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Condensed Matter Nuclear Effects

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Abstract: A brief review is given for introducing the emerging field of condensed matter nuclear science (CMNS), which is born in descendant researches of "cold fusion". Results of research in latest years are claiming 1) deuteron-origin clean fusion and 2) selective nuclear transmutations, as new kind of nuclear processes in the environment of condensed matter. New theoretical aspect is of nuclear processes under the transient (dynamic) ordering (constraint) processes in/on condensed matter, especially metal-hydrogen/deuterium systems. EQPET/TSC theory by the author is shown to compare consequences of theoretical models and various experimental results. Tetrahedral Symmetric Condensate (TSC) is proposed as seeds of multi-body deuteron self-fusion reactions under transient ordering environment and TSC-induced capture (transmutation) reactions with metal-nuclei. Overall consistency between theories and experiments are obtained.

1. Introduction

In spite of very negative mood to the existence of "cold fusion phenomena", a faint stream of research in the world has gradually accumulated convincing results to claim anomalous nuclear reactions in various experimental methods with metal-deuterium/hydrogen systems. Some experiments on transmutations show good reproducibility, but some others on excess heat effects are still difficult to reproduce although many groups reported essentially and qualitatively same physical results like ^{4}He generation with excess heat. Anomalous nuclear effects suggest clean (almost radiation-less) fusion, transmutation and even fission, so that we may expect the opening of new field of science which is expected to apply to nuclear energy science and technology.

We introduce first recent major experimental results in the next section. From the stand-point of Experimentalism, we have to consider seriously the existence of 1) deuteron-origin clean (radiation-less) fusions and 2) selected nuclear transmutations in the room-temperature environments of metal-deuterium/hydrogen systems. We argue on experimental methods and reproducibility.

However, no-established theories of nuclear physics, condensed-matter physics and chemistry can interpret these anomalous results of experiments. From the stand-point of Rationalism, we need to propose and complete new theoretical models which should be compatible to already established theories. New theoretical models should treat linkage between new processes of nuclear reactions and ordering processes in/on condensed matter. Since 1989, more than 50 theoretical models have been proposed[12)]. No consensus of scientists on established models has however ever reached.

On frontiers of science, Skepticism is also helpful to check full consistency of consequences between experimental and theoretical results, to seek truth.

In this brief review, the author tries to introduce status of research through the comparison study of consequences by our theoretical models of Electronic Quasi-Particle Expansion Theory with Tetrahedral Symmetric Condensation (EQPET/TSC) and major experimental results. Summary of results is shown in Table-1.

Table-1: Summary Results[15], experiment vs. theory

Item	Experiment Author/ Method / Results	EQPET/TSC Models
Screening of d-d fusion	Kasagi/D-beam,PdDx/Us=310+-30eV Takahashi/3D,TiDx/ <dd> =1E9 in range	Us=360eV, by dde*(2,2) (1E13)τ with τ = 0.1 ms
^{4}He/^{3}He production	McKubre/Electrolysis/31+-13 MeV/^{4}He Arata/nano-Pd, El./ [^{3}He]/[^{4}He]=0.25	23.8 MeV/^{4}He by $4D \rightarrow {}^4He + {}^4He + 47.6MeV$ [^{3}He]/[^{4}He]=0.25, for H/D=0.6
Max. Heat	El Boher/Super-waveEl./24.8 keV/Pd Gain = 25	23 keV/Pd 46 MW/cc-Pd by 4d/TSC
Transmutation	Iwamura/ Pd-complex, gas/ Cs to Pr Miley/Ni-H, electrolysis/ fission-like FP	4d/TSC or ^{8}Be capture to metal FP by Ni+4p/TSC

2. Major Experimental Results

Not only the originally reported (in 1989) electrolysis method, but also gas-permeation, plasma discharge, particle-beam irradiation, laser irradiation, ultra-sonic wave irradiation, and so on, methods have been tried for stimulation methods, together with metal-H/D samples made with nano-structure designs in recent years.

To understand basic mechanism by relatively pure conditions, implantation (irradiation) of low energy deuteron (D^+) beam into metal-D samples has been tried by several groups. Kasagi[1] and Huke[10] have given effective electron-screening energy of 310 to 320 eV by measuring enhancement-factors of d-d reactions (by detecting proton-yields from d + d to p + t + 4.02 MeV channel) with 1-10 keV beam energy, for Pd/Dx (x<1) sample-targets. Conventional theory of beam-target fusion based on the Thomas-Fermi gas model of electrons in metal-deuterides gives 30 to 70 eV for electron screening energy of Coulomb repulsion to d-d fusion. Experimental results are anomalously high (about 10 times) values. Takahashi[2] showed anomalous enhancement (10^{26} times of conventional random reaction theory) of d+d+d (3D) three-body fusion rate by also using low energy D^+ beam implantation into TiDx (x>1.5) targets.

Most important results for energy application are claims of excess heat with significant amount of ^{4}He production, without visible neutron emission level, as first reported by M. Miles in 1990. Qualitatively same results have been reported by many groups as Arata[4], McKubre[3], Gozzi[12], de Ninno[12], Isobe[12], R. George[12], and others. Many authors asserted that $D + D \rightarrow {}^4He$ + lattice-energy (23.8 MeV) was taking place. However, the assumed process is not possible in the view of nuclear physics[15]. No nuclear physics theory has ever been proposed to change branching ratio of D + D reaction which is predominantly going out to n + ^{3}He + 3.25 MeV (50%) and p + t + 4.02 MeV (50%), with very small branch (10^{-5} %) for gamma-ray transition, ^{4}He + gamma (23.8 MeV)), at low d-d relative kinetic energy. Elegant data[3)] of correlation between excess heat and ^{4}He production is shown in Fig.1. McKubre et al gave 32 MeV per one ^{4}He generation with error bar of 13 MeV.

•After M. McKubre, ICCF11, 2004

Case: "Q"-Value - Energy *vs.* ^{4}He

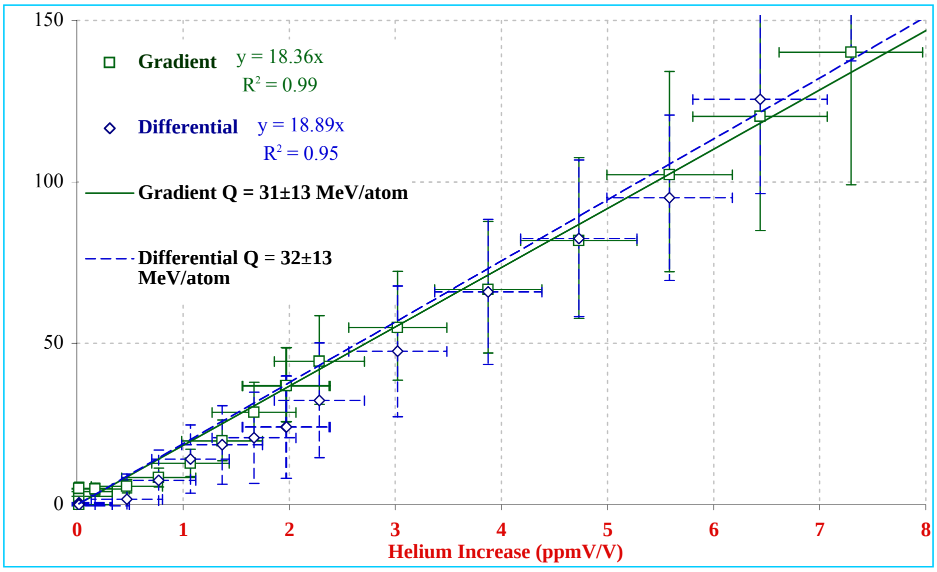


Fig.1: Correlation data between excess heat and ^{4}He generation[3)]

As a champion data of excess heat in metal-heavy-water cell, the Israeli group[5)] has reported surprisingly large (25 times of input energy) excess heat for 17 hours, using the innovative super-wave electrolysis with thin Pd plate cathode. The group is also trying stimulation by super-wave electrolysis plus laser irradiation.

The report[6)] of MHI Iwamura group is most remarkable to claim clean selective transmutation of added elements. They used stimulation of D-gas permeation through Pd-complex samples to find transmutation of ^{133}Cs (added on surface region of complex) to ^{141}Pr, and ^{88}Sr to ^{96}Mo. Measured isotopic ratios of Mo were far from natural ones, namely almost purely ^{96}Mo. With H-gas permeation, they did not see any change of Cs (or Sr). Typical results are shown in Fig.3. This should be selective transmutation with increase of mass-8 and charge-4, namely two alpha-particles or 4D added reactions. These experiments have been reproduced three times at Osaka University, several times at RIKEN Spring-8, and so many times at MHI laboratory.

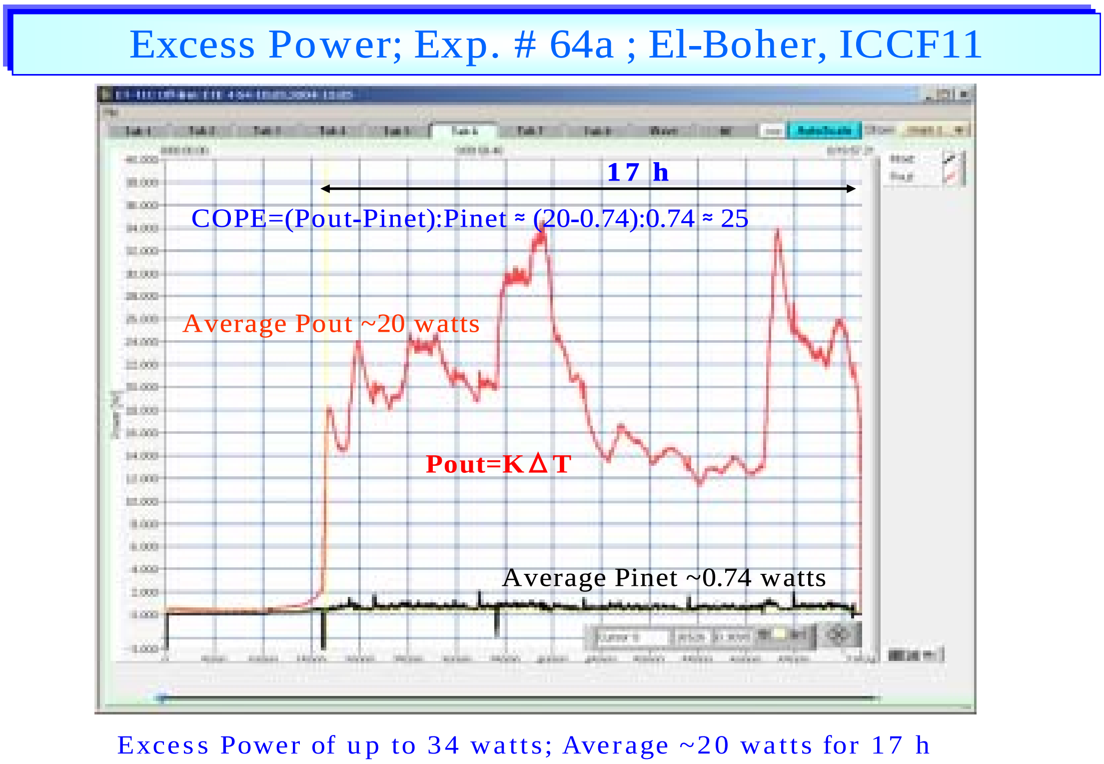


Fig.2: Large excess heat by super-wave electrolysis of heavy water with thin Pd plate[5)]

3. Interpretation by EQPET/TSC models

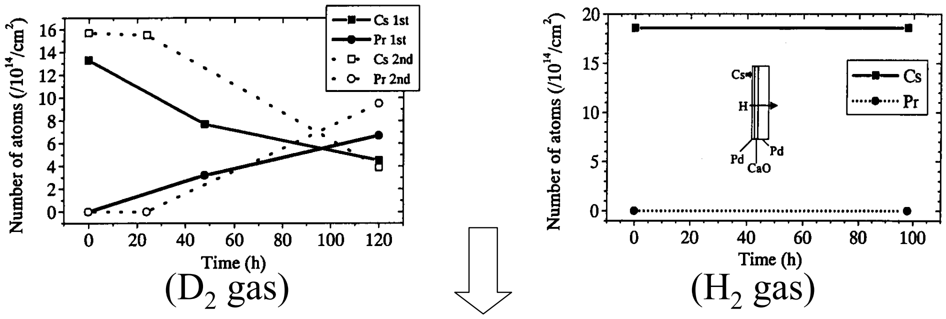
Within our knowledge, it seems impossible to enhance d-d fusion rate in steady state conditions of metal-deuterium systems and approach the d-d fusion rate 10^{-60} f/s/pair for D_2 molecule, because mutual d-d distance trapped in PdDx lattice is about 0.2 nm which is much larger than 0.07 nm of d-d inter-nuclear distance of D_2 molecule. Moreover, our common knowledge on nuclear reactions do not easily accept that major product of ^{4}He by d-d reaction and transmutation of metal nuclei. Can we construct rational theoretical models to explain experimental results systematically?

Since 1989 when “cold fusion” was claimed by Fleischmann-Pons and Jones, the author has been considering possibility in nuclear physics for the multi-body deuteron fusion processes with participation of 3rd and 4th hadrons[8,9,11,13,14,15)]. Multi-body fusion process may be enhanced under the ordering process of condensed matter in transient dynamics motion constraining deuterons and associating electrons. Latest idea of the author is formation of transient pseudo-molecule of tetrahedral symmetric condensate (TSC) that is orthogonally coupled state of two D_2 molecules under central squeezing motion by three dimensionally constraint condition. TSC is charge neutral quasi-particle having 40-80 fs very short life time and composed of orthogonally coupled two regular tetrahedrons of 4 deuterons and 4 electrons respectively. Feature of quantum-mechanical electron clouds of TSC at t = 0, when it is just formed, is shown in Fig.4, comparing with stable D atom and D_2 molecule.

We treated the 3-dimensional squeezing motion of TSC using semi-classical formulation, and calculated barrier penetration probabilities and fusion rates for 2D, 3D and 4D reactions[15, 16].

Method and Results

- Permeate D_2 gas through Pd complex adding Cs or Sr on the surface.
- D_2 gas flow is over 1 sccm and test piece is heated up to 343 K.
- Confirmed decreasing Cs and increasing Pr.



$$^{133}_{55}Cs \rightarrow ^{141}_{59}Pr \text{、} ^{88}_{38}Sr \rightarrow ^{96}_{42}Mo$$

Nuclear Transmutation ?

Fig.3: Selective transmutation results by MHI Iwamura group[5)]

A schematic view of the process for TSC condensation and 4D fusion reaction is shown in Fig.5. For simplicity, electron center by superposition of three combined orbits of two electrons ("bosonized pair") with anti-parallel spins (singlet spin wave function) is drawn as a classical electron particle, in the figure. We assume that charge neutrality is time-dependently kept for TSC of 4 deuterons plus 4 electrons, because of system energy minimum requirement by variational principle. And taking into account the 3-dimensionally symmetric condensation motion of TSC into central focal point, total time-dependent TSC wave function is approximated with the linear combination of time-dependent partial wave functions of normal D_2 molecule dde(1,1)e(1,1) and quasi-molecules (EQPET molecules) dde*(2,2) and dde*(4,4). Here, e*(2,2) is microscopic Cooper pair and e*(4,4) is electron quadruplet (orthogonal coupling of two microscopic Cooper pairs forming regular tetrahedron[8, 9)].

According to the time-dependent decrease of mutual distance of two electron centers, we introduce adiabatic approximation to use the screened electron potential of dde(1,1)e(1,1) for initial condition, then switch to the potential of dde*(2,2) when b-parameter[8)] reaches at one for dde*(2,2) and finally switch to the potential of dde*(4,4) when b-parameter reaches at one for dde*(4,4). With this algorism, we made a computer code and solved the time-dependent problem[16]. Results of time-dependent fusion rates for 2D and 4D reactions are shown in Fig.6. Then we calculated time-averaged fusion rates for the TSC condensation motion, as follows:

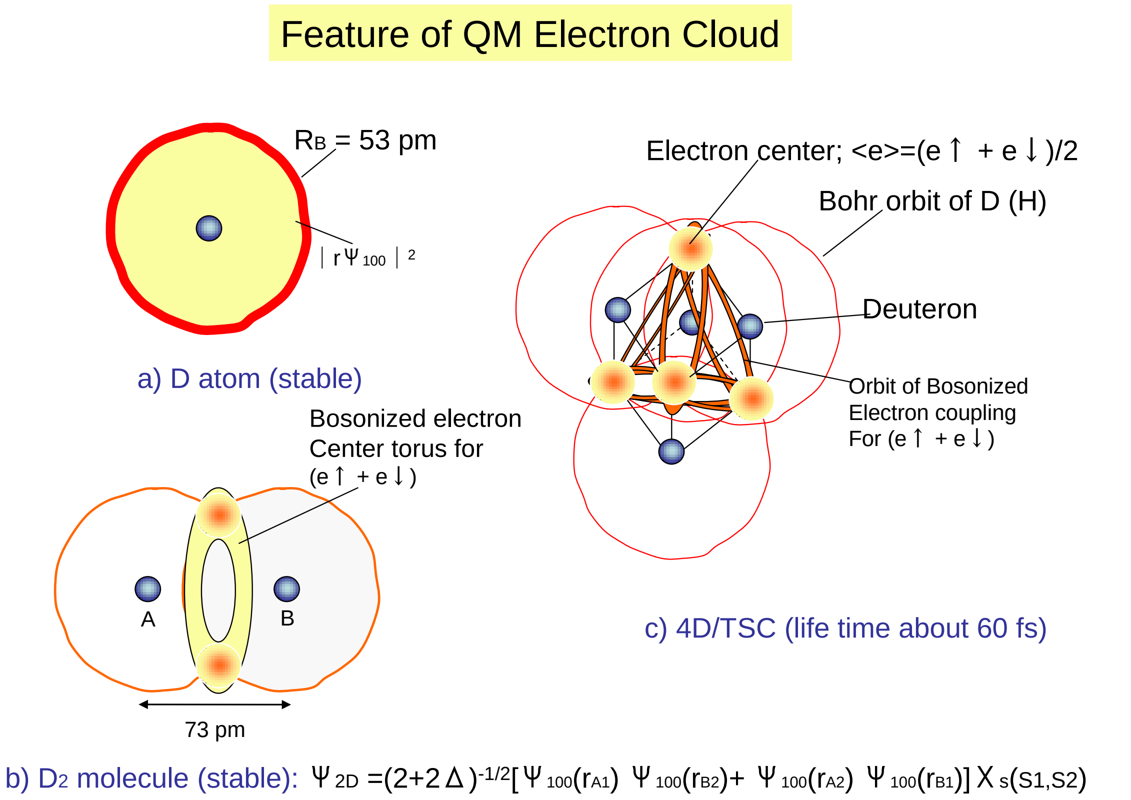


Fig.4: Feature of electron orbits of 4D/TSC (t=0), compared with D-atom and D_2 molecule

$$<\lambda>_{2D} = 3E\text{-}25 \text{ f/s/cl},$$

$$<\lambda>_{4D} = 6E\text{-}8 \text{ f/s/cl}$$

Here cl means cluster of deuterons. Fusion reactions take place effectively in 0.04 fs, so short time interval of squeezing motion. Therefore, the modeled phenomenon is pure transient and dynamic constraint motion. However, λ_{4D} = 2.3E-4 f/s/cl was estimated[15] for minimum state 4D/TSC, and this corresponds to life time 71.7min (so long) of minimum 4D/TSC if strong interaction is only one cause to break charge neutrality. We need further study to take quantum mechanical fluctuation of TSC squeezing motion into account to evaluate more accurately TSC-minimum life time.

By supposing TSC density on the order of 10^{22} tsc/cc, macroscopic 2D fusion rate becomes $3\text{x}10^{-3}$ f/s/cc which is hardly low level to observe neutrons from the d + d $\rightarrow$ ^{3}He + n + 3.25MeV channel. On the contrary, 4D fusion rate becomes $6\text{x}10^{14}$ f/s/cc which corresponds to 6 kW/cc very large power density by energy production rate of 23.8 MeV/^{4}He from the 4D → ^{8}Be* → ^{4}He + ^{4}He + 47.6 MeV channel. Secondary reactions by 23.8 Mev α-particle are with low levels[8, 9].

As shown in Fig.5-2), minimum size of TSC becomes[15] about 10 fm. Since TSC can be regarded as a charge–neutral pseudo-particle, TSC may penetrate through electron clouds of host metal atom, which has about 100 pm radius for outer most orbit and 1 pm for inner most K-shell orbit, as if TSC around its minimum size-state were like neutron. There happens then chance to make direct nuclear

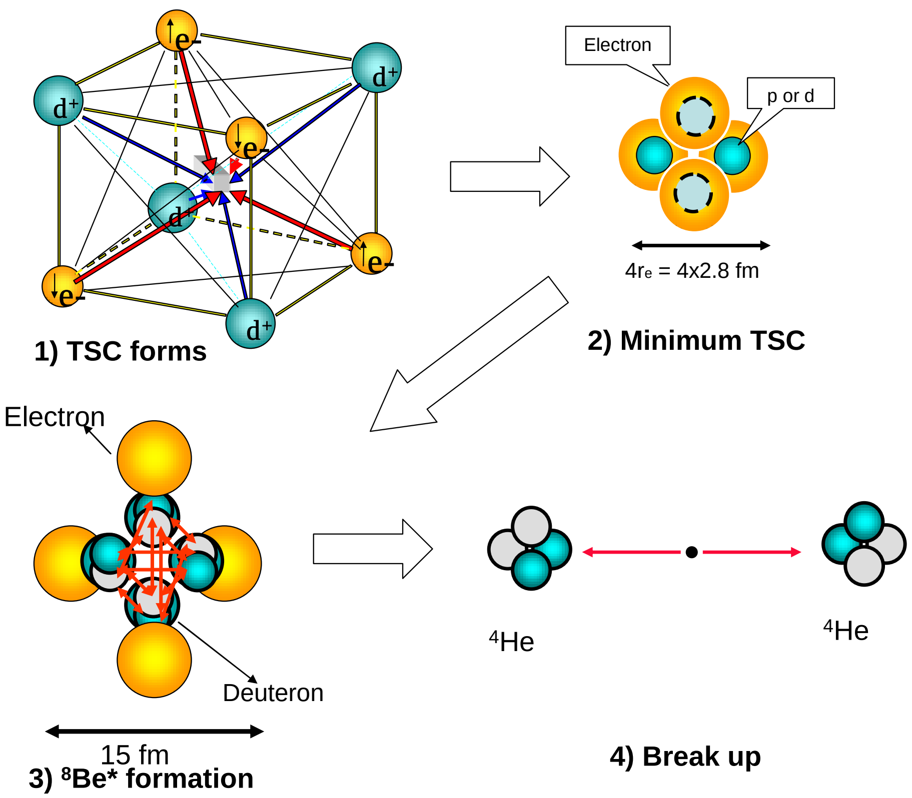


Fig.5: Schematic view of time-dependent condensation motion and 4D fusion by TSC[15]

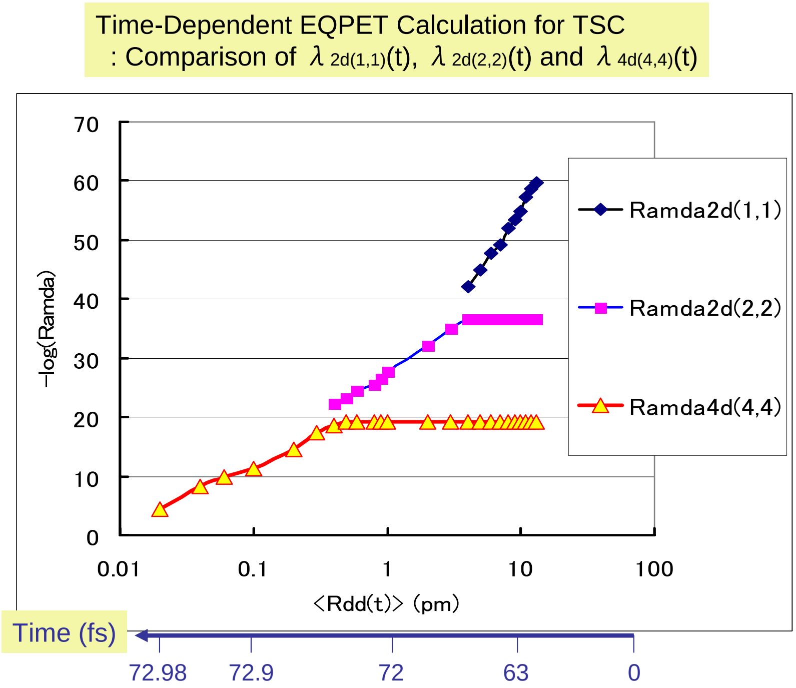


Fig.6: Time-dependent fusion rates for 2D and 4D reactions by TSC condensation motion[16)]

interaction (absorption and transmutation) with host metal nucleus. The feature of such TSC-induced host metal nuclear reaction is shown in Fig.7 and Fig.8.

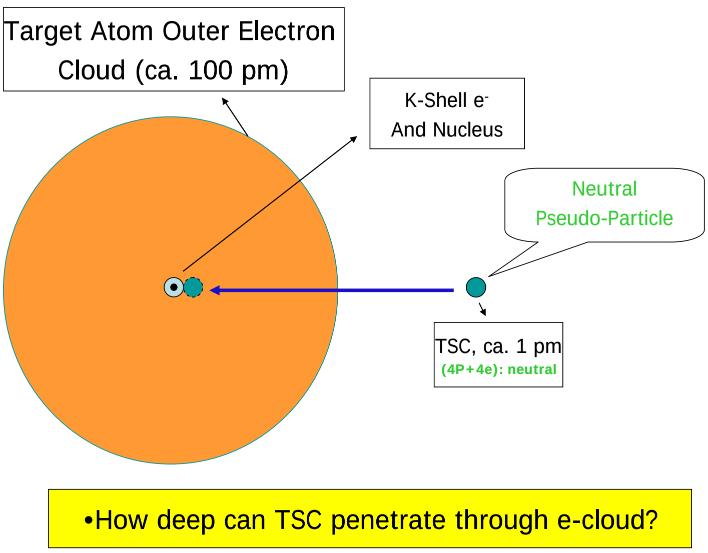


Fig.7: Feature of TSC penetration through electron clouds of host metal atom and approaching central nucleus

Nuclear reaction rates in this process can be approximately estimated by STTBA (sudden tall thin barrier approximation) method[9, 15]. Selective transmutation by Iwamura[6] can be explained by the process of Fig.8.

$$M(A, Z) + 4D/TSC \rightarrow M(A+8, Z+4) + Q$$

And TSC condensation may take place also for 4H/TSC as pure proton-electron system, so that we can extend analyses to M(A, Z) + 4H/TSC nuclear interaction. Since we have no strong interaction between protons around minimum TSC size, the process becomes competing among M + p, M + 2p, M + 3p and M + 4p reactions. Especially, intermediate compound nucleus by M + 4p reactions may have high excited energies as around 30 MeV to induce fission channels. For making analysis of fission product distribution based on a deterministic fission model, we introduced SCS (selective channel scission) theory[13], and got some quantitative results[15]. Anomalous generation of foreign elements without hard radiations as claimed by Miley[7], Mizuno, Karabut, and so on, can be explained consistently by calculated results of the present theory. Fission products of these processes by SCS model can be mostly stable isotopes and neutron emission is very much low[15].

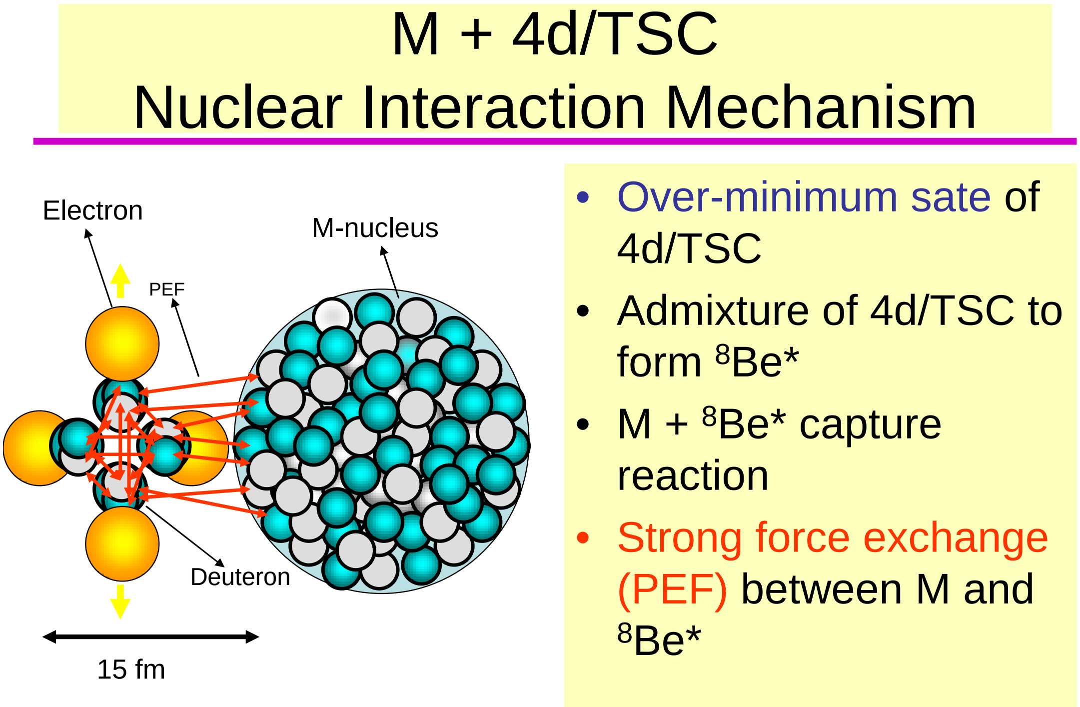


Fig.8: Schematic view of TSC-induced nuclear reaction with host metal nucleus

4. Concluding Remarks

We reviewed major results of recent studies on condensed matter nuclear effects. The phenomena and relevant science field are far from the original thought of "cold fusion", and we have to recognize the emergence of new field of Condensed Matter Nuclear Science.

Clean deuteron-related fusion and cold transmutation of metal are most significant consequences form latest studies. An overall consistency between consequences of EQPET/TSC models and results of various experiments has been reported in this review (see Table-1 as summary).

However, theoretical models are still in primitive stage and experiments need to clear reproducibility with more frequent results.

References

1. J. Kasagi, et al: *J. Phys. Soc. Jpn*. 71(2002)2881.
2. A. Takahashi, et al.: *Physics Letters A*, 255(1999)89.
3. M. McKubre, et al: Proc. ICCF10, Boston, 2003, see http://www.lenr-canr.org/
4. Y. Arata: *Il Nuovo Aggiatore*, Jan. 2005, p.66-71
5. El Boher, et al: ppt slide of ICCF11, Marseilles, November 2004, see http://www.iscmns.org/
6. Y. Iwamura, et al.: *Jpn. J. Appl. Phys.*, 41(2002)4642
7. G. Miley, J. Patterson : *J. New Energy*, 1(1996)5
8. A. Takahashi: Deuteron cluster fusion and ash, Proc. ASTI5 WS, Italy, March 2004, see http://www.iscmns.org/
9. A. Takahashi: Deuteron cluster fusion and related nuclear reactions in metal-deuterium/hydrogen systems, *Recent Developments in Physics*, Transworld Research Network, India, 6(2005), pp.1-28: ISBN=81-7895-171-1
10. A. Huke: Ph D thesis, Technical University of Berlin, 2004
11. A. Takahashi, et al.: *Fusion Technology*, 27(1995)71
12. see many papers in http://www.lenr-canr.org/
13. A. Takahashi, et al: *Jpn. J. Appl. Phys.*, 41(2001)7031
14. A. Takahashi: TSC-induced nuclear reactions and cold transmutations, Siena Workshop on Anomalies in D/H loaded metals, Siena, Italy, 13-16 May 2005: http://www.iscmns.org/
15. A. Takahashi: A theoretical summary of condensed matter nuclear effects, ibid.
16. A. Takahashi: Time-dependent EQPET analysis of TSC, to be presented at ICCF12, Yokohama, Nov. 2005