Evidences of Neutron Trapping in Cold Fusion Materials

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Abstract

New experimental data of neutron trapping by cold fusion materials have been reported which support a basic assumption of the TNCF model proposed by the author. Surveying the experimental data of neutron trapping in the cold fusion experiments, it is shown that they are evidences supporting the basic premises of the TNCF model.

1. Introduction

The theoretical explanation of the cold fusion phenomenon has not been settled to some scientist's satisfaction, although the experimental confirmation of the phenomenon hasn't left much support for the few remaining skeptics. Still, there remains a trace of the initial assumption in the cold fusion research, i.e. the d - d direct fusion must be basic reaction of the cold fusion phenomenon, which occurs in metal deuterides at room temperature.

The experimental data obtained in these nine years have revealed a complex feature of the phenomenon which occurs in materials including hydrogen isotopes. The hydrogen isotopes relevant with the phenomenon are not limited to deuterium, but also include protium. The material in which this phenomenon occurrs is not limited to transition metals which can occlude hydrogen, but also proton conductors, ferroelectrics and superconductors. The characteristic events of the phenomenon are not limited to the excess heat, neutrons with 2.45 MeV and tritium, but ^{4}He, higher energy neutrons up to about 10 MeV, gamma rays up to about 10 MeV and nuclear transmutation (NT), explicable only by a decay or a fission of nuclei formed in the material.

As has been shown in our previous papers, the TNCF model which I proposed at ICCF4 five years ago provides a consistent explanation, qualitative and sometimes quantitative, of more than 50 experimental data of those events obtained in various materials under various conditions. The fundamental premise of the model, i.e. the existence of trapped neutrons in materials with a density n_n, its value determined in the analyses ranges from 10^8 to 10^{13} cm^{-3},

has been a puzzle for many who know that the free neutron decays by beta emission with a constant 887.4 ± 0.7 s. Though I have proposed several mechanisms for neutron trapping and one for stabilization of the trapped neutrons in cold fusion materials, the variety of the cold fusion phenomenon made the validity of the premise rather obscure.

The original idea of the trapped neutrons was suggested by null results obtained by T. Ishida1 in Kamioka, Japan in cooperation with S.E. Jones and by S.E. Jones[2] himself in Utah, USA in a condition without background neutrons. There were also several data showing the effect of the thermal neutrons on the cold fusion phenomenon by from Shani et al.[3] in 1989 through Yuhimchuk et al.[4], Celani et al.[5], Stella et al.[6], Lipson et al.[7] to Oya et al.[8] in 1996 and more recent ones. However, the complexity of behavior of the thermal neutrons, in a sense familiar to atomic pile researchers, has prevented people from accepting the idea of the neutron trapping assumed in the TNCF model.

In this paper, I summarize the experimental data which show trapping of the ambient or artificial thermal neutrons by cold fusion materials in connection with the TNCF model.

2. Experimental Data

There are several data showing thermal neutron trapping by materials used in cold fusion experiments. In this section, we introduce several published in journals accessible to us. The first is a data obtained by a group in Italy several years ago in a system where was occurring a chemical reaction.

2.1 Cerofolini et al.[9]

Measurement of neutron flux change in a system, where was occurring a reaction $H^+ + D^+$ (H^+) to form HD (HH) molecule, was performed in a condition of an average value of neutron background count of (4.63 +/- 0.01) x 10^{-2} s^{-1} by their ^{3}He counter.

Both the homogeneous (H + H) and heterogeneous (H + D) reactions were conducted with the alkaline hydrides KH and KD in an oil dispersion. The hydrides in the latter case were suspended in the original oil or diluted with dodecane ($C_{12}H_{26}$) or dioxan (1,4-$C_4H_8O_2$) and allowed to react either with deuterated acetic acid (CH_3COOD) or with heavy water (D_2O) under vigorous stirring.

The following results were obtained. In all experiments, an appreciable reduction of the neutron background inside the neutron bottle, where the detection was performed, was observed for ~ 200 to 400 s after the start of the reaction. An average neutron count rate during the reaction was (3.2 ± 0.35) x 10^{-2} s^{-1} compared with an average count rate during the surveillance time after the reaction of (5.7 +/- 0.4) x 10^{-2} s^{-1}. The count rate excess after the reaction compensated almost exactly for the count rate defect during the reaction, the average count rate being (4.5 ± 0.3) x 10^{-2} s^{-1} compared with a long-term background of (4.63 ± 0.55) x 10^{-2} s^{-1}, which shows a statistical confidence greater than four standard deviations.

The observed flux reduction in the reaction of 40 to 50% is greater than that which is obtained by insertion in the system of a strong neutron absorber, a Cd foil.

The authors (Cerofolini et al.) concluded as follows: these results (some

of them are introduced above) support the idea that the neutron trap is related not only to HD but also to HH molecular species; evidence for a new phenomenon is presented — neutron depletion during the redox reaction of H^+ with D^+; this effect is by far more intense than the neutron emission reported to occur in redox reactions involving deuterium; this phenomenon can be interpreted in terms of neutron trapping by a molecular species produced during reaction.

This interpretation given by the authors seems a putative one in this stage of cold fusion research. Knowing more data after this work, we are tempted to take into our consideration the condensed phase (oil dispersion) in the system on the surface of which took place the reaction. This point will be discussed in the next section.

2.2 A. Lipson et al.[10]

In the experiment to observe crystallographic change of TGS crystals ($D_{0.6}D_{0.4}$) under a weak neutron flux from a ^{252}Cf source, Lipson et al.[10] observed neutron trapping by the crystal around its transition temperature T, of ferroelectric phase change.

They took up the partially deuterated ferroelectric crystal TGS (containing protium and deuterium simultaneously), considering that an anomalous increase in the thermal neutron capture cross section may be possible as a result of the formation in terms of molecular complexes of the type D^+H^- in the crystal according to the work introduced above.[9]

A single crystal of TGS $(ND_2CD_2COOH)_3 \cdot D_2SO_4$ with total deuterium content ~ 60% (T_c = 57.6°C) were heated and cooled in a linear regime at a rate of 0.15 K/s in the temperature interval 283–373 K. A ^{252}Cf source of neutrons with intensity ~ 270 *n*/s in a solid angle of 4π was used for the experiments with neutron flux of different intensities (above cosmic neutron background) and for calibrating the detector. The neutrons from the source were thermalized by polyethylene block.

The negative effect (decrease of neutron flux in the critical temperature range compared with the control experiments in the off-critical temperature range) in the critical temperature range is observed for both (1) the cosmic neutron background and (2) the ^{252}Cf neutron source. The absolute magnitude of the negative effect is approximately 20 times larger in (2) than in (1). The neutron flux from the ^{252}Cf source decreased by ~ 2.0–2.5% as a result of interaction with the TGS crystal near T_c.

By the authors' calculation based on the physics of thermal neutrons, the number of thermal neutrons crossing the sample per unit time in the experimental geometry was equal to ~ 20 *n*/s, of which almost one third are captured in the crystal. Their conclusion is that the neutron capture cross section for hydrogen in TGS crystals near T_c must be at least three orders of magnitude larger (~ 700 b) than for hydrogen at other temperature range.

This conclusion of the authors presupposes that the decrease of the neutrons is due mainly to capture by hydrogen in the crystal, though they cite a fact from a book[11] that the neutrons thermalized inside the polyethylene shielding can repeatedly cross (several tens of times) the same plane (crystal), undergoing internal reflections from the polyethylene walls. Why the TGS crystal does not work as a material to trap

neutrons in the phase transition region where they appear and disappear in the thermal cycles in the experiment will be discussed in the next section.

2.3 Notoya et al.[12]

Notoya et al. observed gamma ray spectra during electrolysis in 0.5 M $K_2CO_3 + H_2O$ with the use of Ni or Pt cathodes and Pt anodes. The gamma spectra revealed NT in Pt cathode into Os, Ir, Au and Pt isotopes which do not exist in nature. In addition to these data on NT, they observed decrease of 2.22 MeV gamma ray emitted by a reaction

$$n + p = d + \gamma(2.22 \text{ eV}).$$

This result was interpreted by the authors to represent the decrease of the thermal neutron capture of hydrogen (in the system) during electrolysis, i.e. the decrease of neutrons in the cell by electrolysis. The decrease of the counts at 2.225 MeV seemed them to be caused by some neutron capture occurring during electrolysis. The decrease of 3.8 x 10^{-4} cps found to be corresponding to 3 events/s taking account of the efficiency of the used gamma spectrometer for the neutron capture equal to 10^{-4}.

This interpretation by the authors seems reasonable, although they did not identify the mechanism of neutron trapping in their experimental system. This point will be discussed on our point of view in the next section.

2.4 Lipson et al.[13]

Lipson et al. in the NHE Laboratory, Hokkaido, Japan measured gamma ray spectrum during electrolysis of Cu cathodes and a Pt anode in the 1 M KOH + H_2O electrolyte under artificial thermal neutron irradiation. To create neutron flux, the ^{252}Cf neutron source with intensity of about 2 x 10^3 n/s in 4 π solid angle had been used. For thermalization of neutrons inside electrolytic cell, the set up with a detector was surrounded by of about one metric tone of moderator (polyethylene and water).

In the experiments, some increase of gamma counting rate in the foreground runs was detected within the energy interval 1031 ~ 1047 keV that corresponds to ^{66}Cu 1039 keV gamma peak's position. Simultaneously, the decrease of 2.225 MeV peak due to thermal neutron capture by hydrogen was observed.

In the foreground runs with long duration ($t \geq 12000$ s), negative result for the 1039.4 keV peak was observed where difference of counts (foreground minus background runs) was negative. This data was interpreted by the authors that the peak near the 1039.4 keV position was really a signature of ^{66}Cu generation by an absorption reaction of the thermal neutrons

$$n + {}^{64}Cu = {}^{65}Cu^*, \quad (1)$$
$${}^{65}Cu^* = {}^{65}Cu + \gamma(1.39 \text{ MeV}), \quad (2)$$

where the time constant for the gamma decay is 5.1 m.

They said that the effect of ^{66}Cu generation (with the total mean rate v = 1.70 ^{66}Cu/s) is connected with increase in thermal neutron's capture cross section of copper (decrease in 2.225 MeV line intensity in foreground runs) during electrolysis under the thermal neutron irradiation.

Further, they observed that the similar experiments with 100 μm thick Pd foils in 1 M NaOD + H_2O electrolyte had shown significant increase in thermal neutron cross section for these

foils during electrolysis.

Their interpretation of the experimental results on the Cu cathodes was based on the mere change of the absorption cross section of neutrons by ^{65}Cu and had no consistency with the latter result with a Pd cathode. The interpretation should be due to the characteristics of cathodes common to both cases and will be given in the next section.

3. Discussion

In the discussion of the cold fusion phenomenon, it should be kept in mind at least following facts. To accomplish a nuclear reaction where works the nuclear force with an action range ~ 10^{-13} cm, the reactant nuclei must approach each other to a distance of ~ 10^{-13} cm. On the other hand, separation of nuclei in atoms in ordinary materials is several *Å*, i.e. - 10^{-8} cm which is 10^5 times the distance necessary to get work of the nuclear force. Electron confined in this short range of ~ 10^{-13} cm must have an energy of ~ 1 GeV according to the uncertainty principle. On the other hand, phonon in crystals can have the shortest wave length of ~ 10^{-8} cm. Thus, electrons and phonons in solids at room temperature can not work effectively in nuclear reactions there.

In addition to this scale difference, there is another factor, energy difference, to exclude lattice effect on the nuclear reaction in materials. Energy necessary for nuclear fusion in solids is rather large by a factor of order 10^8 than that of ions: It is necessary to accelerate deuteron up to about 1 MeV to induce $d + d$ fusion effectively in vacuum and also in materials where ions move with energies of about 0.025 eV (at 300 K). The difference of 10^8 in the relevant energies in addition to that of force ranges tells us that it is impossible to explain effective $d + d$ fusion reaction in materials by many-body effects of ions and electrons.

It is necessary to confirm an essential point in explanation of the Moessbauer effect, one of typical phenomena in the solid state-nuclear physics. In this case, the energy of the relevant nuclei is the same order of magnitude of the average phonon energy. For instance, ^{67}Zn emits a photon with an energy 93.26 keV which is used in the Moessbauer spectroscopy. In this case, recoil energy of the Zn atom is about 7.0 x 10^{-2} eV, which corresponds to a thermal energy at a temperature 840 K, about three times room temperature.

In consideration of neutron interaction with materials, it should be also noticed that a neutron with thermal energy ~ 0.025 eV has a de Broglie wave length of 1.4 x 10^{-8} cm, which is the same order of magnitude of distances between atoms in molecules and solids. This is the reason neutron diffraction is in effect widely for ordinary crystals using thermal neutrons.

One more thing noticed: that the interaction of neutrons with materials are due to either the nuclear force or to the magnetic force, the former has short range of order ~ 10^{-13} cm and the latter is weak for individual atoms and nuclei. The interaction through the nuclear force has two phases corresponding to duality of the neutron as a quantum mechanical particle. In the case where the neutron behaves as a particle for a nucleus the nuclear force appears as a strong attractive force with a range of - 10^{-13} cm. On the other hand, in the case where the neutron behaves as a wave with a de Broglie wave length fairly

longer than the range of the nuclear force, a concept of diffractive index of a medium, an average effect of the interaction through nuclear force between a neutron and nuclei in it, becomes effective. Neutron diffraction by crystals and the diffraction of neutrons at a boundary of two media are the phenomena showing the second feature.

In general, in the treatment of the cold fusion phenomenon, the various situations summarized above have been obscured and mixed up, often introducing confusion into discussions. We have to express our comment on them that the thermal neutron in the cold fusion materials should be treated as a wave before it undergoes fusion with any nucleus in it and two phases of its interaction with matter should be treated properly depending on the situation.

Two examples will assist understanding of this situation. First, it was natural to consider neutron trapping by artificially arranged crystals[14] on the line extrapolated from neutron diffraction. Second, in the paper[10] introduced above, Lipson et al. cited a description from a book[11] on the low energy neutrons that thermal neutron is trapped in a polyethylene wall (..... the neutrons thermalized inside the polyethylene shielding can repeatedly cross (several tens of times) the same plane (crystal), undergoing internal reflections from the polyethylene walls).

Now, we return to discussion of the experimental data introduced in the previous section. From the investigation given above, it is clear that trapping of neutrons occurs by the short-range nuclear interaction 1) in a small region with nuclear size by a nucleus and 2) in a sub-macroscopic (~ 1 /μm) or macroscopic region by a group of nuclei. We investigate the above experimental data from this point of view.

3.1 Data by Cerofolini et al.[9]

This data is different from others in the absence of solid in the system. Only sub-macroscopic structure relevant with neutron trapping will be oil dispersion of KH and KD if they are not completely dissolved. If the colloidal particle of KH or KD has a dimension of ~ μm, the condition for thermal neutron trapping is fulfilled. Interfaces between the solute and the solvent must be the reflection planes to trap thermal neutrons. The particle may be solid or liquid, depending on the situation in the system, although we have no data to infer further.

3.2 Data by Lipson et al.[10]

In the experiment with TGS it is clear that there was a ferroelectric phase change in the thermocycle and ferroelectric domains were formed in the sample. The size of these domains may be macroscopic or sub-macroscopic to be responsible for the neutron trapping. Domain walls must be reflection planes for the neutron trapping.

3.3 Data by Notoya et al.[12]

In the electrolytic experiment with Pt cathode, an alkaline metal (K in this case) surface layer is formed on the cathode with a thickness ~ 1 μm or more. This layer must be the reflection plane for the neutron trapping, as our analyses of various data have shown. The neutrons trapped in the cathode play the key role in the cold fusion phenomenon as the TNCF model has clearly shown with a consistent analyses of more than 50 experimental data.

3.4 Data by Lipson et al.[13]

The same thing is also said of this data as those of Notoya et al. In the electrolytic system, the surface layer of electrolyte metal on the cathode is most important for the cold fusion phenomenon. As we have already pointed out, compatibility of a cathode and an electrolyte is a well-known decisive factor for the success of cold fusion experiments. Pd - Li and Ni - K combinations are typical examples.

Thus, the data introduced in the preceding section fits with the trapping mechanisms proposed in the TNCF model[15,16] of the total reflection of neutrons at boundary of two media and the band structure effect for neutron trapping. Details will be given elsewhere.

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