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Nuclear Transmutation In Cold Fusion

Hideo Kozima
Department of Physics
Faculty of Science
Shizuoka University
Shizuoka 422, Japan

Synopsis

Experimental results of nuclear transmutation has been analyzed by the trapped thermal neutron catalized model (TNCF model). This model is based on conventional solid state-nuclear physics with an assumed eidstence of quasi-stable neutrons in pertinent solids. The result of the analyses shows the ability of the model to interpret the observed events and gives a consistent understanding of the cold fusion phenomenon including nuclear transmutation.

1. Introduction

Eight years have passed from the discovery[1] of the cold fusion phenomenon, which caused a sensation. The essential points of the confusion induced by the discovery was in the complexity of the observed events. The excess heat was too large to be explained by any known chemical reactions. Further, the observed nuclear products were inconsistent with the simple nuclear reactions which were supposed to occur in metals occluding (absorbing) deuterium:

$d + d = t\,(1.01\ \mathrm{MeV}) + p\,(3.02\ \mathrm{MeV})$,(1)
$= {}^3\mathrm{He}\ (0.82\ \mathrm{MeV}) + n\ (2.45\ \mathrm{MeV})$, (2
$= {}^4\mathrm{He}\ (76.0\ \mathrm{keV}) + \gamma(23.8\ \mathrm{MeV})$. (3)

In addition to these difficult to understand data, there was another decisive factor which puzzles scientists — poor reproducibility.

The cold fusion phenomenon, having such a complex structure as explained above, has been investigated with a model called TNCF model[2] which provides a consistent interpretation for the many events which have occurred. The model assumes the existence of the so-called trapped thermal neutrons which have a quasi-stable nature. The essential scenario of the model is explained as follows:

If the stability of the trapped neutron is lost by a large perturbation in the surface layer or in its volume, the probability of a trigger reaction between a thermal neutron and a nucleus may be calculated by the same formula as the usual collision process in a vacuum:

$$P_f = 0.35 n_n v_n n_N V \sigma n_N \xi, \qquad (4)$$

where $0.35 n_n v_n$, is the flow density of the neutron per unit area and time, n_n and n_N we the density of the trapped neutron and the nucleus, respectively. V is the volume where the reaction occurs, σ_{nN} is the cross section of the reaction. The factor ξ taken into the relation (3) expresses an order of the stability of the trapped neutron in the trapping region[2].

In the electrolytic experiments, we have taken $\xi = 1$ in the surface layer and $\xi = 0$ in the volume, except as otherwise stated. A value of $\xi = 0.01$ imtead of $\xi = 0$ in the relation (1) will result in lower n_n in the electrolytic data by a factor 2 than that determined with a value $\xi = 0$ as had been used in our former analyses. (In this paper, we will cite previous data with $\xi = 0$ as they were.) The trigger reaction is expressed as (5)

$$n + {}^{A}_{Z}M = {}^{A+1-b}_{Z-a} M' + {}^{b}_{a}0M'' = Q$$

$$where {}^{0}_{0}M \equiv \gamma, {}^{0}_{1} M \equiv n, {}^{1}_{1} M \equiv p$$

$${}^{2}_{1}M \equiv d, {}^{3}_{1} M \equiv t, {}^{4}_{2} M \equiv {}^{4}He, etc$$

The excess energy Q may be measured as the excess heat by the attenuation of the nuclear products, γ and charged particles, generated in the reaction (5). Otherwise, the nuclear products may be observed outside with an energy (we assume it as the original one, hereafter) or may induce succeeding nuclear reactions (breeding reactions) with one of other nuclei in the sample.

Typical reactions related with the TNCF model are written down se follows.

The trapped thermal neutron can fuse with a ^{6}Li nucleus in the surface layer formed on the cathode by electrolysis of D_2O (H_2O) + LiOD (LiOH) with a large cross section ~ 1 x 10^3 barns (at 300 °C):

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

The thickness of the surface layer will be assumed as 1 μm throughout the following analysis (allowing one order of magnitude uncertainty in the determined value of n_n) though it has been determined as 1 ~ 10 μm in experiments . Also, the abundance of the isotope ^{6}Li will be assumed as the natural one, i.e. 7.4%, except as otherwise described. Perhaps the first quantitative observation of abundant tritium in the electrolytic experiment was by Storms et al.[3] with an abundance of 0.018% ^{6}Li case.

The triton with an energy of 2.7 MeV generated in this reaction 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 (l_t = 1 ~ 10 μm) determined by the interaction with charged particles in the crystal. In the process of penetration through a crystal, the triton can react with a deuteron on the path of a length l_t with a cross section ~ 1.4 x 10^{-1} barn:

$$t\,(2.7\,MeV) + d = {}^4He\,(3.5\,MeV) + n\,(14.1\,MeV). \qquad (7)$$

One defect in experimental research has been not trying to detect higher energy neutrons up to 15 MeV, which we expect will be generated in this reaction. In the following analysis we assume l_t = 1 μm throughout this paper.

Neutrons with 14.1 MeV generated in this reaction can interact with particles in the crystal, especially with a deuteron elastically, giving a large amount of energy to it or inelastically dissociating it. In the case of an intermediate nucleus there also occurs an inelastic reaction, $(n, 2n)$, (n, p), and (n, a) reactions:

$$n(\varepsilon) + d = n' + d' \quad (8)$$

$$n(\varepsilon) + d = n' + p + n'' \quad (9)$$

$$n(\varepsilon) + {}^{A}_{Z}M = {}^{A}_{Z}M + n' \quad (10)$$

$$n(\varepsilon) + {}^{A}_{Z}M = {}^{A-1}_{\ \ Z}M + n' + n'' - Q \quad (11)$$

$$n(\varepsilon) + {}^{A}_{Z}M = {}_{Z-1}^{\ \ A}M + p - Q \quad (12)$$

$$n(\varepsilon) + {}^{A}_{Z}M = {}^{A-1}_{Z-2}M + {}^{4}_{2}He - Q \quad (13)$$

The reaction cross sections of these reactions for nuclei with $A = 100 \sim 200$ are in a range of 0.1 ~ 2 barn.

In these reactions the original high energy neutrons will be thermalized or will generate some low energy neutrons to be trapped in the sample (breeding process).

When the neutron become thermal it can fuse effectively with a deuteron in volume or with ^{6}Li nucleus in the surface layer;

$$n + d = t\,(6.98\ \text{keV}) + \gamma + 6.25\ \text{MeV}, (14)$$

$$n + {}^{7}Li = {}^{8}Be + \gamma = 2\,{}^{4}He + e^{-} + \nu_{e} + 16.2\ \text{MeV} + \gamma. (15)$$

The reaction (14) for a thermal neutron has a cross section 5.5×10^{-4} barn and the reaction (15) has 4×10^{-2} barn, which will be used in the estimation given in the following section.

The denteron having an energy up to 12.5 MeV accelerated elastically in the scattering (8) by the neutron with 14.1 MeV can fuse with another deuteron in two modes with a fairly large cross section of the order of 0.1 barn (the former reactions (1) and (2) with energetic deuterons):

$$d(\varepsilon) + d = t\,(1.01\ \text{MeV}) + p\,(3.02\ \text{MeV}), (16)$$

$$= He\,(0.82\ \text{MeV}) + n\,(2.45\ \text{MeV}). (17)$$

Depending on the situation in a cold fusion system, the trapped thermal neutrons can induce trigger reactions like the reactions (6), (14) and (15) and the generated energetic particles can sustain breeding chain reactions (7), (8) ~ (13), producing a lot of the excess heat and the nuclear products.

In the case of solids with hydrogen with deuterium, the following reactions should be taken up in the analysis as the trigger and the breeding reaction:

$$n + p = d\,(1.33\ \text{keV}) + \gamma(2.22\ \text{MeV}), (18)$$

$$d\,(1.33\ \text{keV}) + p = {}^{3}He\,(5.35\ \text{keV}) + \gamma(5.49\ \text{MeV}), (19)$$

The fusion cross section of the reaction (18) for a thermal neutron is 3.5×10^{-1} barn.

The photons generated in the reactions (14), (15), (18) and (19) can induce photodisintegration of deuterons and nuclei if they have more energy than the threshold energies of following reactions, (which is 2.22 MeV for reaction (20)):

$$\gamma + d = p + n, \quad (20)$$

$$\gamma + {}^{A}_{Z}M = {}^{A-1}_{\ \ Z}M + n. \quad (21)$$

In samples with deuterons, this reaction (20) with a cross section ~ 2.5 x 10^{-3} barn can work as a neutron breeder.

To analyze the data in electrolytic systems we have taken an abundance of ^{6}Li in LiOD as the natural one 7.5%, an avaage velocity of the trapped neutron v_n = 2.7 x 10^5 cm/s (T = 300 K). Then, we can determine the density of the trapped neutron n_n using the relation (4) between n. and the number of tritium atoms N_t (= N_{He}) generated in a time τ by the reaction (6);

$$N_t = N_{He} = 0.35 n_n v_n n_{6Li} l_o S \sigma_{nLi} \tau \xi, \quad (22)$$

where S is a surface area of the cathode, l_o is a thickness of the Li surface layer, σ_{nLi} = 9.4 x 10^2 barn, n_{6Li} = 3.5 x 10^{21} cm^{-3}. This number of tritium atoms is also number of events generating the excess heat of 4.8 MeV;

$$N_t = N_Q \equiv Q \text{ (MeV)}/4.8 \text{ (MeV)}.$$

The relation between N_n and N_t in a D/Li system; When the n - ^{6}Li reaction (6) is predominant in a electrolytic system with D_2O neutrons are generated by the reaction (7) with a relation with N_n and N_t, assuming half of the generated tritons contribute the reaction (7),

$$N_n \sim 0.5 N_t l_t n_d \sigma_{n\text{-}d}, \quad (23)$$

where the path length of the triton l_t ~ 1 μm, n_d = 6.8 x 10^{22} x (x = D/Pd) and $\sigma_{n\text{-}d}$ ~ 1.4 x 10^{-1} barn. This relation gives a ratio of event numbers N_t and N_n:

$$N_t/N_n \sim 2.1 \times 10^5.$$

2.Experimental Results of the Nuclear Transmutations and Their Analyses

Following twelve experimental data[4-15] were analyzed using the TNCF model and result of the result obtained was tabulated on the Table 1

2-1) J.R. Morrey et al.[4]

Morrey et al.[4] reported experimental results of measurements in six laboratories on helium content of five identically shaped 2 mmø x 10 cm Pd rods supplied by Fleischmann and Pons to check the origin of their reported excess heat.

They could not prove that the minimal excess heating in one of the rods (rod 5) reported by Fleischmann and Pons could be attributed to the formation of ^{4}He on the assumption that the ^{4}He had been generated by the reaction (3) and remained in the sample. Their explanation is as follows: "Rod 5 is reported to have created 1.36 ± 0.34 x 10^{11}, ergs of heat. The fusion reaction 2D → ^{4}He would generate 2.30 x 10^{19} erg/g.atom ^{4}He created. Thus, it could require the generation of 5.9 ± 1.47 x 10^9 g.atom ^{4}He (18.9 ± 4.6 x 10^{-9} g.atom/cm^3 Pd) to generate the heat reported. The quantity of ^{4}He found in rod 5 does not correlated well with the excess heat generated when the rod was electrolyzed. According to our calculations, it would take 36 ± 25 times as much ^{4}He as was measured to account for the reported excess heat."

This report, accepted as giving strong support to cold fusion skeptics, is consistent with the data obtained afterwards. The reaction generating ^{4}He in Pd/D/Li system should be the reaction (6) instead of the reaction (3). If the liberated energy 4.8 MeV in the reaction (6) was thermalized totally in the system, the number 36 pointed out in the paper[4] becomes 179. As we know from several data (Miles et al. Passel, Gozzi et al.), main part of the ^{4}He generated in the surface layer of Li metal on the Pd cathode goes out into liquid and and then to gas. So, it is reasonable to assume that only a small part (let us take as 3% rather arbitrarily) of the generated ^{4}He remained in the sample in a depth of ~ 25 μm which was determined by them[4]. Then, the factor 179 reduces to 5.4. This value is comparable to a factor ~ 5 obtained in the analyses of several data, as we can see in the table of the results of our analysis (cf. Table 1). The factor ~ 5 might be attributed to reactions in the sample generating the excess heat, not ^{4}He. The adjustable parameter n_n was calculated from the excess heat 1.36 x 10^{11} ergs as follows:

$$n_n = 4.8 \times 10^8 \text{ cm}^{-3}.$$

2-2) M.H. Miles, R.A. Hollins, B.F.Bush and J.J. Lagowski[5].

We give a result of the analysis of an experiment where the excess heat and helium in Pd/D_2O+LiOD system[5] using a massive cylindrical Pd cathode with a surface area of 2.6 cm^2 was observed. They measured ^{4}He atoms of 10^{21} ~ 10^{22} cm^{-3} per watt of the excess power (N_Q/N_{He} = 10 ~ 1) in the gas, while they did not measure tritium. Similar analysis to these given above in 1) resulted in the following conclusion with the density of the trapped neutrons n_n and the ratio of numbers of events N_Q and N_{He} producing ^{4}He:

$$n_n = 1.1 \times 10^9 \sim 10^{10} \text{ cm}^{-3}, N_Q/N_{He} = 5.$$

The density n_n is similar to that in 1) showing the main source of the excess heat in this case was the reaction (4).

2-3) R.T. Bush[6]

Bush observed the excess heat generation and nuclear transmutations ^{23}Na → ^{24}Mg and ^{39}K → ^{40}Ca in electrolytic systems Ni(alloy)/H/K(Na). Electrolytic solutions were 0.57 M $K_2(Na_2)CO_3 + H_2O$. In a case of ^{40}Ca production with a Ni cathode, cell 45, the average excess heat was Q = 0.58 → 0.15 J/s and the generated calcium atom was 48 x 10^{17} /15 d. In the case of ^{24}Mg production with a Ni alloy cathode, only the relative excess heat to the former case was given as Q_{Na}/Q_K = 1.90 ± 0.33.

The TNCF model predicts the following reactions (decay time) between the trapped neutrons and the alkali metals:

$$n + {}^{23}\text{Na} \rightarrow {}^{24}\text{Na} \rightarrow {}^{24}\text{Mg} + e^- + \nu_e + Q, \quad (15.0 \text{ h}) \quad (24)$$
$$n + {}^{39}\text{K} \rightarrow {}^{40}\text{K} \rightarrow {}^{40}\text{Ca} + e^- + \nu_e + Q. \quad (1.2 \times 10^9 \text{ y}) \quad (25)$$

In these reactions, the absorption cross sections are 0.82 and 3.2 barn, and the liberated energies Q, including accompanying gamma, are 2.72 and 2.78 MeV, respectively.

If we can assume that the decay time of the second reaction of 1.2 x 10^9 y is largely shortened by the neutron capture reaction to a value of the order of few hundred hours (let us take as 10^2 h), the experimental data showing generations of ^{24}Mg and ^{40}Ca are explained by the TNCF model with values of the parameter n_n given as follows:

$$n_n = 5.3 \times 10^{11} \text{ cm}^{-3}, ({}^{24}\text{Mg})$$
$$n_n = 5.3 \times 10^{10} \text{ cm}^{-3}. ({}^{40}\text{Ca})$$

In this analysis, the size of Ni(alloy) cathode was assumed the same 7.5 x 5.0

cm^2 x 0.125 mm as that used in Mills et al., according to the description in the paper[8]. Also, the thicknesses of the surface alkali layer was assumed as 1 μm for both systems. We have to remember that the decay time of ^{40}K in this calculation was assumed to be largely shortened from the value determined in Nuclear Physics.

2-4) R. Bush and R. Eagleton[7]

We give a result of the analysis of an experiment where excess heat and the nuclear transmutation of Rb into Sr in Ni/H_2O + Rb_2CO_3 system (with Ni sponge cathode)[7] was observed. The reaction supposed to occur in the system were

$$n + {}^{A}\mathrm{Rb} = {}^{A+1}\mathrm{Sr} + e^- + \nu_e,$$

in the surface layer of Rb on the Ni cathode (A = 85 and 87). The fusion cross section for this reaction is 0.7 (and 0.2) barn for A = 85 (and 87). They observed the isotope ratio ^{88}Sr/^{86}Sr changed from 8.5 to 3.5 when the excess heat was Q_1 and to 2.7 when it Was $Q_2 = 5Q_1$. The density n_n was determined by the TNCF model as:

$$n_n = 1.6 \times 10^7 \text{ cm}^{-3}.$$

Correlation of the excess heat and nuclear transmutation (NT) was explained quantitatively by a factor of 3. About the important parameter *S/V* ratio, the sponge cathode used here is difficult to determine its surface area. We may assume fairly large value $S/V \sim 10^4$ comparable to one (3.4 x 10^4 cm^{-1} of sintered Ni powder) used by Notoya et al.[11] though this value itself does nothing in the determination of n_n.

2-5) M. Okamoto et al.[8]

We give a results of the analysis of an experiment where excess heat and a nuclear transmutation from Al into Si in the surface layer on the cathode in Pd/D_2O+LiOD[8] system were observed.

The change of the density of the elements (up to 80% for Al) occurred in a surface above of the Pd cathode with a thickness of ~ 1 μm. The result of the calculation are given as follows:

$$n_n \sim 10^{10} \text{ cm}^{-3}, \quad N_Q/N_{NT} = 1.4.$$

In the calculation of the number of events inducing the nuclear transmutation N_{NT}, we assumed the same value 10^{22}/s of N_Q in this experiment as in an experiment[5] discussed later because of the similarity of experimental conditions. This value of N_Q/N_{NT} shows that the number of events generating the excess heat and the nuclear transmutation are almost the same in this case within the assumption made above.

2-6) P.O. Passell[9]

A Pd cathode with a total surface area 60 cm^2 and a thickness 25 μm (with a weight 0.9g) used in an experiment with an electrolytic solution D_2O + 1.0 M LiOD + 200 ppm Al producing the excess heat of 0.56 MJ was subjected upon comparing measurements of the prompt gamma activation analysis (PGAA) using thermal neutrons in beams from research reactors. A result showed an ~ 18% reduction in the boron impurity ^{10}B. The author (T.O. Passell) had tried to interpret the result on the hypothesis that some reaction other than D + D was the likely heat and helium-4 producing nuclear reaction and took up a reaction

$$^{10}B + d \rightarrow {}^4He + {}^8Be,$$

followed by the breakup of ^8Be into two more ^4He.

The reaction assumed above is compatible with the absence of gamma, the author's most troubling experimental fact, but is equally difficult to understand as occurring in a solid as a D + D fusion reaction without an energetic deuteron or a boron.

This data had been analyzed using the TNCF model, which gives a consistent explanation of this, and those obtained in SRI International, assuming following reactions between the trapped neutrons and the ^{10}B with a large cross section of 3.84 x 10^3 barn as a whole;

$$n + {}^{10}B = {}^7Li + {}^4He + 2.79 \text{ MeV}, \quad (93\%)(26)$$
$$= {}^7Li + {}^4He + \gamma(0.48 \text{ MeV}) + 2.79 \text{ MeV} \quad (7\%)(27)$$

The determined value of n_n was about 10^9 cm^{-3}, consistent with the value obtained in the analysis[16] of the data from SRI International:

$$n_n \sim 10^9 \text{ cm}^{-3}.$$

2-7) I.B. Savvatimova and A.B. Karabut[10]

The researchers in the Institute LUTCH in Podolsk, near Moscow, have been working with glow discharge experiments using D_2 and other gases and with cathodes of Pd and other transition metals (the cathode was with thickness of 100 μm). They measured the excess heat and nuclear transmutation of various isotopes and elements in the surface layer of the multilayer cathodes. Here we take up only one data of an increase of Ag from 20 to 5000 ppm in the glow discharge with D_2 gas and Pd cathode. After the discharge of four hours the sample was sent to mass spectrometry (SIMS) and its isotope composition was analyzed there about three months later. Assuming a continuous production of ^{107}Ag by an $n - {}^{106}Pd$ fusion reaction through 3 months at the surface layer of the cathode, we obtain a following value for the density of the trapped thermal neutron:

$$n_n = 9 \times 10^{10} \text{ cm}^{-3}.$$

2-8) R. Notoya et Ed.[11]

In a series of experiments with Ni cathode in H_2O (and D_2O) solution of electrolytes K_2CO_3 (and Li_2CO_3, Na_2CO_3, Rb_2SO_4, Ca_2SO_4), Notoya et al.[11] observed NT and positron generation in the system by the observation of the gamma ray spectrum. In addition to the production of ^{40}K, ^{56}Co, ^{64}Cu and ^{65}Zn, they detected a 0.511 MeV line due to the positron annihilation.

In the case of a porous Ni cathode with a dimension of 1.0 x 0.5 x 0.1 cm^3 and a density 58% of Ni metal and a electrolytic solution of 0.5 M K_2CO_3 + H_2O (20 to 30 ml as a whole), they observed an increase of ^{40}K by 100% after 24 hours electrolysis and the annihilation gamma ray at 0.511 MeV. The increase by 100% in the solution corresponds to a generation of ^{40}K by 3.0 x 10^{16} nuclei.

Analysis of the data using the TNCF model was performed with success giving following results.

The density of the trapped neutron n_n was determined by the experimental value of the change of ^{40}K by the reaction

$$n + {}^{39}K = {}^{40}K + \gamma(7.8\ MeV).$$

with a fusion cross section for the thermal neutron 2.2 barn as follows:

$$n_n = 1.4 \times 10^9 cm^{-3}.$$

The positron generation which resulted in the observed 0.511 MeV photon was explained by the following series of reactions in addition to the pair creation by the gamma generated in the above reaction:

$${}^{62}Ni + n = {}^{63}Ni \rightarrow {}^{63}Cu + e^- + \nu_e \quad (28)$$
$${}^{63}Cu + n = {}^{64}Cu \rightarrow {}^{64}Ni + e^+ + \nu_e, \quad (29)$$

An analysis of the experimental data gave us that the stability factor x is at most 0.01 in volume where the above two reactions occurred in the case of a negligible pair creation by the gamma.

This value of ξ has been used in our analysis of the experimental data obtained in the cold fusion phenomenon.

Thus, analysis of the NT of ^{39}K and positron generation in a porous Ni cathode gave us the following value: $n_n = 1.4 \times 10^9\ cm^{-3}$ and $(\xi)_{max} = 0.01$ in volume.

2-9) Y. Oya et al.[12]

In the experiment with artificial thermal neutron sourcel[12], the authors observed the excess heat and gamma spectrum. The excess heat amounted to the density of the trapped neutrons:

$$n_n = 3.0 \times 10^9\ cm^{-3}.$$

In the gamma spectrum, there are peaks at 0.511, 2.22, 5.49, 6.15, 6.25 and 7.09 MeV. The first one was interpreted as due to a positron from a pair-creation by gamma, from ^{64}Cu which existed beforehand, or generated by two step reactions in a material including ^{62}Ni in the experimental system:

$$n + {}^{62}Ni \rightarrow {}^{63}Ni \rightarrow {}^{63}Cu + e^- + \nu_e \quad (30)$$

$$n + {}^{63}Cu \rightarrow {}^{64}Cu \rightarrow {}^{64}Ni + e^+ + \nu_e, \quad (31)$$

The peak at 2.22 and 6.25 MeV can be interpreted as due to reactions (12) and (7), respectively. The peaks at 5.49, 6.15 and 7.09 MeV can be due to following reactions:

$$p + d = {}^3He + \gamma(5.49\ MeV), \quad (32)$$

$$n + {}^{108}Pd = {}^{109}Pd + \gamma(6.15MeV), \quad (33)$$

$$n + {}^{104}Pd = {}^{105}Pd + \gamma(7.09MeV), \quad (34)$$

Natural abundance of the isotopes ^{108}Pd and ^{104}Pd are 26.46 and 11.14%, respectively,

2-10) H. Yamada et al.[13]

Yamada et al. observed a neutron burst and precipitation of carbon on the tip surface of positive Pd electrode used in glow discharge with D_2 gas (pressure of 2 atm) and a point-to-plane electrode configuration. The analysis of the experimental data using the TNCF model gave us a possible reaction and a following value of n_n.

$$n + {}^{16}O = {}^{13}C + {}^4He - 4MeV, \quad (35)$$
$$n_n = 2.0 \times 10^{12}\ cm^{-3}.$$

2-11) T. Mizuno et al.[14]

Mizuno et al. observed NT in the surface layer (thickness $l \leq 2\ \mu m$) induced by electrolysis. The identification of isotopes was performed by SIMS (Secondary Ion Mass Spectrometry), AES (Auger Electron Spectroscopy), EPMA, EDX and γ spectroscopy. Many elements including Pt, Cu, Ni, Mo, Cr, Pd showed shifts of isotope ratios from the natural ones.

We take up here only one data of ^{52}Cr in Pd/D/Li system: the isotope ratio of ^{52}Cr observed in the surface layer showed a reduction from 83.8% (natural abundance) to 50% through an electrolysis of 30 days. We assume the cause of the isotope change was a reaction between the trapped neutron and one of Cr nuclei with a natural abundance (origin of which is ambiguous at present)

$$n + {}^{52}\mathrm{Cr} = {}^{53}\mathrm{Cr} + \gamma.$$

The cross section of this reaction is 0.764 barn. Then we can calculate the parameter n_n by the above change of the isotope ratio which occurred in 30 days, the duration of the electrolysis as follows:

$$n_n = 2.6 \times 10\ \mathrm{cm}^{-3}.$$

There was data of many NT with decreasing mass numbers in the paper[14] which are not easy to explain with the neutron absorption reaction. We might be able to treat these cases by the following reactions like (11) ~ (13) induced by high energy neutrons generated by such breeding reactions as (7) and (17):

$$n + {}^{A}_{24}Cr = {}^{A-3}_{22}Ti + {}^{4}_{2}He - Q,$$

$$n + {}^{A}_{46}Pd = {}^{A-3}_{22}Ru + {}^{4}_{2}He - Q'.$$

Numerical data will be given elsewhere.

In some cases it might be possible to assume even a fission reaction induced by a high energy neutron generated in one of breeding reactions.

2-12) Y. Iwamura et al.[15]

Iwamura et al. constructed a new type of Pd/D/Li system apparatus: a Pd plate cathode consisting of a part of the separation wall between electrolysis region A and a vacuum region B. Electrolysis was performed with an electrolytic solution LiOD + D_2O, the Pd cathode and a Pt disc plate anode (16 mmø) over the cathode. The excess heat of 4W for an input energy of 20W was measured once. X-ray spectrometers were set for both A and B region. An X-ray spectrum with a broad continuous peak up to 100 keV was measured only for A region, showing the origin of the X-rays was on the A side of the cathode plate. Foreign elements including Ti, Fe, Cr, Si, Cu, etc. were observed on the Pd cathode only under the Pt anode.

Using the maximum value of the excess heat of 4W and the active region of the Pd cathode with a surface area $S = \pi\ (0.8)^2\ \mathrm{cm}^2$, we can calculate the parameter n_n for the event as:

$$n_n = 7.4 \times 10^{10}\ \mathrm{cm}^3.$$

The product of NT, i.e. Ti, Fe, Cr....... could be treated by successive reactions of (n, a), $(n, 2n)$, (n, np), and so on.

The results of our analyses given above are tabulated in Table 1.

3.Conclusion

From the result of analyses given above, we can deduce several conclusions about the cold fusion phenomenon.

In general, the larger the S/V ratio becomes, the higher the qualitative reproducibility is. This tendency shows its existence in many experiments in-

Authors	System	S/V	Measured Quantities	n_n cm^{-3}	Other Results (Remarks)
J.R.Morrey et al.	Pd/D/Li	20	Q, ^4He($^6Li \to {}^4He+t$) ^4He in $\ell \leq 25 \mu m$	4.8×10^8	$N_Q/N_{He} \sim 5.4$ (If 3% ^4He was in Pd)
M.H. Miles et al.	Pd/D/Li	5	Q, ^4He ($N_Q/N_{He}=1 \sim 10$)	$10^9 \sim 10^{10}$	$N_Q/N_{He} \sim 5$
M. Okamoto et al.	Pd/D/Li	23	Q, NT($^{27}Al \to {}^{28}Si$) $\ell_0 \sim 1 \mu m$	$\sim 10^{10}$	$N_Q/N_{NT} \sim 1.4$
Y. Oya et al.	Pd/D/Li	41	Q, γ spectrum	3.0×10^9	(with ^{252}Cf source)
T.O. Passell	Pd/D/Li	400	NT ($^{10}B \to {}^7Li+{}^4He$)	1.1×10^9	$N_{NT}/N_Q=2$
R. Bush (Sample size assumed)	Ni/H/K Ni/H/Na	~ 160 ~ 160	NT($^{39}K \to {}^{40}Ca$) NT($^{23}Na \to {}^{24}Mg$)	5.3×10^{10} 5.3×10^{11}	$N_Q/N_{NT} \sim 3.5$ (If ^{40}K decay time=0)
R. Bush et al.	Ni/H/Rb	$\sim 10^4$	NT($^{85}Rb \to {}^{86}Sr$)	1.6×10^7	$N_Q/N_{NT} \sim 3$
R. Notoya et al.	Ni/D,H/K	34000	NT($^{39}K \to {}^{40}K$)	1.4×10^9	(Ni powder sintered)
I. Savvatimova	Pd/D_2	100	NT($^{106}Pd \to {}^{107}Ag$)	9×10^{10}	
H. Yamada et al.	Pd/D_2	185	n, NT($^{16}O \to {}^{13}C$)	2.2×12^8	(τ=250h, V=60mℓ)
T. Mizuno et al. (If Cr exists)	Pd/D/Li	3.4	Q, NT($^{52}Cr \to {}^{53}Cr$ $\ell \leq 2 \mu m$)	2.6×10^8	τ=30d, Pd cathode 1cm$\phi \times$ 10cm
Y. Iwamura et al.	Pd/D/Li	10	Q, NT(Ti, Cr etc.) (4 W/2 cm^2)	7.4×10^{10}	(NT unexplained)

Table 1: Nuclear Transmutation Explained using the TNCF Model. Neutron Density n_n and Relations between the Numbers Nx of Event x Obtained by Theoretical Analysis of Experimental Data using the 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 also tabulated.

cluding typical examples of Arata's Pd black, Patterson's beads, Celami's and Celluci's thin wires.

Another feature that appeared is matching of the cathode material and the electrolyte to maximize the cold fusion phenomenon. As is generally recognized empirically, Pd-Li and Ni-K (Rb) are best combinations in the electrolytic experiment of cold fusion phenomenon. A cause of these combination will be the condition for formation of the alkali metal (or alloy) layer on the cathode surface. Another possible cause might be a relation among the neutron affinities of matrix metal, solute hydrogen isotope and electrolyte[17]: the average neutron affinities are 1.2 (Ti), 3.9 (Ni) and 26.5 (Pd); 2.22 (H) an@1 - 0.02 (D); and – 14.8 (Li), – 5.51 (Na), – 1.5 (K) and – 2.7 (Rb).

The analyses given above verifies that the TNCF model is an effective tool for investigating the cold fusion phenomenon. The result also shows that the cold fusion phenomenon is an efficient probe for the solid state-nuclear physics taking place in materials containing thermal neutrons, which had not been noticed until ten years ago. We are in front of a new field of physics waiting development.

References

(1) M. Pleischmann, S. Pons and M. Hawkins, "Electrochemically Induced Nuclear Fusion of DeuteriuriY," *J. Electroanal. Chem.* 261, 301 (1989).

(2) H. Kozima, "The TNCF Model - Its Fundamentals," *Cold Fusion* 21, 19 (1997).

(3) E. Storms and C. Talcott, "Electrolytic Tritium Production," *Fusion Technol.* 18, 680 (1990).

(4) J.R. Morrey, M.R. Caffee, H. Farrar, IV, N.J. Roffman, G.B. Hudson, R.H. Jones, M.D. Kurz, J. Lupton, B.M. Oliver, B.V. Ruiz, J.F.Waocker and A. Van, "Measurements of Helium in Electrolyzed Palladium," *Fusion Technol.* 18, 659 (1990).

(5) M.H. Miles, R.A. Hollins, B.P. Bush and J.J. Lagowski, "Correlation of Excess Power and Helium Production During D_2O and H_2O Electrolysis Using Palladium Cathodes", *J. Electroanal. Chem.* 346, 99 (1993).

(6) R.T. Bush, "A Light Water Excess Heat Reaction Suggest that 'Cold Fusion' may be 'Akali-Hydrogen Fusion'," *Fusion Technol.* 22, 301 (1992).

(7) R. Bush and R. Eagleton, "Evidence for Electrolytically Induced Transmutation and Radioactivity Correlated with Excess Heat in Electrolytic Cells with Light Water Rubidium Salt Electrolytes," (*Proc. ICCF4*) 26, 344 (1994).

(8) M. Okamoto, H. Ogawa, Y. Yoshinaga, T. Kusunoki and O. Odawara, "Behavior of Key Elements in Pd for the Solid State Nuclear Phenomena Occurred in Heavy Water Electrolysis", *Proc. ICCF4*, **3**, 14-1 (1994).
(9) T.O. Passell,"Search for Nuclear Reaction Products in Heat-Producing Palladium," *Progress in New Hydrogen Energy* (*Proc. ICCF6*), 282 (1996).
(10) I.B. Savvatimova, A. B. Karabut, "Change of Elemental and Isotope Contents in Cathode after Ion Bombardment in Glow Discharge," *Proc. RCCFNT3* (Oct. 1995, Sochi, Russia), 20 (1996) and private communication.
(11) R. Notoya, T. Ohnishi and Y. Noya, "Nuclear Reaction Caused by Electrolysis in Light and Heavy Water Solution," *Progress in New Hydrogen Energy* (*Proc. ICCF6*), 675 (1996).
(12) Y. Oya, H. Ogawa, T. Ono, M. Aida and M. Okamoto, "Hydrogen Isotope Effect Induced by Neutron Irradiation in Pd-LiOD (H) Electrolysis," *Progress in New Hydrogen Energy* (*Proc. ICCF6*), 370 (1996).
(13) H. Yamada, H. Nonaka, A. Dohi, H. Hirahara, T. Fujihara, X. Li and A. Chiba, "Carbon Production on Palladium Point Electrode with Neutron Burst under DC Glow Discharge in Pressurized Deuterium Gas," *Progress in New Hydrogen Energy* (*Proc. ICCF6*), 610 (1996).
(14) T. Mizuno, T. Ohmori and M. Enyo, "Isotope Ratio Changes on the Surface of Metal and Ceramic Electrodes induced by Electrolysis," *Proc. Symposium on the Nuclear Transmutation in Solids* (June 1997, Iwate Univ., Morioka, Japan) (to be published in Japanese).
(15) Y. Iwamura, T. Ito, N. Goto, I. Toyoda and H. Sakata, "Detection of Elements (especially Ti) on the Cathode and Generation of the Excess Heat and X-ray in Electrolysis System with Deuterium Continuous Diffusion Type Pd Cathode," *Proc. Symposium on the Nuclear Transmutation in Solids* (June 1997, Iwate Univ., Morioka, Japan) (to be published in Japanese).
(16) H. Kozima, "Excess Energy Data in Pd/D System Examined," *Cold Fusion* 17, 12 (1996).
(17) H. Kozima, "Discovery of the Cold Fusion - Development of Solid State - Nuclear Physics and Energy Problem of 21st Century," Otake Shuppan Co., Tokyo, Japan, 1997. (in Japanese)

Papers Requested

Report your progress in this journal of record for the nascent industry. This will both help attract funding and help other researchers avoid re-inventing things.

Editorial continued from page 45.

landings a NASA hoax? - inner city riots - gangs - the Russian Mafia - the Japanese Yakusa - organized crime - Haitian drug rings - the Arab-Israeli situation - North Korea? - a hundred suitcase nukes missing in Russia - Syria-Lybia-Iran-Iraq - killer bees - the red tide - coral reefs dying - the Royal Family - most TV fare - terrorists - flag burning - school prayer - police corruption - rent control - politicians - police radar - property taxes - are a few things that come to mind.

If the promised (threatened) earth changes do happen, we're going to, more than ever, need elemental energy. The power grids could be gone. Oil could be stuck in the middle east. And here we all are, almost totally dependent on electricity for everything.

Infinite Baloney

I've been trying to steer clear of zero point energy, N-machines, magnetic over unity motors, and other such potential power sources. I'm almost beginning to get interested in magnetic motors since there are suggestions now that they draw their power from either the transmutation of elements, or maybe even the converting of elements into energy.

Having driven the Takahashi scooter myself, I have to admit that it works. So there has to be an explanation of where the energy is coming from. If we use magnets, fine, but why doesn't that gradually demagnetize them? The energy has to come from somewhere. Now I'm hearing that it comes from the direct conversion of the copper in the motor's windings to en-