for 80 days. The electrolytic cell contained a Pd

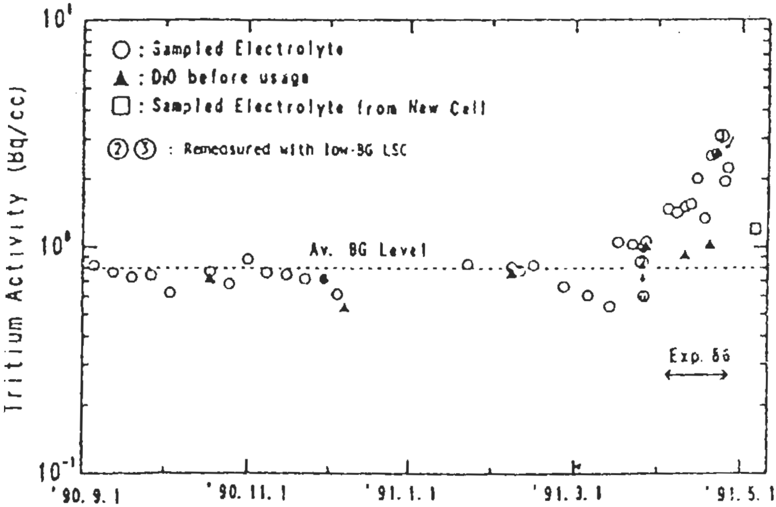

Fig. 1. **Sampling data: Evolution of tritium level in electrolyte.**

cathode (20 mmø x 30 mm, a surface area $S = 25$ cm^2), a Pt anode and 1l D_2O + 0.3 mol/l LiOD. The modes of electrolysis were a sawtooth (35 days), the second sawtooth (6 days), the third sawtooth (8 days), L-H mode (21 days) and another sawtooth (9 days), successively.

At first, the cell generated neutrons only occasionally until a lot of tritium had been generated after 60 days from the beginning for about a month as seen in Fig. 1 (Fig. 5 of the original paper[11]). Total number of neutrons with energies 2.45 and 3 ~ 7 MeV was 6.8 x 10^6 while that of tritium measured in the solution was 4.2 x 10^{11}. This result gives an overall t/n ratio of 8.7 x 10^4.

The data will be analyzed on TNCF model in this paper giving a density of the trapped neutrons in the PdD_x cathode and a consistent explanation of the cold fusion phenomenon occurring there as shown in the next section.

Experimental data explanation using the TNCF model

The TNCF model[1-3] assumes a stable existence of thermal neutrons in a crystal having characteristics for neutron trapping; 1) the crystal is surrounded by "walls" with an appropriate geometry to reflect thermal neutrons in the Bloch state by the difference of neutron band structures in the crystal and in the walls, 2) the neutron affinity of the crystal is positive and large enough to stabilize the neutron Bloch wave against β decay of the neutron and also against absorption by a nucleus in the crystal.

If a crystal has such properties and contains thermal neutrons, the neutrons stay in the crystal forever. The neutron could be considered as standing wave in a finite volume: a superposition of travelling waves with wave vectors of the opposite direction. Each travelling wave is reflected at a boundary with penetration of a short distance.

A large disorder in the periodicity of the crystal potential for neutrons will work as a perturbation on the neutron Bloch wave to destroy its stability resulting in absorption by a nucleus causing the disorder. We will treat, for simplicity, minor elements in the crystal as impurities interacting with the neutron to fuse with it. As the minor elements, we take deuterons in Pd lattice and ^{6}Li nuclei in the Li layer on the surface of the Pd cathode.

According to the presumption of TNCF model, we assume an existence of stable thermal neutron with density n_n in the cathode. The neutron can be absorbed by a deuteron there or by ^{6}Li nucleus in the surface layer with a thickness λ_0 (we take it as 1 μm in the numerical estimation below).

Then, relevant nuclear reactions are listed as follows;

$$\mathrm{n} + {}^6\mathrm{Li} = {}^4\mathrm{He}\ (2.1\ \mathrm{MeV}) + \mathrm{t}\ (2.7\ \mathrm{MeV}), \quad (1)$$
$$\mathrm{t}\ (2.7\ \mathrm{MeV}) + \mathrm{d} = {}^4\mathrm{He}(3.5\ \mathrm{MeV}) + \mathrm{n}(14.1\ \mathrm{MeV}), \quad (2)$$
$$\mathrm{n} + \mathrm{d} = \mathrm{t}\ (2.7\ \mathrm{MeV}) + \gamma\ (6.25\ \mathrm{MeV}), \quad (3)$$
$$\mathrm{d} + \mathrm{d} = {}^4\mathrm{He}\ (0.82\ \mathrm{MeV}) + \mathrm{n}\ (2.45\ \mathrm{MeV}), \quad (4)$$
$$= \mathrm{t}\ (1.01\ \mathrm{MeV}) + \mathrm{p}\ (3.02\ \mathrm{MeV}). \quad (5)$$

The cross sections for the first three reactions are $s_{n\text{-}Li} \sim 1$, $s_{t\text{-}d} \sim 1.4 \times 10^{-1}$ and $s_{n\text{-}d} \sim 9 \times 10^{-4}$ barns, respectively. (1 barn $= 10^{-24}$ cm^2.)

In the experiment[11], tritium was observed only for a month in the final period as shown in Fig. 1 where used the L-H mode. So, we can calculate *nn* assumed as a constant throughout the period by a following relation between tritium number N_t and n_n

$$N_t = 0.35\, n_n \upsilon_n\, n_{6Li}\, \lambda_0 S\, s_{n\text{-}Li} T_1$$

where T is the duration of the tritium generation, $\lambda_0 = 10^{-4}$ cm, $n_{6Li} = 3.5 \times 10^{21}$ cm^{-3} and $\upsilon_n = 2.7 \times 10^5$ cm/s (T = 300° K). Using parameters given above, we obtain

$$n_n \sim 3 \times 10^5\ \mathrm{cm}^{-3}.$$

This value of the density of the trapped neutron is compared with values obtained in the analyses of other experiments; $n_n \sim 10^7$ cm^{-3} in Ni – Rb_2CO_3+H_2O system generating excess heat and nuclear transmutation (NT) of Rb into Sr[6], $n_n \sim 10^{13}$ cm^{-3} in Pd – LiOD+D_2O generating excess heat and NT of Al into Si[7], $n_n \sim 10^{13}$ cm^{-3} in Pd – LiOD+D_2O generating ^{4}He and excess heat[4], and $n_n \sim 10^{15}$ cm^{-3} in Pd-black – LiOD+D_2O generating excess heat and tremendous ^{4}He[5].

These results show that the relative efficiency of neutron trapping in the crystal is higher in samples with smaller size.

On the other hand, the tritium generated in the reaction (1) has an energy of 2.7 MeV and can make fusion reaction (2) effectively to generate a neutron. Taking the range of propagation of the triton with 2.7 MeV as 1 μm, we obtain the number of the generated neutrons as 1.9×10^{-6} /tritium ($t/n = 5.3 \times 10^5$). This value is compared with the experimental value of overall t/n ratio 8.7×10^4. The coincidence is fairly good if we notice that there are some other mechanisms generating neutron except tritium which lower the theoretical value of the t/n ratio.

Let us now investigate mechanisms of the neutron generation observed in the experiment[11] without tritium.

The energy of the observed neutron was 2.45 and 3 ~ 7 MeV. This fact shows that the mechanism of the neutron generation is not restricted to the direct *d* - *d* reaction (4) responsible to the 2.45 MeV neutron which can occur effectively only for a high energy deuteron accelerated by a collision with 14.1 MeV neutron.

About the observed amount of the neutrons, the emission was only for 3 days after 15 days from the start and slight (20 % up over background (BG) level ~ 0.04 /s). Then, it reached an interval where no neutrons were observed for 20 days.

Changing the mode of the electrolysis, higher excess neutrons were obtained reaching 1.6 times the BG level at a period where also observed a lot of tritium. This behavior of neutron emission is too complicated to analyze completely by the simple model we used for the determination of the neutron density n_n from the number of observed tritium atom. We will give some speculations on the simple facts in these data.

The neutrons observed together with tritium could be interpreted as generated by tritium with 2.7 MeV reacting with deuterons in the sample as discussed above which gave a reasonable value of *t*/*n* ratio. Some neutrons, however, were observed independent of tritium in the experiment[11]. It is therefore necessary to take up other mechanisms responsible to the generation of neutrons in Pd/D system without tritium generation measured outside the cathode. For an order of magnitude estimation, we will calculate a possible number of high energy neutrons generated in the reaction (2) by the tritium (with 7 keV) produced in the reaction (3) in the sample. The reaction (3) would be occurring in the Pd cathode and the generated tritium will remain there not going out to the electrolytic solution if it did not fuse with deuteron by the reaction (2) before losing energy in a path with length ~ 10^{-4} cm.

Using the values of the neutron density $n_n \sim 10^5$ cm^{-3} obtained above from the tritium data, we could calculate number of tritium with energy 6.98 keV by the reaction (3) in the sample as

$$N'_t = 3.6 \times 10^7/\text{s}.$$

Here, we assumed the density of deuteron interacting with the thermal neutron as $n_d = 6.8 \times 10^{22}$ cm^{-3}.

The generated tritium with energy 6.98 keV fuses with a deuteron on the path with length ~ 1 μm by a probability of 10^{-3} where the cross section $s_{t\text{-}d} = 3 \times 10^{-6}$ barns (for 6.98 keV) was taken as a constant irrespective of the energy of the triton. This gives a number of high energy neutrons to be observed outside of the sample 2.4×10^{-4} /s. Furthermore, the neutron with 14.1 MeV will make a collision with a deuteron to dissociate it to produce a proton and a neutron with a cross section ~ 0.2 barns. This reaction multiplies the number of neutrons observed outside the sample.

The number of neutrons generated through the channel of $n + d$ and $t + d$ reactions was 4.1×10^3 for 20 days of experiment with high tritium activity. This is too small compared with the total number of neutron 6.8×10^6 observed mainly in the period of tritium activity and lowers the *t*/*n* ratio estimated above a little. Though the value is small, it will be pertinent with the neutrons observed in the earlier period of the experiment where the number is rather low (20% over BG level ~ 8 x

10^{-3}/s) independent of tritium activity observed in the solution.

Now, we have two channels for the neutron generation in Pd/D + Li system; 1) Reactions (1) and (2) giving *t*/*n* ratio of 10^5, and 2) reactions (3) and (2) giving two orders of magnitude lower generation rate of neutron in the Pd crystal.

The alternation of the neutron active and inactive periods and also tritium active and inactive periods in the experiment remain as riddles to be explained by the theory. The modes of electrolysis used in the experiment surely influence the distribution of elements in the cathode and determine the nuclear processes occurring there. It is necessary to clarify those processes to know the details of the cold fusion phenomenon occurring in the complex system of palladium and deuterium covered with lithium metal and/or lithium-palladium alloy layers.

Conclusion

The amount of tritium atoms observed in the experiment gave us the density of trapped neutrons $n_n \sim 10^5$ cm^{-3}. This is the lowest value of the density $10^7 \sim 10^{15}$ cm^{-3} we obtained hitherto in the analyses of cold fusion experiments. It is possible to say from these data that the smaller the size of the Pd (Ni) cathode, the higher the density of trapped neutrons in the sample and the more the excess heat.

Then, the number of neutrons observed together with triton was analyzed consistently using the density of trapped neutrons ~ 10^5 cm^{-3} determined by the tritium data.

This result also gives an explanation of high *t*/*n* ratio noticed in this and other experiments.

It should be noticed that the time evolution of cold fusion events shown clearly in Fig. 1 (Fig. 5 of the original paper[11]). As is well known, it takes a very long time to realize a condition to induce the cold fusion phenomenon as we can see a typical example in this figure. So, we have to be patient to form conclusions for a difficult phenomenon like the cold fusion from such limited data.

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