AN EXPLANATION OF DATA SETS OBTAINED BY MCKUBRE ET AL. (EXCESS HEAT), CLARKE (NULL RESULTS OF 4He, RHe) AND CLARKE ET AL. (TRITIUM) WITH "ARATA CELL"

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Synopsis

Interesting experimental data sets obtained by several research groups using the Arata-style cathodes are investigated by the TNCF model giving a consistent and semi-quantitative explanation for the excess heat and 4He generation outside the cathode and tritium detection in the cathode containing Pd-black but not helium isotopes

1. Introduction

The cold fusion phenomenon (CFP) has been investigated mainly transition-metal deuterides and hydrides giving various data sets including not only excess heat, tritium and helium that are products observed from the first stage but also unexpected heavy elements only explicable as results of nuclear transmutations. Fundamental difficulties of the CFP research are in its qualitative reproducibility and sporadic occurrence of phenomenon. There are several fortunate cases where several data sets are obtained using the same sample.

Recently, there were reported by some research groups several data sets using the so-called Arata type cathodes. Y. Arata et al. have been measuring excess heat and nuclear products using Arata-style cathodes (Arata cells).[1] Their claim is excess heat of the order of 100 MJ and accompanying production of ^{4}He of the order of 10^{14}/cm^3 in the cathodes in about 3 months.

On the other hand, McKubre et al.[2] performed experiments with Arata cells and obtained similar results as those of Arata et al.; excess heat of about 64 MJ from a cathode in about 3 months.

Furtheremore, W.B. Clarke[3] investigated ^{3}He and ^{4}He concentrations in samples of Pd-black from the interior of Arata cells supplied by Y. Arata through R. George. A negative result was obtained which showed that ^{3}He and ^{4}He concentrations were factors of 10^9 and 10^6 times smaller respectively than the results of Arata and Zhang for similar samples. About tritium, W.B. Clarke and B.M. Oliver[4] investigated tritium, ^{3}He and ^{4}He concentrations in samples of Arata cell supplied by Y. Arata and undergone electrolysis by M.C.H. McKubre et al. at SRI. The results for ^{4}He are similar to those of the work by Arata,[1] i.e. very small amounts of 4He which are probably due to trapped atmospheric helium in the samples. ^{3}He is interpreted as a decay product of tritium, and tritium is 2 - 5$\times$ 10^{15} atoms in the hollow cathode.

In addition to these results, Clarke et al. found an upper limit of 5.5$\times$ 10^{10} atoms ^{4}He in the outer 0.1 mm layer of the electrode, as a whole. This means that less than 1 part in 300 million of the "expected" (from d-d fusion reaction) amount of ^{4}He was deposited (or recoiled) into the outer surface of the Pd electrode.

2. Analysis of Experimental Data Sets

We give a theoretical interpretation of experimental data sets[1~4] on the Arata-style cathodes (Arata cells) supporting ^{4}He data by Clarke[3] and Clarke et al.[4] over that by Arata et al.[1] on the bases of consistency with other data sets including[2] and theoretical consideration.

It is confirmed that ^{4}He production in electrolytic cold fusion (CF) experiments, if any, occurs in the surface layer at a thickness less than ~ 25 μm.[5] Two data sets[5,6] have been explained consistently using the TNCF model[7] on the basis of a reaction

$$n + {}^6\mathrm{Li} = {}^4\mathrm{He} + t + 4.8\ \mathrm{MeV} \tag{1}$$

in the surface layer of PdLi alloy (or similarly Li metal).

Based on the same model, we conducted a theoretical investigation on the experimental data sets obtained using the Arata cells.[1~4]

The outer surface area of the cell cylinder, 1.4 cm$\phi$$\times$6 cm, is 29.5 cm^2. Assuming an active surface layer of a composition PdLi$_x$ (x= 1) and a thickness 1 μm, we obtain a density of ^{6}Li nuclei 5.1 $\times$ 10^{21}/cm^3 assuming natural abundance, 7.42 %.

Then, the number of reactions N between the trapped neutrons (assumed in the TNCF model[8]) and ^{6}Li nuclei in the surface layer in a time τ is

$$N = 0.35 n_n v_n n_{Li} V_0 \sigma_{nLi} \tau, \tag{2}$$

where n_n (assumed as a single adjustable parameter in the model) and n_{Li} are densities of trapped neutrons and ^{6}Li nuclei, respectively, in the surface layer, and v_n is the thermal velocity of the trapped neutron, V_0 is the volume of the surface layer, $\sigma_{nLi} = 10^3$ barns is the cross-section of the reaction (1). This number N (2) gives also the number of ^{4}He atoms (N_{He}) generated and corresponds to the number of reactions N_Q producing the excess heat Q of 4.8 MeV per a reaction (1), i.e., $N_{He} = N_Q = N$.

The experimental data shows excess heat of 64 ± 6 MJ[2] in three months, giving

$$N_Q = 8.3 \times 10^{19}.$$

This value and other parameters used in Eq.(2) gives the parameter n_n in the cylinder wall of the Arata cell,

$$n_n = 9.0 \times 10^9 \quad \mathrm{cm}^{-3}. \tag{3}$$

On the other hand, the expected number of ^{4}He from this reaction in this model is

$$N_{He} = 8.3 \times 10^{19} \quad \text{atoms} \tag{4}$$

as a whole if all the heat generating reactions are only the same n-^{6}Li reaction (one ^{4}He atom per 4.8 MeV). It should be remembered that this mechanism had shown its qualitative consistency with experimental data sets obtained by Morrey et al. and Miles et al.[5~7]

We can calculate the amount of tritium N_t generated in Pd-black contained in the cylinder, assuming n_n in the cell is the same as that in the wall (3), and a following reaction with a cross section of 5.5×10^{-4} b,

$$n + d = t + \gamma \ (6.25\mathrm{MeV}). \tag{5}$$

The N_t value obtained using this assumption will give ambiguity of one or two orders of magnitude in the final result due to the assumptions concerning the value of n_n. The γ in this reaction (5) does not necessarily mean a real photon but also a phonon or other modes in solids may also participate in the reaction. The expected amount of tritium produced in three months by this reaction is

$$N_t = 8.1 \times 10^{16} \quad \text{atoms}, \tag{6}$$

(if ^{6}Li abundance is 7.42%). This figure is compared with the experimental value of tritium atoms found in the cell[4]

$$N_t|_{exp} = 2.0 - 4.8 \times 10^{15} \quad \text{atoms}. \tag{7}$$

Therefore, our assumption that n_n in Pd-black is the same as that in the cylinder wall is inappropriate to produce a match with the experimental value by the two orders of magnitude. To meet this experimental value (we take arbitrarily here 2.0×10^{15}), we have to take a value of n_n as

$$n_n = 3.7 \times 10^8 \quad \mathrm{cm}^{-3} \tag{8}$$

instead of the value (3) (assuming natural abundance of ^{6}Li). The value n_n (8) of trapped neutrons in the Pd-black is about two orders of magnitude lower than that in Pd cylinder wall (3). For the present, we do not know what this result means in reality.

It should be noticed here that the value of the parameter $n_n = 9.0 \times 10^9/\mathrm{cm}^3$ in the cathode wall determined above in (3) from experimental data sets[2~4] is in the range of the values ($10^8 - 10^{13}/\mathrm{cm}^3$)[8,9] determined for about 60 data sets obtained in various conditions.

The absence (or more exactly, the very small total number of 5.5×10^{10}) of ^{4}He in the 0.1 mm outer layer detected by Clarke et al.[4] is reconciled with the reaction (1) by the following speculation. As is explained in the paper,[3] the Arata cell used here was subjected to electrolysis with reversed polarity for three months after the experiment with normal polarity. We think that reverse polarity for 3 months caused major changes in the Pd. In this process, the surface layer consisting of $PdLi_x$ and Pd formed in the normal polarity in three months might be almost completely dissolved. It seems likely that Pd also dissolves during reverse polarity. If it is so, the result[4] is consistent with the result[5] showing no ^{4}He inside cathodes deeper than ~ 25 μm.

There remains a problem in this interpretation. Clarke et al.[4] measured the distribution of ^{3}He in the wall of the Pd electrode and found its density gradient directed outwards, i.e. density is higher inside and lower outside in the wall. If the n-^{6}Li reaction producing tritium with the same number as ^{4}He occurs on the outer surface layer and the observed ^{3}He is the decay product of tritons only from outside, the gradient should be opposite. It is possible, however, that the PdLi (or Li) layer on the surface, the existence of which was shown by Okamoto et al.,[10] prevents the flow of tritium inward and the ^{3}He distribution is determined only by the tritium generated inside. Then, the distribution of tritium results in the observed profile of ^{3}He.

The reaction (1) assumed in the above analysis generates helium-4 and tritium with amounts 8.3×10^{19} as a whole corresponding to the excess energy Q = 64 MJ[2] in the outer surface of the electrode. Furthermore, it is probable to have nuclear transmutations in the surface layer generating heavy elements from cathode materials accompanied with excess heat.[9] It is possible, therefore, to make clear what kind of reactions are responsible to the measured excess heat of 64 MJ by measurements of ^{4}He and ^{3}H in the electrolyte and gas, and of transmuted nuclei in the surface layer and electrolyte used in the experiment.

Thus, our model gives a consistent and semi-quantitative explanation of experimental data sets[2~4] obtained for Arata cells using quantum mechanics and knowledge of solid state and nuclear physics. It also gives a fundamental criterion to determine the cause of the excess heat even if there remains the problem of ^{3}He distribution in the cathode wall and an undetermined observables, transmuted nuclei and ^{4}He in liquid and gas and others, in the present case as explained above. From our point of view, the ^{4}He data by Arata et al.[1] is not consistent either with that obtained by others[2~4] or with data sets obtained using simple Pd cathodes.[5,6]

3. Discussion

It has been shown theoretically that *d-d* fusion in solids is not possible at a rate sufficient to explain observed data of the cold fusion phenomenon (CFP).[11,12] This theoretical fact made many physicists avoid CF research. On the other hand, some researchers seek mechanisms to explain the CF data, especially for ^{4}He, by *d-d* fusion assisted by phonons in the solids. The distance between atoms in relevant solids is, however, of the order of 10^{-8} cm and phonons do not have wavelengths less than this order of magnitude. Because the range of nuclear force is 10^{-13} cm, so it is necessary to make the *d-d* distance close to this value to facilitate the possibility of fusion reactions. Phonons with wavelengths of 10^{-8} cm can not enhance the probability of fusion reaction between deuterons because of this wavelength limitation. These theoretical "facts" in addition to experimental facts described above show that we have to seek other mechanisms than *d-d* fusion to explain experimental data of excess heat, ^{4}He and tritium and others in the CFP.

Furthermore, CFP occurs not only in deuterium systems but also in protium systems. If we want to seek a common cause for CFP in both systems, the long-sought *d-d* fusion reaction in solids must not be considered as one of fundamental mechanisms.

From the analysis by the TNCF model given above, we can conclude some data sets are inconsistent with others. The most important difference is the data on ^{4}He of Arata et al.[1] and Clarke[3] and Clarke et al.[4] The data by Arata et al.[1] are inconsistent with others and there might be other possibilities to explain their data of ^{4}He.

From the analysis of the experimental data sets using the TNCF model given above, we can conclude some data sets are inconsistent with others. The most important difference is the data on ^{4}He of Arata et al.[1] and Clarke[3] and Clarke et al.[4] The data by Arata et al.[1] are inconsistent with others and there remain other possibilities to explain their data of ^{4}He, e.g. by contamination in the process of ^{4}He measurements.

It should be pointed out discussions raised by T. Chubb[13] about the credibility of the experiments by Clarke[3] and Clarke and others.[4] There are also replies from Clarke[14] and Clarke et al.[15] to the T. Chubb's comments.[3] Chubb discusses in his comments that a serious mishap occurred in the experiment[4] while the gas from the interior of the Arata cell was being processed in the inlet system of a mass spectrometer and suggests a cause of the negative result[4] that "During the mishap the pumpdown valve in the collecting chamer was briefly opened and then subsequently closed. It weems likely that all the helium initially contained in the intergranular volume was lost at this time."

In the replies,[14,15] Clarke and Oliver explain Chubb's discussion does not apply to their experimental procedure and insist no ^{4}He was produced in the Arata cell they analyzed. They consider the ^{4}He data by Arata et al.[1] should be the well-known instrumental "memory effect" and not true.

Then, there remains a question; how the excess heat of 64 MJ measured by McKubre et al.[2] produced. In the experiment,[4] they did not measure ^{4}He in the electrolyte. As we have discussed above,

there remains a possibility that reactions occurred in the outer surface layer of the cathode. Without confirming this possibility experimentally, it is arrogant to deny CFP as a whole by a limmitted knowlidge and is committing a classical mistake trapped in the "the Idols of the Cave [personalities]" (F. Bacon, *Novum Organum* Vol.1, Sec. XLII (1620)) superposed on "the Idols of the Theatre [establishment]" (*ibid.* Sec. XLIV).

It is very difficult to judge the reliability of experimental data sets from outside because we know that there are very many things only experimenters know well and can not explain in reports appropriately. We have confined, therefore, our discussion to materials written in papers published in Journals and Proceedings. We can understand subtlety of experimental procedures from the data sets[1~4] and also these discussions.[13~15]

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