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Neutron Emission in the Cold Fusion Phenomenon

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Abstract

The physics of the cold fusion phenomenon (CFP), i.e. low energy nuclear reactions in solids including high density hydrogen isotopes at near room-temperature in a non-equilibrium condition including ambient radiations, has not yet been given appropriate explanations in spite of abundant experimental data obtained in these more than twenty years. We focus on the nature of neutrons from cold fusion (CF) materials observed in these years to investigate mechanisms relevant to nuclear reactions responsible to the neutron emission.

In the data sets by Jones et al. (1989), Shani et al. (1989), Takahashi et al. (1990, 1991), Bressani et al. (1991, 1992), and Okamoto et al. (1993) obtained in the early stage of this field, we point out the energy spectrum of the emitted neutrons extends more than about 7 MeV – which is consistent with recent observation of neutrons with more than 9.6 MeV by Szpak et al. (2008).

The data from De Ninno et al. (1989) shows the bifurcation aspects of the CFP as pointed out by us (1999). The neutron vs. tritium ratio N_n/N_t of about 10^{-6} to 10^{-9} observed by Srinivasan et al. (1990) accords with our model ($\approx 10^{-7}$) and is a manifestation of the mechanism relevant to the nuclear reactions simultaneously generating triton and neutron in the CF materials.

There are decisive evidences of the thermal neutron effect on the neutron emission, (1) null results obtained by Ishida (1992), Jones et al. (1994), Forsely et al. (1998), and (2) enhancements obtained by Shani et al. (1989), Celani et al. (1992), Stella et al. (1993).

The neutron energy spectra extending up to about 10 MeV and the existence of the CFP in protium systems exclude the *d-d* fusion from fundamental nuclear reactions responsible for events in this phenomenon. We have presented therefore a phenomenological model with a single adjustable parameter that is able to give explanation of the experimental facts depicted above qualitatively and sometimes

semi-quantitatively.

In this paper, we give explanation of the characteristics of the neutron emission, existence of neutrons with energies up to 10 MeV, the bifurcation of temporal evolution and N_n/N_t ratio of the order of 10^{-6} to 10^{-9}, using concepts developed in the phenomenological explanation of events in the CFP as results of complexity in the CF materials composed of agents (nuclear species) interacting nonlinearly.

1. Introduction

The cold fusion phenomenon (CFP) stands for "nuclear reactions and accompanying events occurring in solids with high densities of hydrogen isotopes (H and/or D) in ambient radiation" belonging to the Solid-State Nuclear Physics (SSNP) or the Condensed Matter Nuclear Science (CMNS). To confirm existence of nuclear reactions in solids at near room temperature, one of the most decisive evidences is detection of neutrons, one of the direct evidences of the nuclear reaction [*Science* Section 2.2.1.1], emitted by the solids as have been performed from the beginning of the cold fusion (CF) research in 1989.

Jones et al. [1.1] observed neutron emission from a TiD_x (x ≈ 2) sample charged deuterium by electrolytic method in the Ti/(D_2O + LiOD)/Pt system showing existence of neutrons with energies from 2.5 up to 8 MeV. At first the data obtained by Jones et al. were considered to show the existence of the *d-d* fusion reaction generating 2.5 MeV neutrons corresponding to the most significant peak in the observed energy spectrum. Later experiments by others [1.2 – 1.7], however, have shown existence of higher energy neutrons up to ~ 10 MeV not only in deuterium but also protium systems. Looking into the spectrum shown in the paper by Jones et al., we notice several small peaks above 2.5 MeV which may be signals corresponding to higher energy neutrons observed later. Recently, Szpak et al. [1.8, 1.9] obtained an interesting data showing existence of neutrons with energies more than 9.6 MeV consistent with previous data sets.

On the other hand, the temporal behavior of neutron emissions show another feature of nuclear reactions resulting in the neutron emission. The data sets obtained by De Ninno et al. [1.10] have shown statistical behavior of the nuclear reactions in the CF materials. Similar data was obtained by Menlove et al. [1.12] The data sets by Srinivasan et al. [1.11] also have shown temporal evolution of neutron emission and tritium production and also the tritium- to-neutron yield ratios in the majority of these experiments were in the range of 10^6 to 10^9 in accordance with our theoretical value $N\mathrm{t}/N\mathrm{n} \approx 10^7$.

Battaglia et al. [1.13] have shown the possibility to estimate that about one reaction with neutron emission occur every 10^{11} reactions in the NiH_x system which has been used to investigate the CFP by their group for more than 10 years.

The data by De Ninno et al. have shown behaviors similar to those discovered in complexity and suggest nonlinear interactions in open and nonequilibrium CF materials resulting in the CFP.

In relation to the mechanism of nuclear reactions in CF materials at near room temperature, it is necessary to recognize the decisive role of thermal neutrons on the neutron emission. Shani et al. [1.14], Celani et al. [1.15], and Stella et al. [1.16] have shown that the existence of the thermal neutrons has induced a positive effect on the neutron emission from the PdD_x samples. On the other hand, Ishida [1.17], Jones et al. [1.18], and Forsely et al. [1.19] have obtained null results when there are no background thermal neutrons. These data sets have given an evidence of the decisive role of thermal neutrons in the CFP.

It is helpful to investigate experimental data sets showing neutron emissions from solid materials including high-density hydrogen isotopes (CF materials) from a point of view consistent with nuclear and solid-state physics to give quantum mechanical explanation of nuclear reactions in them. In this paper, we introduce typical data sets including recent ones and give unified explanation consistent with known knowledge of modern solid-state and nuclear physics.

2. Experimental Data

In these 21 years since the discovery of the cold fusion phenomenon (CFP), very many experimental data sets ranging from excess heat to nuclear transmutation including neutron emission and gamma ray emission have been obtained increasing its variety of experimental conditions and measuring techniques. However, the variety of the experimental data has not met with appropriate theoretical counterparts. We have presented a phenomenological model with an adjustable parameter based on experimental data successfully explaining experimental data qualitatively and semi-quantitatively [2.1 – 2.3].

The experimental data on the neutron emission are divided into two types, one with energy spectrum and the other without it.

2.1. Energy Spectra of Emitted Neutrons

The energy spectra of neutrons emitted from CF materials, TiD_x, PdD_x, NiH_x, have been considered as one of key evidences of nuclear reactions in the system and investigated from the first stage of the research.

The data by Jones et al. [1.1] is the first one which had shown existence of 2.5 MeV neutrons in the spectrum of neutrons from TiD_x (Fig. 2.1). In their spectrum, however, there are indefinite signals showing higher energy neutrons up to about 10 MeV.

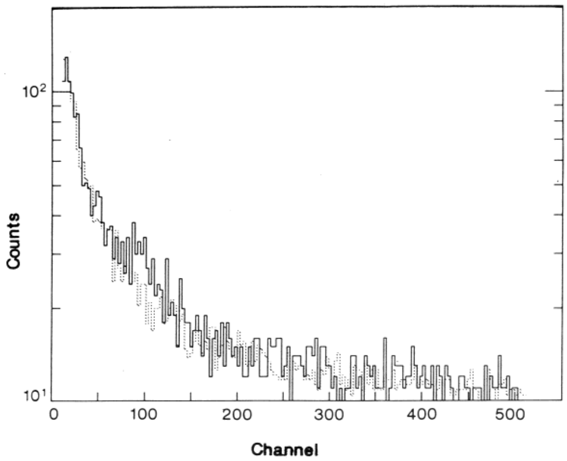

Fig. 2.1 Energy spectrum of emitted neutrons from TiD_x by Jones et al. [1.1]

At the same period, Shani et al. [1.14] measured neutron energy spectrum from a neutron irradiated PdD_x target to show a role of background neutrons to the emission of neutrons from the sample. However, in contrast to their purpose, they had shown enhancement of the reaction rate in PdD_x compared with the gaseous D_2 target.

The existence of higher energy components in the energy spectrum has been shown by Takahashi et al. [1.2 – 1.3] (Fig. 2.2), Bressani et al. [1.4 – 1.6] (Fig. 2.3), Okamoto et al. [1. 7] in the early period of the research.

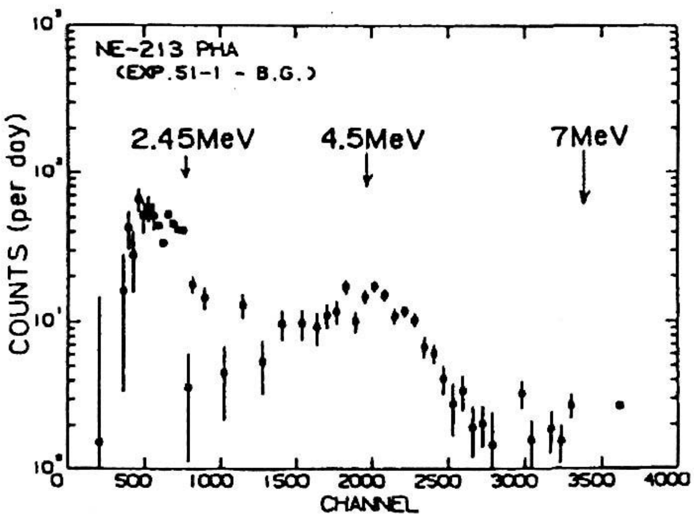

Fig. 2.2 Energy spectrum of emitted neutrons from PdD_x by Takahashi et al. [1.2]

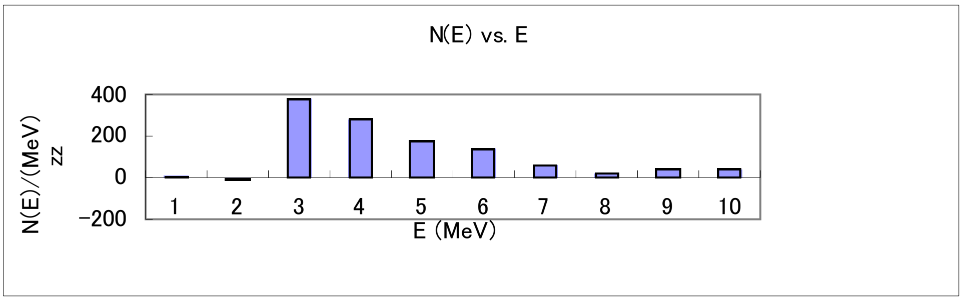

Fig. 2.3 Energy spectrum of emitted neutrons from TiD_x by Bressani et al. [1. 4]

Mosier-Boss et al. [1.8, 1.9] have obtained a new clear evidence showing existence of high energy neutrons with energies more than 9.6 MeV by a different method after similar to the above ones had been obtained by several researchers. In their data [1.9], the presence of three α-particle tracks outgoing from a single point is diagnostic of the $^{12}C(n, n')3\alpha$ carbon break up reaction and is easily differentiated from other neutron interactions occurring within the CR-39 detector. The presence of triple tracks suggests that DT reactions that produce ≥9.6 MeV neutrons are occurring inside the Pd lattice.

2.2. Neutron Bursts

On the other hand, the numbers of emitted neutrons have shown different features of the nuclear reactions in CF materials. The first data of this type was obtained by De Ninno et al. [1.10] followed by Menlove et al. [1.12] in TiD_x systems. In the data obtained by De Ninno et al., two interesting features (Figs. 2.4 and 2.5) exist which are analyzed in the next section.

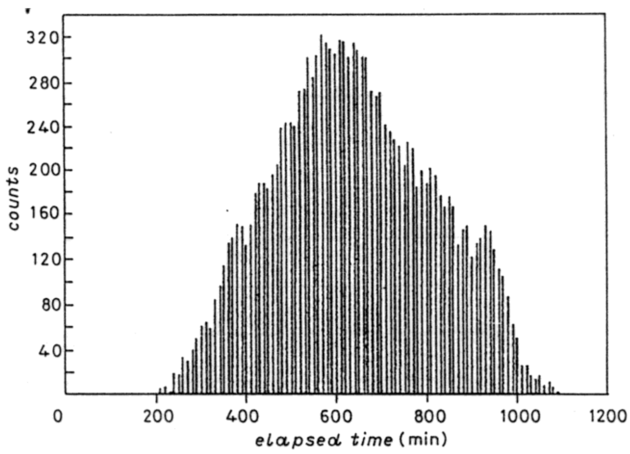

Fig. 2.4 Temporal evolution of neutrons by De Ninno et al. [1.10]

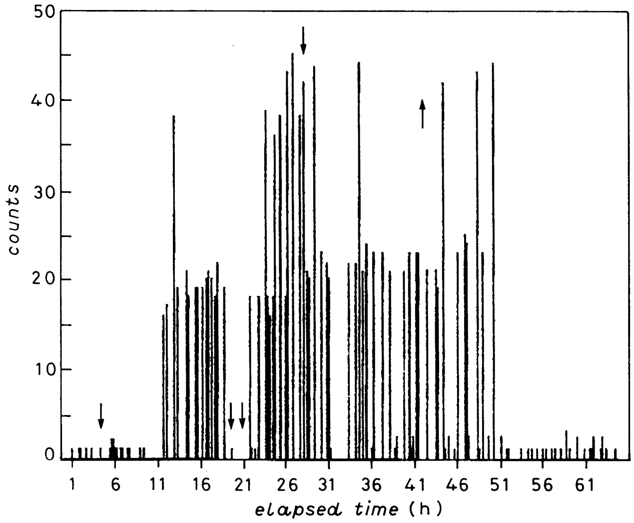

Fig. 2.5 Temporal evolution of neutrons by De Ninno et al. [1.10]

Similar neutron emission pattern was obtained by Iyengar et al. in PdDx systems (Fig. 2.6).

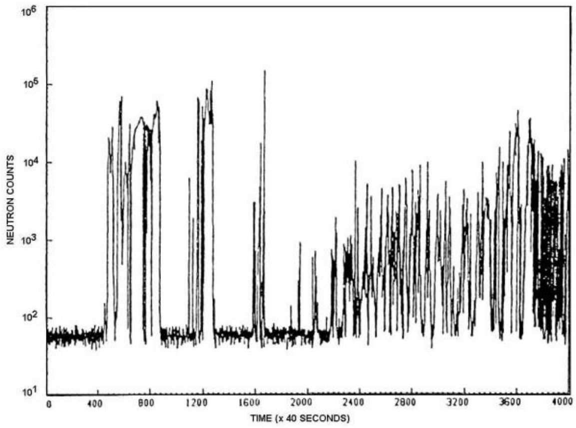

Fig. 2.6 Temporal evolution of neutrons by Iyengar et al. [1.11]

There are several investigations on the number of neutrons in relation to other events as tritium generation and excess heat.

Iyengar et al. [1.11] observed simultaneous production of neutrons and tritium (Fig, 2,7) in a Pd-Ag alloy/NaOD/D_2O system and also concluded that the neutron-to-tritium yield ratios in the majority of these experiments were in the range of 10^{-6} to 10^{-9}.

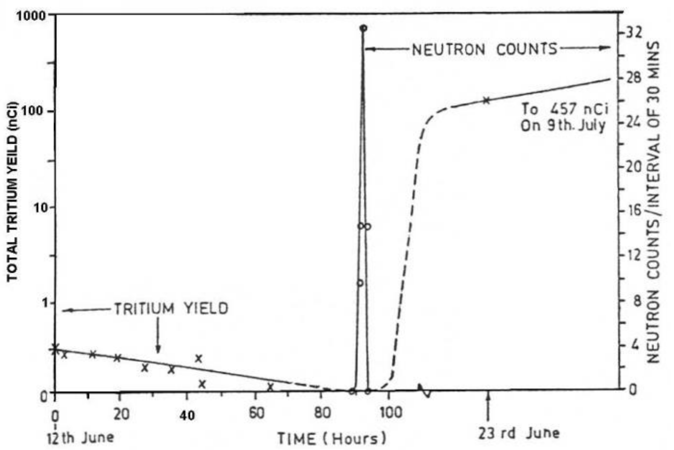

Fig. 2.7 Generation of neutron and tritium in a $PdAgD_x$ system.

Battaglia et al. [1.13] observed neutron emission in Ni-H gas contact systems and concluded that the neutron flux is correlated with the power excess rate increase instead of the power excess level and a neutron emission occurs every 10^{11} reactions related with excess heat generation.

Keeney et al. [2.4] observed neutron emission from gas and acid loaded TiD_x samples with high reproducibility (40%) in almost no background neutrons. In the process of this experiment, the authors emphasize importance of non-equilibrium condition. This result seems in contradiction with the effect of thermal neutrons described in the end of Section 1. We can guess an effect of non-equilibrium conditions on the neutron band in the host material and formation of the cf-matter in the guest material discussed in our paper [2.5].

Effect of non-equilibrium conditions on the CFP has been observed recently by Celani et al. in NiH_x system for excess heat [2.6].

It should be noticed that the reproducibility of events in the CFP is inevitably qualitative as almost all experimental data sets shows (e.g. Fig. 3 and Table 1 of [2.4]) due to the complexity in the CFP as briefly explained in Subsection 3.2.

3. Analysis of the Experimental Data Sets by the TNCF Model

The experimental data sets introduced briefly in Section 2 tell us various facts related to the physics of the cold fusion phenomenon if we see them from an appropriate point. First of all, we would like to see them as a phenomenon caused by a common cause. This is the reason of our approach to the various events from a unified point of view using a model based on the experimental data as a whole. [2.1 – 2.3]

Some of the earlier data sets have been analyzed from our point of view successfully and we give our analysis of data sets given above using the same artifice.

3.1 Energy spectra of emitted neutrons showing a new mechanism

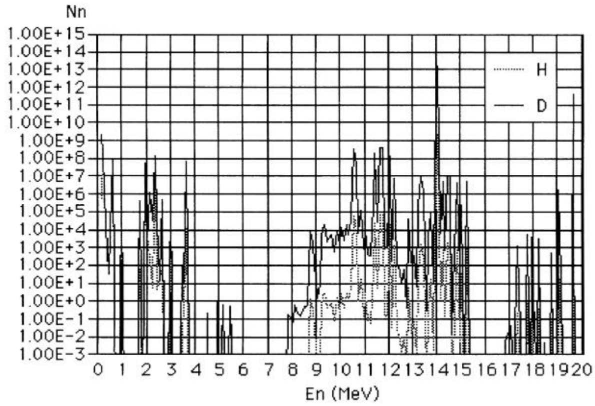

Fig. 3.1 Energy spectrum of neutrons from PdD(H) calculated by simulation. [2.3 Section 3.3.6]

The energy spectra and evidence of high energy neutrons with energies up to about 10 MeV are qualitatively explained by our model as the diagram obtained by simulation shows (Fig. 3.1, [2.3, Fig. 3.1]).

This is a decisive evidence of a new mechanism to induce neutrons in CF-materials other than *d-d* fusion reactions supposed to be fundamental nuclear reactions working in the CFP. The nuclear reactions catalyzed or participated by neutrons in the material may be responsible to the CFP as the simple simulation illustrated in Fig. 3.1 shows.

3.2 Complexity exhibited by neutron bursts

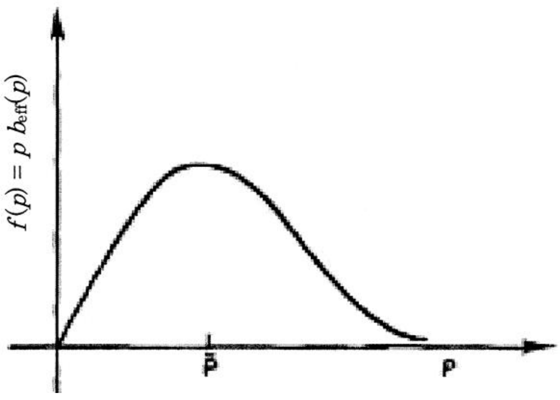

Fig. 3.2 Recursion function $f(p)$ as a function of a variable p: $f(p) = pb_{\rm eff}(p)$

On the other hand, the temporal evolutions of neutron emission depicted in Figs. 2.4 and 2.6 remind us the recursion function $f(p)$ appeared in Feigenbaum's theory [3.1, 3.2]. These data by De Ninno et al. [1.10] and Iyengar et al. [1.11] are a rare fortunate gift exhibiting a nature of nuclear reactions as complexity. The point of view including this factor of complexity has been useful in investigation of the CFP. [3.1, 3.2]

4. Discussion and Conclusion

The experimental data sets showing neutron emission from TiD_x, PdD_x, and NiH_x samples a part of which have been introduced in this paper give clear evidence of nuclear reactions in the CF materials composed of transition metals and hydrogen isotopes. The occurrence of the nuclear reactions resulting in neutron emission in protium and deuterium systems is a decisive evidence of new mechanisms other than *d-d* reactions supposed to be a cause of the CFP by the pioneers of this wonderful field.

As our simple simulation depicted in Fig. 3.1 [2.3] shows, a mechanism participated by neutrons may give a clue to resolve this riddle if we seek a common cause for the CFP both in protium and deuterium systems. The TNCF model proposed by us [2.1 – 2.3] is a trial to explain various observations of physical quantities in the CFP from a unified point of view. The trial is fairly successful giving qualitative and sometimes semi-quantitative explanations for observables in the CFP.

The quantal investigation of the bases of the TNCF model has been employed by us [2.2 – 2.3] using novel data in nuclear physics, solid-state physics and catalytic chemistry. The work has been primitive at present but seems a step to understand the complex feature of the CFP.

It is also helpful to see the CFP from the viewpoint of complexity. We have shown existence of several laws between observables of the CFP consistent with the laws in the complexity [3.1 – 3.3].

In conclusion, we can list up the meaning of the experimental results on the neutron emission as follows;

- 1. Neutron emission with neutron energies *En* up to 10 MeV from CF materials has been observed in TiD_x, PdD_x, and NiH_x systems. Thermal neutron effects (null result and enhancement) are confirmed.
- 2. We have to discover a mechanism applicable to these events in deuterium and protium systems if we seek a common cause for the neutron emission in the CFP.
- 3. Our TNCF model gives a possible mechanism applicable for the both systems.
- 4. Some features of the neutron emission have similarity to the behavior of complexity revealed by logistic difference equation (l.d.e.) as shown in our papers.
- 5. This characteristic of neutron emission suggests nonlinear interaction between

agents in the guest material resulting in events of the CFP including nuclear transmutation and neutron emission and therefore excess energy generation.

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