Excess heat and Mechanism in Cold fusion reaction

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Abstract
The authors have proposed a new "Model" which can reasonably explain the existence of Cold Fusion Reaction and also verify the generation of tremendous excess energy in the DS-cathode which is fifty thousand times higher than chemical reaction energy. The new model is named "Latticequake Model". Cold fusion is caused by high energetic deuterium similar to "hot" fusion.

Key words: Latticequake; cold fusion; molecular dynamics; excess heat; DS-cathode

1. Introduction
The authors pointed out that reactions in a Double Structure cathode (DS-cathode) contained with "Pd-black" continuously generated more than 5x10^4 times of excess energy expected in chemical reactions. 1) So far many researchers have reported on the excess heat generation and the evidence on the generation of nuclear-reaction products. 3) "Cold fusion", however, has not been generally accepted due to the lack of experimental evidences on the stable and/or continuous generation of large amount of excess heat or nuclear reaction products. Furthermore, poor reproducibility of the experimental data tended to obstacle the determination of conditions for the generation of nuclear reactions. Therefore the theoretical works devoted to explain the mechanisms involved in the cold fusion have been failed because of lack in their stand points based on the experimental results with sufficient reproducibility.

In the present paper, the authors would like to propose a new "model" and to clarify the justifications on the cold fusion.

2. Characteristics of DS-Cathode
The principle of the DS-Cathode is schematically depicted in Fig. 1. In moving deuterium from the Pd region A with a deuterium concentration of [D_A^*] (≡D/Pd) to the other Pd region B, each separated by the space C, the problem to be considered here is what is the most appropriate way to get the concentration [D_B^*] in the region B as high as possible.
Here we have considered to compare the following 4 possible ways as schematically illustrated in Fig. 2. First in the case of (a) where the space C is vacuum so that the concentration in the region B becomes \( [D^*_B] = 0 \) and naturally results in the process in the case of (b). In other words, deuterium gas is diffused into the space C and the \( \text{D}_2 \) gas pressure \( P_{\text{D}_2} \) increases with time. So the concentration \( [D^*_B] \) in the region B gradually increases to follow \( [D^*_B] = a + b \log P_{\text{D}_2} \) according to the Sieverts' law. Even with hydrogen gas the condition to achieve \( [H^*_B] = 0.9 \) as shown in Fig. 2 requires the hydrogen pressure higher than at least ten thousand [atm], and approximately 30 times higher pressure is believed to be required to satisfy this condition with deuterium gas. Therefore, as far as experiments performed in the territory of the Sieverts' law, where the high pressure regime is preferred, as has been experienced by many researchers, it is impossible to realize a high concentration of deuterium. Accordingly, they should need a major break-through to get out of this law. Based on these facts, as has been presented by many reports, it should be absolutely unlike to observe the reaction products \( (\text{He}, \text{T}, \text{P}, \text{In} \text{ etc.}) \) and/or the excess heat (excluding the heat caused by the chemical reactions) in the pressure range as low as 1 [atm] during the period of time as short as several days.

The authors have ever pointed out the importance of "micro-defects" to the mechanism of cold fusion. Looking from the bulk material, surfaces are considered to be a kind of the defect. Therefore, it is expected to increase the effects of the surface micro defects with increasing surface area or "relative surface" \( S^* \) (= surface area / volume). One extreme state to realize this idea would be powders, which can be considered to be a key factor for the practical development of the cold fusion in future.

Forty years ago when one of the authors hit upon an idea of "Solid-state plasma fusion", he did not believe that the fusion reactions were obtainable only with electrolysis as are presented later by Fleischmann and others. As in the "hot plasma fusion", one of the absolute conditions for the solid-state plasma fusion was believed to be the high-energy state of the deuterium ions confined in the Pd lattice with external shock-energy supply. This idea has raised questions on the Fleischmann's results, however, the recognition of these facts has lead to the "powder vessel" as one of the best vessels based on the above considerations of the characteristics of powders.

The authors immediately started the examination of the Fleischmanns' experiments using the following two ways with Pd powders. One was the way to use powders as a cathode and the other was performed with Pd cathodes spray-coated with Pd powders onto the surface. The former method (not published yet) resulted in a number of troubles, where we examined the characteristics of the powders. As a result, the principal condition for the cold fusion was concluded to be that "surface effect" inherent to the powders enables the homogeneous and highly concentrated deuterization and the feasibility of large cathode without any
limitation on size.

Thereafter, significant effects are not expected in the ordinary surfaces on the plate- and/or the rod-configurations with small $S^g$ due to the less chemical reactivity. With powders, on the other hand, $S^g$ considerably and thus the reactivity abruptly increases with decreasing powders size and causes "spill over effect".\textsuperscript{5) This causes the powders to function the "Pumping-up action" as shown in Fig. 1 and the powders continuously absorb deuterium up to $|D^g|=1$. Especially, it is well known that $|D^g|=1$ should instantaneously be achieved in the "cluster" (< 100 Å in diameter).\textsuperscript{9) Consequently, characteristics of the deuterium absorption and its variation with pressure are greatly dependent on $S^g$ as shown in Fig. 3.

Fig. 4 shows the recent experimental data on the excess-heat generation. These results show that the new "model" for the cold fusion is requested to describe the possibility of the continuous energy generation over 10 [Watt/cm$^3$].

3. Proposal of the New "Latticequake Model" for Cold Fusion

One of the fundamentally important problems involved in the cold fusion is that the deuterium is in the ionic state in the Pd lattice and their motions are strongly limited by the intense constraint force by the Pd lattice, which is completely different from the physical situations in the "Hot" plasma fusion. This means that the position, the direction and the conditions for the fusion reactions are considerably limited, and thus the reaction process is considered to undergo different mechanism from that expected in the hot fusion. Therefore the theoretical approach for the cold fusion is required first to consider the wave function of the O-site (Octahedron), which is the stable site for deuterium, by assuming that the all of deuterium are confined in this site, and second to obtain the probable distribution to find the deuterium from the O-site to the T-site (Tetrahedron) surrounded by the several O-site. Here when we assume that the achievement of the fusion reactions by putting plural deuterium ions to interatomic distances of about 0.1 Å is explicitly driven by only thermal energy, the Pd lattice may explode out. This consideration has lead to a conclusion that the cold fusion is impossible.

However, as indicated in Fig 4 or similar data repeatedly, excess energy of 10 [W/cm$^3$] is continuously generated and obtained large energy around 100 [MJ] by the use of DS-cathode developed by the authors. The energy is extremely larger when compared to chemical reaction, therefore, no reaction except cold fusion exists. The authors proposed a new model that enables the generation of "CP-CF"(Continuous Powerful Cold Fusion).

Now, as well known, when the motion of atom in lattice exceeds Wigner energy, $\epsilon_w$, the violent vibration is induced in the lattice as schematically shown in Fig. 5. The authors named the phenomena as "Latticequake". Suppose that the reaction occurred one time, as indicated in Appendix, the reaction products with high energy is certainly produced from the well-known two-body collision of deuterium (Rutherford type: [A-type]) to unknown two-body or multi-body collision [B-type]. Therefore, for the sake of simplicity, the reaction products is represented as $^2\text{He}$, and supposing its energy $\epsilon_{\text{He}}=1\sim20$ [MeV].
The necessary energy to generate "CP-CF", i.e., Latticequake is obtained by the collision of \(^{4}\text{He}\) against the atom on Pd lattice that transfers higher-energy to the atom. Then, the energy transfer from high energy \(^{4}\text{He}\) to "cold-Pd atom" is described.

When the \(A_0\) atom in Fig.5(A) moves toward \(A_0(\text{O}_1)\) or \(\text{O}_3\) (Center of O-site) along \(X_1\)-\(X_2\) (\(<100>\)) axis, the neighboring atoms shift to \(B_0 \rightarrow B_1, D_0 \rightarrow D_1, E_0 \rightarrow E_1\) or \(C_0 \rightarrow C_1, F_0 \rightarrow F_1, G_0 \rightarrow G_1\). If the energy of \(A_0\) atom is larger than Wigner energy, \(\varepsilon_{\text{w}}\). \(A_0\) atom jumps over \(A_1\) or \(C_1\) and moves following direction; \(A_0 \rightarrow A_1 \rightarrow B_0 \rightarrow \cdots \), or \(C_0 \rightarrow C_1 \rightarrow \cdots\), and the neighboring atoms quickly return to the original position. Such behavior of \(A_0\) atom induces the collision of neighboring many atoms, and generate the multi collision phenomena, therefore, the outline could be grasped by "molecular-dynamics". For example, as described above, the following energy for \(^{4}\text{He}\) is supposed.

\[
\varepsilon_{\text{He}} = 1 \sim 20 \text{ [MeV]} \tag{1}
\]

The following energy is assumed as a mean value.

\[
<\varepsilon_{\text{He}} > = 3 \text{ [MeV]} \approx 5 \times 10^{-13} \text{ [J]} \tag{2}
\]

As well known, when a particle with mass of \(m\) having energy \(<\varepsilon_{\text{m}}>\) collides head-on against a static particle with mass of \(M\), energy \(<\varepsilon_{\text{M}}>\) of particle \(M\) is expressed as the following.

\[
<\varepsilon_{\text{M}}>=<\varepsilon_{\text{m}}> \left[ \frac{4mnM}{(m + M)^2} \right] \quad \left[ \approx 4 \left(\frac{m\text{/}M}\right)<\varepsilon_{\text{m}}>; (M \gg m) \tag{3}\right]
\]

Supposing that \(m=\text{He}, M=\text{Pd},\) one collision gives about 15\% of energy to Pd and \(\text{He}\) itself is rebounded with 85\% of energy, the reaction occurs at \(\text{O}_3\)-site, if \(\text{He}\) with \(<\varepsilon_{\text{He}} >\) collides head-on against \(A_0\) atom of Pd along \(X_1\)-\(X_2\) axis, \(\text{He}\) atom is rebounded and then goes back and forth several times giving almost \(<\varepsilon_{\text{He}} >\) to \(A_0\) and \(\text{C}_0\) atom, and the atoms are emitted toward \(A_0 \rightarrow A_1 \rightarrow B_0\) or \(C_0 \rightarrow C_1\) respectively with \(<\varepsilon_{\text{He}}>/2\) along \(X_1\)-\(X_2\) axis direction. These \(A_0\), \(A_1\), and \(C_0\) atoms give violent vibration on lattice as seismic atom ("S-atom") thus generate "Latticequake". This Latticequake severely crushes the O-site(include deuterium) along \(X_1\)-\(X_2\) axis, simultaneously expands the O-site along \(Y\) and \(Z\) axis, the maximum expansion is as follows; \(a_0a_0 \rightarrow a_1a_1\) and \(b_0b_0 \rightarrow b_1b_1\). By this expansion both O-site and T-site simultaneously expand and integrates each other forming a cavern more than ten times larger than normal O-site, this a cavern is called "Lattice Hall". If the lattice contains 100\% deuterium \((D^z=1)\), "Lattice Hall" accommodate around 10 deuterons. Such "Lattice Hall" can shrinks rapidly to normal O-site size around \(10^{12}\) s, and severely compress the deuterium clusters with the density of deuterium over 10 times high than its solid one that makes possible.
for the achievement of cold fusion. The phenomena is similar to "Laser implosion". Therefore the phenomena could be called as "Lattice implosion". The necessary condition for the achievement of "CP-CF" by this Lattice implosion is \( D^* \geq 1 \).

Then, Latticequake moves with "S-atom". The energy of \( < \varepsilon > \approx 20 \sim 30 \text{[eV]} \) (Wigner energy in metals) should be consumed by every movement of S-atom from \( A_0 \) to \( B_0 \). Generally, the movement distance \( a^* \), movement frequency \( n^* \), traveling length \( l^* \) and \( < \varepsilon_w > \) are different according to the movement direction of "S-atom". However, In the case of ideal "Latticequake" due to the "S-atom" with the energy \( < \varepsilon_s > \):

\[
n^* = \frac{< \varepsilon_s >}{< \varepsilon_w >}, \quad l^* = (n^* + 1) a^* \quad \text{[4]}
\]

When the historically evaluated result obtained by Vineyard, et al.\(^6\) as shown in Fig. 5(B) is used, \( n^* = 2 \) and \( l^* = 12 \text{[Å]} \) are determined by giving \( < \varepsilon_s > = 40 \text{[eV]}, < \varepsilon_w > = 20 \text{[eV]} \) in the \{100\} plane and \( <100> \) direction. This is an example when the zone of ideal "Latticequake" is almost equivalent to the distance of Frenkel pair.

On the other hand, in the case of Pd in the \{100\} and \( <100> \), when the ideal "Latticequake" due to the "S-atom" with the high energy \( < \varepsilon_s > (= < \varepsilon_{1\text{keV}} > / 2) \) is considered according to the \[2\], \[3\] and \[4\] equations,

\[
n^* = 5 \times 10^4, \quad l^* = 2 \times 10^{-3} \text{[cm]} (= 20 \text{[μm]}) \quad \text{[5]}
\]

In the case, \( < \varepsilon_w > = 30 \text{[eV]} \) was used. In reality, however, a number of cases require \( 60 \sim 80 \text{[eV]} \).

The above description is an example concerning the behavior of an ideal "Latticequake" due to "S-atom" generated under the ideal conditions. It should be quite important in understanding the "limitation" of practical phenomenon, knowing the events under such ideal enviroments.

As shown in Fig. 5(B), in general, a motion of "S-atom", \( A_0' \), is off from an ideal direction as the \( <100> \) direction. This indicates the movement of atoms in the (100) plane obtained on the basis of "molecular dynamics" by Vineyard.\(^6\) when a "S-atom" is shot out at an angle of \( 15^\circ \) off Y axis \( (\angle 100) \). As understood from this figure, the "S-atom" with the energy more than the Wigner energy produces a "Frenkel pair" and "focussion" etc. in Pd Lattice. That is to say, the \( <100> \) and \( <110> \) direction are "focussion channels" for the Pd lattice and are regarded as "reaction roads" for deuteriums. Such reaction roads appear at certain points in any collision in the case of "S-atoms" of ultra-high energy. A "S-atom" of high energy should generally induce an intense cascade phenomenon which produces \( 100 \sim 1000 \) Frenkel pairs instantaneously by chain avalanche collision.\(^7\),\(^8\)

Now let's consider neutron energies generated by the D-D reaction due to hot plasma fusion by way of example. The neutron energies generated by the primary
reaction, $^1^2D(d,n)_2^3He$ and the secondary reaction, $^1^2D(t,n)_2^4H$ are defined as

\[
<\varepsilon_{N1}> <\varepsilon_{N2}>,
\]

respectively, and they are:

\[
<\varepsilon_{N1}>= 2.45 \text{ [MeV]}, \quad <\varepsilon_{N2}>= 14 \text{ [MeV]}
\]

[6]

In both cases, "S-atoms" with high energy can be produced. In the case of $<\varepsilon_{N2}>$, the energy $<\varepsilon_{s}>$ of "S-atoms" is reported to reach 2 [MeV] at maximum (and 0.3 [MeV] on the average). Therefore, such S-atom can supply an energy $<\varepsilon_{D}>$ of approximately 40 [keV] (6 [keV]: average) to deuteriums. Moreover, such high energy "S-atom" would generally induce 10 to 20 sub-cascades, which consists of "vacancy clusters" with a concentration of vacancies 20~30[%,7,8] In the case of Frenkel pair even when only one vacancy is produced, "Latticequake" is induced at the surrounding atoms clustered between a vacancy and internal atom in a Frenkel pair. Consequently, high concentration of deuterons are included in the intense cascade and much high energy levels are achieved there, leading to more opportunities of the D-D reaction. It is taken for granted that more defects should cause an intense shake more frequently and the D-D chain reaction would take place more easily.

The above descriptions are summarized in Fig. 6. In short, at the condition of the deuterium concentration $[D^*] \geq 1$, only if one 'S-atom" is generated, the energy induces the "Latticequake", which acts as two functions. One is that it crushes "O-site". Thereby "Latticequake" hits the deuterium out of the O-site and supplies the deuterium with the high energy $<\varepsilon_{D}>$ as a "Lattice-accelerator". "S-atom" with an energy of 1 [MeV] produces deuterium with an energy of 20 [keV]. The other function of the "Latticequake" is that it makes a cavern, "Lattice-Hall", over 10 times wider than normal O-site by combining with many O-sites and T-sites. Instantly the "Lattice-Hall" accommodates deuterons, it shrinks for an extreme short time of about $10^{-12}$ [s] and thereby the "Latticequake" accelerates the deuterons toward the center of the "Lattice-Hall" as a "lattice accelerator". This enables the deuterons to be concentrated to the degree of 10 times more than its solid state and achieved nuclear fusion reaction. It seems that this phenomenon in cold fusion is similar to the "Laser implosion" in hot fusion, and we name it "Lattice implosion".

The basic differences between the cold fusion and hot fusion, are summarized in Fig. 7. In cold fusion, deuterons are strongly confined by lattice field and, by "Latticequake", can attain the kinetic temperature of several million in spite of low lattice temperature. On the other hand, in hot fusion, the deuterium plasma confined by strong magnetic field is heated by high energy electrons in general. Thus, the lattice atoms play the crucial role in cold fusion, while the electrons in hot fusion. Therefore, in order to maintain the chain avalanche reaction stably for each nuclear fusion, the fundamental conditions are $[D^*] \geq 1$ for cold fusion and "stability" for hot fusion. Both fusions require a similar "High Energetic Deuterons" in order to induce nuclear fusion reaction.
Appendix I : [A-type]. Rutherford fusion reaction.

\( ^1_2 D + ^1_2 D \rightarrow ^2_3 \text{He} + ^2_1 \text{He} \) (3.27 [MeV]) \( ^1_3 \text{T} + ^1_1 \text{P} \) (4.03 [MeV])

When this reaction is continued, \( ^1_2 D (^1_3 \text{T}, _0^1 \text{n})^2_4 \text{He} \) and \( ^1_2 D (^2_3 \text{He}, _1^1 \text{P})^2_4 \text{He} \) are set as a second reaction.

\( \therefore 6,^1_2 D \rightarrow ^2_4 \text{He} (7.1) + 2,^1_1 \text{P} (17.7) + 2,^1_0 \text{n} (16.55) + (1.8) \)

Assuming that the energy of only charged particles transforms to the lattice, where the energy \( \epsilon_D \) for the extinction of one deuterium is produced in lattice

\( \epsilon_D \approx 4 \text{ [MeV]} (=6.6 \times 10^{-13} \text{ [J]} ) \) (2)

total energy \( \epsilon_{cc} \) in Pd lattice of \( 1 \text{ [cm}^3 \text{]} \) volume with \( [D^4] = 1 \),

\( \eta_{D0} = 7 \times 10^{22} \text{ [atoms/cm}^3 \text{]} \)

\( \epsilon_{cc} \approx \eta_{D0} \epsilon_D \approx 4.6 \times 10^3 \text{ [MJ/cm}^3 \text{]} \) (3)

Appendix II : [B-type]. Unknown fusion reaction.

Assuming that the simplest reaction of unknown fusion is

\( ^1_2 D + ^1_2 D \rightarrow ^1_4 \text{He} + 23.4 \text{ [MeJ]} \)

\( \therefore \epsilon_D \approx 12 \text{ [MeV]} (=1.9 \times 10^{-18} \text{ [MJ]} ) \) (4)

\( \epsilon_{cc} \approx 1.4 \approx 1.4 \times 10^3 \text{ [MJ/cm}^3 \text{]} \) (5)

Note:
Since total energy in authors experimental data was \( \epsilon_{cc} > 100 \text{ [MJ/cm}^3 \text{]} \), it is compared with (3) and (5) equations

\( \epsilon_{cc}/\epsilon_{cc}^* \approx 500 \text{ for } [A \text{ type}] \) \( \approx 1500 \text{ for } [B \text{ type}] \)

This means that authors data correspond to extinguish one deuterium among 1000 (\( \sim 100 \)) ones.

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References
2. Proceedings of the Third and Fourth International Conf. on Cold fusion, ICCF3 and 4.
Fig. 1 Schematic diagram for deuterium movement from A to B, which is separated by C-space

Note A: Difference between Vacuum, Gas, Solid and Powder for deuterium movement

Note B: Illustration of "pumping-up action" (Spillover-effect) of fine powder, where \( a_0(C_0), a_1(C_1) \) and \( a_2, a_3, \ldots (C_2) \) are Deuterium Concentration Curve in outer (and inner) Cathode respectively.

Fig. 2 Plot of "P-C-T" relationship at high concentration and pressure after many researchers \( [H^*] = \frac{H}{P} = a + b \log P + 2 \) and \([D^*]\) requires the pressure around 30 times higher than \([H^*]\).
Fig. 3 Relationship between $P_c$ and $\tau$ (where $\tau$ is the incubation period) for a long period.

Fig. 3 Relationship between powder and incubation period $\tau$, relative surface $S^*$ and surface area ($S_5$ and $S_{12}$). $S_5$ and $S_{12}$ are Pd 5 [g] and 12 [g] ($\rho$ : Pd density), respectively. In general,

$$S^* = \frac{\rho}{M_n} S_n \quad (n = 1, 2, 3, 4, \ldots, 12 \ldots) \quad \therefore S^* = S_{12}, \quad (\rho = M_{12} \div 12 \text{[g]})$$

where, surface, $S_n$ [cm$^2$] and mass, $M_n$ [g]. $n = 1, 2, \ldots$.
Fig. 4 Excess heat characteristics of two examples for long period. (upper side: Pd 5 [gr], low side: Pd 3 [gr] and excess heat $Q_{\text{ex}} = \text{output-input, [KJ/hr]}$; $10 \text{ [watt]} = 36 \text{ [KJ/hr]}$)
Fig 5 [B] Demonstration of high energy deuterons which were accelerated by "Latticequake" in \( \{100\} \) of Pd-lattice

Pd-atom: \( A_0 \), S-atom: start, end: stillness

Deuteron: intense, medium, stillness
Chain reaction

1[MeV] → "Cold fusion"

"S-atom" Latticequake

Lattice Hall

"O-site" crushing

Lattice accelerator

\[ \langle \varepsilon_{\text{gy}} \rangle = \frac{m_0}{M_s} \langle \varepsilon_{\text{gy}} \rangle \]

Intense Shock Wave

Rapid shrinkage

(\( \rho \sim 10^{-15} \) [s])

Energetic deuterons and electrons \( \gg 100 \) [eV]

Lattice implosion

"Hot fusion"

"Reference"

Gigantic Laser Beams

(\( \rho \sim (10^{-10}) \rho_0 \), (\( \tau \sim 10^{-14} \) [s])

Lattice Hall

Latticequake

Fig. 6 Schematic diagram of "Latticequake Model" for Cold fusion reaction

Fig. 7 Relation between Cold fusion and Hot fusion