



A Theoretical Summary of Condensed Matter Nuclear Effects*

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Abstract

Key experimental results are compared with the results of Electronic Quasi-Particle Expansion Theory/Tetrahedral Symmetric Condensate (EQPET/TSC) models. Screening energy for d–d pair by theory is 360 eV and is comparable with 310 eV by Kasagi experiment for PdDx. Helium-4 production with scarce neutron is modeled by strong 4D fusion of minimum state 4d/TSC reaction. Maximum level of 4d/TSC fusion is 46 MW/cm³-Pd and 23 keV/Pd, comparable to 24.8 keV/Pd by El Boher experiment. Transmutation with mass-8 and charge-4 increase is explained by 4d/TSC + host metal reactions. Fission-like products by Ni–H systems are in agreement with fission products of 4p/TSC + nickel nuclear reactions.

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Keywords: d-d Screening, EQPET/TSC model, Excess power level, Experimental results, 4D Fusion, Fission, Helium-4, Selective transmutation

1. Introduction

Most impressive experimental results in Condensed Matter Nuclear Science (CMNS) research in last several years are (1) anomalous enhancements of d–d and 3D fusion rates by low energy (1–10 keV) d-beam/metal-target reactions [1,2]. (2) Intense production of helium-4 (⁴He) atoms by electrolysis and laser irradiation experiments [3,4], in correlation with excess heat generation. (3) Very intense excess heat production by super-wave electrolysis [5] with high gain (25 times input) was reported in ICCF11. (4) Selective [6] and fission-like [7] transmutations were reported by deuterium permeation through Pd-complexes [6] and Ni–H systems [7].

A series of elaborated theories on deuteron cluster fusion model is reviewed in two papers [8,9]. The Electronic Quasi-Particle Expansion Theory (EQPET) model was proposed and applied for numerical analyses of D- and H/D-mixed cluster fusion in PdDx systems. Formation and squeezing of Tetrahedral Symmetric Condensate (TSC) were modeled with numerical estimations by Sudden Tall Thin Barrier Approximation (STTBA) [9]. Obtained numerical results could explain major claims of CMNS experiments.

In this paper, we review short summary of theoretical models, in comparison with key experimental results, as briefly listed in Table 1. We have seen very consistent agreements between key experimental results and numerical estimations by EQPET/TSC models.

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Table 1. Summary results, experiment versus theory

Item	Experiment author/method/results	EQPET/TSC models
Screening of d-d fusion	Kasagi/D-beam, PdDx/ $U_s = 310 \pm 30$ eV Takahashi/3D, TiDx/ $\langle dd \rangle = 1 \times 10^9$ in range	$U_s = 360$ eV, by $dde^*(2,2)$ (1×10^{13}) τ with $\tau = 0.1$ ms
$^4\text{He}/^3\text{He}$ production	McKubre/electrolysis/ 31 ± 13 MeV/ ^4He Arata/nano-Pd, El./ $[^3\text{He}]/[^4\text{He}] = 0.25$	23.8 MeV/ ^4He by $4D \rightarrow ^4\text{He} + ^4\text{He} + 47.6$ MeV, $[^3\text{He}]/[^4\text{He}] = 0.25$, for H/D = 0.6
Maximum heat	El Boher/super-wave EL/24.8 keV/Pd gain = 25	23 keV/Pd 46 MW/cm ³ -Pd by 4d/TSC
Transmutation	Iwamura/Pd-complex, gas/Cs to Pr Miley/Ni-H, electrolysis/fission-like FP	4d/TSC or ^8Be capture, FP by Ni + 4p/TSC

2. Screening Effects for d–d Fusion in Condensed Matter

When low-energy d-beam is implanted into condensed matter, e.g., PdDx, incident d^+ picks up and conveys an electron, which is quasi-free in conduction band of PdDx lattice to make charge neutralization. A target D-atom ($d + e$) is waiting for incoming ($d + e$) as illustrated in Fig. 1.

Incident d gives same velocity to convey electron, which has therefore enough momentum of 180° opposite direction to another electron with target deuteron. We easily expect two electrons form a Cooper pair $e^*(2,2)$ with 50% weight for anti-parallel arrangement of spins.

In our previous paper [8], numerical (graphical) result of screened Coulomb potential for d–d interaction $V_s(r)$ is given using the formula, for $dde^*(m,n)$ EQPET molecules,

$$V_s(r) = e^2/r + V_h + (J + K)/(1 + \Delta), \quad (1)$$

$$V_h = -13.6Z^2/(m_e/m^*) \text{ (in eV unit)}. \quad (2)$$

By defining b_0 -parameter to satisfy,

$$V_s(b_0) = 0. \quad (3)$$

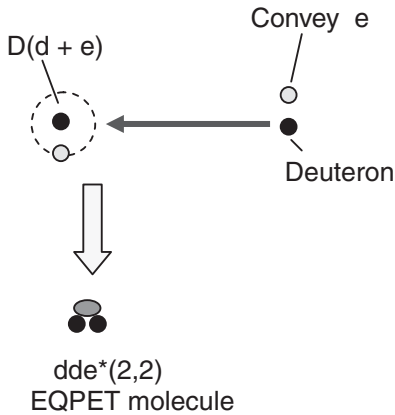


Figure 1. Formation of $dde^*(2,2)$ molecule by d-beam injection into condensed matter.

Table 2. Screened energies for various EQPET molecules

e*(m*/me, e*/e)	Screening energy U_s (eV)		b_0 (pm)	
	dde*	dde*e*	dde*	dde*e*
(1,1); Normal electron	36	72	40	20
(2,2); Cooper pair	360	411	4	2
(4,4); Quadruplet	4000	1108	0.36	1.3
(8,8); Octal coupling	22 154	960	0.065	1.5
(208,1); Muon	7579	7200	0.19	0.20

We obtain screening energy U_s by

$$U_s = -e^2/b_0 = -1.44/b_0 \text{ (in eV and nm unit)}. \quad (4)$$

Calculated b_0 -parameters and screening energies are listed in Table 2.

Kasagi et al. [1] gave $U_s = 310 + -30$ eV for Pd target with 1–10 keV d-beam irradiation, by measuring proton yield from d + d to the p + t + 4.02 MeV reaction channel. Huke [10] gave 320 eV for similar beam target experiments. These experimental values considerably agree with theoretical value 360 eV by dde*(2,2), namely EQPET dd molecule with Cooper pair. These values for screening energy are very large, compared to 72 eV for ddee (D_2).

Takahashi et al. [2] reported anomalously enhanced yield ratios [3D]/[2D] for 3D fusion over 2D fusion, by 50–300 keV d-beam irradiating TiDx ($x > 1.6$) targets with cooling. They gave [3D]/[2D] values on the order of 1×10^{-4} , which were drastically larger than 1×10^{-30} calculated by conventional random nuclear process. They concluded that close d–d-pair (dd) in pico-meter inter-nuclear distance should exist with 1×10^9 pairs in the range (about $1 \mu\text{m}$) of incident d-beam. They used 1–10 μA d-beam, so that there would be (dd) numbers on the order of $(1 \times 10^{13}) \times$ (lifetime of (dd)). To meet with experimental (dd) numbers, life-time of (dd) would be on the order of 0.1 ms, which is significantly large life compared with d-plasma harmonic oscillation period (few fs) trapped in Bloch potential with 0.22 eV depth for PdDx lattice.

3. Formation of TSC

We have proposed multi-body deuteron fusion process by formation of TSC and Octahedral Symmetric Condensate (OSC) [8,9]. Some numerical results were given by EQPET analyses, which could explain 3–78 W/cm^3 power with $1 \times 10^{11} - 1 \times 10^{13}$ f/s/ cm^3 of ^4He -atoms production by 4D and 8D fusion reactions, with less than 10 n/s/ cm^3 neutron production.

There are remained open questions about where TSC is formed. We have proposed two mechanisms, as transient motion forming deuteron-clusters with short lifetime (60 fs).

(A) In the near surface region of PdDx cathode, deuterium full loading ($x = 1$; PdD) may be attained by electrolysis, gas discharge or gas-permeation, at least locally. No experimental techniques have been developed to measure local distribution of x -value, although we know that it should be key information. With very small density (namely 1 ppm was assumed in our paper [8]) PdD₂ states may exist.

Trapped D in Bloch potential has discrete energies with 32 meV ground state and 64 meV one phonon energy for excited states. Over 0.22 eV, all D-ions in lattice diffuse out of solid. By exciting with external UV or EUV laser, due to classical Drude model, transient cluster of TSC can be formed with certain probabilities [8].

(B) We know surface of metal is complex and fractal with ad-atoms, dimmers, and corner-holes, for example, as illustrated in Fig. 2. Somewhere, for instance in corner holes, incident D₂ molecules are trapped by dangling bonds. Free D₂ molecule has freedom of rotation and vibration. Trapped D₂ would lose freedom of rotation, but can vibrate for changing distance between pairing two deuterons, and waiting for incoming D₂ molecule.

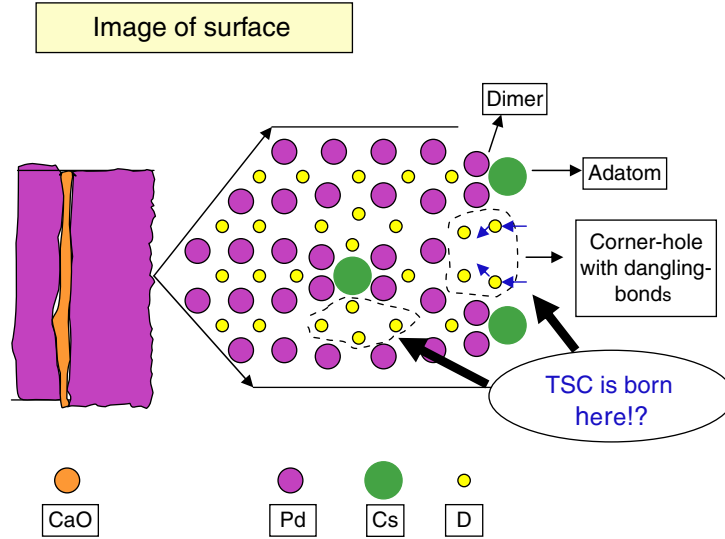


Figure 2. Image of Pd-complex surface.

When incoming D_2 molecule meets near to trapped D_2 , incoming D_2 rotates with 90° maximum against waiting D_2 molecule to neutralize charge (minimize Coulomb repulsion energy) and form an orthogonally coupled two D_2 molecules when there meets coherence in vibration modes and electron-spins are anti-parallel for counter part electrons. In this way, TSC may be formed on surface. Since the scenario is still very speculative, we need further substantiating studies.

4. 4D Fusion by 4d/TSC Itself

Trial to explain excess heat with ^4He production based on $d + d$ two-body fusion in condensed matter has two intrinsic difficulties to overcome;

- (1) Maximum level of d - d fusion rates should saturate on the order of 10 mW/cm^3 ($1 \times 10^9 \text{ f/s/cm}^3$), due to the constraint of trapped deuterons in Bloch potential and not large $S(0)$ value ($1.1 \times 10^2 \text{ keVbarn}$) enough to increase power level [11].
- (2) The dreamed scenario of $d + d$ to ^4He +lattice-energy (23.8 MeV) has no reason supported by nuclear physics (see Appendix).

Macroscopic reaction rate (yield) of two-body and multi-body fusion rate with D -cluster condensates as TSC and OSC is given by

$$Y = N_{nd}\lambda_{nd}. \quad (5)$$

Here, N_{nd} is the time-averaged nD -cluster ($n = 2, 4, 8$) density and λ_{nd} is the microscopic modal fusion rate [8,9], given by

$$\lambda_{nd} = v(S_{nd}(E)/E) \exp(-n\Gamma_{nd}). \quad (6)$$

Table 3. Typical results by EQPET/TSC for fusion rates, power level and products, for TSC in PdDx, assuming $N_{4D} = 1 \times 10^{22}$ (1/cm³)

Multi-body	Microscopic fusion rate (f/cl/s)	Macroscopic yield (f/s/cm ³), power (W/cm ³)	Ash (fusion products)
2D	1.9×10^{-21}	1.9×10 (f/s/cm ³), 1.9×10^{-11} (W/cm ³)	Neutron; 10 n/s/cm ³
3D	1.6×10^{-13}	1.6×10^9 (f/s/cm ³), 1.6×10^{-3} (W/cm ³)	Tritium; 8×10^8 t/s/cm ³
4D	3.1×10^{-11}	3.1×10^{11} (f/s/cm ³), 3.1 (W/cm ³)	Helium-4; 3×10^{11} h/s/cm ³

$S_{nd}(E)$ is the astrophysical S -factor and Γ_{nd} is Gamow integral for d–d interaction in nD-cluster system. The microscopic modal fusion rate for 4D cluster is defined by EQPET as

$$\lambda_{nd} = a_1^2 \lambda_{nd(1,1)} + a_2^2 \lambda_{nd(2,2)} + a_4^2 \lambda_{nd(4,4)}. \quad (7)$$

Here EQPET assumes that the total wave function ψ_{4D} of 4D-cluster is approximated with linear combination of partial wave functions for EQPET molecules, $\psi_{(1,1)}$, $\psi_{(2,2)}$, and $\psi_{(4,4)}$, for normal electron (1,1) state, Cooper pair (2,2) state, and quadruplet state (4,4), respectively.

$$\psi_{4D} = a_1 \psi_{(1,1)} + a_2 \psi_{(2,2)} + a_4 \psi_{(4,4)}. \quad (8)$$

In our previous papers [8,9], we have given calculated microscopic fusion rates for EQPET molecules, dde(1,1), dde*(2,2), and dde*(4,4), using,

$$\lambda_{nd(m,Z)} = v(S_{nd}(E)/E) \exp(-n\Gamma_{nd(m,Z)}). \quad (9)$$

And the Gamow integral for dde*(m, Z) EQPET molecule is given by

$$\Gamma_{nd(m,Z)} = \int_{r_0}^b (V_s(r) - E)^{1/2} dr / ((h/\pi)/(2\mu)^{1/2}). \quad (10)$$

Some numerical results are re-listed in Table 3.

Here typical break-up channels of reactions are:

$$2D \rightarrow n + {}^3\text{He} + 3.25 \text{ MeV} (50\%), \text{ p} + \text{t} + 4.02 \text{ MeV} (50\%), \quad (11)$$

$$3D \rightarrow \text{t} + {}^3\text{He} + 9.5 \text{ MeV} (\text{about } 50\%), \quad (12)$$

$$4D \rightarrow {}^4\text{He} + {}^4\text{He} + 47.6 \text{ MeV} (\text{almost } 100\%). \quad (13)$$

This calculation (Table 3) shows that 4d/TSC fusion is clean with ${}^4\text{He}$ main ash with very low neutron production ($< 1 \times 10^{-10}$ order of ${}^4\text{He}$ rate), although power level (about 3 W/cm³-Pd) is rather low. Tritium production rate (1×10^{-3} order of ${}^4\text{He}$ rate) is however rather high.

Modal fusion rate given by Eq. (7) for 4D fusion is attributed almost 100% to the quadruplet EQPET molecule dde*(4,4) state. Therefore, the accuracy of this model is closely related to what the minimum size state of 4d/TSC is.

Later [9], we have considered that the squeezing motion of TSC can be more simply treated by a semi-classical model, because of the three-dimensionally constrained motion of 4d and 4e particles in TSC into the central focal point. Figure 3 illustrates the feature of the semi-classical treatment. Every particle in TSC can make central squeezing motion with same velocity, to keep charge neutrality of total TSC system – in other words to satisfy minimum system energy

state (as calculated by the variational principle of quantum mechanics). Therefore this squeezing motion can be treated as Newtonian mechanics until when four deuterons get into the range (about 5 fm) of strong nuclear interaction.

$$\langle r(t) \rangle = \langle r(0) \rangle - \langle v \rangle t. \quad (14)$$

$$\langle r(0) \rangle = (3^{1/2}/2)R_B = 45.8 \text{ pm}. \quad (15)$$

Here, R_B is Bohr radius (52.9 pm) and $t < \text{TSC lifetime}$ (about 60 fs).

In Fig. 3, TSC will form in the near surface region of condensed matter by the mechanism (A) or mechanism (B) as discussed in Session 2, with certain probability depending on methods of experiments and near-surface physics of condensed matter: Step 1 (TSC forms). Then TSC starts Newtonian squeezing motion to decrease linearly its size from about 100 pm radius size to much smaller size and reaches at the minimum size state: Step 2 (minimum TSC). Classical squeezing motion ends when four deuterons get into the strong force range (5 fm) and/or when four electrons get to the Pauli's limit (about 5.6 fm for e–e distance). Here for the Pauli's limit, we used the classical electron radius of 2.8 fm, which is determined by equating the static Coulomb energy (e^2/R_e) and the Einstein's mass energy ($m_e c^2$) to obtain

$$R_e = e^2/m_e c^2 = 2.8 \text{ fm}; \text{ classical electron radius}. \quad (16)$$

Since the range of strong interaction (about 5 fm) is comparable to the classical electron diameter (5.6 fm), as shown in Fig.3(2), the intermediate nuclear compound state ${}^8\text{Be}^*$ will be formed just after the minimum size state (“over-minimum” state); Step 3: ${}^8\text{Be}^*$ formation. Immediately at this stage, 4d-cluster shrinks to much smaller size (about 2.4 fm radius) of ${}^8\text{Be}^*$ nucleus, and four electrons should go outside due to the Pauli's repulsion for fermions. Shortly in about few fs or less (note; Lifetime of ${}^8\text{Be}$ at ground state is 0.67 fs), ${}^8\text{Be}^*$ will break up to two ${}^4\text{He}$ particles, each of which carries 23.8 MeV kinetic energy; Step 4: Break up. It will take about 60 fs from about 100 pm initial size of

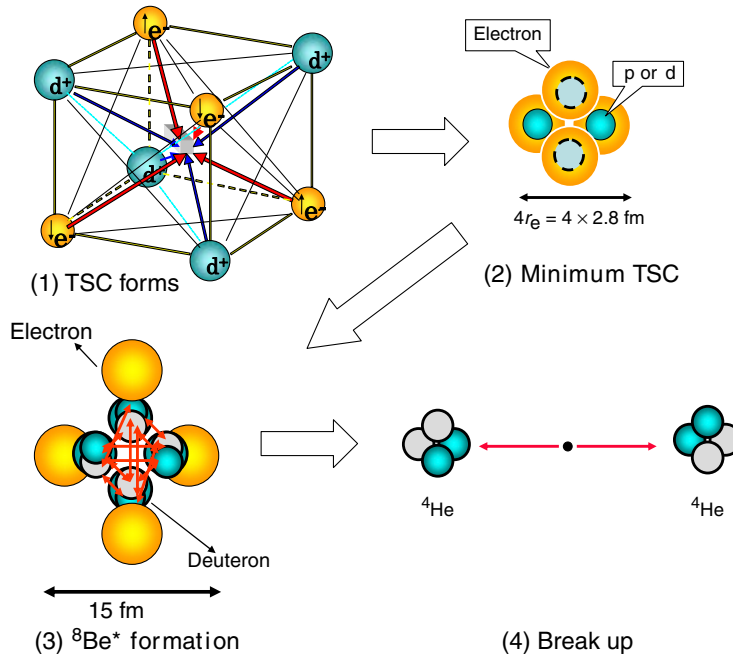


Figure 3. Semi-classical view of squeezing motion of TSC, $\langle e \rangle = (e \downarrow + e \uparrow)/2$ for QM view at four electron centers.

TSC to its minimum size about 10 fm. About 60 fs is regarded as rough measure of TSC lifetime for this very transient squeezing motion.

Figure 4 shows feature of electron orbits when TSC is just formed. Using linear combination of hydrogen atom wave functions for four deuterium-states, variational method can be applied to calculate coupled electron orbits. As a result, averaged electron position (electron center of $\langle e \rangle = (e \uparrow + e \downarrow)/2$, Bosonized electron pair for exchange force) $\langle r(0) \rangle$ locates at vertexes of regular cube with tetrahedral combining orbits and outer dilute clouds. At $\langle r(0) \rangle$, three Bohr wave functions superpose and electron density is about nine times larger than that of outer dilute cloud. Therefore, the semi-classical treatment of central squeezing motion by Newtonian is approximately fulfilled for “coherent” central averaged momentums for eight particles.

When four electrons start to separate at minimum TSC state, four deuterons suddenly start to *feel* mutual Coulomb repulsion. Nuclear interaction at this stage can be approximately treated by STTBA. Figure 5 illustrates the barrier penetration and strong interaction with negative well potential, for STTBA.

Gamow integral of STTBA [9] is given by

$$\Gamma_{nd} = 0.218(\mu^{1/2}) \int_{r_0}^b (V_B - E_d)^{1/2} dr. \quad (17)$$

And bare Coulomb potential is

$$V_B(r) = 1.44Z_1Z_2/r, \text{ in MeV and fm units.} \quad (18)$$

And barrier penetration probability is

$$P_{nd}(E_d) = \exp(-n\Gamma_{nd}). \quad (19)$$

For $V_B \gg E_d$,

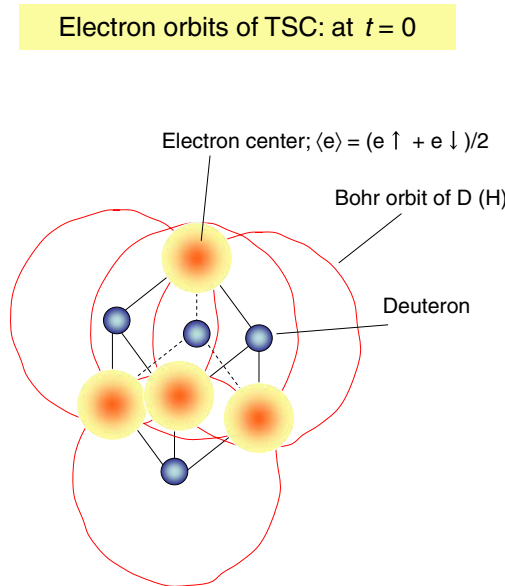


Figure 4. Electron orbits of TSC at $t = 0$, namely orthogonally coupled state of two D_2 molecules as transient motion, with lifetime about 40–80 fs.

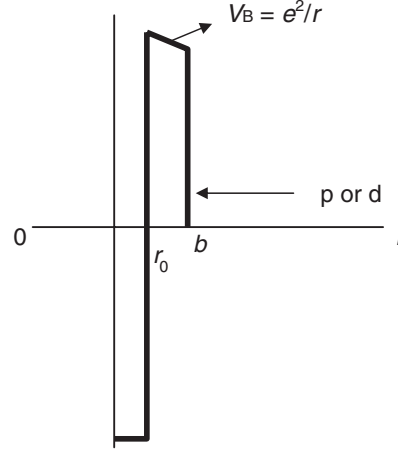


Figure 5. Potential for Coulomb barrier penetration and strong negative well, for Sudden Tall Shin Barrier Approximation (STTBA).

$$\Gamma_{nd} \simeq 0.523(Z_1 Z_2 \mu)^{1/2} (b^{1/2} - r_0^{1/2}). \quad (20)$$

Using $b = 5.6$ fm and $r_0 = 5$ fm, we obtained; $P_{4d} = 0.77$ with $V_B = 0.257$ MeV and using S_{4d} value in Refs. [8,9], we obtained: $\lambda_{4d} = 2.3 \times 10^{-4}$ f/s/cl. This microscopic fusion rate is 1×10^7 times larger value than one given in Table 3. We consider therefore that EQPET model gave significant underestimation for 4D fusion rate when rigid constraint of motion in three-dimensional space is attained as shown in Fig. 3.

Macroscopic reaction rate with $N_{4D} = 1 \times 10^{22}$ (1/cm³) is then given as $Y_{4D} = 4.6 \times 10^{18}$ f/s/cm³-Pd, which is equivalent to 46 MW/cm³-Pd and 23 keV/Pd-atom.

In ICCF11, El Boher et al. reported [5] very intense excess power for about 17 h, by their super-wave D₂O/Pd-thin-pate electrolysis technique, to give 24.8 keV/Pd-atom. This experimental value is close to 23 keV/Pd-atom by the over-minimum state 4D fusion by 4d/TSC. El Boher et al. did not measure helium, and gave no information about nuclear mechanism behind. If they will find corresponding level of helium atoms, we can say very good agreement between experiment and theory.

If we apply $\lambda_{4d} = 2.3 \times 10^{-4}$ f/s/cl for modal fusion rates in Table 3, neutron production level drops to the order of 1×10^{-17} of ⁴He production rate and tritium production rate also drops to the order of 1×10^{-9} of ⁴He production rate. These results are nearer to experimentally observed levels of neutrons and tritium-atoms in CMNS studies [12].

In our 4D cluster fusion model by TSC formation and condensation, two 23.8 MeV α -particles are produced in 180° opposite directions by the final state interaction of ⁸Be* (excited state) break-up. With known knowledge of ionization and X-ray producing cross-sections of 23.8 MeV α -particle in, e.g., PdDx, production of about 22 keV Pd K-X-rays should be with very small rate and main radiation would be bremsstrahlung X-rays in the region less than about 4 keV by slowing down of convey-electrons of α -particle. Components by L- and M-X-rays (in less than 5 keV region) may appear with visible weights (peaks). Production of secondary neutrons by D(α ,n) process by 23.8 MeV α -particle is also with very small rate, since cross-sections are small. Most kinetic energy of 23.8 MeV α -particle will be lost by ionization and knock-on with atoms of PdDx (effectively with Pd atoms), associating with soft X-rays by convey electrons, to deposit finally the released nuclear energy as lattice vibration (phonon) energy of PdDx. Therefore, the detection of Soft X-rays is of key issue. However, due to strong attenuation of soft X-rays in the PdDx layer and cell materials, observation from outside will be difficult.

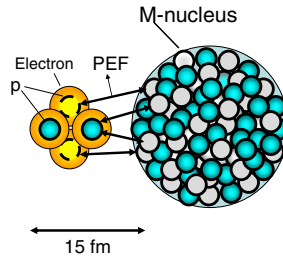


Figure 6. Strong interaction for M-nucleus + 4p/TSC.

5. TSC+Metal Interaction

Since TSC is a charge-neutral pseudo-particle and its minimum size is about 10 fm in diameter, TSC behaves as like neutron and may penetrate through electron clouds (100 pm for outer most shell and 1 pm for inner most K-shell) surrounding host metal nucleus. Hence, we expect direct nuclear interaction between TSC and host metal nucleus, with certain rate, which we have to study deeply [9].

For 4p/TSC+M-nucleus interaction, four protons do not make fusion in the minimum size state [Fig. 3(2)] of TSC and therefore each proton exchanges charged pion with neutron-states of host metal nucleus (see PEF in Fig. 6). There is competing process between one, two, three, and four protons pick-up by M-nucleus, consequently. We applied STTBA calculation for Ni+4p/TSC reaction rates [9]. We can consider Ni+p, Ni+2p, Ni+3p, and Ni+4p capture processes [9]. Estimated level of reaction rates was considerably high as 5 mW/cm² for 1 μm surface Ni layer.

In the case of Ni + H interaction, we estimated fission product distribution and compared with Miley–Patterson experiment [7] for their major products [9], as referred in Fig. 8. Good agreement is seen for two peaked components in higher Z elements, although low-Z elements like C, N, and O are not measured in experiment due to high background of impurities in the low-Z area. Fission products by Ni + 4p reaction become mostly stable isotopes [9] and coming with higher weights from heavier Ni-isotopes as Ni⁶² and Ni⁶⁴.

For 4d/TSC + host-metal–nucleus interaction behaves different from that of 4p/TSC, because of the tight formation of ⁸Be* compound state by strong interaction within TSC. This situation makes M + 4D (or ⁸Be) capture process predominantly selective (see Fig. 7). Assuming that this process happened in Iwamura experiment [6], we estimated production rate for Cs to Pr transmutation.

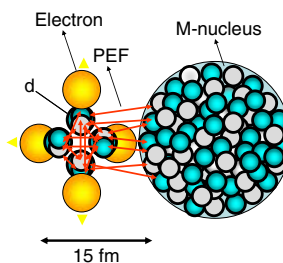
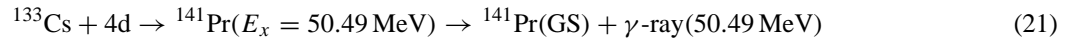


Figure 7. Strong interaction for 4d/TSC + M-nucleus.



or

→ Fission products. (22)

$$[\text{Transmutation rate}] = 4.6 \times 10^{14} \text{Pr-atoms per week.} \quad (23)$$

This transmutation rate is in agreement with Iwamura's experiment.

Another important possibility for formation of 6d/OSC around defect/void of PdD lattice and its induced 6D fusion and M + 6d/OSC is discussed in other paper to this workshop [14].

6. Conclusions

Some essential results of cluster fusion model for condensed matter nuclear effects were summarized in this work. Major experimental results as d–d screening effects, ^4He production without visible neutron emission, correlation of excess heat and ^4He production, very intense excess power level as $46 \text{ MW/cm}^3\text{-Pd}$, selective transmutations and fission-like products, were almost consistently explained by the EQPET/TSC models.

However, theories are still in primitive stage and further elaborations are expected. Some key conditions like TSC formation mechanism and places are speculative, and we need substantiation of problems in views of condensed matter and surface physics.

Time-dependent EQPET analysis of TSC is underway (presented in ICCF12).

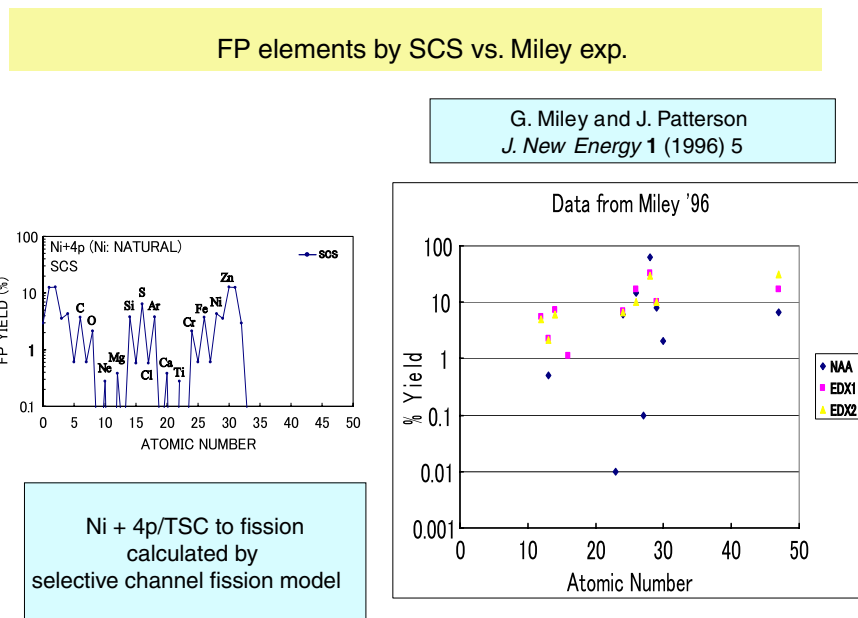


Figure 8. Fission products by Ni + 4p/TSC reaction, calculated by SCS model [13] and experimental data by Miley and Patterson [7].

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Appendix

(1) Oppenheimer-Phillips Process

(Q) OP proposed that if deuteron is polarized to n and p we may have enhanced pick up of triton channel by d–d fusion, because of p–p Coulomb repulsion in d–d reaction?

Is this process explainable to observed anomalous tritium generation in CF experiments?

(A) Deuteron never polarizes as so. If d were polarized to n and p, n will decay to p + e in about 10 min and d should disintegrate: we know this never happens and d is stable isotope. Strong interaction binding “virtual” p and n in d-nucleus, by exchanging charged pions (or equivalently glueons between quarks), is so fast that we cannot distinguish which one is neutron or proton, say changing from p to n or from n to p with very high frequency and there is no chance to be “neutron” for making β -decay of weak interaction, and therefore nucleus is stable.

Tritium preferred d–d reaction is therefore not plausible.

(2) d + d to ^4He process:

(Q1) Very narrow resonance of d–d interaction in condensed matter may exist and make lifetime of $^4\text{He}^*$ (or close pair of d–d admixture) very long and 23.8 MeV excited energy can be transferred “gradually” to lattice phonons without emitting hard radiation?

(A1) No mechanisms, which are consistent with known nuclear physics have ever been proposed to change lifetime of $^4\text{He}^*$. If lifetime of $^4\text{He}^*$ would become very long, this state is less competing to short lives (about 1×10^{-22} s) of n + ^3He (and p + t) out-going channel and branching ratio of ^4He production would become much less than 1×10^{-7} that is for $^4\text{He} + \gamma$ channel. See Fig. 9.

Note that: branching ratio is given as ratio of energy width $\Delta - E/\Delta - E$ -total. The total width is $\Delta - E_{(n)} + \Delta - E_{(p)} + \Delta - E_{(\gamma)}$. And we know for d–d reaction $\Delta - E_{(n)} = \Delta - E_{(p)} =$ about 0.2 MeV, and $\Delta - E_{(\gamma)} =$ about 0.04 eV (corresponding lifetime is on the order of 1×10^{-15} s, namely 1 fs). By Heisenberg uncertainty principle, lifetime is given by $h/\Delta - E$. So, if energy width of $^4\text{He}^*$ would become 1 μeV (corresponding lifetime is about 10 ps) by “very narrow resonance,” branching ratio to ^4He emission becomes 1×10^{-11} . When one said that lifetime of $^4\text{He}^*$ were on the order of several seconds, branching ratio should be on the order of 1×10^{-22} .

So, no way is there to produce ^4He predominantly in d–d reaction, unless energy width could become far greater than 0.2 MeV. Unfortunately, upper most value of possible energy width is 23.8 MeV which could anomalously increase branching ratio to $^4\text{H}/\text{n/t} = 100/1/1$, if at all, and still we should have lethal neutrons from d–d reaction if excess heat were due to such case.

We know the coupling constant of field (force) exchange for electro-magnetic interaction (or QED) is on the order of 1×10^{-2} (1/137 in exact) of nuclear strong interaction. Nuclear reaction cross-section is proportional to square of transition matrix. Transition matrix is proportional to interaction Hamiltonian. Interaction Hamiltonian is proportional to field coupling constant. Ratio of cross-sections (EM/ Strong) is therefore less than the square (1×10^{-4}) of that ratio of field coupling constants. So we have to conclude that the above case of predominant ^4He channel is not plausible.

Even if we assume mega-seconds life for a close d–d pair, if at all, we have nothing to do with changing the lifetime (on the order of 1×10^{-22} s) of $^4\text{He}^*$ in d–d reaction: this means that normal d–d reactions

should take place in stochastic way within the assumed mega-seconds lifetime of the close d–d pair! The coupling constant of nuclear weak interaction is on the order of 1×10^{-14} of nuclear strong interaction. Therefore, any significant enhancement by weak interaction (including EC — electron capture process) for changing drastically the branching ratios is not plausible, either. Here you note; Fusion cross-section of two-body interaction is given by

$$\sigma(E) = (S(E)/E)P(E).$$

And $S(E)$ is the intrinsic strong interaction factor, so called astrophysical S -factor, E is the relative energy of two-body system ($1/E$ is the square of de Broglie wave length, i.e., corresponding to geometrical cross-section of incident wave) and $P(E)$ is the barrier penetration probability through shielded (screened) Coulomb potential.

For cold d–d fusion, $S_{dd}(0) = 1.1 \times 10^2$ keVb: this is strong interaction.

For cold p–p fusion, $S_{pp}(0) = 3.4 \times 10^{-22}$ keVb: this is weak interaction and governing reaction in the fusion reaction cycles in the sun.

So, we roughly estimate the order of $S_{pp}/S_{dd} = 1 \times 10^{-24}$. You understand how weak the weak interaction is. The sun has huge mass and gravitational confinement fusion of p–p reaction can produce huge energy with very much slow speed (more than 1 billion years lifetime) due to very small S_{pp} -value. Hence a scenario to relate observed excess heat to weak interaction is not plausible. We have abandoned to observe p–p fusion in laboratory experiments, because the reaction level is too weak.

(Q2) There has been asserted by some theories that “two deuteron atoms join together to form one helium-4 + lattice energy.” Is it theoretically proved to be correct?

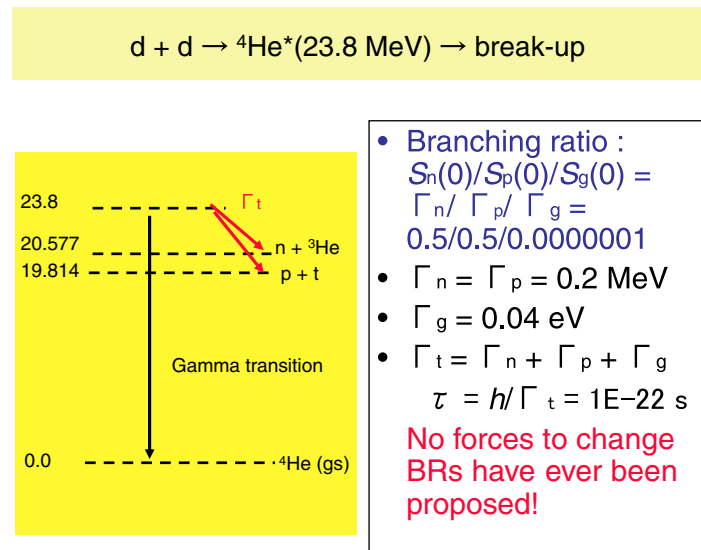


Figure 9. Break-up channels of d–d fusion reaction.

- (A2) The “dreamed” reaction $d + d \rightarrow {}^4\text{He}$ (lattice energy) is simply NOT POSSIBLE from nuclear physics point of view because there is no STRONG nuclear force scenario (ever proposed by theorists with certain quantitative estimation of branching-ratio changing effect) to change known reaction out-going branches of $n + {}^3\text{He}$ and $p + t$ products with 50–50% branching ratio. Please see Q1 and A1.

So their conjecture is to say Cheating Nuclear Physics (Strong Interactions), by a priori “desire.” And furthermore, if one conceives the process $d + d \rightarrow {}^4\text{He}$ ($E_x = 23.8 \text{ MeV}$)* as intermediate compound excited state of ${}^4\text{He}$ with very short life as $1 \times 10^{-22} \text{ s}$, the nuclear excited energy ($E_x = 23.8 \text{ MeV}$) cannot go to lattice phonons (we have to require more than 1 million lattice atoms, say palladiums locating within 30 nm domain, to receive its energy with much faster photon speed -by QED; quantum electrodynamics; coupling is thought there – than light velocity: hence in contradiction to Einstein relativity!).

The Arata-Zhang 5 nm diameter Pd particles experiment with intense ${}^4\text{He}$ production clearly showed that their conjecture is wrong since 5 nm Pd crystal has about 1000 Pd atoms which can receive only about 30 keV (about 0.1% level of 23.8 MeV) in order not to be displaced from lattice (not destroying lattice, namely not destroying story of condensed matter-related reaction). The generation of ${}^4\text{He}$ should be attributed to some other process than the $d + d \rightarrow {}^4\text{He}$ hypothetical (and wrong, the author thinks) scenario. In author’s opinion, we need participation of third and fourth hadrons in d–d system to change reaction products as proposed in this paper and our previous works [8,9,11].

References

- [1] J. Kasagi et al., *J. Phys. Soc. Jpn.* **71** (2002) 2881.
- [2] A. Takahashi et al., *Phys. Lett. A* **255** (1999) 89.
- [3] M. McKubre et al., *Proceedings of the ICCF10*, Boston, 2003, see <http://www.lenr-canr.org/>.
- [4] Y. Arata, *Il Nuovo Aggiatore* **38** (2005) 66–71.
- [5] El Boher et al., *Proceedings of the ppt Slide of ICCF11*, Marseilles, November 2004, see <http://www.iscmns.org/>.
- [6] Y. Iwamura et al., *Jpn. J. Appl. Phys.* **41** (2002) 4642.
- [7] G. Miley, J. Patterson, *J. New Energy* **1** (1996) 5.
- [8] A. Takahashi, Deuteron cluster fusion and ash, *Proceedings of the AST15 WS*, Italy, March 2004, see <http://www.iscmns.org/>.
- [9] A. Takahashi, Deuteron cluster fusion and related nuclear reactions in metal-deuterium/hydrogen systems, Recent Developments in Physics, Transworld Research Network, India, issued June 2005.
- [10] A. Huke, Ph.D. Thesis, Technical University of Berlin, 2004.
- [11] A. Takahashi et al., *Fusion Technol.* **27** (1995) 71.
- [12] See many papers in <http://www.lenr-canr.org/>.
- [13] A. Takahashi et al., *Jpn. J. Appl. Phys.* **41** (2001) 7031.
- [14] A. Takahashi, TSC-induced nuclear reactions and cold transmutations, this Workshop.