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Research Article

Deuteron Cluster Fusion and ASH

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Abstract

This is a review of our studies on theoretical model of deuteron cluster fusion in condensed matter. Considering a transient condensation process of deuteron-cluster in focal points of metal–deuteride lattice, electron screening effect was theorized by the Electronic Quasi-Particle Screening Theory (EQPET) model for a transient deuteron cluster associating attracted electrons. Multi-body resonance fusion of deuterons was proposed by modeling charged-pion exchange for strong interaction in very condensed deuteron cluster to lead to select the tetrahedral resonance fusion (TRF) of 4D and octahedral resonance fusion (ORF) of 8D as possible major reaction channels in extreme case. ^{4}He is the final product of TRF and ORF. Tritium and ^{3}He was suggested as minor products from 3D multi-body fusion. Visible but very small level production of neutron by D + D (2D) fusion was also concluded. Further extension of EQPET model is given to propose a dynamic Bose-type condensation process by orthogonally coupled two D_2 molecules, which play a role of super screening of Coulomb barrier with quadruplet electronic quasi-particle to generate clean fusion product of ^{4}He.

Keywords: Ash, Bosonization, Deuteron cluster fusion, Electronic quasi-particle screening, 4D Fusion, 8D Fusion, Helium-4, Secondary reaction

1. Introduction

The possible occurrence of low energy deuteron fusion in condensed matter at room temperature, so called cold fusion, and other nuclear reactions in solid has been studied in the last 15 years since 1989 by number of people in the world, in spite of totally negative responses [1] by established scientific societies in 1989–1990. Many international conferences [2–10] have been held and numerous papers have been published in journals. Many claims of anomalous observation of excess heat, neutrons, helium, X-rays, charged particles, etc., which are asserted to evidences of "new" nuclear reactions in condensed matter, have been made. However, people have got failed to replicate the claimed results in most cases. Nevertheless, several groups have obtained physically same results for the following key observations.

(A) Generation of large amount of helium-4 (^{4}He), comparable to observed level of excess heat (1–100 W level) in PdDx systems of electrolysis-type experiments, has been confirmed by several groups [11–15,53,54]. In these

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experiments, neutrons and gamma-rays have not been observed with clearly countable level [16,17]. However, emission of continuous X-rays in the region less than 100 keV has sometimes been observed [18,19]. These results suggest us that some "unknown" nuclear reactions took place emitting energetic α-particles, which produced secondary continuous X-rays in slowing down with condensed matter (PdDx) and make energy deposit, comparable to excess heat, as lattice vibration. The known free particle d–d reaction, which is known to emit 2.45 MeV neutron plus 0.8 MeV ^{3}He and 3 MeV proton plus 1 MeV triton, cannot be candidate for explaining observed results.

In the text, d denotes deuteron-particle and D does deuteron with electron.

(B) Observations of anomalous amount of "foreign" elements on metal surface (cathode or permeation sample) region have been claimed by several groups [19–23]. Some new class of low-energy "nuclear transmutation" like "clean fission" without hard γ-ray radiation has been proposed by the researchers. Especially, the latest claim by Mitsubishi H. I. Group [24–27] is extraordinary; They have shown clear-cut results of generation of mass(A)-8-and-charge(Z, atomic number)-4 increased elements (^{96}Mo and ^{141}Pr form ^{88}Sr and ^{133}Cs, respectively), with large amount (10^{14} atoms per week or so), closely related to comparable reduction of test elements (Sr and Cs), by the deuterium gas permeation through multi-layered Pd/CaO/Pd film on which test elements were mounted. How is the selective occurrence of A-8-and-Z-4 increased transmutation made possible ? This is a big challenge to theoretical modeling.

Many theoreticians, and even experimentalists, have made great efforts to propose new theoretical models for "nuclear reaction in condensed matter" and attempted to consistently explain those anomalous observations. A comprehensive review paper [28] exists for the research period of 1989–1994; No theory work was enough consistent to match both of explaining anomalous results and not-violating established physics, although we may have some hopes to several models. Progress in theoretical study was rather slow in 1995–2001. However, well-cited models by researchers have been gradually converged to "coherent fusion" models. Dynamic behavior of deuterons in condensed matter, namely dynamics of solid-state-physics, may induce special conditions to make deuterons "coherent fusion," in either nm-size domain of metal–deuteride (MDx) lattice [28, 29] or more microscopic focal points in MDx lattice [30–34].

The author first proposed multi-body (three-body D + D + D) fusion model [35] as a cascade D-catalyzed reaction: D + D to ^{4}He*, ^{4}He*+ D to d + α + 23.8 MeV in very short time interval, to explain the original claim [36] on large excess heat with anomalous small level of tritium and neutron. Since that time, the author and his collaborators have elaborated [30–32] the multi-body deuteron fusion model in MDx dynamics, to meet the consistency requirements in views of established physics and to attempt to make quantitative studies on reaction rates of "cluster deuteron fusion process," which is another name of multi-body deuteron fusion in condensed matter. Especially in the latest paper [51], for ICCF9 Proceedings, the author has proposed the model of tetrahedral (TRF) and octahedral resonance fusion (ORF) in dynamic condition of PdDx ($x > 1$) lattice, considering the generation of transient "bosonization" of electrons at focal points to make super-screening of Coulomb repulsive force of d–d interaction to enhance resonantly strong interactions for 4D and 8D cluster fusion. Quantitative estimations of cluster fusion have ever been done [31,37,38,60,62]. Further elaboration done is reviewed in this work; the electronic quasi-particle expansion theory (EQPET) model was proposed by the author [48] and some numerical estimations were done by using calculations of screened potentials for dde* (e*; quasi-particle of electrons like Cooper pair and quadruplet-coupling) and dde*e* transient molecular states, to obtain very positive results to support the occurrence of deuteron cluster fusion as 4D or 3D multi-body fusion in PdDx lattice with so large reaction rate level as comparable to experimentally claimed level of excess heat and ^{4}He production. Nuclear transmutation by high-energy ^{8}Be emission of 8D cluster fusion was also proposed [51] to explain the extraordinary Mitsubishi results [24–26]. The model was further extended [60,62] to model super-screening mechanism by quasi-particle of quadruplet electrons with orthogonally coupled two D_2 molecules.

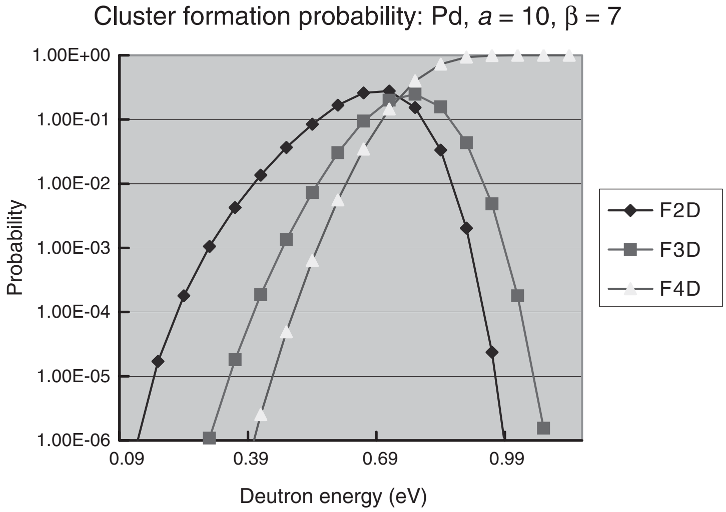

Figure 1. Cluster formation probabilities of 2D, 3D, and 4D condensation [31].

This paper first reviews the EQPET theory of deuteron cluster fusion in condensed matter, to draw a comprehensive story of the model, formulation of equations, quantitative results and discussions. Then extended theory is shown.

2. Transient Condensation of Deuteron Cluster

Since the meaningful enhancement of d–d fusion rate in steady state condition of deuterons trapped in metal lattice like PdDx is not possible [30], we have looked for dynamic conditions.

Using the implantation technique of low energy ion beam (deuteron, proton, and Si) from accelerators into titanium-deuteride (TiDx) plate-samples in vacuum, we have intensively searched if there exists any trace of deuteron cluster fusion [15,37–40,52], especially 3D (D + D + D) fusion which in conventional random motion or stochastic process of nuclear reaction should have very small reaction rate-ratio to d–d (D + D) fusion, [3D]/[2D] less than 10^{-30}. Namely, we should not observe any significant counts of produced particles (4.75 MeV t and 4.75 MeV ^{3}He, typically), according to the conventional theory of random nuclear reactions. On the contrary, our results [15,37–40] of beam implantation experiments provided very large data of [3D]/[2D] = about 10^{-4}, with increasing trend in low energy region less than 100 keV of D^+ beam energy. Namely, anomalous enhancement factor of about 10^{26}–10^{27} was obtained. To explain this with the beam-target reaction as conventional nuclear stochastic process, we need to assume the existence of close d–d pairs within 1 pm (10^{-12} m) inter-nuclear distance with 10^{-10} times population of deuterons in TiDx lattice. And experiments with proton beam [39,40] have suggested us that about half of three-body reactions (H + D + D or D + D + D) was due to the direct beam and close d–d pair reactions, and a remained half was attributed to the indirect (lattice-induced) three-body reactions that could be true deuteron cluster fusion. Therefore, to explain the enhancement factor of 10^{26}, we have sincerely to consider the mechanism of coherently induced cluster fusion in dynamic motion of TiDx and PdDx lattice.

Our preliminary model analyses were given in Refs. [30,31]; We adopted the excitation screening model. We have considered transient motion of deuterons at O-sites of PdDx lattice moving (diffusing) toward a T-site which is a candidate of focal points, for local full loading condition of PdDx, $x = 1.0$. This transient motion was conceived to be stimulated by exciting D-harmonic oscillators at O-sites near to the periodic trapping potential height of 0.22 eV.

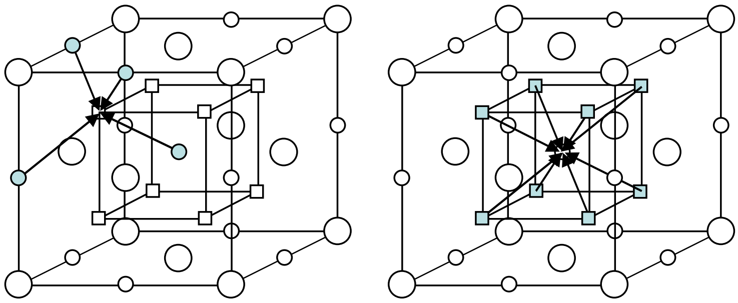

Figure 2. Tetrahedral condensation (a) and octahedral condensation (b); deuterons sit at octahedral sites for PdD and tetrahedral sites for PdD2 as local full or overloading condition.

Then cluster formation probabilities for 2D, 3D, and 4D "atomic" clusters were roughly evaluated, as shown in Fig. 1. This process of tetrahedral condensation is shown in Fig. 2a. This transient process of deuteron condensation at T-sites was considered [30,31] to be realized by squeezing many 4d-shell electrons of Pd atoms, which were quasi-free in the conduction band of Pd lattice. A two-dimensional view of this squeezing motion of deuterons and electrons into T-sites is shown in Fig. 3. Since many number of Pd atoms (more than eight), deuterons (four), and electrons (more than eight) are involved in this condensation process, an orthodox way of quantum mechanical treatment is to solve many coupled time-dependent Schroedinger equations with the potentials of three components, i.e., periodic atomic potential, Coulomb repulsive potential and nuclear strong interaction potential, in order to obtain deuteron cluster fusion rates. Of course this is a difficult task of computation.

For the treatment of zeroth order approximation, we adopted the model of strong coupling of phonons (D-harmonic oscillators) and 4d-shell electrons by D-plasma oscillation in PdDx lattice, and drew time-dependent behavior of periodic potentials which would have a transient deep potential hole (see Fig. 3 of Ref. [31]). We referred –80 eV for the depth of hole from Preparata's work [41]. In the next section, we will show the depth of hole is much deeper as –260 to –20 keV depending on the generation of transient Cooper-like pairs and/or quadruplet-coupling and octal coupling of electrons with anti-parallel spins. When a transient deep potential hole is born, e.g., four deuterons with four electrons are strongly attracted to the hole, namely at focal point (T-site in TRF case), and will accelerate to make a condensed cluster of deuterons within less than 1 pm-radius spherical domain. If we can calculate cluster fusion rates in a steady deep hole, we may convert it to time-averaged one, approximately by multiplying relative ratio of time-window for existence time of deep hole compared to plasma oscillation period, which is in the order of 10 fs. This is the way that we will extend the theory in the next section to make quantitative analysis. The EQPET model treat this by starting with assumption that total electronic wave function in transient deuteron cluster with electrons can be expanded by the linear combination of wave functions for transient molecular states like dde (namely $D_2{}^+$), ddee (D_2 molecule), dde* and dde*e* with transiently Bosonized electronic quasi-particle e* [48,49].

The INFN Frascati group of Celani et al. reported [42] very interesting and important results showing local superconductivity trend for over-D-loaded (D/Pd > 1) thin Pd wire in electrolysis. They reported resistance of wire became almost zero for 10–20 min interval and then quenched to normal resistance value of PdDx ($x = 0.7$). They also reported frequent observation of reduced resistance ratios R/R_0, probably showing tiny local superconductivity.

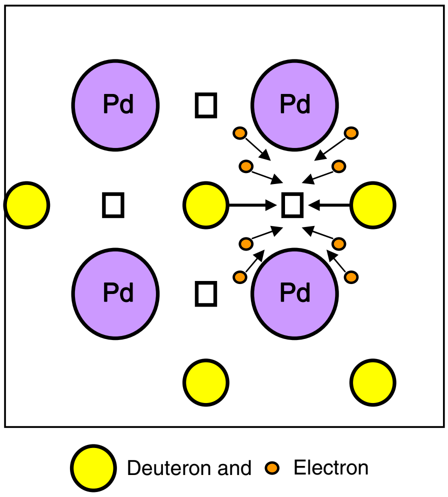

Figure 3. Squeezing of 4d-shell electrons (small circles) to focal point (T-site) of PdDx lattice.

Now we have to notify that PdDx is superconductivity material at low temperature less than 80 K, and over-D-loading ($x > 1$) will be the indication of the trend.

Recently Lanzara et al. published a paper in Nature [43] about observation of quasi-particle generation in high-T_c superconductor hole-doped copper-oxide, by means of angle resolved photo-electron emission spectroscopy. From two-peaked spectral data, they estimated about 1 ps lifetime for the electron quasi-particles (like Cooper pair). It is going to be clear that high-T_c superconductivity is induced by the generation of transient quasi-particle of electrons.

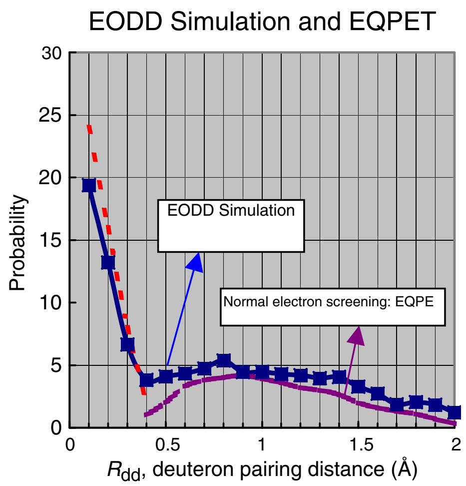

Figure 4. Transient electronic screening effects by EODD simulation [33] and EQPET [48], the lower R_{dd} component (broken line) is described by transient quasi-particle expansion.

This is anyway "transient bosonization" of electrons (fermions). We know that usually, the Pauli exclusion principle rules fermions (electrons) to block enhancement of screening of d–d Coulomb repulsive force. However, miracle of superconductivity may happen and the similar situation for generation of transient electronic quasi-particles will be true for deuteron fusion in condensed matter, by much localized transient bosonization, as we show in the next section.

The famous Japanese book of Solid State Physics [44] teaches us on superconductivity that: "behavior of charged particle in metal is well described by treating the interactions between plasma oscillation, phonons, free electrons, and shielded mutual interaction. Coupling between electron-system and phonon-system is the reason to generate superconductivity. Electron–electron interaction via phonon induces attractive force in the vicinity of Fermi surface, which compensates the shielded Coulomb repulsive force. The electron pair ($\mathbf{k}\uparrow, -\mathbf{k}\downarrow$), Cooper pair is selectively generated and annihilated in the strongly coupled state." The coherent range of Cooper pairs are regarded very long as greater than 100 nm for macroscopic superconductivity. We are going on the similar track for assuming electronic quasi-particles, but we are conceiving transient molecular states with single-particle-like e*. Two 1S- electrons in D_2 molecule have opposite spins in each other and mutual distance of electrons is about 0.1 nm. When one of electrons gets opposite momentum from outside interaction (for instance, by phonon–electron coupling and scattering in condensed matter), Two 1-S electrons may make a transiently Bosonized state (quasi-particle) with far less mutual distance than 0.1 nm and hence e* can be approximately treated as a single particle. So that, we do not necessarily require superconductivity condition in rather macroscopic domain, but do require localized microscopic order to generate transient electronic quasi-particle states with deuteron cluster.

Kirkinskii and Novikov [33] proposed the Electron Orbital Deformation Dynamics (EODD) model to treat the lattice dynamics in similar system as shown in Fig. 3. The EODD method is a kind of Monte–Carlo Molecular Dynamics calculation taking into account deformation of 5s + 4d shell electron-orbits by approach of two counter deuterons. They estimated the probability distribution of minimal pairing distances R_{dd} of deuterons, which showed a broadly peaked distribution in 0.5–2 Å region, probably reflecting minimum potential positions 1.1 and 0.7 Å, respectively, for dde and ddee (D_2) molecular states, and very interestingly steeply increasing component in lower R_{dd} region less than 0.2 Å as shown in Fig. 4. EODD simulation has given about 19% probability to have closely packed transient d–d pairs with less than 0.1 Å (even in 0.01 Å region) inter-nuclear distance which gives very enhanced fusion rate as 10^{-10} f/s/pair level [33]. It is regarded that this component realizes visible "cold fusion events." From our EQPET calculations [48] as reviewed in the next section, this component can be described as linear combination of Transient Electronic Quasi-Particle (TEQP) components, namely dde*(2,2), dde*(2,2), e*(2,2), dde*(4,4), and dde*(8,8), etc., as transient molecular states of EQPET theory [48]. This means that, when we will get three-dimensional EODD simulations for TRF and ORF systems, we will be able to fit the result with the combination of normal electron (dde + ddee) and transient quasi-particle screening (dde* + dde*e*) components. This should give the basis of EQPET.

3. EQPET Model

3.1. Basic Formulation

Some of MDx materials have been studied for high-temperature superconductivity trend, as typical significant effect was reported by Celani et al. [42] for full and over-loaded PdDx ($x = 1$ or > 1). The physics of low-temperature superconductivity is believed to be established by the BCS theory [50] and the physics of high-T_{c} (critical temperature) superconductivity has been studied, albeit not established yet, by extension of the BCS theory and Bogoliubov theory for electronic quasi-particle generation.

Deuteron at O-site (or T-site) in PdDx lattice behaves as an harmonic oscillator with phonon frequency ω_{q}. And motion of electrons is treated with plasma oscillation with frequency $\omega$of the lattice system with many electrons, deuterons and metal-atoms (e.g., Pd). By electron–phonon scattering, momentum $\mathbf{q} = \mathbf{k}–\mathbf{k}'$ is carried by phonon and two electrons having opposite momentum and spin may be born to generate a Cooper pair ($\mathbf{k}\downarrow$, $-\mathbf{k}\uparrow$) as an electronic quasi-particle, due to attractive force to compensate repulsive force of Coulomb interaction, in the phonon–electron coupled motion. Shielded Coulomb interaction potential is given [50] as:

$$V(q,\omega) = 4\pi e^2/(q^2 + {k_s}^2) + (4\pi e^2/(q^2 + {k_s}^2))({\omega_q}^2/(\omega^2 - {\omega_q}^2)) \tag{3.1}$$

$$= (4\pi e^2/(q^2 + {k_s}^2))(\omega^2/(\omega^2 - {\omega_q}^2)), \tag{3.2}$$

where $1/k_s$ is the screening distance for Fermi gas. The first term of Eq. (3.1) shows normal Coulomb repulsive potential between electrons, and the second term shows phonon-mediated interaction. As clearly seen by Eq. (3.2), the potential becomes negative (attractive) if $\omega < \omega_q$. This is a driving force to produce Cooper pairs. When two deuterons with electrons are squeezing from opposite directions to T-site (or O-site) under the TRF (or ORF) transient condensation [51], the condition of opposite momentum and spin for two electrons can be naturally fulfilled (see Fig. 3). However, directions of deuterons in TRF and ORF condensation are not ideally 180° opposite, so that momentum transfer by phonon-electron coupling makes conditioning for transient Cooper-like pairs. Actually, quasi-particle state may be generated by formation of orthogonally coupled two D_2 molecules to associate electronic quadruplet, as we show in Section 4.

Effective mass m^* and effective charge e^* of Cooper-like pair can be approximately given [50] as $m^* = 2m_e$ and $e^* = 2e$. Microscopic Cooper-like pair with short life around lattice focal point can be regarded as single particle, as discussed, with mass $2m_e$ and charge $2e$. Hence we label Cooper-like pair as $e^*(m^*/m_e, e^*/e) = e^*(2,2)$. Cooper-like pair is the s-wave pairing of two electrons with opposite momentum and spin. To explain high-Tc superconductivity, generation of unconventional pairing (e.g., d-wave pairing) and very heavy fermions (several hundred times mass of electron) have been proposed (see Chapter 9 of Ref. [50]), albeit reaching no consensus yet. By considering higher order pairing (s-wave) of binary e*(2,2) quasi-particles to generate a quadruplet-coupling e*(4,4) and moreover octal coupling e*(8,8) by binary e*(4,4) quasi-particles, we may treat the state of high-T_c superconductivity, instead of assuming heavy fermions (electrons), as we see later. “Bosonized” electron wave function Ψ_N for N-electrons system in MDx lattice will be approximated, as discussed in the previous section, by a linear combination of normal electron wave function $\Psi_{(1,1)G}$ and quasi-particle wave functions $\Psi_{(2,2)G}$, $\Psi_{(4,4)G}$, and $\Psi_{(8,8)G}$ as;

$$|\Psi_N\rangle = a_1|\Psi_{(1,1)G}\rangle + a_2|\Psi_{(2,2)G}\rangle + a_4|\Psi_{(4,4)G}\rangle + a_8|\Psi_{(8,8)G}\rangle. \tag{3.3}$$

Here we consider each wave function is further a linear combination of wave functions for single and double electrons or e^*. This may be called the quasi-particle expansion of total electronic wave function. Here suffix G denotes ground state. For MDx system, the normal electron wave function $|\Psi_{(1,1)G}\rangle$ coupled with phonon may be given by a Bloch function with lattice period x_l, combined with harmonic oscillator motion for D, in one-dimensional case; Using Hermite polynomial H_n,

$$|\Psi_{(1,1)G}\rangle = \sum C_l \exp(\mathrm{il}(x - x_l)) \sum \exp(-\alpha_n (x - x_l)^2) {H_n}^2({\alpha_n}^{1/2}(x - x_l)). \tag{3.4}$$

The ground state BCS wave function is defined as,

$$a_1|\Psi_{(1,1)G}\rangle + a_2|\Psi_{(2,2)G}\rangle = \prod (u_k + \nu_k C^*_{k\uparrow} C_{-k\downarrow}|\Psi_0\rangle, \tag{3.5}$$

where $|\Psi_0\rangle$ denotes vacuum, u_k is the un-occupied wave function of Cooper-like pair and ν_k is the occupied wave function of Cooper-like pair; hence ${u_k}^2 + {\nu_k}^2 = 1$ is the normalization condition. $C^*_{k\uparrow}$ and $C_{-k\downarrow}$ are generation and destruction operators, respectively.

We may define production operator $C^*{}_{2k}$ and destruction operator C_{2k} for bosonized (spin zero) e*(2,2) to generate quadruplet-coupling e*(4,4) as,

$$a_1|\Psi_{(1,1)G}\rangle + a_2|\Psi_{(2,2)G}\rangle + a_4|\Psi_{(4,4)G}\rangle = \prod(u_{2k} + v_{2k}C^*{}_{2k}C_{2k})|\Psi_0\rangle \tag{3.6}$$

with ${u_{2k}}^2 + {v_{2k}}^2 = 1$ for normalization. Wave function for e*(8,8) is similarly defined.

To evaluate coefficients a_1, a_2, a_4, and a_8, we may apply the variational method with evaluating the BCS Hamiltonian (see Chapter 3 of Ref. [50]);

$$H = \Sigma\Sigma\varepsilon_k n_{k\sigma} + \Sigma\Sigma V_{kl}C^*{}_{k\uparrow}C^*_{-k\downarrow}C_{-l\downarrow}C_{l\uparrow} \tag{3.7}$$

and

$$\delta\langle\Psi_N{}^*|H|\Psi_N\rangle = 0. \tag{3.8}$$

The above equations are just for formality, and we need further extension to substantiate the problem. However, essential components of the problem can be analyzed as follows.

3.2. Screening Effect and Fusion Rates

For the time-window of potential deep hole [31,51], effective (time-averaged) screening potential, for a d–d pair in a transient D-cluster of 4–8 deuterons for TRF and ORF condition [51], can be defined by a screened potential of quasi-particle complex;

$$V_s(R) = b_1V_{s(1,1)}(R) + b_2V_{s(2,2)}(R) + b_4V_{s(4,4)}(R) + b_8V_{s(8,8)}(R). \tag{3.9}$$

Here R is the inter-nuclear distance of a d–d pair and $V_s(m^*/m_e, e^*/e)(R)$ is the screened potential for a dde($m^*/m_e, e^*/e$) molecule, for $(m^*/m_e, e^*/e)$ = (1,1), (2,2), (4,4), and (8,8). Time-averaging treatment for transient D-cluster condensation with electrons including transient quasi-particles is transferred here to coefficients b_1–b_8. By definition, we need to satisfy the following normalization condition.

$${b_1}^2 + {b_2}^2 + {b_4}^2 + {b_8}^2 = 1. \tag{3.10}$$

For a dde or dde* molecule (one quasi-particle approximation) within the short time-interval of D-clustering, wave function of a d–d pair (2D) is given by the solution of the following Schroedinger equation:

$$(-h^2/8\pi\mu)\nabla^2X(R) + (V_n(R) + V_s(R))X(R) = EX(R) \tag{3.11}$$

with nuclear potential $V_n(R)$ for strong interaction and reduced deuteron mass μ.

By Born–Oppenheimer approximation, we assume as,

$$X(R) = X_n(R)X_s(R). \tag{3.12}$$

Overlapping rate of $X(R)$ at $R = r_0$ gives estimation of d–d fusion rate λ_{2d} as:

$$\begin{aligned}\lambda_{2d} &= G|X(R)|^2{}_{R=r_0}\\ &= G|X_n(R)|^2{}_{R=r_0}|X_s(R)|^2{}_{R=r_0},\end{aligned} \tag{3.13}$$

where G is the scaling constant and r_0 is given to be 5 fm considering deuteron radius plus charged-pion exchange range (about 2 fm) at contact surface configuration of the moment of strong interaction for d–d fusion reaction.

Using WKB approximation for the barrier ($V_s(R)$) penetration probability,

$$|X_s(R)|^2{}_{R=r_0} = \exp(-2\Gamma_n(E_d)); \qquad \text{Barrier Factor (BF)}, \tag{3.14}$$

where E_d is the relative deuteron energy and Γ_n is Gamow integral for a d–d pair in D-cluster (n-deuterons with electrons) that is defined as:

$$\Gamma_n(E_d) = (2\mu)^{1/2}/(h/\pi)\int_{r_0}^{b}(V_s(R) - E_d)^{1/2}\mathrm{d}R. \tag{3.15}$$

Using astrophysical S-factor for strong interaction,

$$\mathrm{G}|X_n(R)|^2{}_{R=r_0} = \mathrm{vS}_{2d}(E_d)/E_d. \tag{3.16}$$

Consequently we can approximately define tow-body fusion rate as:

$$\lambda_{2d} = (\mathrm{vS}_{2d}(E_d)/E_d)\exp(-2\Gamma_n(E_d)). \tag{3.17}$$

We can estimate Gamow integral for dde* molecule, by solving Schroedinger equation to obtain screened potential $V_s(m^*/m_e, e^*/e)$ and evaluate the corresponding Gamow integral $\Gamma_n(m^*/m_e, e^*/e)$ by, for each electron and quasi-particle molecular state,

$$\Gamma_{n(m^*/m_e,e^*/e)}(E_d) = (2\mu)^{1/2}/(h/\pi)\int_{r_0}^{b}(V_{s(m^*/m_e,e^*/e)}(R) - E_d)^{1/2}\mathrm{d}(R). \tag{3.18}$$

Using Eqs. (3.15) and (3.9) with condition of $V_s(R) \gg E_d$; $R < b$, and considering that b-parameter becomes independent own value for each quasi-particle, we can approximately obtain:

$$\Gamma_n(E_d) = b_1\Gamma_{n(1,1)}(E_d) + b_2\Gamma_{n(2,2)}(E_d) + b_4\Gamma_{n(4,4)}(E_d) + b_8\Gamma_{n(8,8)}(E_d). \tag{3.19}$$

To estimate coefficients $b_1 - b_8$, we have to solve coupled channel Schroedinger equations of normal electrons, Cooper pairs, quadru-couplings, e*(8,8) by Eqs. (3.3)–(3.8), to evaluate first relative state densities of a_1–a_8. This is a hard task to do in future. For some simplified cases as in Section 4, we have estimation.

Screened potentials $V_s\mathrm{n}(m^*/m_e, e^*/e)(R)$ were calculated for dde* molecular states using extended solutions for dde state given in a text of quantum mechanics by the well-known technique of variational method [45] as:

$$V_{s(m^*/m_e,e^*/e)}(R) = V_h + e^2/R + (J + K)/(1 + \Delta), \tag{3.20}$$

where the Coulomb integral J, the exchange integral K, and the non-orthogonal integral Δ are given as [45]:

$$J = Z(e^2/a)[-1/y + (1 + 1/y)\exp(-2y)], \tag{3.21}$$

$$K = -Z(e^2/a)(1 + y)\exp(-y), \tag{3.22}$$

$$\Delta = (1 + y + y^2/3)\exp(-y). \tag{3.23}$$

With

$$Y = R/a, \tag{3.24}$$

$$a = a_0/Z/(m^*/m_e) \tag{3.25}$$

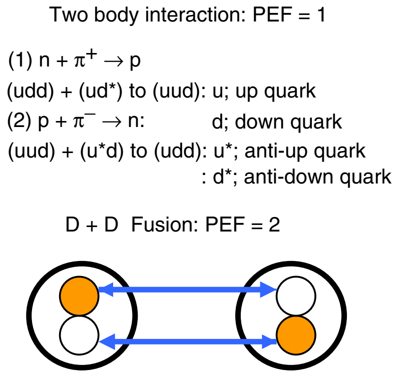

Figure 5. PEF factor to scale strong interaction for nuclear fusion.

with a_0= 0.053 nm (Bohr radius) and $Z = e^*/e$.

We also solved an atomic de* system to obtain ground state energy $V_h$as:

$$V_\mathrm{h} = -13.6Z^2/(m_\mathrm{e}/m^*). \tag{3.26}$$

For dde*e* molecule state with double electrons or e* s, we also extend the solution for ddee given in the text [45] and we have obtained screened potential function $V_{\mathrm{se}^*\mathrm{e}^*}$ as:

$$V_{\mathrm{se}^*\mathrm{e}^*}(R) = 2V_\mathrm{h} + e^2/R + (2J + J' + 2\Delta K + K')/(1 + \Delta^2). \tag{3.27}$$

Here the cross-Coulomb integral J' and cross exchange integral K' are given as:

$$J' = (Z^2e^2/a)(1/y - \exp(-2y))(1/y + 11/8 + 3y/4 + y^2/6), \tag{3.28}$$

$$\begin{aligned} K' = (Z^2e^2/5/a)[&-\exp(-2y)(-25/8 + 23y/4 + 3y^2 + y^3/3) \\ &+(y/6)((0.5772 + \log y)\Delta^2 \\ &+(\Delta')^2E_\mathrm{i}(-4y) - 2\Delta\Delta'E_\mathrm{i}(-2y))] \end{aligned} \tag{3.29}$$

with

$$\Delta' = \exp(-y)(1 - y + y^2/3), \tag{3.30}$$

$$E_\mathrm{i}(y) = -\int_0^{\exp(-y)} (1/\log x)\,\mathrm{d}x. \tag{3.31}$$

We should note here that in these equations corrections were made for mistakes in the text book [45].
For fusion rates of multi-body (nD) reactions in a D-cluster was defined [51] as:

$$\lambda_\mathrm{nd} = [vS_\mathrm{nd}(E_\mathrm{d})/E_\mathrm{d}]\exp(-n\Gamma_\mathrm{n}(E_\mathrm{d})). \tag{3.32}$$

Here we have assumed that a simultaneous multi-body fusion process can be approximately treated by the very fast sequential process, e.g. (D + (D + (D + D))) of cascade two-body reactions for intermediate states [51]. And we have made estimate for $S_\mathrm{nd}(0)$ values by using empirical scaling of known $S(0)$-values of H + D, D + D, and D + T fusion

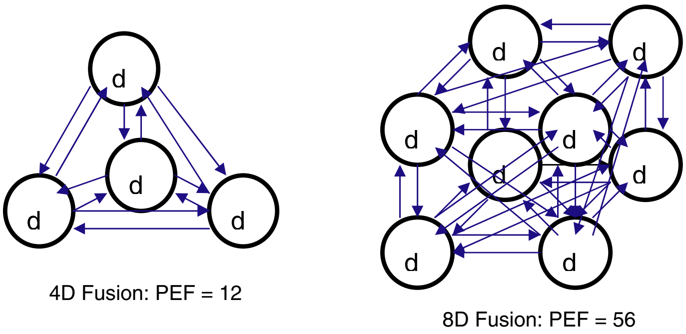

Figure 6. Charged pion exchange for 4D TRF and 8D ORF condensations.

reactions extrapolating up to unknown multi-body $S_{\rm nd}(0)$ values as a function of pion exchange force (PEF) numbers for equilaterally symmetric configuration of strong interaction (Π^+ and Π^- exchange) in TRF and ORF condensation [51]. The second term of Eq. (32) gives multi-body barrier factor.

3.3. TRF-and ORF-Resonance of Strong Interaction

To make an empirical scaling law of effective S-values (astrophysical S-values) for two-body and multi-body deuteron-related fusion cross-sections, PEF parameter which is a relative measure of contact surface area of pion exchange has been defined [17,30,31,32]. The larger is the contact surface area, the larger is fusion cross section. The basic idea is illustrated in Fig. 5. Since the neutral pion exchange corresponds to scattering process between nucleons, exchange of charged pions (positive and negative) is regarded to be attributed to nuclear fusion. Single charged pion exchange between neutron and proton is defined as PEF = 1 as scaling factor of fusion-strong-interaction. By using quarks instead of pions, we obtain same results. So, we can evaluate degree of strong interaction for fusion by using charged pion exchange (Yukawa model). Using this relative PEF unit, pion exchange for D + D fusion is counted as PEF = 2. We extend the idea to others and obtain PEF = 3 for D + T, PEF = 6 for D + D + D (3D), PEF = 12 for 4D, and PEF = 56 for 8D, as illustrated interactions for 4D equilateral tetrahedron and 8D equilateral octahedron (deuteron site at face-center)

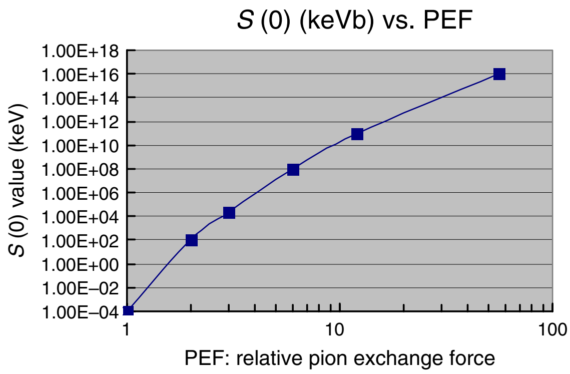

Figure 7. Speculative extrapolation of effective S-values for multi-body fusion.

in Fig. 6. TRF condensation can realize equilaterally tetrahedral configuration in charged pion exchange with same inter-deuteron distance for each deuteron: namely best condition to enhance effective contact surface of pion cloud to form virtual compound ^{8}Be* as intermediate fusion product which breaks up shortly to two α-particles. Equilateral triangle configuration for 3D fusion is next good.

For deuteron clusters of 5D, 6D, and 7D, symmetric pion-exchange condition is geometrically so violated that local 4D cluster-component may have geometrically symmetric tetrahedral configuration and resultantly 4D fusion becomes selective. For 8D cluster, symmetric condition recovers: however, interaction distances are identical and shorter to three neighboring deuterons, but identical and longer to remained four deuterons. Therefore, PEF = 56 for 8D fusion is considerably overestimation: this may mean that degree of strong interaction for fusion should be saturated for high number of nucleons. This looks true when we see changing trend of S-values of reactions between deuteron and higher mass-nuclei (^{6}Li,^{10}Be,^{12}C, and so on). However intrinsic difference, for example, between d + ^{6}Li fusion and TRF 4D fusion (both produces intermediate virtual compound ^{8}Be*) is that about half (3) of nucleons (neutron and proton) of ^{6}Li nucleus sphere are shielded with other half (3) of nucleons to make direct charged pion exchange in contact surface, while TRF 4D fusion realizes completely symmetric exchange without shielding affect. Because of above-discussed reason, we can expect resonantly strong enhancement of fusion cross sections (effectively S-values) for 3D, 4D, and 8D fusion. In addition, because of high PEF values, 4D TRF and 8D ORF may have strongest “resonance” condition. We may say that 3, 4, and 8 are “magic numbers” for deuteron cluster fusion.

Using thus counted PEF values for scaling parameter, we have obtained extrapolated S-value plot for 4D TRF and 8D ORF reactions based on known S-values of H + D, D + D, and D + T reactions, as shown in Fig. 7. We have obtained rough values of 10^{12} keV barn for 4D TRF and 10^{16} keV barn for 8D ORF, which are extremely large values compared to those of conventional two-body fusion.

Using Eq. (3.32) with estimated S-values and BF values, we have got fusion rates per cluster for 2D, 3D, 4D, and 8D fusion. Results (Table 1) will be shown in the next section.

3.4. Numerical Results and Discussions

We have done calculations of screening potentials of dde* and dde*e* molecules with heavy electrons (fermions) for $m^* = 1m_e$ to $208m_e$ (muon), to make comparison with screening effects by quasi-particles of e*(2,2), e*(4,4), and e*(8,8).

Figure 8 shows the effect of first-step bosonization, namely generation of Cooper-like pair, compared with screened potential of D_2 molecule (ddee system) which has minimum transient potential hole (–10.6 eV) at $R_e = 0.07$ nm. Value

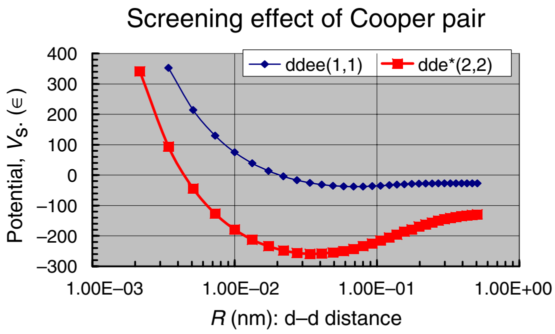

Figure 8. Screening effect of Cooper-like pair for dde* molecule, compared with D_2 molecule.

Table 1. Barrier-Factors (BF) and Fusion-Rates (FR in f/s/cl), by transient quasi-particle screening

$(m^*/m_e, e^*/e)$	2D BF (FR)	3D BF (FR)	4D BF (FR)	8D BF (FR)
(1,1)	10^{-125} (10^{-137})	10^{-187} (10^{-193})	10^{-250} (10^{-252})	10^{-500} (10^{-499})
(2,1)	10^{-53} (10^{-65})	10^{-80} (10^{-86})	10^{-106} (10^{-108})	10^{-212} (10^{-211})
(2,2)	10^{-7} (10^{-20})	10^{-11} (10^{-17})	10^{-15} (10^{-17})	10^{-30} (10^{-29})
(4,4)	3×10^{-4} (3×10^{-16})	10^{-5} (10^{-11})	10^{-7} (10^{-9})	10^{-14} (10^{-13})
(4,4)b	4×10^{-1} (4×10^{-13})	2×10^{-1} (2×10^{-7})	10^{-1} (10^{-3})	2×10^{-2} (2×10^{-1})

of b-parameter for Gamow integral is approximately given by the zero-potential crossing distance; which is essential to barrier penetration calculation. Value of b-parameter moves from 20 pm for D_2 molecule to 4 pm for dde*(2,2) Cooper-like pair. This is drastic effect: as given in Table 1, barrier factor increases from 10^{-50} with $\lambda_{2d} = 10^{-63}$, for D_2, to 10^{-7} with $\lambda_{2d} = 10^{-20}$, for Cooper-like pair dde*. Assuming macroscopic production density of 10^{20} (1% of D-density in PdDx, $x > 1$) Cooper-like-pairs/cm^3, we obtain D + D (2D) fusion yield of 1 f/s/cm^3, that is, so called Jones level and lowest countable level by usual neutron detectors. We can say that Cooper-like pair can make great effect to drastically enhance d–d fusion rate in MDx systems. This may be the first clear theoretical evidence that "cold fusion" exists. Cooper-like pair generates transient deep hole (–256 eV) to attract deuterons and initiate D-cluster condensation [51].

In Fig. 9**,** dde* potentials are compared between Cooper-like pair e*(2,2) and a heavy fermion e*(10,1). Screening effects are comparable. In Fig. 10, comparison is also made for quasi-particle of quadruplet-coupling e*(4,4) and very heavy fermion e*(100,1), to show comparable effects between the two.

Where $E_d = 0.22$ eV is assumed, which is the $n = 3$ phonon excited state of D in PdDx lattice with $h\omega_0 = 64$ meV and $E_d = (n+1/2)h\omega_0$. And (0,0): bare dd reaction, (1,1): dde- molecule, (2,1): dde* with heavy electron, (2,2): dde* with Cooper pairing, (4,4): dde* with quadru-coupled electrons, (4,4)b: dde* with binary quadru-coupled electrons, namely (8,8)

Muon has $m^* = 208m_e$, so that binary Cooper-like coupling, namely quadruplet-coupling e*(4,4) works as strongly as muon for D + D fusion induction. We can say that the very heavy fermion model for high-T_c superconductivity can be replaced with the binary bosonization of two Cooper pairs to make e*(4,4) quadruplet-coupling. Depth of the transient deep hole [45,51] by e*(4,4) generation is so large as –2460 eV, that can strongly attract surrounding deuterons

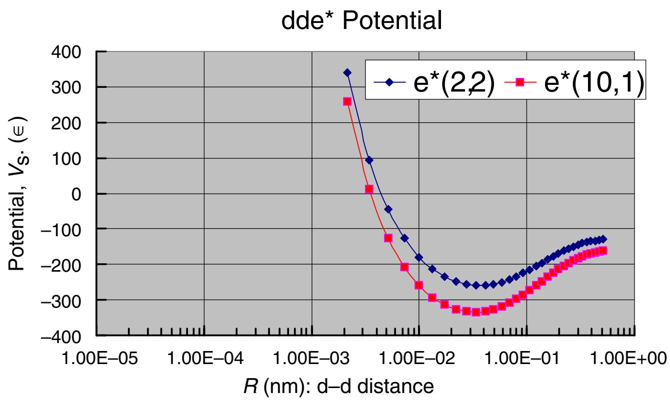

Figure 9. Comparison of screened potentials between Cooper-like pair and mass-10 heavy fermion..

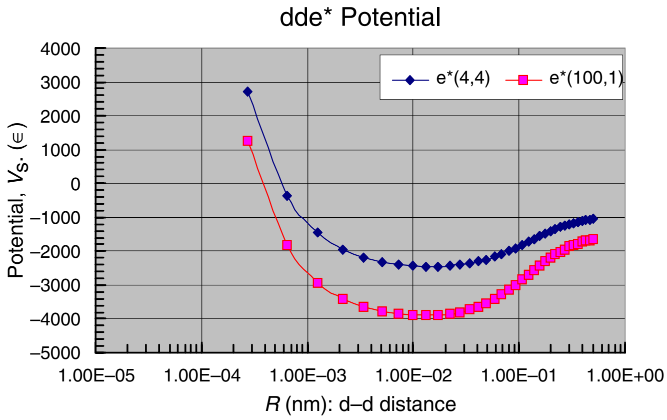

Figure 10. Comparison of screened potentials between e*(4,4) quasi-particle and mass-100 heavy fermion.

with electrons to make TRF and ORF condensations at focal points. Value of *b*-parameter for dde*(4,4) is about 0.5 pm (500 fm), to enhance D + D barrier factor to 3×10^{-4}, and 10^{-5} for 3D and 10^{-7} for 4D multi-body fusion, of which fusion rates (microscopic) are 10^{-16}, 10^{-11}, and 10^{-9}, respectively, for 2D, 3D, and 4D fusion. If we assume D-cluster density of 10^{20} cl/cm^3, we obtain fusion yield (f/s/cm^3) of 10^4, 10^9, and 10^{11}, respectively, for 2D, 3D, and 4D fusion, which are already "miracle" values to meet with major claims of "cold fusion" experiments. 8D fusion yield becomes significant level as 10^7 f/s/cm^3.

Figure 11 shows the bosonization effect of binary e*(4,4) quasi-particles, namely octal-coupling e*(8,8). When this extreme condition is realized as ORF (see Section 4), we have *b*-parameter of 70 fm within which domain deuterons can approach as classical particles to make very condensed D-cluster for very enhanced strong interaction between 3, 4, and 8 resonant deuterons [49,51] simultaneously (within Heisenberg uncertainty) as previously discussed. This screening effect of binary e*(4,4)b, namely e*(8,8) is comparable to that of heavy fermion e*(300,1). Depth of transient deep hole by e*(8,8) is very large as –20.6 keV. When we recall that the first-step goal of DT plasma temperature in TOKAMAK device is around 10 keV, e*(8,8) can provide comparable "acceleration condition," however microscopically "coherent" way. Thus, 8D fusion can be winner of D-cluster fusion as discussed previously [48,51]. 8D fusion emits two high-energy (47.6 MeV) ^{8}Be-particles, which can induce secondary capture reactions to make transmutation with mass-8 and charge-4 increment, as recently claimed by MHI experiment [27].

3.5. Discussions for Nuclear Products

In the TRF or ORF condensation process, we conceive that there happens a competing process of d + d and multi-body deuteron fusion reactions as follows.

(1) 2D → n + ^{3}He + 3.25 MeV, p + T + 4.02 MeV,
(2) 3D → Li^{6*} → t + He^3 + 9.5 MeV,
(3) 4D → Be^{8*} → 2 × He^4 + 47.6 MeV,
(4) 5D → B^{10*} (53.7 MeV),
(5) 6D → C^{12*} (75.73 MeV),
(6) 7D → N^{14*} (89.08 MeV),
(7) 8D → O^{16*} (109.84 MeV) → 2 × Be^8 + 95.2 MeV.

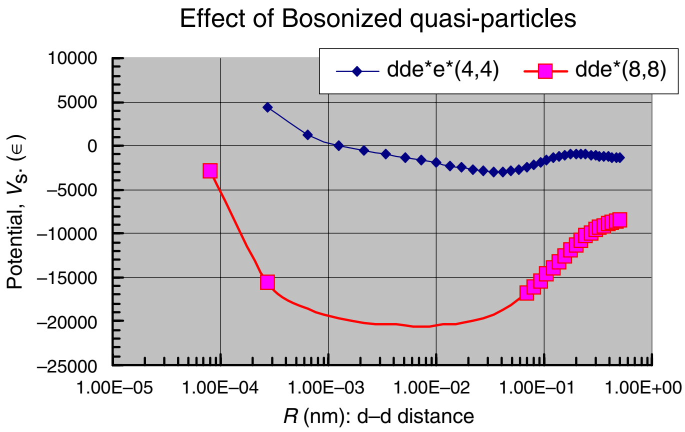

Figure 11. Bosonization effect of e*(4,4) binary quasi-particles, on screened potential.

Nuclear products of 4D fusion was discussed in detail in Ref. [31]. Here we simply assume that two ^{4}He (α-particles) with 23.8 MeV kinetic energy emit into 180° opposite directions each other, and slow down in PdDx lattice by ionization and knock-on process. 23.8 MeV α-particle has very small cross section to ionize K-shell electrons of Pd (therefore there are no emission of K-X-rays of about 22 keV), but has considerable cross sections for L-and M-shell electrons (therefore we see small component of L-and M-X-rays in several keV region). Largest component of X-rays in continuous region less than 3.5 keV is attributed to slowing down of convey electrons by α-particles.

Possible nuclear product of 8D fusion via intermediate virtual excited state of ^{16}O* is shown in Table 2. There are so many exit channels. However, we conceive only two channels are predominant. ^{16}O is a typical α-clustered nucleus. Ground state of ^{16}O is composed of four equilaterally tetrahedral α-particles in combination, and at highly excited state in collective oscillation the nucleus is deformed into two cases; (1) deformation with two ^{8}Be particles, or (2) deformation with

α-Particle and ^{12}C nucleus. Emitted ^{8}Be particles by 8D fusion have very high-kinetic energy of 47.6 MeV which is well over Coulomb barrier height of interaction with neighboring heavier nuclei to make secondary nuclear reaction as capture and fission. ^{8}Be has very short life time as 6.7×10^{-17} s and decays shortly to two ^{4}He, but has enough time to make several interactions with neighboring nuclei in the range.

Nuclear products from 3D fusion were already discussed in other reports [30,31]. 2D and 3D fusion may become minor branches in TRF and ORF deuteron-cluster condensations. This situation is quite in contrast to conventional stochastic two-body fusion reactions. Electron quasi-particles and multi-body resonance fusion play miracle role in condensed matter, which contain fully deuterons and resultantly may induce local superconductivity.

3.6. Explanation to Key Experimental Claims

Explanation to ^{4}He major products in correlation with excess heat has been already mentioned in the above discussions. The reason why we see very scarce neutrons in "cold fusion" experiments is also clear by the competition story of 2D, 3D, 4D and 8D fusion rates since 4D and 8D fusion can be winner of the competition under the strong screening and attraction by transient electronic quasi-particle generation.

The extraordinary result [24–26] of Iwamura et al. reporting mass-8-and-charge-4 increased transmutation is now on discussion. On surface of thin Pd layer they made deposit of thin test element (Sr or Cs). Back side of supporting thick

Table 2. Decay channels of 8D fusion

$8D \rightarrow {}^{16}O^*$	
	$\rightarrow n + {}^{15}O + 94.16$ MeV
	$\rightarrow p + {}^{15}N + 97.70$ MeV
	$\rightarrow d + {}^{14}N + 89.09$ MeV
	$\rightarrow t + {}^{13}N + 84.79$ MeV
	$\rightarrow {}^{3}He + {}^{13}C + 87.03$ MeV
	$\rightarrow {}^{4}He + {}^{12}C + 102.66$ MeV
	$\rightarrow {}^{6}Li + {}^{10}B + 78.95$ MeV
	$\rightarrow {}^{7}Li + {}^{9}B^* + 77.76$ MeV
	$\rightarrow {}^{7}Be^* + {}^{9}Be + 77.97$ MeV
	$\rightarrow {}^{8}Be^* + {}^{8}Be^* + 95.2$ MeV

(0.1 mm) Pd zone was evacuated, and front side of film was filled with D_2 gas. They realized constant D-permeation (1 cm^3/min) through the multi-layered film, which would keep over-loading condition PdDx ($x > 1$) within the first thin zone of Pd, which is thought to be reaction-active zone. They observed the transmutation only in the case of existing CaO layer with D-flow; In cases of H-flow with CaO and D-flow without CaO, they observed no transmutation.

CaO zone enlarges gap of electron Fermi levels in the interface region of Pd and CaO, and same thing may happen in the interface of Pd and Sr or Cs test zone. Enlarged Fermi level gaps may help increase movement of free electrons which will enhance generation of Cooper-like pair or quadruplet-coupling of electrons, i.e., transient bosonization of electrons which would play drastic role of inducing deep potential holes to attract deuteron-clusters with electrons at focal points of T- and O-sites of regular PdDx lattice and some defect points in the interface. Local D-over-loading would have been generated. 4D TRF and 8D ORF, especially the latter was induced there to produce high energy ^{8}Be particles which would be captured by neighboring heavier nuclei as Sr or Cs to make the following transmutation reaction;

$$M(A, Z) + {}^{8}\mathrm{Be}\,(47.6\ \mathrm{MeV}) \rightarrow M(A+8, Z+4)^*(Ex) + KE. \quad (3.33)$$

A cartoon illustration of reactions is shown in Fig. 12. Since ^{8}Be particle with short life (unstable) is thought to be highly deformed as illustrated, we expect enhanced capture cross section by large contact surface exchanging charged pions with target heavy nucleus.

Coulomb barrier heights for reaction (3.33) are 22.5 MeV for $M =$ Sr, and 30.1 MeV for $M =$ Cs, which were calculated using effective contact distance for fusion as $R_f = R_1 + R_2 + \lambda$ with pion wave length λ, $R_1 = 1.2A_1^{1/3}$, $R_2 = 1.2{A_2}^{1/3}$. Possible products of reaction (3.33) for Sr and Cs are shown in Table 3. Excited energy E_x of

Table 3. Products of Be^8 absorption reaction

(1) ^{88}Sr + ^{8}Be (47.6 MeV) $\rightarrow$ ^{96}Mo*(53.43 MeV)	
	$\rightarrow$ ^{96}Mo($Ex.$)* + KE (deposit to lattice) or FP1 + FP2 + Energy :fission (many channels)
(2)^{133}Cs + ^{8}Be (47.6 MeV) $\rightarrow$ ^{141}Pr*(50.47 MeV)	
	$\rightarrow$ ^{141}Pr(Ex)* + KE (deposit to lattice) or FP1 + FP2 + Energy :fission (many channels)

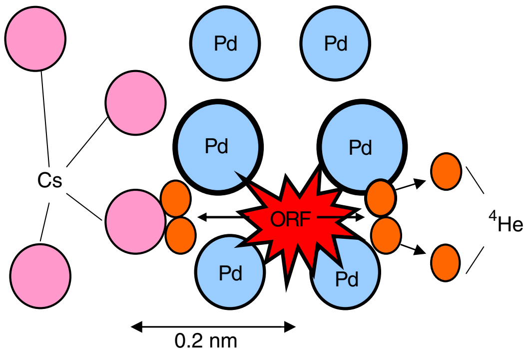

Figure 12. An imagination of 8D fusion and Be^8 capture.

intermediate compound nucleus Mo*(or Pr*) may distribute from 53.43 MeV (50.47 MeV for Pr) to 4.8 MeV (2.9 MeV for Pr) depending on the transferred energy to kinetic energy KE. Imagining liquid-drop like collision character of the reactions (3.33), most energy will be transferred to KE (Mo or Pr kinetic energy), which will make deposit to lattice vibration by heavy particle slowing down in condensed matter without emitting hard and soft X-rays. Thus, major part of experimental results can be explained by the present model. However, when E_x can be large enough to be over fission barrier (about 20 MeV for Mo, and 15 MeV for Pr), distributed mass- and Z-products may be produced. As a function of E_x, fission products distribution can be estimated by the selective channel scission theory [46,47]. Therefore, we need to know data of energy sharing between E_x and KE for reaction (3.33). This is unresolved problem and further study is expected.

4. Further Extension of EQPET Model

4.1. Deuteron Cluster Fusion

Model example of deuteron cluster fusion was proposed as the Tetrahedral Symmetric Condensation (TSC) and the Octahedral Symmetric Condensation (OSC) in PdDx lattice dynamics. As illustrated in Fig. 2, TSC may take place at locally full loaded PdD regions ($x = 1.0$), while OSC may happen much more difficultly at locally overloaded PdD_2 regions ($x = 2.0$). As discussed later on power level, we only need to require local density of 10^{-6} times (ppm order) of Pd density for the OSC condition, while much higher local density, e.g., 10% of Pd atomic density is required for the TSC condition. To generate electronic quasi-particle states, basic mechanism is thought to be the dynamic formation of quadruplet deuteron molecule, which is an *orthogonal coupling of two* D_2 *molecules*, as illustrated in Fig.13.

Three-dimensional motion of TSC can be converted to two-dimensional motion using momentum vector conversion [62]. A two-dimensional view of TSC is shown in Fig. 14. To minimize total energy of the system, charge neutral condensation in average of 4D cluster (four deuterons with alternately coupled four electrons with anti-parallel spins for counter-part electrons with reversed momentums) may cause the central point (T-site in this case) condensation from 4 O-sites of deuterons and 4-sites of electrons. Hence, transient condensate of electrons, namely quadruplet e*(4,4) may be formed at around the central T-site.

We assume a similar condition for the OSC motion, as illustrated in Fig. 15. When four electrons down-spins are happening to be arranged on upper half together with four electrons up-spins on lower half, averaged charge neutral condensation from 8 T-sites to the central O-site may become possible, to form 8D cluster with an octal-coupling state e*(8,8) of electrons at around the central O-site. This condition may realize super-screening for

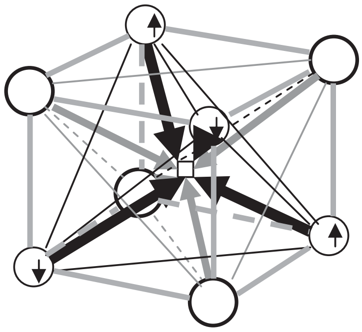

Figure 13. TSC, bigger circles for deuterons and smaller circles with arrow (spin) for electrons.

virtual d-d pairs in the 8D cluster, and 8D fusion rate can be calculated by the rapid cascade reaction model, i.e., D+(D+(D+(D+(D+(D+(D + D)))))) [60,62].

4.2. Advanced EQPET Model

A 4D cluster under TSC condition will cause 2D, 3D, and 4D nuclear fusion in competition, because the TSC state reflects the atomic level motion of deuterons in condensed matter and does not necessarily relate to 4D nuclear fusion reaction as strong interaction. In the same way, an 8D cluster causes the competition process of nuclear fusion reactions between 2D, 3D, 4D and 8D nuclear fusion reactions. We need therefore to define and estimate modal fusion rates to TSC and OSC processes [60]. Modal fusion rates are defined as:

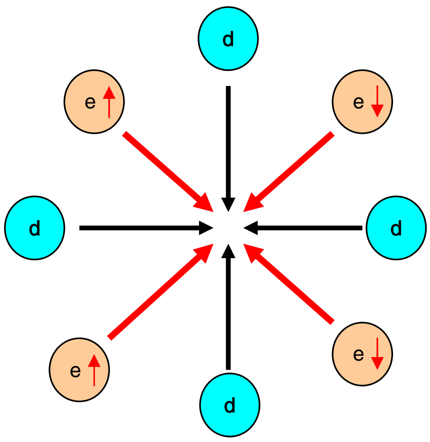

Figure 14. Two-dimensional view of TSC, plus charge for d, minus charge for e.

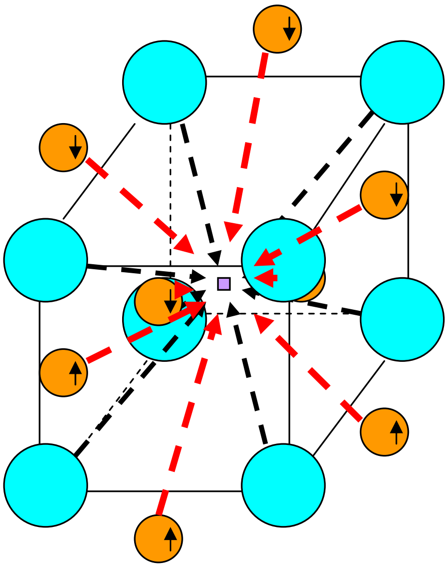

Figure 15. OSC (octahedral symmetric condensation), larger circles for deuterons, smaller circles with arrow (spin) for electrons.

$$\lambda_{2d} = {a_1}^2\lambda_{2d(1,1)} + {a_2}^2\lambda_{2d(2,2)}, \tag{4.1}$$

$$\lambda_{4d} = {a_1}^2\lambda_{4d(1,1)} + a_2^2\lambda_{4d(2,2)} + a_4^2\lambda_{4d(4,4)}, \tag{4.2}$$

$$\lambda_{8d} = {a_1}^2\lambda_{8d(1,1)} + {a_2}^2\lambda_{8d(2,2)} + {a_4}^2\lambda_{8d(4,4)} + {a_8}^2\lambda_{8d(8,8)}. \tag{4.3}$$

Here values for $\lambda_{nd(m,m)}$ intrinsic microscopic fusion rates are defined and calculated for dde*(m,m) transient molecular sates [59], and extended to multi-body fusion rates assuming rapid cascade barrier penetration and multi-body strong interactions [58–60,62]. These values are given in Table 1 of Ref. [60].

Screened Coulomb potentials for dde* EQPET molecules were calculated by the variational method of quantum mechanics [59], to be given as the following equation:

$$V_s(R) = e^2/R + V_h + (J + K)/(1 + \Delta). \tag{4.4}$$

On the right hand side of Eq. (4.4), the first term is the bare Coulomb potential and the second and third terms reflect in the screening effect by e*, which are the measure of "simply defined screening energy", as many experimentalists often use. In Table 4, effective screening energies for dde* EQPET molecules are listed up. We see that screening effects by e*(4,4) and e*(8,8) are very strong, in comparison with that a muon (mass is 208 times of electron mass) works between effects of e*(4,4) and e*(8,8). Thus, EQPET molecules may realize super screening of Coulomb potential.

In Eqs. (3.1)–(3.3), coefficients a_1–a_8 are estimated by evaluating total wave function Ψ for deuteron cluster with electrons which is expanded by wave functions $\Psi(m, m)$ of quasi-molecular states to dde*(m, m) as,

$$\Psi = a_1\Psi_{(1,1)} + a_2\Psi_{(2,2)} + a_4\Psi_{(4,4)} + a_8\Psi_{(8,8)}. \tag{4.5}$$

Table 4. Effective screening energy of dde* molecule

e*	dde*	dde*e*
(1,1)	−14.87 eV	−30.98 eV
(2,2)	−260 eV	−446 eV
(4,4)	−2460 eV	−2950 eV
(8,8)	−21 keV	−10.2 keV

In Ref. [8], approximate values of a_1–a_8 were given by taking simple quantum mechanical statistics for electron spin arrangement in TSC and OSC conditions. Calculated modal fusion rates are shown again in Table 5.

4.3. Products and Power Level of Cluster Fusion

Using modal fusion rates in Table 5, we estimated power levels of multi-body fusion rates for assumed deuteron cluster densities, as shown in Table 6. Height of periodical harmonic potential for deuteron in PdDx lattice is known to be 0.22 eV, so that 0.22 eV of deuteron (plasmon phonon) energy corresponds to excited states of trapped deuterons for dynamic motion in PdDx lattice potentials. Under this excitation condition, all deuterons trapped at O-sites move to the central T-site, and we estimate roughly the average TSC cluster density to be on the order of 10^{22} clusters per cm^3. In this condition, we get power level by 4D fusion rate to be 3 W/cm^3 (3×10^{11} f/s/cm^3) and 10 n/s/cm^3 neutron production rate by 2D fusion. Therefore neutron production rate is very small as on the 10^{-10} order of ^{4}He production rate by 4D fusion.

The OSC condition requires local PdD_2 lattice of overloaded condition, so that we assume here the OSC cluster density is very low as 10^{16} clusters/cm^3 (namely 1 ppm level of Pd atom density). Under this condition, we have still surprisingly high power level as 78 W/cm^3 (8×10^{12} f/s/cm^3) by 8D fusion rates, which produce two high-energy ^{8}Be particles per fusion.

We have speculated that 4D TSC fusion generates two 23.8 MeV ^{4}He-particles in 180° opposite directions as:

$$4\text{D} \rightarrow {}^8\text{Be}^*(47.6\text{ MeV}) \rightarrow {}^4\text{He} + {}^4\text{He} + 47.7\text{ MeV}. \tag{4.6}$$

However, we have at least once to consider the following possible branches of outgoing channels of threshold reactions for ^{8}Be (ground state) break-ups.

Table 5. Modal fusion rates for TSC and OSC

TSC (tetrahedral) (f/s/cl)	OSC (octahedral) (f/s/cl)
$\lambda_{2d} = 1.8 \times 10^{-21}$	$\lambda_{2d} = 7.9 \times 10^{-22}$
$\lambda_{3d} = 1.5 \times 10^{-13}$	$\lambda_{3d} = 3.5 \times 10^{-13}$
$\lambda_{8d} = 3.1 \times 10^{-11}$	$\lambda_{4d} = 7.0 \times 10^{-11}$
	$\lambda_{8d} = 7.8 \times 10^{-4}$

$$^{8}\mathrm{Be(g.s.)} \rightarrow {}^{4}\mathrm{He} + {}^{4}\mathrm{He} + 91.86\ \mathrm{keV}, \quad (4.7)$$

$$\rightarrow {}^{3}\mathrm{He} + {}^{5}\mathrm{He}\,(\mathrm{n} + {}^{4}\mathrm{He}) - 11.13\ \mathrm{MeV}, \quad (4.8)$$

$$\rightarrow \mathrm{t} + {}^{5}\mathrm{Li}\,(\mathrm{p} + {}^{4}\mathrm{He}) - 21.68\ \mathrm{MeV}, \quad (4.9)$$

$$\rightarrow \mathrm{d} + {}^{6}\mathrm{Li} - 22.28\ \mathrm{MeV}, \quad (4.10)$$

$$\rightarrow \mathrm{p} + {}^{7}\mathrm{Li} - 17.26\ \mathrm{MeV}, \quad (4.11)$$

$$\rightarrow \mathrm{n} + {}^{7}\mathrm{Be} - 18.90\ \mathrm{MeV}. \quad (4.12)$$

Other channels than (4.7) are threshold reactions with high threshold energies. Therefore, we have regarded these threshold reactions as minor channels with very small branching ratios, even with high-excited energy state of (4.6). Another possibility of minor channels in relation of (4.6) is break ups from excited states of ^{4}He which may break up to n + ^{3}He or t + p channels as those for 2D fusion. We regard branching ratios to these minor channels are also small, due to very steady core of alpha-clusters of ^{8}Be nucleus [63].

For 8D fusion, we can make a similar discussion that alpha-clustered channels dominate.

$$8\mathrm{D} \rightarrow {}^{16}\mathrm{O}^{*}(109.84\ \mathrm{MeV}) \rightarrow {}^{8}\mathrm{Be} + {}^{8}\mathrm{Be} + 95.2\ \mathrm{MeV}, \quad (4.13)$$

$$\rightarrow {}^{12}\mathrm{C} + {}^{4}\mathrm{He} + 50.12\ \mathrm{MeV}. \quad (4.14)$$

The life time of ^{8}Be(g.s.) is very short as 6.7×10^{-17} s to break up to two alpha-particles. Consequently, major products of 4D and 8D fusion are primarily high energy (23.8 MeV in kinetic energy) alpha-particles. The slowing down and ionization process by 23.8 MeV alpha-particles in PdDx condensed matter has very small cross section to emit K-alpha X-rays (22 keV) from Pd K-shell electron ionization. Major source of X-ray emission is speculated to the bremsstrahlung continuous X-rays in the region less than 3.5 keV by convey electrons, which are hard to observe, due to attenuation in experimental cells. Thus, energy deposit by 23.8 MeV alpha-particles becomes apparently radiation-less, namely "clean".

4.4. Secondary Reactions

High energy (23.8 MeV) alpha-particles by 4D fusion can induce secondary nuclear reactions with host metal nuclei as the following capture reactions:

Table 6. Power level of 4D and 8D fusion rates

Item	TSC (tetrahedral)	OSC (octahedral)
Density	10^{22} cl/cm^3	10^{16} cl/cm^3
Power	3 W/cm^3	78 W/cm^3
Neutron	10 n/s/cm^3	$<$ 1 n/s/cm^3

$$^{105}\text{Pd} + {}^{4}\text{He} \rightarrow {}^{109}\text{Cd}^{*}(1.27\ \text{years}), \tag{4.15}$$

$$^{106}\text{Pd} + {}^{4}\text{He} \rightarrow {}^{110}\text{Cd}, \tag{4.16}$$

$$^{108}\text{Pd} + {}^{4}\text{He} \rightarrow {}^{112}\text{Cd}, \tag{4.17}$$

$$^{110}\text{Pd} + {}^{4}\text{He} \rightarrow {}^{114}\text{Cd}, \tag{4.18}$$

$$^{107}\text{Pd}\,(6.5 \times 10^{6}\ \text{years}) + {}^{4}\text{He} \rightarrow {}^{111}\text{Cd}. \tag{4.19}$$

Impurity Cd production rates in Pd cathode in the deuterium gas glow-discharge experiments by Karabut [61] may be explained by the above secondary reactions. Fission-like products also reported by Karabut [61] and Mizuno [57] can be explained by alpha-particle-induced fission process as reported by Ohta [64] in this meeting.

Even within short life of high energy ^{8}Be-particles by 8D fusion, more than ten metal nuclei exist within the range and we expect capture reactions as

$$M(A, Z) + {}^{8}\text{Be} \rightarrow M(A + 8, Z + 4) + Q. \tag{4.20}$$

The kinetic energy 47.6 MeV of ^{8}Be by 8D fusion is well over the Coulomb barrier height 30.1 MeV for ^{133}Cs + ^{8}Be to ^{141}Pr reaction. Due to the liquid-drop collision-like capture process of this reaction, kinetic energy of ^{8}Be will be transferred to kinetic energy of compound nucleus $M(A + 8, Z + 4)$.

Selective nuclear transmutations reported by Iwamura [55,56] can be explained by this process, although we have few problems of possible radiation (γ-rays) emission in the process, which we will discuss elsewhere.

5. Conclusions

The EQPET model was proposed to explain super-screening for d–d pairs in condensed matter. Deuteron cluster fusion dominated will however take place by TSC and OSC conditions to make resonance multi-body fusion reactions for 3D, 4D, and 8D strong interactions. Helium-4 is the major product, and neutron production rate is very small on the order of less than 10^{-10} of helium production rate. High-energy alpha particles by 4D and 8D fusion reactions will induce secondary transmutation reactions with host or mounted heavy nuclei. Slowing down of high-energy alpha particles as products of 4D and 8D fusion reactions may emit low-energy continuous X-rays which are difficult to observe from outside of experimental cells. We can say that deuteron cluster fusion in condensed matter is clean or almost radiation-less.

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