Neutron Drops and Production of the Larger Mass-Number Nuclides in CFP

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Abstract

Formation of the neutron valence bands (NVB) below zero in transition-metal hydrides is verified by quantum mechanical calculation of interaction between lattice nuclei and occluded protons or deuterons. The local coherence of neutron Bloch waves in the NVB results in formation of high-density neutron liquid (NL) and neutron drops (ND) in boundary regions. The NL and ND interact with lattice nuclei, protons (or deuterons) and minor nuclei in boundary regions to produce cold fusion phenomenon (CFP) in which large change of nucleon and proton numbers of nuclei occur with dissipating channels of liberated energy rather than gamma emission

1. Introduction

The nuclear structure of isolated nuclei ${}^{A}_{Z}X$ has been thoroughly investigated in about sixty years since the discovery of the atomic nucleus in 1911 in order to achieve fundamental understanding in the energy region up to several hundred MeV[1,2]. The global features of the exited levels of nucleons and their energy distribution seem to be fairly well described by the Fermi gas mode, while the results have had been mainly confined to light nuclei and a quantitative analysis is plagued with difficulties in the description of the reaction mechanism.[1)] This is true even now especially for excited levels with energies very close to the zero level; which corresponds to the neutron level with a binding energy of zero in the nucleus ${}^{A}_{Z}X$, or to the state where a neutron and the separated nucleus ${}^{A-1}_{Z}X$ remain still. (We use this energy standard in this paper unless otherwise stated.)

Therefore, it is interesting to investigate some phenomena that are directly related with the excited levels of nucleons at around zero energy in medium and heavy nuclei.

In this paper, these features of excited states of nuclei in solids are semi-quantitatively investigated on the knowledge of nuclear structures established in nuclear physics and apply them to cold fusion phenomenon (CFP). We use the Fermi gas model for nucleons in a nucleus throughout this work.

2. Excited States of Neutrons and its Density of States in Medium and Heavy Nuclei

It is a common knowledge in nuclear physics that average properties of the excitation spectrum are given by the Fermi gas model as a result of dominance of the particle degrees of freedom over the number of collective modes.[1)]

In the Fermi gas model, nucleons in a lattice nucleus at a_i is treated as independent particles and their quantum states $\psi_{\{n\}}(\boldsymbol{x}, \boldsymbol{a}_i)$ are specified by quantum numbers $\{n\} \equiv (n, l, m, s)$;

$$\psi_{\{n\}}(\boldsymbol{x}, \boldsymbol{a}_i) = \psi_{\{nlms\}}(\boldsymbol{x} - \boldsymbol{a}_i, \sigma). \qquad (1)$$

The wave function of a neutron in a nucleus ${}^{A}_{Z}X$, however, extends far away from the nucleus when the energy E of the state is less than but close to zero and then the wave function outsides the nucleus is approximated by

$$\psi_{\{nlms\}}(\boldsymbol{x} - \boldsymbol{a}_i, \sigma) = c_i\, e^{-\eta|\boldsymbol{r} - \boldsymbol{a}_i|}\, Y_{l,m}(\theta_i, \phi_i)\, \chi_s(\sigma), \qquad (2)$$

where $\eta \equiv \eta(|E|)$ is a damping factor of the radial wave function depending on the energy assumed for simplicity to be independent of quantum numbers, and (θ_i, ϕ_i) are angles measured from the lattice point $\boldsymbol{a}_i$. In the following treatment, we use the wave function (1) until we need the wave function (2).

The result of the calculation of the total level density for the Fermi gas in a nucleus ${}^{A}_{Z}X$ is given as:[1)]

$$\rho(N, Z, \varepsilon) = (6^{1/4} g_0 / 12 (g_0 \varepsilon)^{5/4}) \exp((4\pi^2/6) g_0 \varepsilon)^{1/2} \quad (N \quad Z) \qquad (3)$$

where ε is the excitation energy measured from the ground state level and g_0 is the one-particle level density at the Fermi energy g_F, representing the sum of the proton and neutron level densities

$$g_0 \equiv g(\varepsilon_F) = (3/2)(A/\varepsilon_F), \qquad (4)$$

for a case $Z = N = A/2$. These levels seem very sharp and have fairly long lifetime, which we take as an infinite in the following treatment.

The energy range, where the above formula is applicable, is determined by a relation

$$\varepsilon_F/A \ll E \ll \varepsilon_F A^{1/3}, \quad (5)$$

where ε_F 37 MeV for heavy nuclei.[1)] This relation gives an energy range 0.4 – 170 MeV of applicability of the relation (3) for nuclei with mass numbers A 100.

High density of nuclear levels at high excitation energies, amounts of the order 10^6 times higher than that corresponding to single-particle motion, has been revealed by densely spaced, sharp resonances in the slow neutron capture reactions and results in formation of the compound nucleus in a nucleus with A 100.[1,3)] The figure 10^6 will be increased further by several orders when the energy of the slow neutron capture reactions goes down to 1 eV. In the following discussion, we will take this factor as 10^9 at its maximum suggested by experimental data for Ag in the range of 2 to 8 MeV[3)] considering later application to Pd isotopes in the energy range up to 10 MeV.

3. Effective Potential for the Super-nuclear Interaction between Neutrons in Adjacent Lattice Nuclei of Metal Hydrides and Deuterides

In the transition-metal hydrides MeH_x, on the other hand, the crystal structure is dependent on the concentration x of hydrogen isotopes which can be introduced into the crystal lattice of the metal Me continuously until a definite limit and kept stably there (occluded).[4,5)] We confine our investigation to crystals of stoichiometric compounds PdH for our object in the following treatment. In this compound, hydrogen atoms occluded in the crystal are ionized and occupy octahedral interstices having six Pd atoms each as nearest neighbors on the crystallographic axes half way of the lattice constant a. The lattice constant a of the compound PdH_x depends on the composition and that of PdH is a little larger than that of Pd crystal 3.89 Å. In the following treatment, however, we ignore the dependence of a on the composition x and use the value for Pd crystal as for the compound PdH.

Dynamical behavior of the proton occluded in transition-metal hydrides is described as a harmonic oscillator in its ground and lower excited states. The wave function, $\phi_p(R-b_j, \sigma)$, of a proton in a state specified by quantum numbers $p \equiv (n_p, l, m, s_p)$ at an interstice b_j can have finite probability density at nearby lattice point at a_i, a nearest neighbor of b_j, especially when the proton is in its excited states. If we ignore mutual interaction of Z protons on different interstices, the total proton wave function may be expressed as a product of wave functions on the interstices (neglecting anti-symmetrization),

$$\Phi_{\{p_\alpha\}}(X_1, X_2, \quad, X_z) = \Pi_j \phi\{p_j\}(R_j - b_j, \sigma_j), \quad (6)$$

where $\{p_\alpha\} \equiv \{p_1, p_2, \quad, p_z\}$.

The overlapping of the proton wave function $\phi\{p_j\}(R_j - b_j)$ on the interstice b_j with a nucleon (neutron) wave function $\psi\{n\}(r - a_i)$, Eq. (1), of an adjacent lattice nucleus at a_i results in the proton-neutron interaction through the nuclear force. The nuclear interaction is expressed by a potential whose form is taken, for example, as the square-well type;

$$V_s(r - R) = -V^{(s)}_0, \quad (|r - R| < b) \quad (7)$$
$$= 0, \quad (|r - R| > b)$$

where $V^{(s)}_0$ 3.5 MeV and b 2.2×10^{-13} cm.[6)] The choice of this potential out of several possible types does not make a large difference to the result for low energy phenomena we are considering in this paper.

This interaction pulls two neutron states in different lattice nuclei into coupling as shown below that we will call the "super-nuclear interaction." In the following investigation, we concentrate on excited neutrons in lattice nuclei than protons, which needs more energy to be raised to the excited levels with the same energy than neutrons due to the fact $Z \ll N$. (In Pd, $Z = 46$ and $N = 56 - 64$.)

Let us consider a neutron in an excited state $\{n\}$ of one of lattice nuclei. The regularity of the crystal lattice determines the coefficients of the linear combination as required by the Bloch's theorem.[7)] Then in a periodic potential of lattice nuclei, a neutron in an excited state $\{n\}$ of a lattice nucleus at a_i should be expressed by a Bloch function (omitting the spin part)

$$\psi_k(r) = \Sigma_i e^{i(ka_i)} \psi_{\{n\}}(r - a_i). \quad (8)$$

Therefore, the total wave function of the system composed of a neutron Bloch wave $\psi_k(r)$ and z occluded protons in the state $\{p_\alpha\} = \{p_1, p_2, \quad, p_z\}$ at interstices is expressed as (omitting spin parts)

$$\Psi_{k,\{p\}}(r; R_1, R_2 \quad, R_z)$$
$$= \psi_k(r) \ \Phi_{\{p_\alpha\}}(X_1, X_2, \quad, X_z). \quad (9)$$

The total energy $E_{k,\{p_\alpha\}}$ of this system in the second-order perturbation approximation is expressed as follows taking the square well potential for the nuclear interaction:

$$E_{k,\{p_\alpha\}} = E_{\{n,p_\alpha\}}$$
$$+ \Sigma_{k',i,i',j} \exp(-i(ka_i - k'a_{i'})) v_{np}(ii'j), \quad (10)$$

$$v_{np}(ii'j)$$
$$= \Sigma_p(\langle np;ij|V|n'p';ij\rangle\langle n'p';i'j|V|np;i'j\rangle)/(E_{\{n',p'\}} - E_{\{n,p\}}),$$
$$= \Sigma_{\{p'\}\neq\{p\}} P \int dE \rho \times$$
$$(\langle np;ij|V|n'p';ij\rangle\langle n'p';i'j|V|np;i'j\rangle)/(E + \varepsilon_{p'p}), \quad (11)$$

$$E_{\{n,p_\alpha\}} = E_{\{n\}}{}^{(p)} + \Sigma_j \varepsilon_{pj}, \ V(r) = V_s(r), \quad (12)$$

$$\langle np;ij|V|n'p';ij\rangle = \iint dr dR_j \psi^*_{\{n\}}(r - a_i) \phi^*\{p\}(R_j - b_j,)$$

$\times V_s(\boldsymbol{r}-\boldsymbol{R})\ \ \psi_{\{n'\}}(\boldsymbol{r}-\boldsymbol{a}_i)\,\phi_{p'}(\boldsymbol{R}_j-\boldsymbol{b}_{j'}),$ (13)

where summations over i and i' in (10) are only over the nearest neighbor lattice points $\boldsymbol{a}_i$ and $\boldsymbol{a}_{i'}$ of an interstice $\boldsymbol{b}_j$, $\rho_n(E)$ is a density of states for neutron quantum states, $\varepsilon_{p'p} \equiv \varepsilon_{p'} - \varepsilon_p$, and $E \equiv E_{\{n'\}} - E_{\{n\}}$. Further, the summation over {p'} reduces to a factor, $(n_p+1)(n_p+2)$, the degeneracy of the energy ε_{np}. $E_{\{n\}}^{(p)}$ is an energy of a neutron in an excited state $\psi_{\{n'\}}(\boldsymbol{r}-\boldsymbol{a}_i)$ in a lattice nucleus at $\boldsymbol{a}_i$ when occluded protons are in states $\{p_\alpha\}$, and ε_{pj} in (12) is an energy of a proton in a state $\phi_{pj}(\boldsymbol{R}_j-\boldsymbol{b}_{j'})$ at an interstice $\boldsymbol{b}_j$. We ignore, however, p-dependence of $E_{\{n\}}^{(p)}$ hereafter in this work.

For the neutron wave function (1) in the Fermi gas model, we can describe wave functions $\psi_{\{n'\}}(\boldsymbol{r}-\boldsymbol{a}_i)$ by those determined in the nuclear harmonic oscillator potential in a nucleus to calculate matrix elements (13) in the above equation (11):

$\psi_{nlms}(r,\theta,\phi,\sigma)$

$= R_{nl}(r)Y_l^m(\theta,\phi)\chi_s(\sigma),\ \ (|m| \leqq l)$ (14)

$E_{nlms} = (n+3/2)(h/2\pi)\omega_n + \Delta\varepsilon_{lms}$ (15)

where $\Delta\varepsilon_{lms}$ expresses the $l\ s$ and other coupling energies taken symbolically into consideration to distinguish energies of the states with the same n and different l, m, and s, ω_n is the circular frequency of the harmonic oscillator and $Y_l^m(\theta,\phi)$ are the spherical harmonics.

In nuclei of palladium isotopes, we can use an excited neutron state $2f_{7/2}$ as shown by shell model calculation with a Woods-Saxon potential[1] for the order of magnitude estimation of (14):

$\psi_{2f\,7/2,s}(r,\theta,\phi,\sigma)$

$= R_{53}(z)Y_3^m(\theta,\phi)\chi_s(\sigma),\ (|m| \leqq 3)$ (16)

$R_{53}(z) = C_n(32/210)^{1/2}z^{3/2}(1-(2/9)z)e^{-z/2},$ (17)

$C_n = 2(8\alpha_n^3/\pi)^{1/4},\ \ z = 2\alpha_n r^2,\ \ \alpha_n = \pi m_n\omega_n/h,$

where m_n is the mass of the neutron and $\omega_n = 41/A^{1/3}$ MeV.[8]

For the interstitial proton wave functions $\phi_{p'}(\boldsymbol{R}_j-\boldsymbol{b}_{j'})$ in PdH, on the other hand, we can use a wave function $\phi_{1d}(R,\Theta,\Phi)$ in a lattice harmonic oscillator potential centered at an interstice determined by diffusion data;[9]

$\phi_{p'}(\boldsymbol{R}_j) = \phi_{nplms'}(R,\ \Theta,\Phi,\sigma_p)$

$= \xi_{npl}(R)Y_{lm}(\Theta,\Phi)\chi_s(\sigma_p),\ \ (|m| \leqq l)$ (18)

$\varepsilon_{nplm} = 2\pi(n_p+3/2)h\omega_p,$ (19)

$\phi_{1d'}(R,\ \Theta,\Phi) = \xi_{1d}(Z)Y_{20}(\Theta,\Phi),\ (n=2)$ (20)

$\xi_{1d}(Z) = C_p(4/15)^{1/2}Z\exp(-Z/2),$ (21)

$C_p = 2(8\alpha_p^3/\pi)^{1/4},\ Z = 2\alpha_p R^2,\ \ \alpha_p = \{m_p\pi\omega_p/h\},$ $\omega_p = (K/m_p)^{1/2},$

or by Hermite polynomials $H_n(\xi)$;[10]

$\phi_{p'}(\boldsymbol{R}_j-\boldsymbol{b}_j,\ \sigma_p) = u_{nx}(x)\,u_{ny}(y)\,u_{nz}(z)\ \ \chi_s(\sigma_p),$ (22)

$u_{nx}(x) = N_n H_n(\alpha x)\exp(-(1/2)\alpha^2x^2),$ (23)

$\alpha^4 = 4\pi^2 m_p K/h^2,\ N_n = (\alpha/\pi^{1/2}2^n n!))^{1/2}.$

where $\boldsymbol{R} = (R,\ \Theta,\Phi)$, n_p is an integer, $l \leqq n_p$ and $|m| \leqq l$, ε_{nlm} is the proton energy of the state $\phi_{nlm'}(\boldsymbol{R})$, $\omega_p = (K/m_p)^{1/2}$, m_p is the mass of the proton, K is the force constant, and $n_i\,(i = x, y, z)$ are integers.

The proton wave functions thus determined include already effects of screening by itinerant electrons and electrons bound in atoms, and also the effect of Coulomb repulsion by lattice nuclei.

The analysis based on the diffusion data[9] showed that appropriate wave functions for a proton in the NbH is that with n = 2 in the above equation and the corresponding force constant K is given as

$K_H = 1.44\ \times 10^{19}$ eV/m^2 (NbH) . (24)

We use this value for PdH to make an order of magnitude estimation in this paper.

A concrete expression of the matrix element (14) for PdH is expressed as follows using wave functions (15), (19), and others:

$<2f_{\{7/2\}}1d;ij|V|2p_{\{3/2\}}2s;ij>$

$= -\ \iint d\boldsymbol{r}d\boldsymbol{R}_j R_{53}(z_i)Y_{3,0}(\theta_i,\phi_i)\chi_{1d}(Z_j)Y_{2,0}(\Theta_j,\Phi_j)$

$\times V_s(\boldsymbol{r}-\ \ \boldsymbol{R}_j)R_{51}(z_i)Y_{1,0}(\theta_i,\phi_i)\chi_{2s}(Z_j)\ Y_{0,0}(\Theta_j,\Phi_j),$ (25)

$z_i =\ \ 2\alpha_n|\boldsymbol{r}-\boldsymbol{a}_i|^2,\ \ Z_j = 2\alpha_p|\boldsymbol{R}_j-\boldsymbol{b}_j|^2,$

where $\boldsymbol{a}_i$ is a nearest neighbor lattice site of an interstice $\boldsymbol{b}_j$, $K = K_H$ in α_p in Eq.(22), and (θ_i,ϕ_i) and (Θ_j,Φ_j) are angles measured from origins at $\boldsymbol{a}_i$ and $\boldsymbol{b}_j$, respectively.

To estimate an order of magnitude of the effective potential $v_{np}(ii'j)$ (11), we utilize the property of the densely spaced excited states explained before and ignore selection rules associated with single configurations. Furthermore, we put the numerator of (11) as a constant and take it as the value of the matrix element (25) for PdH.

Then, the order of magnitude of the effective potential $v_{np}(ii'j)$ given in Eq.(11) is estimated as follows: the proton wave function $\phi_{p'}(\boldsymbol{R})$ is slowly varying in the range of the nuclear force, and the nuclear wave function $\psi_n(\boldsymbol{r})$ is approximated by a delta-function. Then, an order of magnitude of the matrix elements $<np;ij|V|n'p';ij>$ is given as

$|<np;ij|V|n'p';ij>|$

$\int \psi_n(\boldsymbol{r})^*\ \psi_n(\boldsymbol{r})d\boldsymbol{r}<V>\phi_{p'}(\boldsymbol{R})^*\phi_{p'}(\boldsymbol{R})\Omega$ (26)

$1\times\{4/3\}\pi r_0^3\times|u_2(x_N)|^2|u_0(0)|^2|u_0(0)|^2$

$= 3.2\ \times 10^{-14}$ eV, (27)

where Ω is the volume of the Pd nucleus, $<V> = |V_0^{(s)}| = 3.5$ MeV (Eq.(7)), $\phi_{p'}(\boldsymbol{R})$ is taken as $u_2(x)u_0(y)u_0(z)$ and $x_N = 1.95$ Å is the position of the lattice nucleus measured from the interstice.

Putting this value (30) into Eq.(11), we can estimate the effective potential $v_{np}(ii'j)$ as a function of the principal value of the integration appeared in that equation, assuming the insensitiveness of the matrix elements to the energy:

$v_{np}(ii'j)\ \ \ 1\times 10^{-27}$ eV$^2 I$,

$I \equiv P\int (\rho_n(E)/E)dE.$ (28)

We can estimate the approximate value of the integral I, taking following values $\rho_n(E)$ 10^9 keV^{-1}, $\delta\varepsilon$ 10^{-9} keV, and $\Delta\varepsilon$ 1 keV on the assumption that single particle energy level difference is 1 keV and the level density increases to 10^9 times larger than that of single particle motion:

I $(\rho_n(\varepsilon)/\delta\varepsilon)$ $\Delta\varepsilon = 10^{15}$ eV^{-1}.

$v_{np}(ii'j)$ 1×10^{-12} (eV). (29)

4. Tight-Binding Neutron Bands in Metal Hydrides and Deuterides

The effective super-nuclear interaction energy obtained above is used to calculate band structure of neutron energy in transition-metal hydrides that is originated in the excited states of neutrons in lattice nuclei and mediated by occluded hydrogen isotopes.

To show briefly crystal-structure dependence of the bandwidth, we will make a simplification of the super-nuclear interaction (11) between adjacent nuclei at $\boldsymbol{a}_i$ and $\boldsymbol{a}_{i'}$ assuming that it depends only on the magnitude of the vector $\boldsymbol{a}_l \equiv \boldsymbol{a}_i - \boldsymbol{a}_{i'}$.

Then, we can rewrite the total energy (10) and have energy spectrum of the neutron Bloch waves in the face centered cubic (fcc) lattice (a is the side of the lattice cube);[7]

$$E = E_{\{n,p\alpha\}} - \alpha - 2\times 4\gamma(\cos(1/4)k_ya\ \cos(1/4)k_za + \cos(1/4)k_za\ \cos(1/4)k_xa + \cos(1/4)k_xa\ \cos(1/4)k_ya) - 2\gamma(\cos k_xa + \cos k_ya + \cos k_za) \quad \text{(fcc)} \qquad (30)$$

$$E_{\{n,p\alpha\}} = E_{\{n\}} + \Sigma_j\, \varepsilon_{pj},$$
$$-\alpha = v_{np}(0), \quad -\gamma = v_{np}(ii'j), \qquad (31)$$

The factor 2 in the third term on the right comes from the fact that nearest neighbor lattice nuclei are mediated by two protons at different interstices while next nearest ones are by only one. A characteristic of this energy band formation is the contributions from nearest neighbors ((0, ±a/2, ±a/2) etc.) and also from next nearest neighbors ((±a,0,0) etc.) to the k-dependent terms.

The neutron energy bands originating in the excited states of lattice nuclei are located below zero energy in contrast to those originating in free neutron states above zero worked out in a previous paper.[11] The former could be called *neutron valence band* and the latter *neutron conduction band* to distinguish them in the following discussion of the nuclear reactions in solids.

Using the value of $v_{np}(ii'j)$ given in (29), we obtain a semi-quantitative estimation of the valence band width Δ from Eq.(30):

$\Delta = 24\, v_{np}(ii'j)$ 10^{-8} (meV) (PdH). (32)

Thus, it is concluded that the matrix elements (25) should be 10^5 times larger than the values estimated in (27) to substantially keep the neutron bands below zero which was determined to form in solids with a width Δ 25 meV that is not destroyed by the thermal motion of ions at room temperature. This is realized only when the neutron wave function (1) extends out as the wave function (2) from a lattice nucleus to regions where a wave function of the occluded proton (23) has a larger value by a factor 10^5 than that at the lattice nuclei. The main term of the proton wave function relevant to this behavior is the exponential factor $\exp\{-\alpha^2x^2/2\}$ in (23) and it gives this value at $x_0 = 1.43$ Å from an interstice (or 0.52 Å from a lattice point). If this behavior is coupled with an extension of the neutron wave function (2), then the neutron-proton interaction can contribute to formation of a neutron valence band with a width of Δ 25 meV.

From a point of view of the isolated nucleus treated in conventional nuclear physics, this is an unconceivable situation. While, the extension of a neutron wave function (2) far away to 0.52 Å$= 5.2\times 10^{-9}$ cm over the nuclear extent range of $r_0 = 10^{-13}$ cm, i.e. 10^4 times longer than r_0, is not absurd in the situation we are considering here.

As was shown by numerical calculation in a previous paper,[11] the energy of thermal neutrons interacting with lattice nuclei by attractive nuclear force is pulled down below zero; the states of propagating waves then become quasi-localized states around lattice nuclei with a damping factor depending on the strength of the attractive interaction. The same situation is also realized from opposite direction as a limit of highest bound states as shown in Eq.(2). We consider here an s-type wave function for the state, for simplicity:

$$\psi_\eta(\boldsymbol{r}-\boldsymbol{a}_i) = c_i \exp(-i\eta|\boldsymbol{r}-\boldsymbol{a}i|). \qquad (33)$$

To extend the neutron wave function to the range of $\lambda = 5.2 \times 10^{-9}$ cm referred above, the decay constant of the state $\eta(|E|) = 1/\lambda$ should be 1.9×10^8 cm^{-1} and this corresponds to an energy E:

$$|E| = (h^2/8\pi^2 m_n)\,\eta(|E|)^2 = 7.4 \quad \text{(eV)} \qquad (34)$$

below zero, where $m_n = 1.67\times 10^{-24}$ g is the neutron mass. In other words, the excited states of isolated lattice nuclei with energies of from zero to 7 eV can participate to the *neutron valence band*, or the neutron bands below zero, in transition-metal hydrides considered above.

If the state has less energy, i.e. far from zero, and the extension of the state is less than 5.2×10^{-9} cm, the band state fails to be substantially formed even in PdH and neutrons are essentially in single particle states in isolated lattice nuclei.

5. Discussion

When there are many neutrons in a neutron band, there appear interesting features of neutron's behavior at boundaries that reflect neutrons back into the crystal; "local coherence" of neutron Bloch waves, and therefore, high densities of neutrons (neutron liquid) appear there.[12] High-density neutrons in the boundary region[13] or in neutron star matters [14,15] induce formation of "neutron drops" (or clusters of many neutrons and a few protons and corresponding electrons) in a thin neutron background. These neutron liquid (NL) and neutron drops (ND) in a thin neutron background interact with nuclei to produce new nuclear effects in the boundary region.

Scenario of the CFP will be written down as follows. The background thermal neutrons in ambience trapped in a sample of the transition-metal hydrides or deuterides are in a neutron conduction band. Their density at boundary region becomes high due to the local coherence but may be not so large and not enough to form neutron drops. The neutrons in the band, however, can reacts with nuclei in the boundary region and the reactions are the trigger reactions.[16,17] The nuclear products of the trigger reactions induce breeding reactions resulting in multiplication of the number of neutrons in the conduction band and also excitation of neutrons in lattice nuclei.

The latter effect makes possible formation of neutron valence bands (NVB) in the CF matter we are now considering. The density of neutrons in the NVB will be very large enough to form neutron liquid (NL) and neutron drops (ND) in the boundary region. The ND thus formed may be in a lattice (a Coulomb lattice)

proton numbers from lattice or minor nuclei in the CF matter and the latter gives a possibility to stabilize excited states of nuclides without emission of γ-rays.

In our treatment of experimental data sets in CFP,[11,12,16–18] we have applied the TNCF model to various events only using reactions where occurs absorption of a neutron by a nucleus followed by β- or α- decay or by fission to explain various products with successful results. The nuclear transmutations, however, have shown large changes of mass numbers up to several tens in the experiments showing NT_F[19–23] and recent experiment of NT_A[23–27] which needs possibility to absorb large number of neutrons or sometimes the n-p clusters simultaneously. The formation of NL and/or the neutron drops (ND) gives natural explanation of these absorptions.

As we have seen in this paper, CFP is a wide spread phenomenon including excess heat generation, three types of NT, production of light elements, ^3H and ^4He, emissions of neutrons, gammas and X-rays with various energies up to about 10 MeV, and decay-time shortenings[16,28-30] occurring in complex systems composed of transition-metal hydrides and deuterides and others at about room temperature in ambient radiation.

The events with large variety from nuclear transmutations to emissions of light particles and γ-rays are evidences of nuclear reactions occurring in surface layers of CF materials, especially transition-metal hydrides and deuterides, intermittently

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