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Background for Condensed Cluster Fusion

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Abstract: For explaining the experimentally claimed anomalous excess heat phenomena in metal-D(H) systems, the condensed cluster fusion (CCF) theory has been proposed and elaborated[1-8] since 1989. This paper reviews the latest status of CCF theory development. The paper explains the following key aspects: classical mechanics and free particle fusion, fusion rate theory for trapped D(H) particles, strong interaction rate, condensation dynamics of D(H)-clusters, final state interaction and nuclear products, and sites for Platonic D(H) cluster formation on/in condensed matter.

Keywords: condensed cluster fusion, rate theory, condensation dynamics, nuclear products, cluster formation sites

1. Introduction

The theoretical model of condensed cluster fusion (CCF) of deuterons has been proposed and elaborated since 1989 [1-8], for possible underlying key mechanism of so called cold fusion in the dynamic microscopic environment of condensed matter.

The 4D/TSC model is a typical case of CCF for deuterium multi-body interaction under transient ordering process of d-e-d-e-d-e-d-e tetrahedral symmetric condensate (TSC). Here d denotes deuteron and e does electron. For making analysis of time-dependent D(H)-cluster condensation motion, the theory of quantum-mechanical (QM) Langevin equation was developed [1, 2] and a PC-based computation code was provided [8]. For studying likely products of final state interactions of the compound excited nucleus ^{8}Be*(Ex = 47.6 MeV), a nucleon halo model was applied to speculate the major energy damping process by BOLEP (burst-of-low-energy-photons) and final ash of two 46 keV ^{4}He (alpha) particles.

The model has been extended to the weak-strong (WS) force combined fusion of 4H/TSC (p-e-p-e-p-e-p-e tetrahedral symmetric condensation) [9]. Here p denotes proton.

Some speculative models for TSC cluster formation sites in/on nano-scale catalytic surface zone or inner lattice-defects have been proposed [3, 10, 11], although quantitative studies are yet to develop. A scenario for computational simulation of dynamic process of many deuterons (or protons) with electrons in modeled sites will be proposed in this

paper.

This paper reviews so far the elaborated works and future problems to see the developing status of CCF theories.

2. Classical Mechanics and Free Particle Fusion

In the main stream nuclear physics, two-body collisional process of free particles is regarded as extremely dominant process for nuclear fusion events. Three-body or more multi-body collision events can be neglected in such random motion of particles, as in the cases of plasma thermo-nuclear fusion and beam-target type particle-condensed matter interactions. Once two-body fusion cross section data are available, we can make reaction rate estimation by using classical mechanics solvers such as Maxwell-Boltzmann particle transport equations with statistical averaging over particle kinetic energy distribution and spatial distribution.

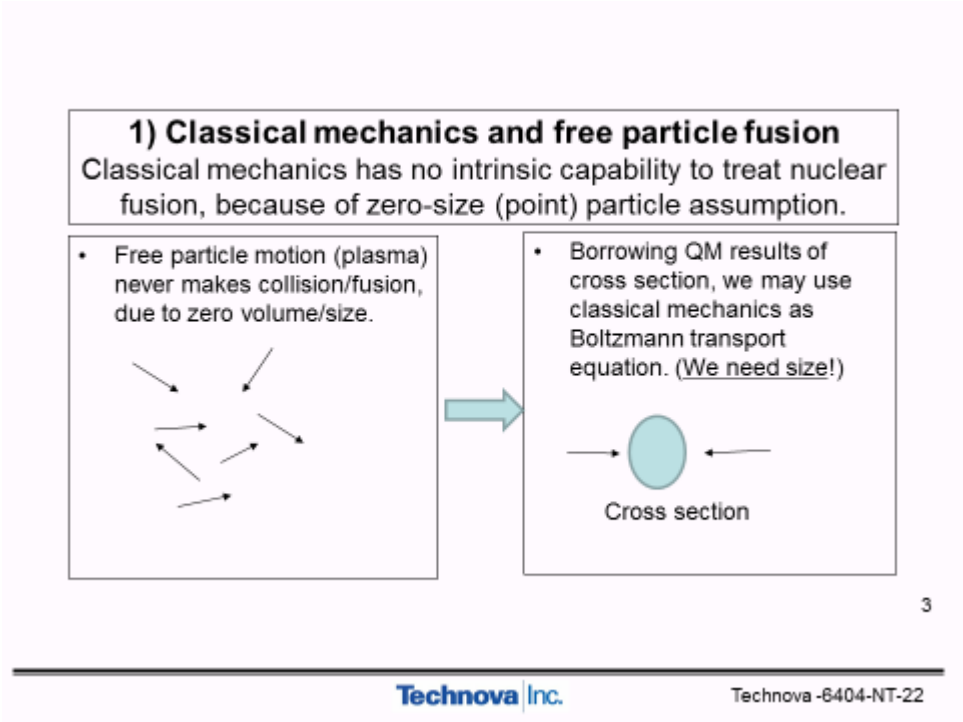

Fig.1: Image of classical mechanics to treat two-body random fusion event

So, we do not use quantum mechanics (QM) explicitly there for estimating reaction rates or power levels of fission reactors and thermo-nuclear fusion reactors. And we are forgetting that fusion cross sections data have been laboriously evaluated by analyzing experimental data with huge quantum mechanical nuclear physics calculations for two-body interactions, as have been done for evaluated nuclear data libraries such as ENDF/B-

VI and JENDL-4 (see their contents by internet search).

For studying newly some unknown nuclear reactions, especially by trapped particles with finite lifetime in chemical potential well in condensed matter, including possibly enhanced multi-body nuclear interactions, we need however to start with quantum mechanics of theoretical tools. An image is illustrated in Fig.1. The classical Newtonian motion assumes particle to be point (size zero), as shown in the left figure, so that we have no chance to make collision between two particles because of zero sizes of particles. However, once finite size cross section (by QM study) is given, as shown in the right figure, particles have chance to make collision. By the QM nuclear physics formulas [4], two-body collision cross section becomes proportional to the square of transition matrix. Such two-body random collision cross sections may be approximately used for some cases of cold fusion analysis [4]. However, if the time interval of trapped particles (deuterons or protons, for instance) in relatively negative potential well of condensed matter is much longer than the collision interaction time (typically 1.0E-22 s for two-body collision), we need to use the Fermi's first golden rule for fusion reaction rate estimation [4], as we recall in the following section. The reaction rate formula becomes proportional to single (not square) transition matrix. Because of elongated life time in trapped state, fusion reaction rate is very much enhanced as calculated for muonic d-d pair molecule [7, 8]. The Thomas-Fermi type charge screening estimation formulas derived for free particles becomes no good approximation, and we need to use real trapping potential having negative well for screening and barrier penetration probability calculation [1, 2].

3. Fusion Rate Theory for Trapped D(H) Particles

As we have studied for the case of D(H)-cluster condensation motion [1, 2], meaningful enhancement of fusion rate (barrier factor of larger than 1.0E-20 is of key issue, in the rough view of Avogadro number 6.023E+23 as order of maximum particle density of condensed matter) may happen by the condensation collapse [8] time-dependently. Some combination of deuterons (protons) and electrons for formation of transient cluster goes to a stable ground state and has no dynamic state to enhance fusion reaction rate to 'visible or detectable' magnitude, as we review in the next section. Therefore, we need to treat particle trapping state in time varying potential well of D(H)-cluster.

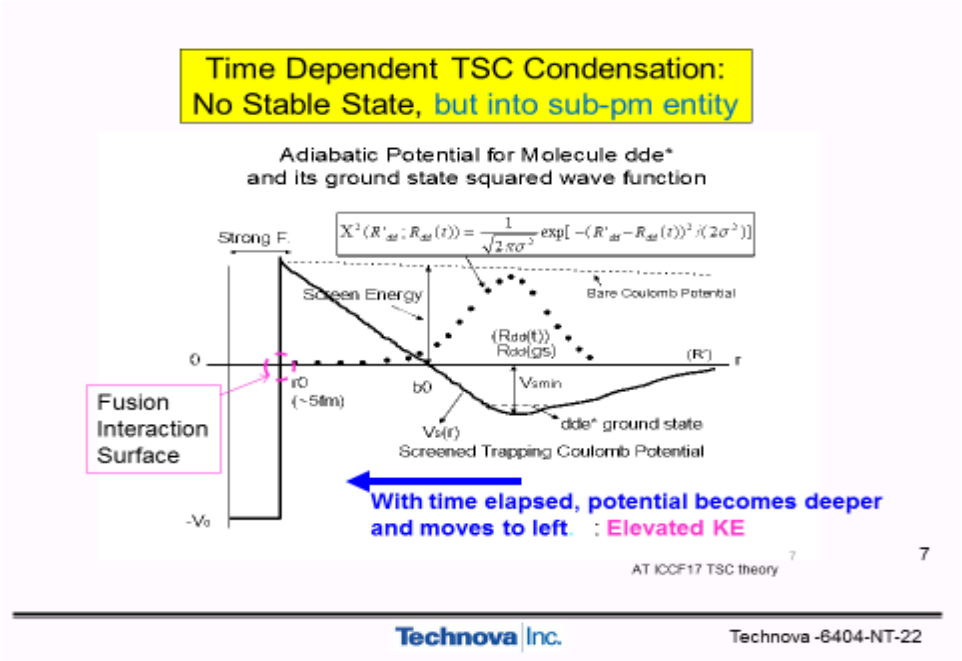

Fig.2: Time-dependent trapping potential, d-d pair Gaussian wave function for a pseudo-stable adiabatic state for a very small time-step width and strong-interaction fusion domain

An image is illustrated in Fig.2. In the collapsing condensation motion, trapping potential shape changes continuously from right to left to become deeper with narrower width as time elapses. To treat the state in numerical calculation with small time-step, we approximate a state at a time to be an adiabatically pseudo-steady state of d-d pair with heavy-mass quasi-particle e*(m, Z) of electron pairing (the HMEQPET method [1, 2]) and Vs1(m, Z) type potential (namely generalized Heitler-London type molecular trapping potential) are used. Using the variational principle of QM, inter-nuclear distance (d-d or p-p distance) and its ground state mutual kinetic energy (energy eigen-value) are calculated [1, 2].

To apply the Fermi's first golden rule, we add the nuclear optical potential (Vn + iWn type) to a Vs1(m*, Z*) potential, in the flow of methodology, to formulate nuclear fusion rate equation. However, for the sake of simplicity to follow the QM equations, we simply write the complex potential by its real part (V) plus imaginary part (W). And also for simplicity we use one dimensional space variable only in the following, to avoid complexity of mathematical equations. By doing so, essence of derivation for fusion rate does not change.

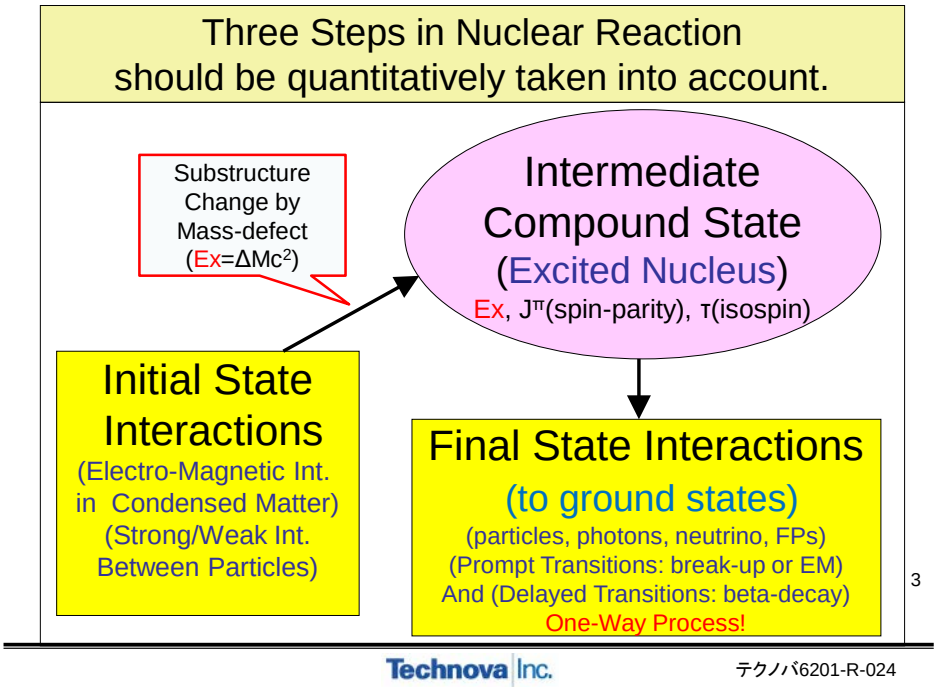

Fig.3: We need to treat one way process of three steps, the initial state interaction, the intermediate state and the final state interaction for studying a nuclear reaction

We are going to derive the rate formula for the initial state interaction (see Fig.3). Explanation for the final state interaction with nuclear products will be treated later.

The forward and adjoint (backward) QM Schroedinger equations are:

$$i\hbar\frac{\partial\Psi}{\partial t}=\left[-\frac{\hbar^2}{2M}\nabla^2+V+iW\right]\Psi \tag{1}$$

$$-i\hbar\frac{\partial\Psi^*}{\partial t}=\left[-\frac{\hbar^2}{2M}\nabla^2+V-iW\right]\Psi^* \tag{2}$$

By multiplying Ψ from the left side to Eq.(1) and Ψ* from the left side to Eq.(2), we make subtraction to get,

$$i\hbar\frac{\partial\rho}{\partial t}=-\frac{\hbar^2}{2M}\left[\Psi^*\nabla^2\Psi-\Psi\nabla^2\Psi^*\right]+i\left[2W\rho\right]=-i\hbar div\vec{j}+i\left[2W\rho\right] \tag{3}$$

Here $\rho=\Psi\Psi^*$ is the particle QM density, and we used the QM current density formula [4]. The second term of the right-hand-side of Eq.(3) shows the particle disappearing (by fusion) rate for negative imaginary part W of the nuclear optical potential.

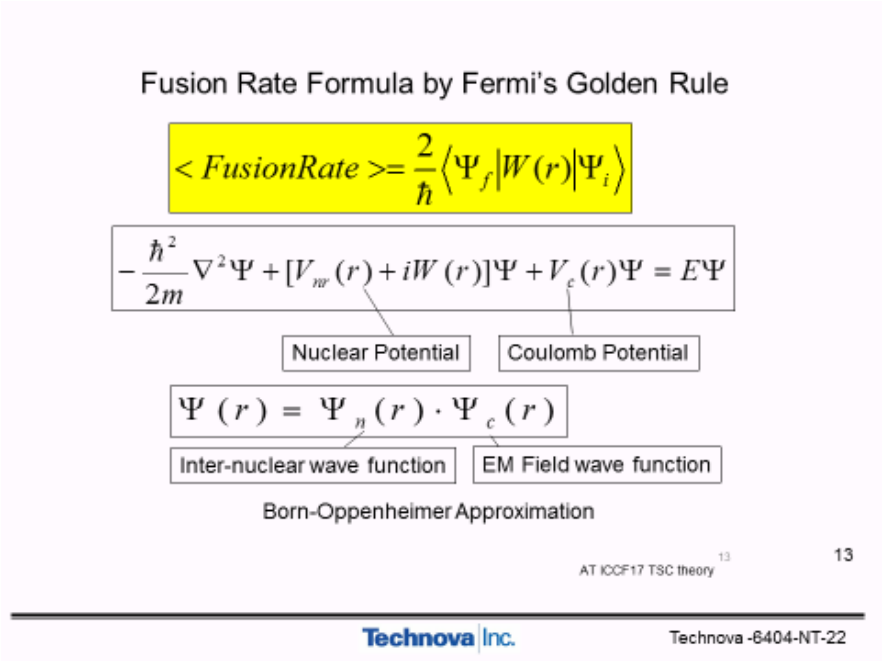

Fig.4: Born-Oppenheimer approximation is adopted to rate calculation. Inter-nuclear wave-function is calculated independently (adiabatically) to electro-magnetic (EM) filed wave function.

The fusion rate formula by the Fermi's first golden rule is then obtained as,

$$< FusionRate >= \frac{2}{\hbar}\left\langle \Psi_f \middle| W(r) \middle| \Psi_i \right\rangle \tag{4}$$

Here suffixes i and f denotes the initial and final state.

Assuming the adiabatic separation of particle (pair or cluster) wave function into two components of the nuclear force field (very short range force) and the electro-magnetic force field (long force range), we solve two independent Schroedinger equations as illustrated in Fig.4 through Fig.6.

The inter-nuclear fusion rate, the bracket integral of W(r) has been estimated by empirical extrapolation of PEF-value dependence of known two-body reactions as p-d, d-d and d-t fusions, in which PEF value is very roughly counted based on the d-d interaction as illustrated in Fig.7. Here PEF denotes the pion exchange force.

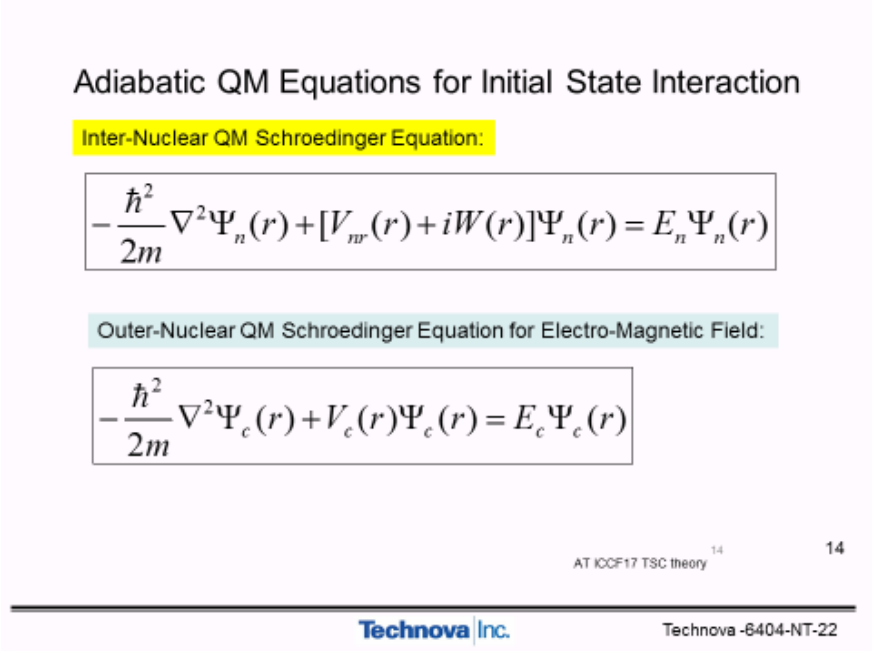

Fig.5: Nuclear force field wave function is solved independently to the EM field wave function

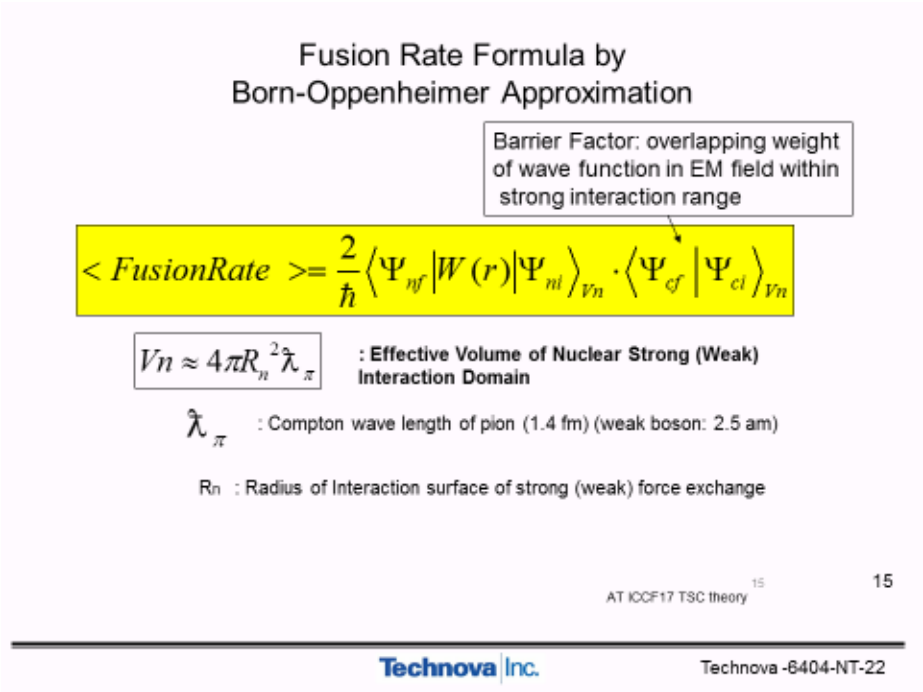

Fig.6: Fusion rate formula for trapped pair (cluster) in condensed matter is written with the product of inter-nuclear fusion rate (nuclear transition matrix element) and Coulomb barrier penetration probability (barrier factor).

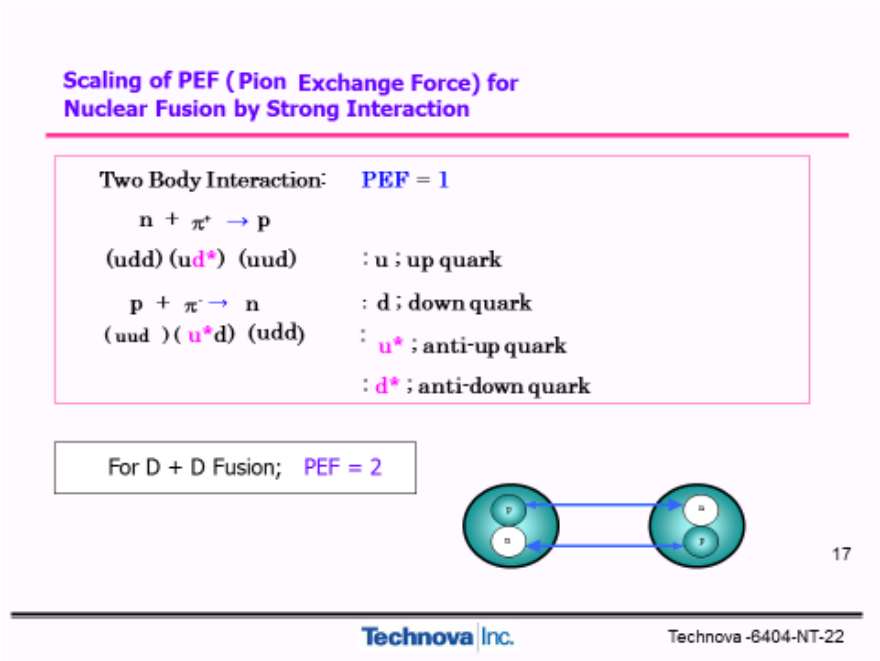

Fig.7: Defining a scale of strong fusion interaction force by PEF value

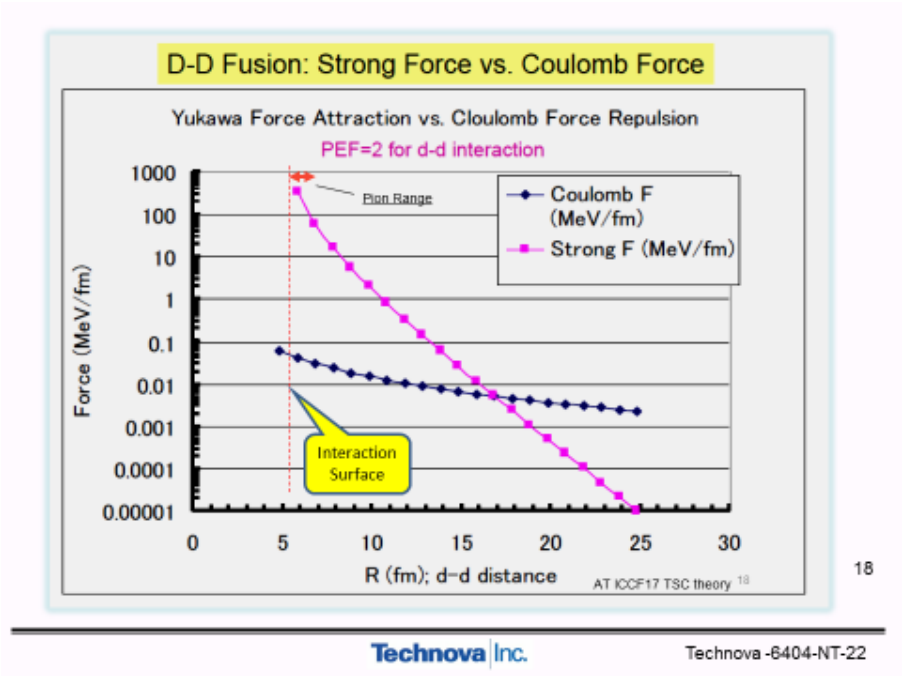

Fig.8: Strong force by one pion exchange potential, cf. Coulomb force

Effective <W> values estimated by the empirical extrapolation is listed in Fig.9.

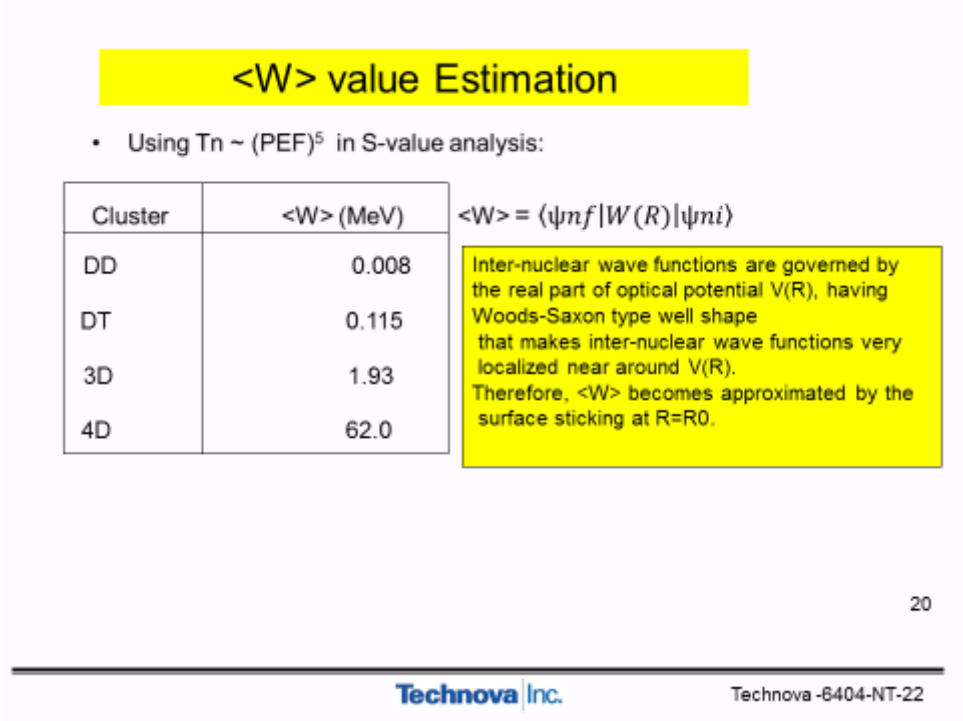

Fig.9: Evaluation procedure of effective transition matrix <W> for two-body and multi-body fusion, estimated by rough extrapolation of known two body reaction values (p-d, d-d and d-t astrophysical S-factors) as a function of effective transition matrix approximation of PEF powered by 5

4. Condensation Dynamics of D(H)-Cluster

The QM Langevin equation has been generalized for treating D(H)-clusters with Platonic symmetry, which means the configuration of orthogonal coupling between deuterons- (or protons-) wave function and electron wave function (or density function) in three dimensional space.

The features of 4D/TSC electron distribution and known electron density distributions for D-atom and D_2 molecule are compared in Fig.10. To derive the QM Langevin equation for a D_2 molecule dynamics calculation, ensemble averaging of QM-observables was done with the Born-Oppenheimer separation of electron-wave function and deuteron-pair wave function, as shown in Fig.11. Used electron wave function is the Heitler-London type well known QM solution (by the variational principle), which is the linear combination of product 1S wave functions according to two deuteron-centers. And the d-d pair wave function was approximated with Gaussian distribution [1, 2]. For the case of a d-e-d three body system (D_2+ molecule), electron wave function is the linear combination of 1S wave functions according to two deuteron centers. The QM Langevin equation for the d-e-d system is shown in Fig.12, which includes information of ground

state parameters. The Vs1(1,1) trapping potential of this d-e-d three body system has been used for a triangle face of Platonic polyhedron to formulate the generalized QM Langevin equation of polyhedrons of many-particles clusters. The generalized QM Langevin equation is shown in Fig.13.

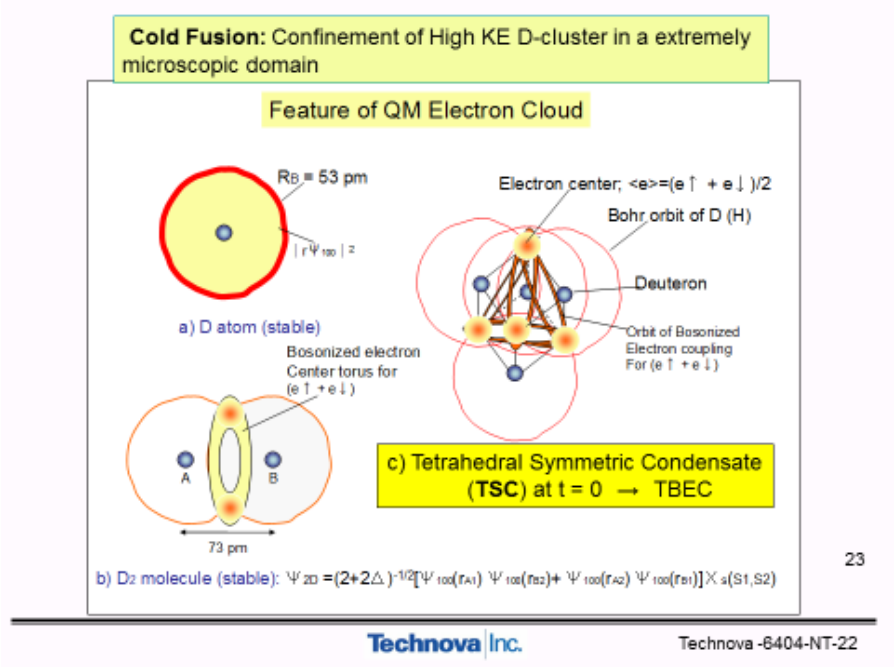

Fig.10: Comparison of electron density distributions between D(H)-atom, D_2 molecule and 4D/TSC (at t=0)

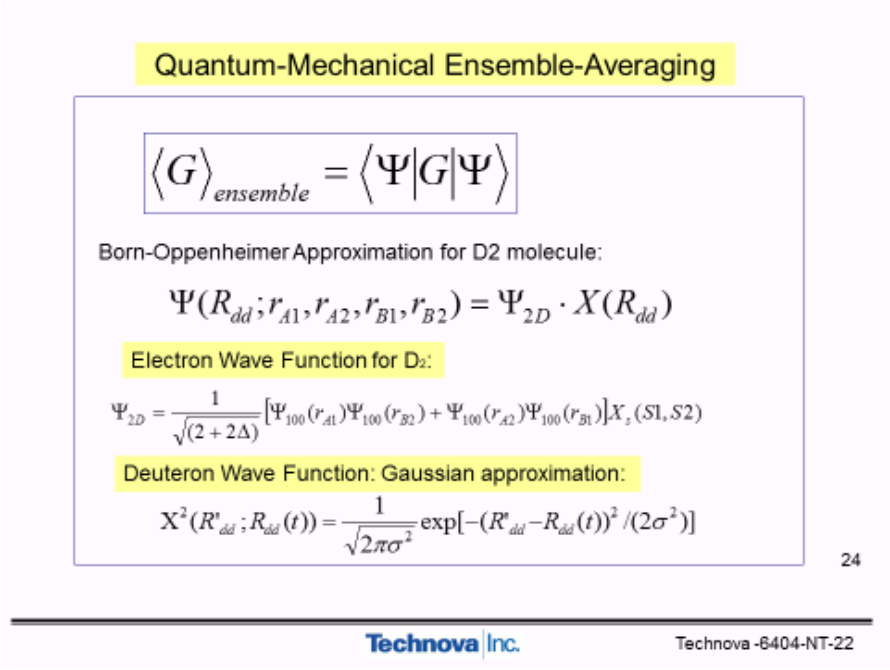

Fig.11: QM ensemble averaging of an observable is done with the Born-Oppenheimer adiabatic wave

function separation between electron wave function and deuteron pair wave function. Figure is shown for the sample case of D_2 molecule

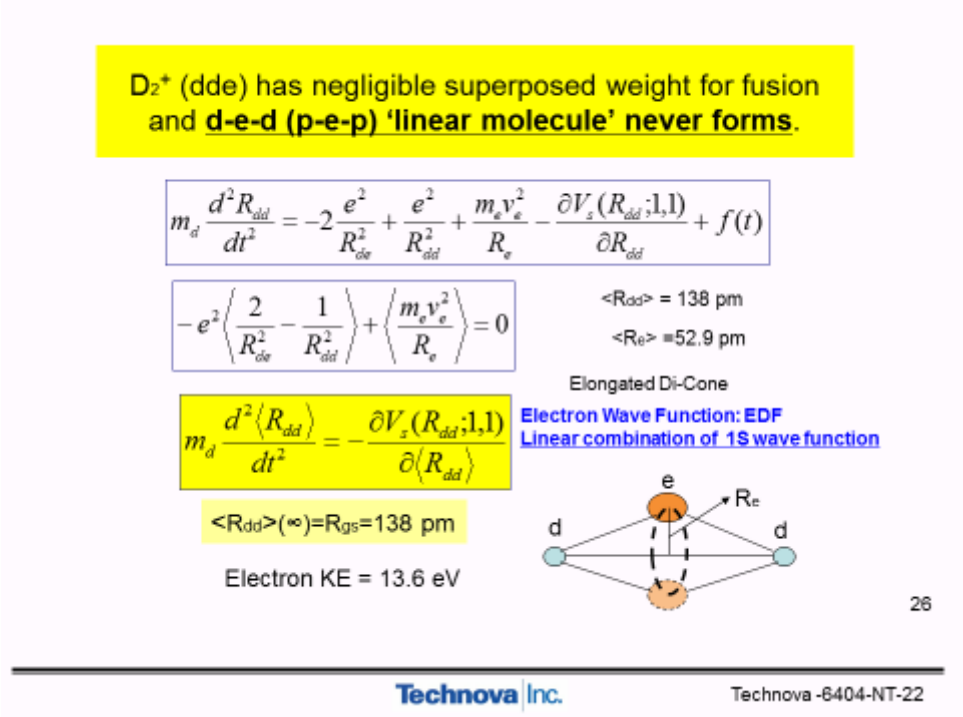

Fig.12: A QM Langevin equation for a d-e-d three-body system (regarded as a cluster) and key ground state parameters as Rdd, Re, electron kinetic energy

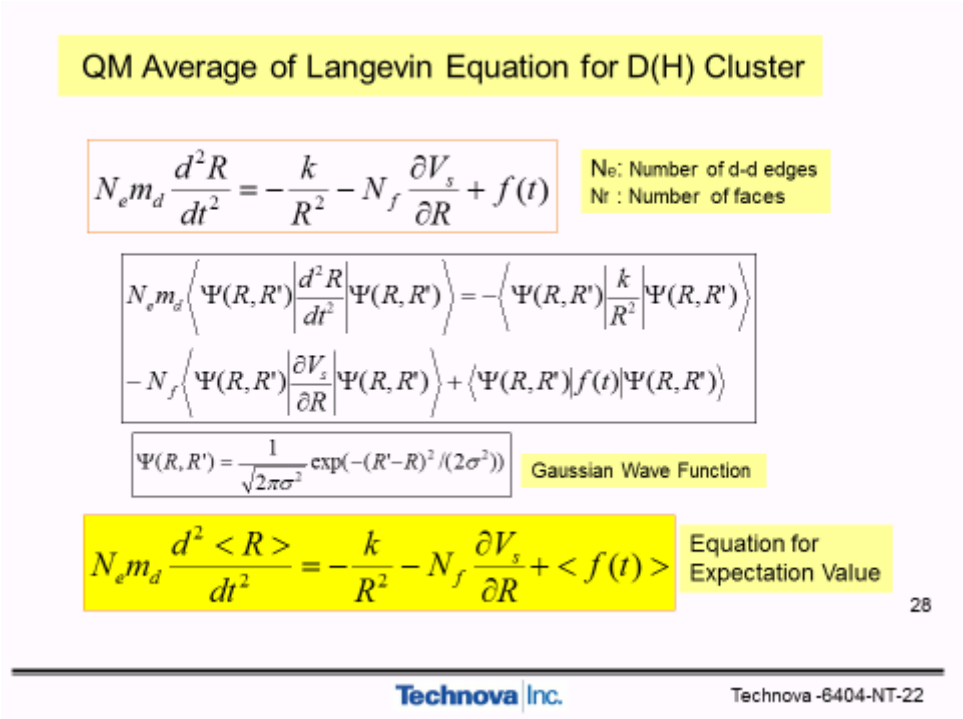

Fig.13: Derivation of generalized QM Langevin equation for D(H)-cluster condensation dynamics

calculation

Parameters for Langevin Cal.: for Electron Friction of Vs1(1,1)

Cluster	k value (keVpm)	Ne	Nf
2D+: d-e-d	0	1	1
3D+	3.65	3	4
4D/TS	11.85	6	4
6D/RD	18.45	12	8
8D/RD	18.45	12	6
12D/RT	15.51	30	20
20D/RT	19.11	30	12

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Table-1: Evaluated parameters for D(H)-cluster condensation calculation

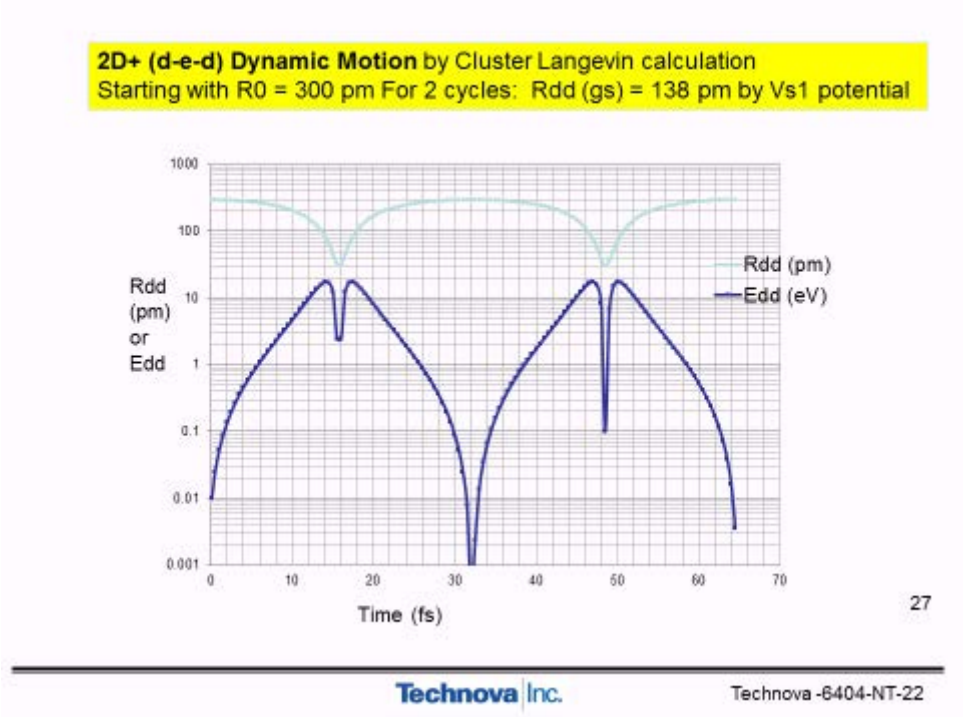

Fig.14: An example of QM Langevin code calculation [8] for d-e-d cluster. Oscillation with 32 fs period continues eternally. We repeat calculations by changing starting Rdd (t=0) value, and make ensemble averaging of oscillations to get ground state behavior.

Evaluated parameters for Langevin code calculations for various clusters are summarized in Table-1.

In Fig.14, example of calculation is shown for a d-e-d cluster for two oscillation cycles. The minimum approaching distance between two deuterons is about 30 pm, barrier factor for which is about 1.0E-60 (see Table-3) to be negligible for d-d fusion events. By changing starting Rdd (t=0) values, we obtain a number of oscillation curves. Ensemble average of these curves converges to the ground state oscillation trajectory, which has eigen-value of Rdd (gs)=138pm. Maximum mutual kinetic energy of deuterons is about 20 eV for a small time interval in the transient motion.

Similar calculation for d-e-d-e-d five body cluster (D_3+ molecule) is shown in Fig.15. Minimum approaching d-d distance is about 20pm, for which the barrier factor for fusion is on the order of 1.0E-45 to be too small to detect d-d or d-d-d fusion events. Maximum relative kinetic energy of deuteron is about 18 eV and ground state d-d distance is 85pm.

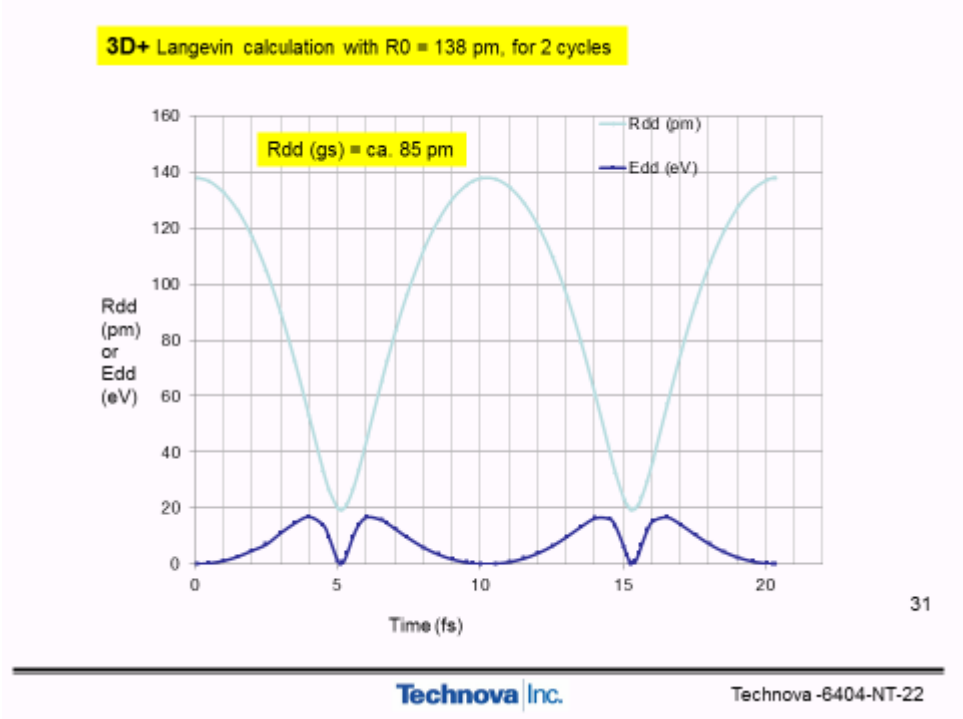

Fig.15: Dynamic behavior (oscillation) of D_3+ molecule (d-e-d-e-d five body cluster), calculated by the QM Langevin code [8]

Most interesting results of similar calculations are of collapsing condensation (one way to collapse), happened for larger clusters as 4D(H)/TSC, 6D(H)/RDC and 8D(H)/RDC. Example of collapse is shown in Fig.16 for the case of 4D/TSC. Here RDC denotes Rohmbic dodecahedron condensation [8]. More detailed feature of near collapse state was shown in Ref. [2] by inverting time axis. In the present calculation, we used Vs1(1,1) trapping potential to get collapsing time 3.61 fs which is larger than 1.4 fs [1, 2] by using the Vs1(2,2) potential assuming bosonized electron pairs on every rectangular face of TSC-configuration.

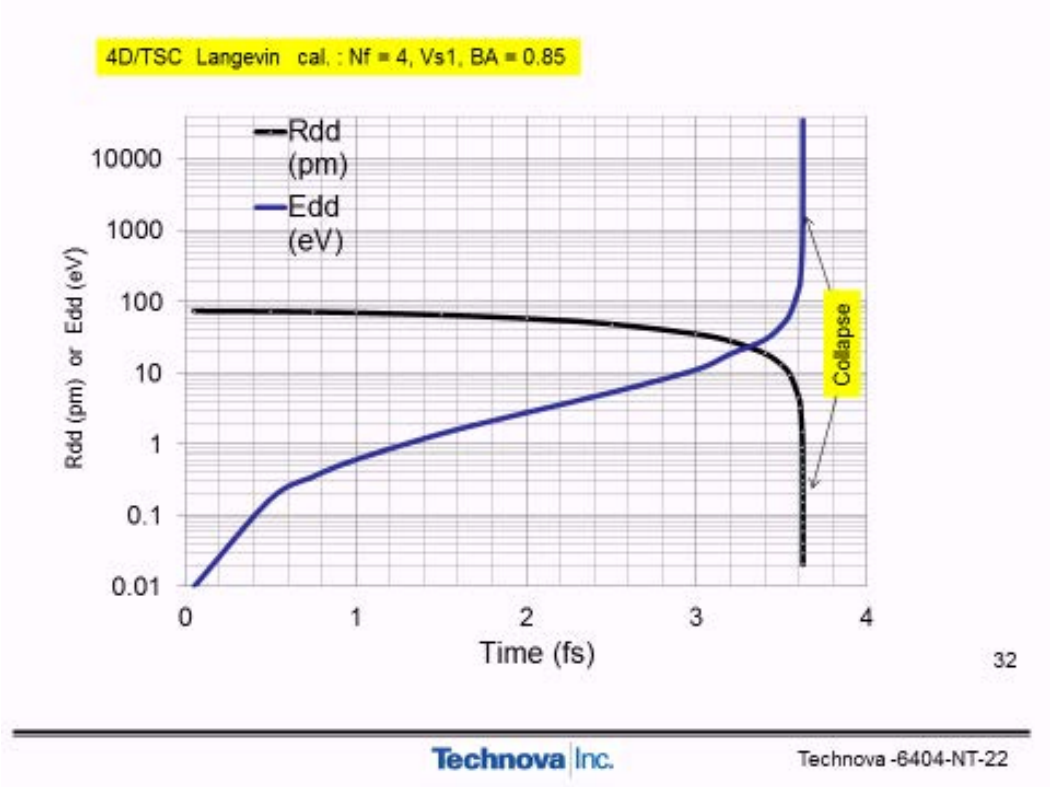

Fig.16: Calculated results of condensation collapse for 4D/TSC

Summary of condensation motions for various clusters is shown in Table-2. Detail was discussed in Ref. [8].

Summary of Results

Cluster Type	Collapse? (Rdd-min ≦ 10 fm)	Rdd (gs)	Remarks
d-e-d (2D+)	N	138 pm	
d-μ-d	N	0.79 pm	DD fusion in 0.1ns
3D+	N	85 pm	
4D/TS	Y		100% 4D fusion
6D/RD	Y		100% 6D fusion
8D/RD	Y		100% 8D fusion or 4D fusion?
12D/RT	N	ca. 80 pm	
20D/RT	Y		What kind of fusion?

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Table-2: Summary of condensation/collapse motions for various D(H)-clusters

Barrier factors were calculated time-dependently
Based on the Heavy Mass Electronic Qausi-Particle Expansion Theory (HMEQPET)

$R_{dd}=R_{gs}$ (pm)	P_{2d} ; 2D Barrier Factor	P_{4d}; 4D Barrier Factor
0.0206	4.44E-2	1.98E-3
0.0412	1.06E-2	1.12E-4
0.103	1.43E-3	2.05E-6
0.206	3.35E-5	1.12E-9
0.412	9.40E-7	2.16E-13
0.805 (μ dd)	1.00E-9	1.00E-18
1.03	9.69E-11	9.40E-21
2.06	6.89E-15	4.75E-29
4.12	9.38E-21	8.79E-41
10.3	2.16E-32	4.67E-64
21.8	1.30E-46	1.69E-92
(dde*(2,2)	1.00E-85	1.00E-170
74.1 (D2 molecule)		

QM Tunneling Probability:

$$P_{nd}(m,Z) = \exp(-n\Gamma_{dd}(m,Z))$$

$$\Gamma_{dd}(m,Z) = 0.218\sqrt{\mu}\int_{r_0}^{b_0(m,z)}\sqrt{V_s(R;m,Z)-E_d}\,dR$$

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Table-3: Calculated time-dependent barrier factors by HMEQPET code [1, 2]

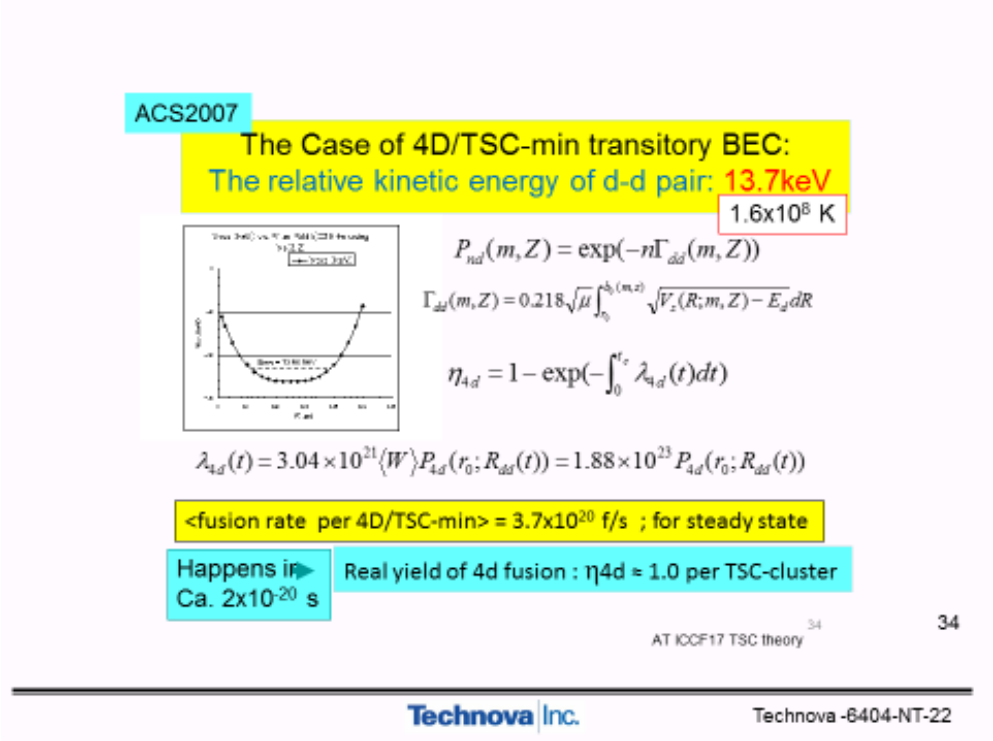

Fig.17: Estimation of 4D-fusion yield per TSC condensation

When condensation-collapse happens, d-d (or p-p) inter-nuclear distance of cluster becomes very short to be less than 20 fm in its final stage before getting into strong nuclear force range (ca. 5 fm typically for d-d). To calculate fusion rate (simultaneous 4D fusion becomes dominant for 4D/TSC [1, 2]), we need to estimate time-dependent barrier penetration probability. The HMEQPET (heavy mass electronic quasi-particle expansion theory) method [1, 2] is an easy mathematical tool for approximate numerical calculation of Gamov integral. Calculated results by HMEQPET code are shown in Table-3.
In the case of 4D/TSC condensation/collapse, 100% 4D fusion (to go to the ^{8}Be* intermediate excited nucleus) was estimated to be happening within about 2.0E-20 s time interval (see Fig.17) in the final stage of condensation-collapse.

5. Final State Interaction and Nucleon Halo Model

It is well established that the final state interaction of two-body d-d fusion happens through the intermediate ^{4}He*(Ex = 23.8 MeV) excited nucleus which then breaks up to two major branches of n + ^{3}He + 3.25 MeV and p + t + 4.02 MeV. The EM (electro-magnetic) transition of ^{4}He*(Ex = 23.8 MeV) to ground state ^{4}He happens with very small

branching ratio (ca. 1.0E-7) for lower mutual kinetic energy of d-d fusion less than 1 keV. For the 'cold fusion' by muonic d-d molecule (see Table-2) [8], the mutual d-d kinetic energy is ca. 180 eV and branching ratios for the three out-going channel do not change.

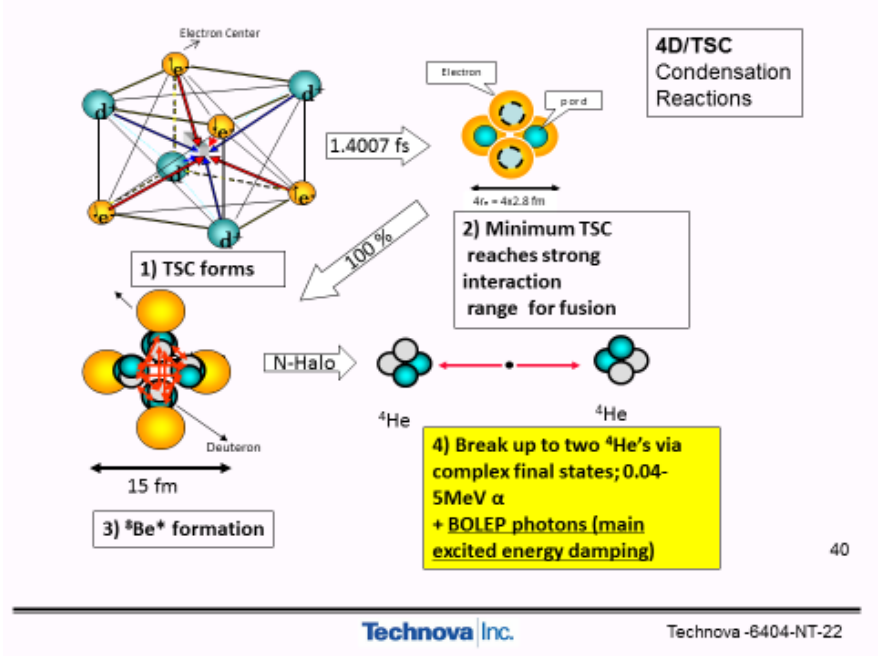

Fig.18: Simplified steps of 4D/TSC condensed cluster fusion

A simplified steps of reaction scheme is copied [3] in Fig.18 for the 4D/TSC condensed cluster fusion.

According to Fig.3, the step-1 to step-2 corresponds to the initial state interaction. The step-3 is the intermediate compound excited state and the step-4 is the final state interaction. We consider that the 4D fusion makes the very highly excited state of ^{8}Be, namely ^{8}Be*(Ex = 47.6 MeV), for which no evaluation studies in main stream nuclear physics are available and we do not know what kind of final state interaction happens (see TUNL library for A=8 and ^{8}Be energy level scheme : http://www.tunl.duke.edu/nucldata/figures/08figs/08_04_2004.pdf).

We have made a speculative analysis by proposing the nucleon halo model of ^{8}Be* [5]. Comparing with inner nucleon clustering (alpha, helion, and triton) model for highly excited states of light nuclei such as ^{8}Li, ^{9}Li, ^{11}Li, ^{8}Be, ^{9}Be, ^{11}Be, ^{12}Be, ^{12}C, etc., with the neutron-state nucleon halo, we speculated that the ^{8}Be*(Ex = 47.6 MeV) would be a n-h-h-n halo excited state as illustrated in Fig.19: Here h is helion (p-n-p) inner nuclear cluster, and t (n-p-n) is the triton inner nuclear cluster.

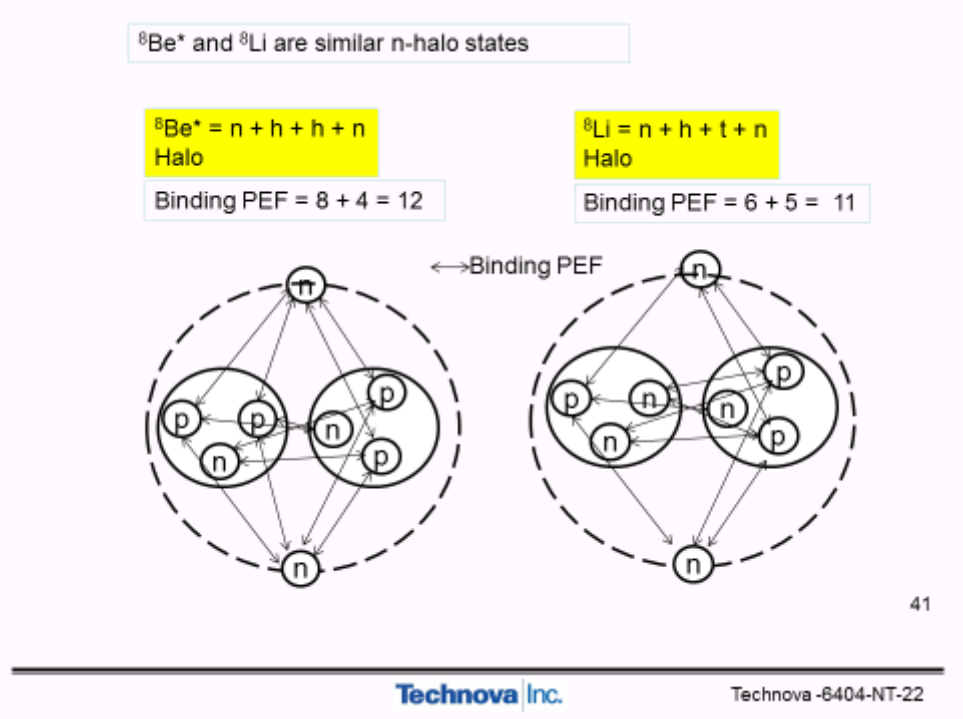

Fig.19: The ^{8}Be*(Ex = 47.6 MeV) intermediate compound excited state by the 4D/TSC fusion is modeled as a n-h-h-n neutron halo state.

The n-h-h-n halo state looks similar to the thought n-h-t-n halo state of ^{8}Li which has 'very long' (in the view of nuclear physics) life time as 0.838 s and makes beta-decay (weak interaction) only, due to its ground state that prohibits EM transition, to transit to the ^{8}Be*(Ex = 3.03 MeV) first excited level state that breaks up to two alpha particles. Since the ^{8}Be*(Ex = 47.6 MeV) is excited state, it has freedom to make EM transitions if life time of the state is so 'long' as that of ^{8}Li. And the excited state would be very highly deformed (m=16 spherical harmonics picture was given [5]) nucleus with many modes/nodes of rotation/vibration coupled states, which would generate bosonic coupling (nuclear phonons) of low energy band quanta (so called rotation-vibration band structure of QM energy levels). We speculated several ten-thousands bosonic levels might couple. If so, we may expect an avalanche type multi-photon emission, namely BOLEP (burst of low energy photons), with mean photon energy ca. 1.5 keV. However, we need to consider other minor decay channels via possible discrete energy levels of ^{8}Be* by α-α clustering, d-^{6}Li clustering, and p-^{7}Li clustering. Detail discussions were made in reference [5] comparing with some experimental data: Especially, it was impressive to find the beautiful coincidence of several discrete alpha-energy peaks below 17 MeV between the halo model and the Roussestki experiment [5]. The speculated final state interaction of ^{8}Be* (Ex = 47.6 MeV) is copied [5] in Fig.20.

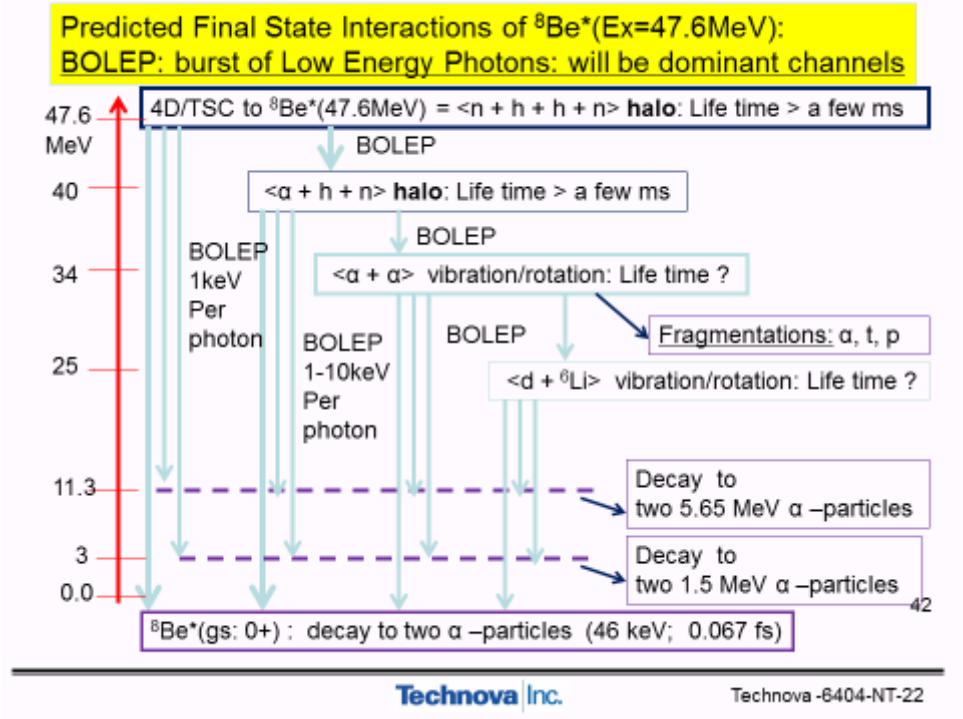

Fig.20: The nucleon-halo model for ^{8}Be* speculates this complex final state decay channels. The BOLEP is thought to be major energy damping to the ground state ^{8}Be.

Now we switch the halo model for the 4H/TSC WS (weak-strong) fusion process [6, 9]. A simplified steps of reaction is shown in Fig.21. Since there are no strong nuclear force (roughly modeled by PEF; charged pion exchange force) between protons, 4H/TSC condensation collapse does not end at around Rpp = 20 fm (around where 4D/TSC disappears 100% by 4D fusion of strong interaction) and continues to condense.

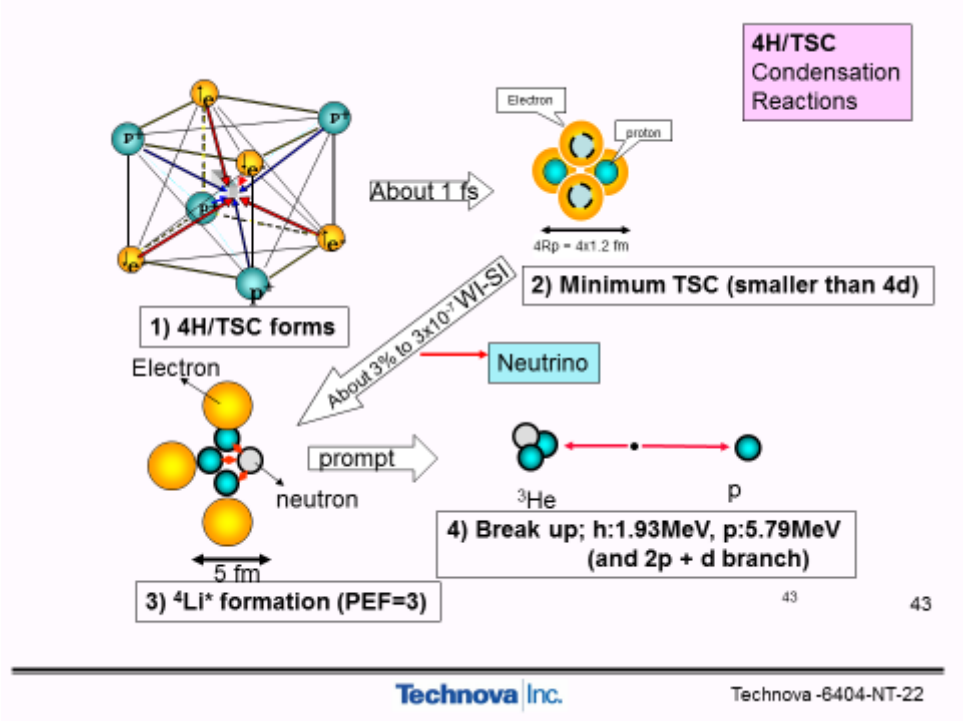

Fig.21: Simplified steps of 4H/TSC WS fusion process [9]

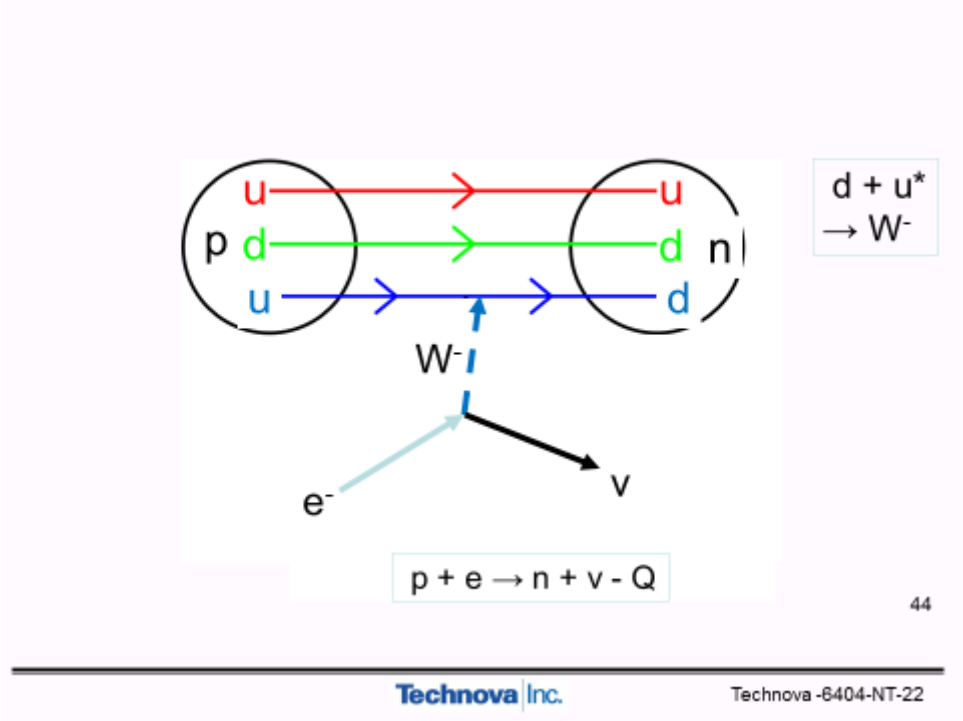

Fig.22: The weak interaction scheme for electron capture to a proton. Via weak boson W-, inner quark configuration changes to that of neutron. Here u denotes up quark and d does down quark.

It was discussed [5, 9] that the collapse state of 4H/TSC would reach the Pauli-type repulsion domain of ca. 2fm p-p distance of tetrahedron and electron kinetic energy would

reach more than 1 MeV. We speculated the possibility of ca. 3% electron capture to a proton (weak interaction as shown in Fig.22) to generate a neutron. This just born neutron would have to make immediate strong interaction (PEF = 3) with three protons existing within the range of charged pion Compton wave length (1.4 fm) for generating the intermediate excited compound nucleus ^{4}Li*(Ex = 4.62 MeV). The decay channels of ^{4}Li*(Ex = 4.62 MeV) excited state is well studied (see TUNL data for ^{4}Li energy levels and decays). If we apply the idea of halo state, it would be a h-p halo or p-d-p halo with very weak PEF binding [6] and with very short life (ca. 1.0E-23 s) to break up to p + ^{3}He + 7.72 MeV and/or p + p + d + 2.22 MeV promptly.

A view of condensation/collapse of 4H/TSC dynamic motion is shown in Fig.23.

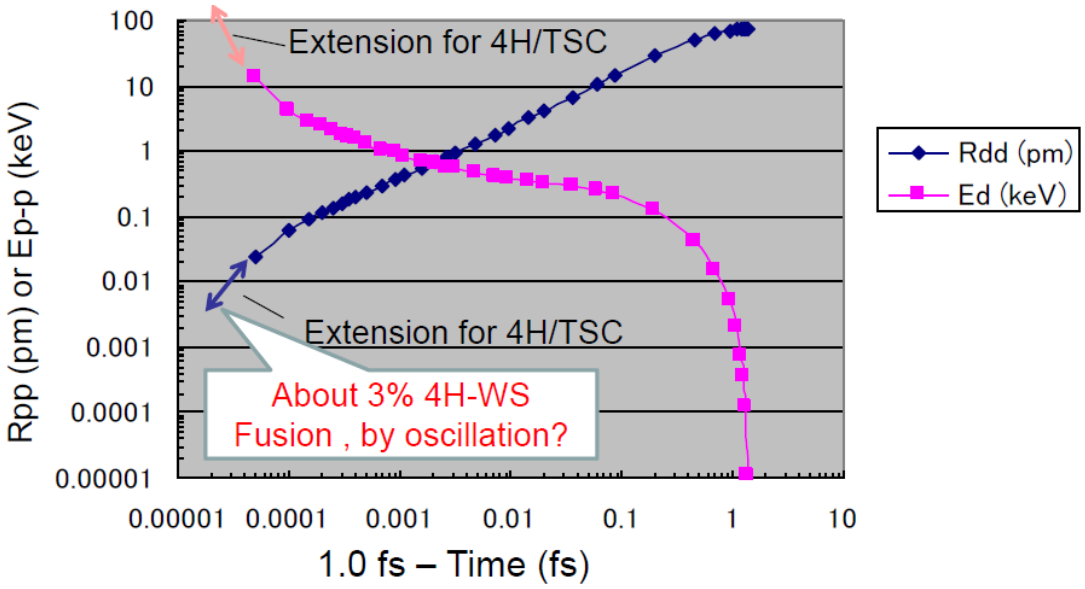

Fig.23: Time-reversed graph of 4H/TSC condensation motion [3], with 1.0 condensation time

One electron may make WI (weak interaction) with a proton due to very short range (2.5am) of W- and no visible multi-body WI is expected. Theoretical approach on very condensed (in several fm p-p distance) 4H/TSC dynamical state getting into relativistic QM state with spin-spin interaction. There electron mean kinetic energy becomes to require relativistic QM treatment. We need to modify QM-Langevin equation or apply Dirac equation for TSC configuration of the multi (8)-particle system.

If the effective life time of 4H/TSC-minimum is on the order of 1 fs or longer, we may expect about 3% or larger ^{4}Li* formation per 4H-cluster to see rational excess power level as 100W/mol-Ni for the Ni-H experiment. We need further study for the effective life rime of collapsed state of 4H/TSC to be more accurately estimated.

6. Sites for Platonic D(H) Cluster Formation

We need to estimate finally the macroscopic condensed cluster fusion rate by modeling D(H)-cluster formation sites and formulate computation formulas and schemes for time-dependent so many-body problem of deuterons (protons) plus electrons around the sites.

A general QM formula is shown in Fig.24.

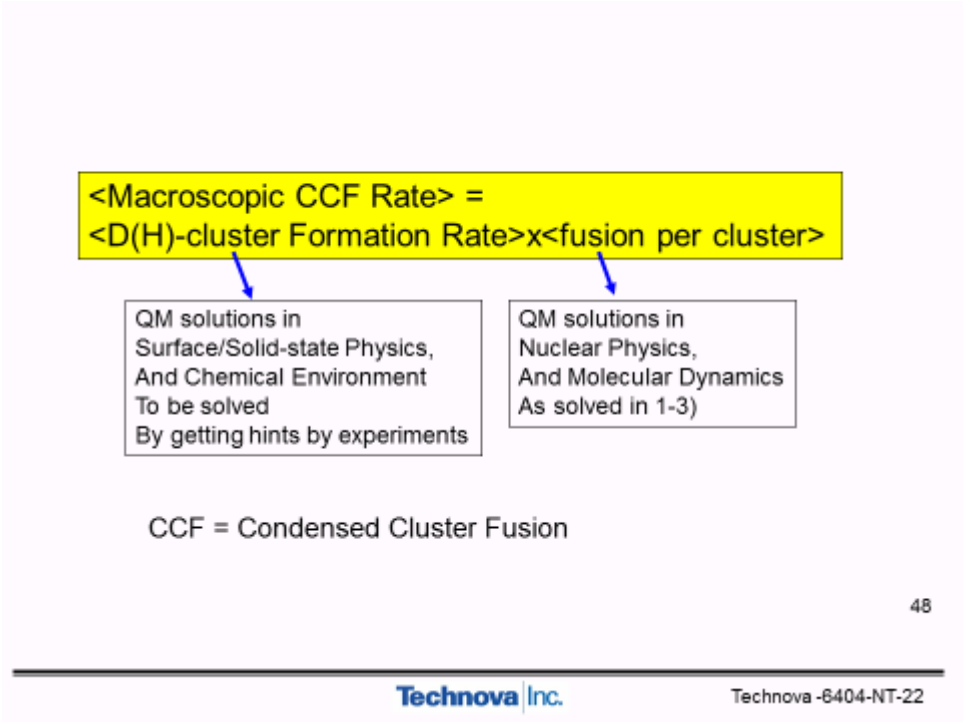

Fig.24: macroscopic fusion rate formula for condensed cluster fusion

A series of theory has been developed (albeit one-through) for calculating cluster fusion rate per cluster generation as explained in the above-written sections. The remained and most complex (and difficult) problem is the cluster formation rate estimation. To approach it, we have to define sites of condensed cluster formation first. Some models for sites have been proposed [3, 10, 11] by getting hints by nano-metal D(H)-gas loading experiments [10-15]. We are looking for the mesoscopic catalysis effect in near surface zone of mono-atomic metal nano particles of Pd and Ni, binary metal nano-particles of Pd-Ni, Cu-Ni, etc. dispersed in some ceramics support material (zirconia and mesoporous-silica were tried in experiments as shown a general idea in Fig.25 [3]).

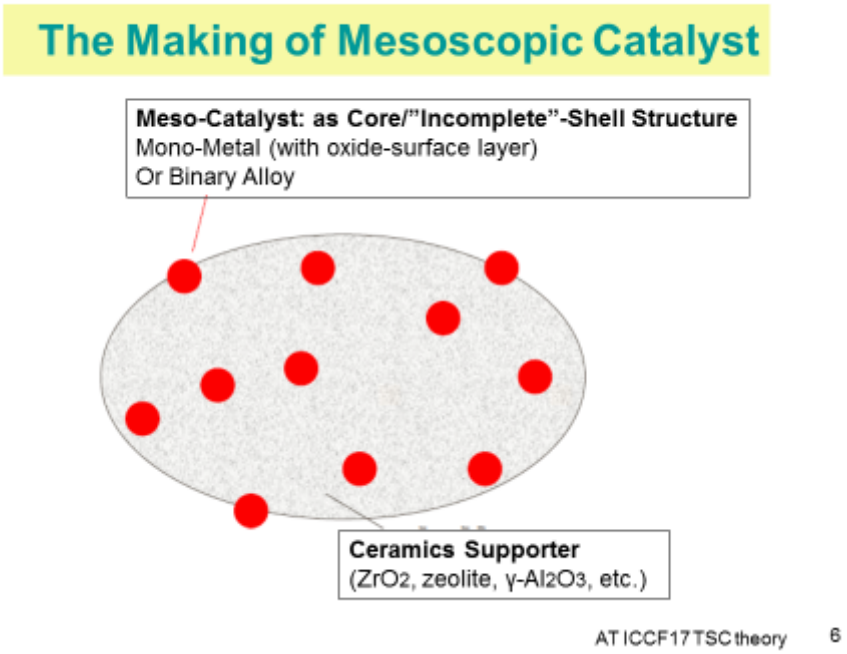

Fig.25: Illustration of image for mesoscopic catalyst for CCF fusion

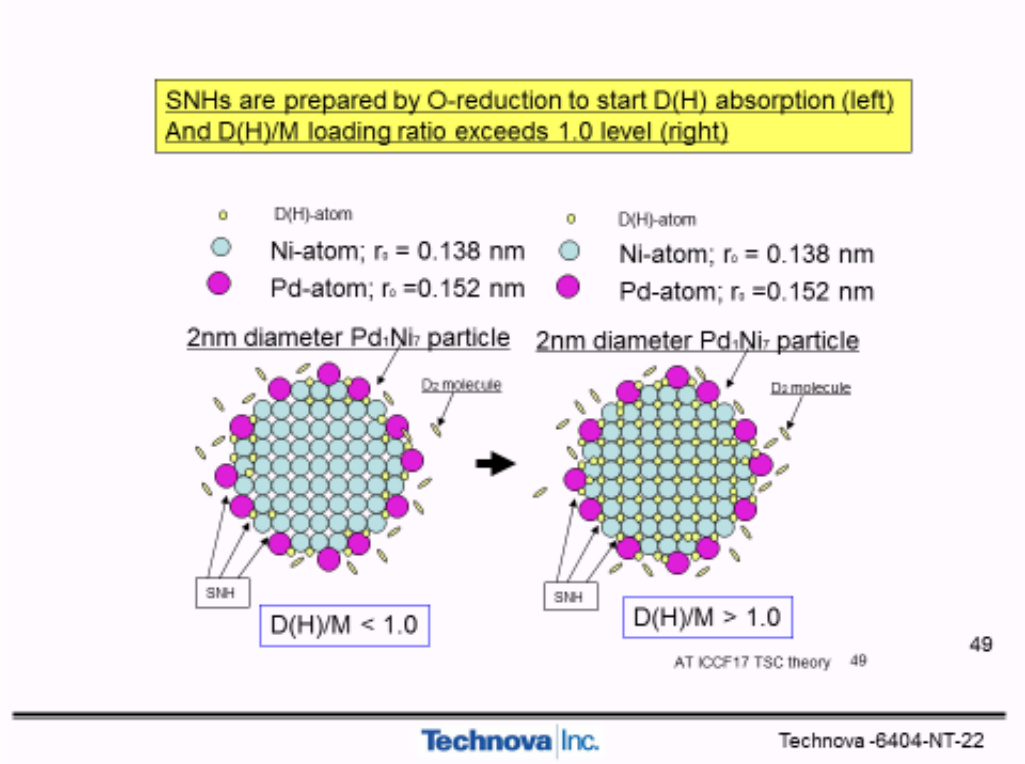

Fig.26: Sub-nano holes (SNH) on surface or inner defects of metal nano-particle may provide sites for CCF

Typically, a three dimensional model of surface SNH (see Fig.27) will be first attacked for simulation calculation of transient 4D(H)/TS (TSC at t=0) generation rate.

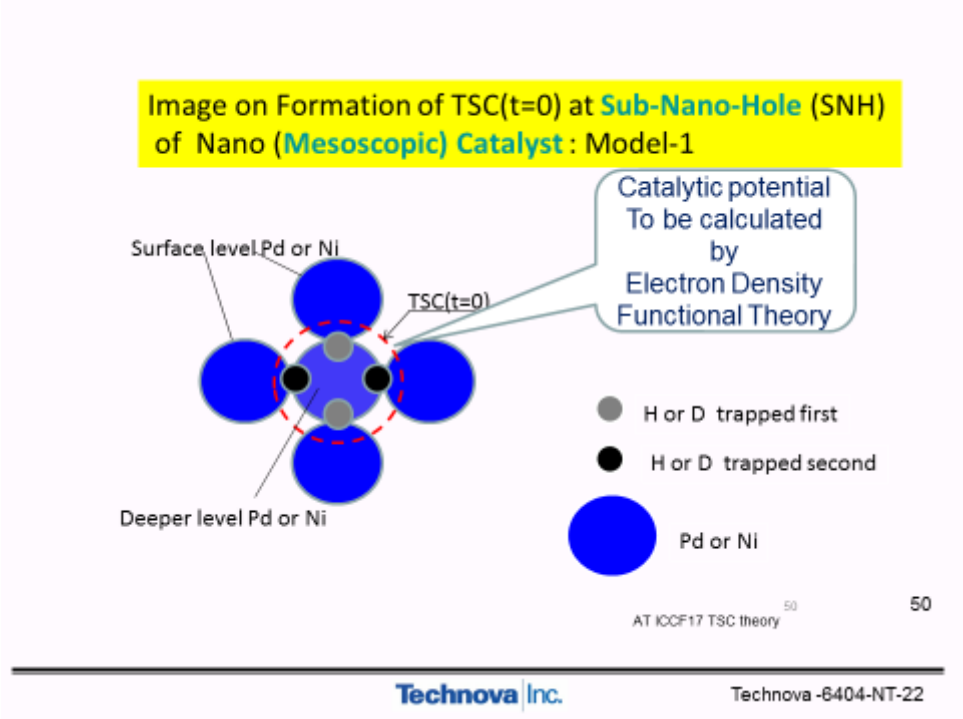

Fig.27: A candidate model of site on surface of mesoscopic catalyst for 4D(H)/TS formation

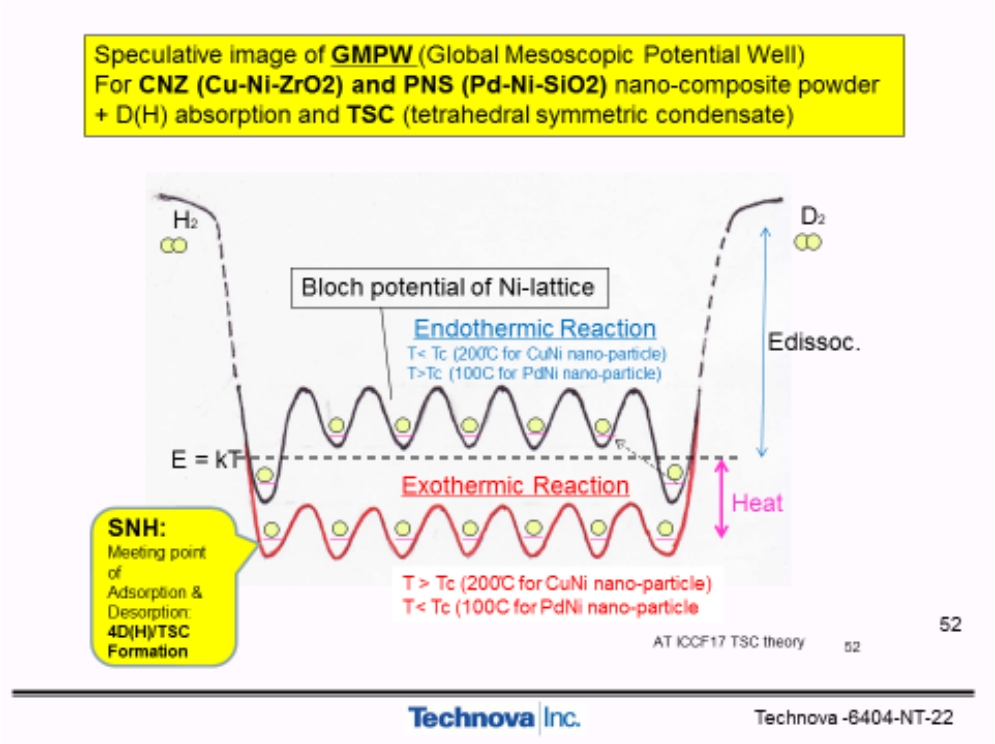

Fig.28：Speculative pseudo trapping potential of nano-metal particle as mesoscopic catalyst [3, 11]

We need to study the catalytic interaction of H(D)-gas and nano-metal particles if the transient BEC type D(H) Platonic clusters [3] are efficiently formed.
So, the QM mathematics there is much more complicated for solving time-dependent many-body system under mesoscopic D(H) trapping potential like Fig.28. Maybe, we need a step-by-step approach with many divided adiabatic states of dynamic processes as surface H_2 (D_2) adsorption, oscillation in trapped potential in the second modified trapping potential for the next incoming H_2 or D_2 molecule, formation rate of transient H(D)-cluster, competition of its dissociation and cluster condensation, penetration of dissociated H and D into inner trapping sites (O-sites and T-sites, for instance) of metal nanoparticle, non-linear oscillation of trapped H(D) in global mesoscopic potential well (GMPW), transient formation of Platonic cluster by non-linear oscillation, estimation of CCF rates, etc. Application of the electron density functional theory (DFT) for such complicated states will be expected by step-by-step computation trials.

It's challenging problem for finding mathematical solvers, especially with use of time-dependent DFT methods.

7. Summary Remarks

For explaining the experimentally claimed anomalous excess heat phenomena in metal-D(H) systems, the condensed cluster fusion (CCF) theory has been proposed. This paper has reviewed the latest status of CCF theory development. In each section, the following key aspects are reviewed and discussed: classical mechanics and free particle fusion, fusion rate theory for trapped D(H) particles, strong interaction rate, condensation dynamics of D(H)-clusters, final state interaction and nuclear products, and sites for Platonic D(H) cluster formation on/in condensed matter.

For studying newly some unknown nuclear reactions aka cold fusion, especially by trapped particles with finite lifetime in chemical potential well in condensed matter, including possibly enhanced multi-body nuclear interactions, we need to start with quantum mechanics of theoretical tools. For the case that the time interval of trapped particles (deuterons or protons, for instance) in relatively negative potential well of condensed matter is much longer than the collision interaction time (typically 1.0E-22 s for two-body collision), we need to use the Fermi's first golden rule for fusion reaction rate estimation. The Thomas-Fermi type charge screening estimation formulas derived for free particles becomes no good approximation, and we need to use real trapping potential having negative well for screening and barrier penetration probability calculation.

To apply the Fermi's first golden rule, we have used the nuclear optical potential (Vn + iWn type) to be added to a Vs1(m*, Z*)-type particle (D or H) trapping potential of the Coulombic field of condensed matter, to formulate nuclear fusion rate equation. The inter-nuclear fusion rate, the bracket integral of W(r) has been estimated by empirical extrapolation of PEF-value dependence of known two-body reactions as p-d, d-d and d-t fusions, in which PEF value is very roughly counted based on the d-d interaction.

The QM Langevin equation has been generalized for treating time-dependent condensation motion of D(H)-clusters with Platonic symmetry, which means the configuration of orthogonal coupling between deuterons- (or protons-) wave function and electron wave function (or density function) in three dimensional space. The QM Langevin equation has been generalized for treating D(H)-clusters with Platonic symmetry, which means the configuration of orthogonal coupling between deuterons- (or protons-) wave function and electron wave function (or density function) in three dimensional space. The Vs1(1,1) trapping potential of the d-e-d three body system has been used for a triangle face of Platonic polyhedron to formulate the generalized QM Langevin equation of polyhedrons of many-particles clusters. The time-dependent minimum approaching distance between two deuterons of the d-e-d three body system was calculated to be about 30 pm, barrier factor for which is about 1.0E-60 to be negligible for d-d fusion events. The ground state oscillation of d-e-d system has eigen-value of Rdd (gs)=138pm. Maximum mutual kinetic energy of deuterons is about 20 eV for a small time interval in the transient motion. Similar calculation for d-e-d-e-d five body cluster (D_3+ molecule) was done. Minimum approaching d-d distance is about 20pm, for which the barrier factor for fusion is on the order of 1.0E-45 to be too small to detect d-d or d-d-d fusion events. Maximum relative kinetic energy of deuteron is about 18 eV and ground state d-d distance is 85pm. Most interesting results of similar calculations are of collapsing condensation (one way to collapse), happened for larger clusters as 4D(H)/TSC, 6D(H)/RDC and 8D(H)/RDC. When condensation-collapse happens, d-d (or p-p) inter-nuclear distance of cluster becomes very short to be less than 20 fm in its final stage before getting into strong nuclear force range (ca. 5 fm typically for d-d). The HMEQPET (heavy mass electronic quasi-particle expansion theory) method is an easy mathematical tool for approximate numerical calculation of Gamov integral of barrier factor. In the case of 4D/TSC condensation/collapse, 100% 4D fusion (to go to the ^{8}Be* intermediate excited nucleus) was estimated to be happening within about 2.0E-20 s time interval in the final stage of condensation-collapse. A nuclear heat-power level of 1 W can be expected by ca. 2.0E11 4D/TSC fusions per second.

We have considered that the 4D fusion makes the very highly excited state of ^{8}Be,

namely ^{8}Be*(Ex = 47.6 MeV), for which no evaluation studies in main stream nuclear physics are available and we do not know what kind of final state interaction happens. We speculated that the ^{8}Be*(Ex = 47.6 MeV) would be an n-h-h-n halo excited state similar to the n-h-t-n halo state of ^{8}Li which has long life time as 0.838 s. Since the ^{8}Be*(Ex = 47.6 MeV) is excited state, it has freedom to make EM transitions if life time of the state is so 'long' as that of ^{8}Li. And the excited state would be very highly deformed (m=16 spherical harmonics picture was given) nucleus with many modes/nodes of rotation/vibration coupled states, which would generate bosonic coupling (nuclear phonons) of low energy band quanta (so called rotation-vibration band structure of QM energy levels). We speculated several ten-thousands bosonic levels might couple. If so, we may expect an avalanche type multi-photon emission, namely BOLEP (burst of low energy photons), with mean photon energy ca. 1.5 keV. The BOLEP process may be main energy damping mechanism of ^{8}Be*(Ex = 47.6 MeV) to the ground state ^{8}Be(0+) which breaks up to two 46 keV alpha-particles.

A series of theory has been developed (albeit one-through) for calculating cluster fusion rate per cluster generation as explained in Sections 2 through 5. The remained and most complex (and difficult) problem is the cluster formation rate estimation. To approach it, we have to first define sites of condensed cluster formation. Some models for sites have been proposed by getting hints by nano-metal D(H)-gas loading experiments. We are looking for the mesoscopic catalysis effect in near surface zone of mono-atomic metal nano particles of Pd and Ni, binary metal nano-particles of Pd-Ni, Cu-Ni, etc. dispersed in some ceramics support material (zirconia and mesoporous-silica were tried in experiments). The QM mathematics there is much more complicated for solving time-dependent many-body system under mesoscopic D(H) trapping potential. Maybe, we need a step-by-step approach with many divided adiabatic states of dynamic processes as surface H_2 (D_2) adsorption, oscillation in trapped potential in the second modified trapping potential for the next incoming H_2 or D_2 molecule, formation rate of transient H(D)-cluster, competition of its dissociation and cluster condensation, penetration of dissociated H and D into inner trapping sites (O-sites and T-sites, for instance) of metal nanoparticle, non-linear oscillation of trapped H(D) in global mesoscopic potential well (GMPW), transient formation of Platonic cluster by non-linear oscillation, estimation of CCF rates, etc.

Further efforts are expected to complete the CCF theory.

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