Physics of Cold Fusion by TSC Theory

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***Abstract*-- This paper gives explanation on the basic physics of cold fusion by the TSC (tetrahedral symmetric condensate) theory. Models of TSC formation conditions in condensed matter are first proposed. Secondly formulas for cold fusion rates per D(H)-cluster are explained with typical quantitative results. The 4D/TSC fusion and the 4H/TSC WS fusion are answers, respectively for the D (deuterium)-system and the H (protium)-system.**

***Index Terms*—TSC theory, D(H)-cluster, 4D fusion, 4H WS fusion**

I. INTRODUCTION

The TSC (tetrahedral symmetric condensate) theory has been elaborated for 23 years since April 1989 [1]. The basic concept (by inspiration) is that the ordering/constraint conditions of particles (namely deuterons, protons and electrons) in condensed matter containing deuterium (D) and/or protium (H) should make unique 'hither-to-unknown' D(H)-cluster fusion reactions measurable, while the known fusion reactions in high temperature plasma are two-body reactions as p-d, d-d, d-t, d-^{3}He and so on which are taking place in random free particle motions. Here, D(H)-cluster includes two deuterons (or protons) systems as d-e-d (p-e-p) and d-e-e-d (p-e-e-p), as well as 3D(H), 4D(H), 6D(H) and so forth. And e denotes electron. Here D denotes deuteron (d) + electron (e), and H does p + e too.

The study of D(H)-cluster dynamics by using the quantum mechanical (QM) Langevin equation [2] has concluded that any transient entity (condensate state) as small as a few tens fm size will not be possible for the d-e-d and d-e-e-d systems, as well as 3D-cluster, while 4D/TSC- and 6D/OSC-neutral-clusters may make ultimate condensation to very small charge-neutral entity, as small as a few tens fm size or smaller to induce significant level reaction rates of nuclear strong interaction between deuterons. The condensation time for 4D/TSC is so short as 1.4 fs and the yield of 4D/TSC fusion per TSC is 1.0 (100%) [3].

The macroscopic fusion rate by the TSC theory is given by the product of two rates as,

$$\langle Macroscopic\ Fusion\ Rate\rangle = \langle D(H) - Cluster\ Formation\ Rate\rangle \times \langle Microscopic\ Fusion\ Yield\ per\ TSC\rangle \qquad (1)$$

And the microscopic fusion rate is defined by the time-dependent cluster condensation motion (inter-nuclear d-d distance R_{dd} and relative d-d kinetic energy) and the rate of strong interaction, by using the Fermi's first golden rule [4]. The D(H)-cluster formation rate should be defined to reflect in dynamic conditions of near-surface-physics/chemistry and finite lattice of solid state physics/chemistry of condensed matter as D(H)-loaded metal electrodes, D(H)-loaded nano-metal-powder composites or some other materials used for cold fusion studies. No formulas of D(H)-cluster formation rate have been given until now and only speculative models have been given [5,6], since the relevant dynamic conditions in condensed matter are so complex with too many-particle systems and our progress in experiments will provide hints to develop the formulas.

II. MODEL OF TSC FORMATION SITES

We employ the idea of 'mesoscopic catalyst' [5,6] for the near-surface condition of condensed matter to provide sites of dynamic TSC formation. A typical design of nano-composite metal powder being used currently in D(H)-gas loading experiments is shown in Fig.1.

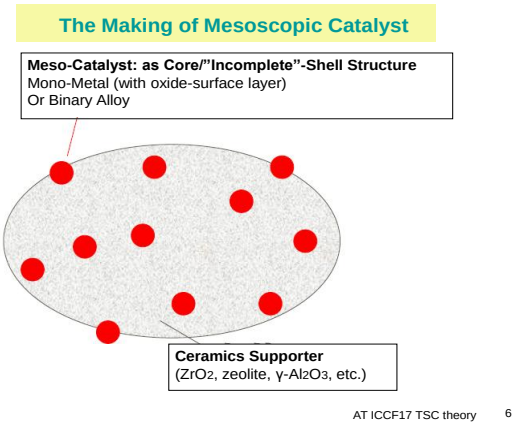

Fig.1. Design of nano-composite sample for D(H)-gas loading

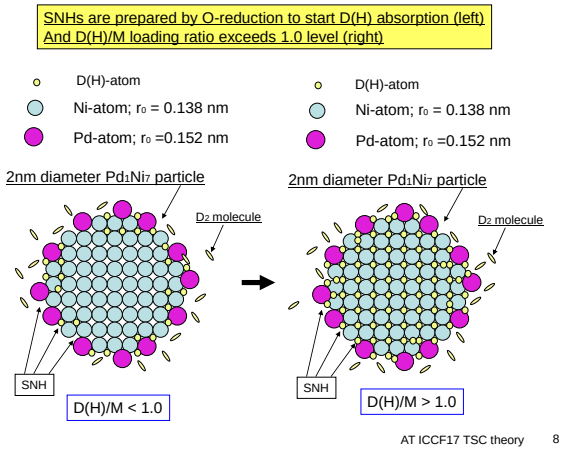

Fig.2. D(H)-adsorption/absorption image via SNHs of nano-particle

An isolated nano-binary-metal particle (1-10 nm diameter is thought to be optimum [5,6]) has 'fractal' surface with many sub-nano-holes (SNH) and inner finite lattice (Bloch) structure. The image of D(H)-adsorption/absorption process is illustrated in Fig.2.

An image of TSC formation site of SNH is shown in Fig.3. First a D_2 molecule is adsorbed at a SNH and before its dissociation the second D_2 molecule is 'orthogonally' adsorbed onto it to form a TSC (t=0) sate.

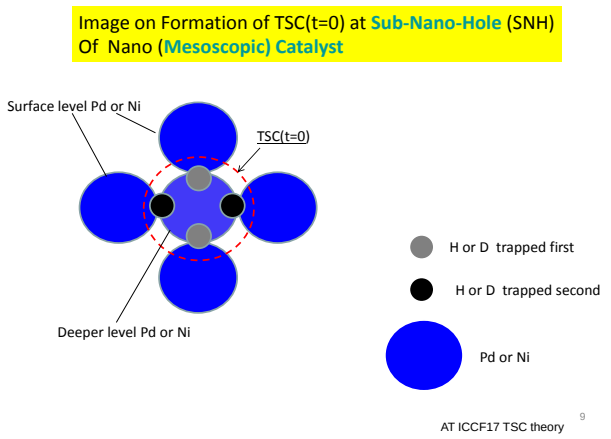

Fig.3 Image of TSC (t=0) formation at a SNH site

An image of absorbed D(H)s in finite lattice of nano-particle is shown in Fig.4 conceiving the case of Ni-core binary nano-particle at lower and higher ambient temperature.

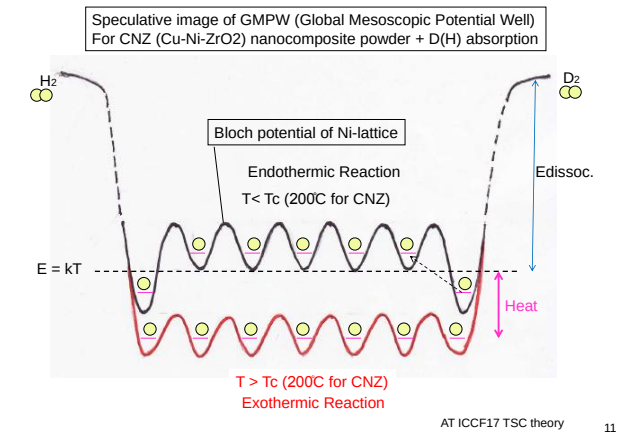

Fig.4.Image of absorbed D(H)s in a global mesoscopic potential well (GMPW) of binary nano-particle

D_2 molecule is adsorbed and dissociated at deep trapping potential, due to many dangling chemical electron bonds there, at SNH on surface and then diffuse into inner finite lattice sites by the quantum-mechanical (QM) 'tunneling' effect which is enhanced at elevated temperature. In thermo dynamics view, system energy is transferred via phonon energy exchange between trapped D(H)s in QM oscillation and outside phonons of substrate (ceramics supporter) as shown in Fig.5 for imagination. The temperature dependence of phonon-frequency distribution of trapped D(H)s in GMPW (global mesoscopic potential well) should be studied.

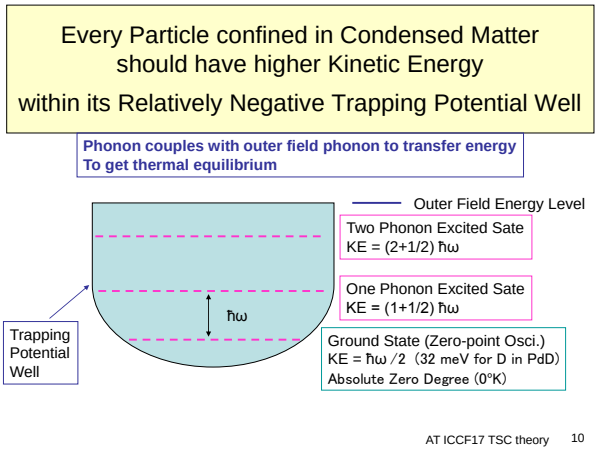

Fig.5. Phonon-energy exchange of trapped D(H)s and outer phonons in substrate (supporter ceramics)

At elevated temperature conditions, probability of TSC (t=0) formation at inner finite lattice sites may be significantly enhanced [1] as illustrated in Fig.6.

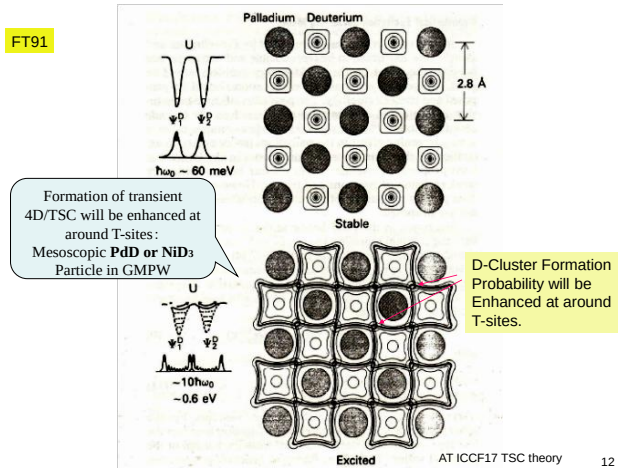

Fig.6. Possibility of enhanced TSC formation at inner lattice sites of nano-particle as mesoscopic catalyst, at elevated ambient temperature (lower figure)

Quantitative QM calculations for these TSC formation process are very complex due to so many-body time-dependent problems under the ordering/constraint conditions of condensed matter, to study further.

III. Cluster Fusion Rates

Once a TSC(t=0) sate forms, the time-dependent TSC condensation motion is so fast as it finishes 4D/TSC condensation in 1.4 fs [2, 3]. During the continuous condensation motion, we can employ an 'adiabatic' state (for digitizing very small time-steps) of 'quasi-molecule' confining potential and 4D (or d-d pair) wave function, as illustrated in Fig.7. In the QM-Langevin calculation, Gaussian-type wave-functions were employed [2, 3] to implement the 'quasi-eigen-values' search for the

adiabatic state, by using the variational method [3]. The detail of QM-Langevin equation and TSC-trapping potential is fully given in references [2, 3].

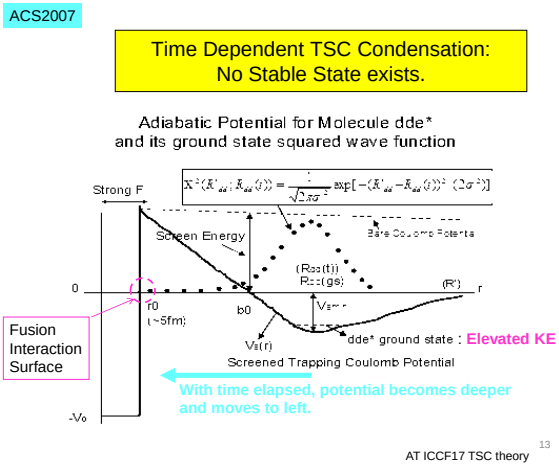

Fig.7. illustration of 'adiabatic state' under continuous condensation motion of 4D(H)/TSC

The cluster fusion rate for an adiabatic quasi-molecule state is given by the following Fermi's golden rule under the Born-Oppenheimer approximation.

$$< FusionRate >= \frac{2}{\hbar}\left\langle \Psi_{nf} \middle| W(r) \middle| \Psi_{ni} \right\rangle_{Vn} \cdot \left\langle \Psi_{cf} \middle| \Psi_{ci} \right\rangle_{Vn} \qquad (2)$$

Here, Ψ_{ni} and Ψ_{nf} are inter-nuclear wave-functions, respectively for the initial state and the final state. Ψ_{ci} and Ψ_{cf} are outer-nuclear wave-functions in the electro-magnetic field, respectively for the initial and the final sate of interaction. V_n is the effective volumetric domain of nuclear interaction by strong (or weak) force to be given approximately as,

$$Vn \approx 4\pi R_n^{\,2}\lambda\!\!\!^{-}_{\pi} \qquad (3)$$

Here R_n is the radius of nuclear- interaction surface as shown in Fig.7, and λ-bar-pi is the Compton wave length (1.4 fm) of pion as virtual force-exchange boson for strong interaction. (In the case of weak interaction, we replace it with the Compton wave length of weak boson 2.5 am.)

W(r) is the imaginary part of nuclear optical potential, which is main factor of strong (or weak) interaction near around the interaction surface r=R_n. To estimate fusion rate by Eq.(2), we need to calculated two 'adiabatic' terms; namely one is the second term that is the effective QM wave-function-weight for the first term of 'inter-nuclear fusion rate' [4]. In other approximate treatment, the second term is calculated by using the WKB approximation with Gamow integral, as called as the barrier penetration probability. The approximate estimation of the first term <W>, an empirical approach with PEF (pion exchange force)-values was used [3, 4].

An image of PEF as a measure of strong interaction is drawn in Fig.8 for the case of PEF =2 (d-d fusion) by using the simplified one-pion exchange potential of Hamada-Johnston [7] of which main part is Yukawa potential of meson exchange. <W> values for multi-body fusion as 3D, 4D and 6D were roughly estimated by using the scaling law with $(PEF)^5$ and cross sections of p-d, d-d and d-t reactions and were given in reference [3].

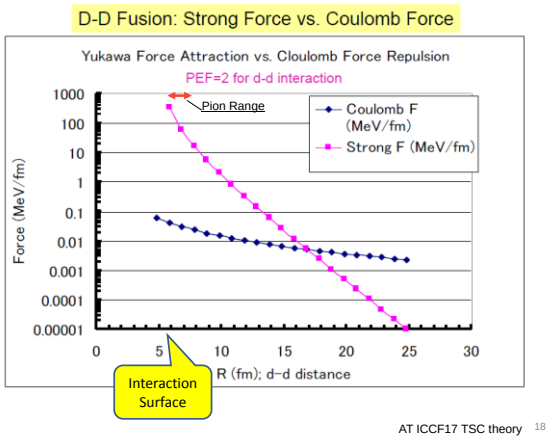

Fig.8. Strong force (attractive) is compared with Coulombic force (repulsive) for the d-d interaction

A general image of nuclear optical potential is illustrated in Fig.9.

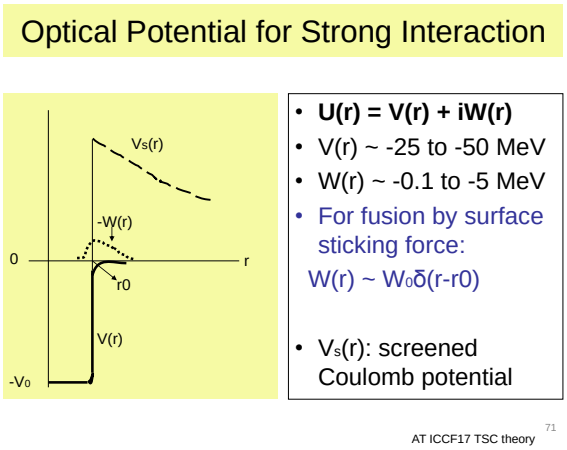

Fig.9. General feature of nuclear optical potential

IV. D-CLUSTER FUSION

As soon as 4D/TSC(t=0) state with D_2 molecule size (R_{dd} = 74 pm) is formed, our code calculation by the QM-Langevin equation gives numerical solution for time-dependent R_{dd} and mean relative kinetic energy of d-d pair of a face of 6 TSC (d-e-e-d-type) faces, as copied from reference[2,3] and shown in Fig.10. The 'adiabatic' size of 4D/TSC reaches at a few tens fm size in 1.4 fs, so fast. With adiabatic 4D/TSC size around 20 fm, 4D-fusion takes place by 100 % yield [2, 3] in $2x10^{-20}$ s, namely,

$$D + D + D + D \rightarrow {}^{8}Be^{*}(Ex = 47.6\ MeV: J^{\pi}) \qquad (4)$$

The break up channels of ^{8}Be* are very complex, according to the very deformed nucleon (n or p) halo

admixture which may have very small level-gap (possibly 1-10 keV) vibration/rotation band structure with relatively long life time, from where complex EM transitions to emit low energy (1-10 keV, possibly) gamma-rays and excitation-damping to the ^{8}Be ground state (two alphas decay) would be considered [8].
4D/TSC disappears after 1.4 fs.

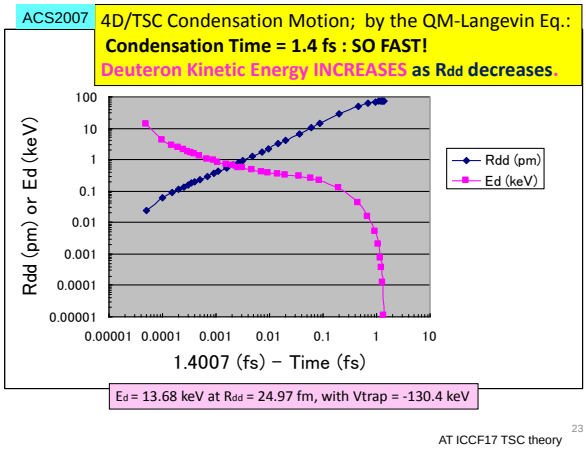

Fig.10. Time variation of R_{dd} and relative d-d kinetic energy under the 4D/TSC condensation

Fusion yield per 4D/TSC generation is calculated by integrating time-dependent fusion rate by the Fermi's first golden rule as precisely explained in reference [3], that was very close to 1.0, namely 100%, during the very small time interval of ca. 2×10^{-20} s in the final stage of condensation. Mean relative kinetic energy of neighboring d-d pair of 4D/TSC-minimum is ca. 14 keV, which is accidental resembling value to the hot fusion experimental devices as ITER (DT plasma). Discussions on mean kinetic energies of d-d pair were given in reference [7] for D_2 molecule (2.7 eV) and muonic d-d molecule (180 eV). These are not 'cold' values as 0.025 eV of room temperature matter. The reason is that the confined d-d pair in 'deep' electro-magnetic (or Coulombic) trapping potential should decrease its de Broglie wave length to be constrained by the Heisenberg Uncertainty Principle (HUP).

A simplified image of 4D/TSC condensation and fusion reaction is copied [1, 2, 3] as shown in Fig.11.

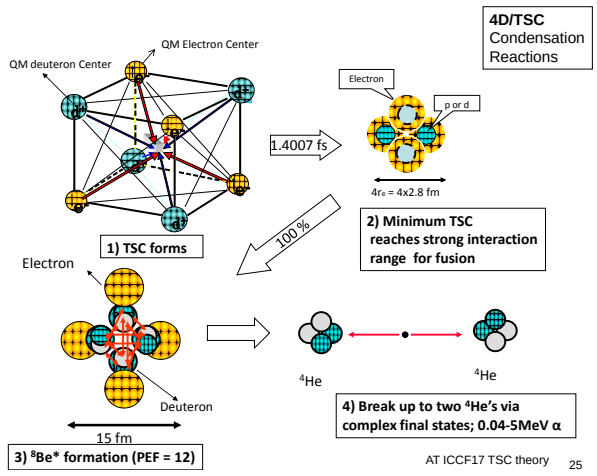

Fig.11. Brief view of 4D/TSC condensation and 4D fusion

V. 4H/TSC WS FUSION

According to the formula of QM-Langevin equation, the velocity of condensation (time-dependent) is inversely proportional to the square-root of mass of confined particle. Therefore, 4H/TSC will condense in 1.0 fs to the small size region of a few tens fm. However, there is no strong-fusion interaction (PEF = 0) between 4 protons of TSC to finally destroy the TSC state. We conceive that 4H/TSC can condense further to be as ultimately small 4H/TSC-minimum state as a few fm size (2.4 fm p-p distance is the limit, due to hard core of proton with 1.2 fm radius). The problem there is how long the 4H/TSC-minimum state can survive.

We need a study by using a relativistic QM equation (the Dirac equation or some equivalent one) to this extremely condensed state, as future task. The TSC trapping potential can be modified with additional term of spin-tensor force of electrons and protons in combination of ordered directions [8].

The converted figure of condensation motion for 4H/TSC is shown in Fig.12.

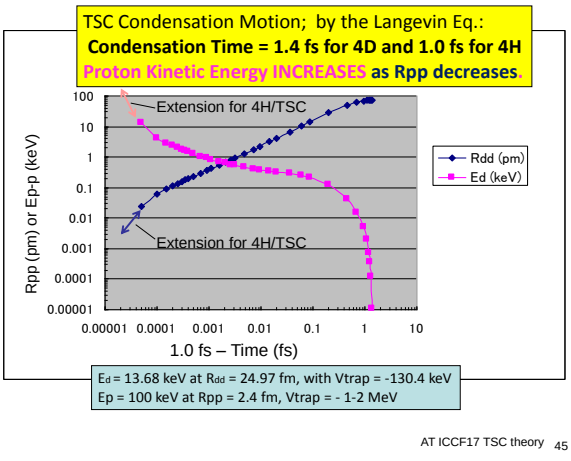

Fig.12. Time variation of R_{pp} and relative p-p kinetic energy under the 4H/TSC condensation

The depth of adiabatic p-p trapping potential on a face of TSC will become so deep as -1.2 to -2.0 MeV at the 4H/TSC-minimum state. There the mean relative kinetic energy of electron E_{eke} in a p-e-e-p system on one face of TSC would be 0.6 to 1.0 MeV. Therefore, we may expect the electron capture process to one of proton of 4H/TSC-minimum, by the weak interaction [9].

$$p + e + E_{eke} \rightarrow n + neutrino + (E_{eke} - 272\ keV) \quad (5)$$

Once a proton-to-neutron transition is generated by the electron capture, we expect instantaneous strong interaction between just born neutron and closely available three protons within the Compton wave length of charged pions 1.4 fm (PEF = 3) as illustrated in step (3) of Fig.13. As the pion range 1.4 fm is the Heisenberg Uncertainty in distance, the n + 3p reaction takes place by

100 % with <W> value of PEF = 3 (comparable to d-t fusion)[9].

$$3p + n \rightarrow {}^{4}Li^{*}(Ex = 4.62\ MeV) \quad (6)$$

The intermediate compound ^{4}Li* has two break-up channels.

$$^{4}Li^{*}(Ex = 4.62\ MeV) \rightarrow {}^{3}He + p + 7.72\ MeV \quad (7)$$

$$^{4}Li^{*}(Ex = 4.62\ MeV) \rightarrow 2p + d + 2.22\ MeV \quad (8)$$

The branch (7) is thought to be a major out-going channel and we will expect ^{3}He as main nuclear product. And 5.79 MeV proton will produce secondary neutron by Ni(n, p) reactions with higher mass Ni isotopes, on the order of 10^{-13} of ^{3}He production rate and Ni(p, gamma) secondary gamma-rays on the order of 10^{-11} per 5.79 MeV proton. Characteristic X-rays from Ni ionization by the proton are also expected.

However, we do not know the branching ratio to the branch (8) which will not produce secondary neutrons and gamma-rays at all.

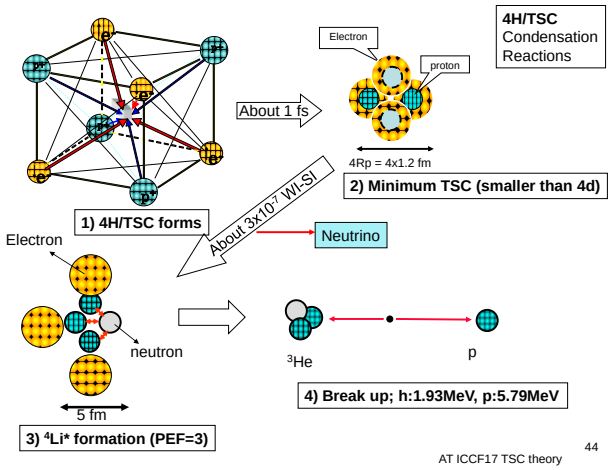

Fig.13. Brief view of 4H/TSC condensation and 4H weak-strong fusion interaction

So the key problem is how much weak interaction rate to generate neutron-nucleon (not free neutron) is probable in the duration of 4H/TSC-minimum state. The weak interaction rate is given by

$$< WIrate >= (4\pi / h) < W >_{w} \left\langle \Psi_{e}(r_{w}) \right\rangle^{2} \quad (9)$$

The detail of weak interaction rate calculation is given in reference [9]. As the Compton wave length of weak bosons (W^{+}, W^{-}) is extremely short as 2.5×10^{-18} m (2.5 am), the second term of Eq.(9), the weight of electron wave function from outer EM field, is so small as 5.9×10^{-5}, and <W> value is also small as 78 eV [9].

If we assume the life time of 4H/TSC minimum to be as same as the 4D/TSC-minimum, namely ca. 2×10^{-20} s, the weak interaction yield is very small as 3×10^{-7} fusion/TSC. However, if the life time of 4H/TSC-minimum would be elongated to ca. 1 fs as comparable as the condensation time, the weak interaction yield can become so large as 3×10^{-2} (3 %)/TSC, which is reasonably large level to explain 100 W/mol-Ni-H level excess heat evolution in the Ni-based gas-loading experiments [10, 11].

The other weak interaction channel is the p + p → d + β^{+} + Q reaction. Its p-p fusion rate at the 4H/TSC-minimum state is estimated to be 10^{-38} f/s, by using the S value 3.4×10^{-22} keVb and the relative p-p kinetic energy 100 keV for the two-body reaction rate formula (Fermi's second golden rule [4]). Assuming that the lifetime is 1 fs of 4H/TSC-minimum, the p-p weak-fusion yield is 10^{-53} f/TSC that is negligibly small.

VI Possibility of 4H/TSC + Ni Fission

As the inner-most (K) electron shell of Ni atom has ca. 1 pm radius of 1S orbit and additional shell electrons 'protect' Ni nucleus from in-coming proton to make Ni + p nuclear reaction, two-body strong interaction between metal nucleus and proton (or deuteron) is impossibly difficult. However, as 4H/TSC-minimum state may have very small size (as small as a few fm) and charge-neutrality, it would easily penetrate through the multi-shell barrier of electrons of metal nucleus. As Ni has much larger 1S orbit than that of Pd, 4H/TSC-minimum may more easily approach to the Ni-nucleus than Pd. As 4D/TSC shall disappear at sizes of e few tens fm, only 4H/TSC may have good chance to approach Ni nucleus. The feature is illustrated in Fig.14.

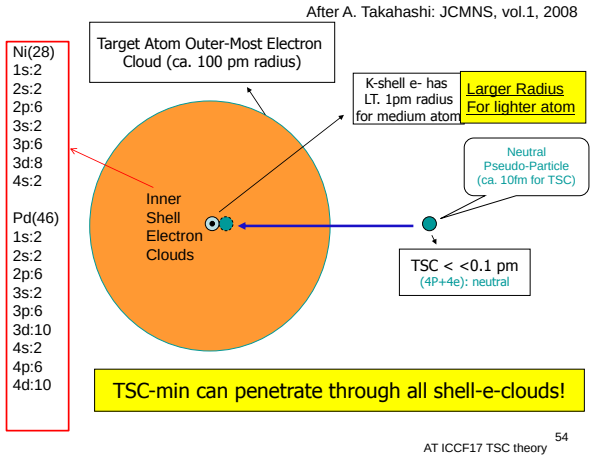

Fig.14. 4H/TSC-minimum may approach Ni-nucleus to make strong interaction (4p capture and fission)

We have reported that fission products from Ni + 4p fission were predicted clean stable isotopes mostly, by the selected channel scission theory [12]. As discussed in the previous section, the life time of 4H/TSC-minimum state may be much longer than we conceived previously, and the size of its neutral entity is much smaller than the past image, the strong interaction with Ni nucleus would be selective to the Ni + 4p capture and 1p to 3p capture processes will be neglected as shown in Fig.15.

Fission products are considered to be mostly from the near symmetric fragmentations of Ge* intermediate compound state as shown in Fig. 16. In the past, there were reports on production of foreign elements

('transmutation was thought') by several authors, typically as reported by Miley-Patterson [13].

Their data was analyzed by TSC-induced fission in reference [12]. Mass spectral analysis for samples before and after use is recommended for Ni-H system experiments as being done by Piantelli-group, Kobe-Technova-group (Sakoh et al) and Celani-group (INFN).

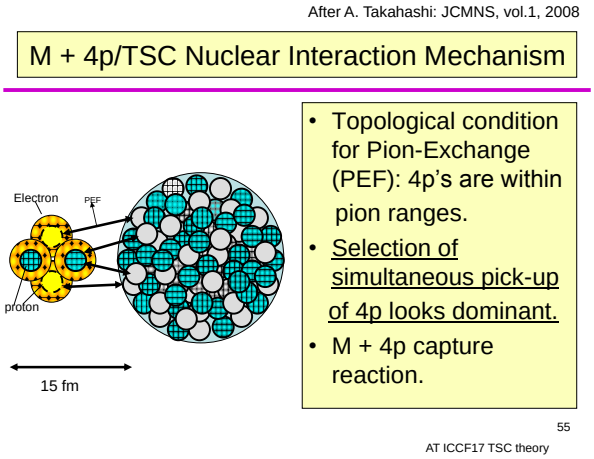

Fig.15. 4H/TSC-minimum can make 4p capture into Ni nucleus

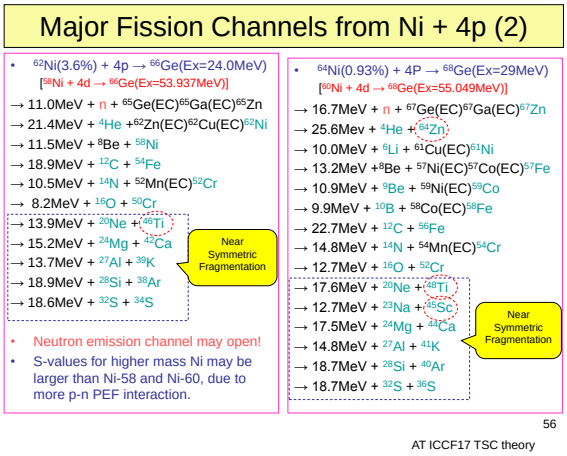

Fig.16. expected major fission products by Ni + 4p process

VII CONCLUSIONS

A systematic theoretical study on possible physics mechanisms of cold fusion in D(H)-contained condensed matter is briefly explained.

As the nature of condensed matter is the ordering/constraint dynamic conditions on confining particles of deuterons, protons and electrons in electro-magnetically induced trapping potentials, D(H)-cluster formation and its transient motion has been thought as a clue to solve the puzzle of cold fusion.

The TSC theory has been proposed and elaborated since April 1989 by the author in three main steps [1]. The most realistic solution with quantitative results of microscopic D(H)-cluster fusion rates have been obtained recently (step-3) by using the QM-Langevin equation for studying their dynamic condensation processes and relevant strong and/or weak nuclear interactions as many-body system. The conventional two-body system has not been able to provide meaningfully observable nuclear reaction rates, in contrast to the hot fusion process.

The 4D simultaneous fusion (^{4}He: ash) and the 4H simultaneous weak-strong fusion (^{3}He, d: ash) are the consequence of the TSC theory that the author has developed until now.

The quantitative formulation of microscopic fusion rates for D(H)-cluster fusions has been made by one-through work. However, the returning work, namely the quantitative study on the TSC formation probability in D(H)-loaded metal systems is yet to be done by solving many-body time-dependent problems under organization field of condensed matter. It is challenging work.

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