An Analysis of Cold Fusion Experimental Data Which Produced Both Excess Power and Helium

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Abstract

Experimental data showing the simultaneous production of excess power and helium during D_2 electrolysis using a palladium cathode were analyzed quantitatively on a model proposed by one of the authors (K.H.). As a density of the trapped neutrons in a palladium cathode, a value ~ 1.1×10^{12} ~ 10^{13} cm^{-3} was obtained. The result showed a good coincidence with the former results. In the analysis of the isotope shift data in an electrolysis experiment, the density of the trapped neutrons in the nickel cathode had been determined as 2×10^7 cm^{-3}; while in the case of data producing huge excess heat and high helium density in the Pd-black cathode, the density of the trapped neutrons was estimated as ~ 10^{15} cm^{-3}.

1. Introduction

Among the experimental results on the cold fusion phenomenon, there are several excellent data showing correlation between excess energy and helium produced in the experiments. From such a data we will examine here a quantitative correlation between them[1,2]; The palladium cathode produced as many as 10^{11} ~ 10^{12} atoms/s of ^{4}He per watt of excess power.

This numerical data is enough for us to analyze the experiment on the Trapped Neutron Catalyzed Fusion (TNCF) model proposed by us before[3]. In the model, the fundamental assumption of the existence of stable trapped neutrons in the cold fusion material had been made. To justify this assumption, the interaction of the neutrons and lattice nuclei was analyzed and a new concept "neutron affinity of nucleus" was proposed which had a good correlation with materials where the cold fusion phenomenon occurred[4].

Using this model qualitative analysis has been successfully determined for various experimental data obtained in previous cold fusion research. After the accomplishment of the fundamental concepts of the model, we have analyzed several experimental data quantitatively and obtained splendid results having good consistency between them. The data[5] showing an isotope shift of Sr in an experiment of Rb electrolyte in H_2O with Ni cathode was explained numerically by a factor three and obtained a value of the trapped neutrons of 2×10^7 cm^{-3} in the Ni cathode[6].

The data[7,8] showing generation of huge excess energy and a large amount of helium as high as $10^{20} \sim 10^{21}$ cm^{-3} in Pd-black was analyzed with the model and obtained a density of the trapped neutrons in the cathode as $\sim 10^{15}$ cm^{-3}[9].

The results of this analysis show the validity of the basic assumption of the TNCF model as an explanation of the cold fusion phenomenon. We have several excellent experimental results available to be analyzed by our model. In this paper, we present a result of an analysis using one of best experiments showing a correlation between the excess heat and helium produced in the experiment.

2. The TNCF model

We have developed a model[3,4] based on the existence of stable thermal neutrons in crystals. The neutrons with the thermal energy in a crystal behaves as a wave interacting with nuclei on the crystal lattice. The state of the thermal neutrons in a crystal is a Bloch wave with a band structure in the energy spectrum. A neutron Bloch wave in a crystal may be trapped in the crystal if the crystal is surrounded with another crystal having a different band structure. A neutron in a crystal with an energy in an allowed band will be trapped if the energy corresponds to a forbidden energy of the surrounding crystal.

Besides the band structure of a neutron Bloch wave, the interaction results in stability of the neutrons against the beta decay and against the capture by a nucleus if the neutron affinity[4] of the crystal is positive and large. There are several experimental results showing the neutron trapping by crystals[10,11].

If stable neutrons trapped in a crystal suffer a strong perturbation induced by disorder of the crystal potential working on the neutrons, the neutrons become unstable and can be captured (or reacted on) by a nucleus causing the perturbation. As a result of the capture (or reaction) there appear nuclear products and the excess energy as shown by direct experimental results[12-16].

In the electrolytic system showing the cold fusion phenomenon the situation will appear where the distribution of deuterons in the cathode metal becomes inhomogeneous or where ^6Li (^{87}Rb) atoms distribute randomly in the surface layer of Li (Rb) metal on the Pd (Ni) cathode.

In the system with Pd cathode and $LiOD+D_2O$ electrolyte solution, the most realizable reaction is between the thermal neutron and ^6Li with a large cross section of ~ 1 barn[17]: (1)

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

The triton with 2.7 MeV generated in this reaction (1) can pass through the crystal along the channeling axis on which is an array of occluded deuterons or can proceed a finite path with a length determined by the interaction with charged particles in the crystal. On these processes, the triton can fuse with a deuteron with a cross section ~ 1.4×10^{-1} barns[18]: (2)

$$t\,(2.7\text{ MeV}) + d = {}^4\text{He}\,(3.5\text{ MeV}) + n\,(14.1\text{ MeV}).$$

A neutron with 14.1 MeV generated in this reaction (2) can interact with particles, especially with deuterons in the crystal elastically giving a large amount of energy to the deuteron and inelastically dissociating it or fusing with it:

$$n + d = n' + d',$$
$$n + d = n' + p + n'',$$
$$n + d = t + \gamma + 6.25\text{ MeV},$$
$$n + {}^7\text{Li} = {}^8\text{Be} = 2\,{}^4\text{He} + e^- + n_e + 16.2\text{ MeV}.$$

The deuteron having an energy up to 12.5 MeV accelerated elastically by the neutron can fuse with another deuteron in two modes with a fairly large cross section of the order of 0.1 barn[18].

$$d + d = t\,(1.01\text{ MeV}) + p\,(3.02\text{ MeV}),$$
$$= {}^3\text{He}\,(0.82\text{ MeV}) + n\,(2.45\text{ MeV}).$$

Depending on the situation in the cold fusion system, the trapped thermal neutrons can induce trigger reactions like the reaction (1) and the generated energetic particles sustain breeding chain reactions (2) ~ (4), (7) and (8) producing a lot of the excess heat and the nuclear products.

3. Experimental Results

In the paper showing the correlation of excess heat and helium production, experimental procedure was explained without ambiguity[1,2]. We can trust their result with confidence. Essential results pertinent with our analysis are summarized as follows: The palladium cathode in a shape of the rod had the area $S = 2.6\text{ cm}^2$ producing ^{4}He $10^{11} \sim 10^{12}$ atoms/s per watt of excess power.

Contrary to the case of the double-structure cathode containing Pd-black inside where the generated helium was piled up in the Pd-black particles, the helium was observed in the electrolysis gas in the above experiment. Therefore, we have to assume that the reaction generating the observed helium was occurring in surface layer of the Pd cathode where Li metal was precipitated by electrolysis.

Then, we can formulate our problem in the scheme of TNCF model as follows.

The relation we have to use first in the analysis is the reaction (1) given in the preceding section. The reaction (1) is induced by thermal neutrons trapped in the sample (and some thermal neutrons from outside) with a cross section ~ 1 barn and release a reaction energy $Q_1 = 4.8$ MeV at the outer surface of the cathode where PdLi alloy and Li metal layers are formed by electrolysis.

In this reaction, neither high energy neutrons nor gammas are generated, in agreement with the well known fact that there were negligible neutron and gamma emissions compared with the thermal effects.

The neutrons generated in the reaction (2) interact with deuterons in the sample and solution and Pd nuclei in the sample. High energy neutrons make mainly elastic collisions losing their energy to become thermal neutrons. A deuteron accelerated by the elastic collision with a high energy neutron can make inelastic or fusion reactions with another deuteron or a nucleus in the cathode generating energy and particles. Neutrons generated in this process can be thermal neutrons losing their energy to maintain the fusion reaction (1).

In addition to the reactions (1) and (2) taken up above, there is reaction (6), which is pertinent with the present experiment. The cross section of the first reaction in (6) is not so large (~ 7 x 10^{-2} barns for thermal neutrons), but the abundance of ^{7}Li (92.5%) is higher than that of ^{6}Li (7.5%). If the cycle of reactions starting from the reaction (1) to (8) is effective, the main source of ^{4}He will be a reactions (1) and (2). Otherwise, the reaction (6) will play an important role in the helium generation. We will concentrate our attention on the cycle started from reaction (1) in this paper.

4. Numerical relation between observed quantities.

Now, let us consider numerical relations between the reactions occurring in the system.

Let us define a probability P_2 and P'_2 of the occurence of reaction (2) following the reaction (1) in the sample and in solution, respectively:

$$P_2 = \zeta \rho L \sigma_{td}, \qquad (5)$$
$$P'_2 = \zeta' \rho' L' \sigma_{td}, \qquad (6)$$

where ζ and ζ' are the relative number ratios of tritons going inwards and outward ($\zeta + \zeta' = 1$), respectively, to generated tritons, ρ and ρ' are the densities of deuterium in the sample and in solution, L and L' are the path length of the triton in the sample and solution, respectively, and σ_{td} is the fusion cross section of the reaction (2) at an energy range from 0.1 ~ 2.7 MeV.

For one reaction (1), the reaction (2) occurs P_2 times in the sample and P'_2 times in solution. Some of the neutrons generated in the reaction (2) will induce several reactions and produce energy Q_3 and Q'_3 as a whole in the sample and in solution, respectively. Total energy ε generated by the successive reactions started from the first reaction (1) is expressed as follows:

$$e = Q_1 + P_2 Q_2 + Q_3 + P'_2 Q_2 + Q'_3. \qquad (7)$$

In this equation, we put values Q_1 = 4.8 MeV and Q_2 = 17.6 MeV, respectively, assuming all energy generated by reactions (1) and (2) is thermalized in the system.

Total excess energy generated in the sample through the time T, in which occurred n events of the reaction (1), is given as:

$$E = N\varepsilon. \qquad (8)$$

The number of helium atom N_h created at the surface of the sample and in solution, which is observed in this experiment, is given, then,

$$N_h = N\,(1 + P_2 + P'_2). \qquad (9)$$

Let us estimate the number ν_1 of reactions (1) per unit of time. Because we consider the reaction (1) induced mainly by the trapped thermal neutrons in the sample (neglecting the effect of the thermal neutrons from outside), ν_1 is given as follows:

$$\nu_1 = 0.35\, N_n v_n \rho_{Li6} l_0 S \sigma_{nLi}, \qquad (10)$$

where $0.35 N_n v_n$ is the flux density of the thermal neutrons (cm^{-2}s^{-1}), N_n and v_n are the density and the thermal velocity of the trapped neutron, respectively, l_0 and S are the width and the area of the surface layer of the cathode, where Li atoms are precipitated forming Li metal or absorbed forming $PdLi_x$ alloy layers, ρ_{Li6} is the density of ^6Li nucleus in the layer and σ_{nLi} is the fusion cross section of the thermal neutron with ^6Li nucleus.

Then, the number ν_2 of the reaction (2) in solution in unit time is given as follows:

$$\nu_2 = \nu_1 P'_2. \tag{11}$$

The helium atoms observed in this experiment are those generated at the surface and in solution. Therefore, we have following relations among the number N of the reactions (1), the total excess energy E, the observed number of helium atoms N_h, and the time of experiment T,

$$E = N\varepsilon, \tag{12}$$

$$N_h = (N_1 + N'_2)\, T, \tag{13}$$

Taking a path length of 2.7 MeV triton $L' = 1\ \mu m$, and $\rho = 6 \times 10^{22}\ cm^{-3}$ for heavy water, we obtain $P'_2 = 3.4 \times 10^{-6}$ with $\sigma_{td} = 1$ barn. A similar value is obtained for P_2 in the cathode. This means there is generated 3.4×10^{-6} neutrons with 14.1 MeV in solution for one triton or for one thermal event generating an energy of 4.8 MeV. The smallness of this value of the probability gives an answer for the main puzzle of negligible neutron and gamma emission compared with the thermal effects: $N_hN_n \sim 1 \times 10^7$, where N_n is a number of events generating neutrons. Therefore, we may assume $P_2 = P'_2 = 3.4 \times 10^{-6}$ for simplicity, considering the similarity hereafter in the sample and solution.

Then, the relations we can use with experimental data reduce as follows:

$$E = N_h\varepsilon, \tag{14}$$

$$N_h = N = \nu_1 T. \tag{15}$$

Using experimental values $N_hT = 10^{11} \sim 10^{12}\ s^{-1}$ for $E/T = 1$ J/s, $S = 2.6\ cm^2$, the neutron thermal velocity $v_n = 2.7 \times 10^5$ cm/s, density of ^6Li $\rho_{Li6} = 3.5 \times 10^{21}\ cm^{-3}$ (for Li metal with natural abundance of ^6Li), $\sigma_{nLi} \sim 1$ barn, we obtain following values:

$$N_n l_0 = 1.1 \times 10^8 \sim 10^9\ cm^{-2}.$$

Assuming the width l_0 of the surface layer of Li metal as 10^{-4} cm, we obtain the density of trapped neutrons in the Pd cathode,

$$N_n = 1.1 \times 10^{12} \sim 10^{13}\ cm^{-3}.$$

In the above calculation, we assumed constancy of the neutron density N_n in the sample. In reality, this is not valid. N_n varies and it makes ν_1 and the power generation fluctuate.

Using the values of E, N_n, Q_1, Q_2 and P_2 in the relation (11) and assuming $Q_3 \sim Q'_3$, we can calculate Q_3 as 26 MeV. This value gives us an estimation of the number of reactions the triton with 2.7 MeV induces. If we assume that one nuclear reaction generates about 5 MeV in average, the number of reactions induced by the triton is about five. This value is not absurd considering a model calculation given before[19].

5. Conclusion

In the fine experimental result by Miles et al.[1,2], there is one ambiguity about the rate of ^4He production, 10^{12} to 10^{13} atom/s. In our model of the cold fusion, the reactions are essentially stochastic phenomena having only a qualitative reproducibility. Therefore, even in the excellent experiment[1,2], there should be a fluctuation in the production rate of helium about one or more orders of magnitude. One should not deny the result[1] for the ambiguity of this magnitude.

One of most excellent experimental results analyzed in this paper, together with results analyzed before, gave us an insight into the physics of cold fusion through quantitative analysis.

In a preceding paper[6], we have analyzed an experimental data on the heat and helium generation and obtained a value as $\sim 10^7$ cm^{-3} of the trapped neutron density in Ni cathode with Rb electrolyte in H_2O. In another paper in which analyzed huge excess heat and a large amount of helium generation[9], we obtained a density $\sim 10^{15}$ cm^{-3} of trapped neutrons in the Pd-black cathode with Li electrolyte in D_2O. In the present analysis, we obtained a value $\sim 10^{12}$ in the Pd rod cathode with Li electrolyte in D_2O.

These results show consistency in all the experimental results obtained hitherto and support TNCF model as a working model for analyzing the cold fusion phenomenon. The fundamental assumption made on which the model is based is the stable existence of trapped neutrons in cold fusion materials. Supplementary assumptions were made about the thickness of the surface layer, the constancy of the density of the trapped neutron, and the path length of the tritium with 2.7 MeV. The new concept "neutron affinity of nuclei in lattice" introduced in the model and the success of the analysis verify the existence of such a stable neutron against the beta decay and against the fusion with one of lattice nuclei. At the heart of the concept is the fact that a neutron in a nucleus (e.g. deuteron) is stable, interacting with a proton in it. Why should a Bloch neutron in a lattice interacting with lattice nuclei not become stable if the interaction has some characteristic[4]? This problem is not solved yet. However, as we've seen, the assumption of trapped neutrons explains various experimental data consistently, and makes it impossible to deny its reality.

Our conclusion supports the reality of the experimental result obtained by Fleischmann et al.[20], which have often been a target of controversy. The model tells us that it is possible by chance for some events to occur where enough excess energy is generated to melt the sample in an optimum situation formed by stochastic processes in the sample. Pioneering works often induce misunderstanding and disbelief in people deficit of scientific mind. A part of the pioneering experimental results[20] is analyzed similarly and the result will be published in the following issue.

We hope further experiments will be done taking into account the results of analyses by TNCF model.

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