Excess Heat and ^4He Generation in Pd-black Cathode by D_2O + LiOH Electrolysis

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Abstract

Quantitative analysis of the electrolysis experiments on the D_2O + LiOH using a palladium double-structure cathode with Pd-black and platinum anode. The huge excess heat and a large amount of helium observed in the experiment were analyzed using the TNCF model. The density of the trapped neutrons in the sample determined by the experimental data is consistent with the value determined by other data on the isotope shift.

Introduction

Among the experimental results of the cold fusion phenomenon, the so-called nuclear products are more quantitative microscopically than the excess energy. In the data of the nuclear products there are a few excellent ones showing quantitative results with good reproducibility. The data by Arata et al[1] reported recently show a high helium density ~ 10^{20} cm^{-3} in their sample with a fantastic structure designed with a clever way to catch nuclear products.

The experimental data on the excess heat[2] and the above result analyzed here using the Trapped Neutron Catalyzed Fusion model is consistant with the preceding analysis[3] of the isotope shifts in the experiment with Rb electrolyte[4] in H_2O.

Summary of the Experimental Results

We will give in this section, a survey of the experimental results[1,2] with a specially designed Pd cathode.

With a philosophy that when nuclear fusion reaction occurs in a deuterated host solid, both huge fusion energy and a large amount of helium as the most important nuclear reaction element at least, should be simultaneously observed. Dr. Arata designed a special type of Pd cathode using a double structure with a cylindrical closed container of Pd and palladium powder (Pd black) contained in it. The smallness (400 nm in diameter) of the spherical particle of the powder made it easy to attain the high D/Pd ratio of ~ 1.

Their experiments showed following results.

(1) In the experiment measuring heat they obtained such a huge excess energy of several hundred MJ/cm^3 for several months from the Pd-black sample.

(2) After three years they analyzed the sample which generated the large excess energy and obtained a large amount of helium as high as 10^{20} ~ 10^{21} cm^{-3}.

Because of ambiguity in their papers we have to assume concrete numerical values for the amount of excess energy and duration of the electrolysis so we can analyze them numerically to give the neutron density in the sample in orders of magnitude. We will take following values: the amount of excess energy 300 MJ in the time of the experiment 3 months on the end of 1992, 3 years before the helium detection.

Theoretical Explanation of the Experimental Results by TNCF Model

1) Fundamental relations

Using the TNCF model[5], it is possible to analyze experimental results obtained in cold fusion research. To analyze the data summarized in the preceding section, we can use following reactions:

$$n + {}^{6}Li = {}^{4}He(2.1\ MeV) + t(2.7\ MeV), \quad (1)$$
$$t + d = {}^{4}He\ (3.5\ MeV) + n\ (14.1\ MeV) \quad (2)$$

The reaction (1) is induced by thermal neutrons trapped in the sample (and neutrons from outside) with a cross section ~ 1 barns and a reaction energy 4.8 MeV at the outer surface of the double-structure cathode where PdLi alloy and Li metal layers are formed by electrolysis.

Reaction (2) is induced by tritons generated in the reaction (1) and directed inwards with a cross section ~ 1 barn (at a triton energy more than 0.1 MeV) and an reaction energy 17.6 MeV.

The tritons generated in the reaction (1) go out from and into the sample according to the initial direction. For simplicity and order of magnitude estimation, let us take a half of the tritons generated in the surface layer go into the sample without loss of energy in the layer.

Then, the tritons interact with the deuterons in the Pd lattice and induces the reaction (2). We can calculate the fusion probability using numerical data in nuclear physics.

The neutrons generated in the reaction (2) interact with deuterons and Pd nuclei. High energy neutrons make mainly elastic collisions, losing energy to become a thermal neutrons. A deuteron accelerated by the elastic collision with the neutron can make inelastic or fusion reactions with another deuteron or nucleus generating energy and particles.

Neutrons generated in this process supply thermal neutrons to maintain the fusion reaction (1).

2) Relations related with present experiment.

Now, let us consider numerical relations in the reaction occurring in the system of Arata's experiment.

Let us define a probabilities P_2 and P_3 of the occurence of reaction (2) in the sample and in the electrolytic solution, respectively, following the reaction (1):

$$P_2 = \zeta \rho L \sigma_{td} \quad (3)$$

$$P_2 = \zeta' \rho' L' \sigma_{td} \quad (4)$$

where ζ and ζ' are number ratios of tritons going inwards and outward to generated, ρ and ρ' are the densities of palladium in the sample and in the solution, L and L' are the linear dimensions of the sample and the solution, respectively, and σ_{td} is the fusion cross section of the reaction (2) at an energy range from 0.1 ~ 2.7 MeV. We have values $\rho/\rho' = 2.2$, $\zeta/\zeta' \sim 1$ for the parameters. Then assuming $L/L' = 2$ for the order of magnitude estimation (taking into consideration of triton channeling in crystal), we have $P_2 = P_3$. For simplicity, we will take up only reactions occurring in the sample, hereafter.

For one reaction (1) occured, the reaction (2) in the sample will occur P_2 times and some of the neutrons (η out of 1) generated here will induce several reactions between deuterons and lattice nuclei. Denoting energy generated by the neutron as ηQ_3, total energy e generated by the successive reactions started from the first reaction (1) is expressed as follows:

$$\varepsilon = Q_1 + P_2 (Q_2 + \eta Q_3). \qquad (5)$$

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

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

$$E = N\varepsilon \qquad (6)$$

The number of helium atoms N_h created in the sample is given, then,

$$N_h \equiv n_h V = NP_2 \qquad (7)$$

where n_h is the density of the generated (and remaining there) helium atoms and V is the volume of the sample.

Let us estimate the number υ_1 of the reaction (1) in unit time. Because we consider the reaction (1) induced by the trapped thermal neutron in the sample, υ_1 is given as follows:

$$\upsilon_1 = N_b \upsilon_b \rho_{Li6} \lambda_0 S \sigma_{nLi}, \qquad (8)$$

where $0.35 N_n u_n$ is the flux density of the thermal neutron (cm^{-2}s^{-1}), N_n and u_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 lithium is absorbed forming PdLi$_x$ alloy (or precipitated as Li metal), r_{Li6} is the density of ^{6}Li nucleus in the layer and is the fusion cross section of the thermal neutron with ^{6}Li nucleus.

Then, the number υ_2 of the reaction in unit time is given as follows:

$$\upsilon_2 = \upsilon_1 P_2 \qquad (9)$$

Between these quantities defined above, there are following relations:

$$N_h = \upsilon_2 T \qquad (10)$$

$$N = \upsilon_1 T \qquad (11)$$

where T is the time where the reactions (1) occurred.

From experimental conditions described in the papers[1,2,] we can use following values for parameters related with experimental condition:

$\upsilon_n = 2.7 \times 10^5$ cm/s $\sigma_{td} \sim 1$ barn
$\sigma_{nLi} \sim 1$ barn
V = 0.68 cm^3, $\rho = 6.8 \times 10^{22}$ cm^{-3}
$\rho_{Li6} = 3.5 \times 10^{21}$ cm^{-3}

for Li metal. (For PdLi substitutional alloy, the value differs a little.)

About the time T for the reaction

(1), we have to include the period where no electrolysis was performed, because in our model there occurs fusion reaction (1) if the trapped neutron and ^{6}Li exist. Therefore, we have to take into our calculation the interval of about 3 years between their energy and the helium measurements. So, we take as $T = 6 \times 10^{7}$ s.

Then, for the total energy E, we multiply a factor 6 to the value observed in the measurement of several (taking as 6) months:

$$E = 3 \times 10^{9} \text{ J}.$$

Using the observed value $n_h = 10^{20}$ cm^{-3}, we obtain total number of helium atom in the sample of 0.1 mol palladium:

$$N_h = 7 \times 10^{19}.$$

This number and the time T give us the value υ_2 by the relation (10),

$$\upsilon_2 = 1.16 \times 10^{12} \text{ s}^{-1}.$$

Then, we can get υ_1 by the relation (9) with the value of $P_2 = 0.034$ calculated using $L = 1$ cm:

$$P = 0.0034, \quad \upsilon_1 = 3.4 \times 10^{13} \text{ s}^{-1}$$

Dividing E given above by $N = \upsilon_1 T = 2.1 \times 10^{21}$, we obtain ε

$$\varepsilon = E/N = 1.5 \times 10^{12} \text{ J} = 9.2 \text{ MeV}.$$

This value gives us with use of the relation (5),

$$\eta Q_3 = 1.1 \times 10^{2} \text{ MeV}$$

The value of h is not determined by this treatment.

Furthermore, using the value υ_1 given above in the relation (8) and S = 3.1 cm^2 assuming a cubic sample containing 0.1 mol Pd, we can estimate $N_n \lambda_0$:

$$N_{n\lambda 0} = 3.4 \times 10^{11} \text{ cm}^{-2}$$

Here, we have made an assumption that N_n is constant throughout the experiment. Then, assuming the width of the surface layer as 10^{-4} cm, we obtain $N_n \sim 3 \times 10^{15}$.

In reality, the assumption of constancy of the N_n is not true. N_n varies and it makes υ_1 and the power generation to fluctuate. Especially, in the period of interval where no electrolysis, N_n may decrease by the decrease of Li nucleus in the surface layer. We have to notice also that this value of the density is for neutrons contributing to the reaction (1). There might be more neutrons in the particles of Pd-black sample. The density in the particle should be one or two orders of magnitude higher than this value.

3) Comparison of the result with the case of isotope shift

In a previous paper[3], we have analyzed an experimental data of the nuclear transmutation with Ni cathode and Rb electrolyte in light water. The decrease of the ratio $^{88}Sr/^{86}Sr$ in the experiment was consistently explained and the density of trapped neutrons in the cathode was determined as about 10^{6} cm^{-3} when the duration of the experiment was assumed as 10 days. This value is compared with the value obtained above, $N_n \sim 10^{15}$ with the assumption $\lambda_0 \sim 10^{-4}$ cm. In the case of Pd-black cathode, there are much excess energy and we understand the high value of the neutron density in it.

On the other hand, we gave a semi-quantitative analysis of the data showing a correlation of the excess heat and helium generations[7]. In the analysis, we determined the number of events without to the events with helium generation as ~6. This value is compared with a ratio:

$$\eta Q_3/Q_2 \sim 110/8 \sim 6$$

The agreement of these values in the order could be taken as a positive evidence supporting the model.

Conclusion

The analysis given above shows clearly that the experimental results obtained by Arata et al[1,2] are reasonable in the light of conventional physics with one assumption on the property of neutrons in a crystal lattice. A condition for the realization of the excess energy generation described in the paper[1] that it is necessary to give preliminary electrolysis for at most several months is interpreted in our model as the time to accomplish the condition to maintain enough neutron density in the sample.

One of several remarkable experimental results with fixed parameters related with the condition employed gave us an insight into the physics of cold fusion through the analysis, even though there remains some ambiguity in parameters used in calculation.

When the necessity is recognized to fix the necessary parameters, it is possible to determine and describe them in the paper. Improvement in the description will make the analysis more quantitative.

In a preceding paper[4], we have analyzed the experimental data on the heat and helium generation and obtained consistent results with that obtained here, as shown in the last section. Numerical consistency in the analysis of the isotope shift[3] and that given here substantiate the reality of the TNCF model.

It will be possible for us to analyze any experimental data when the pertinent parameters are known. A most interesting phenomenon is the Paterson cell. We hope the details of the action of the cell in time and space (structure) become available.

The authors would like to express their thanks to Prof. A. Takahashi of Osaka Univ. for the precious discussions through this work.

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