Analysis of the First Cold Fusion Experiment Using the TNCF Model

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Abstract

The first experimental data on cold fusion by Fleischmann etal. in 1989, which had disclosed the existence of many nuclear reactions in solids at room temperature, are here investigated using the trapped neutron catalyzed fusion (TNCF) model. The surprisingly large excess heat and comparatively small amount of tritons and neutrons which were measured and the observation of some ^{4}He done later can be explained consistently by nuclear reactions in a Pd cathode surrounded by a surface layer of Li metal and/or a $PdLi_x$ alloy. The potential for an explosion, reported in the first paper, was recognized as a possibility, but with a very small probability.

1. Introduction

Since the first report of the cold fusion by Fleischmann et al.[1] in 1989, supplemented with the data on the detection of helium[2] in 1990, there have been several hundred experimental works showing the generation of excess heat, helium-4 (^{4}He), tritium, neutrons, gamma rays and nuclear transmutation products in various crystals containing hydrogen isotopes. There have been five international conferences and many more regional or national conferences on this theme in these eight years. Proceedings of these conferences are valuable sources of experimental facts, along with papers published in several journals open to this newly born branch of science.

We have investigated the cold fusion phenomenon theoretically and experimentally on the bases of a model[3,4] named TNCF (trapped neutron catalyzed fusion) in which the stable thermal neutrons are assumed to exist in crystals with characteristics of 1) trapping and 2) stabilization of the neutrons.

The model has successfully explained the experimental data showing excess heat and nuclear transmutation[5,6], the excess heat and ^{4}He[7-9], the excess heat in Pd—LiOH+H_2O[10], the excess heat in Pd—LiOD+D_2O[11] and tritium and neutrons in Pd—LiOD+D_2O[12] systems.

The first paper[1] by Fleischmann et al. created considerable confusion in the world of science journalism and the confusion regretfully spoiled communication and the publication of works in the newly born interesting science of cold fusion.

The purpose of this paper is to show the scientific validity of the experiments which laid the foundation of the cold fusion science by using the TNCF model to analyze the original data[1] and the supplemental data of ^{4}He detection[2].

2. Experimental facts

In the first paper by Fleischmann et al.[1], there were too many facts on the cold fusion phenomenon to treat in one paper. We, therefore, will take up several features of the phenomenon in this analysis. With a 0.4 cmϕ x 10 cm Pd cathode there was an excess heat of 1.75W (= 1.75 J/s = 1.1 x 10^{13} MeV/s), and neutron generation of 4 x 10^4/s ; in a sample with a dimension of 0.1 cmϕ x 10 cm, an excess heat of 0.079 J/s and a tritium generation of 4 x 10^{11}/s when the electrolyzing current density was 64 mA/cm^2 (except in the neutron generation case, where the current density was not given).

These data gave a large *t/n* ratio of ~ 10^7 in addition to the high excess energy compared with the amount of tritium and neutrons. If we assume the accepted nuclear reactions needed to produce the excess energy, the ratio of events (excess heat/tritium) becomes ~ 10.

A search for the helium expected to exist in the Pd cathode was made in cooperation with several US laboratories using samples provided by Fleischmann et al. and the results were published about two years later[2]. The amount of helium atoms in the Pd cathode which generated the excess heat was higher than that in the Pd which did not generate excess heat. Though the difference between samples with and without the excess heat had been apparent, the conclusion was ambiguous, not only because of the small amount of helium atoms detected, but also the small but non-zero existence of He in the as-received sample.

3. Analysis using the TNCF model

In the TNCF model we assume the stable existence of thermal neutrons in a crystal with positive neutron affinity[4] surrounded by a solid with a different neutron band structure from that of the matrix.

At first, as an illustration, we will show the process for calculating n_n in the following paragraphs. In the following analysis we'll assume that the cause of the events generating the excess heat, neutrons, tritium and helium 4 are the common ones, even though at times some of the data is lacking.

In the case of a Pd cathode used in electrolysis with Li electrolyte, the surface layers of Li metal and/or $PdLi_x$ alloy have precipitated upon the surface of the Pd cathode with positive neutron affinity. This structure satisfies the condition needed to trap thermal neutrons described above. In the surface layer, the periodicity of the crystal lattice should be substantially disturbed and the neutron Bloch wave trapped in the cathode should suffer a strong perturbation, thereby inducing a fusion reaction with the ^{6}Li in the layer, if any: (1)

$n + {}^6\mathrm{Li} = {}^4\mathrm{He}$ (2.1 MeV) + t (2.7 MeV).

The cross section of this reaction for a thermal neutron is fairly large as ~ 1 barn (= 10^{-24} cm^2). We assume the thickness of the surface layer (of Li metal) as 1 μm in the following calculation.

The triton with 2.7 MeV generated in this reaction can fuse with a deuteron before it loses energy to stop within a range of 1 ~ 10 μm. (let us assume it as 1 μm for simplicity in the following:

$$t\ (2.7\ \mathrm{MeV}) + d = {}^4\mathrm{He}\ (3.5\ \mathrm{MeV}) + n\ (14.1\ \mathrm{MeV}). \quad (2)$$

The cross section of this reaction for a triton with 2.7 MeV is also ~ 1 barn.

Using the experimental data on the generation rate of tritons $N_t = 4 \times 10^{11}$/s, we can determine the density n_n of the trapped neutrons in the cathode. Let us assume that the thickness l_0 of the surface layer composed of Li metal as 1 μm and use a following relation between N_t and n_n:

$$N_t = 0.35\, n_n\, v_n \rho_{6_{Li}} l_0 S \sigma_{nLi} \qquad (3)$$

where $\rho_{6_{Li}}$ is the density of ^{6}Li nucleus in the layer, S is the surface area of the cathode, v_n is the thermal velocity of the trapped neutrons and σ_{nLi} is the fusion cross section of the neutrons and $_6$Li nucleus; $\rho_{6_{Li}} = 3.5 \times 10^{21}$ cm^{-3}, $l_0 = 10^{-4}$ cm, $v_n = 2.7 \times 10^5$ cm/s (T = 300 K), $\sigma_{nLi} = 1 \times 10^{-24}$ cm^2, S = 12.8 cm^2.

The relation (3) gives us the density of the thermal neutrons in this Pd cathode in the experiment[1] (where the natural abundance of ^{6}Li in LiOD was assumed): $n_n = 9.7 \times 10^{11}$ cm^{-3}.

Thus we can determine the density of the trapped neutroms from the experimental data of the excess heat (power), tritium and neutrons independently, and can compare them with each other. In the case of excess heat we will assume for simplicity thet the number of events generating the excess heat Q is given by N_Q - Q (MeV)/5 (MeV), assuming the average liberated energy is 5 MeV. Following is an analysis of the data from Fleischmann et al[1].

First, their data in a 0.1 cmϕ x 10 cm sample generated an excess heat of 0.079 J/s (=4.9 x 10^{11} MeV/s) by reaction (1), which determines the density of the trappen neutrons: $n_n = 1.3 \times 10^9$ cm^{-3} by the relation (3). In this calculation we've assumed that all of the liberated energy is the reaction had been thermalized in the system, i.e. $Q = 4.8$ MeV/reaction.

On the other hand, a sample of the same size which generated 4 x 10^{11}/s of tritium by reaction (1) determines the density: $n_n = 5.0 \times 10^9$ cm^{-3} by relation (3), as explained previously. These two values of the density n_n with a difference of a factor of 4 might be taken as consistent, considering the ambiguity of the experimental conditions.

Second, their data in a 0.4 cmϕ x 10 cm sample showed the generation of 4 x 10^4/s neutrons, which corresponds to the number of tritium of 2.5 x 10^{10}/s (= 4 x 10^4 x 6.25 x 10^3) by reaction (2). This value thus determines the density of the trapped neutrons by the relation (3): $n_n = 1.3 \times 10^8$ cm^{-3}.

On the other hand, the excess energy of 1.75 J/s (=1.1 x 10^{13} MeV/s) observed in the sample with the same size determines the density $n_n = 7.1 \times 10^9$ cm^{-3}. The difference in this case is by a factor of 20 and the coincidence is qualitative perhaps due to the experimental ambiguity.

We can see that all these values for n_n are not unreasonable. We have assumed that the cause of the events were common through the data of the excess heat, tritium and neutrons were not measures using the same cathode, supposing that there would be tritium in the cases of neutron and heat measurements. This may be the truth of the phenomenon in the Pd/D/Li system. From our point of view it might be more reasonable to consider that both reactions (1) and (2) were together in a sample generating excess heat, tritium and neutrons than to consider them occurring independently. We have taken this point of view throughout the analysis of cold fusion data.

Then, we can calculate ratios of the number of events N_Q, N_t and N_n for the same density of n_n. $N_Q \equiv Q(\text{MeV})/5$ (MeV).) Theoretical values of N_t/N_n and N_Q/N_t are 5.3×10^5 and 5.5 respectively. On the other hand, experimental values reduced to the same n_n and the same sample size are $N_t/N_n = 4 \times 10^7$ and $N_Q/N_t = 1.0$ respectively.

These values of the density $n_n = 3 \times 10^5 \sim 7 \times 10^9$ cm^{-3} could be compared with the value $10^{10} \sim 10^{11}$ cm^{-3} obtained in a previous analysis where the heat and helium[8] was measured in the ambient gas outside the Pd cathode. The similarity of the amounts of excess heat in these two experiments should be noticed; in the latter case[8], with a rod cathode, it was ~ 1W, similar in value to 1.75W in the former[1] with a wire cathose(0.4 cmϕ x 10 cm).

The large difference of $n_n = 3.1 \times 10^8$ cm^{-3} (from N_n) and 7.1×10^9 cm^{-3} (from Q) might be an indication of other reactions than neutrons generating the excess heat, as shown in the following equations:

$$d + d = {}^3\text{He} + n + 3.27 \text{ MeV}, \quad (4)$$

$$= t + p + 4.03 \text{ MeV}, \quad (5)$$

$$n + d = t + \gamma + 6.25 \text{ MeV}, \quad (6)$$

$$n + {}^7\text{Li} = {}^8\text{Be} = 2{}^4\text{He} + e^- + \upsilon_e + 16.2 \text{ MeV}. \quad (7)$$

The observed value of the t/n ratio 10^7 can be explained as follows. By the reaction (2), high energy neutrons are generated and observed outside the electrolysis system. Using the cross section $\sigma_{t-d} \sim 1.4 \times 10^{-1}$ barn and taking the path length of the 2.2 MeV triton as ~ 1 μm and the density of deuterium near the surface layer as 6.8×10^{22} cm^{-3}, we obtain a ratio 5.3×10^5 in accordance with the experimental value 10^7 in one order of magnitude.

The coincidence of N_t/N_n ratio will be improved largely if we take into consideration the diference of the sample size and the channeling of tritium in the crystal[14,15]. The difference of the sample size gives a factor of 4 to the theoretical value of the ratio if the current density is the same and the ratio is 2.1×10^6 instead of 5.3×10^5, improving the difference with the experimental value of 10^7.

The channeling also improves the experimental coincidence. There are an array of deuterons on an axis of each channel in which a triton can pass without an energy loss unless it fuses with one of the deuterons there. Therefore, deuterons on the channeling axis are apt to be accelerated by the collision with a triton and the accelerated deutron can feasibly fuse with another deuteron on the axis, with the production of a triton (reaction (5)).

4. Discussion

The analysis given above shows

that the TNCF model can give a consistent understanding of quantitative relations in the cold fusion phenomenon observed hitherto since the first publication[1]; relations between amounts of the excess heat, tritium, helium and neutrons. The fundamental assumption of the trapped neutrons presumed in the model shows its usefulness through the success of the interpretation, though it has not proved its validity from the first principles yet. There may be more experimental results which could be discussed along the same line as the above estimation.

There remains the problem of helium generation[2] which is inconsistent with the excess heat. As we have cited, the helium measured outside of the cathode[8] was comparable in its amount with the tritium analyzed in this paper[1]. It is, therefore, reasonable to consider that the main part of helium produced in the reaction (1) in the experiment with the volume cathode of Pd — LiOD+D_2O experiment[2] had gone out from the cathode. Therefore, the ambiguous result of this helium search could not be taken as a decisive negative factor against the reality of cold fusion in Pd cathode[1].

The excess heat measured for different values of current density i changed depending on the density; for instance, 0.153 W for i = 8 mA/cm^2, 1.751 W for 64 mA/cm^2 and 26.8 W for 512 mA/cm^2 in the case of the sample with 0.4 cmϕ x 10 cm. The amount of tritium generated by the reaction (1) and accordingly the excess heat depend on the thickness of the surface layer, on the density of the trapped neutrons and also on the density of deuterium, especially in the near surface region. There are correlations between these quantities: for instance, the thicker the surface layer of Li metal, the higher the density of trapped neutrons. Therefore, the excess heat depends nonlinearly on the electrolyzing current density in accordance with the experimental result. This feature of the cold fusion by electrolysis was discussed in a previous paper[11] in relation with semi-quantitative result obtained in SRI International.

As we have pointed out in a previous paper[13,14], there is a possible chain reaction induced by a high energy neutron with 14.1 MeV generating gigantic excess energy and a large number of nuclear products in an optimum situation, especially in massive samples. Therefore, an occurrence of explosive heat generation shouldn't be ignored simply because its probability is very small and its occurence is stochastic in nature.

5. Conclusion

Several typical experimental results obtained in electrolysis experiments including the pioneering work[1] have been analyzed using TNCF model which provide a consistent understanding of the physics in the cathode materials.

Though the experiments were done in very different situations, a consistent perspective of the cold fusion phenomenon as given by the model[3] supports the fundamental assumption of the stable existence of trapped thermal neutrons in the palladium or nickel crystal in optimum situations in the explored experimental techniques.

On the other hand, the validity of the model was discussed using conventional Quantum Mechanics[4,15], though it was not quantitative enough. In the investigation the new concepts such as a neutron band in the crystal, a neutron Cooper pair and the neutron affinity of a nucleus were introduced to explain dependence of observed physical quantities on the parameters in different materials.

In conclusion, relations between those physical quantities observed in cold fusion experiments have been interpreted on an assumption which has a probable basis using conventional physics.

This analysis provides solid support for the cold fusion phenomenon using conventional physics.

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Errata:

Page 9, 2nd paragraph: The theoretical values of N_t/N_n and N_Q/N_t should be 1.4 x 10^5 and 1.0 respectively. And the experimental values should be N_t/N_n = 4.0 x 10^7 and N_Q/N_t = 0.25. The same corrections should be made in Table I on page 24 in the line: M. Fleischmann et al: Measured Quantities, N_t/N_n = 4.0 x 10^7, N_Q/N_n = 1.0 x 10^5; Other results, N_t/N_n ~ 1.4 x 10^5, N_Q/N_n ~ 1.4 x 10^5, N_Q/N_t = 1.0.