Anomalous Heat Generation in Charging of Pd Powders with High Density Hydrogen Isotopes
(II) Discussions on Experimental Results and Underlying Physics

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Arata-Zhang’s excess heat result demonstrated in May 2008 was replicated by more precise works. Using Pd/PdO/ZrO₂ powders (10 nm Pd particle size; produced by Santoku Co., Kobe Japan), we obtained: 1) D-gas charge in the 1st phase (zero pressure interval) gave 20–90% excess heat than H-gas charge. 2) In the 2nd phase of pressure rise (finally up to 1MPa), significant excess heat (about 2 kJ/g-Pd) for D-gas charge was observed, while near zero level excess heat for H-gas charge was observed.

No increase of neutron counts was seen, nor increase of gamma-ray counts. D/Pd loading ratio in the end of 1st phase was 1.1 in average, and H/Pd ratio was about 1.1 in average. Released energy per D or H-atom in the 1st phase was 2.2-2.5eV or 1.3-2.1eV respectively for D or H. These specific values are anomalously large, compared with known values of 0.5eV and 0.2eV per D or H respectively for surface-adsorption and lattice-absorption of hydrogen gas into bulk Pd metal.

We discuss on the drastic mesoscopic and isotopic effect of surface and lattice rearrangement of nano-Pd particle by full D(H)-absorption to make deeper D(H) trapping potentials of surface adsorption (about 2eV for D). We conclude the anomalously large isotopic and mesoscopic effects in heat generation and D(H) trapping, which will require partially (for the 1st phase) and fully (for the 2nd phase) the explanation by some nuclear reaction mechanisms like our 4D/TSC cluster fusion model. We will report further experimental results by setting higher base-temperature of reaction chamber and changing gas-flow rates.

Anomalous Heat Generation in Charging of Pd Powders with High Density Hydrogen Isotopes (II) Discussions on Experimental Results and Underlying Physics

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The Gas-Phase D(H)-Loading Method [1] with Nano-Fabricated Metal Powders is regarded promising for repeatable CMNS experiments.

We have constructed an experimental system to replicate the phenomenon of excess-heat (and $^4$He generation) and investigate the underlying physics for D(H)-charged Pd powders.

We constructed two identical chambers (twin system); one for $\text{D}_2$ gas foreground run and the other for $\text{H}_2$ gas background run. Each system has an inner reaction chamber containing Pd powders (100nm Pd, Pd-black and nano-Pd/ZrO$_2$).

A water-cooling system is provided for flow calorimetry to estimate heat production rates for two phases.

$\text{D(\text{H})/Pd ratios}$ were measured for the 1$^{\text{st}}$ phase (“zero pressure interval”), for changing conditions (powder, gas-flow rate, base-cell temperature, etc.).

A REM counter was used for monitoring neutron emission. A NaI scintillator was used for monitoring gamma-ray. Furthermore, $^4\text{He}$ analysis will be performed in the future.
Fig. 1(a): A. Kitamura et al., Physics Letters A, 373 (2009) 3109-3112.

A2 system for H2 run
Reaction chamber

A1 system for D2 run

Vacuum gauge
Pressure gauge

D2 gas cylinder

H2 gas cylinder

Vacuum pump

H2 gas cylinder

D2 gas cylinder
Fig. 1(b): A. Kitamura et al., Physics Letters A, 373 (2009) 3109-3112.
New A: Stability of Flow Calorimeter with Zero Input Power
Standard deviation = 14 mW
2. Experimental Procedure

- Set Sample in Inner Cell
- Evacuation and Baking (<300°C)
  - Start D (H) Gas Charge Run #1
  - Take Data: Calorimetry, Pressure, Neutron, Gamma-ray, etc.
- Evacuation and Baking (<300°C)
  - Take De-gas Data
- Start D (H) Gas Charge Run #2
  - Take Data: Calorimetry, Pressure, Neutron, Gamma-ray, etc.
The evolution is divided into 2 phases by the time 30 minutes after the beginning of the pressure rise.

The release of heat of hydride formation should be completed in the 1st phase.

![Graph showing output power and pressure over time for Pd powders (φ0.1μm, 99.5%)](image)
B. Pd black (300 mesh, 99.9%) – comparison of Heat balance

- The output energies in the 1st phase are almost the same for both cases, but seem to be somewhat larger than the nominal values of 100 – 405 J/g ($H_2$) and 80 - 330 J/g ($D_2$)
- On the contrary, the output energy in the 2nd phase appears to be larger for $D_2$ than $H_2$. 

<table>
<thead>
<tr>
<th></th>
<th>$D_2$</th>
<th>$H_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st phase</td>
<td>5.4E+2 J/g</td>
<td>4.5E+2 J/g</td>
</tr>
<tr>
<td>2nd phase</td>
<td>2.6E+3 J/g</td>
<td>-6.2E+2 J/g</td>
</tr>
</tbody>
</table>
Experiments with Pd/PdO/ZrO$_2$ Dispersed Samples

10g (Net Pd weight : 3 g): Three trials for Santoku 1, Santoku 2 and Santoku 3 samples, #1 and #2 runs for each sample

- Nano-Pd/ZrO$_2$ sample was produced by Santoku Co. Japan, based on different protocol from Inoue-Yamaura (Arata-Zhang).
- X-ray diffraction analysis showed composite of Pd/PdO/ZrO$_2$.
- Pd particle size is 10nm in averaged diameter.
- A1 system: 10g for D-gas charging (2-3sccm)
- A2 system: 10g for H-gas charging (2-4sccm)
- Water-flow calorimetry: 6cc/min flow rate
Definition of Phase-I and Phase-II
D-PZ1#1 and H-PZ2#1; Results of Heat Evolution

Gas flow rate: 1.8 (D) and 2.3(H) sccm
No increase of neutron count rate by REM counter was seen, gamma-ray either.
Comparison of heat-power evolutions for 100nm Pd, Pd-black and 10nm Pd/PdO/ZrO₂ samples:

Blue by D-charge cf. Red by H-charge

a) Bulk Character

(b) Near-Nano Character

c) Mesoscopic Character
D-PZ9#1 vs. H-PZ10#1 : -100~300min

Flow Rates: 6.42 (D), 20.5 (H) : sccm

E1st: 1.87eV/D, 2.53eV/H

Sample net Pd weight: 4.2g (Pd particle size : about 8 nm)

9.56kJ

10.23kJ
### Summary table of integrated data for phase-1 and phase-2

<table>
<thead>
<tr>
<th>Run #</th>
<th>weight of Pd [g]</th>
<th>Flow rate [sccm]</th>
<th>Output energy [kJ]</th>
<th>Specific output energy [kJ/g]</th>
<th>D/Pd or H/Pd (1st ph.)</th>
<th>E1st [eV/D(H)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-PP1#1</td>
<td>5.0</td>
<td>2.7</td>
<td>0.5±0.4</td>
<td>0.10±0.07</td>
<td>0.43</td>
<td>0.26±0.14</td>
</tr>
<tr>
<td>D-PP1#2</td>
<td>5.0</td>
<td>3.8</td>
<td>0.5±0.2</td>
<td>0.10±0.05</td>
<td>0.44</td>
<td>0.25±0.09</td>
</tr>
<tr>
<td>H-PP2#1</td>
<td>5.0</td>
<td>5.4</td>
<td>0.4±0.2</td>
<td>0.08±0.03</td>
<td>0.44</td>
<td>0.20±0.07</td>
</tr>
<tr>
<td>D-PB1#1</td>
<td>3.2</td>
<td>3.6</td>
<td>1.7±0.3</td>
<td>0.54±0.10</td>
<td>0.88</td>
<td>0.67±0.12</td>
</tr>
<tr>
<td>H-PB2#1</td>
<td>3.6</td>
<td>4.2</td>
<td>1.6±0.3</td>
<td>0.45±0.08</td>
<td>0.79</td>
<td>0.62±0.11</td>
</tr>
<tr>
<td>D-PB3#1</td>
<td>20.0</td>
<td>2.9</td>
<td>9.3±1.1</td>
<td>0.47±0.06</td>
<td>0.79</td>
<td>0.65±0.08</td>
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<tr>
<td>D-PB3#2</td>
<td>20.0</td>
<td>0.9</td>
<td>3.3±0.5</td>
<td>0.17±0.03</td>
<td>0.23</td>
<td>0.79±0.05</td>
</tr>
<tr>
<td>H-PB3#3</td>
<td>20.0</td>
<td>2.1</td>
<td>3.2±0.2</td>
<td>0.16±0.01</td>
<td>0.24</td>
<td>0.74±0.05</td>
</tr>
<tr>
<td>D-PZ1#1</td>
<td>3.0</td>
<td>1.8</td>
<td>7.0±0.2</td>
<td>2.33±0.05</td>
<td>1.08</td>
<td>2.4±0.05</td>
</tr>
<tr>
<td>H-PZ2#1</td>
<td>3.0</td>
<td>2.3</td>
<td>3.6±0.1</td>
<td>1.20±0.02</td>
<td>1.00</td>
<td>1.3±0.02</td>
</tr>
<tr>
<td>D-PZ3#1</td>
<td>3.0</td>
<td>1.9</td>
<td>6.4±0.2</td>
<td>2.13±0.05</td>
<td>1.08</td>
<td>2.2±0.05</td>
</tr>
<tr>
<td>H-PZ4#1</td>
<td>3.0</td>
<td>3.6</td>
<td>4.8±0.1</td>
<td>1.60±0.02</td>
<td>0.86</td>
<td>2.1±0.03</td>
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<tr>
<td>D-PZ5#1</td>
<td>3.0</td>
<td>2.0</td>
<td>7.1±0.2</td>
<td>2.38±0.03</td>
<td>1.04</td>
<td>2.5±0.03</td>
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<tr>
<td>H-PZ6#1</td>
<td>3.0</td>
<td>5.9</td>
<td>7.1±0.1</td>
<td>2.36±0.02</td>
<td>1.34</td>
<td>1.9±0.02</td>
</tr>
<tr>
<td>Average for PZ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D)</td>
<td>6.9±0.4</td>
<td>4.8±3.0</td>
<td>2.3±0.1</td>
<td>1.6±1.0</td>
<td>1.1±0.0</td>
<td>2.4±0.2</td>
</tr>
<tr>
<td>(H)</td>
<td>5.2±1.8</td>
<td>(-1.1±3.6)</td>
<td>1.7±0.6</td>
<td>(-0.4±1.2)</td>
<td>1.1±0.3</td>
<td>1.8±0.4</td>
</tr>
</tbody>
</table>
Discussions for the 1st Phase

- Pd 0.1 micron: \((\text{Heat/D})_{av} = 0.25 \ (\pm 0.1) \text{ eV}\)
  \((\text{Heat/H})_{av} = 0.20 \ (\pm 0.1) \text{ eV}\)
- Pd-black: \((\text{Heat/D})_{av} = 0.70 \ (\pm 0.15) \text{ eV}\)
  \((\text{Heat/H})_{av} = 0.69 \ (\pm 0.1) \text{ eV}\)
- Santoku1-3: \((\text{Heat/D})_{av} = 2.4 \ (\pm 0.2) \text{ eV}\)
  \((\text{Pd/ZrO}_2) \ (\text{Heat/H})_{av} = 1.8 \ (\pm 0.4) \text{ eV}\)

- After Fukai book: 0.2eV/H for bulk H absorption.
  100kJ/mol-H₂ : 0.5eV/H for surface adsorption.

- Reaction may be Surface Mesoscopic Phenomenon for the 1st Phase (“zero pressure” interval). Isotopic effect is visible. Flow rate dep.
- Pd nano-particle makes deep trapping potential of D(H), probably in fractal defects of its surface!?
- This is the reason of high loading “in vacuum” for Pd-nano.
After evacuation, Santoku sample retains much more (100 times) D(H) than Pd-black: due to mesoscopic effect (rearrangement of surface and lattice) of Pd nano-particles.

4-3. Variation of pressure during sample baking for outgassing.
TEM Image of Pd/ZrO$_2$ Sample

(Courtesy of the Nuclear Science and Engineering Institute and Particulate Systems Research Center at the University of Missouri-Colombia; by R. Duncan)
Metal-Oxide-Nano-Pd Composite

- PdD_{x}
- \( x=1.0 \) by Arachi et al.; D-Absorption in O-sites of Pd-Lattice (We support this data)
- \( x=2.0 \) by Yamaura et al.; deuterons at Pd-ZrO\(_2\) interface (Voids?)
- Arata claimed: \( x=2.5 \)
Irregular and Fractal Sites should form on surface of nano-particle

5 nm Pd particle: 4,000-6,000 atoms

D$_2$ molecule

Octahedral sites

Fractal Trapping points
Potential form of hydrogen adsorption and absorption near surface

For nano-holes:
The heavier is the isotope, the more enhanced adsorption takes place on surface.

Periodical Lattice Potential at O-site for Pd, $E_{\text{sol}} = 0.2$ eV

$E_{\text{diff}}$, $E_{\text{hydr}}$, $E_{\text{H}_2}$, $E_{\text{H}}$, $E_d$,

$E_{\text{H}_2}$ molecule Dissociation Energy

After surface rearrangement

$E_H \sim 0.5$ eV for Pd
A) Bulk Pd Lattice

- Surface

- O-site

- $E_d$

- $E_H \approx 0.5 \text{eV}$

B) Mesoscopic Pd Lattice

- Surface

- Non-Linear Collective Trapping State

  = Thermally Isolated Group State

- Non-Linear Shrunken State

- $E_H \approx 1.8 \text{eV}$
D-Cluster Fusion

D-atom, D-nucleus → Nucleus, D-Cluster, TSC. OSC → PdDx; Nano-Grain Mesoscopic → PdD Lattice, Bulk


(From Few Body System to Many Body System under Constraint (Self-Organization))
Conclusions-1

- Arata-Zhang’s Excess Heat Result was replicated quantitatively.

- For Pd/PdO/ZrO$_2$ powder (Santoku):
  1) D-gas charge in the 1$^{\text{st}}$ phase (zero pressure) gave 20-90% excess heat than H-gas charge.
  2) In the 2$^{\text{nd}}$ phase, significant excess heat (about 3 kJ/g-Pd) for D-gas charge, while zero level for H-gas charge. (0.4 kJ/g-Li for lithium-ion battery)

- No increase of neutron counts was seen.

- D(H)/Pd ratio in the end of 1$^{\text{st}}$ phase was >1.0 (x=1.1 in average) Flow rate dependence.

- The Clumping-Together Effect can be depressed by the Pd/ZrO$_2$ dispersed sample.
• Nano-Pd dispersed sample (Santoku, Pd/ZrO$_2$) retained 100 times more D(H) atoms after evacuation, than the Pd-black case.

• **Mesoscopic effect** by Pd-nano-particle; **deep well plus Bloch potential** for collective state: probably makes **deep D(H) trapping potentials (1.8-2.5eV)**.

• We need study for D(H)-gas flow-rate dependence and Pd-particle size dependence.

• Heat of Pd/ZrO$_2$ in Phase-I was about 10 times of bulk Pd. Peak power increases with flow rate increase.

• Replication by other groups is important.
Supplement Data-1

- Pb Black data
- Clumping-together Effect
- SEM Images
Pd-black (20g) / D-gas charge #1: Nov. 2008

- Heat output
- 反応容器内圧力

D/Pd=0.78

New gas cylinder

Power (W)
Pressure (MPa)

Time (min)

1st phase
2nd phase
出力(W), ΔT(K)

Power (W)

Time (min) 0 500

Pressure Rearrangement Here?

Heat-peak

Pd-black/D-gas charge #1 data
Decreased absorption and heat level for #2

Pd-black (20g)/ D-gas #2
After experiments, Pd black powders stuck to be bigger sizes → Decrease of active surface area
Before experiment, surface was fractal in nano-scale.

After experiment, surface became flatter in about 10 times larger scale → Decrease of active surface area
Summary for Pd-black

- There were seen excess heat in the 1\textsuperscript{st} and 2\textsuperscript{nd} phases, but smaller than those by Pd/ZrO\textsubscript{2}.
- Pd-black powders stuck to be bigger sizes (about 10 times diameter by SEM observation), after the #1 run.
- This is the Clumping-Together-Effect of nano-powders.
- In the #2 run and following runs, no significant excess heat was seen.
- D/Pd ratio for #1 was 0.78 in the pressure zero condition under D-charge.
- D/Pd ratios for #2 and later runs, D/Pd was about 0.23 (much smaller).
- No transmuted elements were seen by PIXE.
Supplement Data 2

- Photographs of experimental systems
- $A_0$ System
- $A_1$ and $A_2$ Twin system
Supplement Data 3

• Detail data for PZ-series runs (PZ=PdZrO$_2$ nano-composite powder)

• Reproducibility of Pase-1 and Phase-2 Data

• Comparison with Arata-Zhang Data
For 1st phase
7.0 kJ → 2.29 kJ/g-Pd → 2.4 eV/D
3.6 kJ → 1.86 kJ/g-Pd → 1.3 eV/H

Heat (D): A1
Heat (H): A2 x0.5

A2 first phase end: H/Pd = 1.0
A1 first phase end: D/Pd = 1.08
Results of Santoku2#1 run

A1: D-gas Charge with 1.9 sccm

A2: H-gas Charge with 3.6 sccm

D/Pd=1.08
H/Pd=0.86

D-gas Charging to Santoku2#1
H-gas Charging to Santoku2#1
Pd · ZrO₂ Santoku 2 #1 Run (A1) for D-gas Charge

Output power [W]
Pressure [MPa]

Output power for D₂
Pressure for D₂

2.15kJ/g-Pd → 2.2eV/D
2.3kJ/g-Pd

D/Pd = 1.08

1st phase
2nd phase

Time [min]
Pd·ZrO$_2$ Santoku 2 #1 Run (A2) for H-gas Charge

1.7 kJ/g-Pd $\rightarrow$ 2.1 eV/H

H$_2$

Output power for H$_2$ run
Pressure for H$_2$ run

H/Pd = 0.86

0.57 kJ/g-Pd

1.7 kJ/g-Pd $\rightarrow$ 2.1 eV/H

Noise

1$^{\text{st}}$ phase

2$^{\text{nd}}$ phase

Time [min]
Arata-Zhang’s 1st Phase Data for Pd/ZrO\textsubscript{2} (7g)

**D\textsubscript{2}-gas charging**

**H\textsubscript{2}-gas charging**

**Arata-Zhang:** \([\text{Heat(D)}/\text{Heat(H)}] \sim (72 - 25)\textdegree C)/(60 - 25)\textdegree C) = 1.34

**Our Exp. Santoku1:** \([\text{Heat(D)}/\text{Heat(H)}] = (7.0\text{kJ})/(3.6\text{kJ}) = 1.94

**Our Exp. Santoku2:** \([\text{Heat(D)}/\text{Heat(H)}] = (6.4\text{kJ})/(5.1\text{kJ}) = 1.26

Agreed!
Results by Large H-Flow Rate And Low D-Gas Pressure

Santoku 3#1 Run

A1: H-gas, Flow Rate = 5.9 sccm
A2: D-gas, Flow Rate = 2.0 sccm

Heat output D2 (A2)
Heat output H2 (A1)
反応容器内圧力D2 (A2)
反応容器内圧力H2 (A1)

A1: H-gas (H/Pd = 1.34) 7.1 kJ

A2: D-gas (D/Pd = 1.04) 7.1 kJ

Pressure: H-gas
Pressure: D-gas
D-PZ9#1 vs. H-PZ10#1 : -100~300min

Flow Rates: 6.42 (D), 20.5 (H) sccm

Sample net Pd weight: 4.2g
D-PZ9#1 vs. H-PZ10#1

![Graph showing the output power and pressure comparison between D-PZ9#1 and H-PZ10#1 over time.](image-url)
Long time lasting heat by D-charge without input power: 29.2kJ Total by 24.4g Pd/ZrO$_2$ sample
For 1\textsuperscript{st} phase: 7.0 kJ by D and 3.6kJ by H; 3.4kJ net excess heat
For 2\textsuperscript{nd} phase: 6.8kJ by D
Total Excess Heat = 10.2kJ → 3.4kJ/g-Pd
Discussions on Total Excess Heat Rates for #1 Runs:
Our results are comparable to Arata’s.

- **Arata-Zhang Exp.**
  - Sample Pd/ZrO\(_2\) by Fukuda P. M. Co.
    - weight: 24.4 g
    - net Pd weight: 7.7 g
  - Observed Excess Heat
    - (0-3000min): 29.2 kJ
  - Excess Heat Rate:
    - 3.79 (kJ/g-Pd)
    - (Anomalous heat by H about 1 kJ/g inclusive)
  → Net Value ~ 2.8 (kJ/g-Pd)

- **Our Exp.**
  - Sample Pd/PdO/ZrO2 by Santoku Co.
    - weight: 10 g
    - net Pd weight: 4.3 g
  - Observed Excess Heat
    - (Example for S2, 0-3000min)
    - S2: (6.4-5.1)+7.0 = 8.3 ± 1.2 kJ
  - Excess Heat Rate:
    - S1: 3.78 ± 0.30 (kJ/g-Pd)
    - S2: 2.77 ± 0.30
TEM Image of Used Pd/ZrO$_2$ Sample
taken by R. Duncan 2009
Supplement Data 4

:Reuse of PZ Samples

• #2, #3 Runs

• “Heat after Death?”
Reuse of Sample: Long Time Lasting Excess Heat by Run: Santoku 2#2

<table>
<thead>
<tr>
<th>run</th>
<th>Gas</th>
<th>Measured flow rate [sccm]</th>
<th>1st phase [kJ]</th>
<th>2nd phase [kJ]</th>
<th>1st phase [J/g]</th>
<th>2nd phase [J/g]</th>
<th>D/Pd or H/Pd</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2-2-2</td>
<td>D</td>
<td>3.87</td>
<td>0.17±0.03</td>
<td>9.89±1.48</td>
<td>40±7.0</td>
<td>2300±345</td>
<td>0.47</td>
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<tr>
<td>H2-2-2</td>
<td>H</td>
<td>3.62</td>
<td>0.58±0.05</td>
<td>1.68±1.46</td>
<td>136±10.9</td>
<td>391±341</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Run: Santoku 2#2: Expanded View of Early –Time Evolution

- Heat output D2 (A1)
- Heat output H2 (A2)
- 反応容器内圧力D2 (A1)
- 反応容器内圧力H2 (A2)

De-oxidation?

Power by D
Power by H
Run: Santoku 2#2: Expanded View of Heat Evolution after Evacuation- “Heat after Death”

Is Evacuation STIMULUS?
Theoretical View

- Tetrahedral Symmetric Condensate
- 4D Fusion and Products
Model b) may correspond to I.

Model a) may correspond to II.

4D/TSC → $^4$He + $^4$He + 47.6MeV
Result of Dynamic Condensation of 4D/TSC by Langevin Equation

1) TSC forms

Electron

2) Minimum TSC

Electron Center

Electron

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

Deuteron

4) Break up to two \(^{4}\text{He}\)

\(1.4007\) fs

\(4r_e = 4 \times 2.8\) fm

15 fm
1. Typical decay channels of 4D fusion; $E_1$ transition may be induced with electromagnetic energy transfer via QED photons to lattice plasma oscillation. Major nuclear products are $^4$He with specified kinetic energies.

Fig. 2: Illustration of extreme scenario of decay channel for 4D fusion; final nuclear products are 46 keV $\alpha$-particles and most energy (47.7 MeV) is transferred to lattice vibration via QED photons.
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\(^{\text{st}}\) excited state of \(^4\text{He}\));
  \(^4\text{He}^*(20.21\text{MeV};0^+,0) \rightarrow p(0.6-2.2\text{MeV}) + t(1.8-3.4\text{MeV})\)
  + (\(\text{Ex}-19.815=0.4\text{MeV}\) ) + (3.6MeV; moving \(^4\text{He}^*)\)

; this triton makes secondary \(d+t\) reaction to emit 10-17MeV neutrons
2) $4D \rightarrow ^8\text{Be}^* \rightarrow ^6\text{Li}(Ex) + d + (25.3\text{MeV} - Ex)$

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

- $2-1) 4D \rightarrow ^6\text{Li}(2.186) + d + 23.11\text{MeV}$
  
  \begin{align*}
  \text{KE} &= 5.77 & \text{KE} &= 17.3 \\
  ^6\text{Li}(2.186\text{MeV}):\text{KE} &= 5.77\text{MeV}: \\
  &\rightarrow ^4\text{He}(3.6-4.1\text{MeV}) + d(1.6-2.4\text{MeV})
  \end{align*}
CP Spectra by 4D/TSC; Predicted

• $^4\text{He}$: 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 $^8\text{Be}^*$ (Ex=47.6MeV)

Others are S-wave Transitions
System-B Experiment for Charged Particle Spectroscopy

- Thermal shield
- Ion-implanted –type SSD
- Nano-Pd/ZrO2 powder
- Water coolant
- Tmermo-couples
Alphas of 5.75, 9.95, 12.8 MeV by minor branch of 4D fusion?

Evolution of total counts in “1-12 MeV “range of SSD detector, 5mm from sample.
Energy loss of $^4\text{He}$ in air/$\text{H}_2$

Energy loss of $^4\text{He}$ in air/$\text{H}_2$

$E_{\alpha}$ (MeV)

in Air

in $\text{H}_2/\text{D}_2$

Thickness, $pl$ (mm·atm)
Charged Particle Spectra by SSBD (200 micron depletion layer) for D-PZ1#3B

Might be 24 MeV alpha; Delta-E by 200 micron SSBD
Charged Particle Spectra by SSD

Yield vs. $E$ (MeV)

- D-PZ14#1B
- D-PZ15#1B
Charged Particle Spectra by SSD

![Graph showing charged particle spectra by SSD](image-url)

**Yield**

**$E$ (MeV)**
sample baking with a shield on the SSD

D-PZ15#1-#2

$P$ (MPa)

T $B$ (deg. C),

Ch. particle counting

Ch. particle