PROGRESS IN CONDENSED MATTER NUCLEAR SCIENCE

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Recent studies of condensed matter nuclear science (CMNS) including cold fusion have accumulated some convincing data and theoretical modeling, and we are about to conclude that (1) deuteron-related clean fusion reactions and (2) cold and special transmutations may take place in the environment of condensed matter containing deuterons and protons. This emerging field of CMNS is expected to give us strong impact on the future of basic sciences for energy-application, fundamental nuclear science, and condensed matter sciences.

1. Introduction

Condensed matter nuclear science (CMNS) was born as a descendant research field of Cold Fusion. In March 1989, S. Pons and M. Fleischmann at University of Utah announced "cold fusion" by D_2O/Pd electrolysis in test tube. The experimental system looked very simple. So many people in the world were involved in hurried trials of replication-experiments. In most trials, however, huge excess heat as claimed by Pons–Fleischmann was not observed. Parallel replication trials for the Nature paper by S. Jones on weak 2.45 MeV DD neutron emission from D_2O/Ti electrolysis cell were not either successful. Very negative mood was seen in almost all scientific communities in the world.[1]

In 1990–1992, some hopeful data on excess heat in D_2O/Pd cells were reported from research teams in USA, Japan, and Italy. Although reproducibility was yet to be attained, great expectation was come back for the clean energy application based on "new nuclear energy process". In Japan, the New Hydrogen Energy (NHE) project was implemented in 1994–1998, at Shin-Sapporo Laboratory, where about 20 researchers from major Japanese industries and several foreign scientists worked together to verify the excess heat effect in Fleischmann–Pons type systems. The NHE effort was concentrated in D/H absorption data in metal-samples and excess heat detection. In spite of energetic efforts by the NHE team, they made final report that excess heat effect was not confirmed. Few positive data on excess heat from foreign researchers and some positive data on nuclear products from Japanese University teams were unfortunately not meaningfully evaluated by the NHE evaluation committee. The NHE project was terminated in 1998.

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In 1999, Japan CF-Research Society (JCF) was founded for minimum-supporting of research activities in Japan. JCF meetings (JCF1–6) held annually have provided opportunities of exchanging hottest results and accumulating reports in its Proceedings.

A faint but steady stream of CF researches has continued in the world after 1990. ICCF-series conferences have counted 11 meetings (ICCF1–ICCF11). The last ICCF conference (ICCF11) was held in Marseilles, November 2004. Other smaller international meetings have been held as Asti-series workshops, Russian cold transmutation conferences, sessions at ANS and APS, and so on. It is thought with rough statistics that about 300 researchers in the world have been continuing CMNS/CF studies. Accumulated research reports are piling up high, as published in ICCF Proceedings,[2–4] Asti-Proceedings,[5,6] and so on. Unfortunately, publication of papers on CMNS/CF works has been rejected by many of highly ranked magazines and journals as Nature, Science and Physical Review Letters, but many peer-reviewed papers have been published in Fusion Technology, Japanese J. Applied Physics (JJAP), Physics Letters A, J. Electro-analytical Chemistry, Il Nuovo Cimento, and so on.

In the end of 2003, re-evaluation of CF works was done by US DoE,[8] based on the report by Hagelstein *et al.*[7] The DoE report concluded that excess heat effect was not confirmed although the continuation of research was necessary.

Latest progress by research reports in 2001–2005 takes over the summary report,[7] and convincing results are given for concluding the existence of excess heat effect with ^{4}He generation and selected nuclear transmutations. In March 2004, CMNS/CF researchers have at last founded the International Society for Condensed Matter Nuclear Science (ISCMNS) registered in England. This is the first international society for CMNS/CF researchers, which will play a role as host society of international meetings as ICCF and Asti-series workshops and exchange information through its web-site http://www.iscmns.org/ for ISCMNS members and related people.

The sustainable development is now widely regarded to be a way of human beings in the 21st century. To solve the energy problem, the idea of best mixing of various available energy sources may be a compromised solution. To mitigate the pollution of environment, cleaner energy resources are being looked for. Solar energy and windmills can merely cover a small portion of energy needs. Extension of nuclear power plants is on the dead lock due to accidents and expensive processing of wastes. Development of thermo-nuclear fusion reactors is also on the dead lock due to the monstrous expensive machine. Some (and probably many) people are seriously dreaming the realization of portably small clean power sources based on some new principles, especially the idea of clean and small-scale source of nuclear energy which can be distributed in private houses and with vehicles (see Slide 1). The emerging field of CMNS including cold fusion is therefore of great potential importance.

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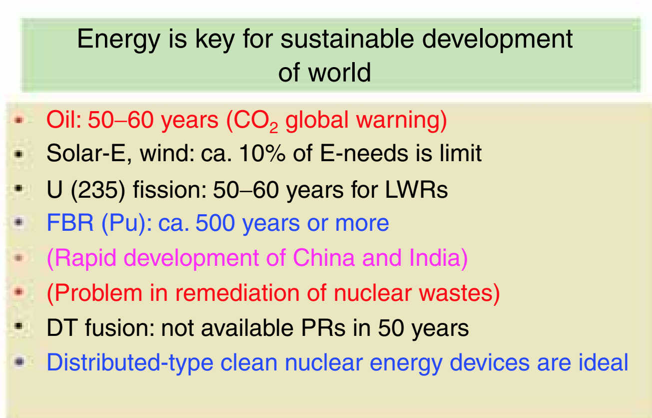
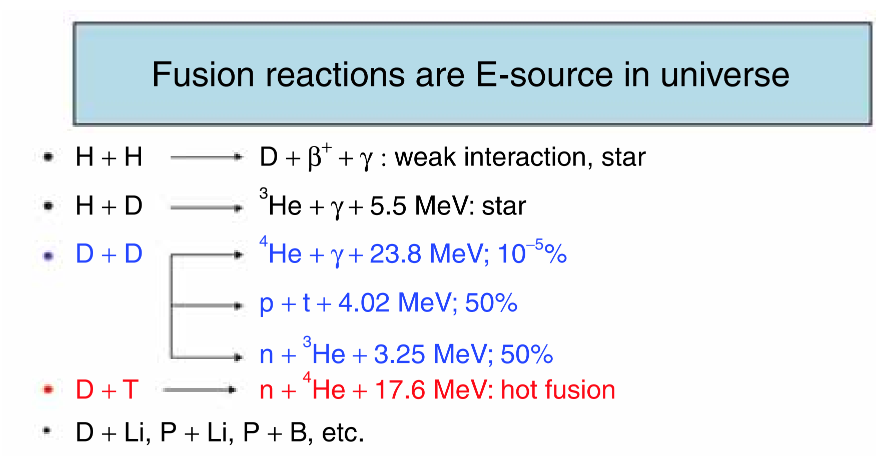


Slide 1

Slide 2 shows the known fusion reactions by hydrogen isotopes. DD reaction was originally considered as fundamental reaction in cold fusion, but claimed experimental results have revealed that condensed matter nuclear effects (CMNE) are quite different.



Slide 2

An amount of 1 W excess power by DD reaction corresponds to 10^{12} f/s reaction rate. Therefore, if excess heat by CMNS experiments were by DD reactions, experimenters should have died[1] by high dose irradiation of 2.45 MeV neutrons. On the contrary, we could have found only very weak level of neutrons in CF experiments.[2–4] We have had to consider new class of nuclear reactions, probably

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related to deuterons, in the environment of condensed matter. Some of theoretical models recently developed have proposed mechanisms to produce cleanly ^{4}He main ash and selected transmutations in metal–D/H systems as discussed later in this report.

In frontiers of science pursuing new phenomena, combined actions between Experimentalism, Rationalism, and Skepticism should support the progress. Aspects to application of the phenomena are also important.

1. *Experimentalism*: The effect should be reproducible with same conditions, qualitatively and quantitatively. Qualitative repeatability of phenomena by other methods and/or other groups is "broadened" reproducibility; the phenomenon with excess heat with ^{4}He production has cleared this criterion. To be perfect, quantitative reproducibility is required: The technological application is only possible by clearing this criterion.
2. *Rationalism*: Theoretical models should be created with original ideas. New theories should be compatible to established theories and should be self-consistent within own theoretical model. All contradictions should be cleared.
3. *Skepticism:* Defects and contradictions in experiments should be attacked. Mutual consistency between experimental results, new models and established theories should be checked to find contradictions.
4. *Applicability*: Feasibility for R&D to distributed clean nuclear energy devices should be critically discussed. Remediation of radioactive wastes from nuclear plants should be also discussed.

Most essential consequences of latest CMNS studies may be summarized into the following three items:

1. Occurrence of deuteron-related clean fusion producing excess heat and ^{4}He.
2. Occurrence of selective transmutations of host metal nuclei and fission-like foreign elements.
3. New theoretical models to interpret qualitatively and quantitatively above results.

Major experimental results and representative authors are summarized in Slide 3. Major results after 1998 are considered in Slide 3. Items (1) and (2) are independent of known DD reaction and should be new kind of nuclear reactions, but items (3) and (4) are closely related to the occurrence of cold fusion phenomena.

2. Generation of Excess Heat and ^{4}He in Metal-D Systems

Processed metal (mostly Pd) test samples with nano-technology have recently been used for heavy-water electrolysis, D_2-gas permeation and gas-discharge experiments. Experiments with heavy water are no longer simple test tube-type, but various kinds of stimulation techniques have been tried as slow and fast pulsed electrolysis-current supply, ultra-sonic wave supply, laser-beam supply, plasma-mode-electrolysis, and so on.

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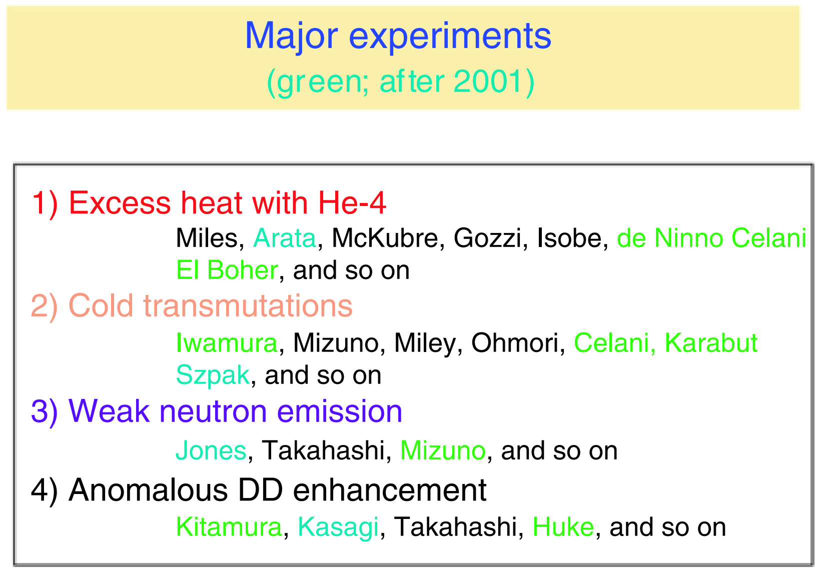

Slide 3

The nano-modification of sample, especially surface modification is of current trend of experimental innovations as well as nano-particles, complex multi-layers, micron-size long wires, and so on.

Positive and convincing data have been reported from Israel + SRI + ENEA group,[9,10] Arata,[11–15] McKubre,[16,17] de Ninno, Celani, NRL-San-Diego, Li, Case, Cravens, Isobe,[18] and so on. Key issues in experiments are calorimetry, mass-analysis, nano-size-condition of sample, stimulation and triggering, diagnostics, and detection.

El Boher *et al.*[9,10] have reported clear excess heat data with 25 times out put lasting long time (17 h typically) using super-wave electrolysis (see Fig. 1). They processed surfaces of sample Pd-cathodes by argon or hydrogen plasma etching. Photograph images by SEM showed finer grain sizes for argon plasma etching. They suggest condition of surface processing relating to success of excess heat. Super-wave for ultrasonic wave was modulated with special wave forms programmed by computer (PC). Averaged frequency was about 20 kHz. Arata and George are doing irradiation of ultrasonic waves to Pd samples in heavy water, with simple sinusoidal function of about 20 kHz. It is interesting how the highly fractal wave form by El Boher *et al.* may effect on dynamic behavior of deuterons in PdDx lattice systems. One of their collaborators is asserting that superposition of super-waves in microscopic limit can induce microscopic ordering of condensed matter and bio-systems and induce nuclear reactions. Effect on ordering in atomic or molecular size level should be interesting, but phonon or electromagnetic wave should not so easily induce directly nuclear reactions.

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In series of their experiments they reported large excess power reaching more than 10 times of input power for time-spans of more than several hours. Reproducibility is in 20–30%. Best data are shown in Fig. 1, where 20 W averaged output with 0.74 W input lasted for 17 h. Gain was 25! This excess power level is corresponding to 24.8 keV per Pd-atom-in-lattice, and is far greater (more than 1000 times) than chemical heat source level.

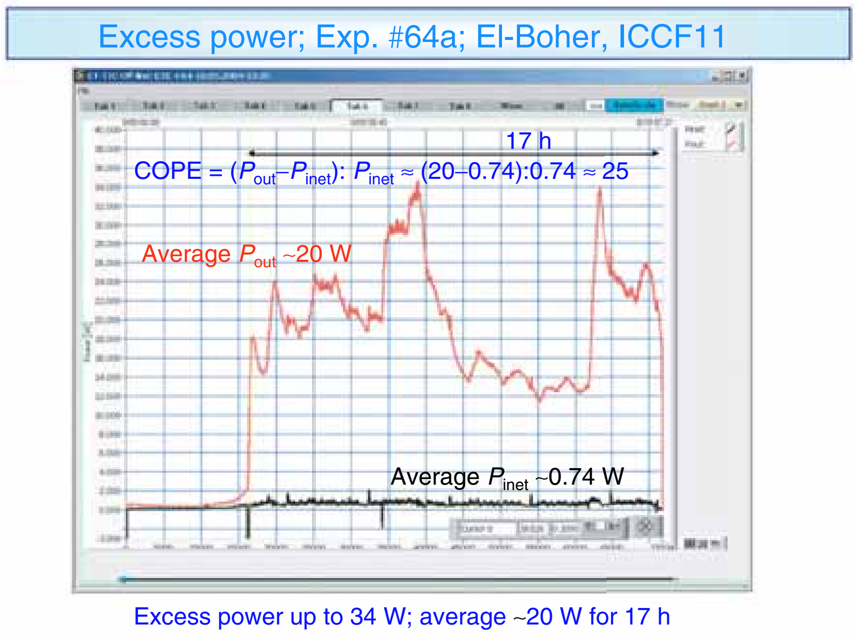

Figure 1. Best output-power data obtained by El Boher *et al.*

This group is trying superposed stimulation with laser beam and ultrasonic wave. This is interesting trial. The group has obtained data for ^{4}He production in correlation with excess heat generation. An example of data is shown in Fig. 2. When we irradiate laser on surface of Pd cathode, we can choose laser wavelength in ultraviolet and EUV region due to the classical Drude formula for frequency dependence of dielectric constant of metal. They used He–Ne laser (632 nm wavelength). Also they observed increase of excess power of several times of laser input power (33 mW). On the right-hand side figure of Fig. 2, time-dependent data of relative resistance ratio of PdDx are drawn. During the laser irradiation and excess power episode, D/Pd ratio kept more than 0.9. However, continuation of laser irradiation induced no excess power and decrease of D/Pd ratio (increase of resistance ratio). This is very interesting data showing relation between excess power and D/Pd ratio under laser stimulation.

Arata *et al.*[11–15] have made significant contribution to provide clear experimental data of ^{4}He production from their own double structure cathode of Pd in heavy water electrolysis cell and from D-gas-phase absorption system of Pd nano-particles

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under laser or ultrasonic wave irradiation. Their ^{4}He analysis by QMAS is reliable. Detection of neutron emission was tried in-situ, but could not observe meaningful events. Tritium production in electrolyte liquid was checked periodically for sampled heavy-water by LSC to observe no significant increase of tritium level compared with BG sample. They observed great amount of ^{4}He from Pd powder by heating.

Arata *et al.* also tried laser irradiation experiment on Pd nano-particles (5 nm in diameter) in ZrO substrate, and observed clear ^{4}He generation.[11,15] This experiment gave important hint to theoretical modeling[57] of CMNE in finite size PdDx lattice system.

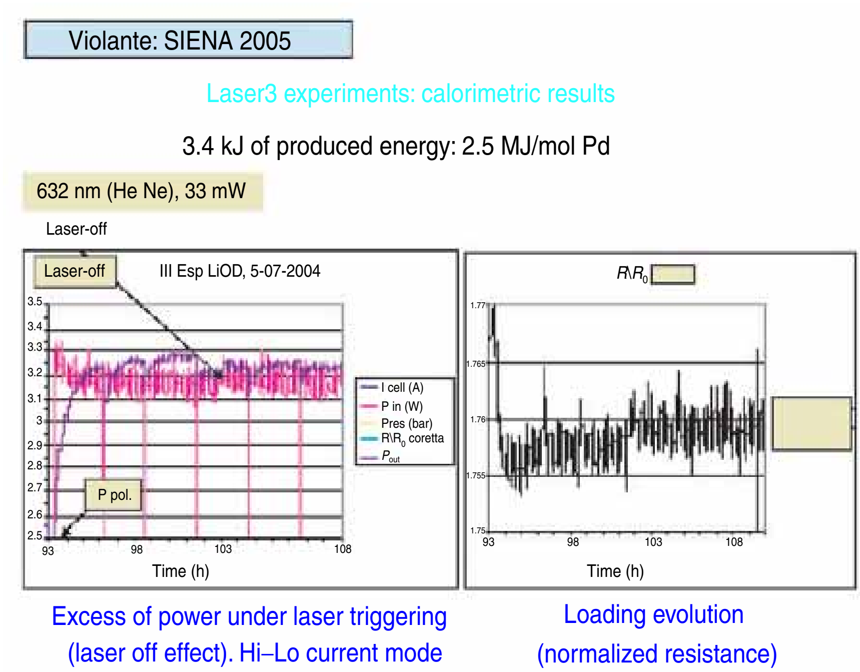

Figure 2. Excess power data triggered by laser (left figure) and variation of resistance ratios (right figure), after Violante *et al.*

McKubre *et al.* in SRI[19−21] have made great efforts in replicating experiments by Arata and Case.[19] They were also involved in their own systems of closed-type heavy-water/Pd electrolysis to detect excess power and ^{4}He and their mutual correlation. Data shown in Fig. 3 were taken in Case-type cell, which employed PVC-deposited Pd layer on carbon.

Produced ^{4}He goes out partially into gas-phase of cell, and other portion will be remained in Pd cathode. They collected both components and made He analysis. They obtained correlation data as 31 MeV per He-atom with 13 MeV error bar. This is important data indicating that ash of excess heat events was ^{4}He-nuclei.

George *et al.*[23] have been studying the effect of excess heat with ^{4}He production using the ultra-sonic wave irradiation into Pd-plate in heavy-water, and reported

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that the effect is real. It was observed that Pd-plate was destroyed into small powders during the experiment. Stringham[24] has been studying the similar method with higher frequency (in MHz range) ultrasonic wave.

We have other reports on ^{4}He production by de Ninno, Isobe,[18] and so on. We can say that the phenomenon of excess heat with ^{4}He generation is "qualitatively" reproducible.

However, conditions for 100% reproducible protocols are yet to be established. To find quantitatively reproducible conditions, we need investigations on nano-modification of samples, procedures to keep high D/Pd ratios and dynamic D-flux through samples and external stimulation methods (electrolysis patterns, laser and ultra-sonic wave irradiations, and so on).

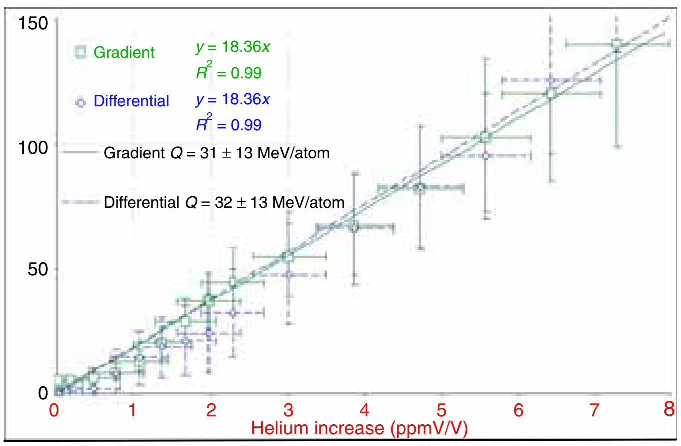

Figure 3. Case: "Q"-value-energy versus ^{4}He (after M. McKubre, ICCF11, 2004).

Many researchers have been asserting the working hypothesis:

$$\mathrm{D} + \mathrm{D} \rightarrow {}^4\mathrm{He} + \text{Lattice-energy} \;\; (23.8\ \mathrm{MeV}). \tag{1}$$

However, this hypothesis has no support from nuclear physics theory as we discuss in the theory section.

3. Nuclear Transmutations in Metal-D Systems

Reports claiming nuclear transmutations in CF experiments using metal-D systems have gradually increased[2–4] since around 1992. People have looked the claims of transmutations with doubtful views since transmutation should overcome very high Coulomb repulsion of two-body nuclear interactions and even cold DD reaction with milder Coulomb repulsion condition looks impossible. Nevertheless, from the latest experimental results, we have to take seriously the case of "special kinds of nuclear transmutations in the environment of condensed matter of metal-D systems".

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Major reports[2–6] are from Iwamura, Mizuno, Celani, Yamada, Karabut, Violante, Miley, Mastromatteo, Savvatimova, Passel, Szpak, and so on. Key issues in experiments are mass-analysis, isotopic-ratio analysis, spectroscopic detection of particles (including X-rays and gamma-rays), nano-modification of samples, and external stimulation (or triggering).

Most remarkable and reproducible transmutation experiments have been reported by MHI Iwamura group.[25–29] They are using Pd-complex samples which have multi-layered structure of about 100 nm surface Pd layer and following four layers of alternative CaO/Pd composition (see Fig. 4) on 0.1 mm thick Pd substrate plate. They put small amount of test elements (Cs or Sr) on surface. They set a sample in a chamber filled with 1-atom D_2 gas and evacuate the volume rear sample plate. D-atoms permeate through sample by keeping permeation rate higher than 1 sccm. They have made *in situ* analyses of surface elements by X-ray-induced Photoelectron Spectroscopy (XPS) or X-ray Fluorescence Spectroscopy (XFS). Amazingly, they observed transmutations of $^{133}\mathrm{Cs} \to ^{141}\mathrm{Pr}, ^{88}\mathrm{Sr} \to ^{96}\mathrm{Mo}$ for the cases of D-permeation, but did not at all for H-permeation.

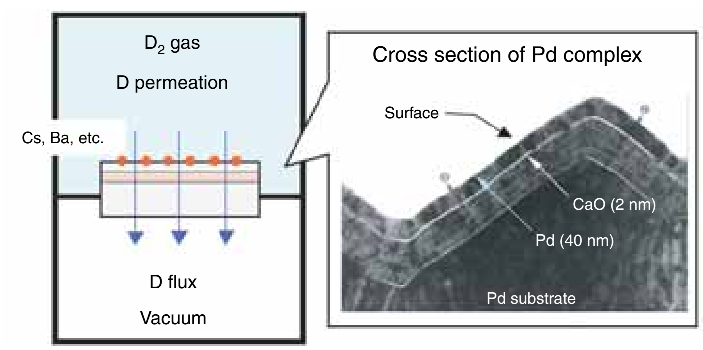

Figure 4. D_2 gas permeation through the Pd complex.

The claimed transmutation channel is strangely selective as

$$M(A, Z) + 4\mathrm{D}\,(\text{or } 2\,^4\mathrm{He}) \to M(A+8, Z+4) + Q. \tag{2}$$

People have checked if there are misunderstandings in experimental procedure, contamination of impurity elements, mistakes in element and mass analyses, and others to find nothing wrong as far as they have checked through. People have started to take this result of "selective transmutation" seriously.

Takahashi-group of Osaka University tried replication[30] of Iwamura experiments to result in observation of Pr production from Cs, three times out of three runs. Iwamura group has been doing separate series of experiments at Spring8 setting

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up new chamber with incidence of strong SOR X-ray beam to make *in situ* FXS analysis of surface elements of Pd-complex under D-permeation. They have repeatedly observed transmutation from ^{133}Cs to ^{141}Pr (see Fig. 5). They have made sample analysis after experiments by Time-of-Flight Secondary Ionization Mass Spectroscopy (TOF-SIMS) to find that transmuted Pr distributed within about 10 nm depth from surface of Pd-complex sample (see Fig. 6). The data in Fig. 6 give insight that the transmutation reaction should have taken place in near surface region.

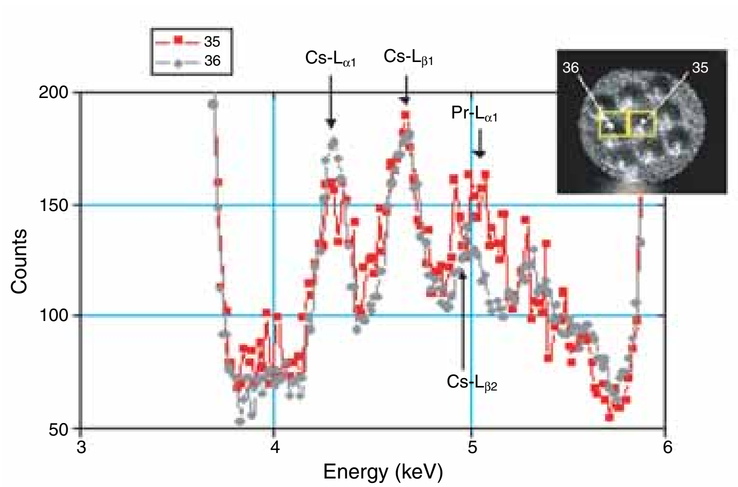

Figure 5. An experiment of Pr detection by the experiments at Spring-8 (Imaura, ICCF11).

To explain theoretically the surprising selective transmutation, Takahashi is developing the EQPET/TSC model of bosonized condensates of deuteron clusters under ordered dynamics of PdDx lattice, and T. Chubb–S. Chubb are proposing coherent reaction models by ion-band state of Bloch wave functions of many deuterons in lattice, as we will discuss in Section 5.

When this transmutation process also takes place for radio-isotopes as ^{137}Cs and ^{90}Sr, the principle can provide a new way for remediation of nuclear wastes.

Observations of anomalous production of foreign elements in D_2O/Pd and Pd/D-gas systems have been reported by Mizuno, Ohmori, Karabut, Szpak[105] and so on. In these cases, they observed also excess heat events. Observed foreign elements are very common among these reports, namely Si, S, Ca, Ti, Cr, Mn, Fe, Cu, Zn, etc. Mizuno[31] reports that production rates of foreign elements were drastically small (several orders of magnitude) when excess heat evolutions were not observed. If these foreign elements, which were distributed in a wide range of mass and atomic number, were generated by some nuclear reaction, some fission process of host metal nuclei should be attributed to the reaction.

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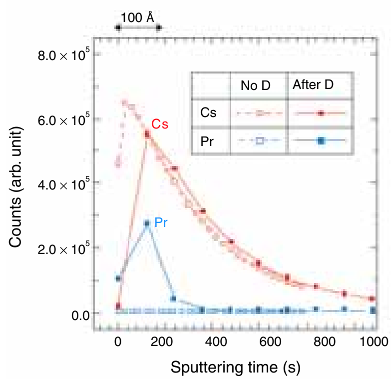

Figure 6. Depth profile of Cs and Pr by TOF-SIMS (Iwamura, ICCF11).

Takahshi *et al.*[32−34] have proposed a deterministic fission theory [Selective Channel Scission (SCS) model] based on rotating liquid drop model of excited nucleus. They checked the model successfully for calculating mass and atomic number distributions of fission products (FP) by ^{235}U+n fission process[33] to be compared with experimental data. Then they applied the model for predicting FP distributions of lower mass nuclei of $A < 200$. Mizuno's foreign element data are compared with Takahashi calculation in Fig. 7.

Theoretically predicted element distribution looks similar to Mizuno experiment. In the SCS process, isotopic ratios of FP element become very different from natural abundances. For example, ^{57}Fe exists with 0.3% in natural iron, but both of FP of SCS theory and experiments by Mizuno gave similar values of about 10% in FP iron

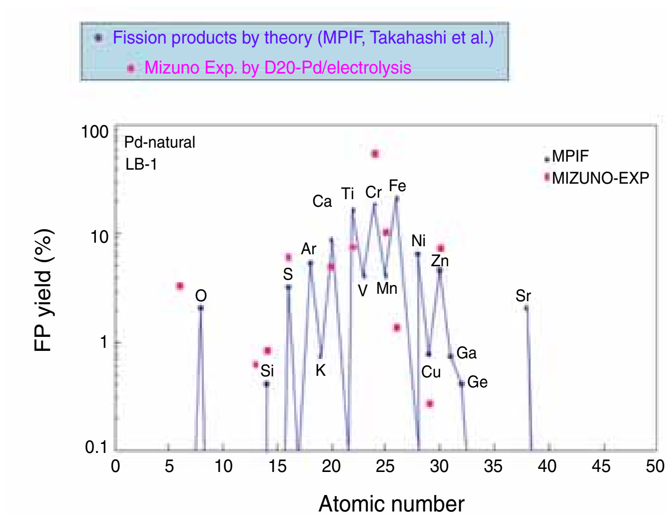

Figure 7. Foreign atom distribution obtained by Mizuno's D_2O electrolysis, compared with theoretical prediction of Pd-fission products calculated by SCS theory by Takahashi *et al.*

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isotopes. These agreements are quite interesting, and further studies are expected to verify if the phenomenon is really nuclear fission process for lighter nuclei in the environment of metal–D systems. Similar results have been reported for Ni–H systems as discuss below. The SCS theory predicts that fission products for $A < 200$ nuclei become very much cleaner (less radio-active and very small neutron emission) due to predominant production of stable isotopes.[32−34]

4. Metal–Hydrogen Systems

Observation of anomalous production of foreign elements and excess heat in metal-ordinary-water/H systems have been claimed[2−6] in reports by Piantelli, Ohmori, Miley, Yamada, Romadanov, Dash, Li, Mizuno, and so on. Key issues of experiments are again calorimetry, mass and isotopic analyses, radiation detection, sample fabrication, and triggering and stimulation techniques.

Piantelli *et al.*[36,37] of Siena University has been doing a H-gas absorption and diffusion type experiments using cylindrical Ni samples in chamber with heating device. They have made claim of large excess heat and gamma-ray emission with production of foreign elements. Figure 8 shows one of their typical data for observation of gamma-ray emission.

They set up a standard ^{137}Cs gamma-ray (661 keV peak) source for calibration. The observed peak at around 744 keV is a surprise, which they say the gamma-line from Mn isotope. A theoretical prediction by Takahashi's 4p/TSC-induced fission[35] interpret that ^{52}Mn and ^{56}Ni as FPs of Ni + 4p fission process can be sources of 744 keV line.

It is well known that Miley–Patterson[38] reported distributed production of transmuted elements and excess heat in their Ni-ordinary-water electrolysis experiments.

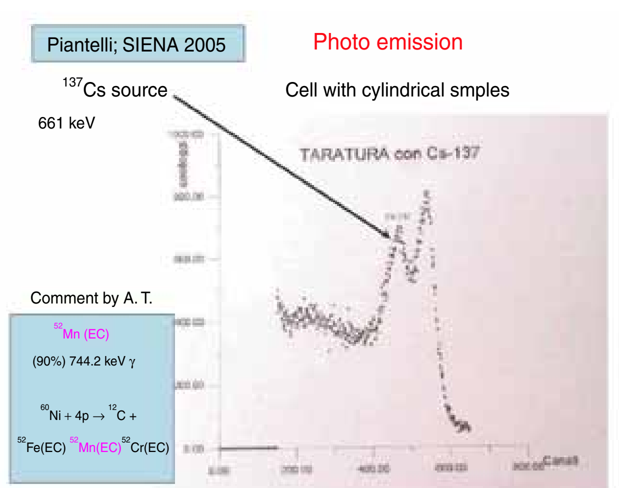

Figure 8. Gamma-ray spectrum obtained in Ni-H-gas experiment by Piantelli *et al.*

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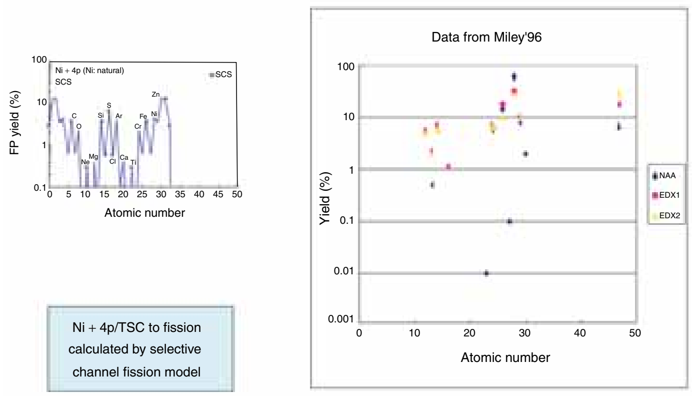
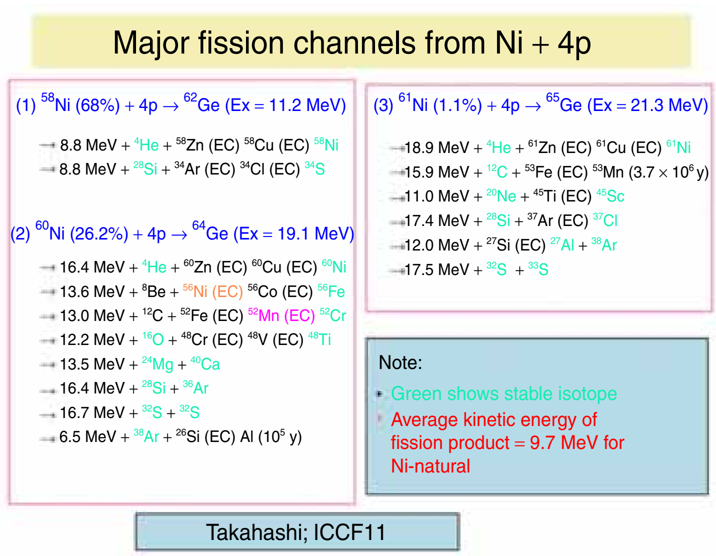


Figure 9. FP elements by SCS versus Miley experiment (G. Miley and J. Patterson J. New Energy, 1996, 1, p. 5).

Specially nano-fabricated multi-layered test samples were used in these experiments. Dominant foreign elements observed are compared with the SCS prediction for Ni + 4p/TSC fission process,[3,39] in Fig. 9. Agreement has to be said surprising. For two peaks near at atomic number 25 and 15, we see almost same distributions. The third peak including C and O in theory is considered to be difficult to identify in experiments due to contaminants. Predominant fission products from Ni + 4p fission come from ^{60}Ni + 4p, and contribution of ^{58}Ni is very small. And FPs are almost stable isotopes (Slide 4).



Slide 4

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The plasma-discharge type experiments[40] using ordinary-water/W-cathode electrolysis is currently of interest. Anomalously large generation of H_2-gas was reported by Mizuno.[40] Amount of H_2-gas production rate reached at the level of 80 times exceeding the Faraday law of electrochemical dissociation of H_2O. Even if this anomalous amount of H_2 production can be attributed to pyrolysis, there should be a great amount of energy source than electrolysis. They reported transmutation-like foreign elements[41] in this experiments, too.

Reproducibility of CMNS experiments is of key issue for convincing the CMN effects and applying to technological devices for energy production and NW-remediation.

Few approaches look establishing the qualitative reproducibility, but we need further efforts to meet the 100% (quantitative) reproducibility. We may rank up hopeful methods as follows.

1. D_2 gas permeation with Pd-complex.[25–30] Iwamura, Higashiyama, Spring-8 (100% for selective transmutation).
2. Super-wave + laser electrolysis with thin Pd.[9,10] Israel + SRI + ENEA (very high reproducibility for large excess heat).
3. Sono-fusion with plate and nano-particles.[23,24] Stringham, R. George, Arata (very high reproducibility for heat and ^{4}He).
4. Plasma electrolyses with W.[31,40,41] Mizuno, Ohmori (transmutation and excess-H-gas production).
5. Micro-wire-Pd with Th, silica-colloid by pulse-electrolysis.[42–44] Celani, Spallone, and Violante (very high reproducibility for rapid full D-loading).
6. Nano-crystals plus gas plus laser: Arata,[15] Mastromatteo,[45] and Israel-group.[10]

Other methods of gas-glow-discharge by Karabut[46] and Yamada[47–49] should be notified for studying transmutation effects.

For more fundamental studies, Low-energy D-beam experiments with metal-deuterides (searching enhancement of d–d and 3d fusion) by Kasagi,[90–94] Huke,[95,96] Kitamura,[97] and Takahashi-Isobe-Ochiai[98–101] have made significant contributions to the progress of CMNS.

5. Theories on Nuclear Reactions under Ordering Process (Strong Interaction)

Several theoretical models have been proposed and elaborated for interpreting possible mechanisms of "new fusion reactions" by deuteron behaviors under ordered (or equivalently constrained) conditions in the environment of metal-D condensed matter.

Typical theories have been proposed as follows.

1. D-cluster fusion models: EQPET/TSC (Takahashi),[50–58] and EODD (Kirkinskii).[59,60]

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2. Bose–Einstein condensation models: Kim[61] and Tsuchiya.[62,63]
3. Resonance tunneling: X.Z. Li.[64−67]
4. Phonon-coupled gauge theory: Hagelstein.[7,68−70]
5. Coherent Bloch-state models: S. Chubb[71,72] and T. Chubb.[73,74]
6. Swimming electron layer model: Hora-Miley.[75,77]
7. SCS fission model: Takahashi–Ohta.[32−35]

For modeling in every theory, we should treat the new aspect how dynamic ordering or particle-constraint conditions in condensed matter (solid state) physics states can be linked or combined with new nuclear reaction channels. We have to clarify how Coulomb repulsion can be overcome, how new nuclear channels are open. We have to quantify theoretical models to give quantitative predictions for nuclear reaction rates, so as to meet the reaction rate levels from experiments.

One practical issue is how ^{4}He can be major ash without associating intense neutron emission. The scenario $\mathrm{D} + \mathrm{D} \rightarrow ^4$ He+ lattice-energy (23.8 MeV) does not have place to stand on, in the view of nuclear physics[57] (see Fig. 10).

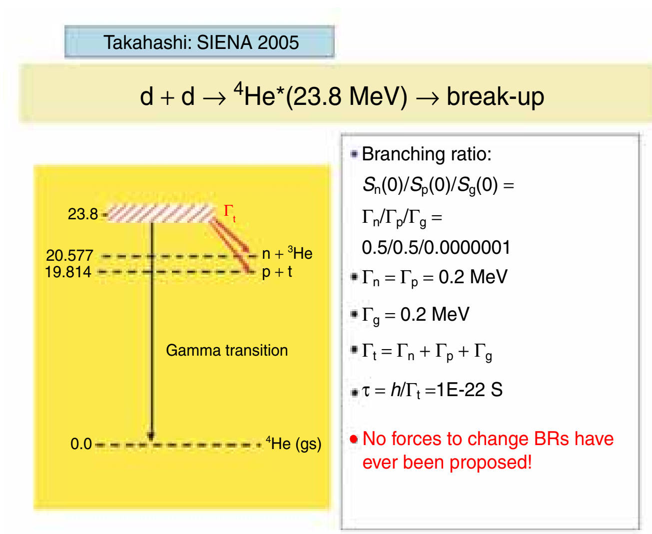

Figure 10. Final state interaction and branching ratios for d-d fusion.

In EQPET/TSC models by Takahashi,[50−58] the *idea of bosonized condensates* was substantiated. To induce ^{4}He production without neutron emission, he made the third and fourth hadrons (deuterons or protons) participating into d–d strong interaction. In consequence, he had to treat multi-body fusion (or cluster fusion) reactions under ordered constraint of Tetrahedral Symmetric Condensate (TSC) motion in PdDx lattice.

In other ways, Chubb–Chubb[71−74] and Hagelstein[69,70] have proposed some sort of coherent fusion processes for so-many-body systems in PdDx lattice to try to

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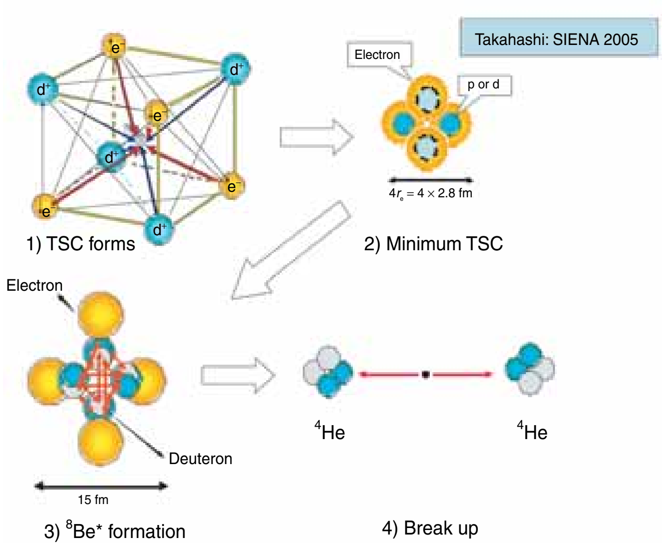

Figure 11. Illustration of TSC squeezed condensation; (a) TSC formation at $t = 0$, (b) minimum size state of condensed TSC, (c) formation of ^{8}Be* by strong interaction, and (d) break-up of ^{8}Be* into two alpha-particles.

reach ^{4}He production channels. Takahashi treats rather microscopic coherence, while Chubb–Chubb and Hagelstein do rather macroscopic coherence in metal–deuterium lattice systems.

In theorizing nuclear effects in CMNS, to point out qualitatively new reaction channels is not enough at all. We have to quantify theoretical models to show quantitative (numerical) predictions that new reaction channels will be feasibly taken place. For example, such reaction channels as $\mathrm{D} + \mathrm{D} \rightarrow^4 \mathrm{He} + \gamma$ (23.8 MeV) or $^{133}\mathrm{Cs} + 4\mathrm{D} \rightarrow^{141} \mathrm{Pr} + Q$ (50.49 MeV) look possible from the mass–energy conservation of Einstein relation, because of exothermic reactions, but actually these do

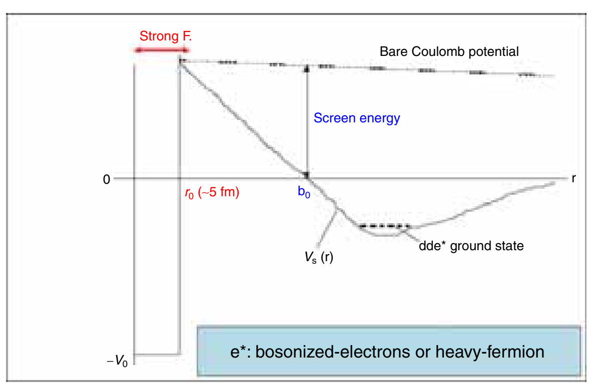

Figure 12. Shielded Coulomb potential for dde* pseudo-molecule under steady-state assumption; relation to screening energy and strong interaction range for d-d reaction is illustrated.

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Table 1. Screening energy of EQPET molecules $U_s = e^2/b_0$ for V_s $(b_0) = 0$ (Takahashi, SIENA 2005).

e*	U_s(eV)		b_0 (pm)	
	dde*	dde*e*	dde*	dde*e*
(1,1)	36	72	40	20
(2,2)	360	411	4	3.5
(4,4)	4000	1108	0.36	1.3
(8,8)	22154	960	0.065	1.5
(208,1)	7579	7200	0.19	0.20

not happen unless high potential barriers of Coulomb repulsion can be overcome by particular ways that we should theorize. We have to estimate how Coulomb repulsion is overcome in the initial state interaction, how intermediate compound state is and what are branching ratios in the final state interaction. Theoretical modeling should be self-consistent so as to be quantified.

The theory of EQPET/TSC by Takahashi[50–58] is trying to give quantified predictions. Recently at ICC10, Takahashi proposed TSC of four deuterons and four electrons in PdDx lattice dynamics forming a transient quasi-molecular state of orthogonally coupled two D_2 molecules and squeezing semiclassically into central T-site to reach TSC-minimum-size state with about 10 fm diameter as charge neutral pseudo-particle. The TSC-minimum state for 4D/TSC causes self-fusion of 4D to $^4He + {}^4He + 47.6\,MeV$, or capture reaction (selective transmutation) with host metal nucleus. This scenario is shown in Fig. 11.

Takahashi treats transiently bosonized states of electron pairs with anti-parallel spins and quadruplet coupling e*(4,4) by Electronic Quasi-Particle Expansion Theory (EQPET).[51–55] He treats virtual pseudo-molecule dde* as illustrated in Fig. 12. He calculated screened potentials for dde* molecules and estimated screen energies and other potential parameters as given in Table 1.

Nuclear strong force for fusion is estimated based on the concept of optical potential (see Fig. 13) and effective surface sticking force PEF[52–58] for multi-body (4D) fusion by TSC.

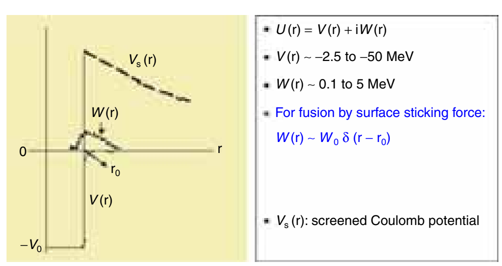

Figure 13. Optical potential for strong interaction

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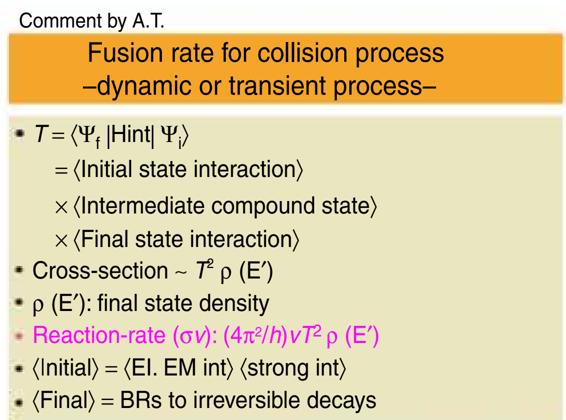
Fusion rate in general is given for collision-like process as shown in Slide 5.



Slide 5

Practical formulas are given in Fig. 14. Time averaged cluster fusion rates for the TSC squeezing motion is given in Table 2. He reports some of key issues in CMNE can be explained by these EQPET/TSC models as shown in Table 3.

Kim[61,62] is studying CMN effects in Bose–Einstein condensation (BEC) process. He assumes that many deuterons, metal ions like Li^+ and electrons are confined in a void cavity in metal lattice and they are behaving as plasma. Superposition of many-body wave functions by BEC is supposed to play role for strong enhancement of dd fusion and d-^{6}Li fusion (source of ^{4}He generation). Deuteron is a boson. To

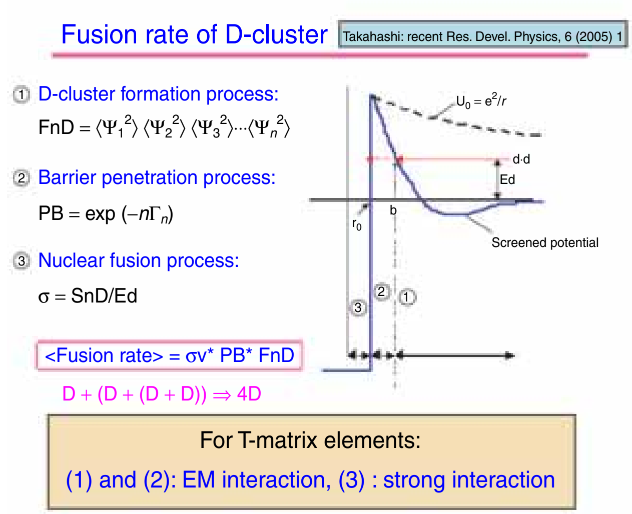


Figure 14. Three-step Born-Oppenheimer treatments in formulating D-cluster fusion rates in condensed matter.

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Table 2. TDEQPET calculation for EQPET molecules (Takahashi, ICCF12).

e* (m, Z)	$\langle\lambda\ 2d\rangle$ (f/s/cl.)	$\langle\lambda\ 4d\rangle$ (f/s/cl.)	$\lambda\ \ 2d$ (0) (f/s/cl.)	$\lambda\ \ 4d$ (0) (f/s/cl.)
(1,1)	4.3×10^{-44}	7.8×10^{-63}	1.9×10^{-60}	7.3×10^{-93}
(2,2)	2.9×10^{-25}	2.5×10^{-24}	2.4×10^{-37}	1.1×10^{-50}
(4,4)	$2.1 \times 10^{-17*}$	5.5×10^{-8}	$5.5 \times 10^{-22*}$	5.9×10^{-20}

*Virtual value.

minimize system Coulomb energy of particles in the cavity should, however, lead to charge neutralization between deuterons and electrons to form D-atoms for dilute gas (or D_2 molecules after collision process for dense gas). Plasma state at room temperature looks no good idea. And D-atoms are fermions due to odd (non-integer) spin for electron. Models by Kim and Tsuchiya need further elaboration.

Takahashi's EQPET/TSC models are kind of bosonized condensate models. However, TSC is bosonized condensate under strong constraint (namely ordering process in lattice), different from BEC of dilute gas at near zero temperature but similar to bosonization of fermions (formation of Cooper pair) for super-conductivity and super-fluid. New aspect as CMNS is "Bosonization in Ordering Process".

X. Z. Li has studied Resonant Tunneling Model.[64,65] Intermediate compound state of fusion reactions in CM may have, he proposes, excited state with very long (as 10^4 s) life time to select resonating decay channel for final state interaction. During his study he has made nice progress to fit fusion cross sections for DD, DT, and D^3He reactions using revised formulas of elementary phase-shift analysis of scattering matrix and optical potential. This is good progress. However, his model cannot change the situation of Fig. 10, namely for drastically increase branching ratio to ^4He channel since longer life time makes the gamma-transition branching ratio smaller.

Hagelstein has been studying a kind of coherent fusion model to explain neutron-less ^4He generation and excess heat. His models do not reach the stage of quantified theory, but are trying to approach to quantification. Recently he is proposing the phonon-coupled gauge models, assuming 'compact' intermediate state of $\langle n\text{-}^3He\rangle$ to evaluate gauge transform between $\langle d\text{-}d\rangle$ state, $\langle n\text{-}^3He\rangle$ state, and irreversible

Table 3. Major results: experiments versus theory.

Item	Experiment Author/Method/Results	EQPET/TSC model
Screening d–d	Kasag/beam/310 eV Takahashi/3D/10^9 $\langle dd\rangle$	360 eV by dde* (2,2) (10^{13}) τ (0.1 ms)
^4He production	McKubre/electrolysis/ $30 \pm 13\,MeV/^4H$	$23.8\ MeV/^4He$ by 4D $\rightarrow$ $^4Hex2 + 47.6$ MeV
Maximum heat	El Boher/EI/24.8 keV/Pd, Gain = 25	23 keV/Pd 46 MeV/cc by 4d/TSC
Transmutation	Iwamura/Perm/Cs → Pr Miley/NiH/Fission-like Pro.	4d/TSC + M 4p/TSC + M reaction

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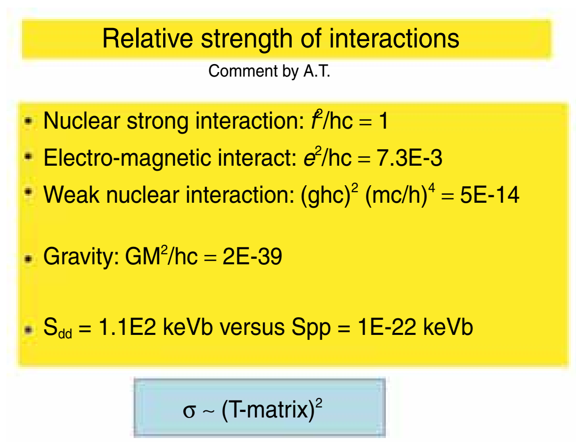
out-going channel to ^{4}He. This is an elegant approach. However, there are some fundamental problems. First, ⟨n-^{3}He⟩ state may not exist with meaningfully large life time to be prohibited to going out to the n + ^{3}He + 3.25 MeV channel with very short life time (on the order of 10^{-22} s) from the intermediate compound state ^{4}He* as shown in Fig. 10. He estimates that the transform strength (QM flow) between states by phonon exchange is on the order of 10^{-4}, which is right but is much smaller than field coupling between strong interactions (see Slide 6, accordingly). Branching ratio to electromagnetic transition (decay channel to ^{4}He) cannot be increased by more than 10^{-4} of those (0.5) for n + ^{3}He or p + t channels.

Chubb–Chubb[71–74] have proposed a kind of coherent fusion model through the D-ion-band state in PdDx lattice Bloch potential. They assume that QM waves of many deuterons inside a well of many-body (more than 10,000 Ds) potential can link widely and, due to the double Bloch symmetry conditions, Coulomb repulsions between deuterons eliminate in scale of 1/Nwell for Nwell more than 10,000. They also assume this coherent condition should change the intermediate compound state (^{4}He*) of DD interaction to form ^{4}He-ion-band state with long life time, for which we can use wave-function form of ^{4}He. This is another elegant theory. To reach quantified predictions by this theory, we need to substantiate many things; to prove definitely the 1/Nwell law, to



Slide 6

quantify ion-band state excitation functions, to evaluate life time of ^{4}He-ion-band state if at all, to propose an intermediate compound state (^{4}He*) with quite different spin–parity state through the interaction with electromagnetic Bloch potential (actually phonons by lattice vibration, harmonic oscillators, for example) to avoid final state irreversible decays to n and t channels in Fig. 10. Elaboration will be tough.

We summarize elaborations for quantification of theories in Slide 7, including other models by Hora's[76] swimming electron layer model, Fisher's poly-neutron model and Kozima's neutron-catalyzed reaction model.

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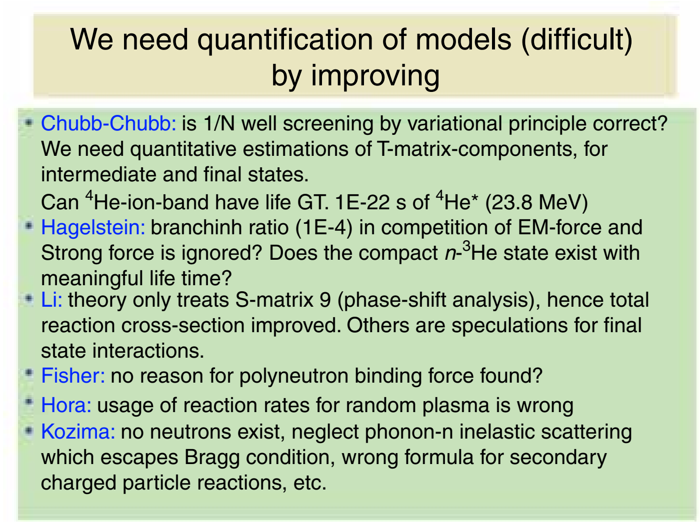

Slide 7

6. Theories with Weak Interactions and Others

Interesting theoretical models are as follows:

1. Mini-H-atom (by heavy electron) formation to zero-momentum neutron model: Widom.[78]
2. Mini-H-atom (by suborbital QM state): Mils,[79] Yamamoto,[80] and Filimonov.[81]
3. Poly-neutron reaction model: Fisher[82] and Kozima.[83]

Here key issue will be how reaction rates via weak interactions can be enhanced. Quantitative predictability is the key.

Brief scenario of Widom's theory is; on the flat surface of metal-hydride, coherent coupling between many-body electron oscillations and proton oscillations makes effective electron mass significantly heavy. Mini-atom orbit of H-atom with heavy electron forms. Electron capture process into proton may be very strongly enhanced to generate near-zero-momentum neutrons. These very low-energy neutrons will be absorbed within very short range near surface to induce neutron-induced reactions.

This kind of theory has many fundamental problems as:

(1) Production cross section of "heavy electron" e* is not given, so that we cannot argue on density of very-low-momentum-neutron (VLMN) available in matter, taking into account of 10 min beta-decay of neutrons and assumed neutron-conversion cross section (see 3). If neutron density were greater than 10^{16} per cm^2 on surface, neutron reaction rate with H and host metal-nuclei were realistic level as experiments claim. According to neutron decay and

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inelastic phonon-scattering with lattice vibration, which is up-scattering to higher neutron energy, we need to estimate mean existing time of VLMN on surface. (The author guesses that VLMNs get phonon energy with several barns of cross-section and very rapidly – in less than one micro-second-leak out from system.)

(2) Proton (deuteron) on metal surface lattice vibrates with $(1/2\pi)\ h\omega$, as Einstein oscillator, and has "recoil energy" of about 30 meV. VLMN converted from proton should conserve this 30 meV as kinetic energy which is a little more than averaged (thermal equilibrium) energy of 25 meV in media at room temperature. (Einstein oscillator can have higher zero-point energy than Debye oscillators of metal atoms.)

(3) Cross section for p + e$*$ to n+neutrino is not given. The author thinks this cross-section (over threshold energy of reaction) should be very much small, of the order of 10^{-26} of usual strong interactions. And neutrino here is different from electron–neutrino and muon–neutrino, and deviates from the three generations scenario of leptons. This cross-section (or transition matrix) estimation is key problem for making their theory realistic!

(4) $^{6}\mathrm{Li} + \mathrm{n}$ to $^{4}\mathrm{He} + \mathrm{t} + 4.8\,\mathrm{MeV}$ channel has about 1000 barn at $E_n = 25\,\mathrm{meV}$, compared with very small cross section 4×10^{-2} barn for n-capture, $^{6}\mathrm{Li} +$ n to^{7}Li + gamma. And ^{7}Li + n to ^{8}Li to ^{8}Be + beta to $^{4}\mathrm{He} +^{4}\mathrm{He} + \mathrm{e}$ process has 4×10^{-2} barn at $E_n = 25\,\mathrm{meV}$, only. So, it is well known that ^{6}Li + n to $^{4}\mathrm{He} + \mathrm{t} + 4.8\,\mathrm{MeV}$ is predominant channel! Since reaction rate per neutron flux is (cross-section) $\times$ (velocity) and cross-section at lower energy than 30 meV has $1/v$ law, all reaction rates keep constant according to the change of momentum or kinetic energy. So that, even at very much low energy, reaction rate does not increase so. Widom–Larson might misunderstand these points.

(5) If p + e$*$ state exists, it should have transition to mini-atom orbit which should emit photons greater than 13.6 eV of H-atom ground state. (This has some sort of relation to Randi Mill's sub-orbital quantum state, hydrino!) We need to estimate life time of e* becoming heavy by Widom's oscillating electro-magnetic plasmon (surface polariton) interaction on surface.

(6) If hard gamma-rays were totally absorbed by e*, we can do easily test using a standard gamma-ray source to measure gamma-peak attenuation through the sample metal-hydride surface. We have no data for Compton scattering with e*, which he assumes very much large to neglect gamma–electron processes with metal-atoms having usually much larger photoelectric, Compton and pair-creation cross sections compared with those for hydrogen atom.

(7) We know, dde*(mass = 208m-electron), namely muonic dd-molecule does not emit low-energy neutrons (but 2.45 MeV neutron by d–d fusion), although Widom theory suggests dde* to d + n + n break-up.

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We can make such skeptical critics easily for other models also. By making clear every question, one by one, one can improve models[84–89] and approach to the target. We need tough efforts of elaborations.

7. Conclusions

1. Recent results of CMNS studies show very important consequences of Clean Fusion and Cold Transmutation.
2. We are in Turning Point for studying deeper and establishing new field of Condensed Matter Nuclear Science (CMNS).
3. New progress is expected at this conference of ICCF12.

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