ULTRADENSE NUCLEAR FUSION IN METALLIC LITHIUM LIQUID

A report on research performed at the R&D Center, Sakaguchi E.H VOC Co. under the auspices of the Swedish Energy Agency

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Preface

This report is concerned with research and development on a new fusion scheme, “chemonuclear fusion”. In this scheme, lithium or deuterium ions are implanted in liquid lithium whereby huge reaction rate enhancements, as much as up to 1015 compared to what is expected for a free two-body deuterium-lithium interaction, are obtained. The enhancement is suggested to be a result of nuclear, atomic and chemical reactions taking place cooperatively.

Experimental studies on the Li – D chemonuclear fusion is supported financially by the Swedish Energy Agency and were initiated at the Department of Analytical Chemistry, Uppsala University. The results of these initial studies appeared in a Bulletin from the Institute of Chemistry, September 2002: Evidence of Enhanced Non-thermal Nuclear Fusion by Hidetsugu Ikegami and Roland Pettersson and in Prog. Theo. Phys. Suppl. 2004, 154, 251: Enormous Entropy Enhancement Revealed in Linked Nuclear and Atomic Li – D Fusion in Metallic Li Liquid by Hidetsugu Ikegami, Roland Pettersson and Lars Einarsson.

The studies were continued in a collaboration with the R&D Centre, Sakaguchi E.H VOC Co. in Tokyo where a new and modified setup was constructed. Here, besides the Li – D chemonuclear fusion, the Li – Li fusion and the D2 – 2Li molecular chemonuclear fusion were developed.

In 2005 at the R&D Centre, molecular ions D_2^+ of energies 30keV were implanted on a surface of metallic Li liquid. Product alpha particles were identified and measured by a single solid state detector. The energies were around 7.6MeV corresponding to what would be expected for the reaction $^7Li + D \rightarrow 2\cdot{}^4He + n$. Under some conditions of the Li liquid, the reaction rate was intermittently so high that the particle detector was saturated and stopped counting simultaneously with an appreciable temperature rise in the Li liquid. The results were discussed in March at the University of Tokyo and in October at the Royal Swedish Academy of Sciences, The Royal Swedish Engineering Academy of Sciences and at Uppsala University. This report presents a full description of the results. It also contains more recent results where an additional detector setup, a E□E detector provided by the Swedish Energy Agency was used for validation of the results in particular the identity of the alpha particles.

It is hoped that this publication will stimulate continued work towards “the third fire”, a name invented by Hidetsugu Ikegami for the presented ideas on an alternative fusion scheme.

Eskilstuna in October 2006

Lars Tegnér
Swedish Energy Agency

Foreword – How Comes Chemonuclear Fusion?

Soon after the discoveries of the concepts, ”nucleus” and ”Rutherford scattering”, Niels Bohr who was a postdoctoral fellow of Rutherford’s laboratory explained that Rutherford scattering was not simply a collision between nuclei but was a collision between whole atoms at very low energies typically several keV/amu on the basis of his atomic model. Nowadays this phenomenon is called nuclear stopping of ions/atoms implanted in condensed matter since the nuclei of the struck ions/atoms acquire significant amounts of kinetic energy in the collision as seen in sputtering phenomena of ions. This implies that collisions of nuclei are fully linked to atomic processes at the energies of nuclear stopping.

Nuclear reactions take place also with a linkage to the atomic processes and thus are controllable through the synchronous formation of atomic- and nuclear- intermediate complexes under appropriate chemical and physical conditions. This feature of nuclear stopping of ions/atoms keeps a hidden potential leading to the new concept ”chemonuclear fusion reactions”.

The above-mentioned state of affairs can be visualized if one considers, for example, the 7Li – 7Li atomic collision at an energy of nuclear stopping, from the microscopic viewpoint. The collision is essentially the Rutherford scattering between two 7Li nuclei dressed with atomic electrons. In the first phase of the collision the atoms tend towards the formation of a diatomic molecule Li2 at the minimal Gibbs energy point of the process. However this Gibbs energy is not the minimum point any longer for the atoms colliding with the energy of nuclear stopping. They are directed to the nuclear collision at their turning point, within a classical physical description.

At the turning point the two atoms form a quasi-C atom, with a shrinkage in volume by a factor of 0.065, within a very short collision time (about 10–18s) that is the period of zero point oscillation of the colliding nuclei. In the shrinking quasi-C atom, the twin colliding nuclei co-exist and are confined at the center of a common K-shell electron orbital with a density of a million times as high as the solar interior density. If nothing happens except an elastic collision between the nuclei at their turning point, the quasi-C atom decays into two Li atoms as before. However, in the liquid phase, since the cohesion in liquid Li is twice or more than that in Hg, the presence of thermodynamic forces in the metallic Li liquid

prolongs enormously the lifetime of the shrinking quasi-C atom and thereby the confinement of the ultra dense 7Li nuclei pair, as explained in papers 1 and 3 in this report. Then the 7Li – 7Li nuclear fusion is likely to take place through the tunneling effect induced by the zero point oscillation.

The new scheme of fusion presented in this report, chemonuclear fusion, is based on the considerations given above. The nuclear reactions are no more, simple two-body reactions but take place cooperatively linked with chemical reactions. Here two body collisions are treated on the basis of quantum mechanics while the chemical processes are treated in the scheme of Gibbs statistical thermodynamics. Huge enhancements in reaction rates, as much as up-to 10^{48}, are thereby predicted. Experimental results presented in an earlier report "Bulletin of Institute of Chemistry, Uppsala University, September 2002", seem to support these large enhancements. Recent experiments conducted at Sakaguchi E. H. VOC Co. in Tokyo give added evidence for enhanced reaction rates and are presented in papers 2, 4 and 5 in this report.

Uppsala in October 2006

Hidetsugu Ikegami

Innehåll

1 Kemonukleära reaktioner med Litium, en väg till en ny energikälla.

Den minsta och lättaste alkalimetallen Litium har en rad unika egenskaper, låg smältpunkt (180 ºC) hög kokpunkt (1347 ºC), högst vämekapacitet av alla metaller och hög ytspänning (stora kohesions krafter) i flytande form. Litium är också en tämligen vanligt förekommande metall i jordskorpan, ungefär som koppar och wolfram.

Den föreliggande rapporten presenterar ett antal papper som argumenterar för att den starka ytspänningen i flytande litium, under gynnsamma omständigheter kraftigt kan öka sannolikheten för nukleära fusionsreaktioner, samma energikälla som får solen och stjärnorna att lysa. I detta fall fusionerar dock litium med tungt väte eller litum och slutprodukter blir, efter sönderfall av mellan produkten, alfa partiklar, dvs. heliumgas. Beroende på val av reaktant, kan även neutroner bildas. Inget kärnavfall bildas. Experimentella data från Uppsala och Sakura (Japan) ger stöd för att en sådan ökad sannolikhet verkligen föreligger. Energimyndigheten har finansierat utrustning för försöken i Uppsala och forskningsutbytet med Japan. I Japan finansierar det högteknologiska företaget Sakaguchi E. H. VOC Co. projektet.

I de försök som genomförts, bombarderades en yta av flytande litium, vid en temperatur straxt över smältpunkten, med joner av tungt väte, sk deuterium (D^+, D_2^+) eller litium (Li^+). Dessa joner skapades i en jonkälla av ”Penning-typ” (PIG). I jonkällan bildas D^+, D_2^+ och D_3^+ om deuterium används. Efter acceleration till en energi mellan 15 och 30 keV separerades den önskvärda jonen (ex. D_2^+) ut med hjälp av ett magnetfält. Den alstrade jonströmmen som var ca. 1 mikroampere mättes med en coulometer. Eftersom accelerationsenergin är låg kommer alla reaktioner att ske inom ett mycket tunt ytskikt mindre än 1 mikrometer. Temperaturvariationer hos smältan registrerades med termoelement (ca 2 mm under ytan) Vidare registrerades produktion av alfapartiklar med en halvledardetektor (SSD) och ett s.k. ΔE/ E-teleskop, som är en partikelspecifik detektor, dessutom registrerades neutroner med en LiI-scintillationsdetektor. Diagnosen bestod således av fyra olika händelser, där alfa- och neutron-detektion var det primära vid lågt utbyte. Vid högt utbyte tillkommer också temperaturhöjning hos smältan samt en

minskning i jonströmmen, pga. repulsion mellan alfapartiklar och t.ex. D_2^+,.som indikation på att en fusionsreaktion har skett. Från en litium yta i fast fas observerades inga reaktionsprodukter medan från en litium yta i vätskefas detekterades både alfapartiklar och neutroner och vid ett tillfälle, med Li^+, även en oväntat kraftig temperaturhöjning samt minskning i jonströmmen.

Hidetsugu Ikegami har presenterat en modell för hur sådana reaktioner uppträder i flytande litium. Vid en kollision mellan t ex D^+ och litium bildas först en intermediär LiD molekyl. Energin hos D^+ är dock tillräckligt stor för att molekylen skall fortsätta att komprimeras till ca 7% av ursprungsvolymen. Därvid tränger de båda kärnorna innanför de nu gemensamma K- och L-elektronskalen så att avståndet mellan dem är mindre än 1 pm och ett kortlivat ^{8}Be liknande tillstånd bildas. Livslängden på detta tillstånd är normalt (fast fas) mycket kortlivat (10^{-18} s) och sannolikheten för fusion, via kvant-mekanisk tunnling, är nästan obefintlig vid dessa låga energier (ca en per år). I flytande fas däremot gör de starka kohesionskrafterna hos litiumsmältan att livslängden för det ^{8}Be liknande tillståndet förlängs dramatiskt. Detta ger en förväntad ökning av sanno-likheten för fusion, via tunnling, med en faktor av upp till 10^{11} för D^+ - Li reaktionen. För D_2^+ - 2Li respektive Li – Li förväntas en ökning av upp till 10^{22} respektive 10^{48} gånger. Dessa värden fås genom en termodynamiskt betraktelse över förändringarna i Gibbs fria energi (ΔG) för reaktanter och produkter. Uttrycket som, för varje kemistudent, är den välkända Arrhenius ekvationen, $K = \exp[-\Delta G/k_B T]$ kan nu tillämpas. Här ger K ökningsfaktorn.
Det förväntade energiutbytet kan exemplifieras med reaktionen
$^7Li + D^+ \rightarrow {}^8Be^* + n \rightarrow 2\,^4He + n + 15.12$ MeV,
och en D^+ energi på 30 keV, dvs man får en faktor 500 för detta fall. I verkligheten blir det dessutom följd reaktioner och parallell reaktioner så att energi utbytet blir över 1000 och **inget kärnavfall.**

Som framgår av rapporterna har ett flertal positiva händelser registrerats. Med tanke på den betydelse denna typ av resultat kan komma att få för världens framtida energiförsörjning är det naturligtvis av största vikt att ha otvetydiga resultat. Det krävs därför ytterligare mätningar där man kan påvisa reproducerbarheten och finna den för energiutbytet optimala konfigurationen för den här typen av reaktioner.
Uppsala november 2006
Roland Pettersson and Kjell Fransson

2 Hyperenhanced Li – Li Chemonuclear Fusion

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Abstract: A new fusion scheme, the Li – Li chemonuclear fusion is presented, where nuclear fusion reactions are linked to atomic fusion reactions. Lithium ions are implanted on a surface of metallic Li liquid at an energy of nuclear stopping (several keV/amu). The ions collide slowly with liquid Li atoms without electronic excitation and lead to the Li – Li chemonuclear fusion through the formation of united atoms or quasi-C atoms at their turning points. Inside the quasi-atoms twin nuclei are confined within respective sub-pm scale spheres of zero-point oscillation and form themselves into ultradense intermediate nuclear complexes. Their density is million times as large as the solar interior density and close to densities of white dwarfs or white-dwarf progenitors of supernovae. This confinement of nuclear complexes is enormously prolonged towards the pycnonuclear reactions induced by the zero-point oscillation under the presence of thermodynamic force specified by the Gibbs energy change in the quasi-atom formation in the liquid. Resulted rate enhancement of nuclear fusion by a factor of 10^{48} has been anticipated. The enhancement is also argued in connection with the Bose-Einstein condensation.

Key words: chemonuclear fusion; quasi-atom; zero-point oscillation; supernova; pycnonuclear reaction; Bose-Einstein condensation

2.1 Thermodynamical Features of Nuclei in Many Atom Systems

Nuclei in many atom systems reveal thermodynamical features under certain conditions [1-4]. For example the rate enhancement of nuclear fusion reactions by a factor of 10–100 orders of magnitudes has been anticipated in metallic liquids inside white-dwarf progenitors of supernovae [5-7]. Contrary to one's first impression this enhancement mechanism is common to entropy producing irreversible processes in liquids [1,8,9]. The well-known examples are the Henry's law on the solubility of gases in liquids [9] and the Arrhenius' rate equation [8] for spontaneous or irreversible ($\Delta G_r<0$) chemical reactions in dilute solutions [1-4]. Here ΔG_r denotes the Gibbs energy (chemical potential) change in the processes. General speaking, the fractional change of reaction rate is exactly proportional to the entropy change in the universe [8]. This general thermodynamic relation is strictly independent of nature of microscopic interparticle interactions and leads to the factor $\exp(-\Delta G_r/k_B T)$ in the Arrhenius' equation [1,8]. These considerations lead to the new concept "chemonuclear fusion" [1-4]. The term "chemonuclear fusion" was coined by S.Kullander, the continuous promoter of this research.

2.2 Chemonuclear Fusion via Ultradense Intermediate Nuclear Complexe Formation

2.2.1 CONCEPT OF CHEMONUCLEAR FUSION

Consider a scheme where ions with an acceleration energy of nuclear stopping (several keV per amu) are implanted on a surface of metallic Li liquid [1]. In this scheme the liquid, consisting of Li ions immersed in a sea of collective conduction s-electrons, takes the part of macroscopically correlated solvent reacting with the implanted solute ions. Because in the metallic Li liquid the atomic potential wells for the electrons are not far apart and the electrons can tunnel through the barriers. Furthermore their de Broglie wave length covers the space of some tens Li atoms and yields the collective activity of the liquid [1,9]. We thus are no longer concerned with energy levels of individual Li atoms and/or ions instead of the bulk of liquid metallic Li ions immersed in the collective conduction s-electrons under the explanation by Wigner and Seitz [10].

At the energy of nuclear stopping, the implanted ions collide slowly with liquid Li atoms/ions. Then orbital electrons adjust electronic states continuously and smoothly to nuclear collision processes and thereby link the atomic fusion reactions to the nuclear fusion reactions (hereafter called chemonuclear fusion) because the orbital electrons gyrate much more rapidly than implanted ion speed.

The chemonuclear fusion reaction

$$\mathrm{Li} + \mathrm{X} \rightarrow \overline{\mathrm{LiX}} \rightarrow \mathrm{M} \tag{1}$$

takes place via the atomic fusion that is the metastable formation of united atoms $\overline{\mathrm{LiX}}$ or quasi-M atoms where twin colliding nuclei coexist at the center of common K-electron orbital. These twin nuclei are confined within respective spheres defined by the spacing r_T of their classical turning points during collision time that is the period τ_T of the zero point oscillation [1],

$$\frac{r_\mathrm{T}}{(\mathrm{pm})} = \frac{z_1 z_2 e^2}{4\pi\varepsilon_0 E} = \frac{1.44 z_1 z_2}{E(\mathrm{keV})} , \tag{2}$$

$$\frac{\tau_\mathrm{T}}{(10^{-18}\mathrm{s})} = \frac{2\mu\, r_\mathrm{T}^{\,2}}{h} = 0.48\mu\, r_\mathrm{T}^{\,2} . \tag{3}$$

Here h, z, μ(amu) and E(keV) denote the Plank constant, the charge, the reduced mass and the relative kinetic energy of nuclei of 1 and 2 species, respectively. For example, at the implantation energy of nuclear stopping the twin nuclei are confined within respective sub-pm scale spheres inside the quasi-atoms and form themselves into ultradense intermediate nuclear complexes for about atto (10^{-18})s towards the nuclear fusion through the tunneling effect induced by the zero-point oscillation. The statistical feature of this complex formation process is dominated by the thermodynamic force in the liquid. Here macroscopically distinct parts of the liquid surrounding the quasi-atoms are correlated and long-range coherence appears [1-4,8].

These aspects reflect the rate of chemonuclear fusion reactions in the form of the Arrhenius' equation for irreversible (spontaneous) chemical reactions in dilute solutions,

$$k(T) = k_0 \exp\left(-\frac{\Delta G_\mathrm{r}}{k_\mathrm{B} T}\right), \quad \Delta G_\mathrm{r} < 0, \tag{4}$$

where k_B is the Boltzmann constant [1]. The factor k_0 coressponds to the Arrhenius' frequency factor, that is the intrinsic rate of nuclear reaction entrance channel and expressed as

$$k_0 = I_X N_{Li} \sigma(E). \tag{5}$$

Here I_X, N_{Li} and $\sigma(E)$ are the number current of implanted ions X, the surface number density of Li atoms on the liquid surface and the nuclear fusion reaction cross-section, respectively. Whereas the exponential factor is the equilibrium constant of atomic reaction that is the quasi-atom formation as the elementary atomic process of chemonuclear fusion. The equilibrium constant is generally defined by the Law of Mass Action as the ratio of the whole product of stoichiometric powers of reaction products to that of reactants [8]. As seen in Eq.(4) the factor provides the reaction rate enhancement caused by the thermodynamic force. The enhancement has a super astronomical magnitude in the cases $\Delta G_r/k_BT << -30$. Here the Gibbs energy change ΔG_r is concerned with the quasi-M atom or united atom $\overline{\text{LiX}}$ formation.

There is an exact correspondence between the reaction rate Eq.(4) and the adsorption or residence time τ of gas molecules implanted on a surface of adsorber as seen in

$$\tau = \tau_0 \exp\left[\frac{U}{k_B T}\right], \quad U > 0. \tag{6}$$

Here τ_0 is the intrinsic residence time for U=0 and a function of degrees of freedom of gas molecules in the adsorber. The quantity U denotes the energy for desorption of a gas molecule and corresponds to $-\Delta G_r$ in Eq.(4). In comparison with the residence time in Eq.(6), an essential significance of the reaction rate Eq.(4) has been made clear. The rate enhancement is caused through the prolongation of residence of quasi-atoms and thereby through the prolonged residence of ultradense intermediate nuclear complexes confined inside the respective quasi-atoms. During the prolonged residence, nuclear fusion of the complexes takes place through the tunneling effect induced by the zero point oscillation.

For instance consider a concrete case where deuterium ions are implanted on a metallic Li liquid surface with the relative kinetic energy E=12keV. The ions form quasi-Be atoms at their classical turning points r_T~0.36pm for the very short

period τ_T~1.0×10^{-19}s. However as will be argued in Section 2.2, the residence of quasi-atoms is prolonged by a factor of about 10^{11} at the melting point of Li metal under the thermodynamic force specified by the Gibbs energy change ΔG_r= – 1.0eV in the atomic fusion or the quasi-Be atom formation. In this case the quasi-atoms resident for 0.01μs except for the nuclear fusion or atomic transitions. Meanwhile the twin colliding ^{7}Li – D nuclei are confined within respective spheres of 0.024(pm)^3 inside the quasi-atoms forming themselves into ultradense intermediate nuclear complexes which are directed towards the nuclear fusion induced by the zero-point oscillation. The density of these complexes (~6.5×10^{11}kg/m^3) is over million times as large as the solar interior density (1.6×10^{5}kg/m^3). It is rather close to densities of white dwarfs (10^8–10^{11}kg/m^3) or white-dwarf progenitors of supernovae (~10^{12}kg/m^3) [5-7]. The confinement defined by the product of density and the residence time (5×10^{28}m^{-3}·s) is also far over the Lawson criterion (1–2×10^{21}m^{-3}·s) for the D – D thermonuclear fusion.

2.2.2 OBSERVATION OF THE LI – D CHEMONUCLEAR FUSION AND ATOMIC FUSION LUMINESCENCE

In a case where deuterium ions are implanted on a surface of metallic Li liquid, if there is no correlation in the liquid at all, the reaction rate is $k(T)=k_0$ and almost all implanted deuterium ions undergo stopping within the depth of a tenth μm on the surface of liquid without fusion reaction. Because the intrinsic probability of nuclear fusion ($=k_0/I_D$) is very faint typically 2×10^{-23} for the ions at the acceleration energy of E_D=10keV (E=7.8keV) and 4×10^{-18} at E_D=20keV (E=16keV) [1-4] in the reaction,

$$^7\mathrm{Li} + \mathrm{D} \rightarrow {}^8\mathrm{Be}^* + \mathrm{n} \rightarrow 2\,^4\mathrm{He} + \mathrm{n} + 15.12\mathrm{MeV}. \tag{7}$$

Here ^{8}Be* denotes an intermediate excited ^{8}Be nucleus.

However under the presence of macroscopic scale correlation in the liquid the chemonuclear fusion reaction takes place, which is dominated by the Gibbs energy change ΔG_r in the quasi-Be atom (united atom $\overline{\mathrm{LiD}}$) formation. In this fusion scheme the value of ΔG_r has been derived to be around –1.25eV from the bond energy of metallic Li liquid and atomic radii of Li and Be metals [1]. This results in the enhancement in Eq.(4)

$$\frac{k(T)}{k_0} = \exp\left(-\frac{\Delta G_r}{k_B T}\right) \sim 5 \times 10^{13}, \tag{8}$$

just above the melting point of Li metal T=460K [1-3]. As seen in Section 3, a more simple evaluation of ΔG_r would be done by using chemical data [11] which give

$$\Delta G_r \sim -1.0\text{eV}, \tag{9}$$

and a corresponding rate enhancement,

$$\frac{k(T)}{k_0} \sim 10^{11}. \tag{10}$$

These predicted enhancements in Eqs.(8) and (10) have been verified in the previous experiments [3,4]. Observed enhancements were deduced from the detection rate of α-particles produced in the reaction, Eq.(7) and found to be a factor of some 10^{15}–10^{10} depending on the deuterium ion energy, typically ~10^{15} at E_D=10keV (E~7.8keV) and 4×10^{10} at E_D=20keV (E~16keV) [3,4].

The prolonged residence (~0.1μs) of quasi-Be atoms argued in Section 2.1 suggests the possibility of direct detection of quasi-atoms through observing the atomic fusion luminescence. Perhaps a near infrared luminescence has been observed under the deuterium ion implantation. However detailed investigations are left for further researches [3].

2.2.3 LIMITATION OF THE Li – D CHEMONUCLEAR FUSION

The Li – D chemonuclear fusion is, however, interfered inevitably with the competing spontaneous chemical reaction,

$$\text{Li} + \text{D} \rightarrow \text{LiD} \tag{11}$$

that is a typical hydrogenation process in a metallic Li liquid. In principle almost all implanted deuterium ions undergo the formation of glassy ionic salt LiD in the Li liquid. When deuterium ions with the beam density of about 1μA/cm^2 were implanted, most parts of Li metal on the surface in the stopping range of the ions of some energy say 20keV change into the ionic salt LiD even within some tens minutes. This change lowers the density of collective conduction s-electrons on the surface and reduces the thermodynamic force or the activity of Li liquid. This deterioration of metallic Li liquid causes the ir-reproducibility of event observation of the Li – D chemonuclear fusion [4].

In general, any nonmetallic material formation in the metallic Li liquid deteriorates its activity. We were troubled with such a deterioration, for example, accumulation of nitride, oxide, hydro-oxide of Li and so on. Except for the LiD formation, this problem was basically overcome through keeping the reaction space clean together with the metallic Li liquid.

2.3 The Li – Li Chemonuclear Fusion

2.3.1 SIGNIFICANCE OF FUSION RATE ENHANCEMENT

As far as the problem of competing chemical reactions is concerned, the Li – Li chemonuclear fusion appears to be one of the best fusion scheme. The cross-section of Li – Li nuclear fusion is however extremely small compared to the D – D and Li – D nuclear fusion cases.

The cross-section of nuclear fusion is generally given in the form,

$$\sigma = \frac{S}{E}\exp\left[-\pi\left(\frac{E_{\mathrm{G}}}{E}\right)^{\frac{1}{2}}\right]. \tag{12}$$

Here,

$$\text{Gamov energy } E_{\mathrm{G}} >> \text{relative kinetic energy of ions } E, \tag{13}$$

has been assumed. In Eq.(12) the cross-section factor S is a quantity intrinsic to the nuclear fusion and the accompanying decay factor is the Gamov Coulomb penetration factor. The Gamov energy E_{G} is given by

$$E_{\mathrm{G}} = 99.2\left(z_1 z_2\right)^2 \frac{A_1 A_2}{A_1 + A_2}\ (\mathrm{keV}), \tag{14}$$

between the nuclei with respective mass numbers A_1 and A_2 [1].

As an example, consider a case of ^{6}Li – ^{6}Li fusion induced by ions implanted with the low acceleration energy E_{Li}=40keV (E=20keV). If one assumes the value S~20,000keV··b estimated from the contribution of quasi-free process ^{6}Li(d, α)^{4}He in the ^{6}Li(^{6}Li, 2α)^{4}He reaction [12], its fusion cross-section is estimated as,

$$\sigma(^6\mathrm{Li} + {}^6\mathrm{Li}) \sim 4.3 \times 10^{-45}\mathrm{b}. \tag{15}$$

This value gives us the impression that it is infeasible to observe the Li – Li nuclear fusion reaction at such a low energy.

Such a circumstantial judgement would however be revised in the scheme of chemonuclear fusion which is dominated through the thermodynamic force specified by the Gibbs energy change in the quasi-atom formation, $\mathrm{Li} + \mathrm{Li} \rightarrow \overline{\mathrm{LiLi}}$, where $\overline{\mathrm{LiLi}}$ denotes the united atom or quasi-C atom. Since the wave function and eigen value of quasi-C atom are expected to be almost identical with those of C atom, the value of Gibbs energy change ΔG_r has been derived simply by using the chemical data [11] under the assumption, $\Delta G_\mathrm{f}(\overline{\mathrm{LiLi}}) = \Delta G_\mathrm{f}(\mathrm{C})$,

$$\begin{aligned}\Delta G_\mathrm{r} &= \Delta G_\mathrm{f}(\overline{\mathrm{LiLi}}) - 2\Delta G_\mathrm{f}(\mathrm{Li}) = \Delta G_\mathrm{f}(\mathrm{C}) - 2\Delta G_\mathrm{f}(\mathrm{Li}) \\ &= -6.95 + 2.56 = -4.39\mathrm{eV}, \end{aligned} \tag{16}$$

where ΔG_f is the Gibbs energy of formation for an atom in the atomic process estimated under the standard state condition but in this paper defined to be zero for an element in its gaseous state. The value of Eq.(16), in turn, leads to the prediction of rate enhancement,

$$\frac{k(T)}{k_0} = \exp\left(-\frac{\Delta G_\mathrm{r}}{k_\mathrm{B}T}\right) \sim 1.4 \times 10^{48}, \tag{17}$$

at the temperature T=460K just above the melting point of Li, resulting in the expected chemonuclear fusion cross-section of about 6000b. The value is much bigger than the cross-section of ^{235}U fission induced by the thermal neutron capture.

It would be instructive to reconsider the significance of this enhancement based on the microscopic view point by referring Figure 1 indicating evolution of the ^{7}Li – ^{7}Li chemonuclear fusion. The quasi-C atoms are formed at the classical turning points r_T~0.65pm of the implanted ions with the relative kinetic energy E=20keV during the very short period τ_T~7.5×10^{-19}s recalling Eqs.(2) and (3). The residence of quasi-C atoms is however prolonged by the factor of Eq.(17) and becomes as long as ~10^{30}s. In practice, the quasi-C atoms are stable except for the nuclear fusion under the thermodynamic force specified by the Gibbs energy change Eq.(16). This dynamical process is indicated in Figure 1(c) as an act of cohesion in the liquid. In fact, the colliding Li atoms collapse with the cohesion and form the quasi-C atoms resulting in the sharp reduction in their atomic

volume by a factor of 0.065 [11]. The cohesion is specified by the formation Gibbs energy of metallic Li liquid ΔG_f(Li) and related closely to the thermodynamic force specified by the Gibbs energy change Eq.(16).

Inside the quasi-C atoms, twin colliding Li nuclei are confined within respective spheres of volume ~0.14(pm)^3 and form themselves into ultradense intermediate nuclear complexes. Their density (1.6×10^{11}kg/m^3) is closer to densities of white-dwarf progenitors of supernovae ($3–9\times10^{12}$kg/m^3) rather than the solar interior density (~10^5kg/m^3). Furthermore this confinement, that is defined as the product of prolonged residence and density (~10^{66}s·m^{-3}), is incomparably over the Lawson criterion ($1–2\times10^{21}$s·m^{-3}) for the D – D thermonuclear fusion.

Quasi-atoms formed in the metallic Li liquid thus are packing units of ultradense Li – Li nuclear complexes which are directed towards the nuclear fusion induced by the zero-point oscillation during the prolonged residence. This nuclear fusion is just the pycnonuclear reaction in the packing units similarly to those in white-dwarf progenitors of supernovae. Here the term “pycnonuclear reaction” was coined by Cameron from the Greek πψκνοσ, meaning “compact dense” to describe the nuclear reaction induced by the zero-point oscillation in ultradense nuclear matters [6]. Finally the chemonuclear fusion via ultradense nuclear complex formation was found to be the pycnonuclear reaction itself. This implies that a considerable fraction of the implanted Li ions undergoes chemonuclear fusion in the metallic Li liquid.

2.3.2 IMPLICATIONS OF α-PRODUCING CHEMONUCLEAR FUSION

In this section, the author will begin again with the ^{6}Li – ^{6}Li fusion for the sake of simplicity and clearness from the statistical view point though the ^{7}Li – ^{6}Li and ^{7}Li – ^{7}Li chemonuclear fusion reactions are, of course, practically more important as useful energy resources which will be discussed in Section 4 and Section 5.

In the three body nuclear fusion reaction,

$$^6\text{Li} + {}^6\text{Li} \rightarrow {}^8\text{Be}^* + {}^4\text{He} \rightarrow 3\,{}^4\text{He} + 20.81\text{MeV}, \quad (18)$$

the importance of quasi-free process ^{6}Li(d, α)^{4}He has been noticed even at low incident energies of ^{6}Li ions [12]. Excitation functions of the process with an α-particle spectator either in the target or in the beam have been studied. The S-factor of the quasi-free process ^{6}Li(d, α)^{4}He is large S=17,400keV·b [13], which is reflected in the large cross-section of the reaction Eq.(18). It is thankful

that all products in the reaction are non-active and even useful helium gas only due to the following mechanisms.

In the reaction, colliding nuclei are identical charged bosons (particles with integer spin). In this case, the α-producing fusion rate must be very large depending on the probability of the Bose-Einstein condensation (BEC) state of the system. This implies that Coulomb repulsion between indentical charged bosons would be effectively suppressed towards the condensation state. In connection with this conjecture a theoretical model of BEC mechanisms has been developed by Kim to describe the cold D – D nuclear fusion in a quantum many body system confined in a micro-nano scale trap [14,15].

The above considerations remind us of an established fact that near the $N\alpha$ break-up threshold in self-conjugate $4N$ nuclei there exist states of dilute density, which are composed of a weakly interacting gas of self-bound α-particles predominantly in relative s-waves [16]. They are identified with an $N\alpha$ condensed state such as the ground O_1^+ state of ^{8}Be, the second O_2^+ state of ^{12}C and the O^+ state at 15.12MeV in ^{16}O. Their common features are broad α-decay widths and large α-transfer reaction cross-sections. Among them the O_2^+ state of ^{12}C has been well-known as the key state for the synthesis of ^{12}C in stars (”Hoyle” state) [16].
The energy difference between the $N\alpha$ breakup threshold and the $N\alpha$ condensed state is very small, for instance [17,18],

$$O_1^+ \text{ state of } {}^8\text{Be (condensed } 2\alpha \text{ state)} = 2{}^4\text{He} + 91.9\text{keV}, \tag{19}$$

and

$$O_2^+ \text{ state of } {}^{12}\text{C (condensed } 3\alpha \text{ state)} = O_1^+ \text{ state of } {}^8\text{Be} + {}^4\text{He} + 287.7\text{keV} \tag{20}$$

These nuclear data indicate that formation energies of condensed 2α and 3α states are, respectively,

$$E_f(\text{cond.}2\alpha) = 91.9\text{keV}, \tag{21}$$

and

$$E_f(\text{cond.}3\alpha) = 379.6\text{keV}. \tag{22}$$

The values in Eqs.(19) and (20) are much smaller than the corresponding Gamov energies Eq.(14),

$$E_G\ (^4He + {}^4He) = 3{,}174keV, \tag{23}$$

and

$$E_G\ (^8Be + {}^4He) = 16{,}930keV. \tag{24}$$

This indicates the strong overlapping between these α-condensed states and the α-break up states. This fact suggests the special significance of these states or more generally α-clustering or quasi-molecular states in the α-producing nuclear fusion [19-21].

Under the BEC mechanisms cooperated with the quasi-free process $^6Li(d, \alpha)^4He$ or the α-transfer process in the $^6Li(^6Li, \alpha)^8Be$ reaction, a new nuclear process takes place in the chemonuclear fusion and it may be dominated by the production of α-particles and/or the formation of α-clustering or quasi-molecular state nuclei such as ^8Be. This conjecture is coincident with the experimental observations on the ^7Li – D chemonuclear fusion where paired α-particles are emitted unidirectionally after releasing a neutron spectator under certain conditions of metallic Li liquid indicating their coherence [3,4].

Now it should be noted that one aspect is, common to the thermodynamic force effect seen in Eq.(17) and the BEC mechanisms argued above, the appearance of long-range coherence. Here macroscopically distinct parts of the atomic and nuclear systems become correlated [1,4,8]. This long-range coherence aspect which is seen in the Henry's law, the Arrhenius' rate equation on the spontaneous chemical reactions or Eq.(4) and now also seen in the BEC mechanisms represents the universal spontaneous tendency of systems of liquid atoms and nuclei to dissipate and have a hunt for maximum entropy as a consequence of the Second Law of Thermodynamics. This problem will be reconsidered in the following section.

2.4 Bose-Einstein Condensation (BEC) and Chemonuclear Fusion

So far the author confined himself mostly to arguments of the ^6Li – ^6Li nuclear fusion reaction. It is, however, of significance to investigate also the ^7Li – ^6Li and ^7Li – ^7Li nuclear fusion reactions. Systems of ^7Li nuclei are not boson systems.

Nevertheless still enhanced chemonuclear fusion of ^{7}Li nuclei could become reality because experiments performed in Uppsala and also later in Sakura(Japan) verified the enormously enhanced ^{7}Li – D chemonuclear fusion already [3,4]. It is now essential to review briefly the BEC mechanisms for further considerations.

On the microscopic quantum level, there are profound differences between fermions (particles with half integer spin) and bosons. How these differences should effect the behaviour of free particles. Certainly the most striking difference is the Einstein's prediction that a gas of non-interacting bosonic atoms will, below a certain critical temperature or over a critical density, suddenly develop a macroscopic population in the lower energy quantum mechanical state [22,23].

This coherent dynamical feature is coincident with that in irreversible processes occurring under the thermodynamic force. But the Einstein's premise of non-interacting particles is not necessarily critical. In the scheme of chemonuclear fusion reactions the criterion of bosonic reactant nuclei is also not so strict. Because the ^{7}Li – D system is favorable to the condensed 2α system through taking out of a neutron spectator as seen in the chemonuclear fusion Eq.(7). Furthermore all nuclear processes take place via the metastable formation of quasi-atoms. This indicates that statistical aspects of atomic systems are essential in the quasi-atom formation as an elementary process of chemonuclear fusion. These considerations have been verified through the enormous enhancement observed in the ^{7}Li – D chemonuclear fusion [3,4].

This is also coincident with our experiences that chemonuclear reactions ($\Delta G_{\mathrm{r}}<0$) in metallic Li liquids reveal the long-range coherence along the universal spontaneous tendency of bulk liquid atoms under the Second Law. It leads to an *a priori* argument that this coherent dynamics can also be re-examined effectively in the scheme of BEC mechanisms. Because the metallic Li bond is closely related to the covalent electron-pair bond having features of bosons. Furthermore even fermionic Li atoms will form bosons through constructing condensation pairs of liquid Li atoms like those of liquid ^{3}He atoms. In the Li – Li chemonuclear fusion bosonic Li atoms and/or condensation pairs of fermionic Li atoms undergo collapse towards the quasi-C atom formation under the presence of thermodynamic force in the liquid as seen in Figure 1(c).

Finally it would be noteworthy that according to the Blatt's careful investigations, the first published suggestion of a Bose-Einstein condensation of electron pairs (nowadays called Cooper pairs) as the cause of super-conductivity was made in 1946, and then not by a theoretical physicist, but rather by an experimental chemist, R.Ogg [24]. Ogg's suggestion was made based on the basis of his experiments, on all things, very dilute solutions of alkali metals in liquid NH_3. Under certain special conditions, Ogg claimed persistent ring currents at temperatures, as high as –180°C and even higher [24].

The present author's aforementioned *a priori* argument is located at the prolongation of Ogg's suggestion.

2.5 The Li – Li Chemonuclear Fusion as New Energy Resources

Besides the ^{6}Li – ^{6}Li fusion reaction in Eq.(18), there are additional Li – Li reactions,

$$^7\text{Li} + {}^6\text{Li} \rightarrow {}^8\text{Be}^* + {}^4\text{He} + \text{n} \rightarrow 3\,{}^4\text{He} + \text{n} + 13.65\text{MeV}, \tag{25}$$

and

$$^7\text{Li} + {}^7\text{Li} \rightarrow {}^8\text{Be}^* + {}^4\text{He} + 2\text{n} \rightarrow 3\,{}^4\text{He} + 2\text{n} + 6.40\text{MeV}. \tag{26}$$

In these reactions, neutrons are slowly released keeping the momentum matching with implanted Li ions because reaction rates are generally maximum under the momentum matching [1-4]. The momentum matching condition requires that the neutron momentum P_n must be $P_n=P_{Li}$ in the reaction, Eq.(25) and $P_n=(1/2)P_{Li}$ in the reaction, Eq.(26). The slow neutrons are immediately captured mostly by ^{6}Li nuclei under certain configurations of the metallic Li liquid and/or Li compound shield and produce tritons which induce associated T – Li nuclear or chemonuclear reactions as seen below,

$$^6\text{Li} + \text{n} \rightarrow {}^4\text{He} + \text{T} + 4.78\text{MeV}, \tag{27}$$

$$^6\text{Li} + \text{T} \rightarrow {}^8\text{Be} + \text{n} + 16.02\text{MeV} \rightarrow 2\cdot{}^4\text{He} + \text{n} + 16.11\text{MeV}, \tag{28}$$

$$^7\text{Li} + \text{T} \rightarrow 2\cdot{}^4\text{He} + 2\text{n} + 8.864\text{MeV}. \tag{29}$$

Considering a case of a series of nuclear reactions, Eqs.(26-28), the maximum energy release is about 48.2MeV for an implanted ^{7}Li ion. This implies that the nominal energy gain — the ratio of the nuclear energy released to the Li ion

acceleration energy — is about 1600 for the 30keV ^{7}Li ion. If one takes into account successive reactions induced by neutrons produced in the reaction Eq.(28) the gain becomes even bigger. The new scheme prescribed in this paper would open up the way towards the compact nuclear fusion science and technology.

Two component α-particles will be produced in both the $^{7}\mathrm{Li}(^{6}\mathrm{Li}, n\alpha)^{8}\mathrm{Be} \rightarrow 2^{4}\mathrm{He}$ and $^{7}\mathrm{Li}(^{7}\mathrm{Li}, 2n\alpha)^{8}\mathrm{Be} \rightarrow 2^{4}\mathrm{He}$ reactions. They are composed of coherently paired α-particles with an each energy $Q/6$ produced from the breakup of ^{8}Be and an unpaired α-particle of energy $2Q/3$. Here Q is the neutron energy substracted nuclear reaction Q-value. Since the coherent pair will be detected as if one particle of twice energy using a conventional Si surface-barrier detector (SSD), resulted energy spectrum reveals dual peaks at the energies of about $Q/3$ and $2Q/3$.

There is an additional reaction channel in the Li – Li fusion,

$$^{7}\mathrm{Li} + {}^{7}\mathrm{Li} \rightarrow {}^{9}\mathrm{Be} + {}^{4}\mathrm{He} + \mathrm{n} + 7.97\mathrm{MeV}. \qquad (30)$$

In this reaction, two peaks will appear in the product particle spectrum. They are a peak of ^{9}Be with a kinetic energy of $4Q/13$ and an α-particle peak of energy $9Q/13$.

2.6 Identity of Chemonuclear Fusion and Pycnonuclear Reactions

It was shown that the chemonuclear fusion took place through the formation of ultradense intermediate nuclear complexes confined within respective spheres of zero-point oscillations inside united atoms or quasi-atoms. This elementary nuclear process of chemonuclear fusion was found to be a pycnonuclear reaction itself. The chemonuclear fusion and pycnonuclear reactions thus are identical in the point that both reactions take place through the tunneling effect induced by the zero-point oscillation in the ultradense nuclear matters. Between these reactions, however, there is a prominent gap in the form of confinement of nuclei.

In the chemonuclear fusion, ultradense intermediate nuclear complexes are formed through the ion implantation and confined within quasi-atoms of which residence is sustained by the thermodynamic force or cohesion in metallic Li liquids. Whereas in the pycnonuclear reactions in white dwarfs / progenitors of supernovae, both formation and sustainment of ultradense matters are achieved by the gravitational force. As an inevitable consequence they are poles apart in scales

of their spaces, that is to say, a table top scale of the former fusion reactions and an astronomical scale of the latter reactions.

Remarkable features of long-range coherence in the chemonuclear fusion reactions were also argued in connection with the Bose-Einstein condensation mechanisms. The long-range coherence revealed in the chemonuclear fusion and the BEC mechanisms were argued commonly based on the Second Law of Thermodynamics.

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Supplementary note

The first experimental evidence of the hyperenhanced ^{7}Li – ^{7}Li chemonuclear fusion was obtained at R&D Center, Sakaguchi E.H VOC Co. (Sakura,Japan) as seen in the following paper [25].

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Figure Captions

Figure 1. Evolution of the ^{7}Li – ^{7}Li chemonuclear fusion

(a) Twin colliding ^{7}Li atoms with an energy of nuclear stopping (E=20keV) in a metallic Li liquid. At this energy a nuclear collision takes place but all electrons (open circles) in the K- and L-shell orbitals adjust electronic states continuously and smoothly to the nuclear collision process, because the electrons gyrate much more rapidly than colliding atom speed. Their de Broglie wave length covers the space of some tens Li atoms and yields the collective activity of the liquid. The liquid, consisting of Li ions and collective conduction s-electrons, thus takes the part of macroscopically correlated solvent reacting with the implanted solute ions in the linked atomic and nuclear processes.

(b) Intermediate diatomic molecule Li_2 formation. On the first phase of collision process the twin colliding atoms tend towards diatomic molecule Li_2 formation at the minimum Gibbs energy point of chemical process. However this Gibbs energy is not the minimum point any longer for the atoms colliding with the energy of nuclear stopping. They are directed to form the new dense intermediate complex —— quasi-C atom at their colliding or turning point.

(c) Quasi-C atom formation associated with the formation of an ultradense intermediate ^{7}Li – ^{7}Li nuclear complex (twin closed circles). During the quasi-C atom formation, the twin colliding Li atoms collapse with the cohesion in the liquid and result in sharp reduction in their atomic volume by a factor of 0.065. The cohesion is specified by the formation Gibbs energies, ΔG_f(Li) and ΔG_f(C) and related closely to the thermodynamic force dominating the chemonuclear fusion as seen in Eq.(16). The collision time is characterized by the period of zero point oscillation of colliding nuclei at their classical turning points and very short τ_0~7.5×10^{-19}s. But under the presence of thermodynamic force (shown by octaval arrows), the collision time is prolonged by a factor of $\exp(-\Delta G_r/k_B T) \sim 10^{48}$ at the melting point of Li metal (460K) and a united atom or quasi-C atom is formed, which residents for τ

$= \tau_0 \exp(-\Delta G_r/k_B T) \sim 2\times10^{22}$y except for the nuclear fusion or atomic transitions. Here ΔG_r (= –4.39eV) denotes the Gibbs energy (chemical potential) change in the quasi-C atom formation. Inside the quasi-C atom the twin colliding nuclei are confined within a sphere of zero-point oscillation $0.14(\text{pm})^3$ and form themselves into an ultradense intermediate nuclear complex. The density of this complex (1.6×10^{11}kg m^{-3}) is million times as large as the solar interior density ($\sim10^5$kg m^{-3}) and compared to white-dwarfs ($10^8\sim10^{11}$kg m^{-3}) or white-dwarf progenitors of supernovae ($3\sim9\times10^{12}$ kg m^{-3}). The confinement ($\sim10^{66}$m^{-3}s) defined by the product of density and the residence time is incomparably over the Lawson criterion ($\sim10^{21}$m^{-3}s) for the D – D thermonuclear fusion.

Quasi-atoms formed in the metallic Li liquid thus are packing units of ultradense nuclear complexes immersed in a macroscopically coherent sea of conduction s-electrons. There is a fair chance of pycnonuclear reactions in the packing units similarly to those in white-dwarfs/ progenitors of supernovae. Now this elementary nuclear process of chemonuclear fusion was found to be a pycnonuclear reaction itself, that is, the nuclear reaction induced by the zero point oscillation in ultradense nuclear matters.

(d) Nuclear fusion releasing spectator neutrons via a highly excited intermediate nucleus $^{12}C^*$ or a pair of $^8Be^*$ and ^4He nuclei. The rate of nuclear fusion is enhanced by the factor of $\sim10^{48}$ and a considerable fraction of colliding Li atoms undergoes nuclear fusion. Orbital electrons are blown off during the nuclear fusion.

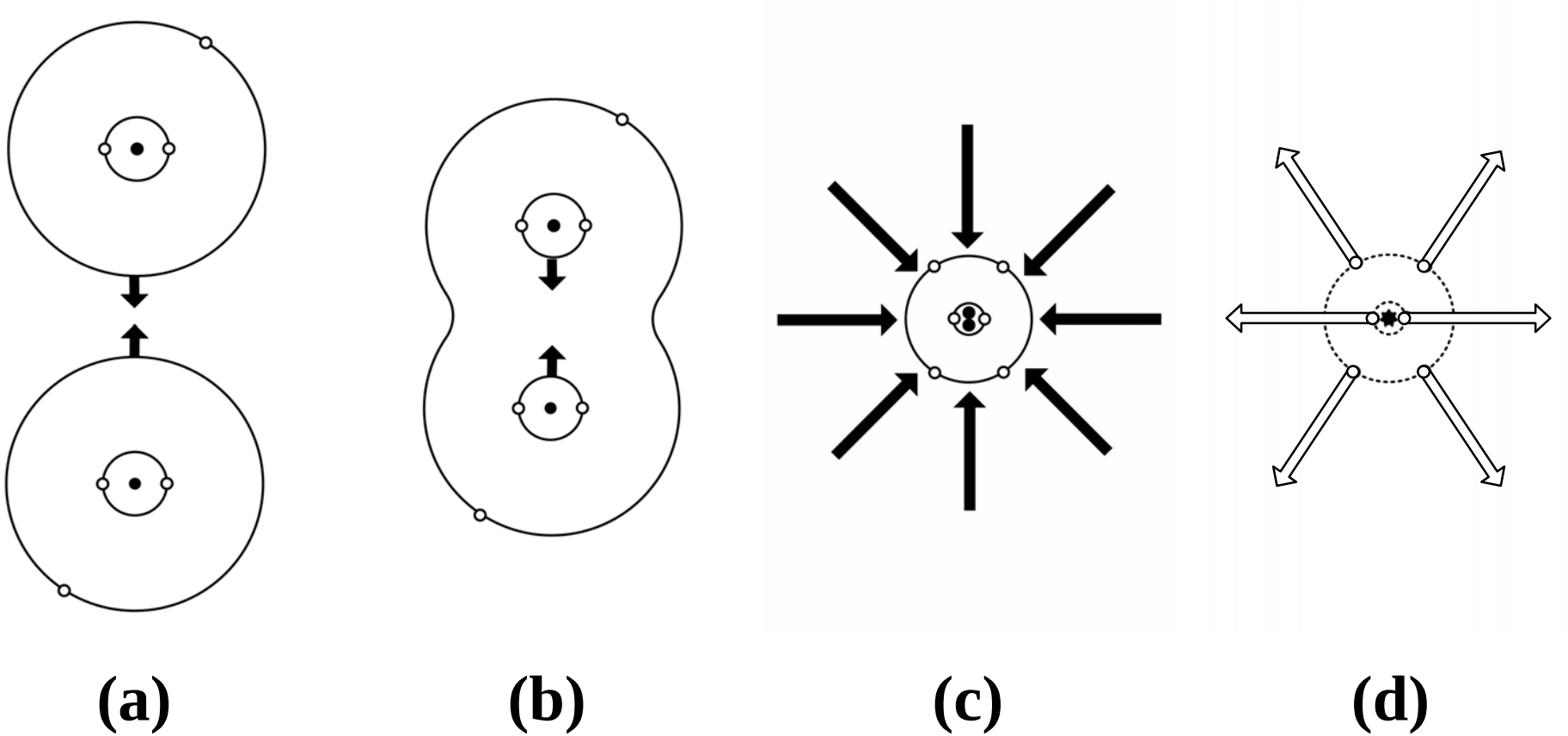

Figure 1.

3 Hyperhigh Rate Enhancement Observed in The Li – Li Chemonuclear Fusion

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Abstract: Lithium ions were implanted on a surface of metallic Li liquid target at energies of nuclear stopping (several keV/amu). Product α-particles from the reaction $^{7}Li(^{7}Li, 2n\alpha)^{8}Be \rightarrow 2\cdot^{4}He$ were identified by using a Si surface-barrier detector (SSD) and thin Al-foil energy degraders. When the Li target was in the solid phase at room temperature, no event was observed as inferred from known nuclear fusion data. In the liquid phase of Li, two broad peaks with an equal intensity were observed in the spectra of α-particles at energies of 4.3MeV and 2.1MeV. The peak at 2.1MeV was actually a sum peak of paired α-particles of 1.05MeV energy produced from the break up of ^{8}Be nuclei. The maximum value of observed rate enhancement of about 10^{56} was however far over the value 10^{48} predicted based on the Li – Li chemonuclear fusion theory. This fact suggests possible existence of additional enhancement mechanisms. Some efforts towards the observation of break even were briefly described.

Key words: Li – Li chemonuclear fusion; metallic Li liquid target; nuclear stopping; $^{7}Li(^{7}Li, 2n\alpha)2^{4}He$ reaction; break even

3.1 Aim of Test Experiments

Nuclei in many atom systems reveal thermodynamical features of nuclear fusion reactions under certain conditions [1]. Already five years ago, it was shown by the author(H.I.) that implanted ions with an energy of nuclear stopping (several keV/amu) were no more isolated in metallic Li liquids from the bulk of surrounding metallic Li atoms. Between the ions and liquid Li atoms, both nuclear collision and nuclear fusion processes thus could be linked to respective atomic processes [1]. In particular the fusion processes (here-after called chemonuclear fusion) are dominated by the thermodynamic force specified by the Gibbs energy change $\Delta G_{\mathrm{r}}(<0)$ in the spontaneous atomic fusion processes [1-5].

In a case of implantation of ions X on a metallic Li liquid, the chemonuclear fusion,

$$\mathrm{Li} + \mathrm{X} \rightarrow \overline{\mathrm{LiX}} \rightarrow \mathrm{M} \tag{1}$$

takes place via the metastable formation of united atoms $\overline{\mathrm{LiX}}$ or quasi-M atoms where twin colliding Li and X nuclei coexist inside a common K-electron orbital. In the metallic Li liquid at the temperature T the rate of this fusion process is expressed in the form of the Arrhenius' equation for spontaneous (irreversible) chemical reactions in dilute solutions,

$$k(T) = k_0 \exp\left[-\frac{\Delta G_{\mathrm{r}}}{k_{\mathrm{B}} T}\right], \ \Delta G_{\mathrm{r}} < 0, \tag{2}$$

where k_{B} is the Boltzmann constant [1,5]. The factor k_0 is the intrinsic nuclear fusion reaction rate and expressed as

$$k_0 = I_{\mathrm{X}}\, N_{\mathrm{Li}}\, \sigma(E), \tag{3}$$

where I_{X}, N_{Li} and $\sigma(E)$ are the number current of ions X implanted with a relative kinetic energy E(keV), the surface number density of Li atoms on the liquid surface and the nuclear fusion cross-section, respectively. Whereas the exponential factor is the equilibrium constant of atomic fusion reaction or the quasi-atom formation and indicates the nuclear fusion rate enhancement caused by the thermodynamic force. Here the Gibbs energy change ΔG_{r} is concerned with the quasi-M atom formation.

In this paper, results of test experiments on the chemonuclear fusion reaction,

$$\begin{aligned} {}^{7}\mathrm{Li} + {}^{7}\mathrm{Li} &\rightarrow {}^{8}\mathrm{Be} + {}^{4}\mathrm{He} + 2\mathrm{n} + 6.31\mathrm{MeV} \\ &\rightarrow 3\,{}^{4}\mathrm{He} + 2\mathrm{n} + 6.40\mathrm{MeV}, \end{aligned} \tag{4}$$

in the metallic Li liquid will be reported. In this case the Gibbs energy change ΔG_{r} has been estimated to be about –4.39eV as indicated in the previous paper [5]. This value leads to the nuclear fusion rate enhancement,

$$\frac{k(T)}{k_0} \sim 1.4\times10^{48} \tag{5}$$

predicted just above the melting point of Li metal (T=460K).

The cross-section of the nuclear fusion reaction Eq.(4) is given in the form,

$$\sigma(E) = \frac{S}{E}\exp\left[-\pi\left(\frac{E_{\mathrm{G}}}{E}\right)^{\frac{1}{2}}\right], \tag{6}$$

$$E_{\mathrm{G}} = 28{,}000\mathrm{keV},$$

where S and E_{G}(keV) are the cross-section factor intrinsic to the nuclear fusion reaction and the Gamov energy, respectively. Typically for ^{7}Li ions of acceleration energies of E_{Li}=20keV, 30keV, and 40keV (respective relative kinetic energies E=10, 15, and 20keV), the cross-sections of the nuclear fusion reaction Eq.(4) are expected to be about 1.3×10^{-69}b, 1.5×10^{-56}b, and 9.0×10^{-49}b, respectively, based on the value of cross-section factor S~20,000keV·b estimated roughly from the contribution of quasi-free process [5].

Combining the cross-section formula Eq.(6) with the Lindhard's stopping power formula [6], the intrinsic nuclear reaction probability of ^{7}Li ions before their stopping (in the range of a tenth μm) on a surface of metallic Li targets has been estimated [2],

$$P_{\mathrm{int}} \sim 8\times10^{-4}\exp\left[-\frac{745}{E_{\mathrm{Li}}{}^{1/2}}\right]. \tag{7}$$

The above equation provides reaction rates around 10^{-56} events/year at E_{Li}=20keV, 10^{-42} events/yr at E_{Li}=30keV and 10^{-34} events/yr at E_{Li}=40keV for

the ion current of 300nA. It is infeasible to observe the reaction at such low energies unless any enormous enhancement mechanism is manifested. On the contrary, detectable reaction rates may be expected under the enhancement predicted in Eq.(5) at acceleration energies E_{Li}>30keV.

3.2 Experimental Procedure and Results

The experiments were carried out for metallic Li targets in both liquid- and solid-phases for comparison using an improved and scaled up Uppsala type device [3,4] of which all Li handling systems were made from stainless steel and alumina against the liquid Li attack. In Figure 1 is shown a schematic arrangement of this device. Special attention was paid to generate clean and stable ion beams but of moderate intensity because the huge enhancement Eq.(5) and the drastic energy dependence Eq.(7) of reaction rate are expected. This moderate beam density operation was found to be useful to keep the thermal equilibrium of the Li liquid or to avoid the local temperature rise of the metallic Li surface due to the non-linear thermal effect [3,4]. For instance, a temperature rise of 20°C of metallic Li surface above the melting point results in a quenching of the enhancement as much as a factor of $\leq 10^{-2}$ as seen in Eq.(2).

In order to match with these requirements a compact ion source of conventional glow discharge type equipped with a Li evaporation cathode was made, which produced Li ion beams of about several μA from 1keV to 35keV energies at the cathode temperature of about 830K. Typically a beam of 2μA was extracted from a slit with a hole of 4mm in diameter and then accelerated before passing through an ion beam focusing and differential pumping system. A Li ion beam of about 200nA entered target chamber was implanted vertically on a surface of metallic Li target. The Li metal was shaped in a rod of 20mm in average diameter and 60mm long and mounted in a heater cylinder equipped with a piston system for lifting up the metal rod as seen in Figure 1. This target system was associated with a scraper so that a fresh surface of metallic Li target was exposed to the ion beam always in a vacuum of about some 10^{-7}Torr. The target current was monitored during experiments as well as electrode- and collimator- drain currents. The target was normal to the beam and tilted by an angle of 17° to the direction of α-particle detection.

The product α-particles from the target were observed by using a 300μm thick Si surface-barrier detector (SSD) with the active area of about 0.7cm^2 which was positioned with the effective acceptance of 0.016% of 4π sr and covered with a 5μm thick Al foil to prevent δ-rays and scattered ions from hitting the detector. Throughout the experiments, detector out put pulses and spectra were monitored comparing with those of α-particles from a calibration source of ^{241}Am(5.58MeVα) covered with a 5μm thick Al foil and mounted near the Li target. Energy loss measurements through a movable 5μm thick Al-foil energy degrader and 1mm thick Al-plate stopper system were useful to identify the particles whether they are single α-particles or paired α-particles emitted in the break up of product ^{8}Be nuclei.

In the solid phase of Li target at room temperature no single event was observed at any energy of Li ions through the α-particle detector, which was consistent with the reaction rate estimated based on the intrinsic nuclear reaction cross-section Eq.(6) as argued in Section 1.

At a thermodynamically stationary state of metallic Li target in the liquid phase, two broad peaks with an equal intensity appeared at 4.3MeV and 2.1MeV in the α-particle spectra. An example is seen in Figure 2 which was obtained at E_{Li}=30keV after the best overall tuning of experimental device for the Li – Li chemonuclear reaction. The 2.1MeV peak was identified with the reaction product ^{8}Be nuclei or paired α-particles produced in the break up of the ^{8}Be nuclei. The ground state of ^{8}Be has been known as the 2α Bose-Einstein condensation state [5]. Momenta of these paired α-particles are exactly in matching with the momentum of α-particle of 4.3MeV. These observation results are in coincidence with the reaction sequence indicated in Eq.(4) in which most nuclear reaction energies released were kinetic energies of α-particles [5].

Observed reaction rates were influenced dramatically by conditions of the implanted Li ion beam and the liquid Li target due to the super astronomical enhancement factor of around 10^{50}. Lithium ion beams contaminated with N–, O– and halogen atoms (ions) dropped seriously the reaction rate and make difficulty in observation of the Li – Li chemonuclear fusion reactions. The formation of glassy LiH and LiD films or oxide and metallic colored Li_3N layer on the surface

of liquid Li target is also the case because of suppression of thermodynamic force in the liquid.

The reaction rate and thereby the increment of particle spectrum acquisition were varied depending on the conditions of ion beam and liquid Li target. This irregular acquisition resulted in the gain shift and slight non-linearity in the particle spectrum. The maximum value of observed reaction rates was enormously enhanced compared to those deduced from the intrinsic nuclear fusion cross-section Eq.(6). In the above case the observed reaction probability of implanted Li ions was about 10^{-7} which corresponded to the enhancement of about 10^{56} compared to the value estimated based on Eq.(7). This value is, however, higher than the enhancement 1.4×10^{48} predicted in the previous paper as much as by a factor of 10^{8} [5]. This gives suggestions of an additional enhancement mechanism in the Li – Li chemonuclear fusion reactions [7].

3.3 Break Even of Li – Li Chemonuclear Fusion

Paired slow neutrons generated in the fusion reaction, Eq.(4) are immediately captured by ^{6}Li nuclei under certain configurations of a reaction chamber which may be covered by Li compounds for instance $LiOH{\cdot}H_2O$ and thereby produce associated energy releases in the reactions [5],

$$^{6}\mathrm{Li} + \mathrm{n} \rightarrow {}^{4}\mathrm{He} + \mathrm{T} + 4.78\mathrm{MeV}, \tag{8}$$

$$^{6}\mathrm{Li} + \mathrm{T} \rightarrow 2{\cdot}{}^{4}\mathrm{He} + \mathrm{n} + 16.11\mathrm{MeV}. \tag{9}$$

Considering a series of nuclear reactions, Eqs(4), (8) and (9), the maximum energy release is about 48.2MeV for an implanted ^{7}Li ion. The nominal energy gain g_{E} —— the ratio of nuclear energy released to the ion acceleration energy —— is given by

$$g_{\mathrm{E}} = \frac{48200}{E_{\mathrm{Li}}} \cdot \frac{k(T)}{k_0} \cdot P_{\mathrm{int}} \sim \frac{5.4\times10^{49}}{E_{\mathrm{Li}}(\mathrm{keV})} \exp\left[-\frac{745}{E_{\mathrm{Li}}{}^{1/2}} \right], \tag{10}$$

recalling Eqs.(5) and (7). Thus the break even of the Li – Li chemonuclear fusion may be defined nominally as $g_{\mathrm{E}} \geq 1$.

3.4 Towards The Break Even Observation

The nominal energy gain deduced from the maximum observed Li – Li fusion rate was $g_E \sim 2\times10^{-4}$, which corresponded to the reaction probability of about 10^{-7}. The drastic increase of intrinsic nuclear fusion probability with the ion energy E_{Li} in Eq.(7) indicated that one could achieve the break even at around E_{Li}=37keV with the nominal value of energy gain of $g_E \sim 100$. This drastic increase of reaction rate was, however, associated with the instability of experiments as argued in Section 2.

The drastic increase of reaction rate reminds us certain unusual phenomena observed in the first successful experiment on the Li – D chemonuclear fusion [3]. In this experiment sometimes very sudden shift was observed in the spectra of simultaneously detected α-particles emitted from the target together with those from a calibration source as seen in Figure 2a in Ref.3, when the rate of α-particle production reached around 10^6cps per 10^3cm^3 of target chamber volume. This was found to be the gain shift of SSD system caused by the charge up inside the target chamber of pyrex due to stopped α-particles. In the present experiments the target chamber of fused quarz was carefully shielded through the stainless steel mesh together with the additional SSD shielding.

Nevertheless still we have disturbed by the gain shift of α-detection system caused by sudden change of counting rate depending on surface conditions of the Li liquid. In fact, the α-spectrum shown in Figure 2 indicates a slight non-linear energy characterestics. The control of Li liquid conditions in particular keeping the clean and thermodynamically steady state of liquid is still the most important problem to be solved. Further efforts have to be paid for this problem together with those of associated research and developements.

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Figure captions

Figure 1. Test device: 1-5, glow discharge ion source; 1, anti-cathode (stainless steel); 2, anode (stainless steel); 3, metallic Li ; 4, cathode equipped with Li evaporation heater; 5, electrode terminal; 6, extraction electorode; 7, acceleration electrode; 8, exhaust port to turbo-molecular pump; 9, insulation frange; 10, drift chamber; 11, focussing electrode; 12, beam steering electrode; 13, exhaust port; 14, metallic frange; 15, target chamber; 16, ion beam; 17, metal mesh; 18, SSD; 19, shield tube; 20, 5μm thick Al foil energy degrader and stopper plate; 21, metallic Li; 22, heater cylinder; 23, piston; 24, coaxial driving shaft for a slag scraper and a thin Al-foil degrader / stopper; 25, base frange; 26, ionization gauge; 27, driver; 28, piston driver.

Figure 2. (a) Spectra of α-particles obtained with a Li-ion beam of 60μC at an energy of 30keV. Two broad peaks with an equal intensity are seen at energies of 4.3MeV and 2.1MeV. The peak at 2.1MeV is actually a sum peak of paired α-particles of 1.05MeV energy produced from the break up of ^{8}Be nuclei. Both peaks observed have been found to be reduced depending on the deterioration in quality of the Li target. (b) A spectrum of α-particles of 4.5MeV energy emitted from a calibration source of ^{241}Am (5.48MeV) covered with a 5μm thick Al foil and mounted near the Li target.

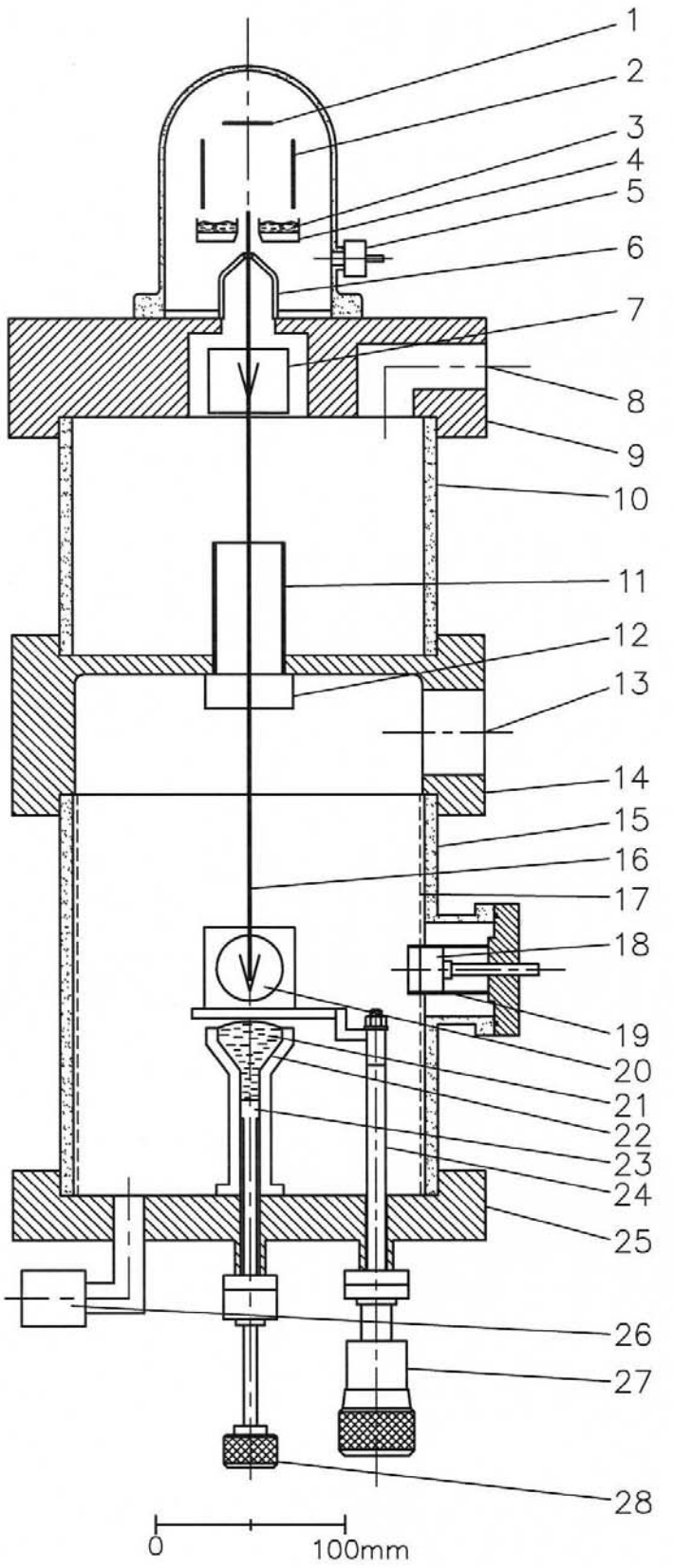
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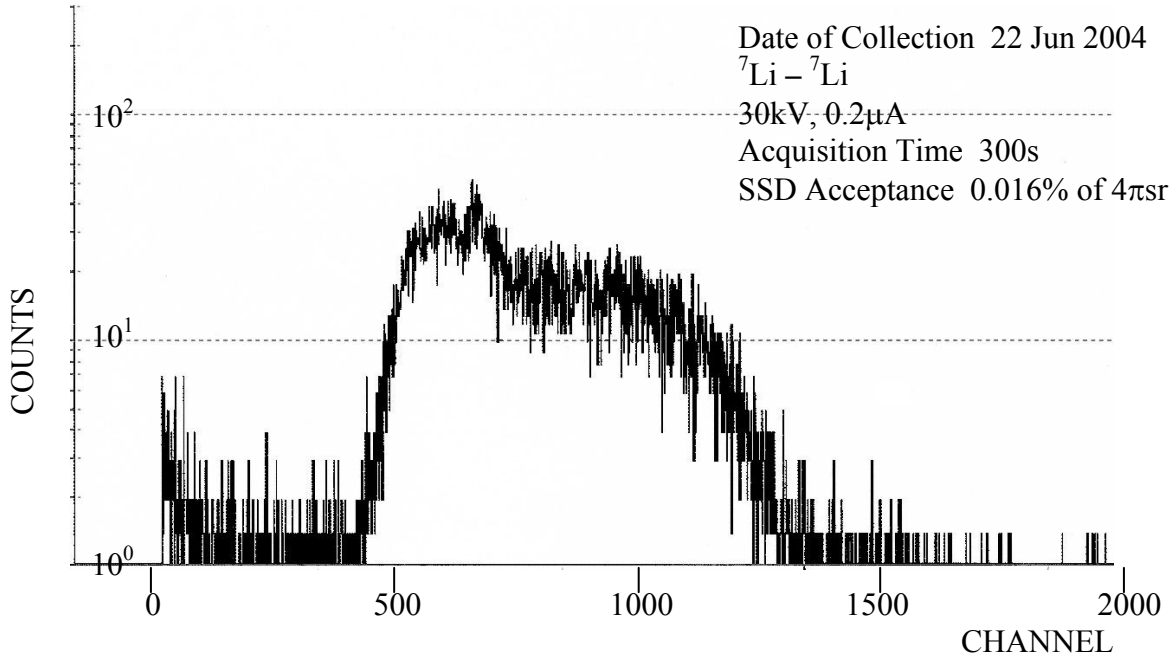
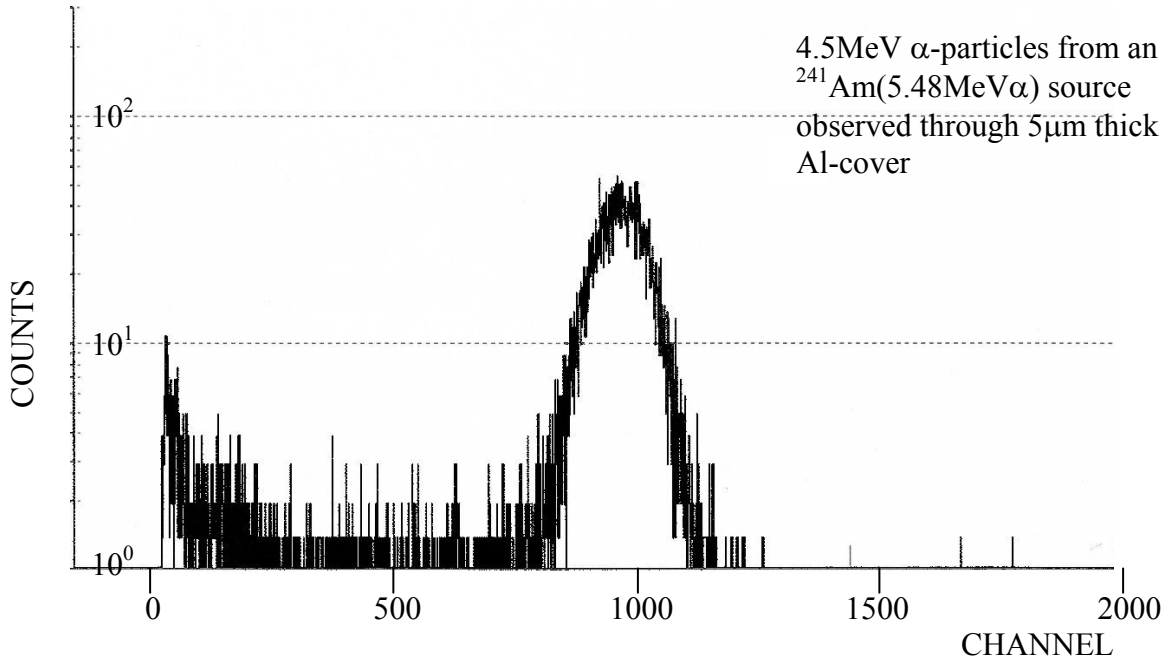
Figure 1.


Date of Collection 22 Jun 2004
^{7}Li – ^{7}Li
30kV, 0.2μA
Acquisition Time 300s
SSD Acceptance 0.016% of 4πsr
COUNTS
10^2
10^1
10^0
0
500
1000
1500
2000
CHANNEL

(a)


4.5MeV α-particles from an
^{241}Am(5.48MeVα) source
observed through 5μm thick
Al-cover
COUNTS
10^2
10^1
10^0
0
500
1000
1500
2000
CHANNEL

(b)

Figure 2.

4 Molecular Chemonuclear Fusion via Ultradense Nuclear Complexes –– Supernovae on The Earth

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Abstract: New schemes of chemonuclear fusion are presented. Ion clusters or molecular ions D_2^+, D_3^+, LiD^+, He_2^+, HeD^+ and Li_2^+ are implanted on a surface of metallic Li liquid at energies of nuclear stopping (several keV/amu). The ions collide slowly with liquid Li atoms through adjusting their electronic state to the nuclear collision process and lead to the molecular chemonuclear fusion reactions. The reactions take place via the formation of respective quasi-Be_2, Be_3, BeC, B_2, BeB and C_2 molecules consisting of quasi-atoms. Inside the quasi-atoms twin colliding nuclei are confined within respective sub pm scale spaces and form ultradense intermediate nuclear complexes with the zero-point energy of some keV. Their density is million times as large as the solar interior density and close to the densities of white-dwarfs/ progenitors of supernovae. This confinement is sustained through the prolonged residence of quasi-atoms under the cohesion or the thermodynamic force specified by the Gibbs energy change in the quasi-molecule formation in the liquid. Under confinement the ultradense nuclear complexes undergo nuclear fusion through the tunneling effect induced by the zero-point oscillation. This results in reaction rate enhancements by super-astronomical factors (10^{22}~10^{96}). Some evidences are presented for the molecular chemonuclear fusion towards the break even.

Key words: molecular chemonuclear fusion; ultradense nuclear complex; nuclear stopping; quasi-atom; supernova; break even

4.1 Historical Inevitability of Chemonuclear Fusion

After the discoveries of concepts, ”nucleus” and ”Rutherford scattering” [1], Bohr who was a postdoctoral fellow of Rutherford’s laboratory explained that Rutherford scattering was not simply collision between nuclei but was collision between whole atoms at very low energies typically several keV/amu on the basis of his atomic model [2]. Nowaday this phenomenon is called nuclear stopping of ions/atoms implanted in a condensed matter since the nuclei of struck ions/atoms acquire significant amounts of kinetic energy in the collision as seen in sputtering phenomena of ions [3]. This implies that collisions of nuclei are fully linked to atomic processes at the energies of nuclear stopping.

This feature of nuclear stopping of ions/atoms keeps a hidden potential leading to the new concept ”chemonuclear fusion reactions” where nuclear reactions take place also with the linkage to the atomic processes and thus are controllable through the synchronous formation of atomic- and nuclear- intermediate complexes under some proper chemical and physical conditions [4-9]. This potential would be seen through giving consideration to the first observation of nuclear reaction $^{14}N(\alpha,p)^{17}$ achieved after the systematic studies of nuclear collisions at Rutherford’s laboratory.

The above mentioned state of affairs would be visualized if one considers the atomic collision at an energy of nuclear stopping from the microscopic viewpoint. In Figure 1 is shown the evolution of elastic ^7Li – ^7Li atomic collision at an energy of nuclear stopping (relative kinetic energy E=15keV). The collision is essentially the Rutherford scattering between two ^7Li nuclei dressed with atomic electrons. On the first phase of collision the atoms tend towards the diatomic molecule Li_2 formation at the minimum Gibbs energy point in the process. However this Gibbs energy is not the minimum point any longer for the atoms colliding with the energy of nuclear stopping. They are directed to the nuclear collision at their turning point.

At the turning point the two atoms form a quasi-C atom within the very short collision time (about 10^{-18}s) that is the period of the zero point oscillation of colliding nuclei as will be argued in Section 2. In the quasi-C atom twin colliding nuclei are co-existing and confined at the center of common K-shell electron orbital. If

nothing happens except an elastic collision between the nuclei at their turning point, the quasi-C atom decays into two Li atoms as before. However the ^{7}Li – ^{7}Li nuclear fusion is likely to take place under the presence of thermodynamic force in metallic Li liquids since the cohesion in the liquids is twice or more bigger than that in Hg and prolongs enormously residence of the quasi-C atom and thereby the confinement of ^{7}Li nuclei pair as explained in Section 2 [8].

4.2 Chemonuclear Fusion via Ultradense Intermediate Nuclear

Complexes

In chemonuclear fusion reactions, ions with an energy of nuclear stopping (several keV/amu) are implanted on a surface of metallic Li liquid [4]. In this scheme the liquid, consisting of Li ions immersed in a sea of collective conduction s-electrons, takes the part of macroscopically correlated solvent reacting with the implanted solute ions [4]. Because in the metallic Li liquid the atomic potential wells for the electrons are not far apart and the electrons can tunnel through the barriers. Furthermore their de Broglie wave length covers the space of some tens Li atoms and yields the collective activity of the liquid [4]. We thus are no longer concerned with energy levels of individual Li atoms and/or ions instead of the bulk of metallic Li ions immersed in the sea of collective conduction s-electrons under the explanation by Wigner and Seitz [10]. Since the orbital electrons gyrate much more rapidly than implanted ion speed at the energy of nuclear stopping, the ions collide with liquid atoms/ions through adjusting their electronic states to the nuclear collision processes. Thereby the atomic fusion reactions link to the nuclear fusion reactions – the origin of the term, chemonuclear fusion [4-8].

For example, the nuclear fusion reaction Eq.(1) induced by an ion or atom X is linked to the atomic fusion Eq.(2),

$$X + {}^{6,7}Li \rightarrow M^{*} \rightarrow Y + Z, \quad (1)$$

$$X + Li \rightarrow \overline{XLi} \text{ (quasi-M atom)}, \quad (2)$$

where M^{*} denotes an intermediate excited nucleus of the fusion reaction. In Eq.(2) $\overline{XLi}$ denotes a united atom or quasi-M atom where twin colliding nuclei are co-existing at the center of common K-shell electron orbital and confined within a sphere of r_T with the zero-point energy E_T during the collision time or

quasi-atom formation time that is the period of the zero point oscillation τ_T [8]. Here r_T is the spacing of the classical turning point of the nuclei with the relative kinetic energy E and nuclear charge $z_X e$,

$$\frac{r_T}{(\mathrm{pm})} = \frac{z_X z_{Li} e^2}{4\pi\varepsilon_0 E} = \frac{1.44\, z_X z_{Li}}{E(\mathrm{keV})}, \tag{3}$$

$$\frac{\tau_T}{(10^{-18}\mathrm{s})} = \frac{2\mu\, {r_T}^2}{h} = 0.48\mu\, {r_T}^2, \tag{4}$$

and

$$E_T(\mathrm{keV}) = \frac{h}{2\tau_\perp} = \frac{2.1E^2}{\mu(z_X z_{Li})^2}, \qquad h \equiv 4.14(\mathrm{keV})(10^{-18}\mathrm{s}). \tag{5}$$

Here h and μ(amu) are the Plank constant and the reduced mass of colliding atoms/ions, respectively.

For example, at an energy of nuclear stopping of implanted ion(atom) the twin colliding nuclei are confined within a sub pm scale sphere inside the quasi-atom for sub atto (10^{-18})s towards the ultradense nuclear fusion reactions through the tunneling effect induced by the zero-point oscillation [8]. The statistical features of this ultradense fusion process are dominated by the thermodynamic force specified by the Gibbs energy change ΔG_r in the quasi-M atom or united atom $\overline{\mathrm{XLi}}$ formation [4]. Here macroscopically distinct parts of the liquid surrounding the quasi-atom are correlated and a long-range coherence appears [4,7,8].

For the quasi-atom or united atom formation in the liquid, the equilibrium constant K is given by the basic equation of chemical reactions,

$$K = \frac{k_{\mathrm{form}}}{k_{\mathrm{decay}}} = \exp\left[-\frac{\Delta G_r}{k_B T}\right], \quad \Delta G_r < 0, \tag{6}$$

where k_{form} and k_{decay} are the formation rate and the dacay rate, respectively. This equation is straight forwardly rewritten in the form,

$$\tau_{\mathrm{decay}} = \tau_T \exp\left[-\frac{\Delta G_r}{k_B T}\right], \quad \Delta G_r < 0, \tag{7}$$

using the mean formation time $\tau_{\mathrm{form}}(=\tau_T)$ and the mean decay time τ_{decay} of quasi-atoms. The abve equation indicates that in the liquid the mean life time of

quasi-atoms τ_{decay} is prolonged by the exponential factor. This life prolongation of quasi-atoms results in the extended collision time of twin nuclei, that is, life prolonging of ultradense nuclear complexes confined in the quasi-atoms and leads to the enhanced chemonuclear fusion.

These aspects reflect the rate of chemonuclear fusion reactions in the form of the Arrhenius' equation for spontaneous (irreversible) chemical reactions in dilute solutions,

$$k = k_0 \exp\left[-\frac{\Delta G_{\mathrm{r}}}{k_{\mathrm{B}}T}\right], \quad \Delta G_{\mathrm{r}} < 0, \tag{8}$$

$$k_0 \equiv I_{\mathrm{X}} N_{\mathrm{Li}} \sigma(E)$$

where k_{B} and T denote the Boltzmann constant and the temperature of the liquid, respectively. In Eq.(8), hereafter called the generalized Arrhenius' equation, the factor k_0 coressponds to the Arrhenius' frequency factor, that is the intrinsic rate of nuclear reaction. Here I_{X}, N_{Li} and $\sigma(E)$ are the number current of implanted ions X, the surface number density of Li atoms on the liquid surface and the nuclear fusion cross-section, respectively. Whereas the exponential factor is the equilibrium constant Eq.(6) of the quasi-atom formation as the elementary atomic process of chemonuclear fusion. As seen in Eqs.(6), (7) and (8) the factor provides the fusion rate enhancement caused by the prolonged residence of quasi-atoms and thereby nuclear complexes. The enhancement has a super astronomical magnitude in the cases $\Delta G_{\mathrm{r}}/k_{\mathrm{B}}T << -30$.

The chemonuclear fusion was predicted in 2001 and later verified by ultra enhanced fusion rates observed in the reactions $^7\mathrm{Li(d,n)}^8\mathrm{Be} \rightarrow 2\cdot{}^4\mathrm{He}$ and $^7\mathrm{Li}(^7\mathrm{Li},2\mathrm{n}\alpha)^8\mathrm{Be} \rightarrow 2\cdot{}^4\mathrm{He}$ [6,7,9]. Nowadays the significance of this mechanism is very clear based on the observed enhancement and the reality of quasi-atoms as argued in the previous paper [8].

In concrete terms consider again the case where ^{7}Li ions are implanted on a metallic Li liquid surface and collide with ^{7}Li atoms with the relative kinetic energy of 15keV. As seen in Figure 1 the ions form quasi-C atoms at their turning points r_{T}=0.86pm for the very short period $\tau_{\mathrm{T}}=1.3\times10^{-18}$s recalling Eqs.(3) and (4). If any nuclear reaction does not take place the quasi-C atoms decay into Li atoms as before. However as argued in Section 7 under the presence of thermo-

dynamic force specified by the Gibbs energy change $\Delta G_r = -4.39$eV in the quasi-C atom formation, the residence of quasi-atoms is prolonged by the factor of $\exp(-\Delta G_r/k_B T) = 1.4\times10^{48}$ at the melting point of Li metal [8]. In this case the quasi-atoms resident for 2×10^{31}s and are in substance stable except for nuclear fusion or atomic transitions. Meanwhile inside the quasi-atoms the twin colliding nuclei are confined within respective spheres of $0.34(\text{pm})^3$ and form ultradense intermediate nuclear complexes which are directed towards the nuclear fusion through the tunneling effect induced by the zero-point oscillation. This confinement defined by the product of density and residence time $2\times10^{66}\text{m}^{-3}\cdot\text{s}$ of the complexes is incomparably beyond the Lawson criterion $1\sim2\times10^{21}\text{m}^{-3}\cdot\text{s}$ for the D – D thermonuclear fusion. The density of complexes ($\sim10^{11}\text{kg/m}^3$) is million times as large as the solar interior density ($1.6\times10^5\text{kg/m}^3$) and even larger than the brown-dwarf interior density ($\sim10^6\text{kg/m}^3$). It is rather close to the densities of white-dwarf progenitors of supernovae (10^{12}kg/m^3) [8].

The nuclear fusion of the ultradense intermediate nuclear complexes formed in the chemonuclear fusion is thus identical to the pycnonuclear reaction induced by the zero-point oscillation in the ultradense white-dwarf progenitors of supernovae.

4.3 Molecular Chemonuclear Fusion

4.3.1 ATOMIC CHEMONUCLEAR FUSION

The concept “chemonuclear fusion” would be extended to a great variety of reaction modes. All considerations on the atomic processes in the chemonuclear fusion are likely applicable to the molecular processes which are induced by implantation of ion clusters or molecular ions. This leads to the new concept “molecular chemonuclear fusion” through the metastable formation of quasi-molecules consisting of quasi-atoms.

For the sake of simplicity and clearness, the author will begin with the diatomic molecular ions consisting of atoms/nuclei X^1 and X^2 with respective nuclear charges z_1e and z_2e and mass numbers A_1 and A_2. Consider the nuclear reactions induced independently by respective atomic ions X^1 and X^2,

$$X^1 + {}^{6,7}\mathrm{Li} \rightarrow M^{1*} \rightarrow Y^1 + Z^1, \tag{9}$$

and

$$X^2 + {}^{6,7}\mathrm{Li} \rightarrow M^{2*} \rightarrow Y^2 + Z^2, \tag{10}$$

which are linked to the respective atomic processes,

$$X^1 + \mathrm{Li} \rightarrow \overline{X^1\mathrm{Li}} \text{ (quasi-M}^1 \text{ atom)},$$

$$X^2 + \mathrm{Li} \rightarrow \overline{X^2\mathrm{Li}} \text{ (quasi-M}^2 \text{ atom)},$$

or generally

$$X^1 + \mathrm{T} \rightarrow \overline{X^1\mathrm{T}} \text{ (quasi-M}^1 \text{ atom)}, \tag{11}$$

$$X^2 + \mathrm{T} \rightarrow \overline{X^2\mathrm{T}} \text{ (quasi-M}^2 \text{ atom)}. \tag{12}$$

Here, T indicates a target atom. The united atoms $\overline{X^1\mathrm{T}}$ and $\overline{X^2\mathrm{T}}$ correspond to the quasi-M^1 atom and quasi-M^2 atom, respectively. The nuclear reactions Eqs.(9) and (10) are enhanced through the thermodynamic forces specified by the Gibbs energy changes in the atomic processes, Eqs.(11) and (12), respectively,

$$\Delta G_{r1} = \Delta G_f(M^1) - \Delta G_f(X^1) - \Delta G_f(\mathrm{T}) < 0, \tag{13}$$

and

$$\Delta G_{r2} = \Delta G_f(M^2) - \Delta G_f(X^2) - \Delta G_f(\mathrm{T}) < 0. \tag{14}$$

Here ΔG_f denotes the Gibbs energy of formation for an atom in the standard state condition but in this paper defined to be zero for an element in its gaseous state [11]. Respective rate enhancements of these atomic chemonuclear fusion reactions are,

$$K_1 = \exp\left[-\frac{\Delta G_{r_1}}{k_B T}\right], \tag{15}$$

and

$$K_2 = \exp\left[-\frac{\Delta G_{r_2}}{k_B T}\right], \tag{16}$$

where any coherent feature between these chemonuclear reactions has been disregarded.

4.3.2 MOLECULAR CHEMONUCLEAR FUSION

Now consider a scheme where molecular ions X^1X^2 with an energy of nuclear stopping are implanted on a surface of metallic Li liquid target. During the collision with liquid Li target atoms, the constituent atoms X^1 and X^2 keep their chemical bond without breaking and induce coherent atomic collision processes. In fact such coherent processes were already known over three decades ago, for instance, coherent sputtering phenomena of molecular ions implanted with energies of nuclear stopping. The sputtering yield was higher as much as a factor of 2^2 instead of 2 for diatomic molecular X_2 ions compared to that for atomic X ions with the same implanted kinetic energy per atom [12].

These effects are explained as follows: At the energy of nuclear stopping the implanted molecular ions collide slowly with liquid Li target atoms. Then their orbital electrons adjust electronic states continuously and smoothly to keep the chemical bond and associated coherent dynamics within the constituent atoms of ions, because the orbital electrons gyrate much more rapidly than implanted ion speed as argued in Section 2. The atomic processes in Eqs.(11) and (12) thus take place coherently and result in the molecular chemonuclear reactions,

$$X^1X^2 + 2T \rightarrow \overline{X^1T}\ \overline{X^2T} \rightarrow M^1M^2, \tag{17}$$

or

$$X^1X^2 + 2T \rightarrow \overline{X^1T}\ \overline{X^2T} \rightarrow M^1 + X^2 + T. \tag{18}$$

This fusion process is going on via the formation of an intermediate quasi-M^1M^2 molecule consisting of quasi-M^1 and quasi-M^2 atoms or united atoms $\overline{X^1T}$ and $\overline{X^2T}$. The statistical features of this fusion process are dominated by the thermodynamic force during the residence of quasi-molecule. The force is specified by the Gibbs energy change in the quasi-M^1M^2 molecule formation,

$$\Delta G_r = \Delta G_{r_1} + \Delta G_{r_2} - \Delta G_f(X^1X^2) + \Delta G_f(M^1M^2), \tag{19}$$

recalling Eqs.(13) and (14) and formation Gibbs energies of molecules.

The enhancement of the molecular chemonuclear fusion, Eqs.(17) and (18) is obtained recalling Eq.(19),

$$K = \exp\left[-\frac{\Delta G_{\mathrm{r}}}{k_{\mathrm{B}}T}\right]$$

$$= \exp\left[-\frac{\Delta G_{\mathrm{r}_1}}{k_{\mathrm{B}}T}\right]\cdot\exp\left[-\frac{\Delta G_{\mathrm{r}_2}}{k_{\mathrm{B}}T}\right]\cdot\exp\left[\frac{\Delta G_{\mathrm{f}}(\mathrm{X}^1\mathrm{X}^2)-\Delta G_{\mathrm{f}}(\mathrm{M}^1\mathrm{M}^2)}{k_{\mathrm{B}}T}\right] .(20)$$

Owing to coherent features of the quasi-M^1M^2 molecule formation, two atomic processes Eqs.(11) and (12) enhance the molecular chemonuclear fusion Eqs.(17) or (18) multiplicatively and even more intensely in the case of $\Delta G_{\mathrm{f}}(M^1M^2) - \Delta G_{\mathrm{f}}(X^1X^2) < 0$ as seen in Eq.(20).

4.3.3 EVOLUTION OF THE D_2 – 2Li MOLECULAR CHEMONUCLEAR FUSION IN METALLIC Li LIQUID

As a concrete example, in Figure 2 is shown the evolution of the D_2 – 2 ^{7}Li molecular chemonuclear fusion at the acceleration energy of E_{D_2}=30keV (relative kinetic energy of deuteron E(D)=11.7keV). At their turning points, paired D atoms form coherently two quasi-Be atoms and produce a quasi-Be_2 molecule within the very short collision time τ_{T}~10^{-19}s recalling Eq.(4).

In this instantaneous formation of quasi-Be_2 molecule, the summed volume of the D_2 molecule and two Li atoms shrinks by the factor of 1/3. However in the metallic Li liquid the cohesion, which is twice or more bigger compared to the cohesion in Hg, sustains this shrinkage and prolongs the lifetime of quasi-Be_2 molecule by the factor of 5×10^{21} as argued in Section 5.

In the respective quasi-Be atoms twin colliding D – Li nuclei are co-existing and confined at respective centers of common K-shell orbitals within the volume of $0.026(\mathrm{pm})^3$ with a zero-point energy of 20keV recalling Eqs.(3) and (5). This results in the creation of ultradense intermediate nuclear complexes of density ρ~6×10^{11}kg·m^{-3}. The density of complexes is higher than the solar interior density by the factor of about 4×10^6 and comparable with densities of white dwarfs or progenitors of supernovae.

The ultradense nuclear complexes are resident in the respective quasi-atoms within their prolonged lifetime of about 500s and likely to undergo pycnonuclear reactions

through the tunneling effect induced by the zero-point oscillation just as ultradense matters in the stars such as white dwarfs / progenitors of supernovae [8].

Considering the mechanism explained above, the significance of chemonuclear fusion thus seems to be the "supernovae on the earth" [13].

4.4 Intrinsic Nuclear Reaction Probability

4.4.1 NUCLEAR REACTION CROSS-SECTION

The enhancement in Eq.(20) is common for the reactions, Eqs.(9) and (10). This is due to the coherent formation of quasi-M[1] atom and quasi-M[2] atom. However such coherent features do not necessarily result in the coherent undergoing of both nuclear reactions as seen in Eq.(18) because of diferent nuclear reaction cross-sections which are dominated by the Gamov Coulomb penetration factors and cross-section factors as seen below.

The respective cross-sections of nuclear reactions Eqs.(9) and (10) are given in the form [4],

$$\sigma_{1,2}(E_{1,2}) = \frac{S_{1,2}}{E_{1,2}} \exp\left[-\pi \left(\frac{E_{G_{1,2}}}{E_{1,2}} \right)^{1/2} \right]. \tag{21}$$

Here the cross-section factors S_1 and S_2 are quantities intrinsic to the respective nuclear reactions. Remaining factors are respective Gamov Coulomb penetration factors. The Gamov energies are given by [4].

$$E_{G_{1,2}} = 99.2\left(z_{1,2} z_T\right)^2 \frac{A_{1,2} A_T}{A_{1,2} + A_T} \text{ (keV)}. \tag{22}$$

The respective relative kinetic energies of atoms, E_1 and E_2 are given by the laboratory energy of molecular ions E_{lab} as

$$E_{1,2} = \frac{A_T}{A_{1,2} + A_T} \cdot \frac{A_{1,2}}{A_1 + A_2} E_{lab}. \tag{23}$$

Combining Eqs.(21)-(23), the nuclear reaction cross-sections are rewritten in the form,

$$\sigma_{1,2}(E_{1,2}) = \frac{S_{1,2}}{E_{1,2}} \exp\left[-31.29 z_{1,2} z_T \left(\frac{A_1 + A_2}{E_{lab}} \right)^{1/2} \right]. \tag{24}$$

4.4.2 4.2 REACTION PROBABILITY

For the molecular ions implanted with the nuclear stopping energy one may treat the problems of reaction probability and penetration based on the assumption of coherent scattering. Furthermore, charge exchange dominates the stopping powers of ions in metallic Li(z_T=3) liquid because both electronic excitation and inner-shell ionization are very unlikely [4,5]. Lindhard has given a very simple formula for the stopping power S_e based on the Thomas-Fermi model of the atom that is reasonable for ions implanted with the speed $v<v_e$, v_e being the speed of K-shell orbital electron on the hydrogen atom [5,14,15].

$$S_e \equiv \frac{dE_{lab}}{n_T dx} \sim \frac{e^2}{4\pi\varepsilon_0} \cdot 8\pi \cdot a_B \cdot \frac{(z_1+z_2)_{eff}\, z_T}{z} \left(\frac{E_{lab}}{E_0}\right)^{1/2}, \tag{25}$$

with $$z \equiv \left[(z_1+z_2)_{eff}^{2/3} + z_T^{2/3}\right]^{3/2}. \tag{26}$$

Here n_T is the number density of target atoms and a_B and E_0=25(A_1+A_2)keV denote the Bohr radius and the energy of implanted molecular ions with mass A_1+A_2 and speed v=v_e, respectively.

The effective charge $(z_1+z_2)_{eff}$ is referred to an equilibrium charge state of the ion with the energy of nuclear stopping. A semiempirical expression has been developed based on measurements on the transmission of ions through thin films [15].

$$(z_1+z_2)_{eff} \sim (z_1+z_2)\left\{1+\left[0.122\left(\frac{E_{lab}}{A_1+A_2}\right)^{\frac{1}{2}}(z_1+z_2)^{-0.45}\right]^{-1/0.6}\right\}^{-0.6}. \tag{27}$$

The respective intrinsic nuclear reaction probabilities P_1 and P_2 of nuclei X_1 and X_2 are

$$P_{1,2} = \int n_T \sigma_{1,2}(E_{1,2})dx = \int \frac{\sigma(E_{1,2})}{S_e} dE_{lab} \tag{28}$$

in the penetration depth $\int dx$.

Substituting Eqs.(24) and (25) into eq.(28) one obtains,

$$P_{1,2} \sim 3.33\times10^{-8}\, S_{1,2}\,(\mathrm{keV\cdot b})\frac{z}{(z_1+z_2)_{\mathrm{eff}}\, z_{\mathrm{T}}}\left(\frac{E_0}{E_{\mathrm{G}_{1,2}}}\right)^{1/2}$$

$$\times\left(\frac{A_{1,2}+A_{\mathrm{T}}}{A_{\mathrm{T}}}\right)^{1/2}\exp\left[-\pi\left(\frac{E_{\mathrm{G}_{1,2}}}{E_{1,2}}\right)^{1/2}\right], \tag{29}$$

recalling Eqs.(22),(23),(26) and (27).

4.5 Deuterium Burning Chemonuclear Fusion

4.5.1 THE D – Li, D_2 – 2Li AND D_3 – 3Li CHEMONUCLEAR FUSION

Due to the lack of detailed informations concerning the Gibbs energies of ions implanted and those at metastable states in the metallic Li liquids, only rough estimations of enhancements and reaction probabilities have been made.

For the atomic process

$$\mathrm{D + Li} \rightarrow \text{quasi-Be}, \tag{30}$$

the Gibbs energy change ΔG_{r} has been derived by using the chemical data [11],

$$\Delta G_{\mathrm{r}} \sim \Delta G_{\mathrm{f}}(\mathrm{Be}) - \Delta G_{\mathrm{f}}(\mathrm{liq.Li}) - \Delta G_{\mathrm{f}}(\mathrm{LiD})$$

$$= -2.97 + 1.28 + 0.70 = -0.99(\mathrm{eV}). \tag{31}$$

Here the formation energy of D ions in the Li liquid has been replaced by $\Delta G_{\mathrm{f}}(\mathrm{LiD})$.

The value in Eq.(31) leads to the enhancement,

$$K(\mathrm{D-Li}) = \exp\left(-\frac{\Delta G_{\mathrm{r}}}{k_{\mathrm{B}}T}\right) \sim 7\times10^{10}, \tag{32}$$

at the temperature of the liquid T=460K (just above the melting point of Li metal).

For the nuclear fusion reaction,

$$^{7}\mathrm{Li + D} \rightarrow {}^{8}\mathrm{Be^{*}} + \mathrm{n} \rightarrow 2\cdot{}^{4}\mathrm{He} + \mathrm{n} + 15.12\mathrm{MeV}, \tag{33}$$

Eq.(29) gives the intrinsic reaction probability

$$P \sim 3\times10^{-5}\exp\left(-132.7E_{\mathrm{D}}^{-1/2}\right), \tag{34}$$

with the values S=2100keV·b and E_G=1389keV [4,5]. This provides atomic chemo-nuclear fusion probabilities,

$$KP = \exp\left(-\frac{\Delta G_r}{k_B T}\right)\cdot P \sim 5\times 10^{-20} \text{ at } E_D = 5\text{keV},$$
$$2\times 10^{-12} \text{ at } E_D = 10\text{keV},$$
$$4\times 10^{-7} \text{ at } E_D = 20\text{keV}. \quad (35)$$

These values are too small for the break even of nuclear fusion which requires at least the probability of some tenths percent [7]. Further it is questionable to apply the criterion of nuclear stopping to the deuterons of E_D>20keV. However this problem will be solved in the scheme of molecular chemonuclear fusion.

For the molecular chemonuclear fusion induced by D_2^+ ions

$$D_2 + 2Li \rightarrow \text{quasi-}Be_2\,, \quad (36)$$

Eqs.(31) and (32) provide the enhancement,

$$K(D_2 - 2Li) \sim [K(D-Li)]^2 \sim 5\times 10^{21}, \quad (37)$$

recalling Eqs.(19) and (20). Here the difference between $\Delta G_f(\overline{Li_2D_2})$ and $\Delta G_f(Be_2)$ has been disregarded. The value in Eq.(37) implies that diatomic ions D_2^+ implanted might result in the break even of nuclear fusion at the laboratory energy of E_{D_2}=20keV (5keV/amu) recalling the probability for the deuterons with the acceleration energy of E_D=10keV in Eq.(35) if the nuclear stopping criterion is well applicable.

For the molecular chemonuclear fusion induced by D_3^+ ions,

$$D_3 + 3Li \rightarrow \text{quasi-}Be_3 \quad (38)$$

the enhancement may be further gained as,

$$K(D_3 - 3Li) \sim [K(D-Li)]^3 \sim 4\times 10^{32}\,. \quad (39)$$

The value in Eq.(39) indicates that triatomic D_3^+ ions would result in the break even of nuclear fusion at the laboratory energy of molecular ions E_{D_3}=15keV (2.5keV/amu) recalling the probability for the deuterons of E_D=5keV in Eq.(35).

The above arguments may also be applicable to the reaction,

$$^{6}\mathrm{Li} + \mathrm{D} \rightarrow {}^{8}\mathrm{Be}^{*} \rightarrow 2\cdot{}^{4}\mathrm{He} + 22.3\mathrm{MeV}. \quad (40)$$

4.5.2 THE LiD – 2Li CHEMONUCLEAR FUSION

The D – Li chemonuclear fusion is interfered inevitably with the competing spontaneous chemical reaction,

$$\mathrm{Li} + \mathrm{D} \rightarrow \mathrm{LiD}, \quad (41)$$

that is a typical hydrogeneration process in metallic Li liquid [8]. The chemical reaction is dominant and transmutes metallic Li into ionic salt LiD which decreases the density of collective conduction electrons in the liquid resulting in the suppression of the liquid activity [8]. This seems to limit the usefulness of deuterium burning chemonuclear fusion. This problem will also be solved in the scheme of molecular chemonuclear fusion.

Molecular LiD ions are implanted on a surface of metallic Li liquid. The ions will form quasi-BeC molecules at their turning points. For the molecular process,

$$\mathrm{LiD} + 2\mathrm{Li} \rightarrow \text{quasi-BeC}, \quad (42)$$

the Gibbs energy change ΔG_{r} and the associated enhancement have been derived as,

$$\Delta G_{\mathrm{r}} \sim \Delta G_{\mathrm{f}}(\mathrm{C}) + \Delta G_{\mathrm{f}}(\mathrm{Be}) - 3\Delta G_{\mathrm{f}}(\mathrm{Li}) - \Delta G_{\mathrm{f}}(\mathrm{LiD})$$

$$= -6.95 - 2.97 + 3.84 + 0.70 = -5.38\mathrm{eV}, \quad (43)$$

and

$$K = \exp\left(-\frac{\Delta G_{\mathrm{r}}}{k_{\mathrm{B}}T}\right) \sim 1\times10^{59}. \quad (44)$$

The enhancement in Eq.(44) indicates that all deuterium atoms implanted as molecular LiD ions undergo nuclear fusion reactions Eqs.(33) and (40) even at E_{LiD}~20keV where the intrinsic reaction probability is P~3×10^{-35}. However this is not the case for the Li atoms implanted as molecular LiD ions. Due to the extermely small probability of the Li – Li nuclear fusion, the enhancement is not necessarily enough for the practical use of Li – Li fusion reaction. This problem will be argued again in Section 7.

4.6 He_2^+ and HeD^+ Ions Induced Chemonuclear Fusion

4.6.1 He BURNING

Helium atoms normally have no valence because all their orbital electrons are paired. However if He atoms are excited to higher levels or ionized by any means, they no longer have their electrons paired. In consequence, excited or ionized He atoms form chemical compounds, as exemplified by the dihelium molecules He_2 when electric discharges are passed through the He gas.

Dihelium He_2^+ ions are stable in vacuum and their bond strength 2.59eV is very close to that of H_2^+ ions 2.64eV [16]. The helium burning thus is achievable efficiently in the scheme of molecular chemonuclear fusion. In this scheme, the nuclear reactions,

$$^6\mathrm{Li} + {}^4\mathrm{He} \rightarrow {}^{10}\mathrm{B} + \gamma + 4.46\mathrm{MeV} \tag{45}$$

and

$$^7\mathrm{Li} + {}^4\mathrm{He} \rightarrow {}^{11}\mathrm{B} + \gamma + 8.67\mathrm{MeV} \tag{46}$$

undergo through the quasi-B_2 molecule formation,

$$2\mathrm{Li} + \mathrm{He}_2 \rightarrow \text{quasi-}\mathrm{B}_2. \tag{47}$$

The Gibbs energy change in the quasi-B_2 formation and the associated enhancement are obtained as,

$$\Delta G_\mathrm{r} \sim 2\Delta G_\mathrm{f}(\mathrm{B}) - 2\Delta G_\mathrm{f}(\mathrm{Li}) = -10.80 + 2.56 = -8.24\mathrm{eV}, \tag{48}$$

considering $\Delta G_\mathrm{f}(\mathrm{He}) = 0$ and

$$K = \exp\left(-\frac{\Delta G_\mathrm{r}}{k_\mathrm{B}T}\right) \sim 2\times10^{90}, \tag{49}$$

at the temperature T=460K.

Recalling Eq.(29), both intrinsic probabilities of the reactions, Eqs.(45) and (46) are estimated as

$$P \sim 2\times10^{-8}\, S \cdot \exp\left(-531 E_{\mathrm{He}_2}^{-1/2}\right). \tag{50}$$

For example, assuming S~1keV·b, P~3×10^{-81} for He_2^+ ions of E_{He_2}=10keV and P~6×10^{-60} for E_{He_2}=20keV. However the ultra-high enhancement, Eq.(49) indi-

cates that all implanted He_2^+ ions undergo chemonuclear fusion reactions even for very small spectroscopic factor S<0.1keV·b.

4.6.2 HeD BURNING

In likewise the He_2^+ ions, HeD^+ and HeD_2^+ ions can also be prepared through discharges in D_2 and He gas mixture. The ions may also be produced by a deuterium ion beam passing through the He gas or *vice versa*. These methods open an extremely efficient D burning way, that is the HeD coburning. Under a certain condition, all HeD^+ and HeD_2^+ ions implanted on a surface of metallic Li liquid would undergo the nuclear reactions, Eqs.(33)(40)(45) and (46) via the respective molecular processes,

$$\mathrm{HeD} + 2\mathrm{Li} \rightarrow \text{quasi-BeB}, \tag{51}$$

and

$$\mathrm{HeD_2} + 3\mathrm{Li} \rightarrow \text{quasi-}\mathrm{Be_2B}. \tag{52}$$

The Gibbs energy changes and associated enhancements of these chemonuclear reactions are,

$$\begin{aligned}\Delta G_\mathrm{r}\,(\mathrm{BeB}) &\sim \Delta G_\mathrm{f}(\mathrm{Be}) + \Delta G_\mathrm{f}(\mathrm{B}) - 2\Delta G_\mathrm{f}(\mathrm{Li}) - \Delta G_\mathrm{f}(\mathrm{LiD}) \\ &= -2.97 - 5.40 + 2.56 + 0.70 = -5.11\mathrm{eV}, \end{aligned} \tag{53}$$

$$K = \exp\left(-\frac{\Delta G_\mathrm{r}}{k_\mathrm{B}T}\right) \sim 1\times10^{56}, \text{ for the quasi-BeB formation,} \tag{54}$$

and

$$\Delta G_\mathrm{r}\,(\mathrm{Be_2B}) \sim -6.10\mathrm{eV}, \tag{55}$$

$$K = \exp\left(-\frac{\Delta G_\mathrm{r}}{k_\mathrm{B}T}\right) \sim 8\times10^{66}, \text{ for the quasi-}\mathrm{Be_2B}\text{ formation.} \tag{56}$$

These evaluations would be under estimates because of disregarding the large bond strengths of BeB and Be_2B. Particularly the latter is known as a compound with high melting or dissociation point (>1970˚C) implying its very large bond strength.

The intrinsic nuclear reaction probability of constituent D atoms is much larger than that of He atoms. For instance, recalling Eq.(29), respective fusion probabilities of D and He atoms in the HeD ion implantation are,

$$P(\mathrm{D}-\mathrm{Li}) \sim 8.4\times10^{-4}\exp\left(-230E_{\mathrm{HeD}}^{-1/2}\right), \tag{57}$$

and

$$P(\mathrm{He}-\mathrm{Li}) \sim 2.4\times10^{-8}\exp\left(-460E_{\mathrm{HeD}}^{-1/2}\right), \tag{58}$$

typically, P(D–Li)~2×10^{-35} and P(He–Li)~2×10^{-71} for the HeD ions of E_{HeD}=10keV and P(D–Li)~4×10^{-26} and P(He–Li)~5×10^{-53} at E_{HeD}=20keV. These probabilities are enhanced by super astronomical factors, Eq.(54) or Eq.(56) in the molecular chemonuclear fusion.

These results indicate that the D-atoms undergo selectively the nuclear fusion reaction at lower HeD ion energy around E_{HeD}=10~15keV and He-atoms play a role of catalysis of deuterium burning molecular chemonuclear fusion.

4.7 Li_2 Induced Chemonuclear Fusion

The bond strength of Li_2 ions is 1.14eV and thus Li_2 ions and Li ion clusters are stable and easily produced. Further their power on the chemonuclear fusion is dramatical as seen below. For the molecular process,

$$\mathrm{Li_2} + 2\mathrm{Li} \rightarrow \text{quasi-}\mathrm{C_2}, \tag{59}$$

the Gibbs energy change ΔG_{r} and the associated fusion enhancement have been derived,

$$\Delta G_{\mathrm{r}} \sim 2\Delta G_{\mathrm{f}}(\mathrm{C}) - 4\Delta G_{\mathrm{f}}(\mathrm{Li}) = -13.91 + 5.12 = -8.79, \tag{60}$$

and

$$K = \exp\left(-\frac{\Delta G_{\mathrm{r}}}{k_{\mathrm{B}}T}\right) \sim 3\times10^{96}, \tag{61}$$

at the temperature T=460K of metallic Li liquid. However this treatment would be an underestimate because of disregarding the difference of formation energies between dilithium Li_2 and dicarbon C_2 molecules. Dicarbons are components of unit cells of diamonds and much more stable compared to dilithium Li_2 molecules. Such the situation would be unaltered even for these molecules formed in the metallic Li liquid.

For the constituent Li atoms in the Li_2 ions of energy E_{Li_2} the intrinsic probability of the nuclear reaction,

$$^7Li + {}^7Li \rightarrow {}^{12}C^* + 2n \rightarrow 3\cdot{}^4He + 2n + 6.40MeV, \quad (62)$$

is

$$P \sim 4\times10^{-8}\, S \cdot \exp\left(-1054 E_{Li_2}^{-1/2}\right) \quad (63)$$

recalling Eq.(29). If one assumes the value S~20,000keV·b for the reaction [9], probabilities are about 2×10^{-111}, 1×10^{-91} and 2×10^{-80} at E_{Li_2}=20keV, 30keV and 40keV, respectively. The most of Li_2 ions with an energy higher than 30keV are expected to undergo the nuclear fusion reaction under the fusion enhancement Eq.(61). The above value of spectroscopic factor S is rather inexact but it does not affect substantially on the present rough estimation of reaction yield. Instead much more precise informations are needed on the states of implanted and produced ions in the metallic Li liquid in order to find the precise value of Gibbs energy change ΔG_r in the molecular chemonuclear fusion.

4.8 Evidences of Molecular Chemonuclear Fusion

4.8.1 EVIDENCES OF D_2 INDUCED CHEMONUCLEAR FUSION

There have been found indirect but clear evidences for the molecular chemonuclear fusion in the observational data for the ^7Li – D chemonuclear fusion reaction [6,7].

1) Enhancements observed in the reaction induced by atomic ion beams were always much below the predicted value, Eq.(32).

2) On the contrary enhancements of the reaction under the implantation of filterless ion beams with a mixture of D_2^+ and D_3^+ ions were much higher than those of atomic ion beam cases and even over the predicted value. In the best condition case of E_{lab}=10keV, the effective enhancement reached as high as a factor of about 10^{15} [6]. This value is about 10^4 times higher than the predicted one. If one assumes that the enhancement might be caused by the D_2^+ ions with a fractional mixture of about 40% which is the common value for conventional glow discharge type ion sources, the intrinsic reaction probability decreases by a factor of about 10^{-7} due to the half kinetic energy (E_D=5keV) of constituent atoms as seen

in Eq.(35). This factor and the fraction of mixing lift up the effective enhancement to the value of about 10^{22} which is consistent with the predicted value in Eq.(37).

3) Whenever very clean and fresh liquid Li surfaces were irradiated by filterless ion beams in a thermal stationary state, the broad peak with a width of about 2MeV was observed in the spectra of produced α-particles at the energy of 15.1MeV which is the full Q-value of the reaction Eq.(33). Energy loss measurements using a thin Al foil showed clearly that the broad peak was actually a sum peak of unidirectionally emitted paired α-particles each having 7.56MeV kinetic energy [7]. However the momentum deficit after the emission of paired α-particles must be covered by the medium consisting of liquid Li atoms [6] or by something else. This puzzling result was now explained mostly in the scheme of molecular chemonuclear fusion.

The 15.1MeV peaks were observed frequently in the experiments revealing the best enhancement, where most of reactions were likely to be molecular chemonuclear fusion. If the density of coherent s-electrons is enough in the Li liquid, some reactions produce coherently paired intermediate $^{8}Be^{*}$ nuclei via the formation of quasi-Be_2 molecules shown in Eq.(36). The paired $^{8}Be^{*}$ nuclei are able to undergo coherent paired 4α break up as the Bose-Einstein condensation process [8]. The coherent 4α break up of Be_2 is exactly coincident with the coherent 4 photon annihilation of positronium molecule Ps_2 in which twin Ps atoms are condensed with a small binding energy of about 0.4eV as a system of two identical p-Ps atoms or that of o-Ps atoms [17].

4.8.2 EVIDENCE FOR THE Li_2 INDUCED CHEMONUCLEAR FUSION

Due to characteristics of the Li – Li chemonuclear reaction which is free from interfering reactions such as the Li – D chemical reactions, ultra enhanced phenomena have been observed. The best value of measured reaction probability was a few tenths ppm for the ions with an acceleration energy of 30keV, which corresponded to the effective rate enhancement of about 10^{56} [9]. The enhancement was, however, about sub billion times higher than the predicted value [8]. This discrepancy would be even bigger if one takes into account possible quenching effects in chemonuclear fusion processes [5,7]. These facts suggest an enhancement review based on the molecular chemonuclear fusion mechanism though the fraction of Li_2 ions mixed was faint in the ion beam.

Since the bond strength (1.14eV) of Li_2 molecules is much smaller than that of D_2 molecules (4.59eV), the fractional formation of Li_2^+/Li^+ (~a tenth percent) is small compared to that of $D_2^+/D^+ \sim 1$ in conventional ion sources of glow discharge type.

The intrinsic reaction probability for Li atoms of acceleration energy E_{Li}=30keV is about 7×10^{-64} by using Eq.(29) and recalling Eq.(15) in the previous paper [8]. Whereas the probability for Li_2 molecules of 30keV acceleration energy is around 1×10^{-91} as argued in Section 6. These reaction probabilities differ by a factor of about 10^{-28}.

If one assumes that observed events of the Li – Li reactions reported in the previous paper [9] were actually induced by the Li_2 molecular ions of 30keV energy rather than the atomic Li ions, the effective rate enhancement is revised to be about 10^{87} recalling the above mentioned enhancement value, fractional mixture of Li_2 ions and the difference in the intrinsic reaction probabilities of atomic and molecular ions. The rate enhancement is smaller than the predicted value in Section 7 but the fractional deviation is a little bit better than the above analysis based on the atomic chemonuclear fusion mechanism.

The rate enhancement of 10^{87} and the intrinsic reaction probability of $\sim10^{-91}$ mean that a fraction of about 0.1% of constituent atoms in the Li_2 ions undergoes nuclear fusion.

4.9 Epilogue: Break Even, Chemonuclear Fusion and Pycnonuclear Reactions

The nominal break even of nuclear fusion seems to be at hand in the scheme of molecular chemonuclear fusion.

Two slow neutrons produced in the reaction Eq.(62) are immediately absorbed under certain configurations of the liquid Li system and the reaction chamber covered by Li and/or B shields. The neutrons yield associated energy releases of about 9.6MeV through the capture by ^{6}Li nuclei as argued in Section 5 in the previous paper [8]. Futhermore an additional energy of 32MeV is released in the successive T–^{7}Li chemonuclear reactions induced by tritons produced in the neutron capture [8]. Thus the maximum energy release is about 48MeV for an

implanted ^{7}Li ion. This means that the nominal enargy gain — the ratio of reaction energy released to the acceleration energy of implanted ion — is about 3200 for the 15keV ^{7}Li ion. As seen in Section 8, almost 0.1% fraction of ^{7}Li ions implanted induced nuclear fusion with the nominal energy gain of about 3200. This fact leads to the conclusion that the nominal break even of molecular chemonuclear fusion might be already at hand or within a single step of achievement.

It was shown that the chemonuclear fusion took place through the formation of ultradense intermediate nuclear complexes confined within respective spheres of zero-point oscillation. This elementary nuclear process of chemonuclear fusion was found to be essentially the same with pycnonuclear reactions. The chemonuclear fusion and pycnonuclear reactions are identical in the point that both reactions take place through the tunneling effect induced by the zero-point oscillation in the ultra dense matters. The chemonuclear fusion thus has the significance ”supernovae on the earth” [13]. Between these reactions, however, there is a prominent gap in the form of confinement of nuclei.

In the chemonuclear fusion reactions, ultradense intermediate nuclear complexes are created through the ion implantation and confined within quasi-atoms of which residence is sustained by the thermodynamic force and/or cohesion in metallic Li liquids. Whereas in the pycnonuclear reactions, both creation and sustainment of ultradense matters are achieved by the gravitational force. As an inevitable consequence they are poles apart in scales of their reaction systems, that is to say, a table top scale of the former fusion reactions and an astronomical scale of the latter reactions.

Remarkable features of long-range coherence in the chemonuclear fusion reactions can also be argued in connection with the Bose-Einstein condensation mechanisms [8]. The long-range coherence revealed in the chemonuclear fusion and the BEC mechanisms can be argued commonly based on the Second Law of Thermodynamics [8].

An additional different feature was found in the molecular chemonuclear fusion. In this scheme plural atomic chemonuclear fusion reactions take place coherently resulting in the super astronomical rate enhancement by factors close to 10^{100}. This scheme introduces a great variety of enhanced fusion reaction modes and

will open up the way towards the compact and highly efficient nuclear fusion science and technology.

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Figure Captions

Figure 1. Evolution of the elastic ^{7}Li – ^{7}Li atomic collision at an energy of nuclear stopping

(a) Twin colliding Li atoms with an energy of nuclear stopping (relative kinetic energy E=15keV). At this energy a nuclear collision (Rutherford scattering) can take place but all electrons (open circles) in the K- and L-shell orbitals adjust their electronic state continuously and smoothly to the nuclear collision process, because the electons gyrate much more rapidly than colliding atom speed.

(b) Intermediate diatomic molecule Li_2 formation. On the first phase of collision process the twin atoms tend towards diatomic molecule Li_2 formation at the minimum Gibbs energy point in the process. However this Gibbs energy is not the minimum point any longer for the atoms colliding with the energy of nuclear stopping. They are directed to form a quasi-C atom at their classical turning point.

(c) Quasi-C atom formation. At the turning point, the twin atoms form a quasi-C atom within the very short collision time of about 10^{-18}s. In the quasi-C atom, twin colliding nuclei (closed circles) are coexisting and confined at the center of common K-shell electron orbital. However, under the presence of thermo-dynamic force or cohesion in the metallic Li liquid their collision time is prolonged by the factor K=1.4×10^{48} through which nuclear reaction rates are likely to be enhanced as argued in Section 2. If any nuclear reaction does not take place the quasi-C atom decays into two Li atoms as before.

(d) Intermediate diatomic molecule formation during the separation of atoms.

(e) Separating twin atoms.

Figure 2. Evolution of the $D_2 - 2\ ^7Li$ molecular chemonuclear fusion in metallic Li liquid

(a) A diatomic D_2 molecule colliding with two Li atoms in a metallic Li liquid. At the acceleration energy of E_{D_2}=30keV (relative kinetic energy of deuteron E(D)=11.7keV), twin D – Li nuclear collisions take place coherently without breaking up the D – D atomic bond. During this collision process all electrons in the K- and L-shell orbitals adjust their electronic states continuously and smoothly to the nuclear collision process.

(b) Intermediate quasi-Be_2 molecule formation. At turning points of colliding atoms, two atomic D – Li pairs form two quasi-Be atoms and produce a quasi-Be_2 molecule within the very short collision time $\tau_T \sim 10^{-19}$s. However the lifetime of this quasi-Be_2 molecule is prolonged by the factor of 5×10^{21} under the presence of cohesion (shown by decade arrows) in the metallic Li liquid. In the quasi-Be atoms, the twin colliding nuclei (closed circles) are co-existing and confined at the respective centers of common K-shell electron orbitals forming ultradense nuclear complexes with a zero-point energy E=20keV. The density of these nuclear complexes is almost 4×10^6 times as large as the solar interior density and compared to the density of white dwarf progenitors of supernovae.

(c) Ultradense nuclear complexes undergoing fusion. During the prolonged residence of quasi-Be_2 molecule and thereby the ultradense nuclear complexes, the complexes undergo pycnonuclear fusion reactions induced by the zero-point oscillation like as ultradense nuclear matters in the stars such as white dwarfs progenitors of supernovae. The significance of chemonuclear fusion reactions thus seems to be the “supernovae on the earth”. In the figure, open circles indicate blown off electrons.

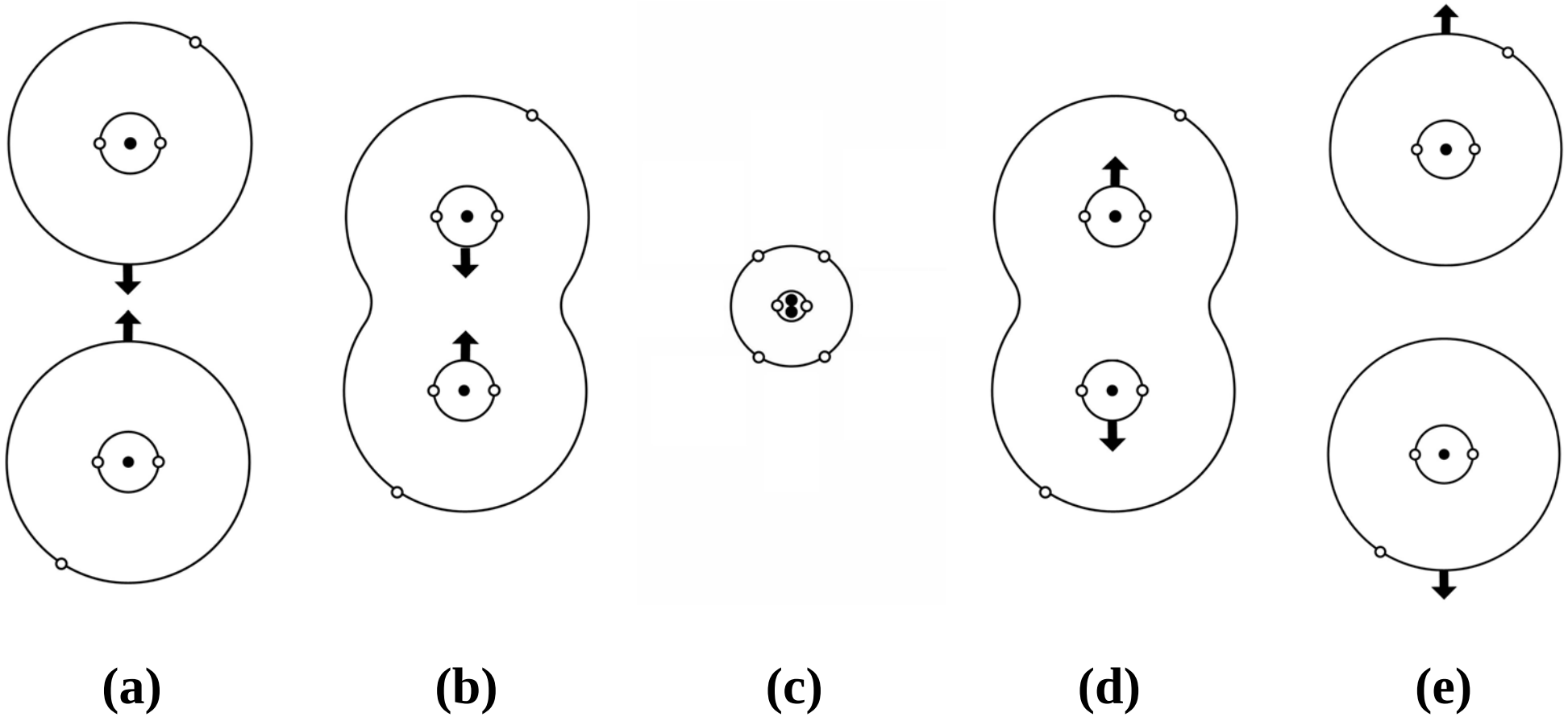
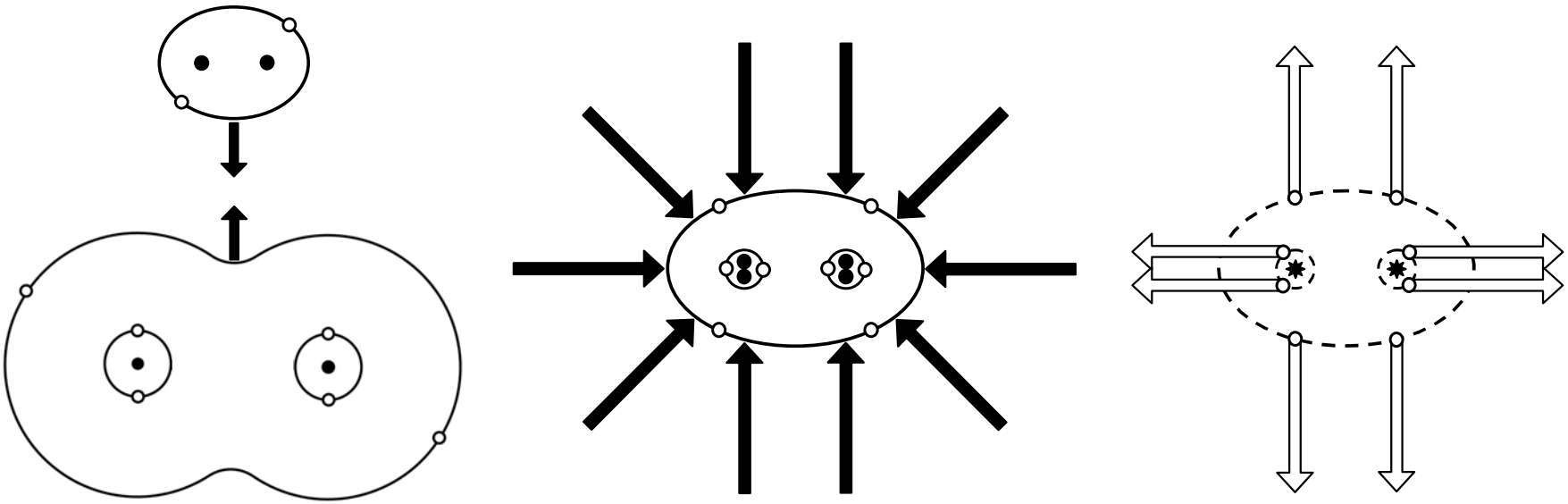


Figure 1.



(a) (b) (c)

Figure 2.

5 The Third Fire Observed in The D_2 – 2Li Molecular Chemonuclear Fusion

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Abstract: Molecular deuterium D_2^+ ions were implanted on a surface of metallic Li liquid target at energies of nuclear stopping (several keV/amu). Alpha particles of 7.56MeV and 15.1MeV energies produced in the nuclear reaction ^{7}Li(d, nα)^{4}He were identified by using a Si surface-barrier detector (SSD). Alpha particles of 15.1MeV were attributable to the 4α break up of coherently produced ^{8}Be nuclei pair. At the ion energy of 30keV the reactions exceeding far beyond the break even were observed just above the melting point of Li metal, where the SSD system stopped running due to the over saturation of counting rate. This enormous α-particle emission cancelled implanted ion charges and resulted in the disappearance of target ion current. Simultaneously the Li liquid target temperature jumped up by 30°C or more which was much higher than the temperature rise of 2°C caused by the steady ion implantation. Analysis showed that implanted D_2^+ ions caused in general nuclear reactions with potentialities of energy gain by 2400 times and created “the third fire”.

Key words: the third fire; molecular chemonuclear fusion; metallic Li liquid target; nuclear stopping; break even

5.1 General Remarks of Chemonuclear Fusion

In the scheme of chemonuclear fusion reactions, ions with an energy of nuclear stopping (several keV/amu) are implanted on a surface of metallic Li liquid [1]. In this scheme the liquid, consisting of Li ions immersed in a sea of collective conduction s-electrons, takes the part of macroscopically correlated solvent reacting with the implanted solute ions [1]. Because in the metallic Li liquid the atomic potential wells for the electrons are not far apart and the electrons can tunnel through the barriers. Furthermore their de Broglie wave length covers the space of some tens Li atoms and yields the collective activity of the liquid [1]. We thus are no longer concerned with energy levels of individual Li atoms and/or ions instead of the bulk of metallic Li ions immersed in the sea of collective conduction s-electrons [1-5].

At the energy of nuclear stopping, the implanted ions collide slowly with liquid atoms/ions through adjusting their electronic states to the nuclear collision processes and thereby the atomic fusion reactions link to the nuclear fusion reactions. This new reaction mechanism is the origin of the term, chemonuclear fusion [5]. The chemonuclear fusion is generally dominated by the thermodynamic force specified by the Gibbs energy change $\Delta G_r(<0)$ in the spontaneous (irreversible) atomic fusion processes [1-5].

The concept "chemonuclear fusion" is extended further to the new concept "molecular chemonuclear fusion" through ion cluster or molecular ion implantations [6]. In cases of molecular deuterium D_2^+ ions implanted on a metallic Li liquid, the molecular chemonuclear fusion,

$$2Li + D_2 \rightarrow \left(\overline{LiD}\right)_2 \rightarrow \text{quasi-}Be_2 \qquad (1)$$

takes place via the metastable formation of quasi-Be_2 molecules consisting of united atoms $\overline{LiD}$ or quasi-Be atoms where twin colliding Li and D nuclei coexist inside a common K-electron orbital of quasi-Be atom and form an ultradense nuclear complex which undergoes the nuclear fusion through the tunneling effect induced by the zero-point oscillation. The rate of this fusion process is described by the generalized Arrhenius' equation,

$$k(T) = k_0 \exp\left[-\frac{\Delta G_r(\mathrm{Be}_2)}{k_B T} \right], \ \Delta G_r(\mathrm{Be}_2) < 0, \tag{2}$$

in the metallic Li liquid at the temperature T. Here k_B is the Boltzmann constant and $\Delta G_r(\mathrm{Be}_2)$ is the Gibbs energy change in the quasi-Be_2 molecule formation Eq.(1) [6]. The Gibbs energy change $\Delta G_r(\mathrm{Be}_2)$ has been estimated to be

$$\Delta G_r(\mathrm{Be}_2) \sim 2\Delta G_r(\mathrm{Be}) \sim -1.98(\mathrm{eV}) \tag{3}$$

as indicated in the previous paper [6]. This value leads to the nuclear fusion rate enhancement K caused by the cohesion or the thermodynamic force in the liquid,

$$K = \frac{k(T)}{k_0} = \exp\left[-\frac{\Delta G_r(\mathrm{Be}_2)}{k_B T} \right] \sim 5 \times 10^{21} \tag{4}$$

estimated just above the melting point of Li metal (T=460K). Here K corresponds to the equilibrium constant of the quasi-Be_2 molecule formation [6].

The factor k_0 in Eq.(2) corresponds to the frequency factor in the Arrhenius equation. Here the factor denotes the intrinsic nuclear fusion reaction rate and expressed as

$$k_0 = I_{D_2} N_{Li} \sigma, \tag{5}$$

where I_{D_2}, N_{Li} and σ are the number current of D_2^+ ions implanted, the surface number density of Li atoms on the liquid surface and the nuclear fusion cross-section, respectively.

In this paper, results of test experiments in the metallic Li liquid will be reported on the molecular chemonuclear fusion Eq.(1), concerning the nuclear reaction

$$^7\mathrm{Li} + \mathrm{D} \rightarrow {}^8\mathrm{Be}^* + \mathrm{n} \rightarrow 2 \cdot {}^4\mathrm{He} + \mathrm{n} + 15.1\mathrm{MeV}. \tag{6}$$

The cross-section of nuclear fusion reaction is given in the form,

$$\sigma = \frac{S}{E} \exp\left[-\pi \left(\frac{E_G}{E} \right)^{\frac{1}{2}} \right], \tag{7}$$

at the low relative kinetic energy E of deuteron, where S and E_G(keV) are the cross-section factor intrinsic to the nuclear fusion reaction and the Gamov energy, respectively [1]. Typically for D_2^+ ions of acceleration energy of E_{D_2}=30keV the relative kinetic deuteron energy is E=11.7keV, and the cross-section of the nuclear fusion reaction Eq.(6) is expected to be about 5×10^{-15}b, based on the cross-section factor S~2100keV·b and the Gamov energy E_G=1389keV [1].

Combining the cross-section formula Eq.(7) with the Lindhard's stopping power formula [7], the intrinsic nuclear reaction probability of D_2^+ ions before their stopping (within the range of a tenth μm) on a surface of metallic Li target has been estimated [2, 6],

$$P_{\text{int}} \sim 6\times10^{-5} \exp\left[-\frac{132.7}{(E_{D_2}/2)^{1/2}}\right]. \tag{8}$$

The above equation provides P_{int}~8×10^{-20} for the ions of E_{D_2}=30keV and corresponding reaction rate of around 16 events/yr at the ion current of 1μA. It is infeasible to observe the reaction Eq.(6) at such a low ion energy unless any enormous enhancement mechanism is manifested. On the contrary, considerable reaction rate may be expected under the enhancement estimated in Eq.(4) or in more concrete terms, a great part of implanted D_2^+ ions would give rise nuclear fusion unless otherwise some marked quenching action does work against the molecular chemonuclear fusion. In the above discussions we have disregarded the contribution of ^{6}Li. Because non-recoilless characterestics in the reaction ^{6}Li(d,α)^{4}He would result in a quenching of chemonuclear fusion rate [2].

5.2 Experimental Procedure and Alpha-Particle Spectra Measurements

The experiments were carried out for metallic Li targets in both liquid- and solid-phases for comparison by using an improved device which was equipped with a magnetic ion separator. In Figure 1 is shown a schematic arrangement of this device. Special attention was paid to generate clean and stable ion beams but of moderate intensity because the huge enhancement Eq.(4) and the drastic temperature dependence Eq.(2) of reaction rate were expected. This moderate beam density operation was found to reduce the local temperature rise of the metallic Li surface caused by the non-linear thermal effect [3]. For instance, a temperature

rise of 100°C of metallic Li surface above the melting point results in a quenching of the enhancement of D_2 induced chemonuclear fusion as much as a factor of 10^{-4} recalling Eq.(4).

In order to match with these requirements a compact ion source of conventional PIG (Penning Ion Gauge) type was made, which produced mixed D^+, D_2^+ and D_3^+ ion beams of about several tens μA from 1keV to 35keV energies. Typically a beam of 20μA was extracted from a slit with a hole of 1.9mm in diameter and then led to the magnetic analyzing system of mean ion radius of 100mm. A separated D_2^+ ion beam of about 1μA entered target chamber was implanted vertically on a surface of metallic Li target. The Li metal was shaped in a rod of 16mm in diameter and 60mm long and mounted in a target capsule of pure alumina cylinder equipped with a piston system for lifting up the metal rod as seen in Figure 1. However, the top of liquid Li target became hemispherical due to the large cohesion in the liquid. This target system was associated with a dual scraper/stirrer system so that a fresh surface of metallic Li target was exposed to the ion beam always in a vacuum of about several 10^{-7}Torr. The shaped metallic Li target was prepared and kept in the clean vacuum at least one day before using. The target was set normal to the beam and tilted by an angle of 17° to the direction of α-particle detection.

Charged particles emitted from the target were observed by using a 300μm thick Si surface-barrier detector (SSD) which positioned with the effective acceptance of 0.016% of 4π str and covered with a 5μm thick Al foil to prevent δ-rays and scattered D_2^+ ions from hitting the detector. Detector out put pulses and spectra were monitored by comparison with those of α-particles from a calibration source of ^{241}Am(5.58MeVα) covered with a 5μm thick Al foil and mounted near the Li target. Energy loss measurements through a movable 5μm thick Al-foil energy degrader and 1mm thick Al-plate stopper system were useful to reject noise backgrounds and to identify the particles whether they were single α-particles or paired α-particles released in the break up of product ^{8}Be nuclei.

In the solid phase of Li target at room temperature no reaction Eq.(6) was observed at any energy of D_2^+ ions through the α-particle detector, which was consistent with the reaction rate estimation based on the intrinsic nuclear reaction probability Eq.(8) as argued in Section 1.

In the liquid phase of bulk of metallic target, however, the chemonuclear fusion did not necessarily take place depending on thermodynamical conditions of surface of the metallic Li liquid. At thermodynamical equilibrium of the Li liquid, broad peaks appeared at 7.56MeV and 15.1MeV energies in the particle spectra. An example is seen in Figure 2 which was obtained at E_{D_2}=30keV. Both 7.56MeV and 15.1MeV peaks were assigned to α-particles from the reaction Eq.(6), however, their relative intensities were different from those observed previously depending on the conditions of the Li liquid surface [4]. The 15.1MeV peak was identified with the reaction product ^{8}Be nuclei or paired α-particles of 7.56MeV emitted coherently in the break up of the paired ^{8}Be nuclei [4]. The ground state of ^{8}Be has been known as the 2α Bose-Einstein condensation state [6]. The paired nuclei $^8Be_2$ are capable of undergoing coherent 4α break up as the Bose-Einstein condensation process [6]. This break up is exactly coincident with the coherent 4 photon annihilation of positronium molecule Ps_2 in which twin Ps atoms are condensed as a system of two identical *p*-Ps atoms or that of *o*-Ps atoms [8].

These observation results are in coincidence with the reaction sequence indicated in Eq.(6) in which most nuclear reaction energies released were kinetic energies of α-particles [6]. Observed reaction rate was, however, influenced dramatically by conditions of the implanted D_2^+ ion beam and, in particular, by thermal and chemical states of the liquid Li target due to the super astronomical rate enhancement factor of around 10^{21} in Eq.(4). The formation of glassy LiD film, Li_2O and other contaminant layer on the surface of liquid Li target is a such kind of case because of suppression of the cohesion or thermodynamic force in the liquid. The maximum value of reaction rate was observed usually around the melting point of metallic Li target and enormously enhanced compared to those deduced from the intrinsic nuclear fusion cross-section Eq.(7) or the reaction probability Eq.(8).

5.3 Observation of Reactions Exceeding Far Beyond the Break Even

The first confirmatory reactions exceeding far beyond the break even was observed in the liquid phase of bulk metallic Li target at the D_2^+ ion acceleration energy of 30keV but not for the same energy atomic ions [9]. The reactions indicating “the third fire” were observed under following conditions.

A lump of Li metal of 10mm in diameter and about 100mm long was molten to shape in the target capsule. The top part of Li was stirred and scrabbled by using a stirrer/scraper system. After shaping the Li target, it was cooled down and kept in the vacuum of about 4×10^{-7}Torr during at least one day.

In the initial stage of experiment, the Li target was preheated up under monitoring the degassing from it without D_2^+ ion implantation so as to avoid the undesired accumulation of chemical reaction products LiD. Near the melting point of Li metal the ion implantation was started with charged particle spectra acquisition under monitoring the temperatures of Li target head and heater of which power was controlled through the target temperature. During the implantation, fluorescence from the surface (within a tenth μm thick) of Li target was also monitored in order to check its condition. If chemical reaction products such as LiD were accumulated the fluorescence was waxy colored. While the ion beam was implanted on a very clean metallic Li liquid surface, the fluorescence was carmine colored indicating the emission from the metallic Li surface.

At the monitoring target temperature of 183°C just above the melting point of the Li metal the reactions exceeding far beyond the break even were observed with non-linear and even fiery aspects. In Figure 2 is shown a charged particle spectrum observed in the first confirmatory molecular chemonuclear reactions exceeding far beyond the break even. The increment of the charged particle spectrum acquisition was varied irregularly. This unusual irregularity impressed a person as those of bumping and intermittent springs. Recognizable gain changes in the spectrum were also observed during the data acquisition depending on the irregular variation of counting rate. When the rate was fairly high the spectrum shifted towards higher gain side indicating a summing up pulse effect. These features were especially remarkable for the most intense peak at 7.56MeV as seen in Figure 2. We had a similar experience during observation of α-particle spectrum in the sub-break even of the Li – Li chemonuclear fusion reaction as shown in Figure 3 [10].

However when the rate jumped up greatly the spectrum shifted towards lower gain side due to the charge up effect in the SSD system. The appearance of multi-sub peaks in the broad peak at 7.56MeV in Figure 2 was likely to be caused by such the gain shift effect. Similar but much more moderate aspects are also seen in

Figure 3. These non-linear aspects were not observed in the spectra obtained far below the break even as seen in the peaks at 7.56 and 15.1MeV in the previous report [4].

While the reaction rate was extremely high the SSD system stopped running completely and indicated the over saturation of counting rate. At the same time, the monitoring current of D_2^+ ion beam on the target shifted towards nothing or frequently disappeared. It implied that a substantial part of D_2^+ ions underwent nuclear reactions and produced enormous α-particles some of which carried out positive charges from the target and cancelled out the ion beam current.

This disappearance aspect of ion current was accompanied with the temperature jumping up of liquid Li target by over 30°C. The jumping must be much more higher considering the slow response characteristics of mechanical thermo-recorder. The temperature jumping up exceeded far beyond the temperature rise of 2°C caused by the steady D_2^+ ion implantation and sometimes cut off the power of temperature controlled heater system as seen in Figures 4 and 5.

The temperature jumping up suppressed immediately the chemonuclear fusion rate as expected based on the argument on the rate equation Eq.(2) in Section 1. The jumping up disturbed the thermal equilibrium of liquid Li, which also suppressed the chemonuclear fusion. This resulted in an interruption of the fusion reactions exceeding beyond the break even. The Li target system then cooled down towards the initial temperature before the reactions started. When the thermodynamical state of Li target surface was restored as before, however, the reactions exceeding far beyond the break even took place again and all aspects described above were repeated as seen in the notched patterns of target temperature shown in Figure 5. Considering these aspects the real charged particle spectra acquisition seemed to be around 10^{-3} of the acquisition time indicated in Figure 2.

Throughout the observation of reactions exceeding the break even, any competing chemical reactions such as the LiD formation did not interfere with the fusion. This indicated that the absence of competing chemical reactions is essential for the D_2-2Li chemonuclear fusion.

5.4 Analysis of Observed Reaction Aspects

If an implanted D_2^+ ion undergoes the ^{7}Li – D reaction Eq.(6) with a reaction probability P_r, α-particles of $4P_r$ will be produced in the target. A fraction $(1-\varepsilon)$ of these α-particles would be emitted from the target and carry out the charge of $4(1-\varepsilon)P_r$. Here ε denotes the fraction of α-particles absorbed in the target. This missing charge cancelles the target ion current and reduces it as much as a factor of $1-4(1-\varepsilon)P_r$. The result observed in the reaction exceeding beyond the break even indicated $1-4(1-\varepsilon)P_r \sim 0$, that is,

$$(1-\varepsilon)P_r \sim 0.25 . \quad (9)$$

The ion undergoing the nuclear reaction Eq.(6) releases the reaction energy $15.1\text{MeV}\times 2P_r$. Most of the energy would be released as kinetic energies of α-particles as seen in Eq.(6). However, only a fraction ε of α-particles would stop in the target and heat up it. The nominal energy gain in the present experiment is thus $\varepsilon P_r \times (30.2\text{MeV}/30\text{keV}) \approx 10^3 \varepsilon P_r$ for the D_2^+ ion of 30keV energy. This gain can be compared very roughly with the ratio of temperature jumping up (>30°C) caused by the reaction and the temperature rise (2°C) due to the steady D_2^+ ion implantation, that is, >15. One obtains,

$$\varepsilon P_r > 0.015 . \quad (10)$$

Combining the results, Eqs.(9) and (10), one may conclude

$$P_r \sim 0.3 \quad (11)$$

, that is, D_2^+ ions implanted in general cause nuclear reactions in the metallic Li liquid. This conclusion is consistent with the predicted values $P_r \sim 5\times 10^{21} P_{int} \sim 1$ for D_2^+ ions of energies higher than 25keV recalling Eqs.(4) and (8).

The temperature jumping up of 30°C or more indicated that the local heating up would be 100°C or more in the range of α-particles within 0.15cm thick on the Li target surface. In fact a reasonable assumption, $\varepsilon \sim 0.25$ requires,

$$\varepsilon P_r \sim 0.075 \quad (12)$$

based on Eq.(11), instead of Eq.(10). This reflects in the jumping up of about 150°C on the surface of target. The jumping up of around 100°C, for example, results in a quenching of reaction enhancement as much as by a factor of 10^{-4} as argued in Section 2. This means that the counting rate of α-particles would change

between about 10^6 and 10^2cps under the temperature jumping, recalling the detection efficiency of SSD and the reaction probability Eq.(11).

The non-linear and even fiery aspects seen in the reaction data acquisition described in Section 3 are found to be quite understandable considering such a dramatical change in the α-particle production rate.

5.5 D_2 – 2Li Chemonuclear Fusion as New Energy Resources

In the ^{7}Li – D reaction Eq.(6), neutrons are slowly released keeping the momentum matching with implanted ions because reaction rates are generally maximum under the momentum matching [1-4]. The momentum matching condition requires that the neutron momentum must equal with the deuteron momentum. Such neutrons have already been observed in the reaction previously [3].

The slow neutrons are immediately absorbed by ^{6}Li and ^{7}Li nuclei under certain configurations of the metallic Li liquid and/or Li compound shield. They produce associated energy releases as seen in the reactions Eqs.(13-16) [2],

$$^6\mathrm{Li} + \mathrm{n} \rightarrow {}^4\mathrm{He} + \mathrm{T} + 4.78\mathrm{MeV}, \tag{13}$$

$$^7\mathrm{Li} + \mathrm{n} \rightarrow {}^8\mathrm{Li}(0.84\mathrm{s}) + \gamma + 2.03\mathrm{MeV}, \tag{14}$$

$$^8\mathrm{Li}(0.84\mathrm{s}) \rightarrow {}^8\mathrm{Be}(3.04\mathrm{MeV\ state}) + \beta^- + \overline{\nu_\mathrm{e}} + 12.96\mathrm{MeV}, \tag{15}$$

and

$$^8\mathrm{Be}(3.04\mathrm{MeV\ state}) \rightarrow 2\cdot{}^4\mathrm{He} + 3.13\mathrm{MeV}. \tag{16}$$

Considering a series of nuclear reactions, Eqs.(6,14-16), if one subtracts the average energy of about 7.7MeV, carried out by an antineutrino $\overline{\nu_\mathrm{e}}$ in the beta decay Eq.(15), the useful energy release is about 51.1MeV for an implanted D_2^+ ion. This implies that the nominal energy gain — the ratio of the energy released to the acceleration energy — is about 1700 for the 30keV D_2^+ ion.

However the secondary reaction, Eq.(13) would be much more valuable compared to the reaction Eq.(14) due to the big cross-section of nuclear reaction Eq.(13) and large useful energies released in its successive nuclear reactions. After slowing down to nuclear stopping energies considerable fraction of T ions produced in the

reaction Eq.(13) may take place the T – Li chemonuclear reactions in the metallic Li liquid,

$$^{6}Li + T \rightarrow 2\cdot{}^{4}He + n + 16.11MeV, \quad (17)$$

and

$$^{7}Li + T \rightarrow 2\cdot{}^{4}He + 2n + 8.86MeV. \quad (18)$$

In a series of nuclear reactions, Eq.(6, 13 and 17), the useful energy release is about 72.0MeV and thus the nominal energy gain is about 2400 for a D_2^+ ion of 30keV acceleration energy. While in the other series of nuclear reactions Eqs.(6, 13 and 18), the useful energy release and the corresponding nominal energy gain are 57.5MeV and 1900, respectively, for a 30keV energy D_2^+ ion.

Based on the above considerations, it may be concluded that the nominal energy gain is expected to be around 2000 for a D_2^+ ion of acceleration energy of 30keV. In the considerations, however, we have disregarded so far energy releases in the successive reactions induced by energetic neutrons produced in the reactions Eqs.(17) and (18), which push up further the above mentioned values of energy gain. This problem is left for further investigations. It is also of importance to investigate chemonuclear reactions and secondary nuclear reactions on the ^{10}B and ^{11}B isotopes, which will be argued in the future.

5.6 Summary of Simultaneous Observation Results and Its Significance

In the present experiments the following four observation results were obtained [9].

1) Alpha-particles emitted from metallic Li liquid target were identified by using a Si surface-barrier detector (SSD) and thin foil energy degraders.
2) Beam current of molecular D_2^+ ions from the Li target to the ground was intermittently disappeared through the enormous emission of α-particles from the target.
3) Temperature of the Li target increased appreciably during the counting rate over saturation of SSD. The temperature increase was larger by a factor of more than 15 times compared to that due to the steady D_2^+ ion beam implantation.
4) The above three phenomena were seen in the liquid phase of metallic Li target but not in the solid phase.

These observation results indicate that a substantial fraction of implanted molecular D_2^+ ions undergo chemonuclear fusion reactions which are expected to release energies with the nominal energy gain of about 2000. The chemonuclear fusion reactions thus seem to realize “the third fire” following the combustion (the first fire — chemical reactions) and the nuclear power (the second fire — nuclear reactions). The third fire (chemonuclear fusion reactions) would lead to the next energy revolution as the peaceful, ecology friendly and wasteless alternative energy, if it is extensively developed.

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Figure captions

Figure 1. Test device: 1.gas inlet tube; 2.magnet; 3.ionizer; 4.flange; 5.extractor; 6.top chamber; 7.exhaust port; 8.acceleration electrode; 9.coil; 10.magnet pole; 11.chamber; 12.focussing electrode; 13.ion beam; 14.flange; 15.exhaust port; 16.fused quarz reaction chamber; 17.metal mesh; 18.^{241}Am-calibration source; 19.dual 5μm thick Al foil/1mm thick Al stopper plate system; 20.SSD; 21.iron shield; 22.dual scraper/stirrer system; 23.metallic Li; 24.heater; 25.piston; 26.base flange; 27.ionization gauge; 28.dual driving rotor; 29.piston driver.

Figure 2. Charged particle spectrum obtained during the observation of the first confirmatory D_2 – 2Li chemonuclear fusion exceeding far beyond the break even at the D_2^+ ion energy of 30keV. Unusual and non-linear aspects in the spectrum are attributable to the extremely irregular fluctuation of reaction rate from some hundreds to sub million cps. Above some ten thousands cps rate the SSD system stopped running due to the over saturation.

Figure 3. (a) Spectrum of α-particles produced in the reaction $^7Li + {}^7Li \rightarrow {}^8Be^* + {}^4He + 2n \rightarrow 3\cdot{}^4He + 2n + 6.40MeV$ with a Li-ion beam at an energy of 30keV. Two broad peaks with an equal intensity are seen at energies of 4.3MeV and 2.1MeV. The peak at 2.1MeV is actually a sum peak of paired α-particles of 1.05MeV energy produced from the break up of ^{8}Be nuclei. Both peaks observed have been found to be reduced depending on the change in quality of the Li target. A non-linear energy aspect is seen in the spectrum, which is attributable to the irregular counting rate fluctuation during the measurement as seen in Figure 2. (b) A spectrum of α-particles of 4.5MeV energy emitted from a calibration source of ^{241}Am (5.48MeV) covered with a 5μm thick Al foil and mounted near the Li target.

Figure 4. Records of fusion power generation observed in the first D_2 – 2Li chemonuclear fusion experiment. The temperature of Li target was controlled by using a coase heater power regulation system and a fine regulation system. The coase system regulates heater power by driving an SSR (solid state relay) through a thermocouple attached to the heater. The fine control system regulates the temperature of Li target head through another thermocouple attached to the head. The latter thermocouple was positioned at about 5mm depth from the surface. The accuracy of temperature control was ±0.2°C. At the target head temperature of

181°C, the ion implantation was started. Thereby the temperature increased gradually. When the temperature reached around 183°C, it suddenly jumped up by about 30°C or more. This jump was not due to the heater power increase. On the contrary it resulted in cut off the temperature controlled heater power as seen in the record of heater temperature. After the target temperature was restored as before (183°C), following jumpings were again observed. A prominent peak seen in the target head temperature indicates the check mark testing the control system.

Figure 5. Fusion power generation observed in the first confirmatory $D_2 - 2Li$ chemonuclear fusion experiment. In this figure the axis of target temperature was scaled up by a factor of 4 compared to the heater temperature. A series of repeated jumps was observed after several times observation of the same pattern of jumps shown in Figure 4. The repeated temperature jumps were so abrupt and of short time duration that the heater power cutting off was not triggered until 8-times repetition of jumps. During the repetition, however, the temperature of bulk Li might increase considerably and thereby the 9-th jumping up attacked the SSR system and cut off completely the heater power system. It is noteworthy that an additional series of temperature jumps was observed still after the cut off of hearter power. This indicates that the Li target surface is still melting due to the generated nuclear fusion power during the natural cooling of the target.

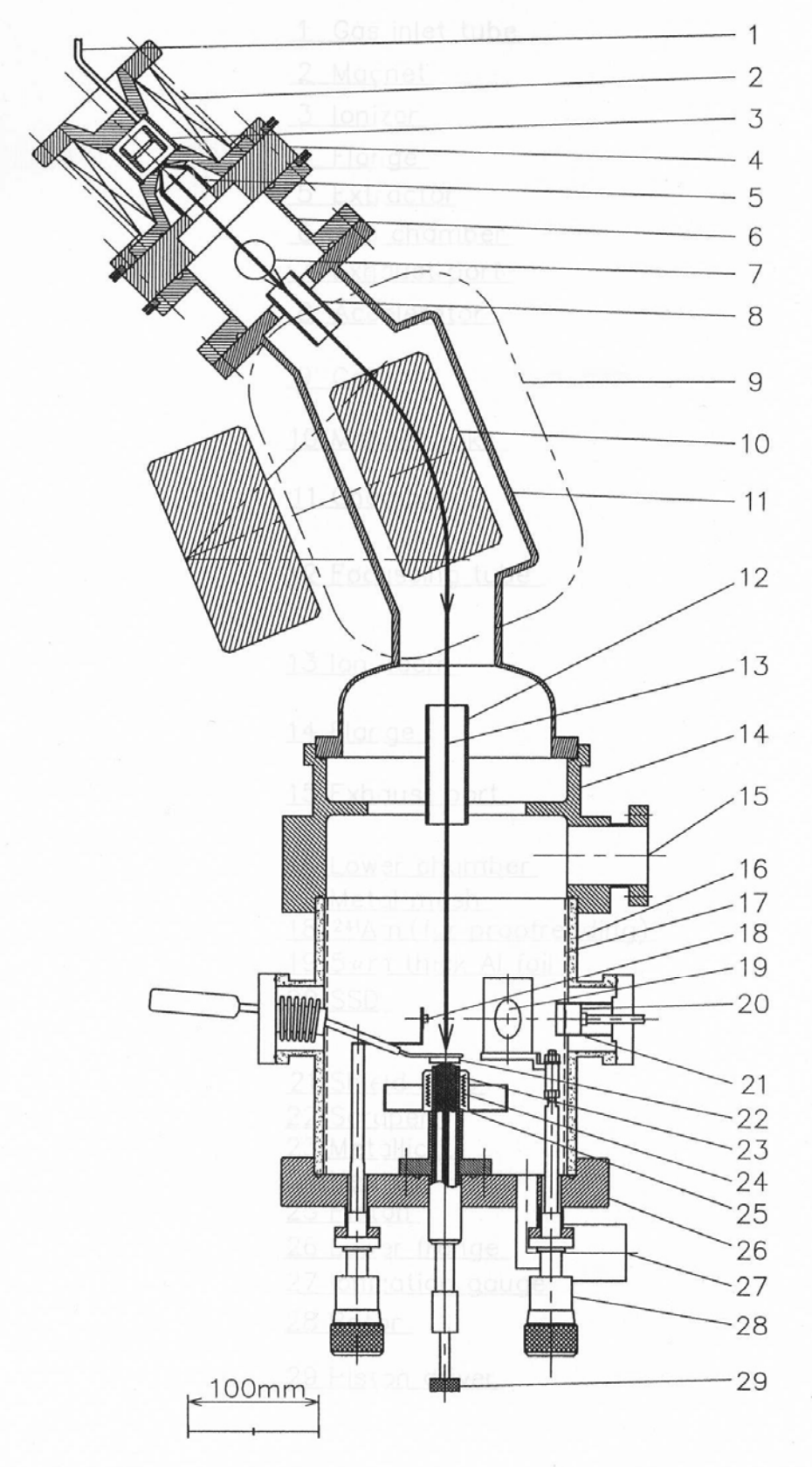
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Figure 1

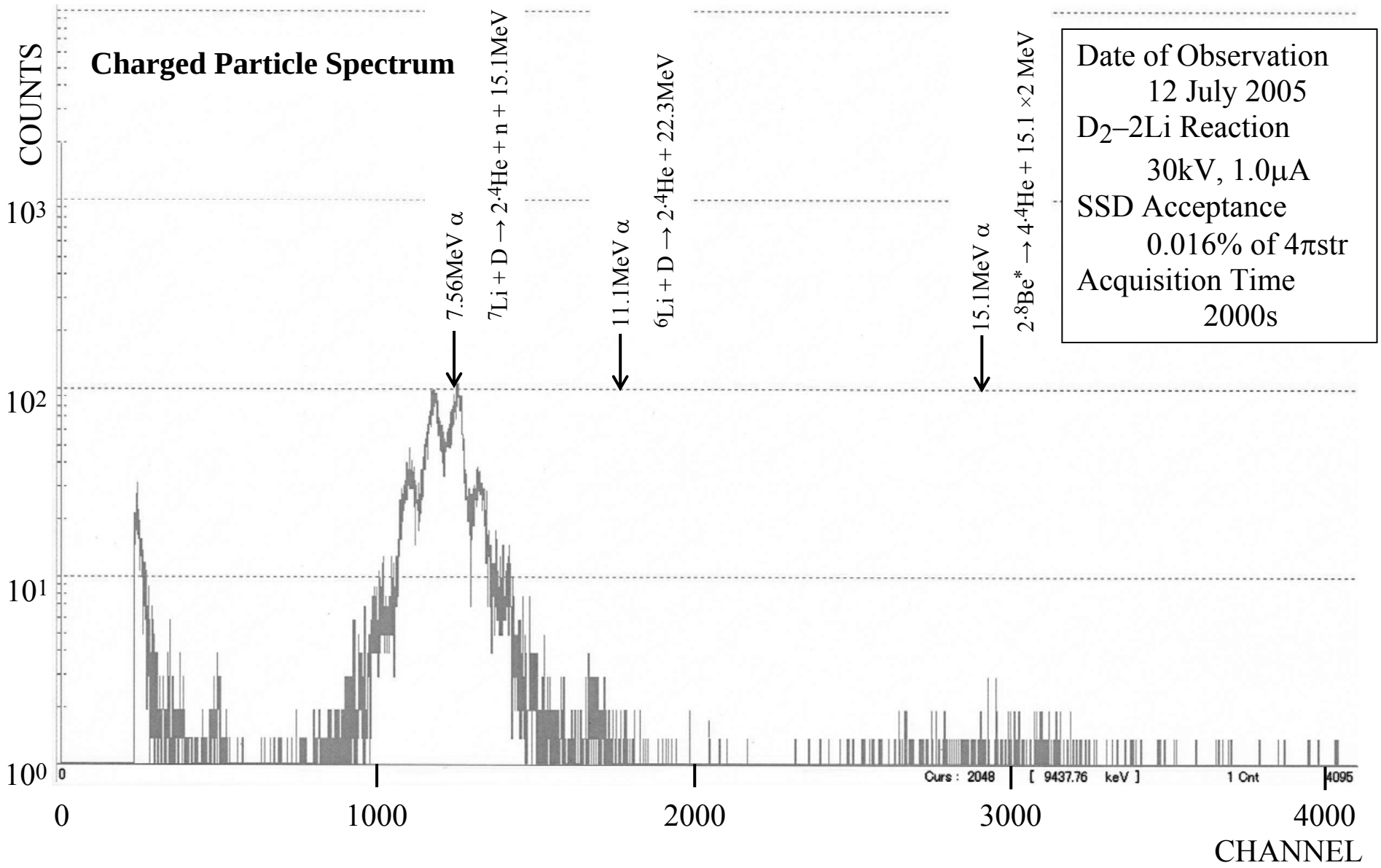
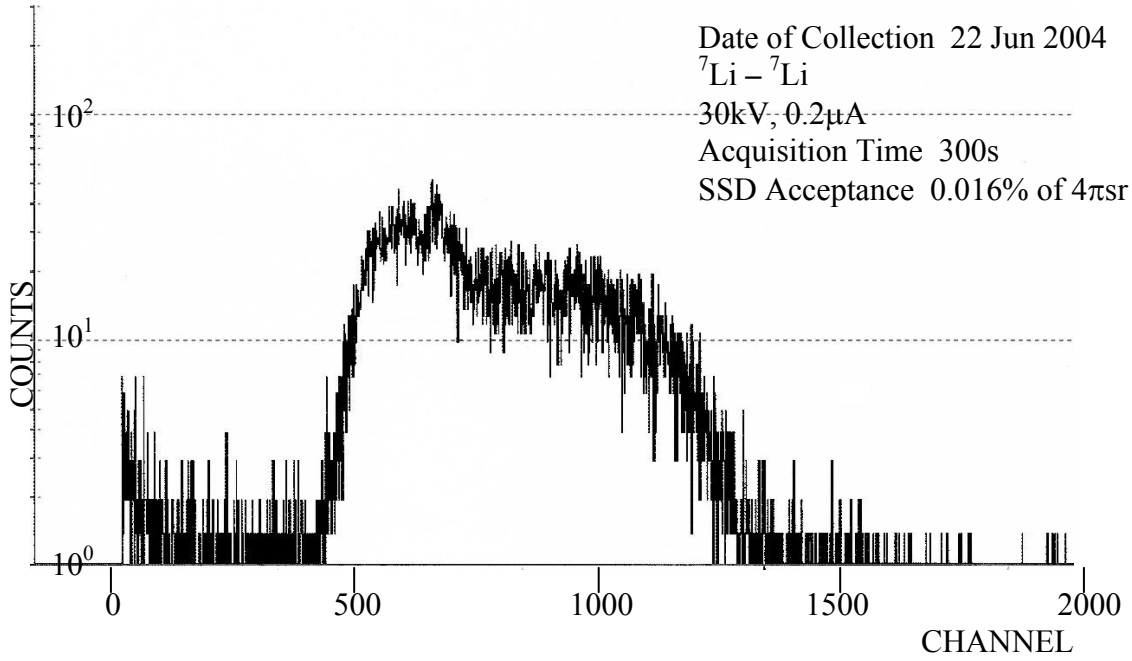
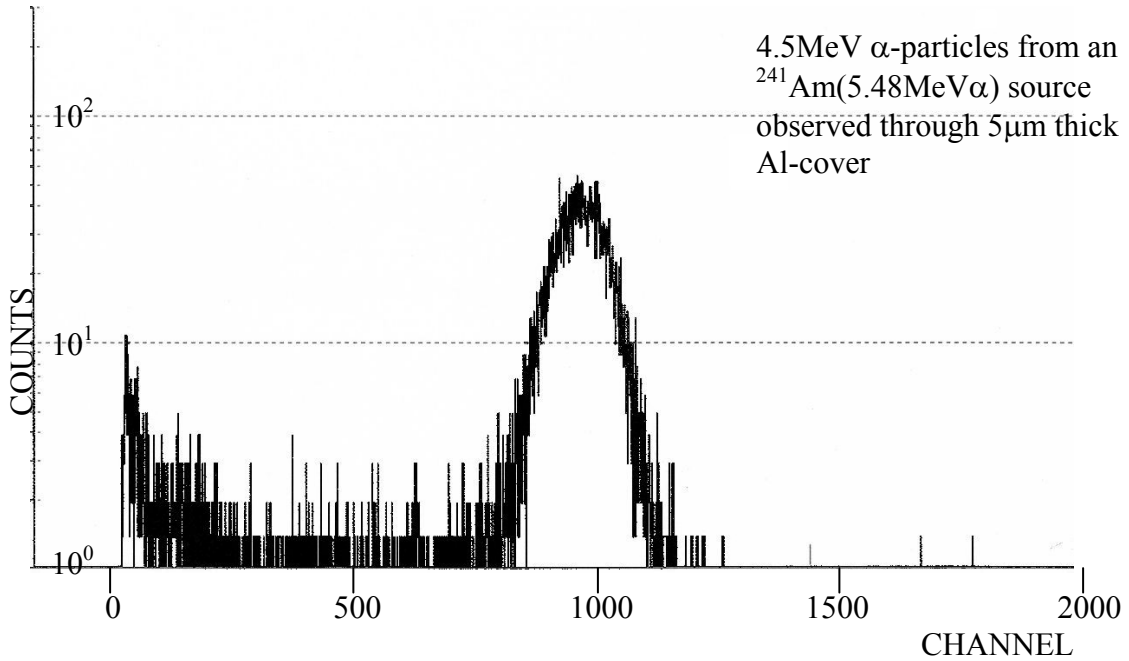

Charged Particle Spectrum
COUNTS
10^3
10^2
10^1
10^0
7.56MeV α
^{7}Li + D → 2·^{4}He + n + 15.1MeV
11.1MeV α
^{6}Li + D → 2·^{4}He + 22.3MeV
15.1MeV α
2·^{8}Be* → 4·^{4}He + 15.1 ×2 MeV
Date of Observation
12 July 2005
D_2–2Li Reaction
30kV, 1.0μA
SSD Acceptance
0.016% of 4πstr
Acquisition Time
2000s
0
Curs : 2048
[9437.76 keV]
1 Cnt
4095
0
1000
2000
3000
4000
CHANNEL

Figure 2.


Date of Collection 22 Jun 2004
^{7}Li – ^{7}Li
30kV, 0.2μA
Acquisition Time 300s
SSD Acceptance 0.016% of 4πsr
COUNTS
10^2
10^1
10^0
0
500
1000
1500
2000
CHANNEL

(a)


4.5MeV α-particles from an
^{241}Am(5.48MeVα) source
observed through 5μm thick
Al-cover
COUNTS
10^2
10^1
10^0
0
500
1000
1500
2000
CHANNEL

(b)

Figure 3.

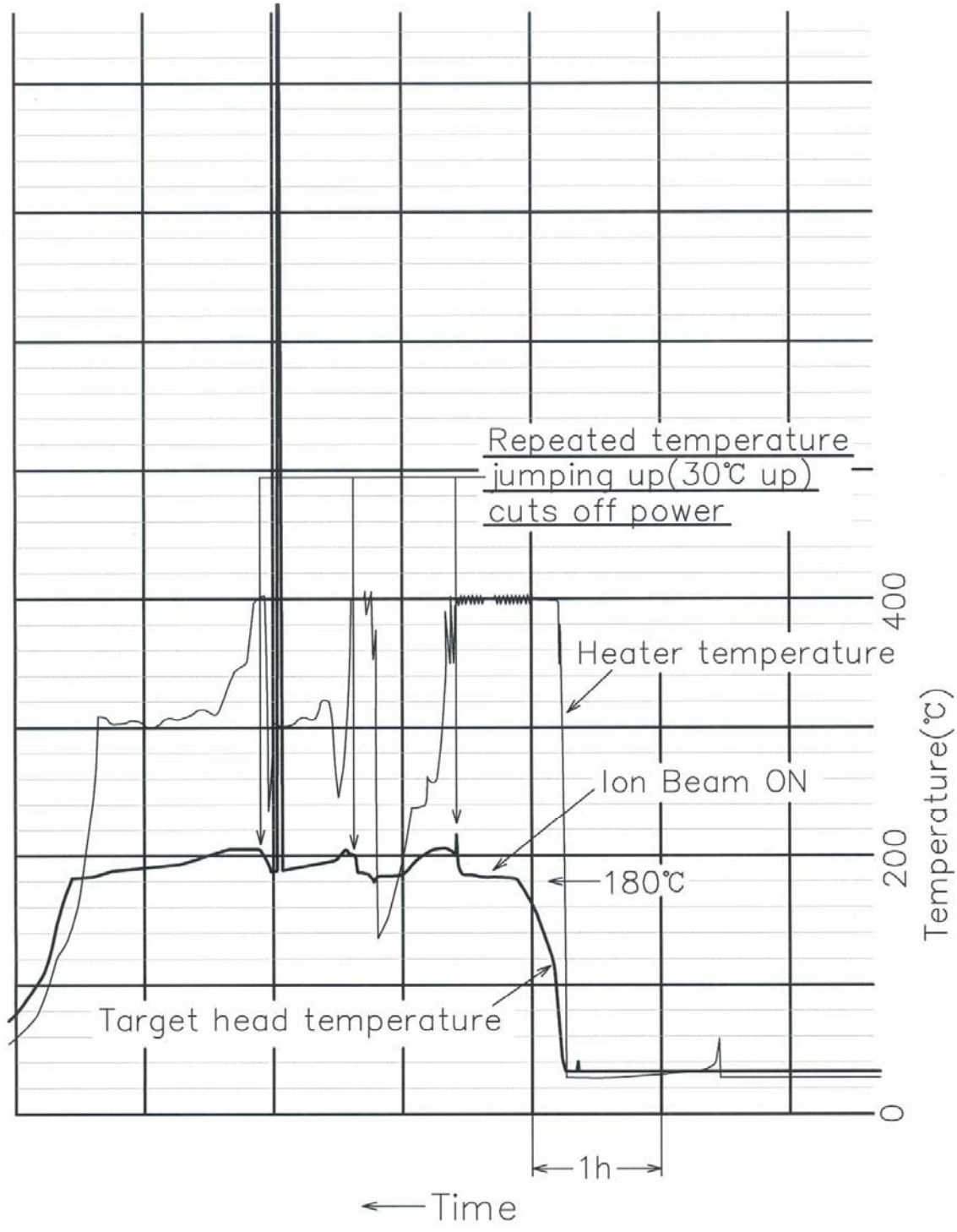

Repeated temperature
jumping up(30℃ up)
cuts off power
Heater temperature
Ion Beam ON
180℃
Target head temperature
400
200
0
Temperature(℃)
1h
Time

Figure4.

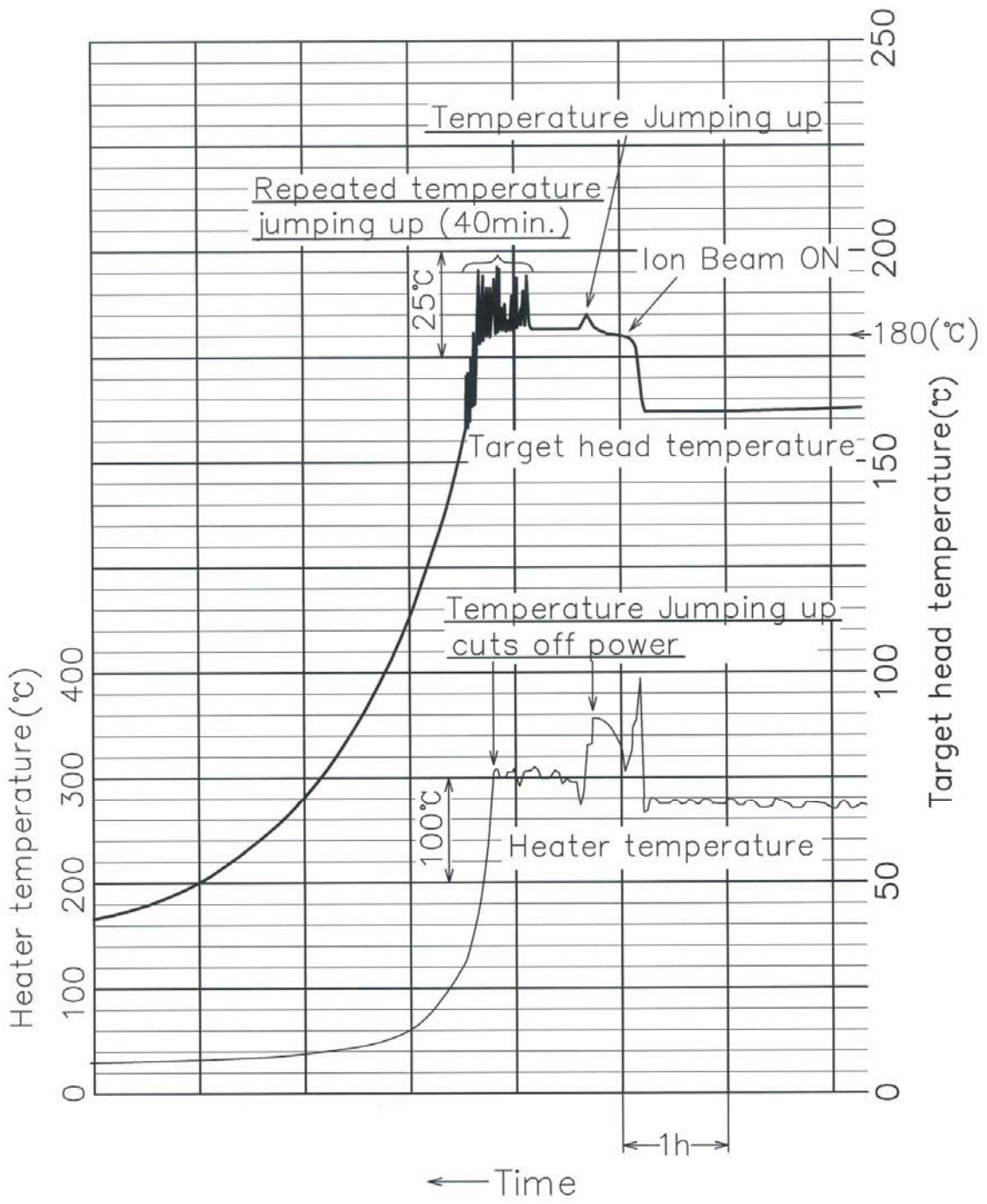

Temperature Jumping up
Repeated temperature
jumping up (40min.)
Ion Beam ON
25℃
180(℃)
Target head temperature
Temperature Jumping up
cuts off power
100℃
Heater temperature
Heater temperature(℃)
Target head temperature(℃)
0
100
200
300
400
50
150
250
1h
Time

Figure 5.

6 Radiation Identification Confirming Ultradense Nuclear Fusion

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Abstract: Recently a never before experienced event has been observed, the D_2 – 2Li chemonuclear fusion, which suggests energy generation exceeding far beyond break even. This paper is concerned with confirmatory experiments on the nuclear fusion reaction ^{7}Li(d, n)^{8}Be $\rightarrow 2\cdot{}^4$He by the identification of produced charged particles and neutrons simultaneously. In the experiments molecular deuterium ions D_2^+ of 30 keV energy were implanted on a liquid surface of metallic Li. The produced α-particles were identified with those of 7.56 MeV energy from the reaction using a $\Delta E - E$ detector. There was, however, also α-particles of 15.1MeV implying the coherent break up of twin Be nuclei. A neutron detector with a LiI scintillator showed the same event rate as for the α-particles. Present results were in agreement with all previous observations.

Key words: ultradense nuclear fusion; break even; $\Delta E - E$ detector; reaction enhancement; coherent break up

6.1 The Origin of Chemonuclear Fusion

After the discovery of the concepts “nucleus” and “Rutherford scattering” [1], Bohr explained that the Rutherford scattering was not simply collisions between nuclei but was collisions between whole atoms at very low energies typically several keV/amu [2]. Nowadays this phenomenon is called nuclear stopping of atoms or ions implanted in condensed matter since the nuclei of the struck atoms acquire significant amounts of kinetic energy in the collision, as can be seen in the sputtering phenomena of ions [3]. This indicates that nuclear collision processes link together with atomic collision processes. This state of affairs may be applicable to nuclear reactions at the energy of nuclear stopping where they take place cooperatively with atomic or chemical reactions and thus, can be controlled, under some chemical conditions.

The potential of linked chemical and nuclear reactions were predicted in 2001 [4,5] and experimentally verified through the observations of enhanced ^{7}Li(d, n)^{8}Be $\rightarrow 2\cdot{}^{4}$He reaction in Uppsala in 2002 [6,7] and enhanced ^{7}Li(^{7}Li, 2n)^{12}C $\rightarrow 3\cdot{}^{4}$He reaction in Sakura in 2004 [8,9]. Here we refer to these as chemonuclear fusion reactions [8].

6.2 Chemonuclear Fusion as an Equivalent to the Ultradense Nuclear Fusion in Supernovae

It is instructive to consider the significance behind Bohr’s explanation of atomic collisions. In Fig.1 [8,10] is shown the evolution of an elastic ^{7}Li – ^{7}Li atomic collision at the relative kinetic energy E = 15 keV. This collision is essentially the Rutherford scattering between two ^{7}Li nuclei dressed with atomic electrons. As seen in Fig.1, nuclear processes are linked with atomic processes.

At the turning point of two atoms, they unite into a quasi-C atom within the very short collision time given by the period of zero point oscillations (1.3×10^{-18}s) of the colliding nuclei at the point. Here a remarkable shrinkage by a factor of 0.065 is seen in the volume of the united atom (quasi-C atom). In the quasi-C atom the twin colliding nuclei are co-existing. They are confined at the centre of a common K-shell electron orbital within the sphere of their zero-point oscillation (0.9 pm) and build up an ultradense nuclear complex (~10^{11} kg/m^{3}) which shows a trend towards the nuclear fusion through the tunnelling effect induced by the zero-point

oscillation. The density is a million times as large as the solar interior density (1.6×10^5 kg/m^3) and close to the densities of white-dwarf progenitors of supernovae (10^{12} kg/m^3) [8,10].

In the normal case nothing happens except an elastic collision between the nuclei at their turning point and the quasi-C atom decays into two Li atoms as before. In a metallic Li liquid, however, the cohesion in the Li liquid tends to keep the shrinkage and prolong the existence of the quasi-C atom and thereby the lifetime of the nuclear complex by the thermo dynamical factor [8,10],

$$K(\mathrm{C}) = \exp\left[-\frac{\Delta G_\mathrm{r}(\mathrm{C})}{k_\mathrm{B}T}\right]. \qquad (1)$$

Here T is the temperature of the metallic Li liquid, parentheses () indicate quasi-atoms and $\Delta G_\mathrm{r}(\mathrm{C}) = -4.4$ eV denotes the chemical potential or Gibbs energy change in the formation of the quasi-C atom [8]. The factor results in a huge enhancement, $K(\mathrm{C}) \sim 1\times10^{48}$ of the nuclear fusion probability through a prolonged lifetime of the nuclear complex just above the melting point ($T = 181^\circ$C) of the Li metal [8].

The ^{7}Li – ^{7}Li chemonuclear fusion was really observed with an enhancement of over 10^{50} in 2004 through the detection of α-particles produced in the reaction [9].

$$^7\mathrm{Li} + {}^7\mathrm{Li} \rightarrow {}^8\mathrm{Be}^* + {}^4\mathrm{He} + 2\mathrm{n} \rightarrow 3\cdot{}^4\mathrm{He} + 2\mathrm{n} + 6.40\ \mathrm{MeV}, \qquad (2)$$

where ^{8}Be* indicates an intermediate excited ^{8}Be nucleus.

6.3 Chemonuclear Fusion reveals Strange Rate Fluctuation and Spectra

Concerning the nuclear reaction,

$$^7\mathrm{Li} + \mathrm{D} \rightarrow {}^8\mathrm{Be}^* + \mathrm{n} \rightarrow 2\cdot{}^4\mathrm{He} + \mathrm{n} + 15.1\ \mathrm{MeV}, \qquad (3)$$

both D – Li chemonuclear fusion and D_2 – 2Li molecular chemonuclear fusion have been observed [6,7,11]. The observed reactions depend, however, super sensitively on the conditions of the liquid Li metal, in particular, on its surface resulting in remarkable fluctuations of the reaction rate.

We have experienced fluctuations in the observed rate enhancements by factors ranging from 10^8 to 10^{15} in the D_2 – 2Li chemonuclear fusion reactions. While the enhancements [10],

$$K(\mathrm{Be}) = 7\times10^{10}, \tag{4}$$

$$K(\mathrm{Be_2}) = 5\times10^{21}, \tag{5}$$

have been predicted for the D – Li and D_2 – 2Li chemonuclear fusion through the formation of quasi-Be atoms and quasi-Be_2 molecules, respectively. For these reactions, the respective Gibbs energy changes are [10],

$$\Delta G_r(\mathrm{Be}) = -0.99\mathrm{eV}, \tag{6}$$

$$\Delta G_r(\mathrm{Be_2}) \sim 2\Delta G_r(\mathrm{Be}) = -1.98\mathrm{eV}. \tag{7}$$

Taking the remarkably large numerical difference between Eqs.(4) and (5) into consideration, the observed fluctuations may be caused by the dissociation of molecular D_2^+ ions on the surface of the liquid Li. In fact some interface chemical reactions or contact catalytic reactions are suspected to induce the dissociation of D_2^+ ions on the surface under the presence of certain contaminants and inhibit the molecular chemonuclear fusion. In this case one cannot expect an enhancement of the fusion reaction over the value 10^{11}.

6.4 Observation of Nuclear Fusion Exceeding The Break Even

In 2005, the experimental apparatus was newly reconstructed for the more detailed observation of the reaction in Eq.(3). Several handling systems were introduced and/or converted to keep the metallic Li liquid surface steadily fresh. Under the implantation of D_2^+ ions of 30 keV energy at the thermal equilibrium of the Li liquid, an intense reaction was observed through the detection of α-particles of 7.56 MeV with the rate enhancement of around 10^{13}.

Sometimes the rate increased further intermittently and then, the surface barrier type Si detector (SSD) was saturated. This phenomenon was accompanied by a temperature jump of the Li liquid by over 30 ˚C far exceeding the temperature rise of 2 ˚C caused by the steady D_2^+ ion implantation. Sometimes it caused the heater power of Li temperature controlling system to be cut off. The temperature jump

was observed some ten times repeatedly and suggested ”energy generation far beyond the break even of nuclear fusion” [12].

All observations of chemonuclear fusion were so far only achieved through the detection of α-particles by using a conventional SSD system. In order to confirm the results in more detail before continuing with further developments, several additional investigations should be carried out such as, detection of produced He atoms, detection of neutrons and identification of α particles.

6.5 Confirmatory Experiment

The present experiment is concerned with the simultaneous observation of α-particles and neutrons produced in the chemonuclear fusion by using a $\Delta E - E$ detector, SSD and a neutron detector. Special attention was paid to the comparison of particle spectra for metallic Li targets in liquid – and solid – phase under the same ion implantation conditions.

Ion optical- and target systems were the same as those in the previous experiment observing the $D_2 - 2Li$ chemonuclear reaction beyond break even [11]. A stable and uniform ion beam was required because of the expected sensitivity to the Li surface temperature. For instance, a temperature rise of 100˚C above the melting point of Li (181˚C) results in a quenching of the reaction rate by as much as a factor of 10^{-4} recalling Eqs.(1) and (5) [11].

Typically a beam of 20 μA was extracted from a PIG type ion source through a slit with a hole of 1.9 mm in diameter and then led to the magnetic analyzing system of mean ion radius of 100 mm. A separated D_2^+ ion beam of a few tenths of a μA entered the target chamber and was implanted vertically on the surface of the metallic Li. The Li metal was shaped as a rod of 16 mm in diameter and 60 mm long and mounted in a cylindrical target capsule of pure alumina equipped with a piston system for lifting up the Li metal rod. A dual scraper/stirrer system ensured that a fresh target surface of metallic Li was exposed to the ion beam, always in a vacuum of a few times 10^{-7} Torr.

The $\Delta E - E$ detector, SSD and neutron detector were set on a common horizontal plane keeping lines of charged particle detectors crossed at right angles. Charged particles were identified by a $\Delta E - E$ detector consisting of a 13 μm thick Si $\Delta E -$

and a 300 μm thick Si E – detector. The detector was positioned at a distance of 55 mm from the target at an angle of 22˚, see Fig. 3, giving an effective acceptance of 0.02% of 4π str It was covered with an 0.5 μm thick Ni foil to prevent δ-rays and scattered D_2^+ ions from hitting the detector. The detector out-put pulses and spectra were monitored by comparing with those of α-particles from a calibration source of ^{241}Am (5.58 MeV α) covered with a 5 μm thick Al foil and mounted near the Li target. The SSD system used so far was preserved as a monitor counter.

Neutrons were detected by using a LiI scintillator of 15 mm in diameter and 5 mm thick covered by a moderating polyethylene case of 100 mm in diameter and 100 mm long positioned to give an effective acceptance of about 0.2% of 4π str.

In the solid phase of the Li target at room temperature, no 7.56 MeV α-particles from the reaction in Eq.(3) was observed at any energy of the D_2^+ ions by the $\Delta E - E$ detector nor by the SSD. This was consistent with the reaction rate estimation based on the intrinsic nuclear reaction probability, typically 8×10^{-20} for the D_2^+ ions of 30 keV and D^+ ions of 15 keV energy as argued in the previous paper [11].

Instead protons of 3.03 MeV from the D(d, p)T reaction were observed through the $\Delta E - E$ detector and SSD after appreciable accumulation of deuterium in the form of LiD on the target surface, as seen in Fig.2a. This implies that the D(d, n)^{3}He reaction takes place also with almost the same rate because cross-sections of both D(d, p)T and D(d, n)^{3}He reactions are about 1 mb. This was supported by neutrons observed in the neutron detector. Since the cross-section of D – D nuclear fusion is larger than the ^{7}Li(D, nα)^{4}He reaction cross-section by a factor of 10^8 for the D^+ ions of 15 keV energy [4], the non-observation of 7.56 MeV α-particles produced in the reaction, Eq.(3), could be expected.

In the liquid phase of the metallic Li target at a thermodynamically steady state, two broad peaks appeared at 7.56 MeV and at 15.1 MeV energies in the SSD spectra. The 7.56 MeV peak was clearly identified with α-particles from the reaction in Eq.(3) as can be seen in the $\Delta E - E$ spectrum in Fig.2b which was obtained at a D_2^+ ion energy of 30 keV. This identification confirmed the previous assignment based on energy loss measurements [7]. Simultaneously the neutron counter

registered neutrons at rate, above background, compatible with the rate of α-particles seen in the $\Delta E - E$ detector.

6.6 Conclusions and Outlook

The present measurements were fully compatible with all previous observations. α-particles and neutrons were produced in a way consistent with the Li – D chemonuclear fusion reaction. The $\Delta E - E$, SSD and neutron detectors have been shown to be useful as monitors of the reactions.

In the near future the studies of chemoculear fusion will concentrate on calorimetric measurements and the detection of He gas produced in the reaction.

Acknowledgements

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Figure Captions

Figure 1. Evolution of the elastic ^{7}Li – ^{7}Li atomic collision at an energy of nuclear stopping [8]

(f) Twin colliding Li atoms with an energy of nuclear stopping (relative kinetic energy E = 15 keV). At this energy a nuclear collision (Rutherford scattering) can take place but all electrons (open circles) in the K- and L-shell orbitals adjust their electronic state continuously and smoothly to the nuclear collision process, since the electons gyrate much more rapidly than the speed of the colliding atoms.

(g) Intermediate diatomic molecule Li_2 formation. In the first phase of the collision process, the twin atoms tend towards the formation of the diatomic molecule Li_2 at the minimum Gibbs energy point in the process. However this Gibbs energy is not the minimum point any longer for the atoms colliding with the energy of nuclear stopping. They are forced to form a quasi-C atom at their classical turning point.

(h) Quasi-C atom formation. At the turning point, the twin atoms form a quasi-C atom within the very short collision time of about 10^{-18} s. In the quasi-C atom, twin colliding nuclei (closed circles) are coexisting and confined at the center of a common K-shell electron orbital. However, under the presence of thermodynamic forces, or cohesion in the metallic Li liquid their collision time is prolonged by the factor K=1.4×10^{48} through which nuclear reaction rates are likely to be enhanced as argued in Section 2. If any nuclear reaction does not take place the quasi-C atom decays into two Li atoms as before.

(i) Intermediate diatomic molecule formation during the separation of atoms.

(j) Separating twin atoms.

Figure 2. $\Delta E - E$ Particle spectra observed with a D_2^+ ion beam of 30 keV and 100 nA (net acquisition time 8 hrs)

(a) Particle patterns observed in the solid phase of the Li target. The pattern located upward indicates α-particles emitted from an ^{241}Am calibration source covered with a 5μm thick Al foil. The lower pattern was identified with protons of 3.03 MeV energy produced in the D(d, p)T reaction based on the tilting angle and total energy of pattern. The reaction takes place in the LiD layer formed on the surface of the Li target. No α-particles of 7.56 MeV produced in the $^7Li(d, n\alpha)^4He$ reaction were observed because the cross-section of this reaction is much smaller than the D – D reaction cross-section by a factor of 10^{-8} at the deuteron energy of 15keV.

(b) Particle spectra observed for the liquid Li target. α-particles emitted from the ^{241}Am calibration source are shown again in the same place. The higher broad pattern indicates α-particles of 7.56 MeV energy produced in the $D_2 - 2Li$ chemonuclear fusion reaction. This data indicates that the reaction rate was enhanced by a factor of about 10^8 and implies the possible Li – D chemonuclear fusion instead of the $D_2 - 2Li$ molecular chemonuclear fusion due to some quenching effects such as the dissociation of D_2 molecules on the surface of the target.

Figure 3. The reaction chamber and the position of the $\Delta E - E$ detector are shown. The ion beam enters from above.

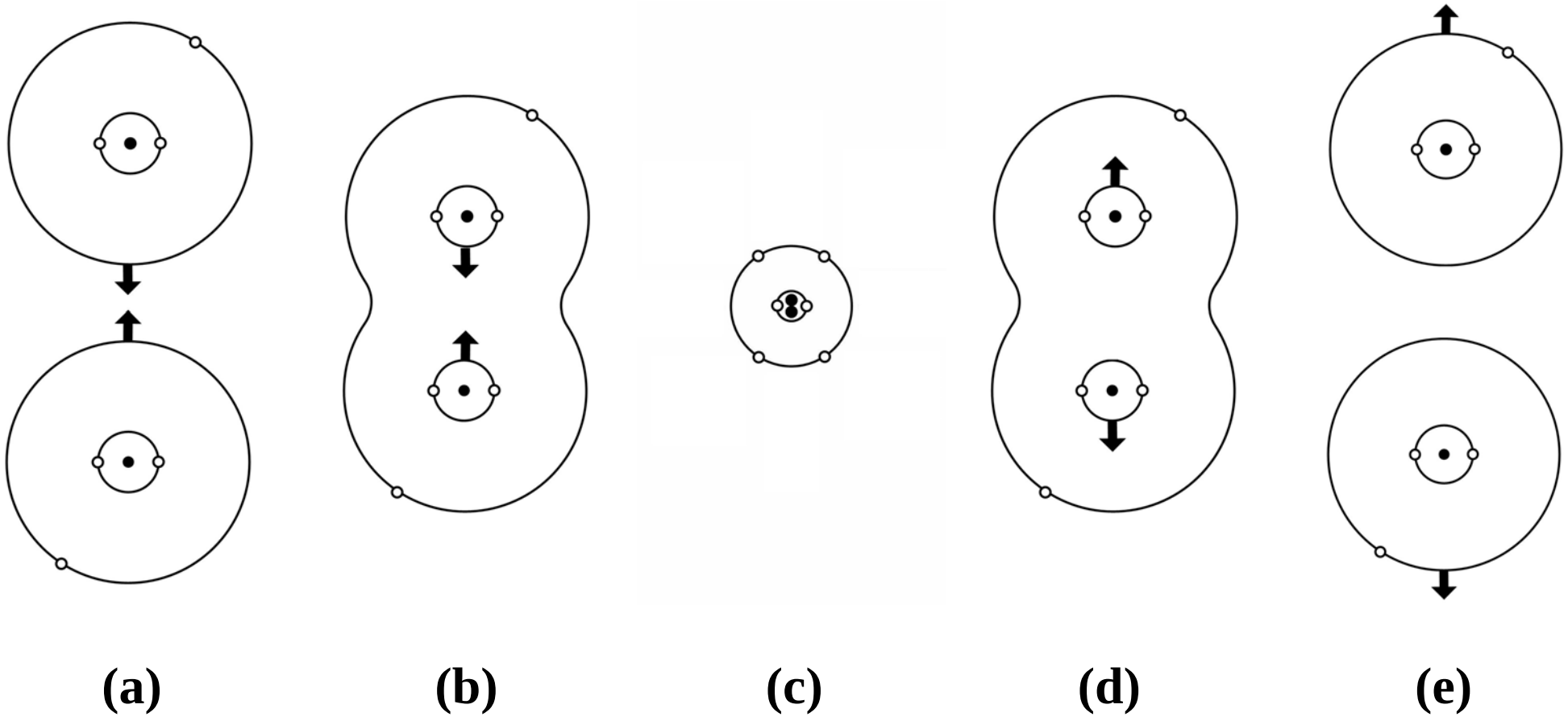

Figure 1.

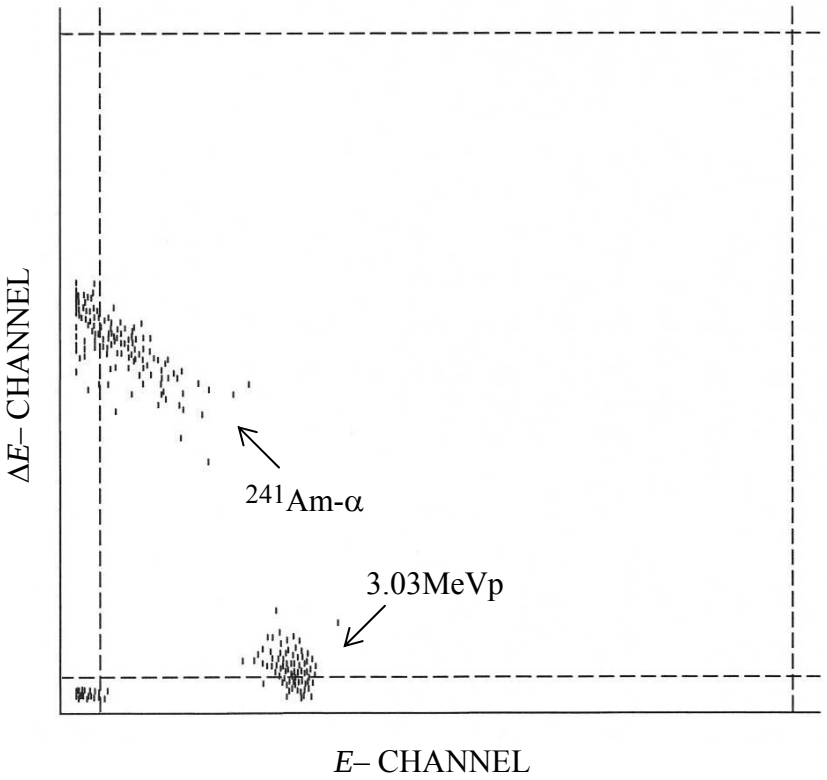

Figure 2.(a)

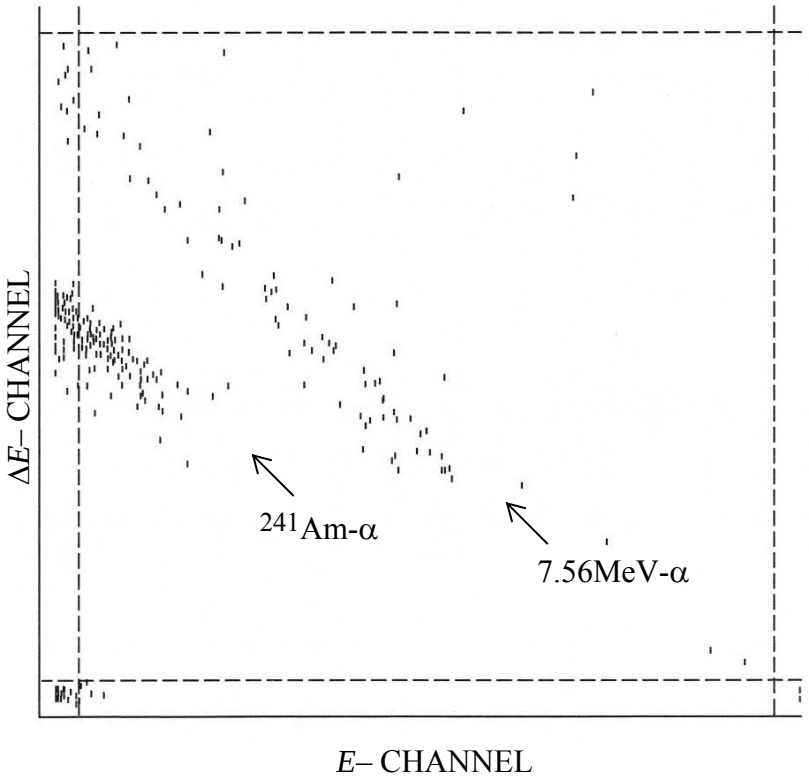

Figure 2.(b)

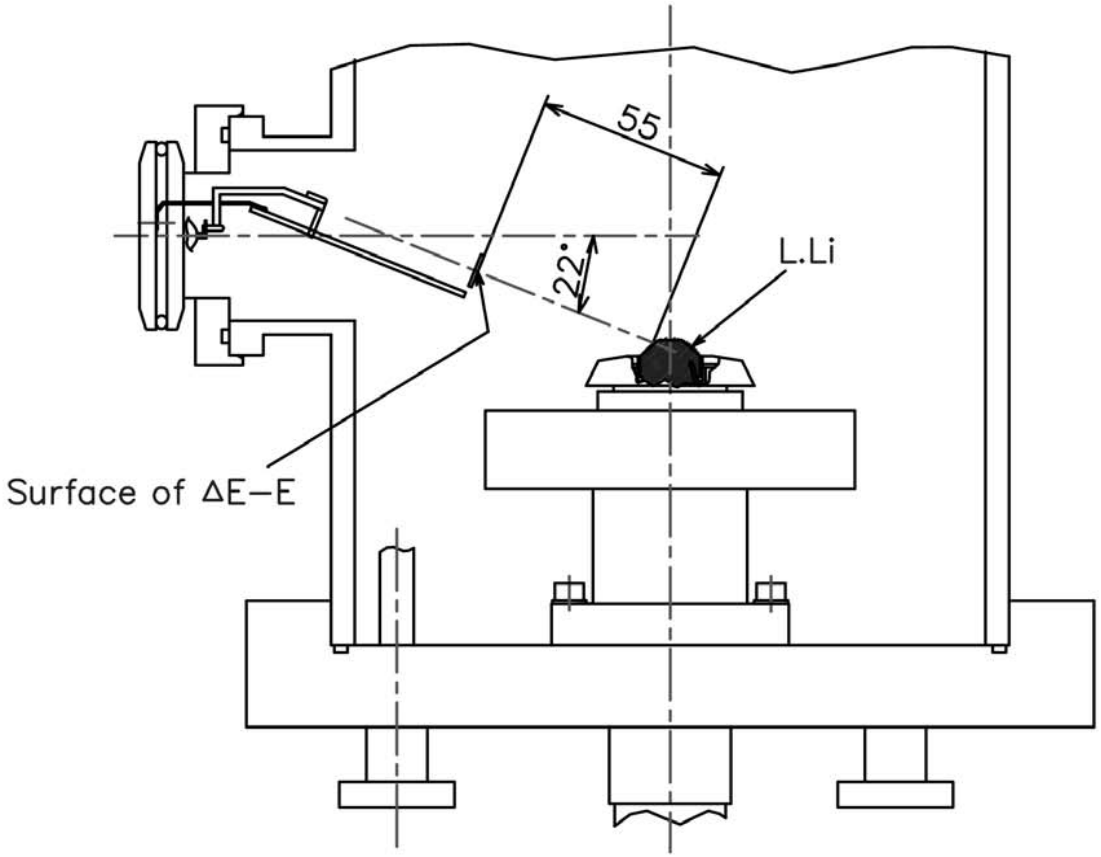

Figure 3.

7 Supporting Evidence of Chemonuclear Fusion Obtained in Kobe University Experiments (Note added in proof)

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Just before the publication of this report, a paper on experiments at Kobe University was sent to the author from the US Patent Office as a reference [1].

In the repeated experiments, Minari et al prepared a sophisticated target system generating liquid Li droplets of around 7mm in diameter in order to keep them as pure as possible. Alpha particles were observed as the products of the ^{7}Li(d,nα)^{4}He reaction with 10 – 24 keV deuterons using an SSD and some sheets of solid-state track detectors. Produced neutrons were also observed with a rem-counter. Also a $\Delta E - E$ SSD telescope was available if needed.

The observed reaction rate enhancement was, for example, 4.8×10^{7} for deuterons of $E_{\mathrm{d}} = 20$ keV energy at a liquid Li temperature of 570 K. The deuteron energy $E_{\mathrm{d}} = 20$ keV is, however, somewhat critical based on the propeties of nuclear stopping and some quenching effects are suspected on the reaction rate enhancement as argued in ref.[2]. In fact, data of Minari et al for deuterons of $E_{\mathrm{d}} = 10$ keV and 13.3 keV seem to show higher rate enhancements than the above value.

In any case, the rate enhancement by a factor of $10^{10} – 10^{15}$ observed in the Uppsala University experiments [3] could not be reproduced in the Kobe University experiments [1]. This sharp discrepancy seems to be seriously inconsistent. The puzzling problem is, however, clearly explainable as a result of different conditions of the deuterium ions based on the theory of molecular chemonuclear fusion [4] and, on the contrary, provides strong supporting evidences of both the atomic- and the molecular- chemonuclear fusion reactions.

In the Kobe University experiments mass analyzed deuterons were implanted, while in the Uppsala University experiments, unfiltered deuterium ions were implanted. They were later to be found mixed with about 40% D_2^+ ions [4]. It is thus essential to reanalyze the data of both experiments based on the refined theory of chemonuclear fusion [4].

In Eq.(31) in ref.[4], a realistic value of the Gibbs energy change, $\Delta G_r = -0.99$(eV) is presented, which is derived directly from the formation Gibbs energies G_f(Li) and G_f(Be) obtained from chemical data [5]. The above value leads to a predicted reaction rate enhancement,

$$K = \exp\left(-\frac{\Delta G_r}{k_B T}\right) \sim 6 \times 10^8 \text{ at } K = 570\text{K (Kobe)}, \quad (1)$$

$$\sim 7 \times 10^{10} \text{ at } K = 460\text{K (Uppsala)}. \quad (2)$$

For deuterons of $E_d = 20$ keV, the value in Eq.(1) may be quenched due to the deviation from the nuclear stopping [2]. Eq.(2.6) in ref.[2] predicts this quenching factor,

$$F_{link} = \exp\left(-0.623 E_d^{\frac{1}{2}}\right) = 0.062 \quad (3)$$

It results in a predicted effective value of the enhancement,

$$F_{link} \cdot K \sim 4 \times 10^7. \quad (4)$$

The agreement between the predicted value Eq.(4) and the observed value in Kobe (4.8×10^7) is excellent and provides a strong supporting evidence of the D – Li chemonuclear fusion.

Besides the evidence of the D – Li chemonuclear fusion, the Kobe University experiments provide another supporting evidence of the D_2 – 2Li molecular chemonuclear fusion by comparing with the Uppsala University experimental data. The above agreement between observed and predicted enhancements implies that one may expect an enhancement for the D_2 – 2Li molecular chemonuclear fusion of $K^2 \sim (4.8\times10^7)^2 \sim 2\times10^{15}$ at $T = 570$ K according to Eq.(20) in ref.[4]. The value corresponds to an enhancement of about 8×10^{21} at $T = 480$ K after the correction for the quenching effects, which agrees with the value $\sim10^{22}$ derived from the re-analysis of the Uppsala data taking into account the D_2^+ ion mixture [4].

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