An Explanation of Nuclear Transmutation in XLPE (Crosslinked Polyethylene) Films with and without Water Trees

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Abstract

An explanation of the nuclear transmutation (NT) observed in the XLPE (closslinked polyethylene) films dipped in aqueous electrolytic solutions with and without application of high-frequency electric field was presented by the neutron-drop model used in the theoretical investigation of the cold fusion phenomenon in transition-metal hydrides/deuterides (CF materials). The NT's K \rightarrow Ca, Mg \rightarrow Al, ${}^{56}{}_{26}$ Fe \rightarrow ${}^{57}{}_{26}$ Fe and Fe \rightarrow Ni are explained by a single neutron absorption with or without a succeeding beta-decay to get final nuclides. The NT's ${}^{56}{}_{26}$ Fe \rightarrow ${}^{64}{}_{30}$ Zn and ${}^{56}{}_{26}$ Fe \rightarrow ${}^{60}{}_{28}$ Ni are explained by an absorption of a neutron drop ${}^{8}{}_{4}\Delta$ and ${}^{4}{}_{2}\Delta$, respectively, in the cf-matter that was supposed to be formed at boundary regions of crystallites in the sample. Production of wonderful elements Li, Pb and Bi is discussed from our point of view.

1. Introduction

We have tried to explain the wide-spread experimental facts in the cold fusion phenomenon (CFP) from a unified point of view using a phenomenological models (the trapped neutron catalyzed fusion model (TNCF model) at first and then the neutron-drop model (ND model), a generalized version of the former). It should be remembered here that the development of the model was demanded to explain NT's with large changes of the nucleon and proton numbers observed in the CFP.

In the process of verification of the basic premises of these successful models, we have developed a quantal investigation of the CF materials such as transition metal hydrides/deuterides composed of lattice nuclei of transition metals and interstitial protons/deuterons. It was shown that it is possible to appear the cf-matter composed of neutron drops ${}^{A}_{Z}\Delta$ with Z protons, Z electrons and (A - Z) neutrons in a dense neutron liquid at

boundary /surface regions of the crystals.

Recently, Kumazawa et al. [1] observed the nuclear transmutation (NT) in XLPE (closslinked polyethylene) including water trees and then detected weak mission of gamma or X-rays from similar samples [2]. Generally speaking, water trees are formed macroscopically at (α) boundaries of XLPE samples and microscopically at (β) amorphous portions of the sample among spherulites composed of crystalline lamellae.

The NT observed in the XLPE films by Kumazawa et al.[1, 2] has common characteristics to that observed in CF materials as a part of the CFP. Therefore, it is natural to apply the same model to explain the NT in XLPE that was successful to explain the NT in the CF materials [3].

Experimental results in XLPE have clearly shown that the NT have occurred when the samples (**Original**) were dipped in the electrolytic solutions (**Blank**) and also when high-frequency (2.4–3.0 kHz), high-voltage (3.0–4.0 kV/mm) electric voltage was applied further (let us call such samples **Experimental** in the following discussion, for simplicity) as shown in Table 1. As electrolytes, (a) **KCL**, (b) **NaCl** and (c) **AgNO**₃ were used for aqueous electrolytic solutions as shown in this Table. It is noticed that the NT's were observed not only in the region where were observed water-trees but also in the region where were not (cf. Dipped in AgNO₃ solution in Table 1) even if this is not always a precise distinction because it was done visually, as the authors commented in their original paper.

Increase (+) and decrease (-) of elements in samples (Experimental) were qualitatively depicted in Table 2 for electrolytes KCl, NaCl and AgNO₃.

In this paper, we give an explanation of the mechanism to produce the observed nuclei in both of XLPE samples, Blank and Experimental, based on the neutron-drop (ND) model proposed by the author [3].

| | Dipped in KCl solution | | | | | | Dipped in NaCl | | | | | Dipped in AgNO ₃ solution | | | | |
|---------|------------------------|--------|----------|--------|--------------|--------|----------------|--------|----------|--------|--------------|---|-----------------|---------------|-----------------|--------|
| Element | Sample-A | | Sample-B | | Blank sample | | Sample-A | | Sample-B | | Blank sample | | Water- treed | Not water- | Original sample | |
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | region | region | 1 | 2 |
| | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] | [ng/g] |
| Li | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | 170 | 36 | <1 | N.D. |
| Na | <1 | N.D. | <1 | N.D. | <1 | N.D. | 54 | .49 | 7000 | 1300 | 6800 | 1500 | 360 | 75 | 50 | 45 |
| Mg | 140 | 70 | 70 | 110 | 230 | 180 | 4 | 2 | 58 | 55 | 49 | 46 | 20 | 14 | 43 | 46 |
| Al | <1 | N.D. | <1 | N.D. | <1 | N.D. | 18 | 130 | 19 | 9 | 22 | 19 | 18 | 21 | 13 | 22 |
| Si | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | N.D. | N.D. | <1 | N.D. |
| K | 20 | N.D. | 20 | 10 | 6 | 60 | 10 | 5 | 9 | 9 | 17 | 2 | 8 | 7 | 15 | 4 |
| Ca | 5100 | 160 | 190 | 3200 | 150 | 170 | 31 | 24 | 73 | 80 | 51 | 49 | 47 | 48 | 79 | 68 |
| Cr | <1 | N.D. | <1 | N.D. | <1 | N.D. | 16 | 6 | 2 | 3 | 3 | 3 | 2 | 1 | 2 | 1 |
| Fe | 100 | 20 | 80 | 60 | 70 | 110 | 300 | 90 | 88 | 60 | 280 | 110 | 14 | 18 | 220 | 160 |
| Ni | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | 9 | 40 | N.D. | N.D. |
| Cu | <1 | N.D. | <1 | N.D. | <1 | N.D. | 17 | 17 | 16 | 12 | 14 | 19 | 7 | 6 | 8 | 14 |
| Zn | 4 | N.D. | 2 | N.D. | 6 | 5 | 8 | <3 | 3 | <3 | 6 | <3 | 4 | 23 | 15 | 13 |
| Ag | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | 19000 | 5200 | N.D. | N.D. |
| Ba | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | <1 | N.D. | N.D. | N.D. | <1 | N.D. |
| Pb | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | 0.7 | 1.5 | N.D. | N.D. |
| Bi | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | N.D. | 2 | 6 | N.D. | N.D. |

Table 1. Results of quantitative analysis for inorganic elements in XLPE sample (Table 6 of [1]).

| | | Sample | | | | | | | |
|------------------|---|------------------------------|-------------------------------|--|--|--|--|--|--|
| Element | Isotopes | Dipped in KCl solution | Dipped in NaCl solution | Dipped in AgNO ₃ solution | | | | | |
| 3Li | ⁶ Li, ⁷ Li | | | + | | | | | |
| 11Na | ²³ Na | | - · | (+) | | | | | |
| 12 Mg | ²⁴ Mg, ²⁵ Mg, ²⁶ Mg | | — | | | | | | |
| 13 Al | ²⁷ Al | | · + / | | | | | | |
| 19K | ³⁹ K, ⁴⁰ K, ⁴¹ K | /-` | | | | | | | |
| ₂₀ Ca | ⁴⁰ Ca, ⁴² Ca, ⁴³ Ca, ⁴⁴ Ca, ⁴⁶ Ca, ⁴⁸ Ca | ÷, | | | | | | | |
| ₂₆ Fe | ⁵⁴ Fe, ⁵⁶ Fe, ⁵⁷ Fe, ⁵⁸ Fe | | | / - `\ | | | | | |
| ₂₈ Ni | ⁵⁸ Ni, ⁶⁰ Ni, ⁶¹ Ni, ⁶² Ni, ⁶⁴ Ni | | | + | | | | | |
| 47Ag | ¹⁰⁷ Ag, ¹⁰⁹ Ag | | | (-) | | | | | |
| ₈₂ Pb | ²⁰⁴ Pb, ²⁰⁶ Pb, ²⁰⁷ Pb, ²⁰⁸ Pb | | | + | | | | | |
| ₈₃ Bi | ²⁰⁹ Bi | | | + | | | | | |

Table 2. Increase (+) or decrease (-) of inorganic elements in samples after voltage application (Table 9 of [1]).

2. Theoretical Basis of the Data Analysis

The XLPE (closslinked polyethylene) used in the experiment [1,2] was made from low density polyethylene (LDPE) adding an organic crosslinking agent and heating. XLPE contains cross-link bonds which changing it into the polymer structure, changing the thermoplastic into a duromer. In general, a LDPE is composed of two components; the crystalline and the amorphous portions. The crystallinities of the LDPE and the XLPE are about 50 and 45%, respectively, at room temperature. The crystalline portion is composed of the spherulites containing radially distributed lammelae, stacks of folded polyethylene chains with a thickness of about 100 angstroms.

Thus, a XLPE sample in a good condition is supposed to include a lattice structure (lamella) with ordered carbon nuclei (lattice nuclei) interlaced with ordered protons. In the structure of lattice nuclei and interstitial protons, there appears the super-nuclear interaction between neutrons in lattice nuclei mediated by interstitial protons as shown in our previous works [3]. The super-nuclear interaction between neutrons in lattice nuclei results in the neutron band in which neutron Bloch waves propagate in the crystal lattice without disturbance unless there are such disorders of the arrangement as impurities and boundaries.

In the boundary region of the crystal lattice where the neutron Bloch waves are reflected, there occurs accumulation of the waves and a state with a high-density neutron appears. In this state, there is a cf-matter composed of neutron drops ${}^{A_{Z}}\Delta$ immersed in a dense neutron liquid.

In the region where are disorders of the arrangement of nuclei, the neutron Bloch wave and therefore the neutron drops interact with these irregular nuclides and results in nuclear reactions generating new nuclides together with liberated excess energy. In these nuclear reactions in the cf-matter, a characteristic mechanism works where the liberated energy is directly accepted by the cf-matter and converted into lattice energy instead of emission of a gamma photon as in a nuclear reaction in free space. This is the essential scenario of the neutron-drop (ND) model for the CFP proposed by us [3].

The nuclear reactions in solids thus induced are characterized by several properties; (1) liberated energy in the nuclear reactions are transferred to the crystal lattice not emitted as gamma rays, (2) the threshold energy for nuclear reactions in free space becomes zero or very low, (3) the threshold energy for fission also becomes zero or very low. The weak radiation observed by Kumazawa et al. [2] may be considered as a proof of the occurrence of nuclear reactions in the system but is a peripheral effect accompanied to the main nuclear reactions that trigger birth of water trees in the samples.

3. Characteristics of the Experimental Result and its Explanation by the ND Model

We give an explanation of characteristics of the experimental data obtained by Kumazawa et al. [1] using the ND model.

3-1 Experimental Results

A part of the extensive experimental data sets on the NT in the XLPE obtained by Kumazawa et al. [1] is given in Tables 1 and 2, in Introduction of this paper.

In the experiments, a XLPE (cross-linked polyethylene) sheet 0.5 mm thick was used. The original sheet (Original sample) was scratched by an Au wire brush on the surface to create the water needle electrodes where the water trees starts. Au was deposited as a ground electrode onto the bottom surface of the sample. Then, the sample was dipped in aqueous solutions of electrolytes (a) KCl, (b) NaCl and (c) AgNO₃ to make the Blank samples. To the Blank samples in the aqueous solutions, electric fields with high -frequency (2.4-3.0 kHz) and high-voltage (3.0 - 4.0 kV/mm) were applied between the voltage application wire above the sample and the ground electrode for 140 - 320 hours to obtain "the samples after voltage application" (let us call them the Experimental samples, for simplicity). Quantitative analysis of elements were performed for (I) the Original, (II) the Blank and (III) the Experimental samples for three electrolytes (a) KCl, (b) NaCl and (c) AgNO₃. In the case (c), there are no data on the blank samples but data on the two distinct regions selected visually (i) with water trees and (ii) without water trees.

Whole experimental data was tabulated in Table 1 and a part of typical data is qualitatively shown in Table 2 where are shown the increase (+) and decrease (-) of elements in Experimental compared to Original samples.

Characteristics in the changes of elements from (I) the Original to (II) the Blank and (III) the Experimental samples were summarized as follows;

In the case (a) (KCl),

(1) K decreased and Ca increased,

(2) ⁵⁶Fe decreased and ⁵⁷Fe increased,

(3) ⁶⁴Zn increased while other isotopes of Zn decreased.

In the case (b) (NaCl),

(4) Mg decreased and Al increased in which the gross weight of the two elements was hardly different compared to the Blank or the Original samples.

In the case (c) (AgNO₃),

(5) Fe decreased and Ni increased,

(6) New elements Li, Na, Pb and Bi were detected, and

(7) There are changes of elements in both regions with and without water trees.

Furthermore, there are interesting features of the blank samples (II) in the case (a).

(8) In Blank samples, Mg and Ca are increased from those in the Original one while Fe is decreased.

In the second paper [2] by Kumazawa et al., they reported detection of weak and burst-like radiation supposed to be low energy gamma or X-ray. In the CFP, there are a few observations of gamma and X-rays but are peripheral (cf. Section 6.3 of [4] for the data of gamma ray observation). We concentrate our investigation in this paper to the data reported in the first paper [1].

3-2 Theoretical Investigation

As discussed in Section 2, the crystalline portion of the XLPE sample has a similar physical properties to the transition-metal hydrides/deuterides where observed various events in the CFP. As we summarized at the end of the previous sub-section, there are several NT in the XLPE films that have corresponding ones in the CFP explained phenomenologically [3].

We give explanations of the seven characteristics of the nuclear transmutations (NT) in XLPE giving counterparts in the CFP for reference.

(1) Decrease of K and increase of Ca in the case (a) are explained by such a reaction in the solids by absorption of a neutron followed by beta decay with a liberated energy $\Delta E = 1.31$ MeV;

 $n + {}^{39}{}_{19}\text{K} \rightarrow {}^{40}{}_{20}\text{K}^* \rightarrow {}^{40}{}_{20}\text{Ca} + e^- + \underline{v}_{e,} (\sigma_{nK39} = 2.10 \text{ b})$ (3-1) where \underline{v}_e is an electron neutrino. As a measure of the reaction cross-section in solids we cited the value in free space in the parenthesis behind the equation. the Corresponding examples of this type of NT in the CFP is given in Section 2.5.1 of [3].

(2) Decrease of ${}^{56}{}_{26}$ Fe and increase of ${}^{57}{}_{26}$ Fe in the case (a) are similarly explained but without beta decay due to the stability of ${}^{57}{}_{26}$ Fe with an energy Q = 1.15 keV transferred to the lattice system instead of gamma ray emission in free space;

$$n + {}^{56}{}_{26}\text{Fe} \rightarrow {}^{57}{}_{26}\text{Fe} + Q. \quad (\sigma_{nFe56} = 2.81 \text{ b})$$
 (3-2)

(3) Increase of ${}^{64}{}_{30}$ Zn and decrease of ${}^{66}{}_{30}$ Zn, ${}^{67}{}_{30}$ Zn and ${}^{68}{}_{30}$ Zn in the case (a) are explained by using the neutron drop ${}^{A}{}_{Z}\Delta$, for example;

 ${}^{56}{}_{26}\mathrm{Fe} + {}^{8}{}_{4}\Delta \rightarrow {}^{64}{}_{30}\mathrm{Zn}.$ (3-3)

Many examples of this type in the CFP are given in Section 2.5.2 of [3]. Decrease of other isotopes may be explained by nuclear reactions to transform them into other elements but its details are left for another work. (4) Increase of Al and decrease of Mg in the case (b) are explained by reactions similar to (3-2) with Q = 7.08 MeV and Q' = 12.11 MeV and a reaction similar to (3-1) with $\Delta E = 2.61$ MeV.

$$n + {}^{24}{}_{12}Mg \rightarrow {}^{25}{}_{12}Mg + Q.$$
 ($\sigma_{nMg24} = 0.05 \text{ b}$)

$$n + {}^{25}{}_{12}\text{Mg} \rightarrow {}^{26}{}_{12}\text{Mg} + Q'.$$
 ($\sigma_{nMg25} = 0.19 \text{ b}$)

 $m + {}^{26}{}_{12}\text{Mg} \rightarrow {}^{27}{}_{12}\text{Mg}^* \rightarrow {}^{27}{}_{13}\text{Al} + e^- + \underline{v}_e.$ ($\sigma_{nMg26} = 0.04 \text{ b}$)

(5) Decrease of Fe and increase of Ni in the case (c) are explained similarly with use of the neutron drop, for example;

 ${}^{56}26$ Fe + ${}^{4}2\Delta \rightarrow {}^{60}28$ Ni.

(6) New elements with nucleon and proton numbers far from those of elements preexisted in the system were observed fairly often in the CFP. There are several types of events producing such nuclides with largely shifted nucleon and proton numbers, A and Z, from those of original nuclides; One of them similar to the case Li, Na, Pb and Bi may be the NT by transformation discussed in Section 2.5.4 of [3]. (There are observations of C from Pd and W systems, Cl from a Pd system, Fe in a carbon system, and Pb in a Pd system.)

(7) The occurrence of the NT in both of regions with and without water trees (by visual observation) might be evidence that the NT is not a result but a cause of the water tree generation. If seeds of water trees were born at boundaries or impurities in the disordered regions of the XLPE sample, as is said conventionally, the position is just where the cf-matter is tend to be formed by accumulation of neutrons in the neutron band. The larger the lamella in the spherulite, the easier the cf-matter formed and the easier nuclear reactions occur there.

Thus, we may imagine a following scenario of growth of a water tree; (i) a NT of impurity nuclides occurs at a boundary region heating there by a liberated energy, (ii) a seed of a water tree is induced by the liberated energy, and (iii) the applied high-frequency electric field makes the water tree grow.

(8) The changes of amounts of elements in the blank samples from those in the Original in (a) support this scenario.

Furthermore, the characteristics (a) and (b) of water-tree formation pointed out in Introduction are consistent with the scenario. The lamella has a crystalline structure with lattice nuclei (C) and interstitial protons favorable for formation of the neutron band and the cf-matte [3]. By our scenario, nuclear reactions between a neutron or a neutron drop ${}^{A}_{Z}\Delta$ and exotic nuclei (e.g. ${}^{39}_{19}$ K) can take place.

4. Discussion

If the above explanation of the various experimental data obtained in XLPE samples consistent with that of data sets in the CFP is trustworthy, we can deduce a prediction for effective occurrence of NT in CF materials in general. Formation of the neutron band is easier in crystals with the more perfect periodicity of lattice nuclei (C) and interstitial hydrogen isotopes (H), i.e. higher crystallinity (lamellae and spherulite formation) in XLPE is favorable for formation of the neutron band. This factor may correspond to the higher average value of the D/Pd ratio in palladium deuterides that is necessary to be more than a minimum value at around 0.85 to realize the CFP in them (cf. Section 2.9.2 of [3]). In the case of XLPE, regularity of proton array in a lamella is secured and remaining factor is the crystallinity of the sample which may depend on how the sample is manufactured. There may be a minimum size of lamellae in spherulites to realize the neutron band and therefore the NT in XLPE.

To realize nuclear reactions resulting in the generation of new nuclides, it is necessary to have appropriate irregularities of the lattice (boundaries and impurities) and appropriate nuclides in addition to the regularity of the nuclear arrangement for the neutron band formation,. The imbalance of samples A1, A2, B1 and B2 shown in Table 1 may be explained by the inhomogeneous distribution of regular portions with spherulites and also density of such impurities as electrolyte ions. In this paper, it was explained that the NT well known in the CFP occur also in the XLPE samples. Characteristics of the phenomenon in both of systems, transition- metal hydrides/deuterides and XLPE films, are very similar despite of the difference in the lattice nuclei and hydrogen isotopes: lattice nucleus is the transition metal (Ti, Ni, Pd) in the former and is carbon (C) in the latter; hydrogen isotope is proton or/and deuteron in the former and is proton in the latter. This shows that the mechanism responsible to the NT in both systems is independent of the species of lattice nuclei (Pd, Ni, Ti or C) and also of the species of hydrogen isotopes (proton or deuteron), if it is natural to assume a common cause for them.

Another remarkable point proved by the extensive data by Kumazawa et al. [1,2] is that the water tree in XLPE is, at least partially, induced by the NT in the sample. Effects of the high-frequency electric field (HFEF) may be multiple; (1) HFEF make the electrolyte ions diffuse into the sample (especially at amorphous portions) to become irregular ions. When a NT occurs at an irregular ion nucleus, the liberated energy induces a seed of water trees. (2) HFEF then accelerates growth of the water trees into a larger scale.

The fact that silver (Ag) has larger effect in water-tree formation, the tree in this case has a special name "the silver tree," may be a result of the large cross section of n – Ag reaction (38.62 and 90.53 b for ¹⁰⁷Ag (51.82%) and ¹⁰⁹Ag (48.18%), respectively) compared to small values of 0.53 and 2.1 b for n – ²³Na and n – ³⁹K reactions, respectively (1 b = 10^{-24} cm²).

Based on the above mentioned scenario of the NT in XLPE, we may give speculation about possible nuclear reactions in it.

First, the silver isotope has a large cross section for a neutron absorption followed by a beta decay as mentioned above;

 $n + {}^{107}_{47}\text{Ag} \rightarrow {}^{108}_{47}\text{Ag}^* \rightarrow {}^{108}_{48}\text{Cd} + e^- + \underline{v}_{e}, (\sigma_{nAg107} = 38.62 \text{ b})$

 $n + {}^{109}_{47}\text{Ag} \rightarrow {}^{110}_{47}\text{Ag}^* \rightarrow {}^{110}_{48}\text{Cd} + e^- + \underline{v}_{e}$ ($\sigma_{nAg109} = 90.53 \text{ b}$)

with liberation energies ΔE of 1.65 and 2.89 MeV, respectively. We can expect generation of cadmium if there occur these reactions with single neutron participation in the sample.

Second, proton has a cross section of about 0.332 b for thermal neutron absorption;

 $n + p \rightarrow d + Q$, ($\sigma_{np} = 0.332$ b) with Q = 2.22 MeV thermalized in the sample as we assume in our model. We can expect enrichment of deuterium in the sample if the n - p reactions effectively occur in amorphous portion surrounding spherulites in XLPE. This reaction may play an important role in formation of seeds of water trees if the deuterium enrichment is confirmed in clean XLPE samples without addition of exotic ions.

The complicated phenomenon of water trees in XLPE films will give further interesting examples of the CFP thoroughly investigated in transition-metal hydrides and deuterides.

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