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Neutron Energy Bands in the Compound and Composite CF Materials – Speculation on the Bases of the TNCF and ND

Models -+

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Abstract

Using a phenomenological approach by the TNCF (trapped neutron catalyzed fusion) and the ND (neutron drop) models, we have given a unified explanation of the complex features of the cold fusion phenomenon (CFP). In the phenomenological approach, the necessary and sufficient condition for the cold fusion phenomenon (CFP) has been established as the formation of the neutron energy bands in the super-lattice of host elements and the hydrogen isotopes realized by the self-organization in complexity.

In this paper, the bases and applicability of the TNCF and the ND models are investigated in the CF materials with rather complicated structures in the compound (multilayered materials and materials on substrates with interfaces) and composite (alloys, ceramics and polymers) structures investigated very often recently. In the investigation we used analogy of the neutron energy bands (neutron bands) to the electron energy bands (electron bands).

The neutron bands in the compound CF materials are investigated with reference to the electron bands in PN junctions. On the other hand, the neutron bands in the composite materials are investigated with reference to the characteristics of the electron bands in alloys at around symmetrical points in the Brillouin zone. The analogy between the electron bands and the neutron bands legitimates qualitatively the use of the concepts of the neutron bands for investigation of the CFP in compound and composite CF materials.

In the investigation of the neutron band in alloys, we noticed two kinds of effects of

the minor elements to the CFP, active (or positive) elements including the 3d and 4d transition elements and inactive (negative) elements including other than those in the active ones. The former enhances the nuclear reactions in the CFP and the latter reduces them. Direct evidence of this classification was given by experimental data by Claytor et al. and indirect evidence was given by the HER (hydrogen electrode reaction) and the UPD (underpotential deposition) in the electrochemistry. This problem will be discussed extensively in another paper.

It is shown that the effects of the interfaces of the CF materials on the CFP are essential to induce the nuclear reactions between the neutrons in the bands and nuclei at disordered positions generated by the thermal motion, by the statistical distribution at a finite temperature, and by the specific situation at around interfaces.

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1. Introduction – Phenomenological Approach to the Complex Phenomenon

When we engage in contemplation of the truth hidden behind phenomena in the environment surrounding us, it is necessary to use some kinds of logic. In the modern science established in 16th century and lasted exclusively until the middle of 20th century, its main scheme was overwhelmed by the *deductive logic* based on the established principles in simple linear systems discovered by the *inductive logic* and confirmed by the *deductive logic* thereafter.

It is possible to say in general that our contemplations on the relation with environment have been essentially interlaced with inductive and deductive logics as noticed in the beginning of our civilization born about 2500 years ago. It had been recognized the importance of the *intuition* in the inductive logic as expressed by two geniuses Plato in his letter and A. Einstein in a writing (cf. Appendix A1). We must notice the importance of intuition in the inductive logic to find out a *tentative principle* from our experience in a world and of the alternative use of inductive and deductive logics to proceed our contemplation to find out the *final principle* in a realm of the world as we see in the referred sayings of the geniuses.

In the investigation of the cold fusion phenomenon (CFP) that includes the nonlinear interaction among component particles in a nonequilibrium condition and therefore belongs to complexity, it has been necessary to use the inductive logic to find out fundamental principles for the science of the CFP. We have engaged in the task as practiced in our phenomenological approach to the CFP [Kozima 1998, 2006] unintentionally and explained its meaning definitively in our recent paper [Kozima 2019a].

The CFP observed in the various CF materials have been investigated successfully using our models while we have left the data sets obtained in materials with rather complicated structures such as compound (with interfaces showing outstanding roles) and composite (multi-component host substances). Even if the structures of the CF material differ one from another, we may be able to apply the same approach to analyze the phenomenon having common characteristics as we had shown in our paper [Kozima 2019a] that it is possible to use the inductive logic and meta-analysis for experimental data sets as a whole.

In our recent papers, we have investigated the CFP in the compound and composite CF materials rather deductively using the TNCF model [Kozima 2020, 2021a, 2021b]. In the analysis, we had noticed the importance to take into our consideration the

characteristics of the hydrogen electrode reaction (HER) and the underpotential deposition (UPD) at interfaces of the composite CF materials. We have presented at this Conference a paper on the composite CF material [Kozima 2021a] and another paper on the effects of the interfaces on the CFP in the compound materials [Kozima 2021b]. We will investigate the general relation of the HER and UPD themselves with the cold fusion phenomenon (CFP) in another paper [Kozima 2021c].

In this paper, we discuss the applicability of the TNCF (trapped neutron catalyzed fusion) and the ND (neutron drop) models to the composite and compound CF materials used in these papers [Kozima 2021a, 2021b]. The speculative discussion in this paper depends mainly on the knowledge of the electron energy band (electron bands) obtained mainly in the semiconductor physics.

1.1 In the Beginning

It was an accidental coincidence to have similar exclamations by John Dash and by me at the 4th International Conference held five years after the declaration of the discovery of the cold fusion phenomenon by Fleischmann et al. [Fleischmann 1989] as follows:

"A key to open the door to solve the riddles of the Cold Fusion has been neglected by researchers until now is the thermal and cold neutrons existing abundantly everywhere." [Kozima 1994]

"On the other hand, these elements could have been produced by transmutation if slow neutrons were present." [Dash 1994]

To investigate the applicability of the TNCF model to composite and compound CF materials, we give first a brief summary of the structure of the TNCF model.

Fundamental premises and logics of our theory:

- (0) Inductive logic and meta-analysis are needed in the analyses of data in the CFP. [Kozima 2019a]
- (1) Adsorption of hydrogen isotope atoms (H/D), molecules(H₂/D₂) or ions (H⁺/D⁺) by the host material composed of elements X (${}^{4}Z$ X). Adsorption of ions on the electrode is a subtle problem of catalytic nature investigated

in electrochemistry (cf. e.g. [Bockris 1970a, 2000, Quaino 2007, Seo 2012]) and we do not discuss it in this paper even if we had touched it before [Kozima 2000].

(2) Absorption of hydrogen isotope ions H⁺/D⁺ (p/d) by the hydrogen electrode reaction (HER) into the specific host material where the proton/deuteron wavefunctions are nonlocalized in the interstices but overlap with the lattice nuclei.
[Bockris 1970a, 2000, Kita 1971, 1973, Kozima 2009]

- (3) Formation of the CF material composed of the host element X and the hydrogen isotopes H/D where the nuclei ${}^{A}_{Z}X$ have neutron energy levels at around the evaporation level the neutrons in them have rather extended wavefunctions. [Kozima 2014a]
- (4) Generation of the superlattice XH/XD (^A_ZX-p/^A_ZX-d) by the self-organization in a non-equilibrium condition as a process in the complexity.
 [Kozima 2013, 2014a]
- (5) Formation of neutron energy bands by the super-nuclear interaction (n-(p/d)-n) interaction) between neutrons in different lattice nuclei catalyzed by interstitial protons/deuterons.

[Kozima 2006, 2009]

(6) Supply of initial neutrons into the neutron energy bands (let us call the neutrons in the energy band "trapped neutrons") with a number density n_n . It may be supplied from outside by environmental background neutrons in the first step.

Null result [Jones 1994, Forsley 1998]

Neutron effects [Shani 1989, Yuhimchuk 1992, Celani 1992, Stella 1993, McKubre 1993 (p. 11), Oya 1996]

(7) Multiplication of n_n by nuclear reactions between the trapped neutrons and disordered nuclei Y (let us write a displaced host element (X) in bulk or a foreign element X' at a boundary or at a surface as Y). The nuclear reactions result in the multiplication of n_n.

[Kozima 1998 (Sec. 17.1), 2006 (Sec. 3.7.2.3), 2013 (p. 149), Miley 1996a (p. 21), Iwamura 2006].

- (8) The nuclear reaction of the trapped neutron with the nuclei at disordered sites caused by (a) the thermal motion of host elements, (b) the statistical imbalance of arrangement, (c) the disorder accompanied to the structure change at interfaces. The thermal motion of the nuclei results in the temperature effect of the CFP as summarized in our recent paper [Kozima 2020].
- (9) Then, the positive feedback occurs to increase n_n.
 [Kozima 2012b (pp. 10 − 12), 2013 (pp. 149 − 151, Sec. 3.2)]"

The discussions on the experimental data obtained in the composite CF materials [Kozima 2021a] and the compound CF materials [Kozima 2021b] are based on the steps (7) to (9). The discussion in this paper takes up the steps (4) and (5) in the composite and compound CF materials in reference to the electron energy bands investigated in the semiconductor physics. The complicated atomic processes related to the steps (1) and (2)

will be taken up in the paper scheduled in near future [Kozima 2021c].

1.2 Development of the TNCF Model

It is helpful to survey the development of our model in relation to the progress of our investigation as tabulated below. Some premises of the model suffered change according to the deepening of our knowledge in the experimental facts and theoretical understanding of the structure of CF materials XH_x/XD_x composed of the host element X and the hydrogen isotope H/D:

- a. Free quasi-stable neutrons as the *trapped neutrons* in a box surrounded with infinite potential walls [Kozima 1998 (Sec. 11.1, Premise 1)] ← Free electron model of metals (cf. Appendix A2)
- *Emission of phonons* by the nuclear reaction between the trapped neutron and a nucleus instead of emission of a photon in free space ← Premise to meet experimental facts (Premise 6).
- c. Instability parameter ξ of trapped neutrons [Kozima 1998 (Sec. 17.1)] to meet the experimental fact of the surface nature of nuclear reactions in the CFP (Premise 2).
- d. Formation of the superlattice XH/XD by the self-organization in the open, nonequilibrium condition \rightarrow Qualitative reproducibility of the events in the CFP.
- e. The super-nuclear interactions among neutrons in different lattice nuclei mediated by interstitial protons/deuterons → Dissipation of the intermediate nucleus through phonons to explain Premise 6.
- f. Neutrons in neutron energy bands which are formed by the super-nuclear interaction \rightarrow Explanation of the trapped neutron assumed in the Premise 1.
- g. The *accumulation of trapped neutrons* at reflecting walls results in the formation of cf-matter with high-density neutrons containing *neutron drops* ${}^{A}Z\Delta$ [Kozima 2006 (Sec. 3.7.2.3) \rightarrow Explanation of nuclear transmutations with large changes of A and Z.
- h. The interaction of neutron Bloch waves (trapped neutrons) and nuclei at disordered sites \rightarrow Explanation of the meaning of the instability parameter ξ assumed in Premise 2 [Kozima 2018 (Sec. 4.1.6), 2019b (Sec. 3-2-1)]
- i. The *neutron bands in alloys and at boundaries of two materials* have been investigated in this paper (cf. Sections 3 and 4).

1.2.1 Trapped Neutrons – Neutrons as a free particle trapped in a square well potential –

The instability parameter was introduced into the model [Kozima 1998 (Sec. 11.1a)]

to adjust it to the experimental facts that the nuclear reactions occur at surface regions with thickness around a few micrometers [Morrey 1990, Okamoto 1994, Qiao 1997].

"If the stability of the trapped neutron is lost by a large perturbation in the surface layer or in volume, the number of trigger reactions (per unit time) between trapped thermal neutrons and a nucleus ${}^{A}{}_{Z}M$ may be calculated by the same formula as the usual collision process in vacuum but an instability parameter ξ ,

(11.1)

 $P_{\rm f} = 0.35 n_{\rm n} v_{\rm n} n_{\rm M} V \sigma_{\rm nM} \xi,$

where $0.35n_nv$ is the flow density of the trapped thermal neutron per unit area and time, n_M is the density of the nucleus, V is the volume where the reaction occurs, σ_{nM} is the cross section of the reaction. The instability parameter ξ as taken into the relation (11.1) expresses an order of the stability of the trapped neutron in the region as explained in premises 2 and 3, and also in the next paragraph." [Kozima 1998 (p. 145)]

1.2.2 Neutrons in a neutron energy band in a box with a periodical potential array.

The success of the TNCF model to explain consistently various experimental data from excess heat generation to the nuclear transmutation through neutron, tritium, helium emission obtained in various types of the CF materials [Kozima 1998 (Tables 11.2, 11.3)] have given a reality to the existence of neutrons in the materials composed of host elements and hydrogen isotopes. The first mechanisms supposed for the neutrons trapped in the CF materials was the Bragg reflection of the environmental neutrons by the surface alkali-metal layers and by the surface distributions of hydrogen isotopes. [Kozima 1998 (Sec. 11)]

To explain the surface nature of the nuclear transmutations, the idea of the accumulation of neutrons at surface regions was necessitated. For this end, the energy band structure of the neutrons in the CF materials was used. Neglecting differences of isotopic distribution of host elements in the transition metal hydrides and deuterides, the trapped neutrons were identified with the band neutrons; the neutron drops formed at boundary regions by coherent reflection at boundaries could explain the surface nature of the nuclear transmutations of the CFP [Kozima 2006 (Sec. 3.7)].

The neglect of the variety of nucleon numbers of the host elements is justified by the analogy of the electron band in alloys where the band structure is characterized by the preservation of the band character at high symmetry points (such as Γ , L, P) of (In, Ga) N [Popescu 2010] (cf. Appendix A5). If it is possible to infer the same preservation of the band character at high symmetry points, especially at the gamma point, the use of the TNCF model with the free neutron is justified by the behavior of the neutrons in the bottom of the conduction band which behave like the free neutrons.

The same consideration is closely related to the explanation of the CF data in alloys and ceramics that have not been treated in our works due to the complex structure they have [Romodanov 1998a, 19998b, Kitamura 2018]. If we can use the same assumption to verify the use of the free neutron approximation in such complex CF materials as alloys and ceramics, we can understand the experimental data sets in them with the application of the TNCF model [Kozima 2020].

1.2.3 Neutrons in neutron energy bands formed by the super-nuclear interaction between lattice nuclei mediated by interstitials of H/D in the superlattice. [Kozima 2006]

The application of the electron bands in alloys to the case of the neutron bands in compound CF materials is not straight forward due to the following reason related to the nuclear reactions between a neutron and host elements. Neutron captures occur between by lattice nuclei in the CF materials with different A in a simple host element (or with different A and Z in a compound host elements) in the direction to homogenize the host elements.

We can assume that the process considered in the above paragraph is a positive factor to justify the application of the idea obtained in electron bands to the neutron bands. Then, we may apply the idea of the super-nuclear interaction developed in the CF material with a simple host elements to the cases of the CF materials with compound host elements.

The process of the superlattice formation by the self-organization may be influenced largely by the existence of multiple elements in the CF material with compound host elements. The catalytic nature of the electrodics [Bockris 1970a, 1970b, 2000, Horiuti 1970, Kita 1971, 1973] should be taken into our consideration in our forthcoming paper [Kozima 2021c].

It is noticed that the two processes depicted above, the self-organization and the catalytic nature of the electrodics, gives rise to the qualitative reproducibility of the CFP by the nature of complexity of the first [Kozima 2006, 2019b] and the subtle catalytic nature of the second processes [Kozima 2021a, 2021c].

1.3 Some Relations deduced from the TNCF Model and Three Laws found by the Phenomenological Approach

In Appendix A2, we will explain the structure of the trapped neutron catalyzed fusion model (TNCF model). In this subsection, we give several remarkable conclusions deduced from the TNCF model and their relations with experimental data closely related to the assumptions of d - d fusion reactions in the CF materials.

1.3.1 Reactions between two deuterons occluded in the CF materials

The original idea of nuclear fusion reactions between two deuterons occluded in the palladium metal had it origin in the following reactions known in the nuclear physics;

$$d + d \rightarrow {}^{4}_{2}\text{He}^{*} \rightarrow t \text{ (1.01 MeV)} + p \text{ (3.12 MeV)}, \qquad (1.3.1.1)$$

$$\rightarrow {}^{3}_{2}\text{He} (0.82 \text{ MeV}) + n \text{ (2.45 MeV)}, \qquad (1.3.1.2)$$

$$\rightarrow {}^{4}_{2}\text{He} (0.08 \text{ MeV}) + \gamma (23.8 \text{ MeV}), \qquad (1.3.1.3)$$

The branching ratios of the reactions (1.3.1.1) to (1.3.1.3) are known to be $1 : 1 : 10^{-7}$ in the low energy region down to a few keV. Despite of the severe criticism on the possibility of the nuclear reactions (1.3.1.1) to (1.3.1.3) in solids without any mechanisms to accelerate deuterons, it is necessary to check the relation in terms of the experimental data.

It is a natural conclusion that the nuclear products of these reactions satisfy following relations between the numbers N_x of observable x;

$$N_{\rm t} = N_{\rm p} = N_{32\rm He} = N_{\rm n} \approx 10^7 \, N_{42\rm He} = 10^7 \, N_{\gamma}. \tag{1.3.1.4}$$

Let us define the number N_Q of excess energy generation Q (measured in MeV) as follows to compare with the values N_x given in Eq. (1.3.1.4);

$$N_Q = Q (MeV)/5 (MeV).$$
 (1.3.1.5)

In this definition, 5 MeV is taken for the sake of convenience from the weighted mean (2.5 MeV) of the excess energies given in the above three reactions (1.3.1.1) - (1.3.1.3).

Then, N_Q has following relations with experimental values of other observables

$$N_{\rm t} = N_{\rm p} = N_{\rm 32He} = N_{\rm n} = 2 N_Q \tag{1.3.1.6}$$

It has well been known that the relations (1.3.1.4) and (1.3.1.6) are in severe contradiction with the corresponding values determined by experiments.

1.3.2 Relations between observables generated by nuclear reactions in the CFP

When there are several observables related to common parameters in a system, we can expect definite relations between observed quantities of these observables. In the TNCF model, there is a single adjustable parameter n_n which is determined by an observed value of an observable, e.g. the number N_t of tritium atoms (or tritons) in the system. If we can observe another observable, e.g. the number N_n of neutrons in the same system simultaneously, we can compare the observed value with the theoretically calculated value using the value n_n determined by N_t .

The theoretical relations between the N_a and N_b for the observables *a* and *b*, respectively, have been given as follows [Kozima 2006 (Sec. 3.3.1)]:

$$N_Q = N_{\rm t} \approx 10^6 \, N_{\rm n},\tag{1.3.2.1}$$

$$N_{\rm He3} \approx 0,$$
 (1.3.2.2)

$N\gamma pprox 0,$	(1.3.2.3)
$N_{\text{He4}} \approx m N_O$ ($m^{-1} = 2 - 4$, in systems with ⁶ ₃ Li).	(1.3.2.4)

The comparison of these relations with the experimental data had been given already in our previous works (e.g. [Kozima 1998 (Tables 11.2 and 11.3), 2006 (Tables 2.2 and 2.3)].

It is interesting to cite several experimental data related to the above theoretical results about the observed values of the observables from the data discussed in the papers [Kozima 2021a, 2021b] presented in this Conference.

The data obtained by Yamaguchi et al. [Yamaguchi 1993] gives us more interesting facts than it had shown us superficially. They had given us the experimental result; "In the final stages of ⁴He production, a peak attributable to HT appears and increases with the time." This result shows us that the ⁴₂He they observed was a result of the n - t reaction not of the d - d reaction and the triton was released afterward [Kozima 2021b (Section 4.4.1)].

The experimental data by Srinivasan et al. [Srinivasan 1990] gives us accumulation of tritium in highly localized spots (fraction of a millimeter or less in size) each containing typically about 10^{12} to 10^{14} atoms (2 to 200 K Bq) of tritium. This accumulation was explained by the catalytic nature of the deuteron deposition on the electrode [Kozima 2021b (Appendix A2)]. Furthermore, their data of the small ratio of neutron-to-tritium yield in the range of 10^{-8} to 10^{-9} is explained by the theoretical result (1.3.2.1).

The experimental data obtained by Claytor et al. [Claytor 1991a, 1991b, 1993, 1996] had given us small values of the ratio of numbers of neutron N_n to tritium N_t with such a very low ratio of N_n/N_t as 10^{-9} [Kozima 2021b (Appendix A3)]. This is another example showing the validity of the TNCF model for the explanation of the CFP.

We have further evidence of the small value of the ratio N_n/N_t contradicting the d - d fusion reaction (1.3.1.4). Romodanov et al. [Romodanov 1993] obtained the values

 $N_{\rm n}/N_{\rm t}|_{\rm max} = 8.5 \times 10^{-6} \text{ to } 0.6 \times 10^{-9},$

 $N_{\rm n}/N_{\rm t}|_{\rm min} = 1.7 \times 10^{-3} \text{ to } 8 \times 10^{-7}$

in several metals including Mo, Ti and Fe, alloys including SS and ceramics including TiC and ZrB_2 . These values of N_n/N_t show again the validity of the TNCF model to the wide range CF materials [Kozima 2021a (Appendix A4)].

1.3.3 Emission of Neutrons with Energies up to about 20 MeV

We can also expect the energies of neutrons generated in the nuclear reactions in the CFP up to 20 MeV [Kozima 1999] exceeding largely the value 2.45 MeV expected by the d-d reaction (1.3.1.2) erroneously assumed by many researchers.

It is well known that the first observation of the energy spectrum of neutrons emitted from cold fusion materials (CF materials) was performed by Jones et al. [Jones 1989] in BYU in the State of Utah, USA. A unified explanation of their data in addition to the data of excess energy observed by Fleischmann et al. was given by us [Kozima 1997, 1998]. Even if they insisted the discovery of the $E_n = 2.45$ MeV neutrons emitted by the reaction Eq. (1.4) of *d*-*d* fusion reactions, there remained possibility of higher energy neutrons at channels 230 – 300 ($E_n = 5.8 - 7.5$ MeV) in their data (cf. [Kozima 2006 (Fig. 1.2)].

The experimental data showing existence of higher energy neutrons than 2.45 MeV had been shown by many researchers including Bressani et al. [Bressani 1991], Takahashi et al. [Takahashi 1991]. We have given discussions on them in our papers and books [Kozima 1999, 2006, 2016 (Sec. 3.3)].

1.3.4 Three Laws found by the Phenomenological Approach

Analyzing experimental data phenomenologically, we found three laws or regularities between observables [Kozima 2012a]. We give here the three laws in enumeration leaving its explanation to the original paper.

(1) First Law. The stability effect for nuclear transmutation products.

(2) **Second Law**. The inverse power dependence of the frequency on the intensity of the excess heat production.

(3) **Third Law**. Bifurcation of the intensity of events (neutron emission and excess heat production) in time.

There are two corollaries of the first law:

Corollary 1-1. Production of a nuclide ${}^{A'}_{Z+1}X'$ from a nuclide ${}^{A}_{Z}X$ in the system.

Corollary 1-2. Decay time shortening of unstable nuclei in the system.

2. Formation of Neutron Energy Bands in Simple CF Materials

The neutron diffraction developed in the solid state physics [Shull 1951, 1956] revealed the wave nature of the neutrons explicitly suggesting existence of the neutron energy bands by analogy to the electron energy bands [Kozima 2006 (Sec. 3.7)]. The idea of the neutron energy bands had taken its quantum mechanical image by the nuclear interaction between interstitial protons/deuterons and neutrons in lattice nuclei suggested by overlapping of the extended proton/deuteron wave functions from the interstitial site and the extended neutron wavefunctions from lattice nuclei [Kozima 1998 (Sec. 12.4), 2009]. The neutrons in different lattice nuclei interact directly with the super-nuclear interaction mediated by interstitial protons/deuterons in the CF materials.

The development of the research of the exotic nuclei with the large excess of the neutron number over the proton number from nuclei with the small mass number A such as $_2$ He, $_3$ Li and $_4$ Be to rather large A such as $_{11}$ Na, $_{13}$ Al and $_{14}$ Si (cf. Appendix A4) gives reality of our expectation that the host elements like $_{28}$ Ni and $_{46}$ Pd in the CF materials participate in the super-nuclear interaction for the neutron bands in them.

The isolation of halo neutrons in exotic nuclei, as explained in Tables and Figures in Appendix A4 for nuclei with rather small values of proton numbers known by the time, gives indirect support for the mechanism of the super-nuclear interaction between neutrons in lattice nuclei mediated by interstitial protons/deuterons [Kozima 2006 (Sec. 3.7.2, Fig. 3.3)].

3. Neutron Bloch Waves at Interfaces of the Compound CF Material

The neutron Bloch waves are eigenstates of neutrons in a regular lattice and do not interact with lattice nuclei at absolute zero at all. The neutrons can interact with lattice nuclei that displaced from the equilibrium position by some reason, lattice oscillation or displacement by statistical reason or by surface conditions. The problem at present is the case of interfaces where nuclei of different species or lattice nuclei at displaced sites are. The interfaces of such chemically active metals used as catalytic substances as Ti, Ni, Pd and other alloys are complicated with many characteristics uncovered yet. So, our investigation into their influence on the CFP will be qualitative at present and the quantitative investigation should be left for future.

3.1 Roles of the Boundary Layers in the CF Materials on the CFP

There are almost always boundaries in the CF materials used in the CF experiments. The CF materials are in contact with three kinds of contacting materials, gases (gas and plasma contact systems), liquids (electrolytic systems) and solids (another CF material or substrates).

The boundaries of a CF material work on the CFP in various physical and chemical ways. The physical roles of a boundary include (1) as substrates to make the CF material stable in the severe condition to make the material appropriate for the CFP, (2) as barriers to contain H/D in the CF material, and (3) to induce nuclear reactions between the trapped neutrons and nuclei at disordered sites around the boundaries. The chemical roles of a boundary include (1) chemisorption of active elements on the boundary from environment to make easy completion of the necessary conditions for the CFP, (2) generation of effective molecules by catalysis from molecules in environment. The subtle

roles of the chemical reactions at the boundary will be discussed in more detail in the following subsections 4.2 and 4.3.

The physical roles of the boundary layers have been used in many experiments including [Yamaguchi 1993, Miley 1996a, 1996b, Iwamura 2006],

The chemical roles have been noticed already [Kozima 2000] and used in several experiments [Fleischmann 1989, Jones 1989, McKubre 1993, Celani 2020a].

"from 0.1 M LiOD in 99.5% $D_2O + 0.5\%$ H₂O solutions." [Fleischmann 1989 (p. 302)] "The electrolyte is typically a mixture of ~ 160 g D₂O plus various metal salts in ~ 0.1 g amounts each: FeSO₄ - 7H₂O, NiCl₂ - 6H₂O, PdCl₂, CaCO₃, Li₂SO₄ - H₂O, Na₂SO₄ -10H₂O, CaH₄(PO₄)₂ - H₂O, TiOSO₄ - H₂SO₄ - 8H₂O, and a very small amount of AuCN. The pH is adjusted to < 3 with HNO₃. All 14 runs reported here began with this basic electrolyte." [Jones 1989 (p. 738)]

"A PTFE liner was employed in order to prevent the highly corrosive electrolyte, 1 M LiOD + 200 ppm Al, from making contact with the metal cell body." [McKubre 1993 (p. 7)]

"The oxidation of the wires by pulses of electrical current in air creates a rough surface featuring a sub-micrometric texture that proves particularly effective at inducing thermal anomalies when temperature exceeds 400°C. This effect appears also to be increased substantially by deposing segments of the wire with a series of elements (such as Fe, Sr, Mn, K, - -). Furthermore, an increase of AHE was observed after placing the treated wires inside a sheath made of borosilicate glass (B–Si–Ca; BSC), and even more after impregnating the sheath with the same elements used to coat the wires." [Celani 2020a (pp. 25 - 26)]

3.2 Chemistry of Boundary Layers of CF Materials

It should not be forgotten that the process of the formation of a CF material is an atomic process working in the formation of a CF material, a structure composed of a host material (e.g. Ni, Pd and other metals which had been used as catalysts) and hydrogen isotopes with interfaces in between them. In the process, it is possible that other materials are sometimes participating with (as substrates or as a component of the CF material).

It is necessary, therefore, to know the chemical state of the interface in the compound CF materials for better understanding of the necessary conditions for the CFP. There have been observed (1) effects of chemical components on the CFP on one hand, and (2) atomic behaviors at the boundary of noble metals working as catalysts on the other. However, we

have not enough knowledge yet about the relation between the phenomena pointed out above, it will be helpful to summarize present situations of them for the development of CFP.

We will give summary of the surface effect on the CFP in this section. In the next section, we will introduce subtle effects of transition metal catalysts on the molecules at their boundary. Extensive investigation on the effect of the interfaces between gas, liquid and solid phases where electrochemical characteristics of electrodics are taken into consideration will be given in another paper scheduled to publish recently [Kozima 2021c].

Srinivasan et al. [Srinivasan 1990, 1993] had given extensive investigations on the CFP where were interesting facts related to the electrodics [Bockris 1970a, 2000] which we had left for almost 30 years.

"One of the most interesting findings to emerge out of the autoradiographic imaging of deuterated Ti samples from different experiments is the fact that tritium is invariably concentrated in highly localized spots (fraction of a millimeter or less in size) each containing typically about 1012 to 1014 atoms (2 to 200 kBq) of tritium. If this is viewed in the light of the observations of other groups notably, the Los Alamos work, that neutrons are produced in bunches of 30 to 300 within time spans of microseconds and also that the neutron-to-tritium yield ratio is in the range of 10-8 to 10-9, it is tempting to speculate that in these titanium samples perhaps some kind of a cascade reaction or micronuclear explosion probably occurs in specific sites in the near surface region resulting in 1010 to 1012 fusion reactions during each event. This intriguing possibility warrants further experimental study." [Srinivasan 1990 (pp. 1 – 2)]

"On the whole 15 experiments out of 29 have indicated tritium levels significantly above background values so far. These include K_2CO_3 in 25% D_2O , Li_2CO_3 in 50% D_2O , K_2CO_3 in H_2O as well as Li_2CO_3 in H_2O combinations. Surprisingly most of the natural lithium carbonate in ordinary-water-cells run so far have generated detectable amounts of tritium whereas some enriched Li_2CO_3 in H_2O cells have not. For other combinations also for every successful case there has been at least one cell with that particular combination which has not yielded tritium. While the maximum amount of tritium generated has been in a K_2CO_3 in 25% D_2O cell (3390 Bq/ml), the second highest (1454 Bq/ml) was with a Li_2CO_3 in H_2O cell." [Srinivasan 1993 (p. 129)]

The localization of the active region for the tritium generation is discussed in another

paper presented at this Conference [Kozima 2021b (Appendix A29)].

To understand the CFP in the multilayered CF materials [Claytor 1991b, Miley 1996a, 1996b], it is necessary to investigate the neutron energy bands at around the solid-solid interface between two CF materials (cf. Appendix A9 for more details). Experimental data by Claytor et al. is analyzed in [Kozima 2021b (Appendix A3)] and by Miley et al. is in Appendix A10 in this paper.

We may contemplate the neutron bands in the compound CF materials using the electron band at the P-N junction of semiconductors (cf. e.g. [Shockley 1950] and Appendix A5).

The difference of the Fermi energies in the adjacent materials A and B causes a flow of neutrons from A with a higher Fermi energy to B with a lower one generating energy corresponding the difference of the Fermi energies of each material. This contributes the excess energy production in the cold fusion phenomenon (CFP) in addition to the nuclear reactions between band neutrons and nuclei at disordered position such as at boundaries of a material and at positions shifted by the thermal motion at finite temperature.

The heterogeneous catalysts, Ni, Pd, Ti, Au, etc., in contact with three kinds of contacting materials, gases (gas contact systems), liquids (electrolytic systems) and solids (substrates for CF materials), may work at least three ways for the CFP. (1) Decomposing H_2/D_2 molecules into 2H/2D atoms as catalysts facilitating absorption and occlusion of H/D atoms in the CF materials. (2) Formation of the superlattice of host elements and hydrogen isotopes feeding plenty of the latter generating the neutron bands containing the trapped neutrons. (3) Forming surface/boundary layers at the boundary where are induced nuclear reactions between the trapped neutrons and disordered nuclei.

The tremendous amounts of transmuted nuclei comparable to the fission products of uranium observed by Miley et al. [Miley 1996a, 1996b] are explained by the existence of Ni/polystyrene or Pd/polystyrene boundary in their beads of Patterson Power Cell. Their data sets are introduced and investigated in our paper presented at this Conference [Kozima 2021b (Appendix A4)].

There is an interesting experimental data on the generation of ${}^{4}_{2}$ He and ${}^{3}_{1}$ H by Yamaguchi et al. [Yamaguchi 1993] in Au-Pd-MnO_x compound structure with deuterium. The data shows us an interesting feature of the effect of the interface between MnO_x and PdD_x layers even if it had been accepted as an evidence of the ${}^{4}_{2}$ He generation in the popular CF material, PdD_x as shown in another paper presented at this Conference [Kozima 2021b (Sec. 4.4.1)].

The extensive data sets on the CF materials composed of the alloys based on the constantan and several kinds of substrates in H_2 gas obtained by Celani et al. [Celani 2019, 2020a, 2020b] gives us the CFP in the CF materials with various kinds interfaces such as gas-solid and solid-solid ones. The data are analyzed in our paper presented at this Conference [Kozima 2021b (Appendix A5)].

Iwamura et al. had worked on the CF materials so called "Pd Complexes" where D_2 gas was permeated [Iwamura 2006a, 2006b]. The CF material of Pd complex Pd-Pd/CaO-Pd is composed of a following structure Pd (40nm)-CaO/Pd(100nm)-Pd(100µm) with two solid-solid interfaces. There should be subtle catalytic actions in the interfaces suggested by the electrochemistry as pointed out already (e.g. [Bockris 1970a, 1970b, 2000]), and the localization of the nuclear transmutations observed by the authors might be reflecting the catalytic action which we had not pointed out in our former analyses [Kozima 2014b (Sec. 5.2)]. The data by Iwamura et al. are discussed from our present point of view in another paper presented at this Conference [Kozima 2021b (Sec. 4.4.5)].

It should be mentioned on the extensive works with the CF materials including Pd-Ni-Zr, Cu-Ni and other alloys on the zirconia and silica in hydrogen isotopes [Kitamura 2014, 2018]. They observed the excess heat in various experimental conditions which include several types of solid-solid and gas-solid interfaces. We have given a brief comment of on their data [Kozima 2020] and an extensive introduction to their data sets is given in our paper presented at this Conference [Kozima 2021a (Appendix A5)].

3.3 Effects of Transition Metal Catalysts on the Molecules at the Interfaces

We are apt to neglect effects of "the hydrides of the main-group metals" on the CFP regardless of the fact that chemists have noticed its importance as expressed in a review article as follows:

"In the same period little has been made of the hydrides formed by the main-group metals, despite their importance in chemical synthesis, notably as precursors to other metal hydrides and as reducing agents for a wide range of inorganic and organic substrates." [Aldridge 2001 (p. 3306, Introduction)]

In the investigation of the CFP in the CF materials with interfaces in between, we

encounter inevitably with this problem which we do not take into our consideration in this paper. The problem had been taken up partially in our papers presented at this Conference [Kozima 2021a, 2021b] and will be investigated more extensively in the paper published elsewhere [Kozima 2021c]. The specific characteristics of the chemical properties of the host material in the CFP having essential importance in the realization of the nuclear reactions in the CF materials are the hydrogen-electrode reaction [Kita 1971, 1973] and the characteristics of the heterogeneous catalysis (active sites and supports) [Wikipedia Catalysis, Kozima 2021a, 2021b, 2021c].

Keeping these facts in our mind, we have given only several important properties of the transition metal hydrides seemingly have close relation to the CFP in the above Section 3.2 and give several more below on the papers by Zaera et al. [Zaera 1996], Belkova et al. [Belkova 2016] and Takagi et al. [Takagi 2017].

"Here we will discuss the results reported to date on the structure and reactivity of the different types of hydrocarbon moieties that form on transition metal surfaces. One of the goals of this review is to provide an organometallic guide for the possible interactions of hydrocarbons with transition metals with the idea of examining their relation to the corresponding surface chemistry." [Zaera 1996 (p. 2651, Introduction)]

"The dihydrogen bond —-- an interaction between a transition-metal or main-group hydride (M - H) and a protic hydrogen moiety (H - X) —-- is arguably the most intriguing type of hydrogen bond. It was discovered in the mid-1990s and has been intensively explored since then. Herein, we collate up-to-date experimental and computational studies of the structural, energetic, and spectroscopic parameters and natures of dihydrogen-bonded complexes of the form $M - H \cdots H - X$, as such species are now known for a wide variety of hydrido compounds." [Belkova 2016 (p. 8545, Abstract)]

It should be noticed the complexity of the interaction of the transition metals and hydrogen atoms as the various metal-hydride complexes are formed on the surfaces of transition metals Re, Tc, Mo, W, Nb, and Ta as shown by Takagi et al. [Takagi 2017]: "Ninefold coordination of hydrogen is very rare, and has been observed in two different hydride complexes comprising rhenium and technetium. Herein, based on a theoretical/experimental approach, we present evidence for the formation of ninefold H-coordination hydride complexes of molybdenum ([MoH₉]³⁻), tungsten ([WH₉]³⁻), niobium ([NbH₉]⁴⁻) and tantalum ([TaH₉]⁴⁻) in novel complex transition-metal hydrides,

Li₅MoH₁₁, Li₅WH₁₁, Li₆NbH₁₁ and Li₆TaH₁₁, respectively." [Takagi 2017 (p. 1, Abstract)]

[Yvon 1998]

It is interesting to notice new transition metal complexes which take in a lot of hydrogen atoms compared to the host elements. One of their materials are reviewed by Yvon as materials for hydrogen storage as follows:

"Complex transition-metal hydrides provide new opportunities for hydrogen storage. Their hydrogen-to-metal ratios reach values of up to H/M = 4.5 (BaReH9) and thus surpass the hydrogen-to-carbon ratios of hydrocarbons (methane: H/C = 4); their hydrogen-volume efficiencies exceed that of liquid hydrogen by a factor of up to two (Mg₂FeH₆), their weight efficiencies exceed 5% (Mg₃MnH₇), and their hydrogen dissociation temperatures under 1 bar hydrogen pressure range from ca. 1000 (NaKReH9) to 4000 (CaMgNiH₄). Their crystal chemistry is extremely rich and shows a large inventory of transition-metal hydrido complexes that often conform to the 18electron rule. New synthetic methods are likely to yield further members of this class of materials." [Yvon 1998 (p. 613, Abstract)]

If the structure of these materials fits to the necessary conditions for the CFP as we formulated before [Kozima 2006] and explained briefly in Sec. 1.2, it may be possible to use these materials for the CF materials to realize the CFP.

3.4 Nuclear Reactions between a Neutron Bloch Waves and Nuclei at Disordered Sites

The neutrons in a neutron band do not interact with lattice nuclei at their regular points as the electrons in an electron band do not with atoms at lattice points. Therefore, the interaction of the trapped neutron with the nuclei in the CF materials occurs when the nuclei exist at disordered sites; (1) nuclei displaced by lattice oscillation at finite temperature, (2) foreign impurity nuclei substituted the host nuclei, (3) foreign impurity nuclei at interstitial positions, (4) nuclei at boundary and surface regions where the array of nuclei is necessarily irregular.

4. Neutron Energy Bands in the Compound and Composite CF Materials

In the development of the phenomenological approach to the CFP based on the

inductive logic, we investigated quantum mechanically the bases of the premises of the TNCF model. The neutron energy bands had been a key concept for the realization of the trapped neutrons and the cf-matter; the neutron bands have been realized by the neutrons in lattice nuclei interacting mutually through the super-nuclear interaction mediated by the interstitial hydrogen isotopes (cf. Appendix A4). Extending the experimental data in CF materials with rather simple host elements to those with complicated constituents and structures, we must encounter necessity to justify the applicability of the TNCF model [Kozima 1998, 2006] to these complicated CF materials [Kozima 2021a, 2021b]. In this chapter, we try to investigate this problem using the TNCF model with reference to the electron bands in semiconductors where the same problem in solid state physics had been investigated for a long time.

It should be noticed that we assume existence of the superlattice in the CF material composing the compound CF material beforehand while it is not necessarily apparent. The investigations of hydrogen isotopes at around the interfaces in the multi-layered metals performed by the Iwate University group guided by Dr. H. Yamada and Dr. S. Narita for more than 10 years have revealed their complex behavior depending on the temperature, loading/deloading processes, species of the component metals and other factors such as coating on the surface [Narita 2008, Hosokawa 2013, Kataoka 2016, Sato 2018, Endo 2020]. We should take these works into our consideration in the detailed investigation of the bases of our phenomenological model for the composite and compound CF materials.

4.1 Neutron energy bands in compound CF materials speculated with reference to the electron energy bands in alloys

We give the model in the solid state physics, the electron energy band in alloys in Appendix A6 and that around P/N junction in Appendix A7.

It was shown that the preservation of the band character at high symmetry points (such as Γ , L, P) of (In, Ga)N (Appendix A6, [Popescu 2010]). So, we may be able to use the picture of the neutron energy band to the CF materials with alloy host elements when the trapped neutrons (neutrons in the neutron band) is localized at high symmetry points in the k-space. In the cases where the density n_n of the trapped neutrons is not high, this situation is realized as the simple TNCF model has been successful to give consistent explanations for various data sets [Kozima 1998].

In the case of the neutron energy bands at around the solid-solid interface, we can refer to the electron energy bands at P-N junction depicted by Shockley [Shockley 1950] (cf. Appendix A7).

The neutron energy bands in alloys speculated in reference to the electron bands (cf. Appendix 6) may be used to understand the experimental data obtained by Dufour et al. in stainless steel [Dufour 1993] (cf. [Kozima 2021a (Sec. 4.1.1)]), by Celani et al. in constantan [Celani 2019] (cf. [Kozima 2021b (Appendix A4)]), by Kitamura et al. in Pd-Ni-Zr Deposit [Kitamura 2018] (cf. [Kozima 2021a (Appendix A6)]).

4.2 Neutron energy bands at a boundary of two materials

With reference to the electron bands in semiconductor devices, we may speculate the neutron bands at the interface of a CF material and a substrate or another CF material. We give here a glimpse of the neutron band at the interface and their effects on the CFP. More details of this problem are given in Appendix A9.

According to the flow of holes in the right region to the left region in Fig. A7-1 (f), we can assume accumulation of neutrons in the boundary region flowing into there from the higher potential region as shown in Fig. A9-3 (c) making the density n_n very high. Then, there are formed the neutron drops ${}^{A}z\Delta$ with large values of A and Z which make the generation of new nuclides corresponding to the natural abundances as shown in Fig. A9-4 observed by Miley et al. [Miley 1996a (p. 635, Fig. 2)] in accordance with the stability law for the nuclear transmutation [Kozima 2006 (Section 2.15), 2012].

4.3 Neutron energy bands in composite CF materials

As illustrated in Appendix A6-1, it is possible to preserve the band character of the quantum states of the electron at high symmetry points (such as Γ , L, P) of (In, Ga)N [Popescu 2010].

If it is possible to infer the same preservation of the band character at high symmetry points, especially at the gamma point, the use of the TNCF model for the behavior of the neutrons in the bottom of the conduction band when their density is not high is justified. This may be the reason that our phenomenological approach had been successful neglecting the variety of nucleon numbers of the host elements (${}^{A}_{28}$ Ni and ${}^{A}_{46}$ Pd, for example) in our explanation of the CFP in the CF materials based on Pd and Ni.

The same consideration may be applicable to the explanation of the CF data in alloys and ceramics that have not been treated in our works due to the complex structure they have [Romodanov 1993, 1998a, 1998b, Kitamura 2018]. If we can use the same assumption of verification of the use of the free neutron approximation in such complex CF materials as alloys and ceramics, we can understand the experimental data sets in them with the application of the TNCF model [Kozima 2020].

4.4 Formation of exotic nuclei by the absorption of neutrons

Exotic nuclei investigated in free space developed very much in recent years extending its realm to larger values of A and Z. When the environment of the exotic nuclei is extended to the CF materials from the free space, the stability of the formed exotic nuclei increases very much due to the interaction with the interstitial hydrogen isotopes and the investigation of their characteristics should be accelerated. The data of quantum halo compiled by Jensen et al. are useful to speculate possible existence of exotic nuclei with proton numbers larger than 10 in the CF materials where we can expect stabilization of the exotic nuclei by interaction with the interstitial protons/deuterons.

"The neutron dripline is currently not known with certainty above Ne. Possible halos with low S_n are specified in Table I. The valence neutron in $4^{11}Be_7$ is an s-state halo, as seen in Fig. 2. The relatively large S_n for $5^{14}B_9$ indicates that even for the expected s state the halo should not be much extended. In contrast, $6^{19}C_{13}$ satisfies the halo criterion of Fig. 2 while $6^{17}C_{11}$ is too small, indicating a dominating l = 2 component. Other candidates are $10^{31}Ne_{21}$ and $13^{40}Al_{27}$, in which the neutron bindings are unknown but positive and probably very small." [Jensen 2004 (p. 235)]

5. Conclusion

Since 1990, we have investigated the CFP observed in the CF materials composed of host elements and hydrogen isotopes either protium or deuterium using a phenomenological approach [Kozima 1990, 1998, 2004, 2005, 2006]. The TNCF model with an adjustable parameter n_n (the density of the trapped neutron) had been useful to give a unified explanation of various experimental data sets in both protium and deuterium systems due to the common nature of the CF material characterized by the superlattice of host elements and hydrogen isotopes in them [Kozima 2019a].

In search of effective CF materials to produce the CFP, the composite and compound materials had been investigated more often recently improving the qualitative reproducibility. The essential mechanism of the CFP in these materials seems common to the rather simple CF materials and then we do not need to change our point of view to analyze the phenomenon. However, it is desirable to investigate the applicability of the phenomenological approach so successful in explanation of the data obtained in rather simple CF materials to the composite and compound materials. This is the main theme of this paper to contemplate the justification of the phenomenological approach to use for the analysis of the CFP obtained in the composite and compound CF materials.

Due to the complex structure of these composite and compound materials, we must use analogy of the electron energy bands developed in the semiconductor physics to the neutron energy bands in the CFP depending on the physical similarity of the two cases.

Applicability of the concept of the neutron energy band to the composite CF materials (alloys and ceramics) might be qualitatively justified by the analogy from the electron bands in semiconductor alloys where the investigation on this problem has been kept deep and a long period. At least in the high-symmetry points of the k-space where the trapped neutrons stay long time in CF materials where we observe main events in the CFP, we may be able to use the neutron energy band for the investigation of the nuclear reactions in the CF materials. The CFP with generation of new nuclei having large shifts of A and Z (the experiment by Miley et al. [Miley 1996a, 1996b], for instance) may needs special attention for this point different from that mentioned above.

The applicability of the neutron energy band to the compound CF materials (with interfaces between different CF materials) speculated in Appendix A9 seems very promising to give satisfactory explanations for the nuclear transmutations with large changes of *A* and *Z* observed by Miley et al. [Miley 1996a, 1996b]. The flow of neutrons from a CF material C_1 to another C_2 through the boundary speculated in Appendix A9 will elevate the density n_n in the C_2 very much to generate the neutron drop ${}^{A}Z\Delta$ with large values of *A* and *Z* there. According to the nuclear transmutation by the transformation [Kozima 2006 (Sec. 2.5.4)], the neutron drop ${}^{A}Z\Delta$ transforms into the transmuted nucleus ${}^{A}ZX$ with largely shifted *A* and *Z* from the original nuclei in the host material as explained in Appendix A10.

Appendices

Appendix A1. Meditations of Geniuses

Appendix A2. The Trapped Neutron Catalyzed Fusion (TNCF) Model

Appendix A3. The Neutron Drop (ND) Model

Appendix A4. Valence Neutrons in Exotic Nuclei

Appendix A5. Neutron Energy Bands due to the Super-nuclear Interaction mediated by Interstitials and Halo Neutrons

Appendix A6. Electron Energy Bands in Alloys and Neutron Energy Bands in Composite CF Materials (Alloys and Ceramics)

Appendix A7. Electron Energy Bands at P/N Junctions in Semiconductors **Appendix A8.** Surface States at the Boundary between CF Material and Oxide/Ceramic **Appendix A9**. Neutron Energy Bands in Compound CF Materials – Pd-Ti and Ni-Pd multilayers

Appendix A10. Nuclear Reactions at Interfaces. Experiments by Miley et al. [Miley 1994, 1996a, 1996b]

Appendix A1. Meditations of Geniuses

When we engage in contemplation of the truth behind phenomena in the environment surrounding us, it is necessary to use some kinds of logic. In the modern science established in 16th century and lasted until the middle of 20th century, its main scheme was overwhelmed by deductive logic based on the established principles discovered by inductive logic and confirmed by deductive logic thereafter.

Contemplation of human, generally speaking, has been essentially interlaced with inductive and deductive logics as noticed in the beginning of our civilization born about 25 century ago. It had been recognized the importance of intuition in the inductive logic as expressed in the letter of Plato and also in a writing of A. Einstein as cited below. We have to notice the importance of intuition in the inductive logic to find out a tentative principle from our experience and also the use of inductive and deductive logic alternatively to proceed our contemplation to the final principle as we see in the sayings of the geniuses.

The importance of intuition in the inductive logic had been expressed in the letter of Plato:

"For it does not at all admit of verbal expression like other studies, but, as a result of continued application to the subject itself and communion therewith, it is brought to birth in the soul on a sudden, as light that is kindled [341d] by a leaping spark, and thereafter it nourishes itself." [Plato 1966 ([341c] – [341d])].

Similar consideration had been expressed by A. Einstein as follows:

"I believe in intuition and inspiration. ... At times I feel certain I am right while not knowing the reason. When the eclipse of 1919 confirmed my intuition, I was not in the least surprised. In fact, I would have been astonished had it turned out otherwise. Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution. It is, strictly speaking, a real factor in scientific research." [Einstein 1931 (p. 97)] In addition to these word of wisdom, it is interesting to read a sentence by one of the pioneers of the CFP about his recognition of a positive role of the trapped neutrons who had surely read the book *Discovery of the Cold Fusion Phenomenon* (1998, Ohtake Shuppan, Tokyo, Japan) presented him by the author at the publication of the book.

"Three points summarize the historical significance of the discovery of LENR: - - -

2. The work must give rise to modifications of the theory of the nucleus. However, new physics is probably not needed. Classical nuclear physicists have maintained an agnostic stance for so long because their knowledge of fusion is concerned with reactions in plasma, and they have paid little attention to the effects of a solid lattice upon nuclear activity within it after injection of H and D at high fugacity, or to the effect of free neutrons in the lattice." [Bockris 1999 (p. 71)]

Appendix A2. The Trapped Neutron Catalyzed Fusion (TNCF) Model [Kozima 1998 (Sec. 11, pp.142 – 146)]

For the sake of convenience of readers, we summarize the premises of the trapped neutron catalyzed fusion (TNCF) model in this Appendix A2.

Premises of the TNCF Model [Kozima 1998 (Sec. 11.1a)]

Premise 1. We assume a priori existence of the quasi-stable trapped neutron with a density n_n in pertinent solids, to which the neutron is supplied essentially from the ambient neutron at first and then by breeding processes (explained below) in the sample.

The density n_n is an adjustable parameter in the TNCF model which will be determined by an experimental data set using the supplementary premises which will be explained below concerning reactions of the trapped neutron with other particles in the solids. The quasi-stability of the trapped neutron means that the neutron trapped in the crystal does not decay until a strong perturbation destroys the stability while a free neutron decays with a time constant of 887.4 ± 0.7 s.

Premise 2. The trapped neutron in a solid reacts with another nucleus in the surface layer of the solid, where it suffers a strong perturbation, as if they are in vacuum. We express this property by taking the parameter (the instability parameter) ξ , defined in the relation (A2.1) written down below, as $\xi = 1$.

We have to mention here that the instability parameter ξ in the surface layer is not known at all and it can be, as noticed recently, more than one $(1 > \xi)$ making the determined value of the parameter n_n smaller. This ambiguity is suggested by various anomalous changes of decay character of radioactive isotopes and by unexpected fission products in the surface layer.

Premise 3. The trapped neutron reacts with another perturbing nucleus in volume by a reaction rate given in the relation (11.1) below with a value of the instability parameter $\xi > 0.01$ due to its stability in the volume (except in special situations such as at very high temperature as 3000 K).

Following premises on the measured quantities of nuclear products and the excess heat are used to calculate reaction rates, for simplicity:

Premise 4. Product nuclei of a reaction lose all their kinetic energy in the sample except they go out without energy loss.

Premise 5. A nuclear product observed outside of the sample has the same energy as its initial (or original) one.

This means that if an energy spectrum of gamma-ray photon or neutron are observed outside, it reflects directly nuclear reactions in the solid sample. The same is for the distribution of the transmuted nucleus in the sample. Those spectra and the distributions of the transmuted nuclei are the direct information of the individual events of the nuclear reaction in the sample.

Premise 6. The amount of the excess heat is the total liberated energy in nuclear reactions dissipated in the sample except that brought out by nuclear products observed outside.

Premise 7. Tritium and helium measured in a system are accepted as all of them generated in the sample.

The amounts of the excess heat, tritium and helium are accumulated quantities reflecting nuclear reactions in the sample indirectly and are the indirect information of the individual events.

Premises about structure of the sample are expressed as follows:

Premise 8. In electrolytic experiments, the thickness *l* of the alkali metal layer on the cathode surface (surface layer) will be taken as $l = 1 \mu m$ (though the experimental evidences show that it is $1 \sim 10 \mu m$).

Premise 9. The mean free path or path length l_t of the triton with an energy 2.7 MeV generated by $n + {}^{6}\text{Li}$ fusion reaction will be taken as $l_t = 1 \ \mu\text{m}$ irrespective of material of the solid. Collision and fusion cross sections of the triton with nuclei in the sample will be taken as the same as those in vacuum.

Premise 10. Efficiency of detectors will be assumed as 100 % except otherwise described, i.e. the observed quantities are the same as those generated in the sample and to be observed by the detector in experiments if there are no description of its efficiency.

A premise will be made to calculate the number of events N_Q producing the excess heat Q;

Premise 11. In the calculation of the number of an event (a nuclear reaction) N_Q producing the excess heat Q, the average energy liberated in the reactions is assumed as 5 MeV unless the reaction is identified: N_Q = Excess heat Q (MeV)/ 5 (MeV).

The number of trigger reactions (per unit time) between trapped thermal neutrons and a nucleus AZM may be calculated by the same formula as the usual collision process in vacuum but an instability parameter ξ :

 $P_{\rm f} = 0.35 n_{\rm n} v_{\rm n} n_{\rm M} V \,\sigma_{\rm nM} \,\xi \tag{A2.1}$

Where $0.35n_nv_n$ is the flow density of the trapped thermal neutron per unit area and time, n_M is the density of the nucleus, V is the volume where the reaction occurs, and σ_{nM} is the cross section of the reaction.

Appendix A3. The Neutron Drop (ND) Model

Formation of the cf-matter including the neutron drop in the neutron energy band by the super-nuclear interaction between neutrons in different lattice nuclei mediated by the interstitial hydrogen isotopes, ¹₁H or ¹₂D, replaced the trapped neutrons in the square-well potential for the neutrons assumed in the TNCF model explained in Appendix A2. The ND model has more realistic bases on the properties of constituent nuclei in the CF materials and gives wider applicability to explain nuclear transmutations observed in experiments. We give here an outline of the basis of the ND model explained above.

1. Generation of the CF Material

Hydrogen isotopes and the material composed of host elements interact electrochemically through the interfaces surrounding the material. This electrochemical interaction is fundamentally include catalytic nature and has subtle nature sensitive to the nature of the interface [Bockris 1970a, 1970b, 2000, Horiuti 1970, Kita 1971, 1973]. \rightarrow Qualitative reproducibility

- Formation of the Superlattice of the Host Elements and the Hydrogen Isotope The formation of a superlattice XH/XD of the host element X and the hydrogen isotope H/D is realized by the nonlinear process in the nonequilibrium condition as a process of the complexity [Kozima 2012b, 2013]. → Qualitative reproducibility
- Generation of the Neutron Energy Bands through the Super-nuclear Interaction among the Neutrons in Different Lattice Nuclei Mediated by the Interstitial Hydrogen Isotope [Kozima 2006 (Sec. 3.7)]
- 4. Formation of the CF-matter composed of the Band Neutrons and the Itinerant Hydrogen Isotopes [Kozima 2006 (Sec. 3.7)]
- 5. Formation of the Neutron Drops ${}^{A}Z^{\Delta}$ composed of Z Protons and (A Z) Neutrons

[Kozima 2006 (Sec. 3.7)]

 Interaction of Neutrons and Neutron Drops in the Neutron Bands and Nuclei in the Disordered Sites in the CF material [Kozima 1998, 2006 (Sec. 2.4.5), 2021b (Appendix A4)]

Appendix A4. Neutrons in Exotic Nuclei

A4-1. Distribution of Valence Neutrons in Halos of Small A Nuclei

A4-2. Theoretical Distribution of Valence Neutrons in Halos of Large A Nuclei

A4-3 In Search of a New Picture of the Atomic Nucleus

Appendix A4-1. Distribution of Valence Neutrons in Halos of Small A Nuclei [Kozima 2006 (Sec. 3.7), Riisager 1994, Mizutori 2000, Jensen 2004]

Large extension of halo neutrons outside the ordinary nuclear radius is effective to realize the super-nuclear interaction between neurons in lattice nuclei mediated by the interstitial protons/deuterons [Kozima 2006]. The large extension of wavefunctions of halo neutrons of two-, three and many-body halos of small nucleon number (A) nuclei have been worked out recently (cf. e.g. [Jensen 2004]). These features of the valence neutrons in the exotic nuclei are favorable for the realization of the super-nuclear interactions between neutrons in lattice nuclei if they exist in the large A nuclei in the CF materials known by now. Following figures and tables show the large extension of the valence neutron wavefunctions for the small A nuclei.

	Ex	$S-E^{a}$			
Nucleus	(MeV)	(keV)	Configuration	l	K
¹¹ Be	g.s.	504	$n + {}^{10}\text{Be}$	0	
¹¹ Be	0.32	184	$n + {}^{10}\text{Be}$	1	
$^{17}\mathbf{F}$	0.50	105	$p + {}^{16}O$	0	
⁶ He	g.s.	973	$n + n + {}^{4}\text{He}$		2
¹¹ Li	g.s.	310	$n+n+{}^{9}Li$?
¹⁴ Be	g.s.	1340	$n + n + {}^{12}\text{Be}$?

Table A4-1. Halo states. For each state the excitation and separation energies and the angular momentum of the halo particle(s) are listed. [Riisager 1994 (Table I)]

^aFrom Audi and Wapstra, 1993.



Fig. A4-1. Scaling plot for two-body halos. The ratio of the halo and the potential square radii as a function of the scaled separation energy. The dashed line corresponds to a pure s-wave Yukawa wave function. The solid and dash-dotted lines are results for square-well and r^{-2} potentials, respectively. The thin horizontal lines indicate where 50% of the wave function is outside the potential. Filled and open symbols are derived from experimental data or from theoretical calculations. (M is the reduced mass and B the binding energy $B = \hbar^2 \kappa^2 / (2M)$) [Jensen 2004 (Fig. 2)]



FIG. A4-2. Scaling plot for three-body halos. The ratio of the halo and effectivepotential square radii is plotted vs the scaled separation energy. The solid lines are theoretical, scaled curves for different hyper momentum K. The dashed lines show the Efimov states for a symmetric system, v = 1.012 51, and for minimum attraction, v = 0. Filled symbols are derived from experimental data and open symbols are from theoretical calculations. (*m* is the reduced mass and B the binding energy $B = \hbar^2 \kappa^2 / (2M)$) [Jensen 2004 (Fig. 3)]



FIG. A4-3. Scaling plot for three-body halos as in Fig. 3: dashed line, the Efimov

curve for v = 0 [see Eq. (8)]; ∇ , \blacktriangle , *, masses corresponding to ¹¹Li (⁹Li + n + n); \Box , \blacksquare , \circ , \bullet , ³_Л H (_{Л+}n + p); realistic points are indicated by a large closed triangle and circle; +, ×, three different particles with two fixed scattering lengths while the third is varied. The arrows indicate transitions between Borromean, tango, and boundstate regions. We used ρ_0 from Eq. (10). See text for further discussion. [Jensen 2004 (Fig. 5)] (ρ_0)

The hyper-radius ρ is given by

 $m\rho^2 \equiv (1/M)\sum_{i < k} m_i m_k (r_i - r_k)^2$,

where *m* is an arbitrary mass unit. And ρ_0 is defined by

 $M\rho_0^2 \equiv (1/M) \sum_{i < k} m_i m_k R_{ik}^2$,

where R_{ik} is the two-body scaling length of the system *i* and *k*.

Table A4-2. Two-body halo candidates (only for neutron halos). The columns give cluster division of the system, excitation energy E^* (MeV), separation energy S (MeV), orbital angular momentum quantum number l of the dominating components and references. ([Jensen 2004] Table I)

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System	<i>E</i> *	S	l	References
${}_{1}^{2}\mathrm{H}_{1}(n+p)$	0.0	2.2	0	Audi and Wapstra, 1995
${}^{11}_{4}\text{Be}_{7} ({}^{10}_{4}\text{Be}_{6} + n)$	0.0	0.50	0	Audi and Wapstra, 1995
${}^{14}_{5}B_{9} \left({}^{13}_{5}B_{8} + n \right)$	0.0	0.97	0	Ajzenberg-Selove, 1991
${}^{15}_{6}C_{11} \left({}^{16}_{6}C_{10} + n \right)$	0.0	1.22	0	Ajzenberg Selove, 1991
${}^{19}_{6}C_{13} \left({}^{18}_{6}C_{12} + n \right)$	0.0	0.53	0,2	Nakamura et al., 1999
$^{31}_{10}$ Ne ₂₁ ($^{30}_{10}$ Ne ₂₀ +n)	0.0	>0	1,3	Sakurai, 2002
$^{34}_{11}$ Na ₂₃ ($^{33}_{11}$ Na ₂₂ + n)	0.0	?	1,3	Audi and Wapstra, 1995
$^{35}_{12}Mg_{23}$ ($^{34}_{12}Mg_{22}+n$)	0.0	?	1,3	Audi and Wapstra, 1995
$^{40}_{13}\text{Al}_{27}$ ($^{39}_{13}\text{Al}_{26}+n$)	0.0	>0	1,3	Sakurai, 2002
$^{43}_{14}\text{Si}_{29}$ ($^{42}_{14}\text{Si}_{28}+n$)	0.0	. >0	1,3	Notani et al., 2002
${}^{4}_{2}\text{He}_{2} ({}^{3}_{2}\text{He}_{1} + n)$	20.21	0.36	0	Tilley et al., 1992
$^{10}_{4}\text{Be}_{6}(^{9}_{4}\text{Be}_{5}+n)$	6.26	0.55	0	Ajzenberg-Selove, 1990
${}^{10}_{4}\text{Be}_{6} ({}^{9}_{4}\text{Be}_{5} + n)$	5.96	0.85	0	Ajzenberg-Selove, 1990
${}^{11}_{4}\text{Be}_{7} ({}^{10}_{4}\text{Be}_{6} + n)$	0.32	0.18	1	Endt, 1990
${}^{12}_{5}B_7 ({}^{11}_{5}B_6 + n)$	2.62	0.65	0	Ajzenberg-Selove, 1990
${}^{12}_{5}B_7 \left({}^{11}_{5}B_6 + n \right)$	2.72	0.55	1	Ajzenberg-Selove, 1990
${}^{14}_{5}B_{9} \left({}^{13}_{5}B_{8} + n \right)$	0.74	0.23	1	Ajzenberg-Selove, 1991
${}^{17}_{6}C_{11} \left({}^{16}_{6}C_{10} + n \right)$	0.29	0.44	0,2	Tilley et al., 1993
${}^{18}_{7}N_{11} \left({}^{17}_{7}N_{10} + n \right)$	2.61	0.22	1	Tilley et al., 1995
${}^{21}_{8}O_{13} \left({}^{20}_{8}O_{12} + n \right)$	3.08	0.73	?	Endt, 1990
$^{25}_{10}$ Ne ₁₅ ($^{24}_{10}$ Ne ₁₄ +n)	3.32	0.96	?	Endt, 1990
$^{25}_{10}$ Ne ₁₅ ($^{24}_{10}$ Ne ₁₄ +n)	4.07	0.11	?	Endt, 1990

Table A4-3. Three-body halo candidates (only for neutron halos). The columns give division of the system, excitation energy E^* (MeV), separation energy $S = S_{2n}$ (MeV), orbital angular momentum quantum number l of the dominating nucleon-core components, remarks (B for Borromean, T for tango) and references as in Table A2-1. Excited states are indicated by a star on the separation energy. ([Jensen 2004] Table II)

System	S	l	R	References
${}^{6}_{2}\text{He}_{4}({}^{4}_{2}\text{He}_{2}+n+n)$	0.97	1	В	Audi and Wapstra, 1995
${}_{2}^{8}\text{He}_{6}({}_{2}^{6}\text{He}_{4}+n+n)$	2.13	1	В	Audi and Wapstra, 1995
${}^{11}_{3}\text{Li}_{8} ({}^{9}_{3}\text{Li}_{6} + n + n)$	0.30	0,1	В	Audi and Wapstra, 1995
${}^{14}_{4}\text{Be}_{10} \left({}^{12}_{4}\text{Be}_{8} + n + n \right)$	1.33	0,2	В	Audi and Wapstra, 1995
${}^{17}_{5}B_{12} \left({}^{15}_{5}B_{10} + n + n \right)$	1.4	0,2	в	Audi and Wapstra, 1995
${}^{19}_{5}B_{14} \left({}^{17}_{5}B_{12} + n + n \right)$	≈0.5	0,2	В	Audi and Wapstra, 1995
${}^{22}_{6}C_{16} \left({}^{20}_{6}C_{14} + n + n \right)$	≈1	0,2	В	Audi and Wapstra, 1995;
${}^{29}_{9}F_{20} \left({}^{27}_{9}F_{18} + n + n \right)$	≈0.9	0,1,2	в	Audi and Wapstra, 1995
${}^{31}_{9}F_{22} \left({}^{29}_{9}F_{20} + n + n \right)$	>0	0,1,2,3	В	Sakurai, 2002
${}^{32}_{10}\text{Ne}_{22} \left({}^{30}_{10}\text{Ne}_{20} + n + n \right)$	≈1	0,1,2,3	Т	Audi and Wapstra, 1995
$^{34}_{10}$ Ne ₂₄ ($^{32}_{10}$ Ne ₂₂ +n+n)	>0	0,1,2,3	В	Notani et al., 2002
$^{35}_{11}$ Na ₂₄ ($^{33}_{11}$ Na ₂₂ +n+n)	≈0.5	0,1,2,3	в	Audi and Wapstra, 1995
$^{37}_{11}$ Na ₂₆ ($^{35}_{11}$ Na ₂₄ +n+n)	>0	0,1,2,3	в	Notani, 2002
$^{38}_{12}Mg_{26} (^{36}_{12}Mg_{24} + n + n)$	≈1	0,1,2,3	В	Audi and Wapstra, 1995; Sakurai <i>et al.</i> , 1997
$^{41}_{13}\text{Al}_{28}$ ($^{39}_{13}\text{Al}_{26} + n + n$)	>0	0,1,2,3	Т	Sakurai, 2002
$^{43}_{13}\text{Al}_{30}$ ($^{41}_{13}\text{Al}_{28} + n + n$)	?	0,1,2,3	В	
$^{44}_{14}\text{Si}_{30}$ ($^{42}_{14}\text{Si}_{28} + n + n$)	?	0,1,2,3	?	
$_{14}^{46}$ Si ₃₂ ($_{14}^{44}$ Si ₃₀ +n+n)	?	0,1,2,3	?	

Table A4-4. Multibody halo candidates. The columns give cluster division of the system, four- and two-neutron separation energies (in MeV) S4n, S2n, indication with B if Borromean property is known, and references as in Table A2-1and Table A2-2. ([Jensen 2004] Table III)

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System	S _{4n}	S _{2n}	B?	References
${}^{8}_{2}\text{He}_{6}({}^{4}_{2}\text{He}_{2}+4n)$	3.10	2.13	В	Audi and Wapstra, 1995
${}^{14}_{4}\text{Be}_{10} \left({}^{10}_{4}\text{Be}_{6} + 4n \right)$	4.00	1.33	В	Audi and Wapstra, 1995
${}^{19}_{5}B_{14} \left({}^{15}_{5}B_{10} + 4n \right)$	≈1.9	≈0.5	В	Audi and Wapstra, 1995
${}^{22}_{6}C_{16} \left({}^{18}_{6}C_{12} + 4n \right)$	≈4.7	≈1	В	Sakurai et al., 1999
${}^{31}_{9}F_{22} \left({}^{27}_{9}F_{18} + 4n \right)$	>0	>0	B	Sakurai, 2002
$^{34}_{10}\text{Ne}_{24}$ ($^{30}_{10}\text{Ne}_{20} + 4n$)	>0	>0	?	Lukyanov et al., 2002; Notani et al., 2002
$^{37}_{11}$ Na ₂₆ ($^{34}_{11}$ Na ₂₂ +4n)	>0	>0	?	Lukyanov et al., 2002; Notani et al., 2002
$^{43}_{13}\text{Al}_{30}$ ($^{39}_{13}\text{Al}_{26}$ +4n)	?	?	?	
${}^{46}_{14}\mathrm{Si}_{32}$ (${}^{42}_{14}\mathrm{Si}_{28}$ +4 <i>n</i>)	?	?	?	

Appendix A4-2. Theoretical Distribution of Valence Neutrons in Halos of Large A Nuclei [Kozima 2006 (Sec. 3.7)] [Mizutori 2000]

The distribution of valence neutrons in exotic nuclei with small numbers of the nucleon number A has been determined by experiments hitherto. However, it was difficult to measure it in nuclei with large values of A and we must rely on the theoretical values in our investigation of the CFP in the CF materials containing nuclei with A larger than 20 such as Ni an Pd. We give some examples from a recent paper supporting our conjecture.



Fig. A4-4. Top: neutron densities calculated in the RHB/NL3 model for ^{120,150,170}Sn. Bottom: the corresponding form factors. Positions of the first and second zeros in the form factors are indicated by arrows. [Mizutori 2000 (Fig. 1)]



Fig. A4-5. Two-neutron separation energies S_{2n} for the neutron-rich Ni (top) and Sn (bottom) isotopes calculated in the HFB/SLy4, HFB/SkP, RHB/NLSH, and RHB/NL3 models. [Mizutori 2000 (Fig. 7)]



Fig. A4-6. Two-neutron separation energies S_{2n} for the neutron-rich Pb isotopes calculated in the HFB/SLy4 and HFB/SkP models. [Mizutori 2000 (Fig. 8)]

Table A4-5. Characteristics of neutron distributions in ⁴⁰Ca and ²⁰⁸Pb: diffraction radius R_0 , surface thickness σ , and geometric radius R_{geom} (all in fm), obtained in the HFB and RMF models employed in this work. [Mizutori 2000 (Table I)]

Nucleus		SLy4	SkP	NL3	NLSH
⁴⁰ Ca	$egin{array}{c} R_0 \ \sigma \ R_{ m geom} \end{array}$	3.827 0.905 4.353	3.844 0.923 4.388	3.844 0.845 4.296	3.841 0.793 4.274
²⁰⁸ Pb	$egin{array}{c} R_0 \ \sigma_n \ R_{ m geom} \end{array}$	6.870 1.022 7.252	6.849 1.033 7.244	7.076 0.971 7.409	7.075 0.929 7.374

A4-3 In Search of a New Picture of the Atomic Nucleus [Baumann 2007, Crawford 2014, Middleton 2019]

The picture of the atomic nucleus has changed from the first "structureless liquid drop of protons and neutrons" to the next "nuclear shell model where protons and neutrons experience a central potential generated by the other nucleons and therefore, as quantum particles, must exist in discrete energy levels." [Middleton 2019]

The investigation of the exotic nuclei ⁴⁰₁₂Mg and ⁴²₁₃Al [Baumann 2007, Crawford 2014] opened the door to envisage a new picture of the atomic nucleus as Middleton says "When ⁴⁰Mg was finally observed as a bound state⁴ in 2007, it showed itself to be an even more neutron-rich Mg nuclide for studying the effects of weak binding on the nuclear structure." [Middleton 2019]

We have now in the nuclear physics a developing story about the new picture of the atomic nucleus with new interactions between nucleons is on the nucleus in free space. On the other hand, we have encountered a new interaction of a neutron in the lattice nucleus with a proton/deuteron at an interstitial site in the CF materials to explain the wonderful events observed in the CFP [Kozima 2006, 2019b]. We might be able to imagine a happy marriage of the two developing investigations resulting in a new solid state-nuclear physics.

Appendix A5. Neutron Energy Bands due to the Super-nuclear

Interaction mediated by Interstitials and Halo Neutrons [Kozima 2006 (Sec. 3.7), 2013 (Sec. 3.3)]

We give an illustration of the essential idea of the neutron band formation due to the super-nuclear interaction between neutrons in lattice nuclei mediated by interstitial protons/deuterons.



Fig. A5-1. Schematic diagram showing the optimum superlattice of host nuclei (Pd or Ni) at lattice points and hydrogen isotopes (d or p) at interstitials formed by self-organization in the open, non-equilibrium condition. Nuclear wavefunctions with extension of only a few femtometers of lattice nuclei are exaggerated largely to be seen on the figure. The extension of deuteron (proton) wavefunctions centered at interstitials is represented by a single circle in contact with nuclear wavefunctions at nearest lattice points [Kozima 2013 (Fig. 3.8)]



Fig. A5-2. Super-nuclear interaction of two neutrons in different lattice nuclei at site *i* an *i*' mediated by interstitial protons at sites *j*'s [Kozima 2006 (Fig. 3.3), 2013 (Fig. 3.9)]

Appendix A6. Electron Energy Bands in Alloys and Neutron Energy Bands in Composite CF Materials (Alloys and Ceramics) – CF Active and CF Inactive Elements

A6-1 Electron Bands in Alloys

A6-2 Neutron Energy Bands in Composite CF Materials (Alloys and Ceramics)

A6-1 Electron Bands in Alloys

We cite here an example of the theoretical justification of the electron energy band formation in alloys in (In, Ga)N alloy.

"Yet, many alloy experiments are interpreted phenomenologically precisely by constructs derived from wave vector **k**, e.g. effective masses or van Hove singularities." "Conclusions –

We have shown that, while keeping the more appropriate polymorphous picture in describing the physical properties of disordered alloy via supercells, one can still obtain an effective band structure (EBS) in the underlying primitive cell. We applied this tool to (In,Ga)N and Ga(P,N) contrasting the preservation of the band character at high symmetry points (such as Γ , L, P) of (In, Ga)N with the rapid disintegration of the valence band Bloch characteristic and the appearance of a pinned impurity band in Ga(N,P)." [Popescu 2010]



Fig. A6-1. Standard labels of the symmetry points and axes of the Brillouin zones of the fcc and bcc lattices. The zone centers are Γ . In (a) the boundary point at $(2 \pi/a)$ (100) is X; the boundary point at $(2 \pi/a)$ (1/2 1/2 1/2) is L, the line Δ runs between Γ and X.





Fig. A6-2. Calculated band structure of germanium, after C.Y. Fong. The general features are in good agreement with experiment. The four valence bands are shown in grey. The fine structure of the valence band edge is caused by spin-orbit splitting. The energy gap is indirect; the conduction band edge is at the point $(2 \pi / a) (1/2 1/2 1/2)$. The constant energy surfaces around this point are ellipsoidal. [Kittel 1976 (Fig. 15)]

A6-2 Neutron Energy Bands in Composite CF Materials (Alloys and Ceramics) – CF Active and CF Inactive Elements –

It is possible to extend the investigation of the electron bands given above to the case of the neutron bands in composite CF materials, where we could use the TNCF model successfully applied to CF materials composed of simple host elements (e.g. [Kozima 1998]) and to the case of the compound CF materials investigated in Sec. 4. In the latter case, it is necessary to assume the minor element (Cu or Co, for example) alloyed to the main element (Ni or Pd, for example) is an active element defined in Sec. 4.1.4 of [Kozima 2021a] for the use of the TNCF model.

In the program to extend the phenomenological approach to the cases of the composite CF materials, it is necessary to care about the species of minor elements added to the host elements (for instance Pd or Ni) due to the following reason.

(1) It is revealed by Claytor et al. [Claytor 1998] that addition of minor elements to a host element (Pd, for instance) causes increase of tritium generation by some element (e.g. B, Cu) and its decrease by some other (e.g. Li, Be, Hf) (cf. [Kozima 2021a (Sec. 4.1.3)].

(2) On the other hand, there are several evidence that iron-group elements are active in the HER (hydrogen electrode reaction) [Kita 1973] and UPD (underpotential deposition) [Akiyama 1986, Fukushima 1993, Nakano 1998].

Considering the experimental data given above (1) and (2), we define tentatively (a) CF active (or constructive) elements and (b) CF inactive (or destructive) elements as follows:

- (a) *CF active elements*; elements in 3d and 4d transition metals.
- (b) *CF inactive elements*; other elements than those in the group (a).

Then, we may be able to use the analogy of the electron bands in the (In, Ga)N alloy given above (A6-1) to the neutron bands in the CF materials composed of Pd (or Ni) and *CF active elements*. Fortunately, these CF materials include those used in recent works by Celani et al. (Constantan Cu₅₅Ni₄₄Mn₁) and Kitamura et al. (Pd_xNi_{0.35-x}Zr_{0.65}).

Appendix A7. Electron Energy Bands at p-n Junctions in Semiconductors

We can find out an example of the electron energy bands at around the interface between the two semiconductors in the textbook by Shockley [Shockley 1950]. Fig. A7-1 shows the distribution of holes and electrons and energy as a function of position in a p-n junction under applied biases. [Shockley 1950 (Fig. 4-4)]



Fig. A7-1. Distribution of Holes and Electrons and Energy as a Function of Position in a p-n Junction under Applied Biases. [Shockley 1950 (Fig. 4-4)]

Appendix A8. Surface States at the Boundary between CF Material and Oxide/Ceramic

A8-1. Electron Surface States at the Boundary between Metal and Vacuum

A8-2. Neutron Surface States at the Boundary between CF Material and Substrate

A8-1. Electron Surface States at the Boundary between Metal and Vacuum

We must notice the electron surface states in the solid-vacuum interface in relation to the catalytic effect of the solid-gas interface in the CF materials in which the neutron surface state has not yet been investigated at present. The examples shown in Fig. A8-1 illustrate several features of the surface states which may be useful to speculate the corresponding features of the neutron case discussed in the next subsection.



Fig. A8-1. Schematic description of electron surface states at a metal/vacuum boundary. (a) Simplified one-dimensional model of a periodic crystal potential terminating at an ideal surface. (b) Real part of the type of solution to the one-dimensional Schrödinger equation that corresponds to the bulk states. (c) Real part of the type of solution to the one-dimensional Schrödinger equation that corresponds to surface states (Shockley states). (d) Atomic like orbitals of a Pt-atom. [Wikipedia Surface-state (Figs. 1, 2, 3, 5)]

A8-2. Neutron Surface States at the Boundary between CF Material and Substrate

We can speculate the neutron surface states in analogy to the electron case shown in Fig. A8-1. We may expect the catalytic effect of the surface states in the solid-solid or solid-gas interface in the CFP.



Fig. A8-2. Speculative neutron boundary states at a boundary of CF material $(NiH_x)/Oxide \cdot Ceramic$. (a) Schematic of NiH_x vs. an Oxide/Ceramic boundary. The nuclei in the latter are expressed by X and the transition region at the boundary is roughly depicted as a mixture of Ni, H and X nuclei. (b) The schematics of the squares of the wavefunction $\phi_{n,S}$ of a neutron Shockley state (in upper figure) and that $\phi_{n,T}$ of a neutron Tamm state (in lower figure). (c) The schematics of the energies E_S of a Shockley state and E_T of a Tamm state in relation to the neutron conduction and valence bands in

the CF material NiH_x.

Appendix A9. Neutron Energy Bands in Compound CF Materials – Pd-Ti and Ni-Pd multilayers

Using the electron energy bands around the p-n junction, we can imagine the neutron energy bands around the interface in the compound CF materials.

To make our image of the compound CF materials clear, consider the Patterson beads used in elaborate experiments by Miley et al. [Miley 1996a, 1996b]

"Experiments using 1-mm plastic and glass microspheres coated with single and multilayers of thin films of various metals such as palladium and nickel, used in a packedbed electrolytic cell (Patterson Power Cell TM configuration), have apparently produced a variety of nuclear reaction products." [Miley 1996b]

"Results from a thin film (500-3000A) nickel coating on 1-mm microspheres in a packedbed type cell with 1-molar Li₂SO₄-H₂O electrolyte were reported recently at the Second International Conference on Low-Energy Nuclear Reactions (Miley and Patterson, 1996). Key new results are now presented for thin-film Pd and for multiple Pd/Ni layers." [Miley 1996a]

"Thin-film coatings on 1-mm-diameter plastic microspheres, ranging from 500A thick single layers of **Pd** or **Ni** to multiple **Ni/Pd** layers, were used in a flowing packed-bed-type electrolytic cell with an I-molar Li₂S0₄ light water electrolyte." [Miley 1996b]



Fig. A9-1 Patterson Bead (Schematic illustration) used with H₂O + 1 M Li₂SO₄ electrolyte ([Miley 1996b]). [Kozima 2011 (Fig. 2.5)]

We can depict the neutron energy bands around the Ni/Pd interface as shown in Fig. A9-2 by analogy of the electron energy bands shown in Fig. A7-1.



Fig. A9-2. Speculative neutron bands of a Ni-Pd compound structure. (a) The conduction and the valence bands in a Ni/(Ni+Pd)/Pd structure as a function of position at around the Ni-Pd boundary, (b) the conduction and the valence bands of Ni and Pd in the Brillouin zone.



Fig. A9-3. Speculative distribution of neutrons in the neutron conduction bands around a boundary region of a Ni-Pd compound CF material as a function of position. (a) The structure of a Ni-Pd CF material at its boundary region, (b) the density of the trapped neutrons n_n (cm⁻³) at the boundary region, and (c) the schematic distribution of the trapped neutrons in the neutron conduction bands at the boundary region.

Then, we can imagine the distribution of neutrons in the Ni/Pd interface region as depicted in Fig. A9-3.

The neutrons are accumulated in the lower potential side of the boundary region by the neutrons flowing into there from the higher potential region and the density n_n of the trapped neutron becomes very high there. Then the high density trapped neutrons constitute the neutron drops ${}^{A}z\Delta$ with large values of A and Z. The neutron drops can induce various nuclear transmutations observed in various CF materials. A classification of nuclear transmutation had been given in our book published in 2006 [Kozima 2006 (Sec. 2.5)].

One of the remarkable example is the generation of new nuclides corresponding to the natural abundances as shown in Fig. A9-4 in accordance with the stability law for the nuclear transmutation [Kozima 2006 (Section 2.15), 2012]



FigureA9-4. Comparison of atomic production rates for all runs [Miley 1996a (p. 635, Fig. 2)]

Considering the importance of the experimental data obtained by Miley et al. [Miley 1994, 1996a, 1996b], we cite a detailed reproduction of their data in Appendix A10 reliable for the bases of the ND model and existence of the neutron drops in CF materials.

Appendix A10. Nuclear Reactions at Interfaces – Experiments by Miley et al. –[Miley 1994, 1996a, 1996b]

Miley et al. had worked on the CF materials with solid-solid and solid-liquid interfaces composed of Pd/Ti and Pd/Ni multilayers to investigate the nuclear transmutations accompanied with the excess heat obtaining astonishing results of large changes of proton Z and nucleon A numbers [Miley 1994, 1996a, 1996b]. We take up their remarkable experimental data sets in this Appendix A10 while we have given already preliminary introductions of their data sets before [Kozima 1998, 2006].

A10-1. Alternating Pd/Ti multilayers [Miley 1994] (Pd/Ti) LiOD + D₂O

As the Abstract cited below shows their intention of this experiment, their works on the multi-layer type experiments started in 1994 and accomplished an astonishing results in 1996 presented in the Appendices A10-2 and A10-3.



Fig. A10-1. Diagram of the multilayer thin-film electrode, showing the deposited layers of alternating Pd and Ti, topped by a barrier layer of Cr. [Miley 1994 (Fig. 4)]

"Abstract

A key advantage of this approach is that the enhanced reaction rate at interfaces between select metals is predicted to produce a high-power density throughout the volume of layers. Initial studies of heat production using a multilayer thin-film cathode in an electrolytic cell-type device, described here, was encouraging, but premature flaking of the films prevented definitive measurements." (Cf. Fig. A3-1) "Several separate experiments were carried out. In each case, shortly after startup, the temperature of the multilayer-cathode cell was consistently 1.5 ± 0.5 °C higher than that of the reference cell. However, the length of the experimental runs was limited to ≤ 2 hours, due to damage to the cathode caused by flaking of the thin films. The observed temperature increase prior to flaking corresponds to ≈ 2 KW/cm³ energy production in the thin-film interface region." [Miley 1994 (p. 316)]

A10-2. Ni film coated plastic microspheres [Miley 1996a] H₂SO₄ + H₂O

"Abstract

Experiments using 1-mm plastic and glass microspheres coated with single and multilayers of thin films of various metals such as palladium and nickel, used in a packedbed electrolytic cell (Patterson Power Cell TM configuration), have apparently produced a variety of nuclear reaction products. The analysis of a run with 650-Å film of Ni is presented here. Following a two-week electrolytic run, the Ni film was found to contain Fe, Ag, Cu, Mg, and Cr, in concentrations exceeding 2 atoms % each, plus a few additional trace elements. These elements were at the most, only present in the initial film and the electrolyte plus other accessible cell components in much smaller amounts. That fact, combined with other data, such as deviations from natural isotope abundances, seemingly eliminates the alternate explanation of impurities concentrating in the film." [Miley 1996a (Abstract)]



Fig. A10-2. Schematic Diagram of a Patterson Cell. The microspheres are in contact with the cathode screen, hence serve as the cathode. An electrically insulating nylon screen separates the microspheres from the upper anode screen. While platinum is shown here as screen material, titanium was used in present experiments. [Miley 1996a (Fig. 1a)]

Table A10-1. Yield Data from the Combined SIMS/NAA Analysis [Miley 1996a (Table 3)]

				Change (Reacted-			Difference		
Mass			Notural	fresh)	Erech MS	Pagatad MS	%		Difference in
No.		Element	a/o	(in micro-grams)	Atoms	Atoms	(atomic)	SMS a/o	Natural)
1.01	28	Si	0.92	1.02E-01	8.14E+16	3.02E+17	1.29E+00	4.67E-01	-45.46
	29	Si	0.05	9.80E-03	0.00E+00	2.04E+16	9 79F-01	3 55E-01	30.81
	30	Si	0.03	5.07E-03	0.00E+00	1.02E+16	4 89E-01	1 78E-01	14.66
	32	S	0.05	9.54E-03	0.00E+00	1.80E+16	8.63E-01	1.00E+00	5.00
	45	Sc	1.00	2.54E-05	0.00E+00	5.96E+13	2.87E-03	1.00E+00	0.00
	46	Ti	0.08	2.00E-04	0.00E+00	2.62E+14	1.26E_02	1.00E+00	2.05
	40	Ti	0.03	2.00E-04	0.00E+00	3.58E+14	1.20E-02	6.79E-02	-2.95
	49	Ti	0.06	2.52E-04	0.00E+00	3.10E+14	1.49E-02	5.88E-02	0.37
	50	Ti	0.05	3.60E-03	0.00E+00	434E+15	2.08E-01	8.24E-01	77.01
	50	V	0.00	5.52E-07	3.54E+10	7.01E+11	2.79E-05	2.45E-03	0.00
	51	v	1.00	2 30F-04	1 44E+13	2.86E+14	1 14E-02	9.98F_01	-0.04
<u> </u>	52	Cr	0.84	9.22E-02	5.63E+14	1.07E+17	5.07E+00	8.70E-01	3.21
	53	Cr	0.04	1 19E-02	6 27E+13	1.36E+16	6.42F-01	1 10E-01	1.51
<u> </u>	54	Cr	0.02	2.27E-03	1.53E+13	2 55E+15	1 20E-01	2.06E-02	-0.30
<u> </u>	54	Fe	0.02	1 34F-02	2 82E+15	1.78E+16	3.96E-01	5 72E-02	-0.30
<u> </u>	55	Mn	1.00	7 30E-02	0.00E+00	8.00E+16	3.85E+00	1.00E+00	-0.10
	56	Fe	0.92	2 11F-01	29E+16	2 70E+17	6.01E+00	8 69F-01	-4.82
	57	Fe	0.02	1.24E-02	.27E+10	1.41E+16	5 14E-01	7 42E-02	5.23
	59	Co	1.00	1.83E-02	23E+14	1.99E+15	7 58E-02	1.00E+00	0.00
	63	Cu	0.69	1.17E-01	57E+15	1.16E+17	4 99E+00	7.00E-01	0.00
	64	Zn	0.49	1.63E-02	.42E+15	1.67E+16	5.74E-01	3.64E-01	-12.47
	65	Cu	0.31	5.19E-02	.54E+15	4.97E+16	2.14E+00	3.00E-01	-0.80
	66	Zn	0.28	9.24E-03	7.82E+14	9.22E+15	3.16E-01	2.01E-01	-7.72
	67	Zn	0.04	2.28E-03	1.14E+14	2.16E+15	8.55E-02	5.43E-02	1.32
	68	Zn	0.19	1.41E-02	5.08E+14	1.30E+16	5.42E-01	3.44E-01	15.84
	69	Ga	0.60	7.59E-05	0.00E+00	6.64E+13	3.19E-03	5.50E-01	-5.40
	70	Zn	0.01	1.42E-03	1.64E+13	1.24E+15	5.70E-02	3.62E-02	3.00
	71	Ga	0.40	6.39E-05	0.00E+00	5.43E+13	2.61 E-03	4.50E-01	5 40
	72	Ge	0.27	5.39E-03	0.00E+00	4.51E+15	2.17E-01	4.84E-01	21.04
	73	Ge	0.08	4.23E-03	0.00E+00	3.49E+15	1.68E-01	3.75E-01	29.74
	74	Ge	0.37	8.94E-04	0.00E+00	7.28E+14	3.50E-02	7.81E-02	-28.69
	75	As	1.00	4.89E-02	0.00E+00	3.93E+16	1.89E+00	1.00E+00	0.00
	76	Ge	0.08	7.34E-04	0.00E+00	5.82E+14	2.80E-02	6.25E-02	-1.51
	76	Se	0.09	1.63E-02	0.00E+00	1.29E+16	6.21 E-01	1.29E-01	3.88
	77	Se	0.08	1.65E-02	0.00E+00	1.29E+16	6.21 E-01	1.29E-01	5.32
	80	Se	0.50	4.29E-02	0.00E+00	3.23E+16	1.55E+00	3.23E-01	-17.54
	82	Se	0.09	5.71 E-02	0.00E+00	4.20E+16	2.02E+00	4.19E-01	32.75
	85	Rb	0.72	4.03E-07	0.00E+00	2.86E+11	1.37E-05	5.00E-01	-22.20
	87	Rb	0.28	4.12E-07	0.00E+00	2.86E+11	1.37E-05	5.00E-01	22.20
	87	Sr	0.07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-7.02
	88	Sr	0.83	2.13E-05	0.00E+00	1.46E+13	7.01 E-04	1.00E+00	17.40

Data sheet for change in isotope atom % in metal film after run; comparison to natural abundance (Data from* SIMS; isotopes in **bold** use NAA element weight)

						Difference		Difference
			Change (Reacted-	-	Reacted	%	an (a	in a/o
	D1	Natural	fresh)	Fresh MS	MS	Metal	SIMS	(SIMS-
Mass No.	Element	a/o	(in micro-grams)	Atoms	Atoms	(atomic)	a/o	Natural)
89	Y	1.00	3.37E-05	0.00E+00	2.28E+13	1.10E-03	1.00E+00	0.00
93	Nb	1.00	8.13E-05	0.00E+00	5.27E+13	2.53E-03	1.00E+00	0.00
95	Mo	0.16	1.20E-04	0.00E+00	7.62E+13	3.66E-03	3.33E-01	17.63
96	Zr	0.03	7.85E-05	0.00E+00	4.93E+13	2.37E-03	1.00E+00	97.20
98	Mo	0.24	1.24E-04	0.00E+00	7.62E+13	3.66E-03	3.33E-01	9.53
100	Mo	0.10	1.26E-04	0.00E+00	7.62E+13	3.66E-03	3.33E-01	23.70
107	Ag	0.52	1.22E-01	7.32E+15	7.61E+16	2.47E+00	5.70E-01	5.17
108	Pd	0.27	3.27E-03	0.00E+00	1.83E+15	8.78E-02	2.73E-01	0.57
109	Ag	0.48	9.90E-02	6.68E+15	6.14E+16	1.87E+00	4.30E-01	-5.17
110	Pd	0.12	8.89E-03	0.00E+00	4.87E+15	2.34E-01	7.27E-01	60.93
111	Cd	0.13	2.33E-02	0.00E+00	1.27E+16	6.08E-01	1.12E-01	-1.60
112	Cd	0.24	5.38E-02	0.00E+00	2.89E+16	1.39E+00	2.56E-01	1.50
113	Cd	0.12	2.37E-02	0.00E+00	1.27E+16	6.08E-01	1.12E-01	-1.10
113	In	0.04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.28
114	Cd	0.29	6.33E-02	0.00E+00	3.35E+16	1.61E+00	2.96E-01	0.70
115	In	0.96	4.86E-05	0.00E+00	2.55E+13	1.22E-03	1.00E+00	4.30
116	Cd	0.08	4.87E-02	0.00E+00	2.53E+16	1.22E+00	2.24E-01	14.82
117	Sn	0.08	8.85E-04	0.00E+00	4.56E+14	2.19E-02	1.48E-01	7.20
118	Sn	0.24	2.45E-03	0.00E+00	1.25E+15	6.02E-02	4.07E-01	16.74
119	Sn	0.09	7.87E-04	0.00E+00	3.99E+14	1.92E-02	1.30E-01	4.38
120	Sn	0.33	1.47E-03	0.00E+00	7.41E+14	3.56E-02	2.41E-01	-8.73
121	Sb	0.57	5.05E-03	0.00E+00	2.52E+15	1.21E-01	1.00E+00	42.80
124	Sn	0.06	4.69E-04	0.00E+00	2.28E+14	1.10E-02	7.41 E-02	1.47
125	Те	0.07	5.82E-03	0.00E+00	2.81E+15	1.35E-01	3.75E-01	30.51
126	Те	0.19	3.91 E-03	0.00E+00	1.87E+15	8.99E-02	2.50E-01	6.30
128	Те	0.32	5.96E-03	0.00E+00	2.81E+15	1.35E-01	3.75E-01	5.70
135	Ba	0.07	5.39E-05	0.00E+00	2.41E+13	1.16E-03	9.26E-02	2.67
137	Ba	0.11	6.93E-05	0.00E+00	3.05E+13	1.47E-03	1.17E-01	0.43
138	Ba	0.72	4.71 E-04	0.00E+00	2.06E+14	9.88E-03	7.90E-01	7.31
151	Eu	0.48	1.74E-05	0.00E+00	6.94E+12	3.34E-04	3.33E-01	-14.47
152	Sm	0.27	2.46E-05	0.00E+00	9.74E+12	4.68E-04	2.14E-01	-5.27
153	Bu	0.52	3.52E-05	0.00E+00	1.39E+13	6.67E-04	6.67E-01	14.47
154	Sm	0.23	9.12E-05	0.00E+00	3.57E+13	1.72E-03	7.86E-01	55.87
155	Gd	0.15	3.92E-04	0.00E+00	.53E+14	7.33E-03	9.09E-01	76.21
156	Gd	0.21	3.95E-05	0.00E+00	.53E+13	7.33E-04	9.09E-02	-11.41
163	Dy	0.25	2.90E-05	0.00E+00	.07E+13	5.16E-04	1.00E+00	75.00
165	Но	1.00	3.42E-05	0.00E+00	.25E+13	6.00E-04	1.00E+00	0.00
172	Yb	0.22	5.24E-05	0.00E+00	.83E+13	8.82E-04	1.00E+00	78.20
206	Pb	0.24	2.67E-03	0.00E+00	7.82E+14	3.76E-02	2.67E-01	3.07
207	Pb	0.23	2.69E-03	0.00E+00	7.82E+14	3.76E-02	2.67E-01	4.07
208	Pb	0.52	4.75E-03	0.00E+00	1.37E+15	6.57E-02	4.67E-01	-5.63

Table 3 (continued)

"Most profiles peak in the nickel volume or near the film-plastic interface, suggesting an internal source rather than diffusion in from the surface. For example, the key elements Ag and Fe peak near the Ni-plastic interface, ($at \sim 650$ Å corresponding to about 12 min. sputtering time). Cu peaks further out in the film. However, the amplitude of the peaks is too small to draw definitive conclusions about diffusion vs. an internal source. The product concentrations decrease into the plastic substrate. However, the decrease is gradual, indicating strong interdiffusion has occurred under run conditions." [Miley 1996a (p. 21)]

"Conclusion

The results presented here defy conventional views in many ways. First, chemically assisted nuclear reactions are not widely accepted by the scientific community. The present results not only confront that disbelief, but add a new dimension to the issue by reporting copious light and heavy element reaction products that seem to imply multibody reactions due to the formation of heavier elements such as Cu and Ag from Ni. Further, a reaction which does not emit intense high-energy gammas is required by the experimental results. All these features are difficult to comprehend and at first glance seem to point to impurities. However, as stressed, an extensive effort to find an impurity source has not uncovered one. Also, there is other strong evidence (such as isotope shifts, the different products occurring when the coating material is changed, and the similarity in yield trends with results from other researchers), which supports the conclusion that the elements observed are reaction products." [Miley 1996a (Conclusion)]

"The analysis of a run with 650-Å film of Ni is presented here. Following a two-week electrolytic run, the Ni film was found to contain Fe, Ag, Cu, Mg, and Cr, in concentrations exceeding 2 atom% each, plus a number of additional trace elements." [Miley 1996a (Abstract)]

The generation of the transmuted nucleus ${}^{A}ZX$ with largely shifted A and Z from the original nuclei in the host material has been explained by the nuclear transmutation by transformation [Kozima 2006 (Sec. 2.5.4)]. The flow of neutrons from a CF material C_1 to another C_2 through the boundary speculated in Appendix A9 will elevate the density n_n in the C_2 very much to generate the neutron drop ${}^{A}Z\Delta$ with large values of A and Z there transforms into the transmuted nucleus ${}^{A}ZX$ with largely shifted A and Z from the original nuclei in the host material.

"Most profiles peak in the nickel volume or near the film-plastic interface, suggesting an internal source rather than diffusion in from the surface. For example, the key elements Ag and Fe peak near the Ni-plastic interface, (at ~ 650 Å corresponding to about 12 min. sputtering time). Cu peaks further out in the film." [Miley 1996a (p. 27)]

This data shows clearly the nuclear reactions are due to the neutron Bloch waves in the cf-matter formed in the superlattice of Ni and H, the neutron Bloch waves interact strongly with nuclei displaced from ordered position especially at around boundary regions between Ni and plastics.

"In view of the large yields obtained, the reactants must involve some of the key species present, namely: Li, S, or O from the electrolyte; C and H from the plastic microsphere core; Ni from the thin films (cathode); and protons (p) from the light water." [Miley 1996a (p. 35)]

"Other key features observed in Fig. 8 and Fig. 9 that must be accounted for by any theory include the "gaps" between high yield products and the high Ag and Cd yields. Ag (and Cd) production is particularly challenging, since Ag occurs in large quantities but is not favored energetically." [Miley 1996a (p. 35)]

A10-3. Pd, Ni, and Pd/Ni thin film layers on plastic microspheres with electrolytic liquid H₂O + H₂SO₄ [Miley 1996b]

"Abstract

Several research groups previously identified new elements in electrodes that appeared to be transmutation products (Bockris et al., 1996a; 1996b). However, due to the low concentrations involved, the distinction from possible impurities has been difficult. Now, by using a unique thin-film electrode configuration to isolate the transmutation region, plus measurements based on neutron activation analysis, the authors have achieved, for the first time, a quantitative measure of the yield of transmutation products. Results from a thin film (500-3000A) nickel coating on 1-mm microspheres in a packed-bed type cell with 1-molar Li₂SO₄-H₂O electrolyte were reported recently at the Second International Conference on Low-Energy Nuclear Reactions (Miley and Patterson, 1996 [Miley 1996a]). Key new results are now presented for thin-film Pd and for multiple Pd/Ni layers. The transmutation products in all cases characteristically divide into four major groups with atomic number Z = 6-18; 22-35; 44-54; 75-85. Yields of ~l mg of key elements was obtained in a cell containing ~1000 microspheres (~½ cc). In several cases over 40 atom% of the metal film consisted of these products after two weeks' operation."

"[Bockris. 1996] Bockris, J.O'M and G.H. Lin (organizers), 1996a. Proceedings of the First International Conference on Low Energy Nuclear Reactions Conference, J. New Energy, in press.

"[Lin 1996] Bockris, J.O'M, G.H. Miley, and G.H. Lin (organizers), 1996b. Proceedings of the Second International Conference on Low Energy Nuclear Reactions Conference, J. New Energy, 1, I, 111-118." [Miley 1996b (Abstract)] It is necessary to correct the citation in the above sentence from [Miley 1996b (Abstract)]. The citation "*(Bockris et al. 1996a and 1996b)*" does not correspond to any paper in *J. New Energy* Vol. 1 and Vol. 3 (*Proc.* 1st and 2nd *International Conference on Low Energy Nuclear Reactions*). Possible papers corresponding to the intention of the citation may be the following papers: [Bockris 1996] and [Lin 1996].

"Results from a thin film (500-3000A) nickel coating on 1-mm microspheres in a packedbed type cell with I-molar $LiSO_4$ - H_2O electrolyte were reported recently at the Second International Conference on Low-Energy Nuclear Reactions (Miley and Patterson, 1996)." [Miley 1996b (Abstract)]

"Key new results are now presented for thin-film Pd and for multiple Pd/Ni layers. The transmutation products in all cases characteristically divide into four major groups with atomic number 2=6-18; 22-35; 44-54; 75-85." [Miley 1996b (Abstract)] "Thin-film coatings on 1-mm-diameter plastic microspheres, ranging from 500A thick single layers of Pd or Ni to multiple Ni/Pd layers." [Miley 1996b (p. 629)]

<u>Run ID</u>	Packing*	<u>Run 10.0</u> Duration (hours)	Excess Power (W)
<u>5</u>	#59 PS/NPNPN	520	~2 ±0.5
<u>7A</u>	C1 PS/PN-E	197	~4 ±0.8
<u>8</u>	#60 PS/N	311	~ 0.1-0.9
<u>11</u>	#63 PS/P	211	~ 0.1-0.9
<u>13</u>	#61 GL/N	293	~ 0.1-0.9
<u>18c</u>	#76 PS/N	358	~ 0.1-0.9

Table A10-2. Summary of runs [Miley 1996b (Table 1)]

*see Table 2 for microsphere data

"The coatings were found to be quite stable in this configuration, so experiments were undertaken to study reaction products using thin-films (500- to 3000-A thick) laid down by a special sputtering process." [Miley 1996b (p. 630)]

"The following nomenclature is adopted: P: palladium, N: nickel, PS: Polystyrene, G: glass. Thus, a PS/P/N microsphere has a plastic core with a first coating of palladium and a second coating of nickel." [Miley 1996b (p. 631)]

"Multi-layers gave larger excess power, approaching 4 W." [Miley 1996b (pp. 631-632)]

This result ("Multi-layers gave larger excess power, - -.") is interesting to test the TNCF model how we can grapple with this event. The nuclear reactions at boundaries are natural results due to the existence of many disordered nuclei in and around these regions as already had shown in the previous work [Miley 1996a]. Further, there is another possibility, as we will give a speculation in another paper on the CF materials of multilayer host elements [Kozima 2021a], the density of the trapped neutrons n_n will increase in one of the layers of the CF material and will induce much nuclear reactions in proportional to the density. This may contribute as the principal cause to the larger excess power observed in the multi-layer cases than the single layer cases.

"Most element profiles distinctly peak in the metal volume or near the metal-core interface, suggesting an internal source rather than diffusion in from the surface." [Miley 1996b (pp. 634)]

This is a result explicable from our point of view that the neutron Bloch waves interact with nuclei at disordered position from the ordered arrangement.

Further explanation of the experimental results follows:

"The two multi-layer runs (#5 and #7a included in Fig. 2) follow the same general trend as the single-layer runs. Physically #7a differed from #5 by having fewer layers (two vs. five) and used much thicker (~ 1 μ m vs. 300-500A) layers made by electroplating. Run #5 shows a rich array of products (like the PS/N run #18c) whereas #7a has few products in the region of the third and fourth yield peaks. Interestingly, - - -, the multiple layers also produced the most excess heat of all six runs; see Table 1 (Table A4-1 above). The depth probe scans for the multi-layer runs confirm that the product concentrations decrease with distance from the Pd/N interface(s), suggesting that the reaction occurs preferential there, - - - ." [Miley 1996b (p. 639)]

A schematic picture of the polystyrene sphere used in the experiments explained in the above sentences is given in another paper presented at this Conference [Kozima 2021a (Appendix A8, Fig. A8-1)].

"Characteristics of the thin-film coated rnicrospheres used are summarized in Table 2 (Table A4-2 below)." [Miley 1996b (p. 631)]

Table A10-3 Data for various thin-film microspheres [Miley 1996b (Table 2)]

S/N/P/N/P/N	(#59:	used II	n Run #5	
				<u> </u>

Layer	Volume (cc)	Mass of layer (g)	# of atoms
PS (core)	6.22E-04	6.09E-04	-
Ni(300A)	1.06E-07	9.41E-07	9.64E+15
Pd(500A)	1.76E-07	2.11E-06	1.19E+16
Ni(400A)	1.41E-07	1.25E-06	1.29E+16
Pd(800A)	2.82E-07	3.38E-06	1.90E+16
Ni(350A)	1.23E-07	1.10E-06	1.13E+16

PS/P/N-E (#C1; used in Run #7A)

Layer	Volume (cc)	Mass of layer (g)	# of atoms
PS (core)	6.22E-04	6.09E-04	-
Pd(1micron)	3.54E-06	4.24E-05	2.39E+17
Ni(0.5 micron)	1.76E-06	1.57E-05	1.61E+17

PS/N (#60; used in Run #8)

Layer	Volume (cc)	Mass of layer (g)	# of atoms
PS	6.22E-04	6.09E-04	•
Ni(2650A)	9.34E-07	8.31E-06	8.52E+16

PS/P (#63; used in Run #11)

Layer	Volume (cc)	Mass of layer (g)	# of atoms
PS (core)	6.22E-04	6.09E-04	
Pd(2000A)	7.05E-07	8.46E-06	4.76E+16

G/N (#61; used in Run #13)

Layer	Volume (cc)	Mass of layer (g)	# of atoms
Glass (core)	6.22E-04	1.01E-03	•
Ni(850A)	3.00E-07	2.67E-06	2.73E+16

PS/N (#76; used in Run #18C)

Layer	Volume (cc)	Mass of layer (g)	# of atoms
PS	6.22E-04	6.09E-04	(7. 2)
Ni(3000A)	1.06E-06	9.41E-06	9.64E+16

"Results from a thin film (500-3000A) nickel coating on 1-mm microspheres in a packedbed type cell with I-molar $LiSO_4$ - H_2O electrolyte were reported recently at the Second International Conference on Low-Energy Nuclear Reactions (Miley and Patterson, 1996)." [Miley 1996b (Abstract)]

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