Conference Proceedings Vol. 70
"ICCF8"
F. Scaramuzzi (Ed.)
SIF, Bologna, 2000

NUCLEAR TRANAMUTATION IN SOLIDS EXPLAINED BY TNCF MODEL

H. Kozima, M. Ohta[1], K. Arai[2], M. Fujii[3], H. Kudoh[3] and K. Yoshimoto[4]

Cold Fusion Research Laboratory
Yatsu 597-16, Shizuoka, 421-1202, JAPAN
Tel/Fax +81-54-278-0327, e-mail cf-lab.kozima@nifty.ne.jp

Abstract

It have been observed in these several years occurrence of nuclear transmutation (NT) of elements with the atomic number Z larger than 4 in the surface region of cathodes in electrolytic systems. The NT is divided into two types: NT_D explained by a decay of elements and NT_F by a fission of them. These experimental facts are explained by a model with an adjustable parameter n_n (TNCF model) consistently with other data in CFP.

1. Introduction

The cold fusion phenomenon (CFP) was declared its discovery in 1989 by Fleischmann and Pons (and Hawkins)[1] with an expectation of fusion of two deuterons in a palladium hydride PdD_x.

After controversial period on the reality of CFP in solids, there have appeared new data showing unexpected nuclear products of reactions between nuclei in the crystal lattice (the lattice nuclei) in or on the cathodes used in electrolytic experiments. It is now recognized that the nuclear transmutation (NT) occurs widely and frequently in a surface region of solids occluding hydrogen isotopes used in experiments of CFP.

The feature of NT is rather striking than its occurrence itself. The transmuted nuclei have been found in near-surface region with a width of few tens μm and the ratio of transmuted nuclei to that existed originally becomes very high reaching in typical cases to several tens %. Furthermore, atomic numbers of the transmuted nuclei shift from that of the original nucleus in the solids with very large variety from one to several tens. It is clear at a glance of these data that the transmuted nuclei result from decaying of the elements or from fission of them by some causes.

There had been a systematic explanation of various events of CFP by a model with a single adjustable parameter (TNCF model) proposed by the present author.[2] In the model, the fundamental premise is an existence of thermal neutrons trapped in solids inducing CFP and reactions of a neutron with a lattice nucleus are taken into explanation of these various events in CFP.[3,4]

To explain the whole spectra of NT, it is necessary to assume a simultaneous absorption of several neutrons by a lattice nucleus.[5,6] In this paper, NT as a whole, i.e. NT_D and NT_F, is explained by the TNCF model with extension of the Premises to allow the simultaneous reaction of neutrons with a lattice nucleus.

2. Experimental Facts of Nuclear Transmutation

Before explanation of NT by the TNCF model, we give a brief introduction of experimental data on NT_D and NT_F successively in this section.

[1] Present address: Department of Nuclear Engineering, Osaka University, Osaka.
[2] Present address: Materials and Energy Research Institute Tokyo Ltd., Tokyo.
[3] Present address: Department of Energy Engineering, Yokohama National University, Yokohama.
[4] Present address: Oki Software Co. Ltd., Tokyo.

2-1. Nuclear Transmutation by a Decay NT_D

The nuclear transmutation in solids has been observed in CF experiments from around 1994 by R.T. Bush et al., I. Savvatimova et al., M. Okamoto et al. and others in its NT_D form.

Data by R.T. Bush[7]

R. Bush observed the excess heat generation and nuclear transmutations $^{23}_{11}Na \rightarrow ^{24}_{12}Mg$ and $^{39}_{19}K \rightarrow ^{40}_{20}Ca$ in electrolytic systems Ni(alloy)/H/K(Na). It should be noticed that the decay time of $^{40}_{19}K$, formed by a reaction n + $^{39}_{19}K$, into $^{40}_{20}Ca$ by β -decay is known as $\sim 10^9$ y in nuclear physics.

Data by R.T. Bush and D.R. Eagleton[8]

R.T. Bush and R. Eagleton observed the excess heat and the nuclear transmutation of Rb into Sr in $Ni/H_2O + Rb_2CO_3$ system (with Ni sponge cathode). Natural abundance of $^{85}_{37}Rb$ and $^{87}_{37}Rb$ are 72.15 and 27.85 % and decay times of $^{86}_{37}Rb$ and $^{88}_{37}Rb$ are 19.5 d and 17.8 m, respectively. Observed decrease of the isotope ratio $^{88}_{38}Sr/^{86}_{38}Sr$ ($\equiv 1/\eta$) was from the original value of $1/\eta\ )_{orig} = 8.5$ to $1/\eta\ )_1 = 3.5$ when the excess heat was Q_1 and to $1/\eta\ )_2 = 2.7$ (the ordinate of point 2) when it was Q_2 ($= 5Q_1$).

Data by I. Savvatimova et al.[9]

I. Savvatimova and her collaborators measured the excess heat, NT (nuclear transmutation) of various isotopes and elements in the surface layer of the multi-layer cathodes in discharge experiments. After the discharge of 4 hours, the sample was analyzed its isotope composition about 3 months later. Here we take up only one data set of an increase of $^{107}_{47}Ag$ from 20 to 5000 ppm in the glow discharge with D_2 gas and Pd cathode. The decay time of $^{107}_{46}Pd$ formed by n + $^{106}_{46}Pd$ into $^{107}_{47}Ag$ is known as $\sim 10^6$ y in nuclear physics.

Data by T.O. Passell[10]

A Pd cathode used in an experiment with an electrolytic solution D_2O + 1.0M LiOD + 200 ppm Al producing the excess heat of 0.56 MJ was subjected upon comparison measurements of the prompt gamma activation analysis (PGAA) using thermal neutrons in beams from research reactors. A result showed an $\sim$ 18 % reduction in the boron impurity $^{10}_{5}B$.

Data by M. Okamoto et al.[11]

M. Okamoto et al. observed the excess heat and the changes of key and minor elements in the cathode. We take up here, the nuclear transmutation from Al into Si in the surface layer on the cathode in Pd/ D_2O + LiOD system. The change of the density of the elements (up to 80 % for Al) occurred in the surface layer with a thickness of $\sim 1\ \mu$m.

Data by H. Yamada et al.[12]

To confirm the cold fusion phenomenon under glow discharge condition, a point-to-plane electrode configuration in slightly pressurized (2 atm) deuterium gas for highly non-uniform electric field was employed by Yamada et al. A neutron burst took place in 2 runs out of total 37 runs. X-ray photo-electron spectroscopy (XPS) was used to investigate black deposit observed covering the tip surfaces of two positive Pd electrodes which was used in the runs with neutron bursts to reveal the black deposit was carbon, mixed with palladium on the surface of palladium point electrode. The relative number of oxygen atom in the surface layer is the same order as that of carbon atom ($N_O/N_C \sim 1$).

Data by G. Miley et al.[13]

Miley et al. performed electrolysis experiment with an electrolytic solution 1M Li_2SO_4 + H_2O with a cathode composed of 1000 microspheres (ms's) coated by a Ni layer. The excess heat was 0.5 ± 0.4 W from 1000 ms's. The NT products were determined by NAA and SIMS (for $^{55}_{25}Mn$) for 1000 ms's (using only 10 ms's for analysis).

Data by J. Dash et al.[14]

There were two kinds of the Pd cathode used in the experiment by Dash et al. The Pd cathodes were (A) a cold-rolled 0.35 mm-thick polycrystalline sheet and (B) a 5.5×10^{-2}

mm thick foil. The anodes were Pt foils of 3×10^{-2} mm thickness in both cases. H_2O and D_2O were used. In the case A, several regions on the deformed Pd cathode gave EDS spectra which showed an appreciable amount of Pt and Au. The concentration of Au on the heavy-water cathode appeared to be greater than on the light-water cathode. In the case B, chemical composition was determined in regions which had topography suggestive of localized melting. The average surface composition of the entire area of the cathode was about 85 % Pd and 15 % Pt. In spectra from several points of the cathode, there are a predominant peak at 2.98 keV corresponding to Ag.

Data by R. Notoya[15]

In a series of experiments with Ni cathodes in H_2O (and D_2O) solution of electrolytes K_2CO_3, Notoya et al. observed the excess heat, NT and positron generation in the system by the observation of gamma ray spectrum. The observed new elements supposed to be results of NT were ${}^{A+1}_{20}Ca$ and ${}^{64}_{28}Ni$ in an electrolytic system Ni/H/K with a Ni plate cathode.

The experimental data sets introduced in this subsection as a whole suggest that there are nuclear transmutations in the surface layer of materials (electrodes) explained by an existence of thermal neutrons in them. Furthermore, it will be noticed in the analysis of these data that decay times of some unstable isotopes seem shortened largely from the values in normal states as explained in the next section.

2-2. Nuclear Transmutation by a Fission NT_F

The nuclear transmutation by a fission has been observed from around 1995 by J.O'M. Bockris et al., T. Mizuno et al., T. Ohmori et al., R. Notoya et al., G. Miley et al. and others.

Data by J.O'M. Bockris et al.[16]

Bockris and his collaborator performed an experiment in which hydrogen was electrolyzed from water in contact with a palladium electrode. Using XPS and EDA, it was determined that the concentration of the new elements (Mg, Al, Cl, K, Ca, Ti, Fe, Cu, Zn, and so on) was in the range 1 ~ 10 atomic %. These elements have no relationship to the impurities in the solution.

Data by T. Mizuno et al.[17]

Mizuno et al. observed NT in the surface layers (thickness $\ell \leq 2\ \mu m$) of Pd and other cathodes induced by electrolysis. The identification of isotopes was performed by several methods and many elements including Pt, Cu, Cr, Pd, and others were observed and showed shifts of isotope ratios from natural ones. We take up here only one data set of ${}^{52}_{24}Cr$ in Pd/D/Li system: isotope ratio of ${}^{52}_{24}Cr$ observed in the surface layer showed a reduction from 83.8 % (natural abundance) to 50 % through an electrolysis of 30 days.

Data by T. Ohmori et al.[18]

T. Ohmori et al. observed NT, i.e. increases of ${}^{57}_{26}Fe$ and ${}^{54}_{26}Fe$, generation of C and S, in light water electrolysis with electrodes Au and Pd and electrolytes Na_2SO_4, K_2CO_3 and KOH in H_2O. In the electrolysis with a gold electrode and an electrolyte Na_2SO_4 in H_2O for a week, a notable amount of iron atoms in the range of 1.0×10^{16} to 1.8×10^{17} atoms/cm^2 are detected at surface together with the generation of a certain amount of excess energy.

Data by Iwamura et al.[19]

Iwamura et al. measured the excess heat and nuclear products simultaneously in PdD_x $(0.8 \leq x)$ system using a new type of experimental apparatus. The excess heat measured in the system with a Pd plate cathode ($25 \times 25 \times 1$ mm^3) was about 10 % at maximum for the input power of 40 W. Tritium was observed qualitatively with similar characteristics to the data obtained in the former experiments. New elements of Ti, Cr, and so forth were detected.

Data by G. Miley et al.[13]

The electrolytic experiments with cathodes of the packed-bed cell (about 1000 microspheres (ms's)) in a electrolyte 1M $LiSO_4$ + H_2O were performed with nickel, palladium and Pd-Ni multilayer cathodes and titanium electrodes. We take in this paper only one data set, Run #11, where Pd thin-film of 200 μm was on the polystyrene microsphere. The analysis of the sample microspheres by NAA (Neutron Activation Analysis) after an experiment lasted 211 hours showed appearance of elements with yields of Al, Cu, V, Ni, Fe, Co, Cr, Zn and Ag with amounts (in 10^{-3} μg/ms) 233, 277, 4.06, 388, 153, 2.18, 60.4, 806 and 70.6, respectively. These amounts corresponds to number of atoms (in 10^{13}/ms) of 520, 262, 4.80, 398, 165, 223, 699, 742 and 39.4, respectively.

Data by G.S. Qiao et al.[20]

The experiment on the Pd/D_x and Pd/H_x systems were performed by Qiao et al. in a stainless steel Dewar with a piece of incandescent tungsten filament in it. The vacuum annealed palladium wire (900 °C in a pressure of 10^{-3} Pa for 3 hours) was sealed in the Dewar and hydrogen isotope gas with a pressure of less than 1 atm was filled. Comparison of the element composition after and before the experiment showed remarkable increase of Zn at points near the surface of the Pd wire. The large change of element composition of Pd and Zn, if it correlate, could only be explained by fission reactions, i.e. nuclear transmutation by a fission (NT_F), in the surface region of the sample.

The above experimental data sets introduced in this subsection suggest that there are nuclear transmutations by a fission in the surface layer of cathodes containing trapped neutrons. This fact could be understood that there is a nuclear fission of elements induced by the trapped thermal neutron (TN induced fission) in cold fusion materials not noticed until the CF phenomenon was observed even if these elements are stable against fission by an energetic neutron irradiated under several tens MeV in free space.

The decay time shortening explained in the subsection 1 and the threshold energy lowering of fission in the subsection 2 are new features of solid state - nuclear physics in complex systems composed of trapped neutrons and solids with the surface layer of an isotope with a large value of the mass number.

3. Explanation by the TNCF Model

The experimental data sets showing NT_D and NT_F in surface regions of materials used in CF experiments have successfully been analyzed by the TNCF model. A brief explanation of the analyses is given in this Section.

3-1. Premises related with NT explanation

The Premises of the TNCF model related with NT at the boundary region is Premises 1 and 2.[3,4]

3-2. Nuclear Transmutation by Decay NT_D

· Fundamental reactions used in the analysis of NT_D are such reactions between a trapped neutron and nuclei in the material followed by a beta or an alpha decay as follows:[3]

$$n + {}^{23}_{11}\mathrm{Na} = {}^{24}_{11}\mathrm{Na} = {}^{24}_{12}\mathrm{Mg} + e^- + \bar{\nu}_e, \quad (1)$$

$$n + {}^{39}_{19}\mathrm{K} = {}^{40}_{19}\mathrm{K} = {}^{40}_{20}\mathrm{Ca} + e^- + \nu_e, \quad (2)$$

$$n + {}^{16}_{8}\mathrm{O} = {}^{17}_{8}\mathrm{O} = {}^{13}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He}. \quad (3)$$

These reactions with the assumption of the decay time shortening were used to analyze the data sets introduced in the subsection 2-1 and the results were tabulated in the Table 1 on the end of this section.

3-3. Nuclear Transmutation by Fission NT_F

As relevant nuclear reactions in nuclear transmutation by a fission (NT_F), we may take up a fission reaction with emission of several (say ν) neutrons induced by an energetic or a

Table 1: Analysis of NT data. Neutron Density n_n and Relations between the Numbers N_x of Event x Obtained by Theoretical Analysis of Experimental Data on TNCF Model ($N_Q \equiv Q$ (MeV)/5 (MeV)). Typical value of the surface vs. volume ratio S/V(cm^{-1}) of the sample is tabulated, also.

Authors	System	S/V cm^{-1}	Measured Quantities	n_n cm^{-3}	Other Results (Remarks)
Bush[7]	Ni/H/K Ni/H/Na	~ 160 ~ 160	$NT_D(Ca)$ $NT_D(Mg)$	5.3×10^{10} 5.3×10^{11}	$N_Q/N_{NT}\sim 3.5$ if $\tau=0$ for ^{40}K)
Bush[8]	Ni/H/Rb	$\sim 10^4$	$NT_D(Sr)$	1.6×10^7	$N_Q/N_{NT}\sim 3$
Savvatimova et al.[9]	Pd/D_2	100	$NT_D(Ag)$	9×10^{10}	
Passell[10]	Pd/D/Li	400	NT_D	1.1×10^9	$N_{NT}/N_Q=2$
Okamoto et al.[11]	Pd/D/Li	23	Q, NT_D $\ell_0 \sim 1\ \mu$m	$\sim 10^{10}$	$N_Q/N_{NT}\sim 1.4$ (^{27}Al$\rightarrow$ ^{28}Si)
Yamada[12]	Pd/D_2	185	n , $NT_D(C)$	2.0×10^{12}	
Miley[13]	Pd/H/Li	150	NT_F(Ni,Zn,$\cdots\cdots$)	4.5×10^{12}	
Dash[14]	Pd/D,H_2SO_4	57	Q, NT_D	$\sim 10^{12}$	Pt $\rightarrow$ Au
Notoya[15]	Ni/D,H/K	3.4×10^4	$NT_D(Ca)$	1.4×10^9	(Sintered Ni)
Bockris et al.[16]	Pd/H/		NT_F(Mg,Si,Cs,Fe, etc. in 1μm layer)	3.0×10^{11}	Only Fe(10%of Pd) is taken up
Mizuno[17]	Pd/D/Li (If Cr in Pd)	3.4	Q, NT_D $\ell \leq 2\ \mu$m)	2.6×10^8	τ=30d, Pd 1cm$\phi\times$ 10cm
Ohmori[18]	Au/H/K	200	Q, NT_F(Fe)	$\sim 10^{11}$	(Au plate)
Miley[13]	Ni/H/Li	50	NT_D(Fe,Cr,$\cdots$)	1.7×10^{12}	
Iwamura[19]	PdD_x and Pd /CaOPd_x/Pd	20	$Q\sim$ 1W,$N_{NT}/N_Q\sim 1$ NT_F(Ti, Fe, Cu etc.)	3.1×10^{10}	$N_{NT}/N_Q)_{th}=$ $1\sim 3$
Qiao[20]	Pd/H_2	185	NT_F(Zn)	3.8×10^{10}	(40%NT in 1y)

thermal neutron (and/or an energetic charged particle generated by a cold fusion reaction):

$$n\ (\varepsilon) + {}^A_Z\mathrm{M} \ = \ {}^{A-A'+1}_{Z-Z'}\mathrm{M} + {}^{A'}_{Z'}\mathrm{M}, \tag{4}$$

$$n\ (\varepsilon) + {}^A_Z\mathrm{M} \ = \ {}^{A'}_{Z-Z'}\mathrm{M}' + {}^{A''}_{Z'}\mathrm{M}'' + \nu\ n, \quad (A+1 = A' + A'' + \nu). \tag{5}$$

In the cold fusion, the possible maximum energy of a particle generated by a reaction assumed in the TNCF model is that of the neutron generated by a breeding reaction

$$t + d \ = \ {}^4_2\mathrm{He}\ (3.5\mathrm{MeV}) + n\ (14.1\mathrm{MeV}),$$

and is 14.1 MeV. Therefore, the experimental result showing NT_F should be an evidence of the lowering of threshold energies for fission reaction occurring in materials from those in vacuum.

The fission reactions illustrated above with the lowering of threshold energies were used to analyze the data sets introduced in the subsection 2-2 and the results were tabulated in the Table 1.

3-4. Determined values of n_n

As a result of analysis of a data set, it is possible to determine the parameter n_n defined in the TNCF model. The determined values of n_n are tabulated also in the Table 1 with other results.

4. Conclusion

It should be emphasized here that the single parameter n_n is determined uniquely even in such cases where are several events, e.g. the excess heat Q and NT, in a sample. This is a strong support to the model and suggests that the model reflects some phases of physics of CFP in it. Meaning of the Premises 1 and 2 and also that of n_n, however, should be investigated in terms of the physics of neutrons in solids which will be given in another paper presented in this Conference.[21]

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