

Analysis of Nuclear Transmutation in Micro-craters and Excess Heat Data in W/H/Na(K) Systems

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Synopsis

Excess heat and NT data obtained in tungsten cathode with light water and an electrolyte Na₂SO₄ or K₂CO₃ obtained by Ohmori et al. were analyzed on the TNCF model. Production of the new elements Fe and Cr in the micro-crater observed by them were explained by nuclear fission of compound nuclei $^{A+1}_{74}\text{W}^*$ formed by $n + ^{A}_{74}\text{W}$ reaction. Using the products density at boundary of the crater as those over whole surface, the adjustable parameter n_m the model was determined by the data of NT as $1.5 \times 10^{14} \text{ cm}^{-3}$ somewhat (2 orders of magnitude) larger than values determined in other experimental situations assuming the factor in the model $\xi = 1$. The data of the excess heat and NT were explained quantitatively and consistently in a factor of 2. Formation of the micro-crater was explained by the model showing the factor ξ should be as large as 10^5 by observed crater's size. It is probable to occur nuclear reactions in metal hydrides and deuterides used in other applications in the optimum condition.

1. Introduction

There have been obtained in these several years many experimental data sets showing nuclear transmutations (NT's) not only in D₂O but also H₂O system explained only taking into possibilities of induced decay and fission of compound nucleus formed from nucleus in solids by absorption of a thermal neutron, as shown in our previous papers.^{1,2)} These facts show clearly main reactions in the cold fusion (CF) phenomenon are not $d - d$ but other reactions where participate electrolyte elements, cathode metals and others including background thermal neutron from our point of view. The assumed

nuclear reactions in the explanation of these NT's are difficult to consider their occurrence by absorption of a thermal neutron in free space. This fact should be taken as a characteristic of the CF phenomenon.

A group in Hokkaido University has been working extensively with the excess heat and NT observation in electrolytic systems with light water and various electrode metals (Pd, Pt, Ni, Au, Ag). Their data has shown occurrence of NT producing various element with fairly large amount exceeding extent of errors in the experiments.

The experimental data³⁾ presented at ICCF7 by T. Ohmori et al. are quantitative in the excess heat and transmuted nuclei feasible to analyze them on the TNCF model and the result is given in this paper. Several parameters of experimental setup are not explicitly written in the paper and we have to guess them from relevant description which is noticed in the places.

2. Experimental Results

A flat-bottomed fused quartz vessel was used as the electrolytic cell in which were a plate tungsten (W) cathode and a platinum gauze anode in electrolytic solution of $\text{H}_2\text{O} + 0.5\text{M Na}_2\text{SO}_4$ (or $0.5\text{M K}_2\text{CO}_3$). The size of the cathode is taken as $0.01 \times 0.49 \times 0.49 \text{ cm}^3$ from the data of current density 1.4 A/cm^2 (current 0.7 A) and analogy from the case of Au cathode used before⁴⁾ though not described explicitly in this paper.

When the voltage of electrolysis increased up to 160 V exceeding 140 V , the cathode was heated incandescent and reddish purple glow emerged in the solution around the cathode in an experiment lasting 10 min . In this experiment, the excess heat evolved after the ignition was estimated by the authors at 183 W .

About the neutron emission, they estimate the maximum production rate at $6 \times 10^4 \text{ n/s}$ for K_2CO_3 and $1.5 \times 10^4 \text{ n/s}$ for Na_2SO_4 electrolyte assuming the signals obtained by a portable REM counter are due solely to neutron.

The cathode surface after the electrolysis (with incandescence) revealed quite different structure from that before the electrolysis; the whole surface changed into a lava-like structure with several craters (the number, size and depth of the crater are not clear). Distribution of new elements C, O, Cr, Fe detected by EPMA (Electron Probe Microanalyzer) are overlapping and concentrate at the center part of the crater where the ratios of Fe, Cr and W

to all of the constituting elements were estimated at 67.4, 16.9 and 7.9 at.%, respectively.

Toward the edge of the crater, however, the amount of these elements decreased markedly and they were estimated at 6.7, 1.9 and (91.4) at.%, respectively at the edge. (In the analysis given in the next section, we take this value as the average amounts of the produced elements over the surface region with a thickness $1 \mu\text{m}$ of the cathode while there are no description about them. This is, perhaps, too large amount to be an adequate value for overall NT and give too large value of the parameter n_n as remarked below.)

The major nuclear products observed in the edge region with a thickness $\approx 160 \text{ \AA}$ were $^{56}_{26}\text{Fe}$ and $^{52}_{24}\text{Cr}$. Isotopic compositions of Fe and Cr in the region were as follows; $^{56}_{26}\text{Fe}$ and $^{57}_{26}\text{Fe}$ are 91.0 (91.66) and 2.9 (2.19) %, $^{50}_{24}\text{Cr}$, $^{52}_{24}\text{Cr}$ and $^{53}_{24}\text{Cr}$ are 6.1 (4.31), 79.1 (83.75) and 12.4 (9.55) %, respectively.

It should be noticed that there is detected also lead (Pb) in this experiment which has been reported several times in experiments including by other researchers and is difficult to explain from present knowledge of nuclear reaction we have. In this paper, we confine our investigation to the production of Fe and Cr; carbon (C) could be explained as the same mechanism⁵⁾ as that for the data by Yamada et al.⁶⁾

3. Theoretical Investigation

The experimental data explained in the preceding section is summarized as follows; surface area of the cathode is 0.5 cm^2 , the maximum excess heat is 183 W with Na_2SO_4 electrolyte, the maximum emission rate of neutron (by the counter) is $6 \times 10^4 \text{ n/s}$, ^{56}Fe and ^{52}Cr are 6.7 and 1.9 %, respectively, in the surface region of the crater edge with thickness 160 \AA .

To analyze the experimental data summarized above, we assume that the excess heat and the nuclear transmutation have the same cause, i.e. the same nuclear reactions in the sample are responsible to them, for simplicity. This assumption give neglect of other reactions than that generating NT and the excess heat will be underestimated in this analysis.

The nuclear reactions taken up in the explanation of the experimental data obtained in the light water system by the TNCF model are written down as follows assuming existence of thermal neutrons in cathode with a density n_n :

$$n + {}^A_{74}\text{W} = {}^{A+1}_{74}\text{W}^*, \quad (1)$$

$${}^{A+1}_{74}\text{W}^* = {}^A_{\text{B}}\text{M} + {}^{A-A+1}_{74-\text{B}}\text{M}' + \text{Q}. \quad (2)$$

We consider only unstable compound nuclei ${}^{A+1}_{74}\text{W}^*$, i.e. original isotopes with $A = 180, 184, 186$ natural abundance of which are 0.114, 30.64 and 28.41 % and absorption cross sections for thermal neutron (10), 1.70 and 37.9 b, respectively.

From possible channels of the compound nuclei ${}^{A+1}_{74}\text{W}^*$ transform, we take here only those give ${}^{56}_{26}\text{Fe}$ and ${}^{52}_{24}\text{Cr}$ on the end of successive decays simultaneously with other elements having boiling points lower than 3000°C considering the detected elements of Fe and Cr and the maximum temperature of the incandescent cathode of more than 3000°C in this experiment.

Then, the relevant reactions are written down as follows (neglecting reactions accompanying neutron emission for their expected small branching ratios):

$${}^{181}_{74}\text{W}^* = {}^A_{\text{B}}\text{M} + {}^{181-A}_{74-\text{B}}\text{M}' + \text{Q}, \quad (3)$$

$${}^{187}_{74}\text{W}^* = {}^A_{\text{B}}\text{M} + {}^{187-A}_{74-\text{B}}\text{M}' + \text{Q}, \quad (4)$$

The compound nuclei ${}^{A+1}_{74}\text{W}^*$ have several channels to transform including the one relevant with Fe and Cr generation. If the fission probabilities of the above two compound nuclei, ${}^{181}_{74}\text{W}^*$ and ${}^{187}_{74}\text{W}^*$, can be taken the same and their decay times are short compared with the experimental time, the cross section and abundance of the original isotopes give predominance of the second reaction (4) for explanation of the Fe and Cr generation by a factor 10^2 and, therefore, we take only it in the following analysis.

Then, we can write down main reactions (4) resulting in ${}^{56}_{26}\text{Fe}$ and ${}^{52}_{24}\text{Cr}$ as follows:

$${}^{187}_{74}\text{W}^* = {}^{131}_{50}\text{Sn} + {}^{56}_{24}\text{Cr} + 98.3 \text{ MeV}, \quad (5)$$

$${}^{131}_{50}\text{Sn} \rightarrow {}^{131}_{51}\text{Sb} \rightarrow {}^{131}_{52}\text{Te}, \quad (6)$$

$${}^{56}_{24}\text{Cr} \rightarrow {}^{56}_{25}\text{Mn} \rightarrow {}^{56}_{26}\text{Fe}, \quad (7)$$

$${}^{187}_{74}\text{W}^* = {}^{135}_{52}\text{Te} + {}^{52}_{22}\text{Ti} + 92.7 \text{ MeV}, \quad (8)$$



The arrows (\rightarrow) in the above reactions express beta-decay of the element on the left and time constants are at most 100 minutes. The elements appearing in the above reactions except Fe and Cr have boiling points lower than 3000 °C and are not observed in the cathode heated up to more than 3000 °C.

The branching ratios of the reactions (5) and (8) generating Fe and Cr, respectively, are, in our approximation, given by the ratio of the products $^{56}_{26}\text{Fe}$ and $^{52}_{24}\text{Cr}$, i.e. 6.7 vs. 1.9 at.% or 3.5 vs. 1.

Taking the experimental time as $\tau = 10$ min. (600 s) (as informed by private communication with Dr. T. Ohmori), we can determine the adjustable parameter n_n of the TNCF model by the following relation between the number of a generated element N_{Fe} (e.g. for $^{56}_{26}\text{Fe}$) and reaction parameters:

$$N_{\text{Fe}} = 0.35 n_n v_n n_W V \sigma_{n-W} \tau \xi, \quad (11)$$

where $0.35 n_n v_n$ is the flow density of the thermal neutron per unit area and time, n_W is the density of $^{186}_{74}\text{W}$ in the reaction region with a volume V , σ_{n-W} is the cross section of the reaction, and τ is the experimental time. The factor ξ expresses an order of instability of the trapped neutron in the reaction region; we take $\xi = 1$ for reactions which occur in the surface layer with thickness of 160 Å (reaction region) in this case according to the recipe of the TNCF model.¹⁾ (It is noticed in recent analyses that ξ should be taken larger than 1 if we consider large reactivity of the trapped neutron in the surface layer resulting in anomalous nuclear reactions like decay-time shortening and induced fission.)

With parameters and the experimental result (3.1×10^{15} $^{56}_{26}\text{Fe}$ atoms in 600 s), the relation (11) gives us a following value for n_n :

$$n_n = 1.2 \times 10^{14} \text{ cm}^{-3}.$$

This value is too large to be consistent with other values of n_n determined from other data sets in our previous works ($10^8 - 10^{12} \text{ cm}^{-3}$). The reason is clear that we have used the amount of the transmuted nuclei observed at the boundary of the crater as the value over all surface. The crater on the surface

of cathodes have been observed by Ohmori et al. not only in this experiment³⁾ but also in a previous paper⁴⁾ with Au cathode where the size of the crater was determined as $\approx 20 \mu\text{m}$ in diameter and $30 \mu\text{m}$ in height.

In view of the strong interaction of the neutron Bloch waves and a nucleus in the surface layer resulting in large amount of the transmuted nuclei there due to anomalous nuclear reactions, i.e. decay time shortening and induced fission, we have to consider that the instability factor ξ of the trapped neutron is rather larger than 1 (meaning that the cross sections are the same to those in free space) assumed in our analysis of more than 50 experimental data sets hitherto giving the parameters of $10^8 - 10^{12} \text{cm}^{-3}$.

We have not had any explicit data before to determine the value of ξ , i.e. or interaction cross section between the trapped neutron as a Bloch wave and a nucleus, in the boundary layer where the neutron is reflected in the classical sense. The craters observed by Ohmori et al. could be a key to determine the factor ξ in the surface layer.

Let us assume that the craters on the surface of the cathodes (W or Au) are formed by localized nuclear reactions induced by the neutron-nuclear interaction. To make our discussion concrete, we take tungsten cathode and electrolyte discussed above rather than gold one in the following analysis. We can determine ξ demanding that nuclear products given in the reactions (1)–(11) (and extended reactions producing several neutrons per reaction) induced succeeding reactions in a range comparable to the size of the craters ($\approx 10 \mu\text{m}$ determined in Au case).

Assuming the fusion cross section in free space of a neutron and a nucleus of Au or W as 1 b ($= 10^{-24} \text{cm}^2$), for an order of magnitude estimation, the generated neutrons in the similar fission reactions to (1)–(11) can proceed a length l_n of 10^2cm before they are absorbed in the solid with a number density of the nucleus about 10^{22}cm^{-3} . If the cross section is changed by a factor ξ , the length becomes ξ times smaller or $l_n = 10^2/\xi$. To make this value $\approx 10 \mu\text{m} = 10^{-3} \text{cm}$, we have $\xi \approx 10^5$ in the situation of the experiment by Ohmori et al.:

$$\xi = 10^5.$$

This is a very large value out of our imagination if we forget the local coherence⁷⁾ of the trapped neutrons in the Bloch wave states. As was shown by a model calculation, the Bloch wave reflected by a boundary layer where is mismatching of allowed and forbidden bands for an energy, the Bloch

waves in the allowed band have coherence in their phase in the boundary layer. If the number of the trapped neutron is of an order of 10^5 , we can expect the instability factor ξ of about 10^5 making the product neutrons of nuclear reactions confined in the range of the size of the observed craters confining succeeding reactions with nucleus in this region.

Although we do not know details of this intensified interaction of the Bloch wave and a nucleus in the surface layer, the experimental data obtained by Ohmori et al. seems telling such a peculiar interactions in appropriate situations realized in the CF experiments in accordance with anomalous nuclear phenomena like decay-time shortening and threshold energy lowering of the induced fission observed in many experiments.

If we can generalize the consideration given above to other data sets, the values of n_n obtained hitherto^{1,2)} ($10^8 - 10^{12} \text{ cm}^{-3}$) have to be multiplied by a factor of an order of 10^{-5} and become to be $10^3 - 10^7 \text{ cm}^{-3}$, more acceptable to scientists familiar with large neutron flow densities in the nuclear pile who sometimes raised questions against the TNCF model for its conclusion of large values of n_n .

Turning to the excess heat, we can calculate the liberated energy per unit time expected from our model Q_{th} by the reactions (5) and (8) easily and the result is given as

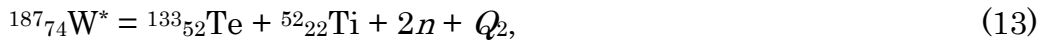
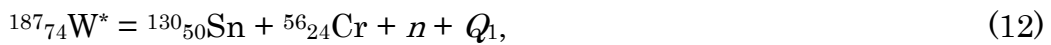
$$Q_{\text{th}} = 99.6 \text{ W.}$$

This value is compared with the maximum excess heat Q_{exp} obtained in the experiment

$$Q_{\text{exp}} = 183 \text{ W.}$$

The coincidence is fairly good even if we consider ambiguities in the experimental parameters used in the calculation.

The number of neutrons up to $6 \times 10^4 \text{ n/s}$ observed by neutron counter in the experiment might be explained in the TNCF model as follows. This maximum amount of the neutron count may correspond generation of 10^7 n/s in the sample taking the efficiency of the counter as 0.1 %. We can take up several fission reactions of the compound nuclei $^{A+1}_{74}\text{W}^*$ with neutron emission, some examples are written down as follows:



where $Q_1 = 93.1$ MeV and $Q_2 = 81.8$ MeV.

Although we do not know the branching ratios of these reactions (5), (8), (12) and (13), the number of the observed neutrons (up to 10^4 n/s) and the isotope $^{56}_{26}\text{Fe}$ ($5.2 \times 10^{12} \text{ s}^{-1}$) or $^{52}_{24}\text{Cr}$ ($1.3 \times 10^{12} \text{ s}^{-1}$) will give information about them if the observation is performed with high reliability.

4. Discussion

The analysis of the experimental data³⁾ of the excess heat and NT in light water system obtained by T. Ohmori et al. given in this paper has shown again reality of the CF phenomenon not only in D_2O but also in H_2O system and effectiveness of the TNCF model. These facts show importance of neutron and consistency of the model to explain the CF phenomenon in the frame of present Quantum Mechanics. A new phase revealed by the experimental results obtained by Ohmori et al. is the strong interaction of the neutron Bloch wave and nuclei in the surface layer expressed by a large value of the instability factor ξ in our model as large as 10^5 to explain the formation of micro-craters where occurred strong NT. This result is intimately related with the occurrence of NT in the surface layer observed in many experiments as reviewed by us⁸⁾ and with the localized coherence of neutron Bloch waves.⁷⁾

It is emphasized, as pointed out before²⁾ and in this paper, that there occur anomalous nuclear reactions in CF materials, which are characterized by complex structure, especially their surface layers formed in the process of electrolysis to feed hydrogen isotopes into cathodes, not expected to occur in free space even if there are the same staffs working in the solids.⁹⁾ In our point of view, the essential factor to realize the CF phenomenon is the existence of the trapped neutron, as neutron Bloch waves, in the sample with surface layers of alkaline metals and/or inhomogeneous distribution of hydrogen isotopes. In our model, we do not ask explicitly the origin of the trapped neutron but sometimes explained it implicitly as the background neutron in the first place and then the breeding reactions in the system.¹⁾

There are, however, some other proposals about the origin of the trapped neutrons used in the Ytncfm proposed 5 years ago in ICCF4.¹⁰⁾ One example of them is seen in the paper by T. Ohmori et al.⁴⁾ analyzed in this paper where proposed a mechanism generating neutron by $p + e$ fusion reaction, inverse of neutron decay. If we consider the fact that a neutron liberates

0.782 MeV in its beta-decay, it is understandable difficulty of the inverse process in electrolytic system only from the energy point of view except consideration of selection rules. Other proposals to use such neutral particles as a tight-bound proton-electron complex or a multi-neutron complex seem too fantastic to consider in the present stage of CF research where we can rely on Quantum Mechanics established in these 70 years for phenomena in microscopic world of atomic nuclei, atoms, molecules and solids.

Finally, it is noticed the fact shown in many CF experiments including those analyzed in this paper that there occur nuclear reactions generating products of NT in metal hydrides and deuterides in optimum circumstances. This fact should be taken into consideration in any applications of metal hydrides.

Acknowledgment

The authors would like to express their thanks to Dr. T. Ohmori of Hokkaido University for private communication about some details of his experiment used in this analysis. They are also indebted to J. Dash of Physics Department of Portland State University for valuable discussions in preparation of this paper. This work is supported partially by a gift from the New York Community Trust and by the U.S. Army Research Office under grant number DAAG 55-97-1-0357.

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