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Research Article

Are Ni + H Nuclear Reactions Possible? *

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Abstract

Various cases of possible orthodox nuclear reaction processes, including newly proposed 4H/TSC fusion by simultaneous weak and strong interactions, 4H/TSC + Ni induced fission products, Ni + p reactions and reaction by deuteron impurity, are comparatively discussed for feasibility.

(1) Ni + p nuclear reaction is impossibly difficult to make the Coulomb-field penetration of proton through so many inner electron shells (K, L, M), usually non-active in chemical reactions, of Ni-atom. Also the proton capture with Ni-nucleus, if any with kW level power, should emit lethal prompt gamma-rays which have never been observed. So, this type of nuclear reactions is unlikely.
(2) Deuteron impurity (1/6700 in H_2 gas usually) may induce (3H+D)/TSC fusion to be considered. Conditioning of 3-dimensional symmetry of QM-wave function for TSC is however of problem to condense into microscopic neutral entity small enough for causing any strong interactions.
(3) The newly proposed 4H/TSC WS (weak–strong interaction simultaneously) fusion is a plausible scenario to have clean products (^{3}He and proton, or deuterons) with significantly enhanced reaction rates in Ni nano-particles, for rare-conditioned (as discussed) visible heat generation with very weak secondary neutrons (10^{-13} order of ^{3}He primary product) and gamma-rays (10^{-11} order of ^{3}He primary product). Degrees of the generation rate of 4H/TSC ($t = 0$) transient clusters in Ni–H nano-particles and the life-time elongation of 4H/TSC-minimum state are speculatively studied. The auto-recovery capability of Ni nano-catalyst is considered as the key.
(4) The 4H/TSC + Ni-isotope capture-and-fission process, previously proposed in our paper of *JCMNS* **1** (2007) 86–96 is another plausible scenario, to result in generation of clean fission products in $A < 60$ mass region. More enhanced 4p + Ni to fission rates than the previous prediction is expected due to the possible elongation of 4H/TSC-minimum-state life time without complete nuclear break-up of the symmetric cluster under dynamic condensation.

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Keywords: Clean fission, 4H/TSC WS fusion, Ni + H CF experiments, Ni + 4H/TSC capture, Nuclear reaction models

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1. Introduction

In the 23 years history of CMNS/CF (condensed matter nuclear science/cold fusion) experiments, unusual claims of finding excess heat and transmutation by nickel metal plus H_2 loading or H_2O electrolysis have been made by several researchers/research-groups. Most remarkable claims have been done by Siena-Bologna Group [1–3] and Miley group [4,5], about anomalously large excess heat and nuclear-like (transmutation-like) products. Recently, a demonstration of 10 kW 'commercial grade device' in January 2011 at Bologna (by Rossi et al.) has attracted great interest in the Internet debate/discussions. The scientific content as technical data of the Rossi demonstration has not been disclosed, and the CMNS community has to continue controversial opinion-exchanges about whether his claim is real or not. On the other side, the latest progress in CMNS experiments based on D(H)-gas loading method is significant with the usage of nano-fabricated metal samples such as nano-size (2–10 nm) Pd mono and Pd–Ni binary powders dispersed in ZrO_2 ceramic flakes by Arata group [6,7], Kobe University–Technova group [8–14], and NRL group. Reproducibility of these gas-loading experiments is almost 100% to show the existence of anomalously high (cf. known chemistry) heat generation with zero nominal input power and significant isotopic effect (D-loading gave larger heat). Takahashi et al. wrote [10,14] that about 70% of anomalous heat would be generated by 'new chemical absorption' on/into Pd-based nano-particles as 'mesoscopic catalyst' which would have deep GMPW (global mesoscopic potential well) and however about 30% could be nuclear heat by such fusion reaction as the 4D/TSC simultaneous 4-body fusion to produce helium-4 and clean heat (without neutrons as primary product). The 4D/TSC formation process was speculated to enhance on surface sub-nano-holes (SNH) of nano-particle and inside lattice points. The TSC theory was extended to predict that the 4H/TSC condensation on/in nano-nickel particle would have possibility of the 4H/TSC weak/strong fusion [15] and the clean fission by 4H/TSC capture into Ni isotope-nucleus [16]. These basic studies on observed phenomena in D(H)-gas loading experiments and explaining theoretical models as the TSC theory [17] will open a window to explore theoretical possibilities of 'feasible' nuclear reactions in Ni + H systems. The present paper discusses such possibilities.

As supporting data of anomalously large heat generation in nano-Ni/H-gas loading experiments, which is difficult to explain by known chemistry, Kobe–Technova group [18,19] and Celani group at INFN Frascati Italy (private communication) have been or will be reporting in latest/forthcoming meetings.

2. The Proton Capture Process into Ni Nucleus is Unlikely

As people would imagine first the Ni + p capture reaction to transmuted products, we briefly discuss that the process is unlikely to be feasible due to two main reasons: namely, the Coulomb barrier penetration of proton through 28 shell-electron layers of Ni for low energy seems impossible, and the lethal prompt gamma-rays by proton capture (if it were happened) to Ni-nucleus have never been observed.

Before discussing any nuclear reactions, we need to recall Fig. 1 that we have to treat substantially and quantitatively (as much as possible) the three steps of nuclear reactions, namely, (1) the initial state interactions where weak and/or strong nuclear interaction take place under the condensed matter conditioning (environment) of dynamic electromagnetic (or Coulombic) interactions of protons (deuterons), metal nuclei (Ni in our case) and electrons, (2) the intermediate (sometimes virtual) compound nucleus state with excited energy (by mass defect energy, delta-$m - c^2$), spin-parity and isospin states, and (3) the final state interactions to going out with break-up particles (hadrons, photons, neutrino, and fission fragments). The mass defect by nuclear (strong/weak) interaction induces the shift of substructures (quarks–gluons bonding) of nuclei from the initial state particles to the intermediate compound nucleus, to be reflected in Ex, J-pi and isospin, and makes the returning path to the initial state impossible due to the drastic increment of system entropy (randomness). The situation of one-way process is same for the procedure from the intermediate compound state to the final state interactions. Such condition of nuclear reaction implies that the electro-magnetic interaction in the initial state interaction becomes 'adiabatic' to the nuclear strong/weak interactions.

Thus we can use satisfactorily the Born–Oppenheimer separation of wave functions between the QM (quantum

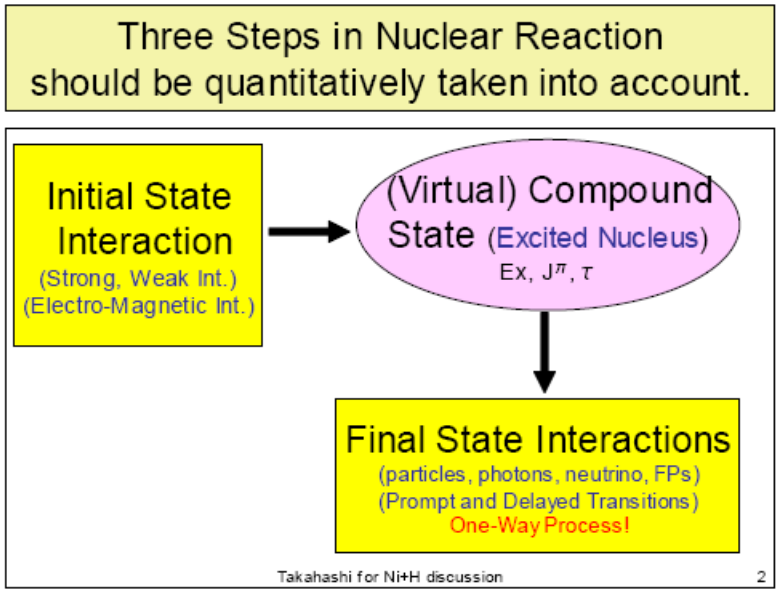

Figure 1. Three steps of nuclear interaction should be substantially treated in theory.

mechanical) wave function of EM (electromagnetic) field and the QM wave function in the strong/weak force field.

The first main problem is of extreme difficulty for low energy (<5 keV) proton to penetrate through the thick multiple QM electron-cloud layers (K shells to M shells) and to get close enough to make meaningful level strong interaction rate. We here have to remind that one watt power level heat needs huge reaction rate on the order of 10^{12} f/s by Ni + p capture reaction. One molar Ni metal (58.693 g) may absorb 1.8×10^{24} hydrogen-atoms at O-sites and T-sites, if at most. This means microscopic Ni–p fusion rate should exceed the level of 10^{-12} f/p–Ni-pair. Assuming that Ni–p strong interaction rate by 100% proton penetration through the barrier is written as $\nu S_{pNi}(0)/E$ per a p–Ni pair and $S_{pNi}(0)$ = ca. 10^5 kevb. At $E = 1$ keV (ν = ca. 2×10^7 cm/s), we get 2×10^{-12} f/s/(p–Ni-pair/cm^3) (here 1 b = 10^{-24} cm^2). There the required barrier factor is ca. 0.5 for a p–Ni pair. Assuming $E = 0.025$ eV (energy at room temperature), we get 1×10^{-9} f/s/ (p–Ni-pair/cm^3) for 100% penetration. So, the barrier factor 10^{-3} is required to the thermal proton injection into Ni-atom with many electron shells, to meet the 1 W/mol–Ni/cm^3 level heat level. Remembering the barrier factor for d–d pair of D_2 molecule [20] (d–e–e–d system) is 10^{-85}, for nucleus with only 1S electron, barrier penetration of 10^{-3} for a p–Ni pair is too difficult to realize. The feature of difficulty can be understood by Fig. 2, as we can imagine. Three steps of nuclear interaction should be substantially treated in theory

The inner most electron shell (K-shell) of nickel has about 1pm radius of 1S orbit with 8.3 keV binding energy. There are other 26 electron shells before the K shell. Bare incident proton nucleus should be trapped with the outer most (valence) electron shell to form NiH chemical compound, and should never approach to inside nucleus. Considering total ionization energy of Ni atom, the kinetic energy of incident proton should exceed 1 MeV to approach the Ni bare nucleus for making meaningful strong interaction with Ni nucleus having about 10 MeV barrier height at the contact surface of strong interactions between Ni and p. Therefore, low kinetic energy (KE) proton in Ni–H system, even at dynamic/transient condition, cannot overcome this very strong barrier of many electron shells.

It is obvious that only very small (as small as 0.1 pm in diameter or less) charge-neutral entity may penetrate

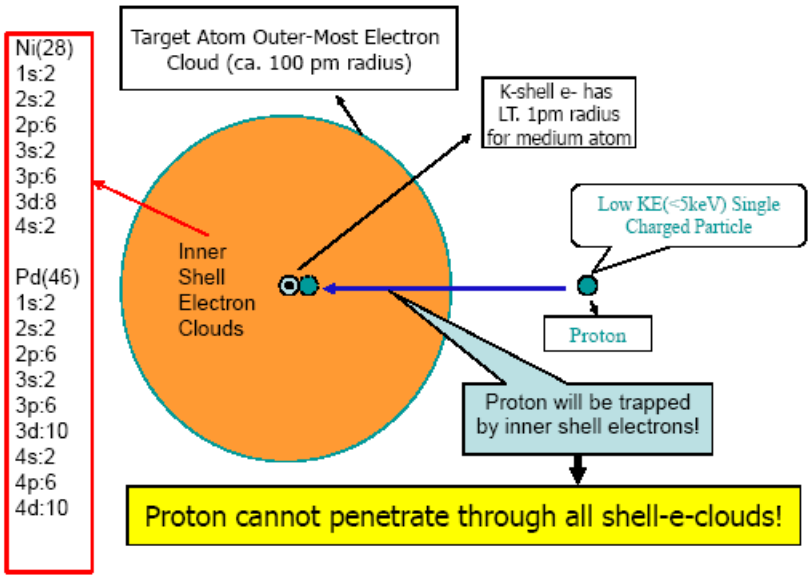

Figure 2. Procedure of Coulomb barrier penetration of proton through many layers of shell-electron clouds of Ni.

through the barrier of Fig. 2. Widom-Larsen has proposed [21] the generation of ultra-low momentum neutron (which can penetrate the Ni electron-shell-barrier) by 'heavy (more than 1MeV KE equivalent)' electron in metal-H lattice plasmon/surface-polariton state, although the assumed condition looks almost impossible and free neutrons leakage must be lethally observed, if at all [15]. Another idea might be a generation of sub-pm size mini-atom of H (p + e system), wishfully proposed by some models as hydrino [22] and lochon [23]. However, these mini-atom theories are based on non-QM (classical) mechanics, and therefore their existence in nature is very questionable or never observed. Y. Kim (private communication) is proposing Ni + 2p capture process, to avoid emission of prompt gamma-ray by p-capture, without showing how 2p pair can penetrate through the huge barrier (Fig. 2). The p–e–p three body and p–e–e–p 4-body dynamics have no sub-pm state QM solutions as discussed in [20].

The second main problem of Ni–p reaction is the fact that claimed large heat power has never associating lethal level prompt gamma-rays. The capture, intermediate compound state and decays (final state interactions) are shown in Fig. 3 for ^{58}Ni + p nuclear reaction.

The intermediate compound state ^{59}Cu*(Ex = 3.417MeV) emits, by no other means, EM-transition prompt gamma-rays (in a few fs) in its cascade excitation decay levels of ^{59}Cu. The initial explanation by Rossi–Focardi in their blog (*J. Nuclear Physics*) is wrong because of ignoring the prompt gamma-rays by proton capture before making transition to the ground state of ^{59}Cu which is radio-active positron-emitter. For all p-capture process for Ni isotopes (^{60}Ni, ^{61}Ni, ^{62}Ni, and ^{64}Ni), we should observe prompt gamma-rays in similar ways. Of course, in the following decay paths via positron emission, most energy is carried off by neutrino and 0.511 MeV annihilation gamma-rays should be observed, so that it is difficult to expect heat deposit in reaction chamber of Ni powder/bulk sample.

In summary, it seems extremely difficult (we can say impossibly) to propose any quantitatively proven mechanisms to overcome the Ni–p Coulomb barrier penetration obstacle of multi-layered shell electron clouds.

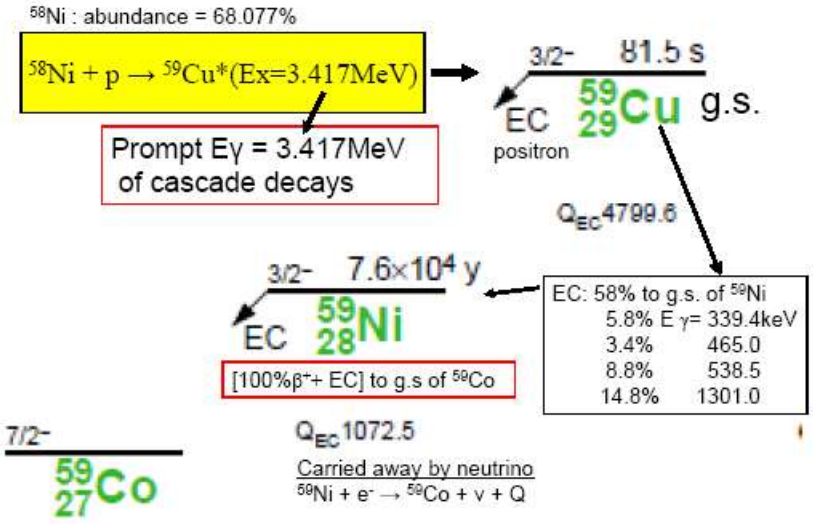

Figure 3. Ni + p reaction, its intermediate compound and decay scheme chart.

3. 4H/TSC Formation in Ni-contained Condensed Matter

We have proposed that the tetrahedral symmetric condensate (TSC) of four protons and four electrons, with orthogonal coupling of their 3-dimemsional QM wave-functions, will provide a dynamic chance of condensing into very small (as small as several fm in diameter) charge neutral entity for very short time interval (but enough long for self nuclear interaction and capture reaction to host metal nucleus). From the heat and D(H)-loading evolution of experiments with Pd–Ni binary nano-particle (PNZ2B) [13,14], we proposed a model for the catalytic effect of binary metal nano-particle as Pd_1Ni_7 in 2 nm size, as shown in Fig. 4. Pd ad-atoms may be replaced with other metal atoms as Cu, as we discuss later for the nano-catalyst effect (mesoscopic catalyst).

The formation of 4H/TSC is supposed to occur at SNHs (sub-nano-holes) on surface as explained with the inserted sentences in Fig. 4. One SNH with trapped D_2 image is shown in Fig. 5. First, a D_2 molecule will be trapped with active dangling electron bonds at SNH and be arranged at points illustrated. Before dissociation of D_2 and D-hopping into deeper site, next D_2 molecule may be trapped at the same SNH and arranged orthogonally, due to charge balance with the first trapped D_2, to form 4D(H)/TSC ($t = 0$) state. The second plausible mechanisms of 4D(H)/TSC formation is speculated [14] as the non-linear oscillation of D(H)-oscillators at O-sites of inner Bloch potential of GMPW (global mesoscopic potential well) of nano-catalyst to enhance TSC formation probability around T-sites of Ni inner local lattice. When ambient temperature of reaction chamber is elevated (300–500°C in experiments [18]), the TSC formation rate may be enhanced.

The image of GMPW is shown in Fig. 6, for the case of Ni-based nano-catalyst which experimentally [18] showed endothermic characteristics in lower temperature than 200°C (473 K) and exothermic characteristics in higher temperature than 250°C (523 K).

A simplified image of H(D) oscillator trapped in GMPW is shown in Fig. 7. The ambient temperature of reaction chamber is at the Outer Field Energy Level. Nano-catalyst with active dangling electron bonds works well to adsorb D_2 at room temperature (e.g., 300 K = 27°C) level ambient condition, but the weights of higher phonons ($n > 3$ phonons) oscillation in the phonon-frequency distribution are small at 300 K.

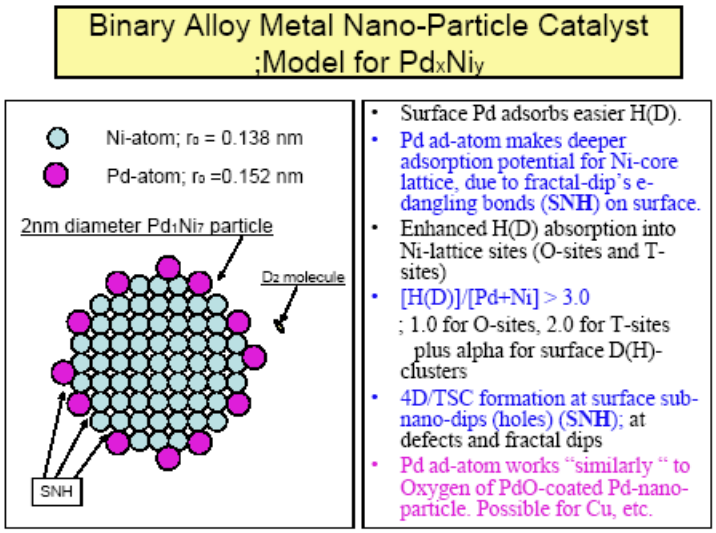

Figure 4. Working model of binary metal nano-particle as mesoscopic catalyst for D(H) gas[14].

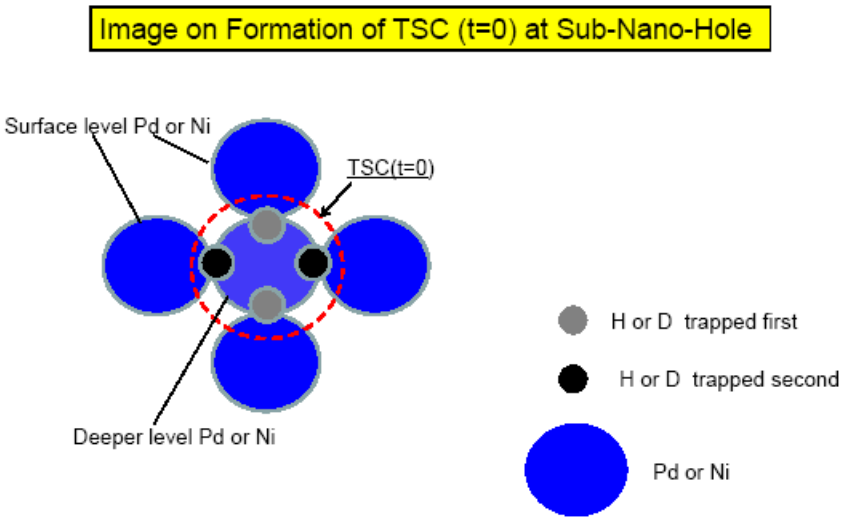

Figure 5. Image of 4H/TSC formation at a SNH (sub-nano hole) of Ni (Pd) nano-catalyst.

By elevating ambient temperature of reaction chamber, weights of higher phonon states are increased and the formation rate of TSC around inner T-sites is correspondingly enhanced by the non-linear QM oscillation in the coupled motion of long-pendulum oscillator of GMPW and short pendulum oscillators of inner O-sites of Bloch periodical (but local) potential. Image of such TSC enhancement process is illustrated in Fig. 8. However, proof quantitative QM

calculations by some simulation techniques are yet to be done.

Once a 4H(D)/TSC(t = 0) state forms, it makes very rapid condensation in about 1 fs to get to the 4H(D)/TSC-minimum state as calculated by the QM Langevin equation [20] as shown in Fig. 9. At 4H/TSC-minimum state, mean electron kinetic energy will exceed 600 keV within TSC trapping potential depth of –1 to –2 MeV and R_{pp} = 2.4 fm.

4. 4H/TSC Fusion by Simultaneous Weak and Strong Interactions in Ni–H System

We now show the first plausible model of clean heat generation by the self-nuclear interaction of four protons and condensed electrons in the dynamic condensation process of 4H/TSC. The theory of 4H/TSC fusion by the simultaneous weak/strong interaction is first reported in the latest work by the author [15].

The results of quantitative analyses of weak/strong interaction rates based on Fermi's golden rule are shown in simplified illustrations in Fig. 10 for 4H/TSC, and Fig. 11 for 4D/TSC for comparison purpose.

The detail of QM estimation procedure is given in [15]. In this paper, we discuss some ambiguous points in the first step dynamic condensation in Coulombic field, the weak interaction (electron capture to proton), the immediate strong interaction between just-produced neutron and three remained protons and the final state interaction (break up to ^{3}He + p).

In the case of 4D/TSC condensation/fusion reaction, 100% 4d fusion by strong interaction takes place in about 2×10^{-20} s time interval of the R_{dd} = ca. 20 fm (4D/TSC-minimum state) adiabatic time step with the 4D barrier factor of 1.98×10^{-3}. Thus 4D/TSC disappears for $R_{dd} < 20$ fm. Contrarily in the case of 4H/TSC condensation motion, there is no strong interaction fusion process among four protons. Therefore, the condensation motion of 4H/TSC continues further into very short R_{pp} distances. As proton behaves as a hard sphere with one positive electric charge in the EM (Coulombic) field of TSC, R_{pp}-minimum = 2× (proton radius: 1.2 fm) = 2.4 fm must be the end point of condensation, where the following weak interaction rate was estimated to be about 3×10^{-7} per 4H/TSC generation [15].

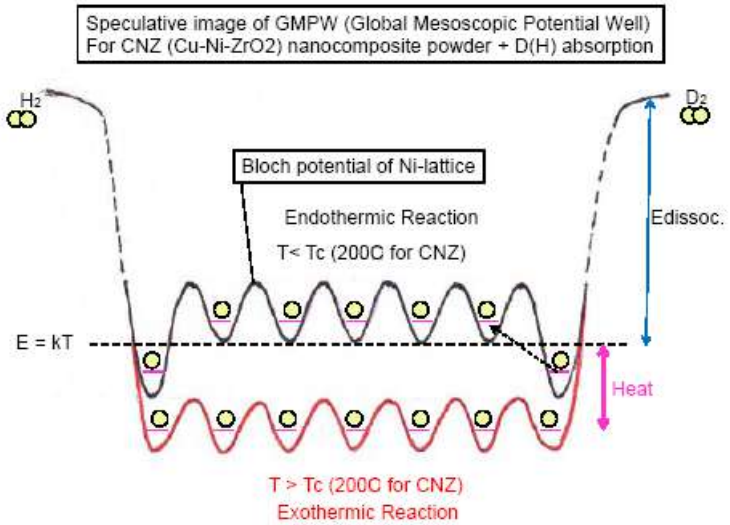

Figure 6. Image of global mesoscopic potential well (GMPW) of Ni nano-catalyst.

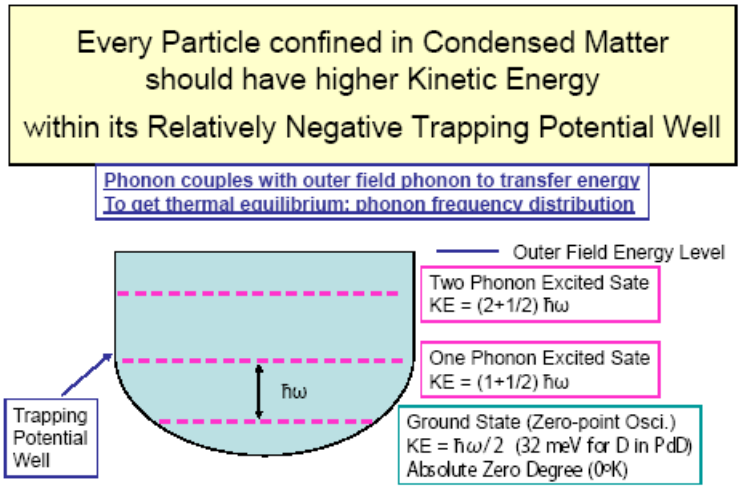

Figure 7. Image of phonon oscillator of trapped deuteron in GMPW.

$$\mathrm{p} + \mathrm{e}^{-} + E_{\mathrm{ke}} \rightarrow \mathrm{n} + \nu + (E_{\mathrm{ke}} - 272\,\mathrm{keV}). \tag{1}$$

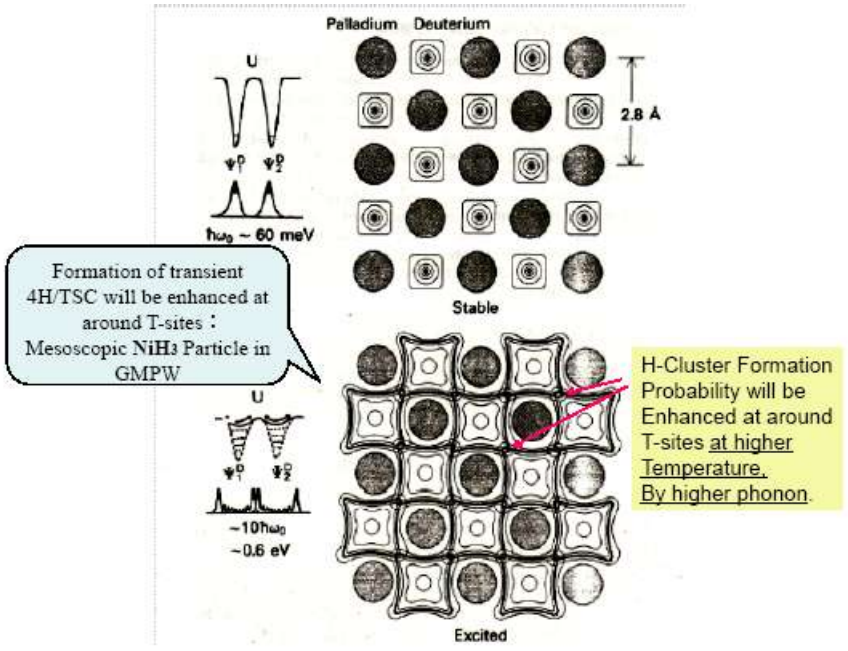

Figure 8. Image of the enhancement of TSC formation rate at elevated temperature of nano-catalyst.

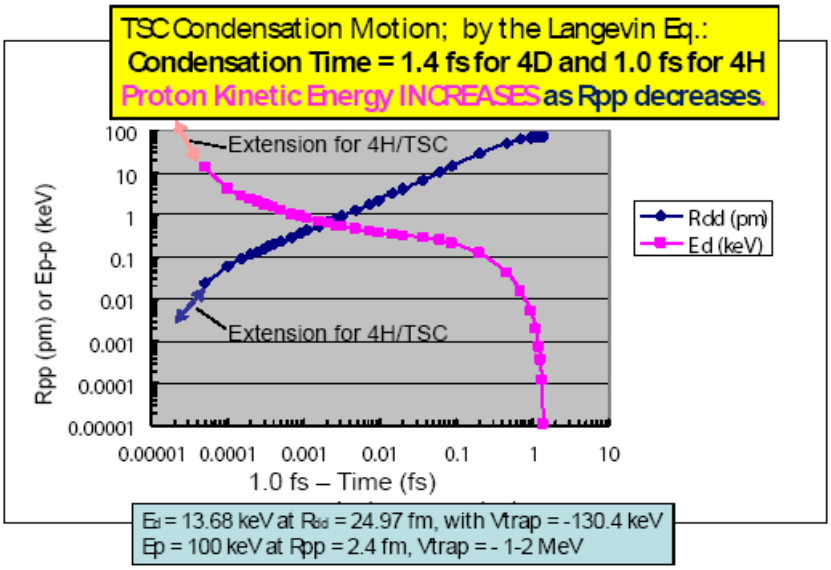

Figure 9. Rapid condensation of 4H/TSC, as shown with variation of p–p distance R_{pp} and relative kinetic energy of p–p pair of TSC.

We assumed the adiabatic time interval of 4H/TSC-minimum state is the same (namely 2×10^{-20} s) with that of the 4D/TSC-minimum adiabatic state, to calculate the weak interaction yield of 3×10^{-7}.

However, the adiabatic time interval of 4H/TSC-minimum can be very much longer than that, because the weak interaction rate is so small and the state does not disappear by the reason of weak interaction. How much is the actual life-time of 4H/TSC-minimum state is of important problem. We have not yet quantitatively estimated it. Considering that the electron kinetic energy (KE) of 4H/TSC-minimum (we supposed 0.6–1.2 MeV in the previous work [15]) is not stably kept because of dynamic state (non-ground state), we may imagine an oscillation state of R_{pp} values around 3 fm or so with ca. 0.6 fm amplitude. How much time may the oscillation last? We do not know at the moment. We need to study it further. By the way if we may assume the life time is on the order of a few fs (comparable to the condensation time), the following n + 3p simultaneous strong interaction (100% per n generation by the weak interaction [15]) fusion yield becomes a big value on the order of 10^{-2} (a few %);

$$\mathrm{n} + 3\mathrm{p} \rightarrow {}^{4}\mathrm{Li}^{*}(4.62\ \mathrm{MeV}) \rightarrow {}^{3}\mathrm{He} + \mathrm{p} + 7.72\ \mathrm{MeV}. \tag{2}$$

However, it is still 1/100 of the 4D fusion yield. The intermediate compound state ^{4}Li*(Ex = 4.62 MeV) may have another break-up channel as,

$$^{4}\mathrm{Li}^{*}(\mathrm{Ex} = 4.62\ \mathrm{MeV}) \rightarrow \mathrm{d} + 2\mathrm{p} + 2.22\ \mathrm{MeV}. \tag{3}$$

We have presumed in [15] that Eq. (2) is predominant, but we do not know the branching ratio.

The high KE (5.79 MeV) proton by Eq. (2) should induce PIXE photons by ionization of the K-shell electron of Ni. The characteristic X-ray from Ni has K-alpha and beta peaks at around 8 keV, which must be a target of radiation measurement. The 5.79 MeV proton will slow down in sample powder and induce Ni(p,n) and Ni(p,γ) reactions.

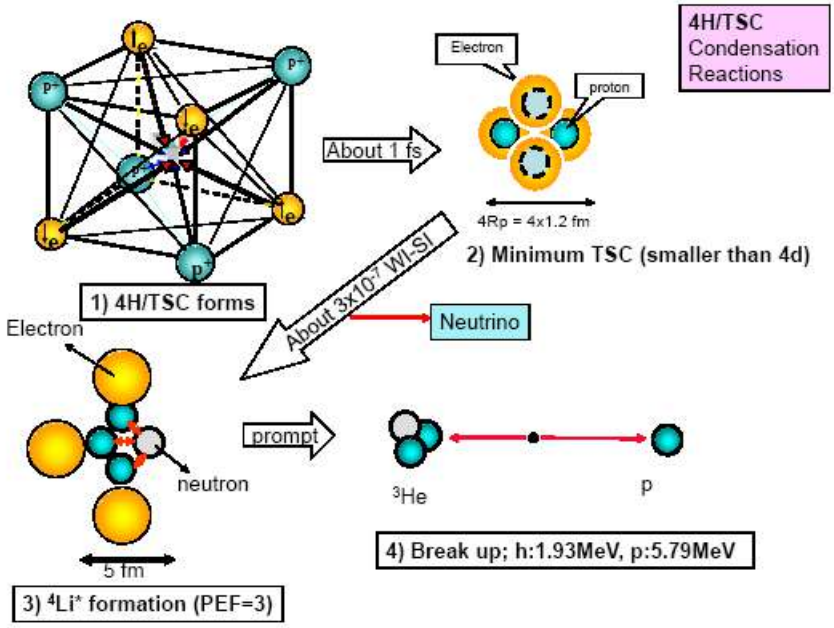

Figure 10. Illustration of 4H/TSC condensation motion and weak/strong fusion reaction [15].

Secondary neutron production by the Ni(p,n) is over threshold for higher mass isotopes (^{61}Ni, ^{62}Ni and ^{64}Ni) with yield of 10^{-13} n/p: this means 1MW 4H/TSC weak/strong fusion reactor will produce ca. 10^5 n/s that is very weak level as a level of weak checking neutron source. The yield of Ni (p,γ) will be two orders of magnitude greater than the neutron yield [15], but it is still very weak level to be well Pb-shielded for biological safety.

However, if the branch Eq. (3) were the major out-going channel, there were happening almost no emission of gamma-rays (nor neutrons) as secondary products, and weaker PIXE events by ca. 1 MeV proton may be searched in experiments.

Now we refer some typical experimental data of heat evolution by H(D)-gas loading with CNZ ($Cu_{0.08}Ni_{0.35}/Zr_{0.57}$) sample (Cu–Ni binary nano-particles dispersed into many ZrO_2 flakes), currently on-going at Kobe–Technova group [18,19]. Heat production is endothermic for $T < 200^oC$ sample temperature, but exothermic for $T > 250^oC$ and heat-enhancing trend for higher temperature. At 300^oC, they have observed 1–1.5 W/g-Ni level average heat by H-gas-loading for a week of run continuously. The D-gas loading gave smaller level heat power (0.2–0.3 W/g-Ni) also continuously.

Total integrated heat data for one-week period were 380 eV/atom-Ni for H and 90 eV/atom-Ni for D, respectively. (They later found that the heat-power level of D-gas charging made catch-up with the level of H-gas charging in the later phase of several weeks of run-time.) These characteristic data of heat are anomalously large, compared with chemical reaction heat of several eV at most, and are very difficult to be explained by known chemical reactions. We need to consider if our nuclear reaction models discussing in this paper have feasibility rationally. Main issues are: (A) Why and how can H-system produce much higher heat than D-system, in the earlier weeks? (B) How can 1.0 W/g-Ni (or 60 W/mol-Ni) level nuclear heat be attained?

The quantitative results shown in [15] do not answer about questions A and B, clearly. In addition, some aspect

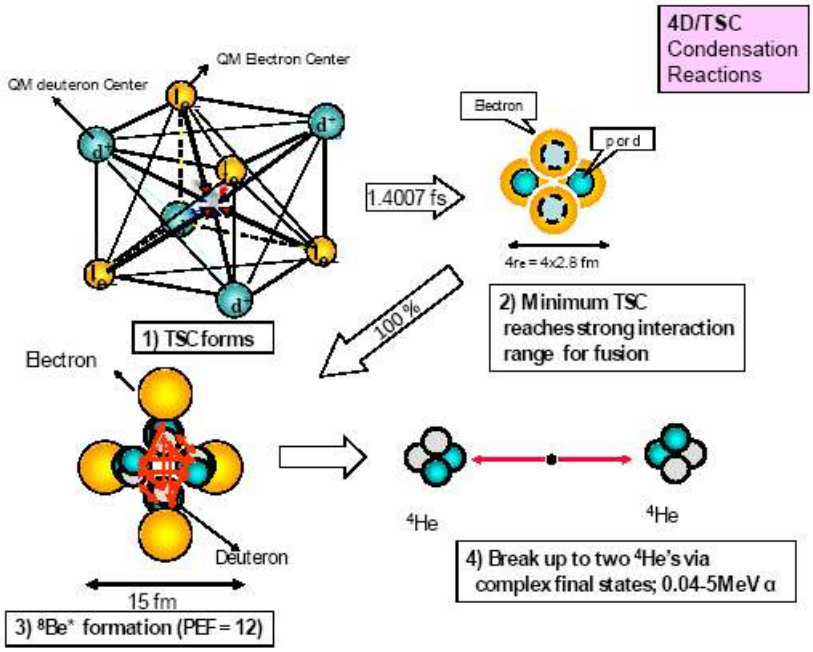

Figure 11. Illustration of 4D/TSC condensation motion and simultaneous 4d fusion [15].

on possible mechanisms to transit from the endothermic to exothermic heat evolution by elevating sample temperature should be discussed, concerning to Fig. 6. Namely, how GMPW shape has changed by changing sample temperature is of problem. The author is imagining the formation of auto-recovering nano-catalyst, similarly as Pd perovskite used for automobile exhaust gas cleaner (see Internet Googling), by cyclic damage/healing process under D(H)-gas charging at elevated temperature. If the CNZ binary Cu–Ni nano-particle (provided by Santoku Co.) were working in that way, it would be surprise. 4D fusion emits 47.6 MeV/f with alpha-particles and may damage harder CNZ sample than the case of 4H WS (weak/strong) fusion with 7.72 MeV, 75% energy of which are carried off by proton with several microns range of ionization/knock-on slowing down process in CNZ sample. Such damage mechanisms pertaining to the auto-recovery cycle of CNZ sample is of further interest to explore. For the t-phase (beginning phase of gas-pressure transition) of CNZ sample, D-gas loading gave larger heat release than H-gas, as is the case of Pd-based samples [8–14]. They have not yet done experiments with Pd-based samples at elevated temperatures. We shall wait for such results at higher temperature for Pd samples, to see the consistency with the case of Ni-based sample. We may speculate that the role of Cu ad-atoms on Ni nano-particle would be arranging SNHs in cyclic auto-recovery procedure.

One-watt heat-power by the 4H/TSC WS fusion events corresponds to the order of 10^{12} f/s. The observed power level of 60 W/mol-Ni corresponds to 10^{-22} W/atom-Ni. Our optimistic yield per TSC for the 4H/TSC WS fusion was on the order of 10^{-2}, so that the required 4H/TSC generation rate is $10^{12} \times 10^{-22}/10^{-2} = 10^{-8}$ TSC/s/atom-Ni: It is dissipative level events in dynamics of Ni–H condensed matter (or solid state physics/chemistry), and is too small fractional events to be visible in ordinary chemistry measures. Supposing the order of 10^4 displacements/WS-fusion of knocked-on Ni atoms from their 'lattice structure' in nano-catalyst, we obtain the damage-estimate of 100% displacements of all Ni atoms in $1/10^4/10^{-8} = 10^4$ s = 2.77 h.

This means that the proposed cyclic auto-recovery mechanism of CNZ nano-catalyst would be working with about 3 hours repetition period, which is not contradictory with the observed heat-power level fluctuations [18,19]. For the case of D-gas loading, observed heat-power level in average was about 20% of that for H-gas loading. One-watt power corresponds to 10^{11} 4D-fusions/s. The 4D fusion produces about 10-fold energy (47.6 MeV) of the 4H/TSC WS fusion, and damage rate will be on the order of 10^6 Ni-displacements/4D-fusion. In rough estimation, the proposed auto-recovery mechanism needs to work with about one hour repetition period that is 1/3 of the H-case: This condition might be the explanation of weaker heat-power of D-gas loading than that of H-gas loading, in the CNZ experiments [18,19]. F. Piantelli (Siena University, private communication), B. Ahern (in Boston, private communication) and F. Celani (INFN, Frascati, private communication) are reporting also weaker heat power data with D-gas loading, compared with significantly enhanced heat power data with H-gas loading. Any way, to provide nano-catalyst samples with the auto-recovery capability seems the key for long lasting (more than weeks can be expected) sustainable clean heat source with high heat power density.

One more discussion is for the possibility of D/H mixed TSC fusion [24]. As the natural H_2 gas contain 1/6700 portion of deuterium as impurity, strong interaction of (H+3D), (2H + 2D) and (3H + D) TSC fusion might take place with significant weight in considering Ni–H systems. Conventionally sold D-gas is 99.5% pure, and contains 0.5% H-gas also as impurity. However, our later study of TSC condensation by the QM Langevin equation [20] has suggested that asymmetric 3-dimensional configuration of centripetal force components for H/D mixed TSC will prohibit the continuous condensation as is seen in the cases of 4D/TSC and 4H/TSC. Therefore, we now consider the feasibility of H/D-mixed TSC fusion is very low.

5. Clean Fission of Ni + 4H/TSC Interaction

The author proposed TSC-induced fission process of host metal nuclei in CMNS experiments [16] to explain 'transmuted' elements observed in the Miley–Patterson experiments [4,5] using Ni-based electrodes in H_2O electrolysis. As we have discussed in the previous section, the life time of 4H/TSC-minimum may be much longer than the thought one in the previous work [16] and we may have more significant feasibility of heat generation and transmutation-products by Ni + 4H fission in currently on-going Ni–H gas-loading systems.

As 4H/TSC-minimum may be as small as 5 fm radius and charge neutral against many layers of shell electron clouds of Ni, it may rather easily penetrate through the Coulomb barrier to approach very close in several fm distance to Ni nucleus, as illustrated in Fig. 12, supposing momentum is given for TSC.

Since Ni K-shell is larger than that of Pd, TSC-induced Ni reaction is more plausible. And since 4H/TSC has much longer life-time than that of 4D/TSC-minimum, Ni + 4H/TSC fission process becomes more probable. Analysis of fission products of highly excited medium-heavy nuclei was proposed in [25]. Kobe–Technova group has made PIXE (particle induced X-ray emission) analysis of CNZ powder samples before and after use [18,19]. They have found visible increase of Ti and Zn in 'after' samples. Impurity was found also for Cr, Fe, and Ni, but these might be contaminants from reaction chamber made of SS304. In Fig. 13, we show typical clean fission products by,

$$^{62}\mathrm{Ni} + 4\mathrm{H} \rightarrow\ ^{66}\mathrm{Ge}^{*}(\mathrm{Ex} = 29\ \mathrm{MeV}) \rightarrow\ \text{Fission products}$$

and $^{64}\mathrm{Ni} + 4\mathrm{H} \rightarrow\ ^{68}\mathrm{Ge}^{*}(\mathrm{Ex} = 29\ \mathrm{MeV})$. ^{58}Ni + 4D/TSC will have similar FPs as Eq. (4).

If selective scission channels are dominant for near symmetric fragmentation channels, clean fission products by Ni + 4H induced fission are ^{20}Ne, ^{23}Na, ^{24}Mg, ^{27}Al, ^{28}Si, ^{32}S, ^{36}S, ^{38}Ar, ^{40}Ar, ^{39}K, ^{41}K, ^{42}Ca, ^{44}Ca, ^{45}Sc, ^{46}Ti, and ^{48}Ti; all are stable isotopes.

The sensitivity of PIXE is not enough for detecting lower Z element than Sc. As Kobe–Technova group [18,19] has found meaningful increase of Ti in CNZ samples after use, we shall wait for the analysis of sample by TOF-SIMS to search the lower Z elements, if any.

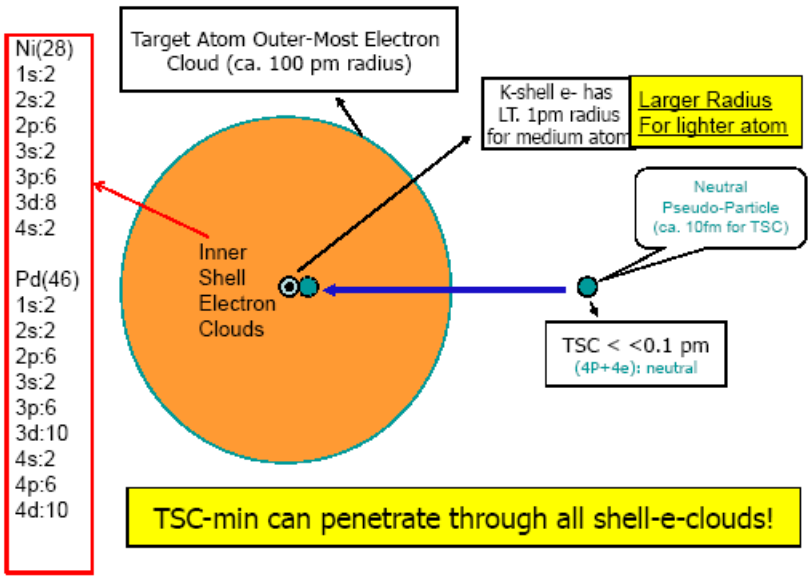

Figure 12. Image of barrier penetration of 4H/TSC-minimum through many layers of Ni shell electron clouds.

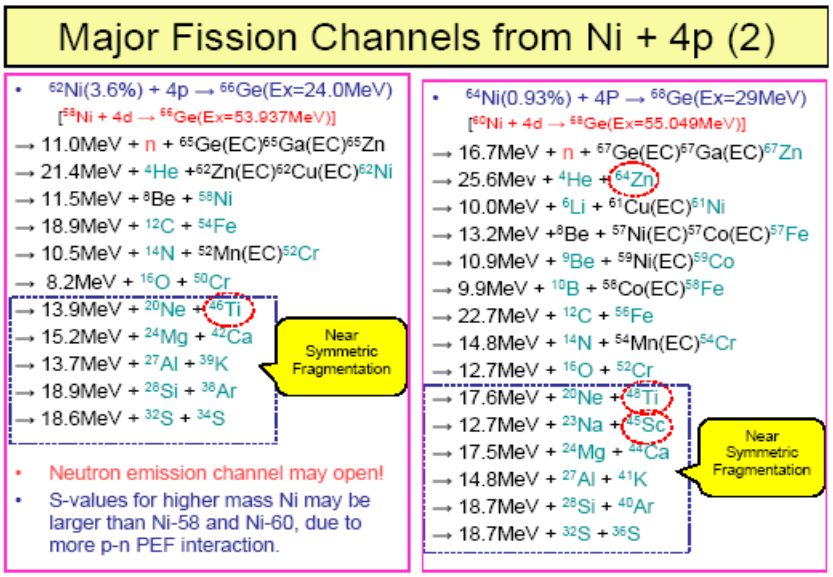

Figure 13. Typical radiation-less (clean) fission products by near symmetric fragmentation of ^{66}Ge*.

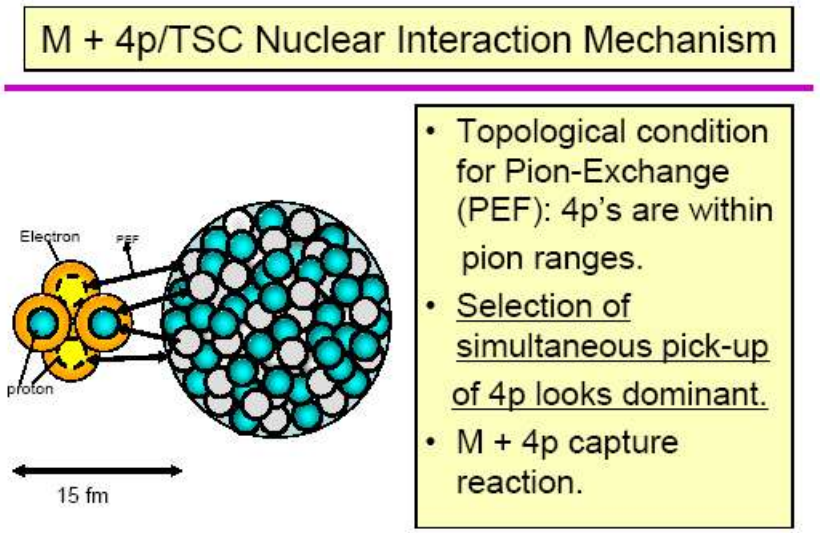

Figure 14. Image of strong interaction between 4H/TSC-minimum state and Ni nucleus.

In the previous paper [16], we considered 1p, 2p, 3p, and 4p pick-up processes in competition in the initial state nuclear interaction between 4H/TSC and Ni-nucleus. Now, we reconsider about the condition that simultaneous 4p capture to Ni is predominant because all four protons and surface nucleons of Ni-nucleus are within the range (1.4 fm of pion Compton wave length) of strong interaction (PEF) due to the further condensation of 4H/TSC to much smaller neutral entity (5 fm size) than the previous model. The image of such configuration is shown in Fig. 14. The nuclear reaction rate is estimated by the STTBA (sudden tall thin barrier approximation) method [16].

The clean fission process by Ni + 4H/TSC interaction is a plausible scenario for Ni–H systems, as 4H/TSC minimum has much longer life time than 4D/TSC-minimum.

Every fission event competes with the EM transition of deformed intermediate compound nucleus with high excited energy to emit cascade gamma-rays promptly. The ^{235}U + thermal-neutron fission (^{236}U* fission) competes with the ^{236}U* to ^{236}U (ground state) transition emitting gamma-rays, with [gamma]/[fission] = 98.7 b/585 b = 0.17 branching ratio [26]. Therefore, the gamma-ray emission level by U-fission is strong. Another example of fragmentation of lighter nuclei with high excited energy is the case of ^{6}Li + n to ^{7}Li* to t + α + 4.8 MeV competing with the EM channel ^{7}Li (gs) + γ. The branching ratio of [gamma]/[t] is 3.85×10^{-4} b/940.3 b = 4.1×10^{-7}: Very weak gamma emission in this case. In the case of ^{10}B + n to ^{11}B* to $\alpha+^{7}$Li competing with the EM channel of ^{11}B (ground state) + γ, [γ]/[α] = 10^{-4}. We also know that the [γ]/[t] branching ratio for d–d fusion is ca. 10^{-7}. At the moment, we have no exact knowledge about [γ]/[fission] branching ratios for Ni-isotopes + 4H/TSC induced selective channel fragmentations.

The mystery of Iwamura claim of A-8 and Z-4 increased transmutation (Cs + 4d capture to Pr) [27] should be discussed, pertaining to the present discussions, but we will make it in other occasions.

There are other problems to study, e.g., such problem as how momentum (or velocity of the center-of-mass system) of 4H/TSC is generated at the TSC formation site to be able to approach a host metal nucleus locating nearby. The TSC formation at SNH on surface of nano-catalyst (see Fig. 5) may have a mechanism to generate TSC momentum.

6. Summary

The Ni + p nuclear reaction is impossibly difficult to make the Coulomb-field penetration of proton through so many inner electron shells (K, L, M), usually non-active in chemical reactions, of Ni-atom. And the proton capture with Ni-nucleus, if any, should emit lethal prompt gamma-rays which have never been observed. So, this type of nuclear reactions is unlikely.

Deuteron impurity (1/6700 in H_2 gas usually) may induce (3H+D)/TSC fusion to be considered. Conditioning of 3-dimesional symmetry of QM-wave function for TSC of H/D-mixed configuration is however of problem to make complete condensation into microscopic neutral entity small enough for causing any strong/weak nuclear interactions.

The newly proposed 4H/TSC WS (weak–strong interaction simultaneously) fusion is a plausible scenario to have clean products (^{3}He, deuteron and proton) with considerably enhanced reaction rates in Ni-nano-particles, for rare-conditioned (as discussed as 'dissipative') visible heat generation with very weak secondary neutrons (10^{-13} order of ^{3}He primary product) and gamma-rays (10^{-11} order of ^{3}He primary product). Degrees of the generation rate of 4H/TSC ($t = 0$) transient clusters in Ni–H nano-particles and the life-time elongation of 4H/TSC-minimum state are to be studied. Probably the damage of nano-catalyst by 4H/TSC WS fusion products is much lighter than that by 4D/TSC fusion products. This difference may make longer life of Cu–Ni binary nano-catalyst in cyclic auto-recovering of damaged catalyst, specifically for H-gas loading. So, this model may be explanation of clean heat for long time span as observed in CNZ samples to be the Ni–H nuclear effect. We shall wait for heat evolution data with Pd-based samples at elevated sample temperatures, whether the isotopic (D or H) difference is consistent with that with Ni-based samples or not.

The 4H/TSC + Ni-isotope capture-and-fission process, previously proposed in our paper [16] is another plausible scenario, to result in generation of clean fission products in $A < 60$ mass region. More enhanced 4p + Ni to fission rates than the previous prediction is expected due to the possible elongation of 4H/TSC-minimum-state life time without complete nuclear break-up of the symmetric cluster under dynamic condensation. However, we need further detailed analysis on predominant scission channels in Ni + 4H fission processes for Ni isotopes. Here, we need also the consistency search with experimental data of possible fission-like products by Pd + 4H systems, if any.

Acknowledgement

The author is grateful to Technova colleagues (A. Kitamura, R. Seto, and Y. Fujita) and Kobe University members (A. Taniike, Y. Miyoshi, H. Sakoh, and Y. Furuyama).

Appendix

A.1. Reviewer's Comments and Reply

Critical comments on the basic QM methodology on the TSC theory were thrown by a reviewer. This would raise a never-ending debate due to difference of individual approach. However, for the better understanding of readers, copy of commnets/reply is given below.

Thank you, reviewer for valuable comments. I (the author) reply as follows:

> Over the years Takahashi has been important contributions to the field, and we have great respect for him. He can take credit for numerous important experimental results; he has had a profound impact on the field in Japan; he has provided leadership for the International Society; and he continues to make an impact with new results, and with his contributions at conference meetings. Because of this, I take no satisfaction in drawing

attention in what follows to some issues in his theoretical approach to explaining the excess heat effect; it would be much preferred for his model to be free of such issues.

Right, albeit the compliment, the quality of original paper should be irrelevantly evaluated.

Basic issue

Takahashi and collaborators make use of Langevin equation for modeling the dynamics of atom clusters, which from our perspective should be able to give reliable answers in principle. We take issue with how this has been implemented in the models that Takahashi relies on. In particular, the electronic localization energy has not been properly accounted for. We can see this from a simple argument involving the scaling of the cluster size, which will take a few paragraphs in what follows to illustrate

The present paper discusses on how Ni + H nuclear reactions are possible. It uses the results of published papers in ACS LENRSB Vols. 1 and 2 by the author and extended to 4H/TSC condensation and possible nuclear reactions. The reviewer's comments are on the basis of these already published papers which made analysis with Langevin equations. As the author wrote in these published papers, the Langevin equations, quantum mechanically modified, have been solved for special geometric configurations of clusters constituted with deuterons and electrons, however using several steps of approximations. It has been done so because the immediate direct rigorous approach for the so many body dynamic problems is too complicated to solve.

This means that the rigor of the analyses should be checked by some proper ways later on. So the theory is not completed.

To this respect, comments by the reviewer are appreciated.

A.2. Classical Potential

If we first consider electrons and nuclei to be classical initially, then we could develop ai associated potential energy assuming fixed relative positions to obtain

$$V_{\mathrm{tot}} = \left[\sum_{i<j} V\right]_{\mathrm{nn}} + \left[\sum_{i<j} V_{ij}\right]_{\mathrm{ee}} + \left[\sum_{ij} V_{ij}\right]_{\mathrm{en}}, \tag{4}$$

where the first term is the (repulsive) Coulomb interaction between nuclei; the second is the (repulsive) Coulomb interaction between electrons; and the third is the (attractive) interaction between electrons and nuclei. This can be expanded out as

$$V_{\mathrm{tot}} = \left[\sum_{i<j} \frac{Z_i Z_j e^2}{|R_i - R_j|}\right]_{\mathrm{nn}} + \left[\sum_{i<j} \frac{e^2}{|r_i - r_j|}\right]_{\mathrm{ee}} + \left[\sum_{ij} \frac{Z_i e^2}{|R_i - r_j|}\right]_{\mathrm{en}}. \tag{5}$$

This gives the attractive interaction for the different cases considered by Takahashi and colleagues For example, in the case of d–e–d, we end up with

$$V_{\mathrm{tot}} = -2\frac{e^2}{R_{\mathrm{de}}} + \frac{e^2}{R_{\mathrm{dd}}}, \tag{6}$$

which is in agreement with the result given in the ACS Volume 2 paper.

For tetrahedral symmetric condensation there are four D (or H) and four electrons assumed a the eight corners of a cube. If we assume that the distance between nearest neighbors is a then wh

$$V_{\rm tot} = \left[6\frac{e^2}{\sqrt{2}a}\right]_{\rm ee} - \left[4\left(3\frac{e^2}{a} + \frac{e^2}{\sqrt{3}a}\right)\right] = \left[6\sqrt{2} - \frac{4}{\sqrt{3}} - 12\right]\frac{e^2}{a} = -5.824\frac{e^2}{a} = -11.65IH\frac{a_0}{a}. \quad (7)$$

These classical attractive potentials appear in some of the models presented by Takahashi.

I agree.

A.3. Electronic Kinetic Energy

I remarked some years ago in the review of an earlier paper about the problem with the electronic kinetic energy in the models. To their credit, Takahashi and collaborators responded by including a contribution associated with the kinetic energy in their model. Unfortunately, their model does not appear to deal with localization properly as the collapse occurs in their model.

Consider for example an idealized version of the model where the electrons are localized at the corner of the cube (such localization is required, since delocalization will result in a severe reduction of the attractive term in the equation for $V_{\rm tot}$ above). Let us assume a simple Gaussian wave function for an electron at one corner of the form

$$\pi(\mathrm{r}) = \left[\frac{1}{\pi L^2}^{\frac{3}{2}}\right]\exp\left(-\frac{|\mathrm{r}-\mathrm{r}_0|^2}{2L^2}\right). \quad (8)$$

The associated kinetic energy for this electron is

$$\mathrm{KE} = \left\langle \pi(\mathrm{r}) \left| -\frac{\hbar^2\nabla^2}{2m_{\rm e}} \right| \pi(\mathrm{r}) \right\rangle = \frac{3\hbar^2}{4m_{\rm e}L^2}. \quad (9)$$

In order for the electron to remain localized as the collapse occurs, we require the size of the Gaussian to remain smaller than a

$$\sqrt{\langle \triangle x^2\rangle} = \frac{L}{\sqrt{2}} \ll a. \quad (10)$$

If so, then the associate electronic kinetic energy must increase as a decreases

$$\mathrm{KE} \gg \frac{3\hbar^2}{4m_{\rm e}(2a^2)}. \quad (11)$$

I do not see what is a here. As written in my ACS papers, a synthesis of known electron wave functions (linear combination of coupled S-waves) for a d–e–e–d face of TSC was used as approximation, which however treated electron localization in QM way. I did not treat so far the electron wave functions as Gaussians. Gaussian wave-functions were employed only for deuterons (protons).

A.4. Potential and Kinetic Energy

If we augment the total classical potential with the electronic localization energy, then we may write for tetrahedral symmetric condensation an effective potential given by

$$V_{\rm eff} = V_{\rm tot} + 4\left(\frac{3\hbar^2}{4m_{\rm e}L^2}\right). \quad (12)$$

Next, let us pick a particular value for Lwhich is the largest it could reasonably be consistent with some screening

$$L = \frac{a}{3}, \tag{13}$$

which leads to

$$\begin{aligned} V_{\text{eff}} &= V_{\text{tot}} + 27\frac{\hbar^2}{m_{\text{e}}a^2} \\ &= -5.824\frac{e^2}{a} + 27\frac{\hbar^2}{m_{\text{e}}a^2}. \end{aligned} \tag{14}$$

Well, this is a different approach from the author and seems less meaningful for me.

A.5. Equilibrium Condition

As the scale length a decreases, the kinetic energy increases faster than the Coulomb attraction. This suggests that there should be a minimum total Coulomb potential plus electron kinetic energy for some value of a. It seems interesting to solve for it. We find the minimum according to

$$\begin{aligned} \frac{\text{d}}{\text{d}a}V_{\text{eff}} &= \frac{\text{d}}{\text{d}a}\left[-5.824\frac{e^2}{a} + 27\frac{h^2}{m_{\text{e}}a^2}\right] \\ &= 5.824\frac{e^2}{a^2} - 54\frac{h^2}{m_{\text{e}}a^3} \\ &= 0 \end{aligned} \tag{15}$$

We solve to obtain

$$a = \frac{54}{5.824}\frac{\hbar^2}{m_{\text{e}}e^2} = 4.635a_0 = 2.45\ \text{Å} \tag{16}$$

This is not too far from the observed distance for tetra-hydrogen in a cryogenic argon matrix.

This is less meaningful, according to the ACS papers, as argued above. Argon has many inner shell electrons which should be properly treated in your case but not applicable to hydrogen isotopes which have 1S electron only and bare nucleus.

A.6. Discussion

Takahashrs model for the collapse of the tetrahedral symmetric arrangement of D or H and electrons would require electron localization commensurate with the size of the structure at any stage in the collapse. The electron kinetic energy associated with this electron localization very quickly becomes large, and makes the collapse energetically unfavorable below the Angstrom scale. Although Takahashi and collaborators have made an attempt to include the effect of the electronic kinetic energy in their formulation, this inclusion must be incomplete since they do not find what we might expect for the increase in the electronic kinetic energy as the spatial scale decreases.

I strongly encourage Takahashi to take this argument seriously, and to respond appropriately.

Discussion on this point is given in my paper at JCMNS Vol. 2: please see it: showing the dynamic TSC collapse is reasonable.

A. Takahashi, Dynamic mechanism of TSC condensation motion, *JCMNS* **2** (2009) 33–44. We have no stable (static) solutions there for TSC, as the reviewer argued in classical static way.

A.7. Other issue

There is one other issue that needs to be addressed in the paper. En many places Takahashi uses a language that seems to suggest that there is an issue for a proton to tunnel through electronic shells; for example:

> *The first main problem is of extreme difficulty for low energy (less than 5 keV) proton to penetrate through the thick multiple QM electron-cloud layers (K shells to M shells and) to get close enough to -make meaningful level strong interaction rate.*

I would think that the biggest issue is that the Coulomb repulsion between the proton charge and the charge of the metal nucleus is the big issue. The electrons provide screening, so that if you are outside many orbitals, the nuclear-nuclear interaction is screened. However, at close range when the proton is inside the outer shells, there can be essentially no screening from the outer electrons. In this case, the proton sees a very large repulsive potential.

This kind of wording appears several times in the paper, and would need to be fixed throughout.

Again, I have different view in atomic physics with inner shell electrons. The argued proton-nucleus Coulomb repulsion is irrelevant unless the proton passes through all the shell electrons surrounding nucleus. This is essential problem when people model Ni + H nuclear interaction, as simple plasma model for inner shell electrons is not rational in atomic physics and usual chemistry views.

Thank you for considerable comments. The essence of submitted paper is somewhat (or very much) off from the above discussions, however. It's pity.

(The second reviewer's comments and author's response are cut, for these contained unappropriate words for disclosure.)

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