Deuterons-to-$^4\text{He}$ Channels

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Major criteria of theoretically modeling the process of “radiation-less excess heat with $^4$He ash” as condensed matter nuclear effects (CMNE) are:

A) How can the mutual Coulombic repulsion between deuterons be overcome, so as to reach at significant level of deuteron-related fusion rates?

B) How can $^4$He generation channel be predominant?

C) How can hard radiations be suppressed?

D) What kinds of environments in/on condensed matter are incubating CMNE?
Outline

• Two-Body d + d fusion and Out-Going Channels

• Third Interaction to d + d strong force for Changing Out-Going Channels

• D-Cluster Fusion to Produce $^4$He
Major Experiments
(green; after 2001)

1) Excess Heat with He-4
   Miles, Arata, McKubre, Gozzi, Isobe, de Ninno,
   Celani, El Boher, and so on

2) Cold Transmutations
   Iwamura, Mizuno, Miley, Ohmori, Celani, Karabut,
   Szpak, and so on

3) Weak Neutron Emission
   Jones, Takahashi, Mizuno and so on

4) Anomalous DD Enhancement
   Kitamura, Kasagi, Takahashi, Huke and so on
[Essential Conclusions of Recent Studies] :

① Clean Fusion Phenomena producing $^4$He ash and energy

② Occurrence of Cold Transmutation and Fission

③ Consistent Theoretical Models for Condensed Matter Nuclear Effects
Three Steps in Nuclear Reaction

1. Initial State Interaction
2. (Virtual) Compound State
3. Final State Interaction
Level scheme of He-4
\[ d + d \rightarrow ^4\text{He}^*(23.8\text{MeV}) \rightarrow \text{Break-up} \]

- **Branching Ratio:**
  \[ S_n(0)/S_p(0)/S_g(0) = \Gamma_n/\Gamma_p/\Gamma_g = 0.5/0.5/0.0000001 \]

- \( \Gamma_n = \Gamma_p = 0.2 \text{ MeV} \)
- \( \Gamma_g = 0.04 \text{ eV} \)
- \( \Gamma_t = \Gamma_n + \Gamma_p + \Gamma_g \)

- \( \tau = h/\Gamma_t = 1E^{-22} \text{ s} \)

- No forces to change BRs have ever been proposed!
$d + d + E_k = {^4}\text{He}^*(E_x) = {^4}\text{He}^*(Q + E_k)$

- Broad Resonance
  \[ E_x = Q + 1.5\text{MeV} \]
  \[ E_x = Q + 0.025\text{eV} : \text{CF?} \]

- No negative $E_k$!
  : reverse kinetic reaction is forbidden

$Q = 23.8\text{ MeV}$

Schwinger-Preparata P-wave State?
\[ d + d \rightarrow {}^4\text{He}^*(23.8\text{MeV}) \rightarrow \text{Break-up} \]

- Branching Ratio: 
  \[ S_n(0)/S_p(0)/S_g(0) = \frac{\Gamma_n}{\Gamma_p/\Gamma_g} = 0.5/0.5/0.0000001 \]
  for \( E_k = 0 \) to 200 keV

- \( \Gamma_n = \Gamma_p = 0.2 \text{ MeV} \)
- \( \Gamma_g = 0.04 \text{ eV} \)
- \( \Gamma_t = \Gamma_n + \Gamma_p + \Gamma_g \)
- \( T = \frac{h}{\Gamma_t} = 1E^{-22} \text{ s} \)
- \( T_{\gamma} = \frac{h}{\Gamma_g} = 1E^{-15} \text{ s} \)
Summary of d+d fusion

• Life Time of Virtual Compound State $^4$He* is too short, $\sim 10^{-22}$ s, to change final state interaction (Branching Ratios) by External Field.

• No lower excited state than n- and p-emission channels is possible, due to non-existence of negative kinetic energy.

• $[n]/[t]/[\gamma] = 0.5/0.5/10^{-7}$ for $E_d = 0.025\text{eV}$ to $0.1\text{ MeV}$; almost constant branching ratios.
Third Interaction to d+d fusion

- To change Final State Interaction of d+d process for producing $^4\text{He}$, we need some **Third Interaction Field during Initial State Interaction**.

- As External Interaction Fields, we have in principle;
  1. Gravity,
  2. Weak Interaction,
  3. Electro-Magnetic Interaction
  4. Strong Interaction
Scaling of PEF (Pion Exchange Force) for Nuclear Fusion

Two Body Interaction: \( \text{PEF} = 1 \)

\[ n + \pi \rightarrow p \]

\( (\text{udd}) (\text{ud}^*) (\text{uud}) \) : \( u \); up quark

\( p + \pi \rightarrow n \) : \( d \); down quark

\( (\text{uud}) (u^*d) (\text{udd}) \) : \( u^* \); anti-up quark

\( d^* \); anti-down quark

For D + D Fusion; \( \text{PEF} = 2 \)

What External Force?

We need additional force in the initial state interaction, to change final state Branching Ratio and Products.
Fusion Rate for Collision Process
- dynamic or transient process -

- \( T = \langle \Psi_f | H_{\text{int}} | \Psi_i \rangle \)
  - \( \langle \text{Initial State Interaction} \rangle \times \langle \text{Intermediate Compound State} \rangle \times \langle \text{Final State Interaction} \rangle \)

- **Cross Section** \( \sim T^2 \rho(E') \)
- \( \rho(E') \): final state density
- **Reaction-Rate** \( (4\pi^2/h)vT^2 \rho(E') \)
- \( \langle \text{Initial} \rangle = \langle \text{El. EM Int} \rangle \langle \text{Strong Int} \rangle \)
- \( \langle \text{Final} \rangle = \text{BRs to Irreversible Decays} \)
Relative Strength of Interactions

Comment by A.T.

- Nuclear Strong Interaction: $f^2/hc = 1$
- Electromagnetic Interaction: $e^2/hc = 7.3 \times 10^{-3}$
- Weak Nuclear Interaction: $(g\hbar c)^2(mc/h)^4 = 5 \times 10^{-14}$
- Gravity: $Gm^2/hc = 2 \times 10^{-39}$

- $S_{dd} = 1.1 \times 10^2$ keVb vs. $S_{pp} = 1 \times 10^{-22}$ keVb
  
  (Strong Interaction) (Weak Interaction)

$\sigma \sim (T\text{-matrix})^2$
Third Interaction by Photon/Phonon

• About 4 MeV from close $<d-d>$ pair should be removed by multiple $<d-d>/P/P$ coupled channels. $<d-d>$: out of strong force range!

• Photon energy quantum should be less than D displacement energy in lattice (about 40 eV): we need more than $10^5$ photon-coupled channels.

• $<d-d>$ Life Time should be greater than $3\text{nm} \times (3 \times 10^{-18} \text{s}) \times 10^5 = 9 \times 10^{-13} \text{s} \sim 1 \text{ ps}$
Third Interaction by Photon/Phonon

- The many-body interaction process between the d+d pairing and the third field of photon-phonon coupling (more than $10^5$ channels) in the lattice of condensed matter may be considered.

- Due to the very short range force of d+d strong interaction and its very short life time of virtual intermediate compound state, no processes have ever been proved to remove the 4 MeV gap energy. (Avoid single photon transition from $^4\text{He}^*$ -P-wave!)

- Moreover, the field coupling constant of electromagnetic interaction looks too weak, on the order of $10^{-2}$ of that for the strong interaction, to drastically change the state of d+d strong interaction for fusion. Quantitative studies on transition probabilities will be needed.
Deuteron-Cluster Fusion

- Third (plus 4\textsuperscript{th}) Field by Strong Interaction requires D-Cluster Fusion under Ordering Process.

- 4D Fusion by TSC (Tetrahedral Symmetric Condensate) is proposed by Takahashi.
Basic Mechanism (Takahashi Model)

- **Tetrahedral Symmetric Condensate (TSC):**
  4d+4e can squeeze to Transient Bose Condensation (TBC), under 3-Dimensional Symmetric Constraint at some site in CM, to form a very small Charge-Neutral Pseudo-Particle
1) TSC forms

2) Minimum TSC

3) $^8\text{Be}^*$ formation

4) Break up
TSC Condensation Motion calculated by TSC-Langevin Code

TSC Step2 Averaged $\langle f(t) \rangle$ (2,2)

$E_d = 13.68$ keV at $R_{dd} = 24.97$ fm, with $V_{trap} = -130.4$ keV
Fusion Rates of Steady State dde* Molecules:

\[ \lambda_{nd} = \frac{2}{\hbar} \langle W \rangle P_{nd}(r_0) = 3.04 \times 10^{21} P_{nd}(r_0) \langle W \rangle \]

Regarding \( b_0 \) as \( R_{gs} \), we get \( P_{nd}(r_0) \) values.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>( R_{dd} = R_{gs} ) (pm)</th>
<th>( P_{nd}(r_0) ) ; Barrier-Factor</th>
<th>( \langle W \rangle ) (MeV)</th>
<th>( \lambda_{2d} ) (f/s)</th>
<th>( \lambda_{4d} ) (f/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D_2 ) dde*(2,2)</td>
<td>74.1</td>
<td>1.0E-85</td>
<td>0.008</td>
<td>2.4E-66</td>
<td>3.2E-27</td>
</tr>
<tr>
<td>( \mu dd )</td>
<td>21.8</td>
<td>1.3E-46</td>
<td>0.008</td>
<td>3.2E-27</td>
<td>2.4E+10</td>
</tr>
<tr>
<td>4D/TSC-min</td>
<td>0.805</td>
<td>1.0E-9</td>
<td>0.008</td>
<td>2.4E+10</td>
<td>3.7E+20</td>
</tr>
<tr>
<td></td>
<td>0.021</td>
<td>1.9E-3</td>
<td>62</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4D/TSC-min exists within \( \Delta t = 2 \times 10^{-20} \) s at final stage of condensation:

Decay of TSC: \( \exp(-\lambda_{4d}\Delta t) = \exp(-7.6) = 0.0006 \rightarrow 4D \text{ fusion by 100\% per TSC Gen.} \)
4D Fusion and \(^4\)He Production Rate by TSC

- \(t_c\): Condensation Time of TSC (1.4007 fs)
- \(\eta_{4d}\): 4D Fusion Yield per TSC

\[
\eta_{4d} = 1 - \exp\left(-\int_0^{t_c} \lambda_{4d}(t)\,dt\right)
\]

\[
\lambda_{4d}(t) = 3.04 \times 10^{21} \langle W \rangle P_{4d}(r_0; R_{dd}(t)) = 1.88 \times 10^{23} P_{4d}(r_0; R_{dd}(t))
\]

\[
\int_0^{t_c} \lambda_{4d}(t)\,dt = 1.88 \times 10^{23} \int_0^{t_c} P_{4d}(r_0; R_{dd}(t))\,dt
\]

\[
Y_{4d} = Q_{tsc} \eta_{4d}
\]

\(Y_{4d} \approx Q_{tsc}\)  
\(Q_{tsc}\): TSC Generation Rate
Energy Level Scheme of Be-8
$4D \rightarrow ^4\text{He} + ^4\text{He} + 47.6\text{MeV}$

(Final State Interaction)

$^4\text{He} + ^4\text{He}$

$4d (47.6 \text{ MeV})$

$^4\text{He} + ^4\text{He}$

11.4 MeV 4+

3.04 MeV 2+

$^8\text{Be g.s.}$

$-0.0917 \text{ MeV}$

Life time : $6.7\text{E}-17 \text{ s}$

Two alpha-clusters

Transient Cube

Transition to Two regular Tetrahedrons
Decay-Channel of $^8\text{Be}$

$^8\text{Be}$

$^{4}\text{He} + ^4\text{He} + 91.86\ \text{keV}$: Major Ch.

$^{3}\text{He} + ^5\text{He}(n+^4\text{He}) - 11.13\ \text{MeV}$

$t + ^5\text{Li}(p+^4\text{He}) - 21.68\ \text{MeV}$

$d + ^6\text{Li} - 22.28\ \text{MeV}$

$p + ^7\text{Li} - 17.26\ \text{MeV}$

$n + ^7\text{Be} - 18.90\ \text{MeV}$

$^8\text{Be}$ Excited State may open to threshold reactions
Branching Ratio
(Final State Interaction)

\[
\begin{align*}
\text{4He} + \text{4He} & \rightarrow \text{4d (47.6 MeV)} \\
\text{4He} + \text{4He} & \rightarrow \text{11.4 MeV 4+} \\
\text{4He} + \text{4He} & \rightarrow \text{3.04 MeV 2+} \\
\text{4He} + \text{4He} & \rightarrow \text{8Be g.s.} \\
\text{4He} + \text{4He} & \rightarrow \text{-0.0917 MeV}
\end{align*}
\]

\[
\begin{align*}
\text{4He} + \text{4He} + \text{4He} & \rightarrow \text{6d (71.4 MeV)} \\
\text{4He} + \text{4He} + \text{4He} & \rightarrow \text{9.64 MeV 3-} \\
\text{4He} + \text{4He} + \text{4He} & \rightarrow \text{7.65 MeV 0+} \\
\text{4He} + \text{4He} + \text{4He} & \rightarrow \text{4.439 2+} \\
\text{4He} + \text{4He} + \text{4He} & \rightarrow \text{Gamma transition} \\
\text{4He} + \text{4He} + \text{4He} & \rightarrow \text{0.0 0+} \\
\text{4He} + \text{4He} + \text{4He} & \rightarrow \text{12C g.s.}
\end{align*}
\]
Channels for CP Generation by 4D

I. Symmetric Fragmentation

1) $4D \rightarrow ^8_{\text{Be}}*(47.6\text{MeV};0^+,0)\rightarrow ^4_{\text{He}}*(\text{Ex}) + ^4_{\text{He}}*(\text{Ex}) + 47.6\text{MeV} - 2\text{Ex}$

• 1-1) $\text{Ex}=0$;
  $^4_{\text{He}}*(\text{gs};0^+,0): 4D\rightarrow \alpha+\alpha+47.6\text{MeV}; E_\alpha = 23.8\text{MeV}$

• 1-2) $\text{Ex}=20.21\text{MeV} \ (1^{\text{st}} \text{excited state of } ^4_{\text{He}})$;
  $^4_{\text{He}}*(20.21\text{MeV};0^+,0)\rightarrow p(0.6-2.2\text{MeV}) + t(1.8-3.4\text{MeV})$
  + (Ex-19.815=0.4MeV) + (3.6MeV; moving $^4_{\text{He}}*$)

  ; this triton makes secondary d+t reaction to emit 10-17MeV neutrons
1) \[ 4D \rightarrow {}^8\text{Be}^*(47.6\text{MeV};0^+,0) \rightarrow {}^4\text{He}^*(Ex) + {}^4\text{He}^*(Ex) + 47.6\text{MeV}-2Ex \]

- continued -

- \( Ex=21.01\text{MeV}(0^-,0), 21.84\text{MeV}(2^-,0), 22.33\text{MeV}(2^-,1), 23.04\text{MeV}(1^-,1) \) are forbidden by odd parity

Therefore, no neutron emission channels are allowed!
II. Asymmetric Fragmentation

1-3)

- $^4\text{D} \rightarrow ^4\text{He}^*(20.21\text{MeV};0^+,0) + ^4\text{He}(\text{g.s.};0^+,0) + 27.39\text{MeV}$ \hspace{1cm} \left( E_\alpha = 13.69\text{MeV} \right)

- $^4\text{He}^*(20.21\text{MeV}); \text{KE} = 13.69\text{MeV}$:

  $\rightarrow t(10.2\text{-}10.6\text{MeV}) + p(3.5\text{-}3.9\text{MeV})$

This channel would be the second source of tritium generation.
2) $4D \rightarrow ^8\text{Be}^* \rightarrow ^6\text{Li}(E_x) + d + (25.3\text{MeV} - E_x)$

- Even parity states: $E_x = 2.186\text{MeV}(3+,0)$, $3.563\text{MeV}(0+,1)$, $4.31\text{MeV}(2+,0)$, $5.31\text{MeV}(2+,1)$, $5.65\text{MeV}(1+,0)$, $15.8\text{MeV}(3+,0)$

- $2-1) \ 4D \rightarrow ^6\text{Li}(2.186) + d + 23.11\text{MeV}$
  
  \[
  KE = 5.77 \quad KE = 17.3
  \]

  $^6\text{Li}(2.186\text{MeV}): KE = 5.77\text{MeV}:$
  
  $\rightarrow ^4\text{He}(3.6-4.1\text{MeV}) + d(1.6-2.4\text{MeV})$
## 2-1) to 2-6)

<table>
<thead>
<tr>
<th>Ex (MeV)</th>
<th>K.E. of $^4$He (MeV)</th>
<th>K.E. of d (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.186</td>
<td>3.6-4.1</td>
<td>1.6-2.4</td>
</tr>
<tr>
<td>3.563</td>
<td>2.9-4.3</td>
<td>0.2-2.6</td>
</tr>
<tr>
<td>4.31</td>
<td>2.6-4.5</td>
<td>1.9-3.6</td>
</tr>
<tr>
<td>5.31</td>
<td>2.1-4.6</td>
<td>0.9-4.2</td>
</tr>
<tr>
<td>5.65</td>
<td>1.9-4.7</td>
<td>1.1-4.4</td>
</tr>
<tr>
<td>15.8</td>
<td>4.0-5.6</td>
<td>8.0-11.1</td>
</tr>
</tbody>
</table>
2) $4D \rightarrow ^{8}\text{Be}^*(47.6\text{MeV};0^+,0)$
   $\rightarrow ^{6}\text{Li}^*(\text{Ex}) + d + (25.3\text{MeV} - \text{Ex})$

- 2-7) $^6\text{Li}^*(25.3\text{MeV}) \rightarrow \alpha(7.9\text{MeV}) + d(15.9\text{MeV})$

- 2-8) $^6\text{Li}^*(25.3\text{MeV}) \rightarrow ^4\text{He}^*(20.21\text{MeV};0^+,0) + d$
   $\quad + 3.6\text{MeV}; \text{this may be path to } \text{Ex}=20.21\text{MeV}$

$^4\text{He}^*(20.21\text{MeV};0^+,0) \rightarrow p + t + 0.4\text{MeV}$

**Triton** from moving $^4\text{He}^*$ makes secondary d+t reaction to emit 10-17MeV neutrons
3) $4D \rightarrow ^8{\text{Be}}^*(47.6\text{MeV};0^+,0) \rightarrow ^4{\text{He}}^*(\text{Ex}) + (d+d) + (23.8\text{MeV}-\text{Ex})$

- 3-1) $\text{Ex}=0$;
  \[ E_\alpha=11.9\text{MeV}, \quad E_d=5.95\text{MeV} \]

- 3-2) $\text{Ex}=20.21\text{MeV}(0^+,0)$;
  $^4{\text{He}}^*(20.21\text{MeV};0^+,0)$: moving with $1.8\text{MeV}: \rightarrow t(1.2\text{MeV})+p(0.7\text{MeV})$
  \[ E_d=0.9\text{MeV} \]
Odd Spin-Parity

Fig. 2: Illustration of extreme scenario of decay channel for 4D fusion; final nuclear products are 46 keV α-particles and most energy (47.7 MeV) is transferred to lattice vibration via QED photons.

1: Typical decay channels of 4D fusion; E₁ transition may be induced with electromagnetic energy transfer via QED photons to lattice plasma oscillation. Major nuclear products are ⁴He with specified kinetic energies.
CP Spectra by 4D/TSC; Predicted

- $^4$He: **0.046, 1.52, 3.6-4.1, 2.9-4.3, 2.6-4.5, 2.1-4.6, 1.9-4.7, 4.0-5.6, 5.75, 7.9, 9.95, 11.9, 12.8, 13.69, 23.8** (MeV)
- Triton: **1.8-3.4, 10.2-10.6** (MeV)
- Deuteron: **0.9, 1.6-2.4, 0.2-2.6, 1.9-3.6, 0.9-4.2, 1.1-4.4, 5.95, 8.0-11.1, 15.9** (MeV)
- Proton: **0.6-2.2, 3.5-3.9** (MeV)

**Purple** values are by odd spin-parity of $^8$Be*(Ex=47.6MeV)

**Others** are S-wave Transitions
Tetrahedral Symmetric Condensate (TSC)  
Or  
Octahedral Symmetric Condensate (OSC)

4D/TSC, 6D/OSC

Self-Fusion of 4d, 6d  
23.8 MeV/\(^4\)He; Heat 
[t]/[\(^4\)He]; 1E-3 to 1E-9 
[n]/[\(^4\)He]; <1E-10

4d/TSC + M reactions  
(A+8, Z+4) Transmutation  
(A+12, Z+6) Transmutation  
Clean Fission Products

4H/TSC

4p/TSC + M Reactions  
M + p reaction  
M + 2p reaction  
M + 3p reaction  
M + 4p reaction:  
Clean Fission, heat

D or d: deuteron, H or p: proton
Conclusion-1

• The lowest excited energy of $^4$He*, intermediate compound nucleus, by two-body d+d fusion reaction is 23.8 MeV. Lower excited energy than 23.8 MeV is forbidden by kinematics. As a result, $[n]/[t]/[^4\text{He}]$ branching ratio becomes almost constant values as 0.5/0.5/10$^{-7}$ for $E_k = 0\text{eV}$ to 100keV (relative kinetic energy of reaction)
Conclusion-2

- If there happens the $^4\text{He}^*$ (Ex) state with Ex < 19.8 MeV, the final product becomes $^4\text{He}$ with ground state, after electromagnetic transition. To realize this process by d+d reaction, there should exist the third coupling field which must take more than the 4 MeV difference energy ($23.8 - 19.8$) of the d-d system in the initial state interaction.
The many-body interaction process between the d+d pairing and the third field of photon-phonon coupling in the lattice of condensed matter may be considered. Due to the very short range force of d+d strong interaction and its very short life time of virtual intermediate compound state, no processes have ever been proved to remove the 4 MeV gap energy. Moreover, the field coupling constant of electro-magnetic interaction looks too weak, on the order of $10^{-2}$ of that for the strong interaction, to drastically change the state of d+d strong interaction for fusion. Quantitative studies on transition probabilities will be needed.
Deuteron-cluster fusion, i.e. 4D fusion, may produce $^4$He final product as major ash of reaction, and triton, p, d as minor products. To realize the conditions of 4D fusion, the microscopic ordering/constraint process for the dynamic Platonic symmetry should be satisfied. The EQPET/TSC model is one of theoretical models, although we need further investigations to establish.