^{3}HE/^{4}HE PRODUCTION RATIOS BY TETRAHEDRAL SYMMETRIC CONDENSATION

AKITO TAKAHASHI
Osaka University, Yamadaoka 2-1, Osaka, 565-0871 Japan, E-mail:akito@sutv.zaq.ne.jp

The present paper treats application of the EQPET (Electronic Quasi-Particle Expansion Theory) model for TSC (Tetrahedral Symmetric Condensate) of H/D mixed systems for Pd host metal. Production ratios of ^{3}He/^{4}He for multi-body fusion reactions in H/D mixed TSC systems are calculated as a function of H/D mixing rate. The model is further extended to treat direct nuclear interactions between host-metal nucleus and TSC of pure 4 protons (or 4 deuterons), since TSC can become very small (far less than 1 pm radius) charge-neutral pseudo-particle. Results for the case of Ni + 4p/TSC are discussed with Ni + p capture reactions and Ni + 4p fission reactions.

1 Introduction

Tetrahedral Symmetric Condensate (TSC), for example, by orthogonal coupling of two D_2 molecules (4 deuterons plus 4 electrons), has been proposed as a seed of clean fusion in condensed matter$^{1)}$. Applying the EQPET (Electronic Quasi-Particle Expansion Theory) model, modal fusion rates for 2D, 3D, 4D and 8D fusion reactions in TSC and OSC (Octahedral Symmetric Condensate) were numerically estimated. These analyses could explain consistently the major experimental results of excess heat with ^{4}He ash, minor tritium generation, very weak neutron emission, and transmutation and fission of host metal nuclei [1, 2, 3].

In this work, the theory was extended to analyses for H/D mixed systems. It is concerned that usual D_2O electrolysis experiments with open cells and Pd cathodes would be contaminated with hydrogen (H) as experimental time elapses. Modal fusion rates for HD, DD, DDDD, HDDD and HDHD fusion reactions were calculated by EQPET, as a function of H/D mixing ratio. ^{3}He is produced by HDHD and HDDD reactions. As a result, ^{3}He/^{4}He ratios were given as a function of H/D ratio, to be for example ^{3}He/^{4}He = 0.1% for H/D=1% and ^{3}He/^{4}He=25% for H/D=60%. Secondary transmutation reactions by ^{3}He-particles were estimated to have very small reaction rates.

Discussions are added for the pure hydrogen TSC (4p plus 4e). Since the EQPET model gives approximate size of TSC to be less than 1 pm in radius, TSC will behave as a “charge-neutral pseudo-particle” when it approaches to a host metal atom which has much larger atomic (electron cloud) radius than 100 pm (1 angstrom). We may expect therefore direct nuclear interaction between TSC and host metal nucleus, because TSC can drastically reduce Coulomb barrier to host nucleus. Thus, we have a possibility of nuclear reactions as Ni+p, Ni+4p, Pd+4d, W+4p, Cs+4d, etc. with highly enhanced reaction rates. The present theory may therefore explain a variety of claims for H- or D-systems.

For candidate places where TSC is formed, we have considered two cases;

A) TSC may be formed within a thin layer (1-100 nm thickness) of the surface lattice of metal-deuteride with full D-loading. TSC-induced multi-body fusion in PdDx lattice dynamics is modeled for this case [1-3].

The following case of theoretical modeling of H/D mixed systems with PdDx has done for the case of A), namely for regular metal-deuteride lattice.

B) D_2 trapping points on fractal metal surface which is such place like corner holes near ad-atoms plus dimmers will be the second candidate.

In the case B), we consider a trapped D_2 has lost freedom of rotating motion but is vibrating and waiting for coming-in D_2 molecule to make an orthogonal TSC coupling. When there meets coherence in vibrations of two D_2 molecules with anti-parallel spin arrangement, TSC formation probability will be drastically increased. The following case of theoretical modeling for Ni + H systems has done for the case of B).

2. H/D MIXED SYSTEMS

Some works have reported observation of significant amount of ^{3}He generation in heavy water electrolysis with Pd cathodes. They claimed that observations were ascertained by high resolution mass spectrometry (QMAS). Especially, Arata and Zhang [4] claimed very high amounts of ^{3}He production, namely ^{3}He/^{4}He atomic ratio 0.25 with 1E+18 to 1E+19 ^{4}He atoms which are comparable to excess heat level assuming 23.8 MeV per ^{4}He. Note that 4D/TSC fusion produces two 23.8 MeV ^{4}He particles in 180 degree opposite directions by the break-up (final state interaction) of ^{8}Be* compound nucleus of 4d multi-body fusion [1-3].

The author predicts that ^{3}He have come from products of multi-body fusion reactions in H/D mixed TSC pseudo particles. In open-cell-type electrolysis experiments, experimentalists are concerned of contamination of hydrogen in liquid (electrolyte) when we continue long time runs of experiments.

By applying the TSC model with EQPET, we can estimate ^{3}He/^{4}He production ratios for H/D mixed systems. By replacing one or two deuterons in 4D/TSC with one or two protons, we treat the system. Basic 4-body fusions in mixed H/D systems will be the following three multi-body fusion reactions;

$$D + D + D + D \rightarrow {}^8\text{Be}^* \rightarrow {}^4\text{He} + {}^4\text{He} + 47.6\ \text{MeV} \quad (1)$$

$$D + D + D + H \rightarrow {}^7\text{Be}^* \rightarrow {}^3\text{He} + {}^4\text{He} + 29.3\ \text{MeV} \quad (2)$$

$$D + H + D + H \rightarrow {}^6\text{Be}^* \rightarrow {}^3\text{He} + {}^3\text{He} + 11.0\ \text{MeV} \quad (3)$$

Minor out-going channels of three reactions are discussed elsewhere [5].

Combination probabilities of TSC for H/D mixed system can be approximately estimated using Y = H/D atomic density ratio, as follows:

$$C_{DDDD} = k(1 - Y)^4 \quad (4)$$

$$C_{DDDH} = k(1 - Y)^3Y \quad (5)$$

$$C_{DHDH} = k(1 - Y)^2Y^2 \quad (6)$$

$$C_{DHHH} = k(1 - Y)Y^3 \quad (7)$$

$$C_{HHHH} = kY^4 \quad (8)$$

We set here normalization constant k to keep total probability to be unity.

Calculated combination probabilities as a function of H/D ratio are shown in **Fig. 1**.

The contamination rate of hydrogen is given as Y/(1 + Y), and we need to convert it from Y value. For instance, 50 % H/D ratio corresponds to contamination of 33.3 %.

Microscopic fusion rates for mixed H/D EQPET molecules are calculated by the following equations. Here barrier penetration probability for 4-body reaction is approximated by the product of two-body probabilities as rapid sequential two-body processes [3]. P(dd) denotes the barrier penetration probability for d-d interaction, and P(pd) denotes for p-d interaction.

$$\lambda_{dddp} = (S_{dddp}/E)vP(dd)P(dp) \quad (9)$$

$$\lambda_{dpdp} = (S_{dpdp}/E)vP(dp)P(dp) \quad (10)$$

We estimate S-values using PEF = 9 for DDDH and PEF = 6 for DHDH, as we have discussed for strong interaction and shown scaling law in Ref.3.

S_{dddp} = 1.0E+9 keVb (11)

S_{dpdp} = 1.0E+8 keVb (12)

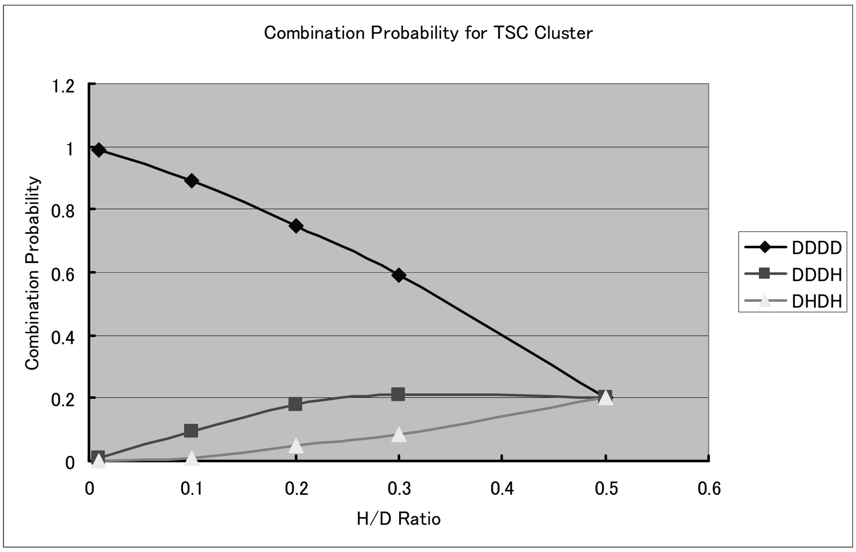

Fig. 1: Combination probabilities of H/D mixed TSCs as a function of H/D ratio

And the barrier penetration probability P(dp) for d-p fusion (or d-d fusion) is given as,

$$P(dp\ or\ dd) = \exp(-2\Gamma_n) \quad (13)$$

And Gamow integral is given by,

$$\Gamma_n = \int_{r0}^{b} (V_s - E)^{1/2} dE/((h/\pi)/(2\mu)^{1/2}) \quad (14)$$

Here we carry out integration from r_0 (5 fm) to b-value. Screening potentials for pde* become the same curves as dde* EQPET molecules which we have shown elsewhere [1, 3]. And μ is reduced mass for two-body system, which is 0.667 for d-p pair and 1.0 for d-d pair, respectively.

Microscopic fusion rates of EQPET molecules for mixed H/D system are calculated and given in **Table I**. We omit here 3-body reactions for simplicity.

Table I: Fusion rates of H/D mixed EQPET molecules; values with parenthesis show virtual reaction rates.

EQP e*	dde* (f/s/cl)	dpe* (f/s/cl)	dddde* (f/s/cl)	dddpe* (f/s/cl)	dpdpe* (f/s/cl)
(1, 1)	1.0E-137	1.0E-120	1.0E-252	1.0E-232	1.0E-228
(2, 2)	1.0E-20	1.0E-23	1.0E-17	1.0E-16	1.0E-14
(4, 4)	(1.0E-16)	(1.0E-21)	1.0E-9	1.0E-10	1.0E-10

Electronic quasi-particle states are represented here as e*(1,1) for normal electron, e*(2,2) for Cooper pair and e*(4,4) for quadruplet [1,3], respectively. Wave function of TSC cluster is written by EQPET [1-3] as linear combination of EQPET molecule dde* wave functions;

$$\Psi_{tsc} = a_1\Psi(1,1) + a_2\Psi(2,2) + a_4\Psi(4,4) \qquad (15)$$

Modal fusion rates are given by,

$$\lambda = a_1^2\lambda(1,1) + a_2^2\lambda(2,2) + a_4^2\lambda(4,4) \qquad (16)$$

Using the same weights (a-parameters) for spin arrangement given in Reference 1 and 3, and using fusion rates of EQPET molecules in Table I. We obtain modal fusion rates as shown in **Table II**.

Table II: Modal fusion rates for H/D mixed TSC

DDDD-TSC	DDDH-TSC	DHDH-TSC
λ_{dd} = 2E-21 (f/s/cl)	λ_{dp} = 1E-23 (f/s/cl)	λ_{dp} = 1E-23 (f/s/cl)
λ_{4d} = 3E-11 (f/s/cl)	λ_{dddp} =4E-12 (f/s/cl)	λ_{dpdp} = 1E-12 (fr/s/cl)

Here fusion rates are given as fusions per sec per cluster.

Using combination probabilities in Fig. 1 and modal fusion rates in Table II, we obtain ^{3}He/^{4}He production ratios as shown in **Fig. 2**.

With H/D ratio of 1 %, we predict to have ^{3}He/^{4}He ratio of 0.1 %. With H/D ratio of 50 % , we have ^{3}He/^{4}He ratio of 16 %. To get the same value of ^{3}He/^{4}He ratio by Arata-Zhang experiment [4], we assume H/D ratio of 60 % (37.5 % H-contamination in heavy water).

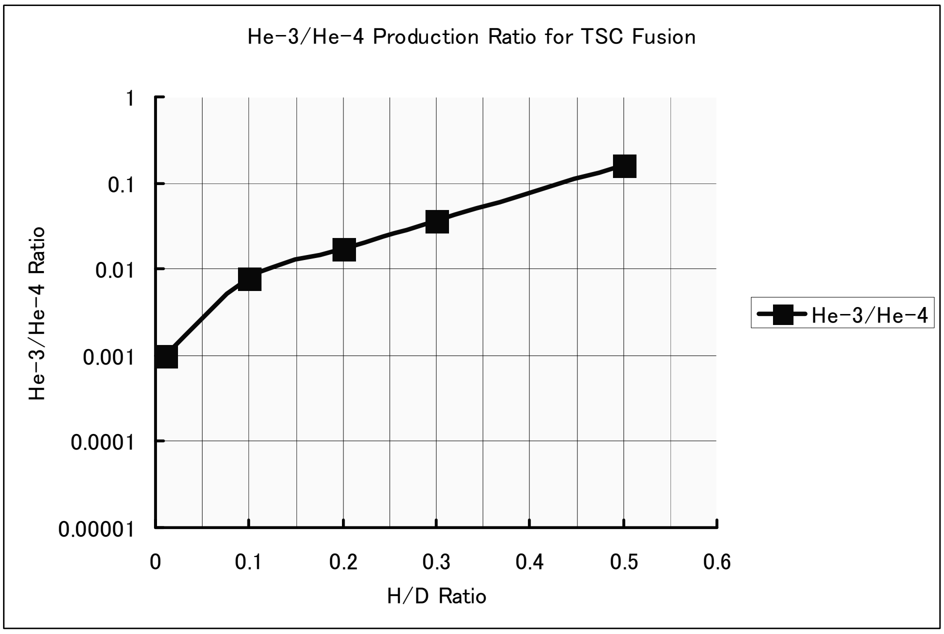

Figure 2: ^{3}He/^{4}He production ratios as a function of H/D atomic density ratio

The production of ^{3}He by H/D mixed systems must become very important, when it will be confirmed by experiments. Since ^{3}He is stable isotope and we can convert to tritium by irradiating with fission reactor neutron flux and extract tritium rather easily, ^{3}He production has a great potential for stable nuclear fuel.

3. TSC-INDUCED NUCLEAR REACTIONS

3.1 Minimum Size of TSC

In our theoretical view, size of TSC (Tetrahedral Symmetric Condensate) of 4 deuterons (or protons) + 4 electrons (with anti-parallel spin arrangement) will become very small as far less than 1 pico-meter, as shown in Fig. 3. This is because of the 3-dimensionally constrained charge-neutral (energy-minimum for Coulomb interaction) squeezing motion to a central focal point, and TSC will expand finally when 4 deuterons reach the strong force range (in the domain of several femto-meter radius volume) to make a pseudo-atomic state e*(4,4)^{8}Be* which has 0.8 pico-meter radius for e*(4,4) orbit (atomic radius). The charge-neutral state of TSC corresponds to the energy-minimum state of system Hamiltonian, and therefore satisfies the solution of variational principle of quantum mechanics. This special condition of TSC makes semi-classical treatment of motion possible.

We note here that electrons do not make strong interaction, and thus have to go outside of ^{8}Be* compound nucleus when 4d/TSC gets into the range of strong interaction.

The size (radius) of TSC pseudo-particle decreases linearly and semi-classical treatment of motion is possible, due to 3-dimensionally constrained motion to central focal point, until the time when TSC charge-neutrality is broken by getting into the range of nuclear strong interaction (about 5 fm range). This feature is illustrated in **Fig. 3**

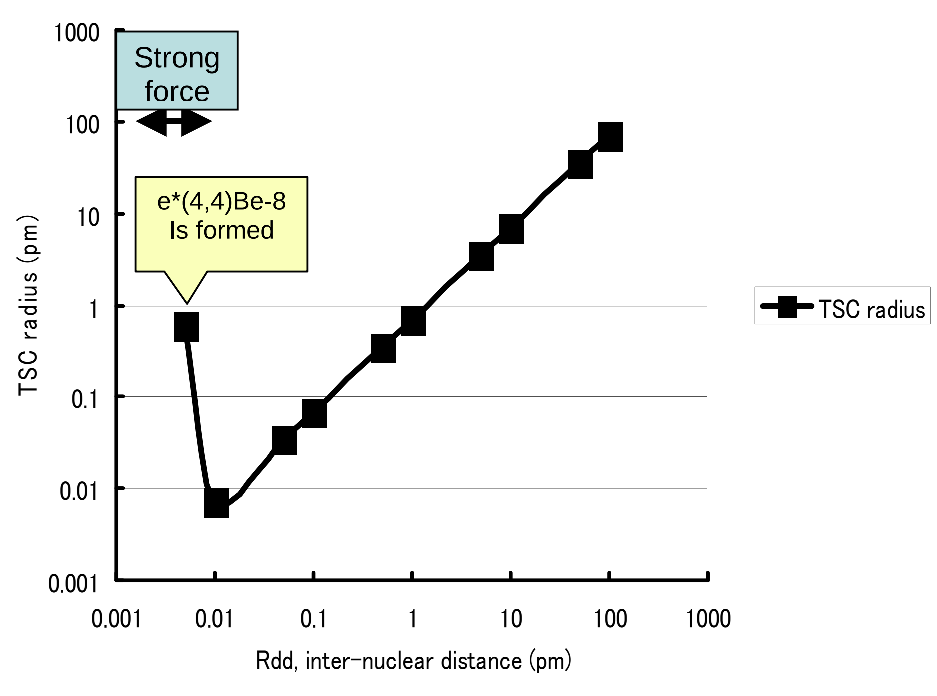

Figure 3: Squeezing of TSC by 3-dimensionally constrained motion

3.2 Sudden Tall Thin Barrier Approximation

In the case of 4p/TSC, we have no strong interaction for fusion (except scattering among protons) and Pauli's exclusion principle for fermions will be the only limitation to stop squeezing of 4p/TSC. This is why heavy water electrolysis produces ^{4}He ash of 4d multi-body fusions with excess heat, but light water electrolysis makes neither ^{4}He production nor excess heat, by cluster fusion induced in TSC itself. However, we have had to consider more for pure proton-TSC.

There is the case that very small condensate of TSC can behave as a CHARGE-NEUTRAL PSEUDO-PARTICLE; not only 4d/TSC but also 4p/TSC can "freely" (like a neutron) penetrate through shell-clouds of electrons (which have outer-most radius more than 100 pm and inner-most K-shell radius of about 1 pm), thus "almost" avoiding Coulomb repulsion, to make direct nuclear-strong interaction with host metal nucleus with drastically enhanced reaction rate. The feature is illustrated in **Fig. 4**.

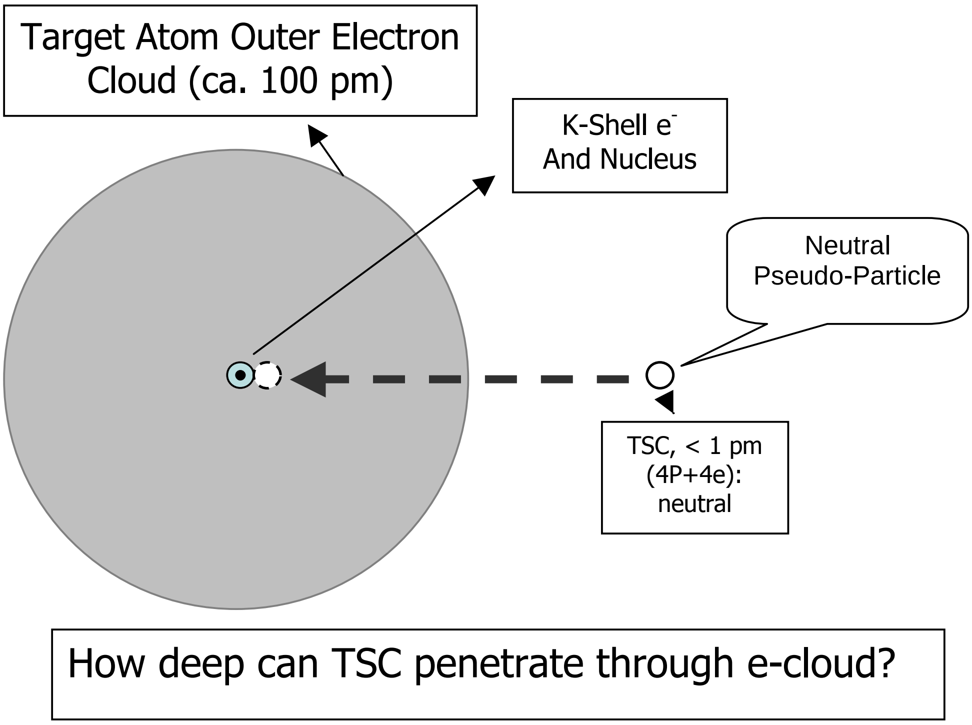

Figure 4: Penetration of neutral-pseudo-particle of TSC through electron clouds of host metal atom, of which inner most K-shell electron orbit has about 1 pm radius for Z>30. Minimum size of TSC attained in about 60 fs will be far less than 1 pm.

Therefore we have the possibility that TSC will make a direct nuclear interaction with host metal nucleus, when TSC gets into the strong interaction range, as shown in **Fig. 5**.

Strong interaction between M-nucleus (host-metal) and TSC takes place as charged-pion exchange between protons of TSC (or virtual-neutrons and virtual-protons for deuteron-TSC) and virtual-neutrons in nucleus. Number of PEF (Pion Exchange Force) is again the scaling rule for estimating the reaction S-values [3]. Electrons in the TSC do not make strong interactions, and are rejected outside when the TSC gets into the strong interaction range for exchanging charged pions (for fusion) and neutral pions (for scattering). Note here that the conjecture of neutron plus proton states in nucleus is virtual, since no independent n with long life or p particles exist within nucleus. An independent neutron decays in about 10 minutes (hence it destroys nucleus to disintegration). Therefore strong force exchange (pion-exchange between virtual n and p) is so fast that n plus p image is only virtual for hadron-admixture of nucleus.

When the strong interaction starts, the charge-neutrality of TSC is suddenly broken and 4 protons (or 4 deuterons) suddenly feel Coulomb repulsion against M-nucleus. The Coulomb barrier height is very large as 10 MeV, but its width is very small since the TSC has already approached very close (2-5 fm distance) to M-nucleus. Because of such special conditions, we can formulate simple mathematics to treat the M-nucleus plus TSC nuclear interaction, which we call the Sudden Tall Thin Barrier Approximation (STTBA), as follows.

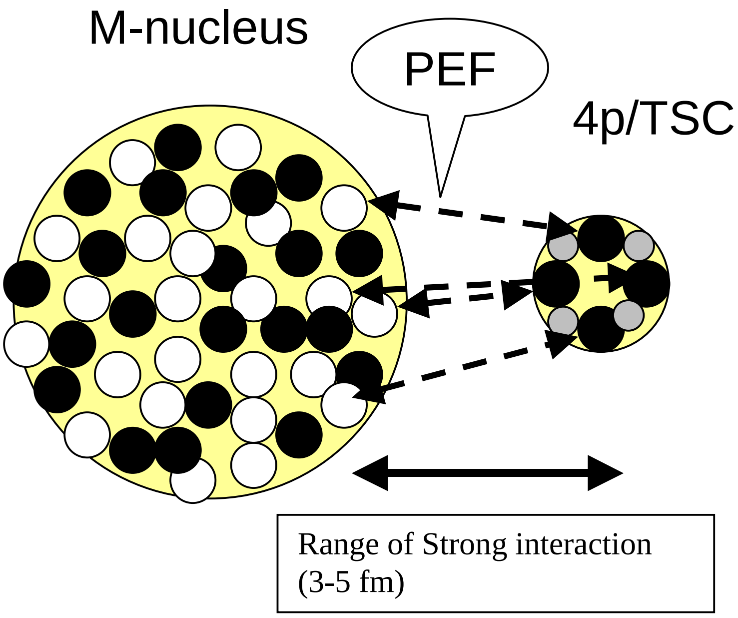

Figure 5: M-nucleus + TSC nuclear interaction mechanism; smaller circle in TSC show electron.

As shown in Fig. 5, we need to consider the topological conditions for charged-pion exchange (PEF), the selection process of plural protons (or deuterons) to be picked up by M-nucleus and the M + (1 to 4) protons (or deuterons) capture reactions. When p (or d) of TSC gets into the strong force range, electrons in TSC will have to separate and p (or d) will "feel suddenly" a very tall but thin Coulomb repulsion barrier against the host metal nucleus. And 4 protons (nor 4 deuterons) of TSC are not combined by the strong force and therefore behave independently.

The nuclear reaction rate between TSC and M-nucleus can be calculated by the following sudden tall thin barrier approximation (STTBA).

$$\lambda = S_{Mp}(E)vP_M(E)P_n(E)/E \tag{17}$$

$$P_M(E) = \exp(-G) \tag{18}$$

$$G = 0.436(\mu V(R_{1/2}))^{1/2}(b - r_0) \tag{19}$$

Here we write V in MeV unit and r in fm unit. The Gamow integral Eq.(14) is replaced with a simple approximated formula G. And,

$$R_{1/2} = r_0 + (b - r_0)/2 \tag{20}$$

$$b = r_0 + \lambda_\pi \tag{21}$$

$$r_0 = 1.2A^{1/3} \tag{22}$$

And $P_n(E)$ gives the co-existence probability of plural p (or d) in the strong interaction range. The range of pion λ_π is used here to be 2.2 fm. $P_n(E)$ is approximated by using barrier penetration probability of p-p pair for sudden tall thin barrier height V_{pp} (about 0.24 MeV) in mutual distance R_{pp} (about 6 fm) for minimum radius of TSC drawn in Fig. 3.

$$P_n(E) = \exp(-\ 0.218n(\mu V_{pp})^{1/2}R_{pp}) \qquad , \text{for } n > 1, \qquad (23)$$

$$= 1.0 \qquad , \text{for } n = 1, \qquad (24)$$

In Eq.(17), S-values for M + p to M + 4p (M + d to M + 4d) reactions are treated as same values, since PEF numbers for M(A, Z) + p to M(A+3, Z+3) + p are considered not to change significantly due to the saturated trend of charged pion exchange between p of TSC and neutron-nucleons in the near surface of M-nucleus.

An example of STTBA calculation for Ni of host atom, we obtain microscopic reaction rates as 3.7E-8 (f/s/pair) for Ni + p, 2.1E-7 (f/s/pair) for Ni + d, 1.0E-8 (f/s/pair) for Ni + 4p, 3.4E-9 (f/s/pair) for Ni + 4d reactions, respectively. Here we use $S_{Mp}(0)$ = 1.0E8 keVb and $S_{Md}(0)$ = 1.0E9 keVb, and P(pp) = 0.527 and P(dd) = 0.404.

With assumption of M+TSC pair density of 1.0E17 in 10 nm layer of Ni surface, we obtain 1E+9 f/s/cm^2 reaction rate, which is about 5 mW/cm^2 for Ni + 4p to fission process [6]. Fission products for Ni + 4p reactions have revealed to be mostly radiation-less (clean), coming from higher mass isotopes of Ni as ^{62}Ni for example,

$$^{62}\text{Ni} + 4p \rightarrow {}^{66}\text{Ge(Ex=24.0 MeV)} \rightarrow \text{fission products} \qquad (25)$$

Major fission channels of ^{62}Ni + 4p fission is shown in Table III.

Table III: Major fission channels for ^{62}Ni + 4p reaction, after one month cooling

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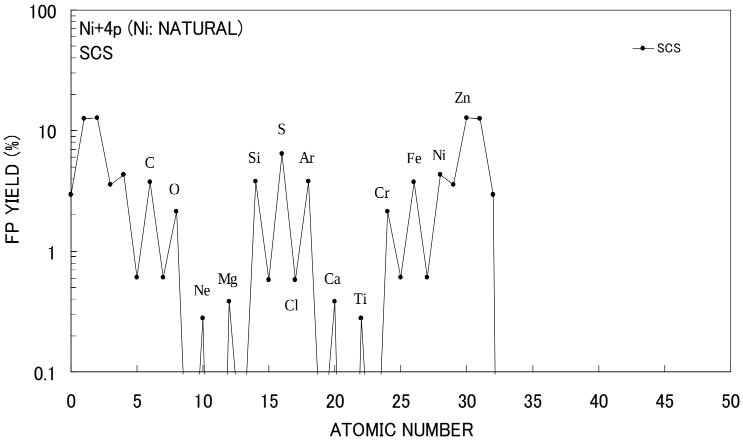
^{62}Ni(3.6%) + 4p → ^{66}Ge(Ex=24.0MeV)*

→ 11.0MeV + n + ^{65}Ge(EC)^{65}Ga(EC)^{65}Zn
→ 21.4MeV + ^{4}He +^{62}Zn(EC)^{62}Cu(EC)^{62}Ni
→ 11.5MeV + ^{8}Be + ^{58}Ni
→ 18.9MeV + ^{12}C + ^{54}Fe
→ 10.5MeV + ^{14}N + ^{52}Mn(EC)^{52}Cr
→ 8.2MeV + ^{16}O + ^{50}Cr
→ 13.9MeV + ^{20}Ne + ^{46}Ti
→ 15.2MeV + ^{24}Mg + ^{42}Ca
→ 13.7MeV + ^{27}Al + ^{39}K
→ 18.9MeV + ^{28}Si + ^{38}Ar
→ 18.6MeV + ^{32}S + ^{34}S

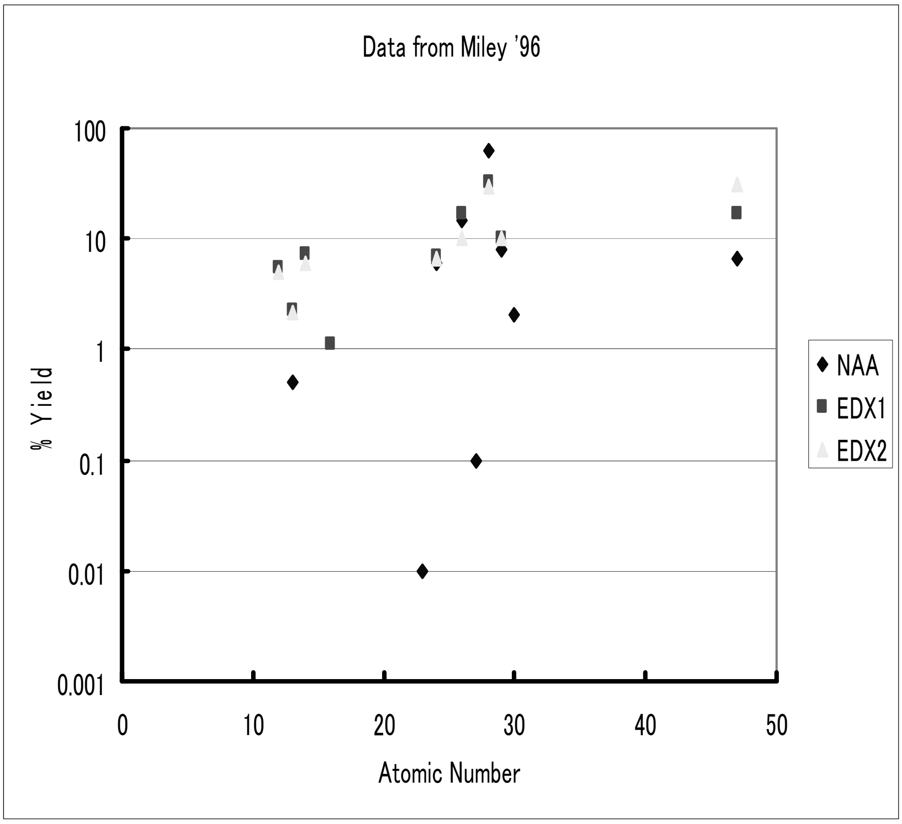
Note: natural abundance of ^{62}Ni is 3.6 %

From Table III, we see fission products are almost all stable isotopes. However we may have small branch (less than 3 %) of neutron emission channel, of which we need further careful study.

Element (Z) distribution of fission products for natural Ni is shown in **Fig. 6** (a), compared with Miley-Patterson Ni-H system experiment [7].



(a) SCS theory calculation [6]



b) Miley-Patterson data [7]

Fig. 6: Comparison of Ni + 4p fission products and Miley-Patterson results

We see consistent agreement for two peak groups over Z = 10 (Ne), though law Z data are not available in experiments [7]. Probably O and C, if they exist, are difficult to analyze due to contaminants.

The formation of TSC in near surface region of host Ni layer will be classified by the mechanism B) as written in Introduction, since it is well known that volumetric hydrogen (deuterium) absorption with full loading is very difficult for a nickel layer. The situation will be in quite a different form in the case of hydrogen (deuterium) loading into Pd layer, for which we proposed the mechanism A). We speculate therefore that Ni + H reaction will be catalyzed on the highly fractal surface to form TSC with incoming H_2 (or H^+) flux. As shown in Fig. 3, the size of TSC is changes dynamically from about 100 pm radius to its minimum radius of about 6 fm within its lifetime (about 60 fs). During this dynamic motion, TSC will approach the host metal nucleus. We have not yet studied how to treat this dynamic motion correctly. STTBA is the first order approximation. The inner most K-shell orbit of electron for Ni has 1.9 pm radius, which is larger than 1.15 pm for Pd and 0.58 pm for U, respectively. Therefore the charge-neutral pseudo-particle TSC can have a longer interaction time for M + TSC nuclear interaction for lighter elements like Ni. When TSC makes a strong interaction from a more distant b-parameter than we used in the above mentioned example calculation of STTBA, s proton of 4p/TSC has much larger barrier penetration probability than the deuteron of 4d/TSC: this may be the reason why Ni + protons interaction were thought to be more easily observed in experiments [7, 8].

So, we need further studies with different host metals with different size K-shells, according to the dynamic interaction between M and TSC. Applications of STTBA to other M + TSC reactions as Pd + 4p, W + 4p, Cs + 4d, Au + 4p, U + 4p, etc are under way.

When we apply STTBA to 4d fusion, we get λ_{4d} = 4.9E-5 f/s/cl which is a very high value, and by assuming TSC density as 1E20 (per cc) we predict the macroscopic yield (see below) to be on the order of 1E15 f/s/cc that is equivalent to a power level of 10 kW/cc. This will give maximum 4D fusion rate attainable in PdD systems. For assuming TSC density, we considered the mechanism A) with high phonon excitation (0.22 eV for PdD) and about 3 % weight for anti-parallel spin arrangement for 4 electrons of TSC, also assuming D density on the order of 1E22 (atoms/cc).

The macroscopic reaction rate Y (f/s/cc) for M+TSC reaction is given by

$$Y = N_{M+TSC}\lambda \qquad (26)$$

Here we have to estimate the density N_{M+TSC} of "united molecule" M+TSC in atomic level.

$$N_{M+TSC} = \sigma_A N_M N_{TSC} v \tau_{TSC} \qquad (27)$$

N_M is the host metal atom density, N_{TSC} the time-averaged TSC density, σ_A the atomic level cross section (about 1.0E-16 cm^2) for M+TSC combination, and τ_{TSC} the mean life of TSC (about 60 fs), respectively. If we can assume N_M = 1E23 (per cc) and N_{TSC} = 1E20 (per cc), we obtain roughly N_{M+TSC} = 1E19 (per cc).

4. CONCLUSIONS

From our studies, we can conclude first:

(1) The Cluster Fusion Theory was elaborated to give numerical results, and revealed that anomalous experimental results were explained by Clean Fusion with ^{4}He Ash, and TSC-induced Nuclear Reactions including Selective Transmutation and Cleaner Fission.

(2) Experimental results show the existence of linked phenomena between nuclear physics and condensed matter physics.

(3) The EQPET theory was applied for H/D mixed systems to estimate ^{3}He production rates in addition to ^{4}He production.

Secondly, Tetrahedral Symmetric Condensate (TSC) was proposed as Seed of Condensed Matter Nuclear Effects. And we may speculate future studies:

(4) Further studies on TSC-induced nuclear effects are likely, since the STTBA model has well explained the Ni + H experiment transmutations.
(5) When the principles of Clean Fusion, Cleaner Fission and Transmutation are established, we can be very hopeful they will be applicable to portable energy sources and radioactive waste incineration.

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