Physics of Cold Fusion by TSC Theory ICCF17 slides

1 author:

Akito Takahashi
Osaka University

show

Physics of Cold Fusion by TSC Theory

Akito Takahashi

(Osaka University and Technova Inc.)

Invited talk at ICCF17, Daejeon, Korea,

August 12-17, 2012

show

Outline of presentation

- Model principle of cold fusion processes in nano-metal mesoscopic catalysts (Pd, Ni, alloys) are proposed and discussed
- Brief show on modeling transient/dynamic D(H)-cluster formation on/in a nano-metal particle with surface sub-nano-holes (SNH)
- comparison is made between 4D/TSC and 4H/TSC condensation motions and resultant strong and weak nuclear interactions.
- 4D/TSC fusion, 4H/TSC WS fusion and their products
- 4H/TSC induced clean fission of host metal nuclei

The Case of Hot Plasma Fusion

- **Confinement of high kinetic energy deuterons (plasma) in a very large scale (torus) room** , like Tokamak magnetic field confinement.
- Average kinetic energy of d-d (or d-t) reaction for ITER is aimed to be about 10keV (E_k).
- <Macroscopic Fusion Rate> = < $N_d(E_k)^2 v\sigma_{dd}$ (E_k)>

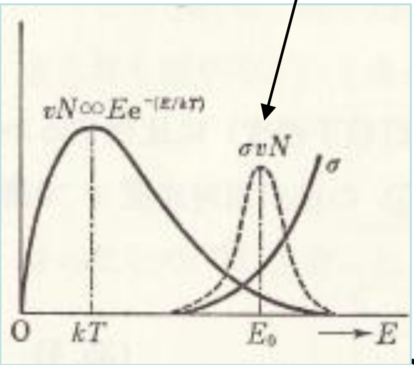
Gamow-Teller peak

N_d : deuteron density, v: relative d-d velocity,

$\sigma_{dd} = (S(E_k)/E_k)\exp(-\Gamma_{dd})$: fusion cross sec

E_k: relative d-d kinetic energy

Γ_{dd} : Gamow factor



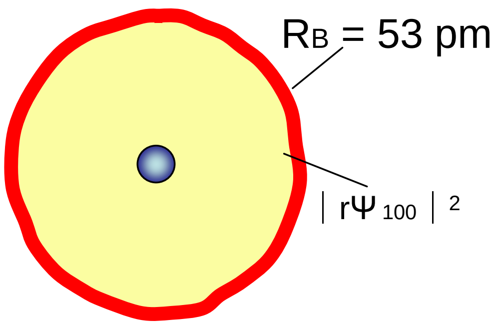
- Free particle motion and collision pro

$N_d(E_k) = N \cdot (E_k/T^2)\exp(-E_k/T)$: Maxwell-Boltzmann distr.

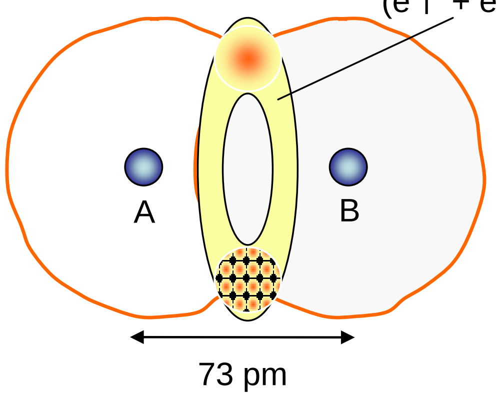
Cold Fusion: Confinement of High KE D-cluster in a extremely microscopic domain

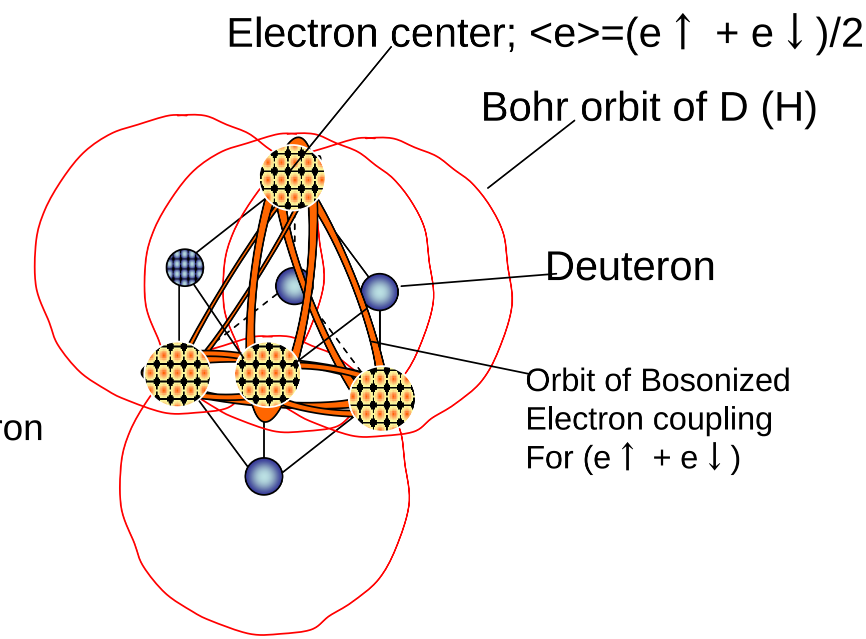
show

Feature of QM Electron Cloud



a) D atom (stable)



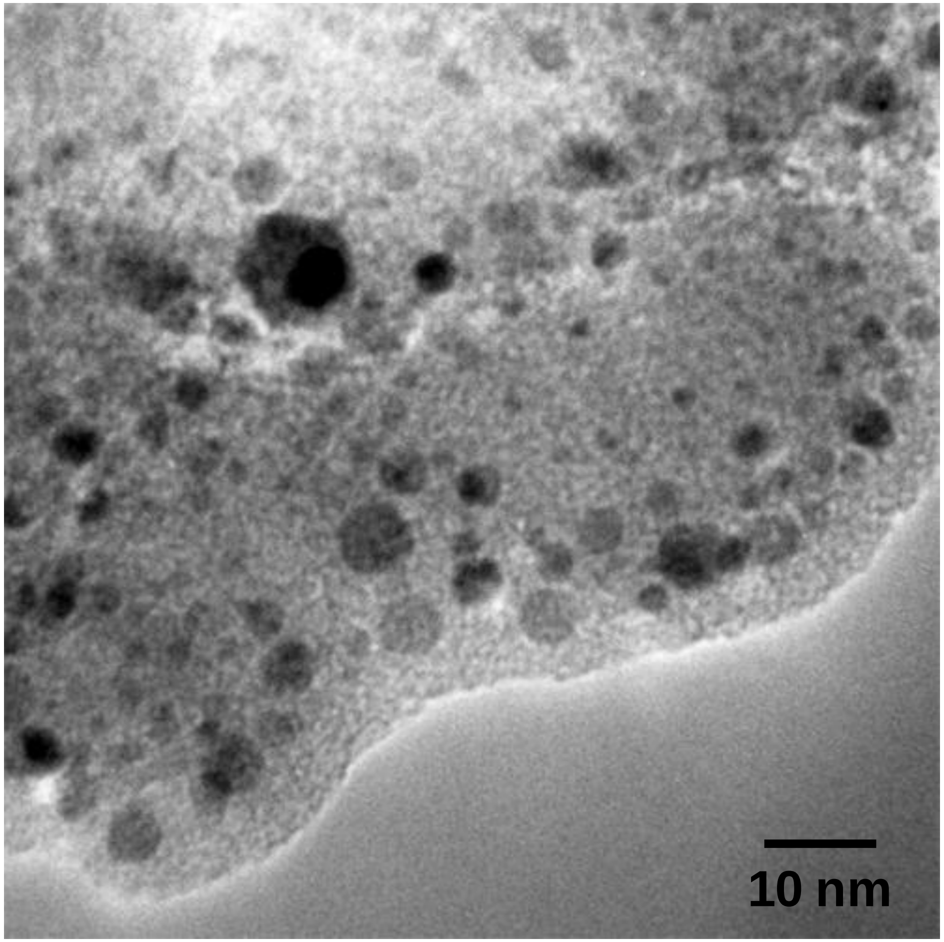


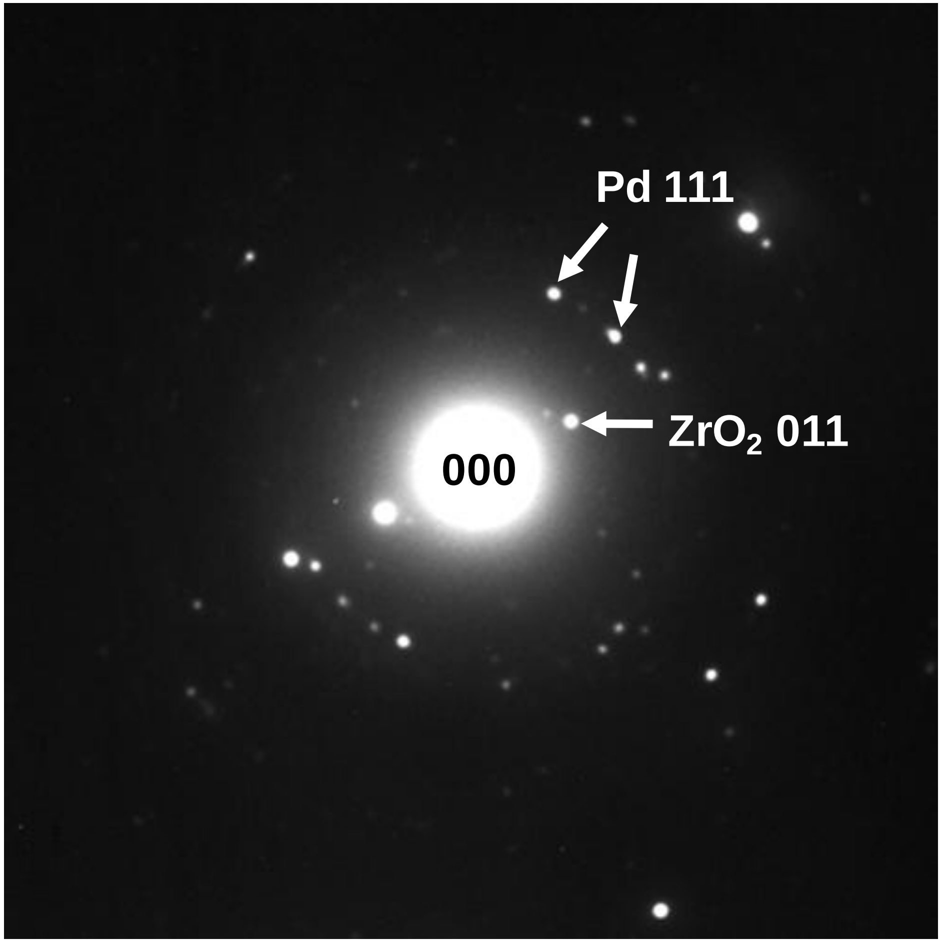
c) Tetrahedral Symmetric Condensate (**TSC**) at t = 0 → TBEC

b) D_2 molecule (stable): $\Psi_{2D} = (2+2\Delta)^{-1/2}[\Psi_{100}(r_{A1})\Psi_{100}(r_{B2}) + \Psi_{100}(r_{A2})\Psi_{100}(r_{B1})]X_s(S1,S2)$

show

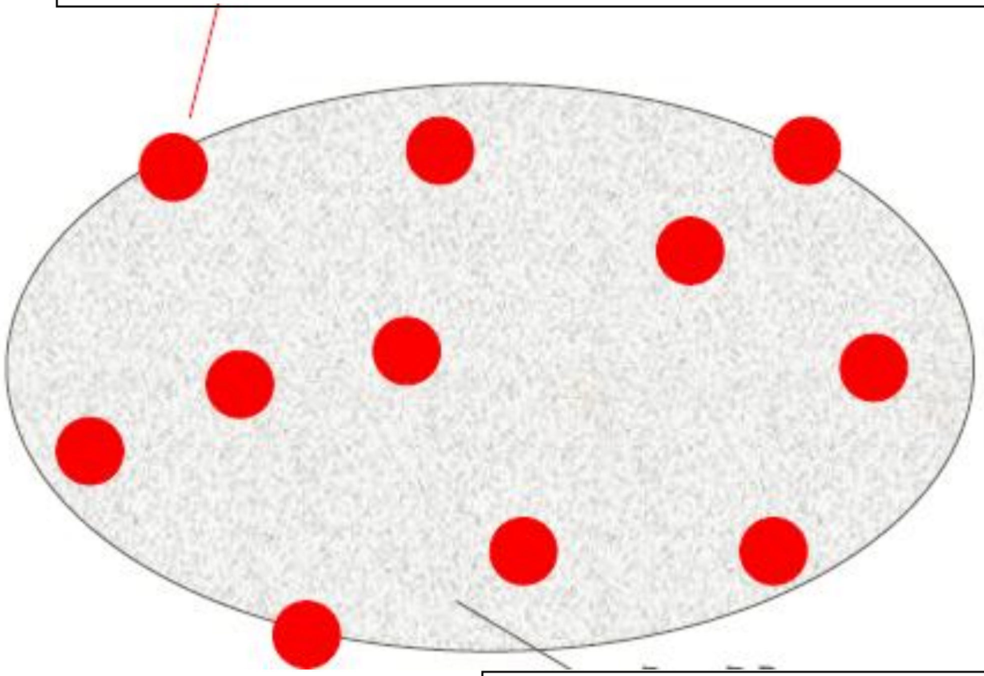
A TEM Image of a $Pd_{35}Zr_{65}$ sample made by melt-spinning procedure
(By courtesy of Prof. T. Oku, University of Shiga Prefecture)
As a reference to the B. Ahern's Pd sample





The Making of Mesoscopic Catalyst

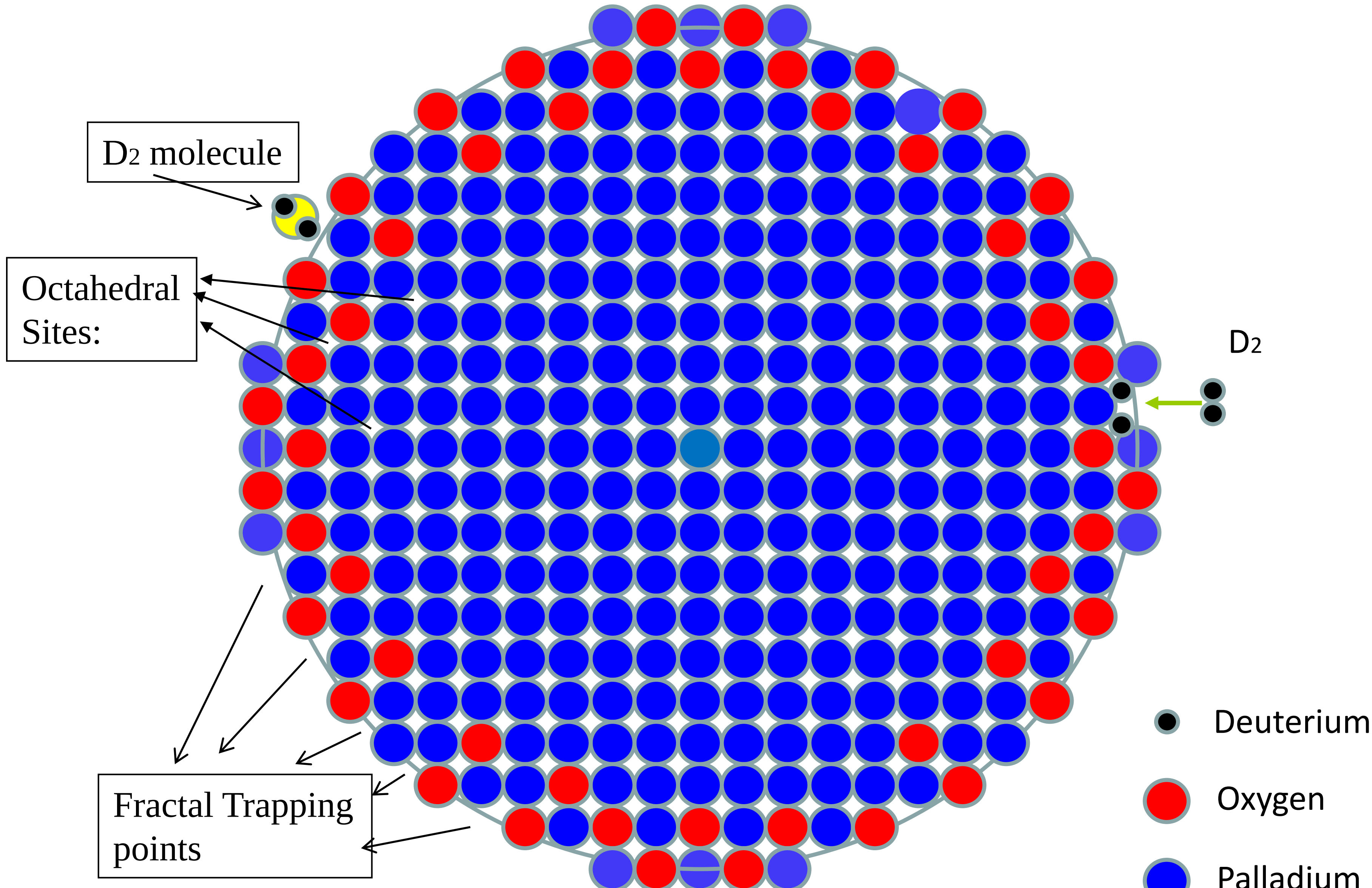
Meso-Catalyst: as Core/"Incomplete"-Shell Structure
Mono-Metal (with oxide-surface layer)
Or Binary Alloy



Ceramics Supporter
(ZrO_2, zeolite, γ-Al_2O_3, etc.)

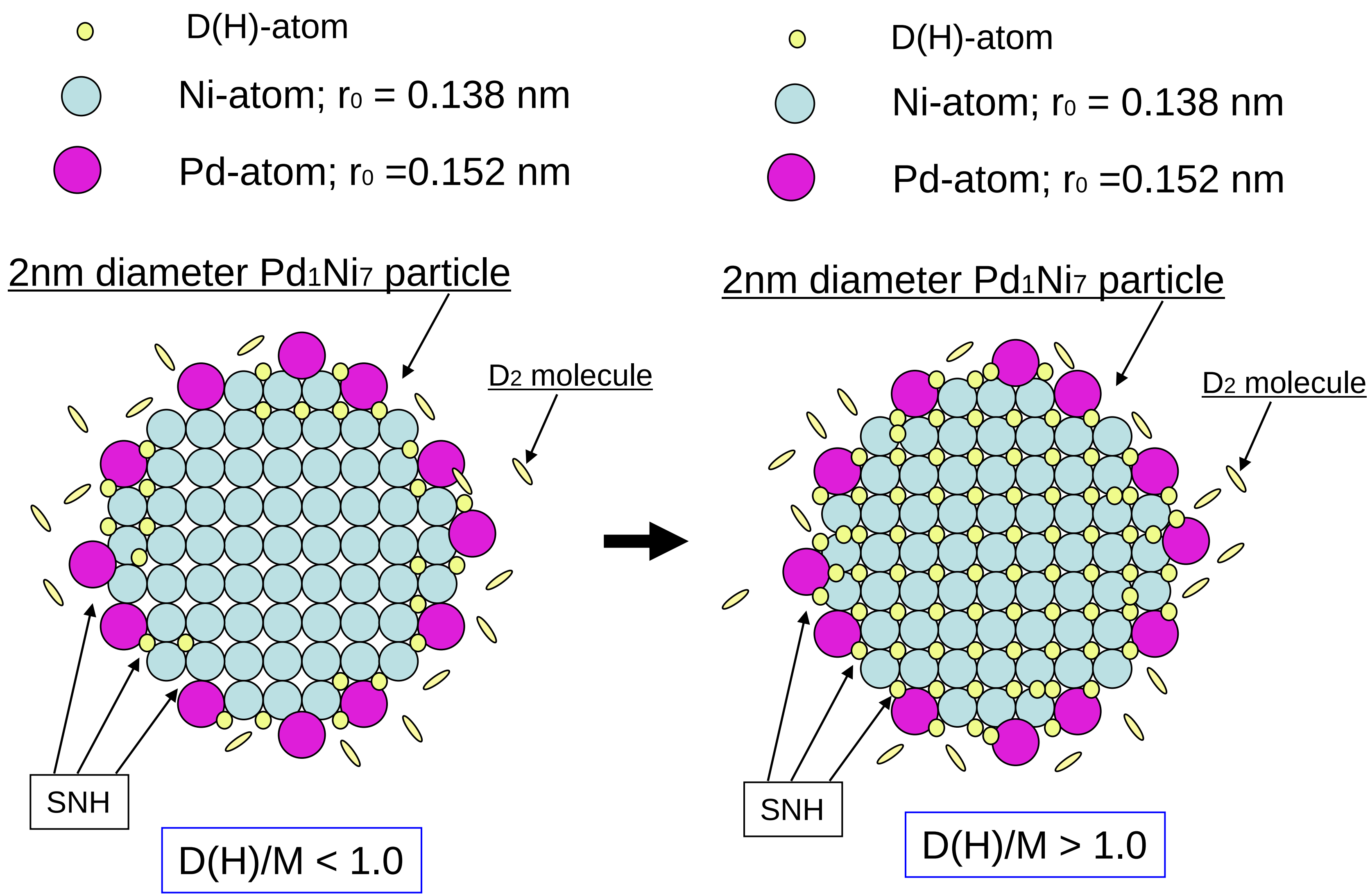
show

Another D_2 comes onto trapped D_2 at SNH (**Sub-Nano Hole)**



AT ICCF17 TSC theory

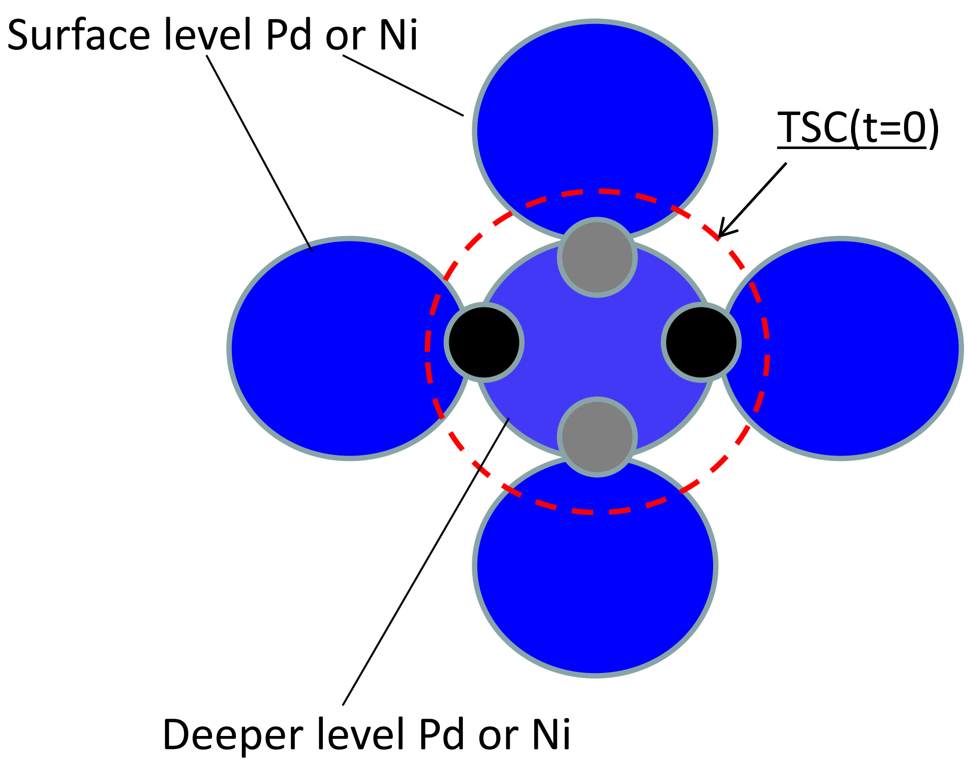
SNHs are prepared by O-reduction to start D(H) absorption (left) And D(H)/M loading ratio exceeds 1.0 level (right)

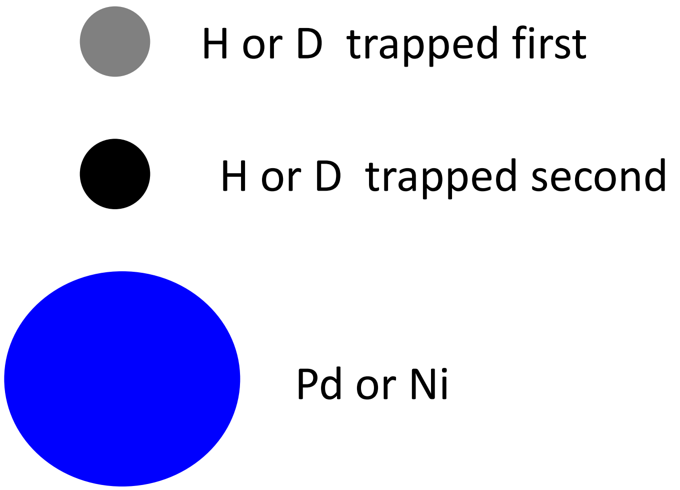


show

JCF-11, 2011

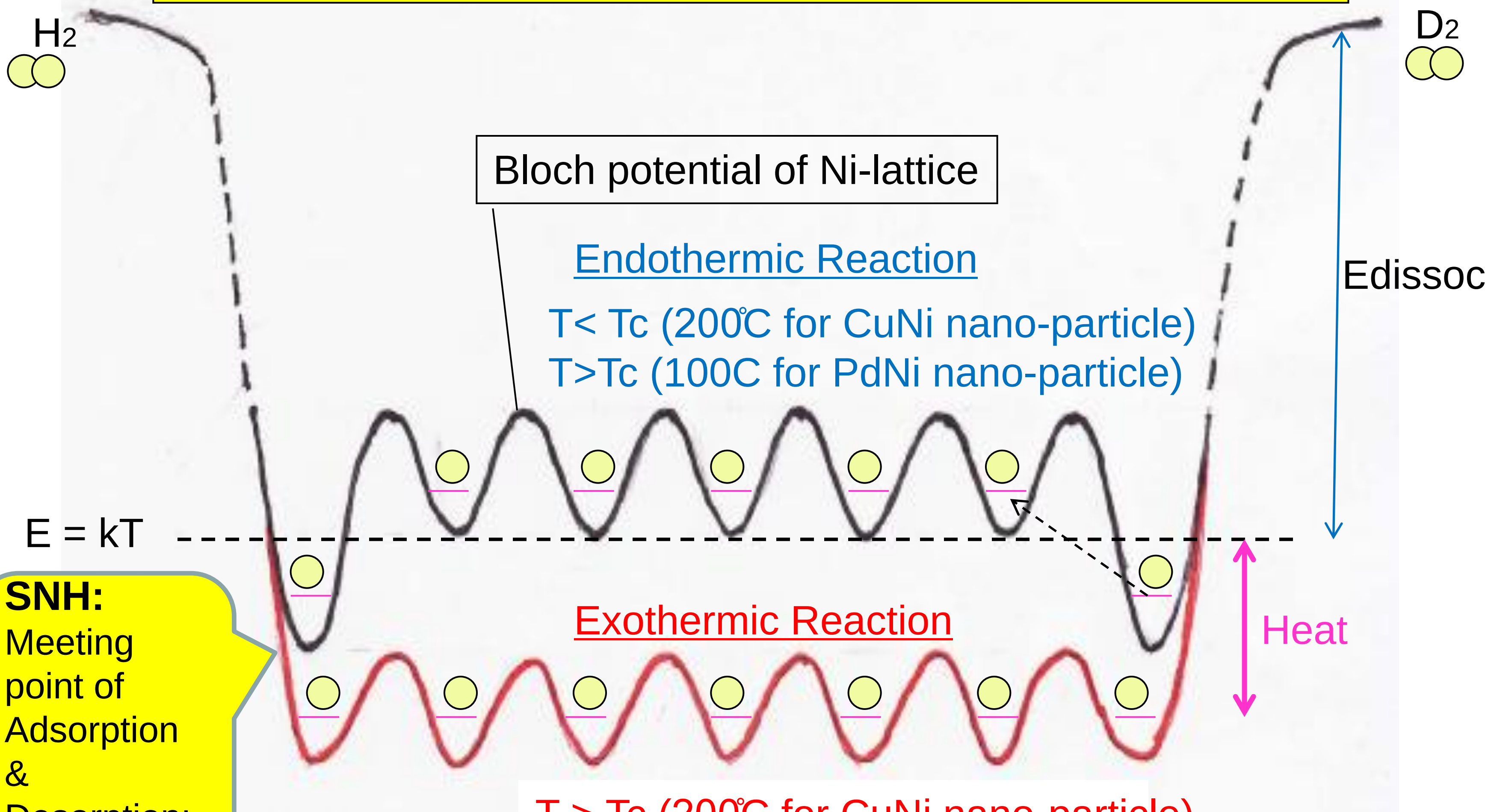
Image on Formation of TSC(t=0) at **Sub-Nano-Hole** (SNH) Of Nano (**Mesoscopic) Catalyst**





show

Speculative image of **GMPW** (Global Mesoscopic Potential Well)
For **CNZ (Cu-Ni-ZrO2) and PNS (Pd-Ni-SiO2)** nano-composite powder
+ D(H) absorption and **TSC** (tetrahedral symmetric condensate)



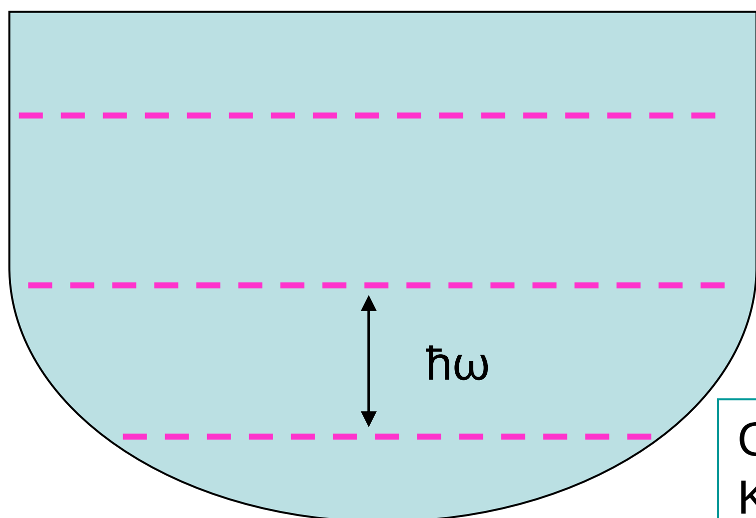
T > Tc (200℃ for CuNi nano-particle)
T< Tc (100C for PdNi nano-particle

SNH:
Meeting point of Adsorption & Desorption:
4D(H)/TSC Formation

show

Every Particle confined in Condensed Matter should have higher Kinetic Energy within its Relatively Negative Trapping Potential Well

**Phonon couples with outer field phonon to transfer energy
To get thermal equilibrium**



Outer Field Energy Level

Two Phonon Excited Sate
KE = (2+1/2) ħω

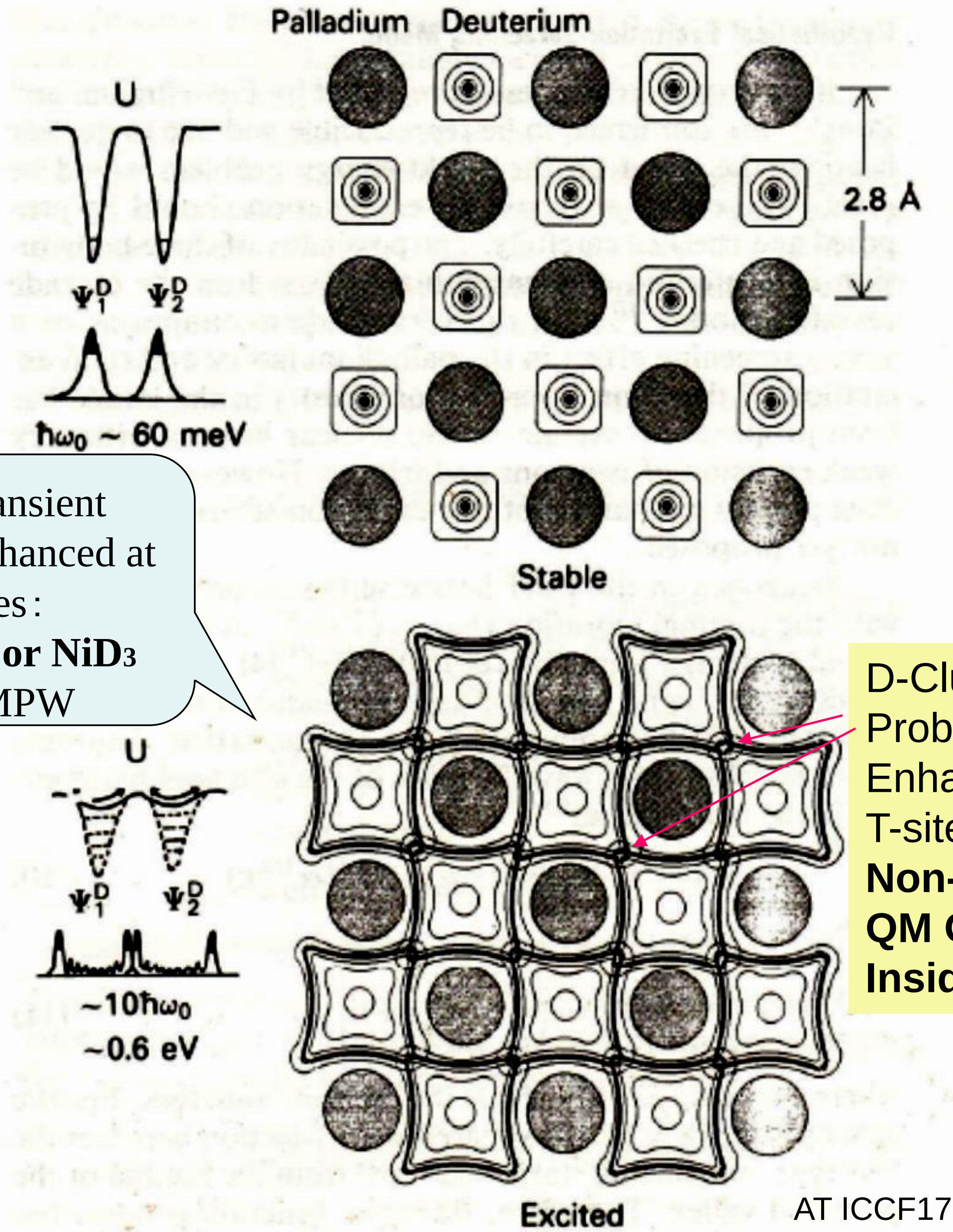
One Phonon Excited Sate
KE = (1+1/2) ħω

Ground State (Zero-point Osci.)
KE = ħω /2 (32 meV for D in PdD)
Absolute Zero Degree (0°K)

Trapping Potential Well

show

P191



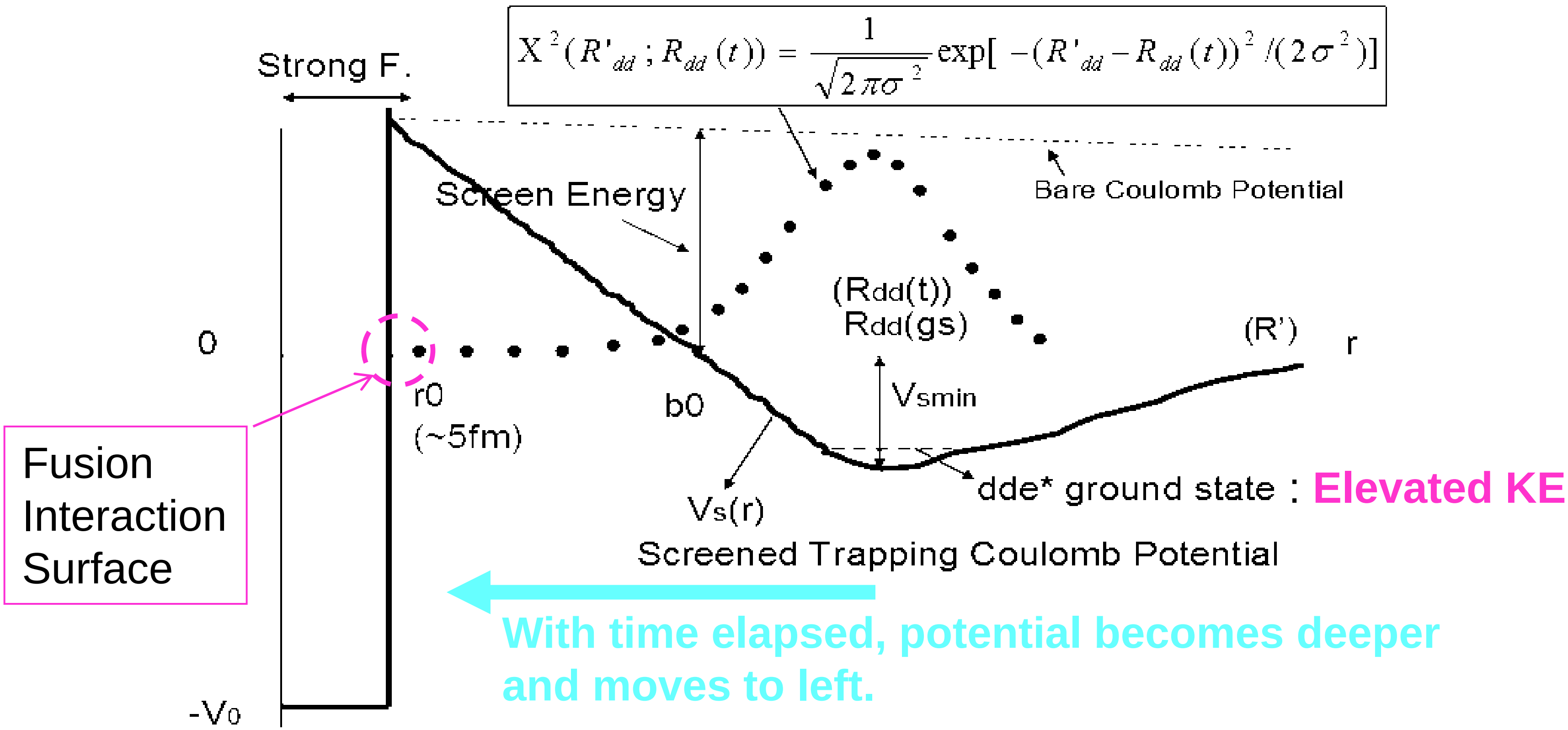
Formation of transient
4D/TSC will be enhanced at
around T-sites :
Mesoscopic **PdD or NiD3**
Particle in GMPW

D-Cluster Formation
Probability will be
Enhanced at around
T-sites, by
Non-linear Coupled
QM Oscillation
Inside GMPW.

show ACS2007

Time Dependent TSC Condensation: No Stable State, but into sub-pm entity

Adiabatic Potential for Molecule dde*
and its ground state squared wave function



With time elapsed, potential becomes deeper and moves to left.

Fusion Rate Formula by Fermi's Golden Rule

$$< FusionRate >= \frac{2}{\hbar} \langle \Psi_f | W(r) | \Psi_i \rangle$$

$$-\frac{\hbar^2}{2m} \nabla^2 \Psi + [V_{nr}(r) + iW(r)]\Psi + V_c(r)\Psi = E\Psi$$

Nuclear Potential

Coulomb Potential

$$\Psi(r) = \Psi_n(r) \cdot \Psi_c(r)$$

Inter-nuclear wave function

EM Field wave function

Born-Oppenheimer Approximation

show

Fusion Rate Formula by Born-Oppenheimer Approximation

$$< FusionRate >= \frac{2}{\hbar}\left\langle \Psi_{nf} \middle| W(r) \middle| \Psi_{ni} \right\rangle_{Vn} \cdot \left\langle \Psi_{cf} \middle| \Psi_{ci} \right\rangle_{Vn}$$

$$Vn \approx 4\pi R_n{}^2 \lambda\!\!\!^{-}_{\pi}$$

: Effective Volume of Nuclear Strong (Weak) Interaction Domain

$\lambda\!\!\!^{-}_{\pi}$: Compton wave length of pion (1.4 fm) (weak boson: 2.5 am)

Rn : Radius of Interaction surface of strong (weak) force exchange

Fusion rate of D-cluster is estimated by time-integration of barrier factors.

Using Fermi's golden rule(8), fusion rate is obtained by,

Skip

$$\lambda_{nd} = \frac{2}{\hbar}\langle W \rangle P_{nd}(r_0) = 3.04 \times 10^{21} P_{nd}(r_0)\langle W \rangle \qquad (32)$$

Nuclear **Strong Interaction: Inter-nuclear fusion rate**

Coulomb Interaction: **Barrier Factor: Weight (within nuclear domain) of Cluster wave function of outer field**

Here <W> value is in MeV unit.

...ule, and also for EQPET dde*(2,2) molecule, respectively.

PEF: derivative of One-Pion-Exchange-Potential

The imaginary part of optical potential <W> for effective interaction, namely fusion, is estimated by the empirical rule for PEF (pion exchange force number) values(8), and given in **Table-III**. Fusion rates are shown in **Table-IV**. Here we used the following relations between astrophysical S-value S_{nd}, T-matrix for the effective interaction Hamiltonian of nuclear fusion T_n and pion-exchange number PEF, in <W> estimation(8).

$$S_{nd} \propto T_n^{\ 2} \propto (PEF)^{10}$$

$$T_n = \langle W \rangle \propto (PEF)^5$$

Charged Pion Exchange (Isospin/Spin)
Can be scaled by **PEF-value(-),** empirically.
Astrophysical S-values are estimated for
Multi-body hadronic **fusion** interactions.

And we used known S-values at E_d=0 and <W> values for DD[16)] and DT reactions, as reference values.

One Pion Exchange Potential and PEF

Skip

One Pion Exchange Potential (Hamada-Johnston Potential)

$$V_{OPEP}(x) = v_0 \cdot (\vec{\tau}_1 \cdot \vec{\tau}_2)\left\{\vec{\sigma}_1 \cdot \vec{\sigma}_2 + (1 + \frac{3}{x} + \frac{3}{x^2})S_{12}\right\}\frac{\exp(-x)}{x}$$

Minus 3 for p-n; fusion

$$x = \frac{m_\pi c}{\hbar} r = \frac{r}{1.43}[fm]$$

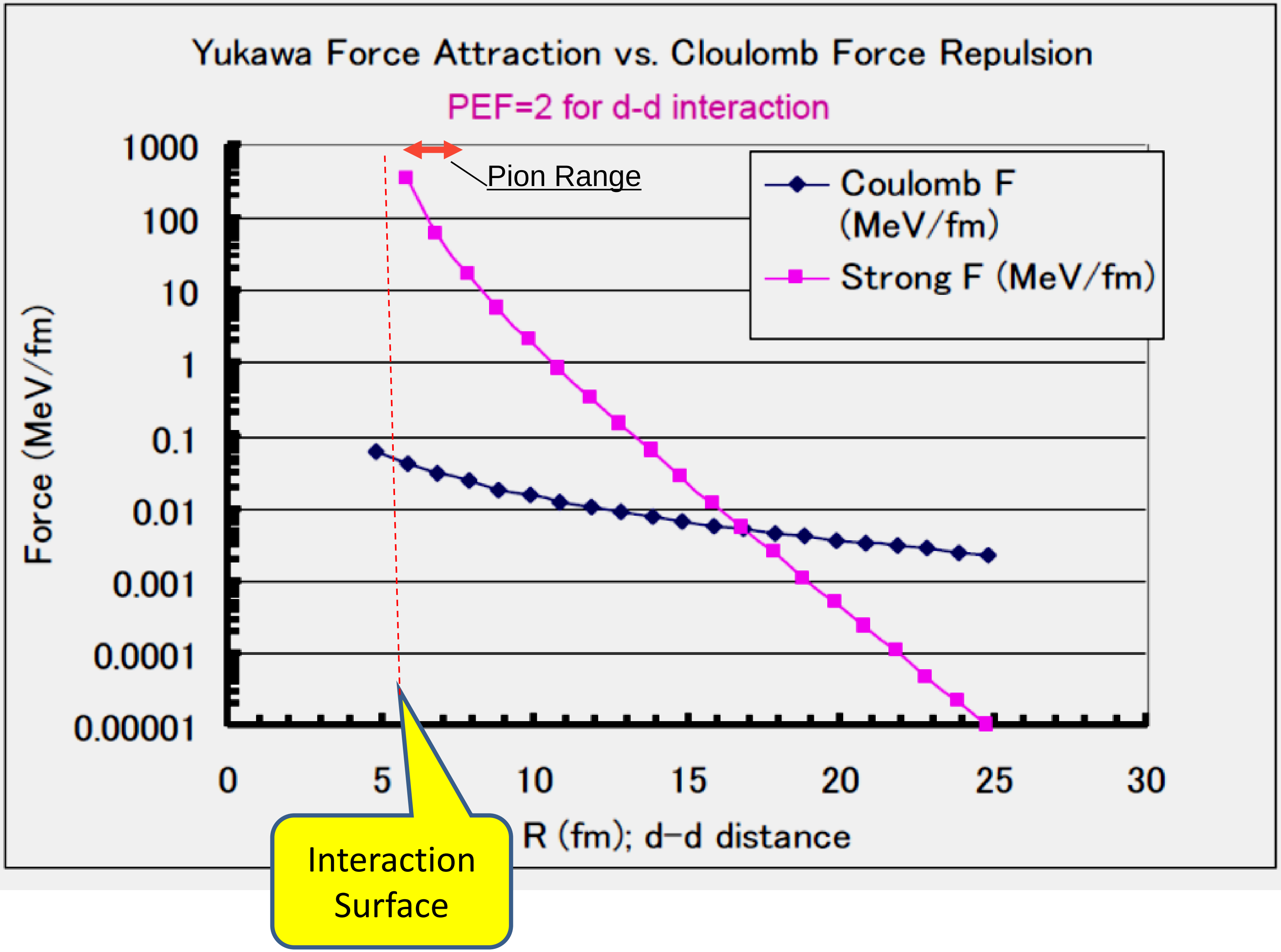
Yukawa Potential $Y(x) = \frac{\exp(-x)}{x}$

$$v_0 = \frac{1}{3}\frac{f^2 m_\pi c^2}{\hbar c} = 3.65[MeV] \qquad S_{12} = 3\frac{(\vec{\sigma}_1 \cdot \vec{r})(\vec{\sigma}_2 \cdot \vec{r})}{r^2} - \vec{\sigma}_1 \cdot \vec{\sigma}_2$$

$$\langle OnePEF \rangle = -\frac{\partial \langle V_{OPEP}(x) \rangle_{\tau,\sigma}}{\partial r} = -\frac{1}{1.43}\frac{\partial \langle V_{OPEP}(x) \rangle_{\tau,\sigma}}{\partial x}$$

show

D-D Fusion: Strong Force vs. Coulomb Force



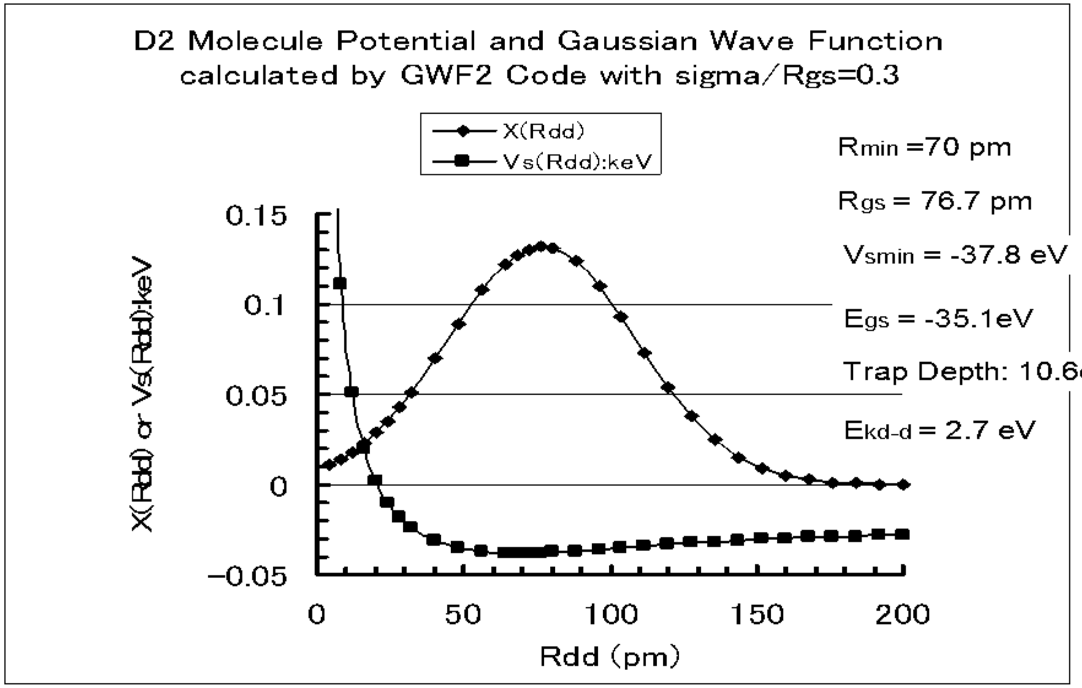
show

ACS2007

The Case of D_2 Molecule:

The relative kinetic energy of d-d pair: 2.7eV

3.2×10^4 K



Impossible to detect

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

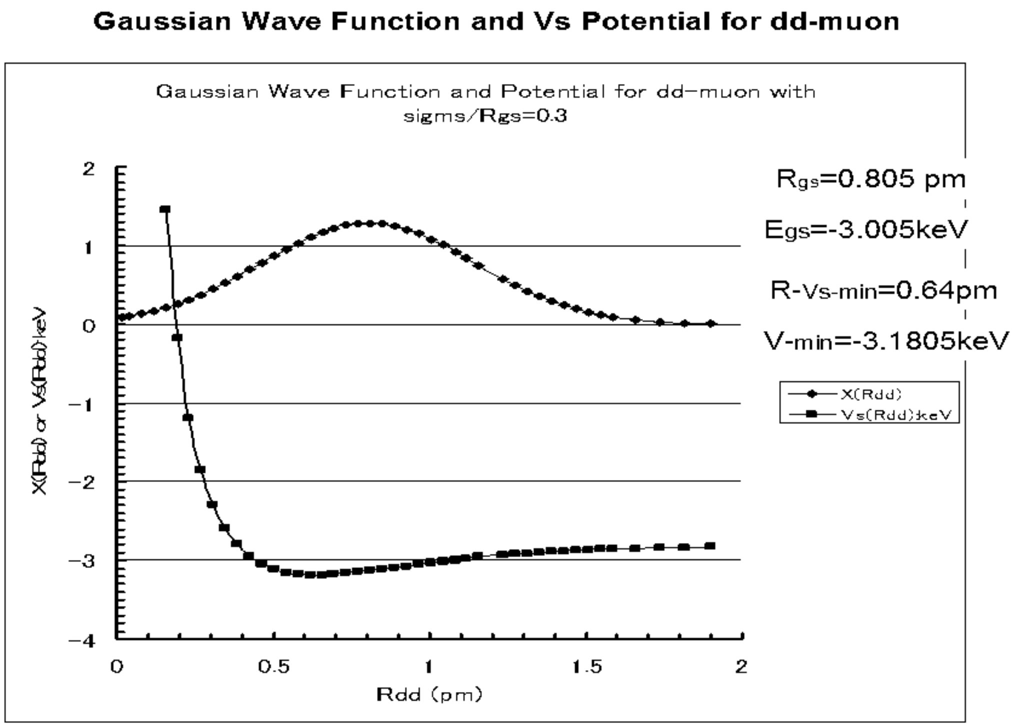
<Fusion Rate per Molecule> = 2.4×10^{-66} f/s

show

CS2007

The Case of Muonic d-d Molecule:
The relative kinetic energy of d-d pair: 180eV

2.16×10^6 K



DD fusion Finishes In 200 ps

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

<Fusion Rate per Molecule> = 2.4×10^{10} f/s

show

ACS2007

TSC Langevin Equation:

$$6m_d \frac{d^2\langle R_{dd}\rangle}{dt^2} = -\frac{11.85}{\langle R_{dd}\rangle^2} - 6\frac{\partial V_s(\langle R_{dd}\rangle; m, Z)}{\partial \langle R_{dd}\rangle} + 6.6\left\langle \frac{(R' - R_{dd})^2}{R_{dd}{}^4} \right\rangle$$

Coulombic Centripetal Force

Friction By electron Cloud

Deviation From Platonic symmetry

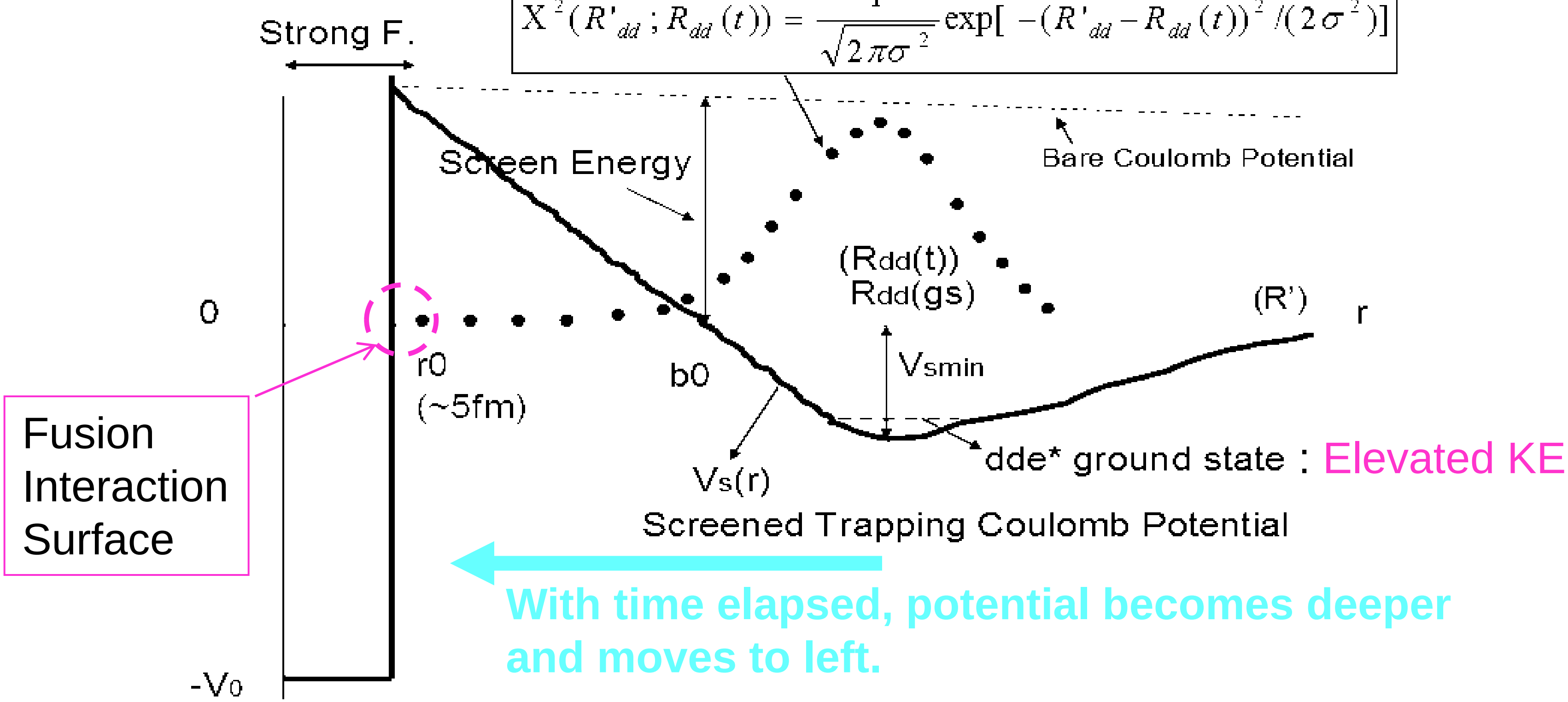
TSC Trapping Potential:

$$V_{tsc}(R' : R_{dd}(t)) = -\frac{11.85}{R_{dd}(t)} + 6V_s(R_{dd}(t); m, Z) + 2.2\frac{|R' - R_{dd}(t)|^3}{[R_{dd}(t)]^4}$$

Time Dependent TSC Condensation: No Stable State

Adiabatic Potential for Molecule dde*
and its ground state squared wave function

$$X^2(R'_{dd}; R_{dd}(t)) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp[-(R'_{dd} - R_{dd}(t))^2/(2\sigma^2)]$$



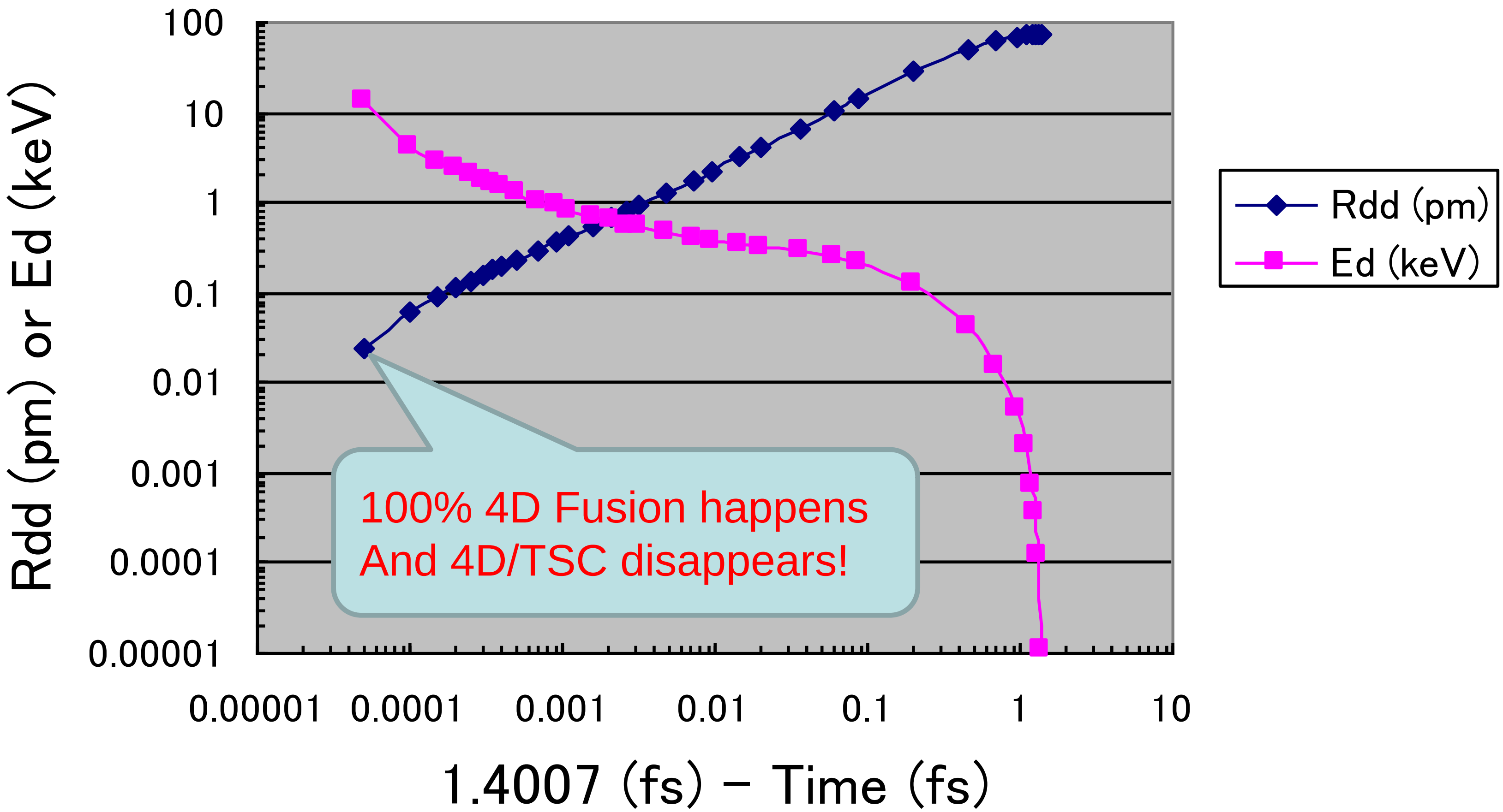
show

CS2007

TSC Condensation Motion; by the Langevin Eq.:

Condensation Time = 1.4 fs : SO FAST!

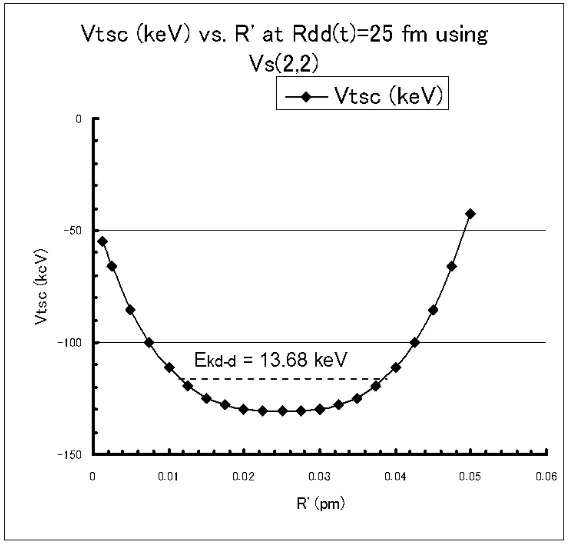
Deuteron Kinetic Energy INCREASES as R_{dd} decreases.



E_d = 13.68 keV at R_{dd} = 24.97 fm, with Vtrap = -130.4 keV show 2007

The Case of 4D/TSC-min transitory BEC: The relative kinetic energy of d-d pair: 13.7keV

1.6x10^{8} K



$$P_{nd}(m,Z) = \exp(-n\Gamma_{dd}(m,Z))$$

$$\Gamma_{dd}(m,Z) = 0.218\sqrt{\mu}\int_{r_0}^{b_0(m,z)}\sqrt{V_s(R;m,Z)-E_d}\,dR$$

$$\eta_{4d} = 1-\exp(-\int_0^{t_c}\lambda_{4d}(t)dt)$$

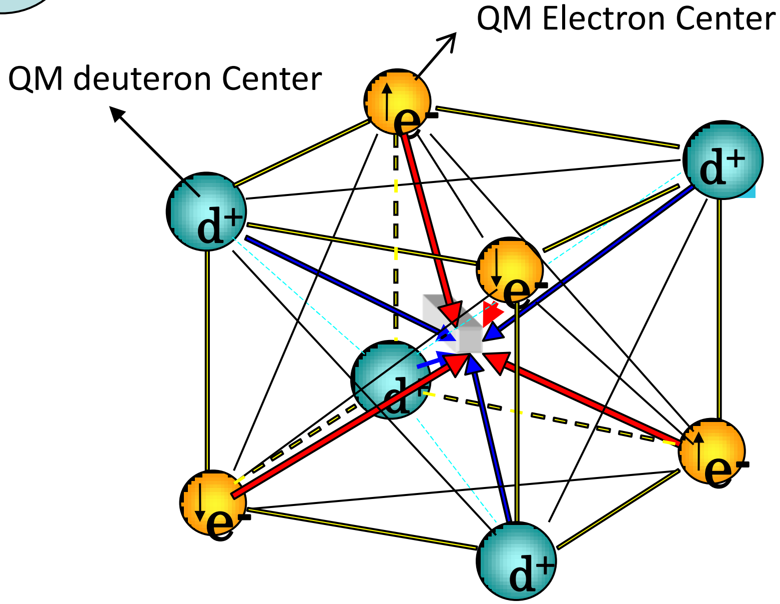
$$\lambda_{4d}(t) = 3.04\times10^{21}\langle W\rangle P_{4d}(r_0;R_{dd}(t)) = 1.88\times10^{23}P_{4d}(r_0;R_{dd}(t))$$

<fusion rate per 4D/TSC-min> = 3.7x10^{20} f/s ; for steady state

Happens in Ca. 2x10^{-20} s → Real yield of 4d fusion : η_{4d} ≈ 1.0 per TSC-cluster

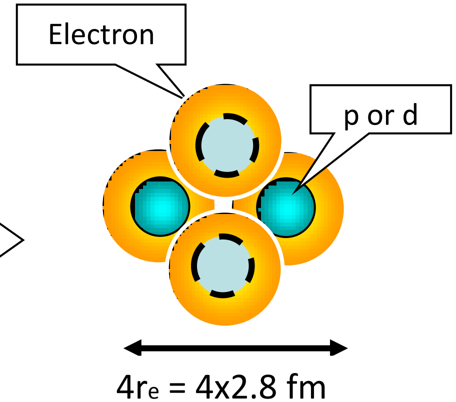
show

4D/TSC
Condensation
Reactions



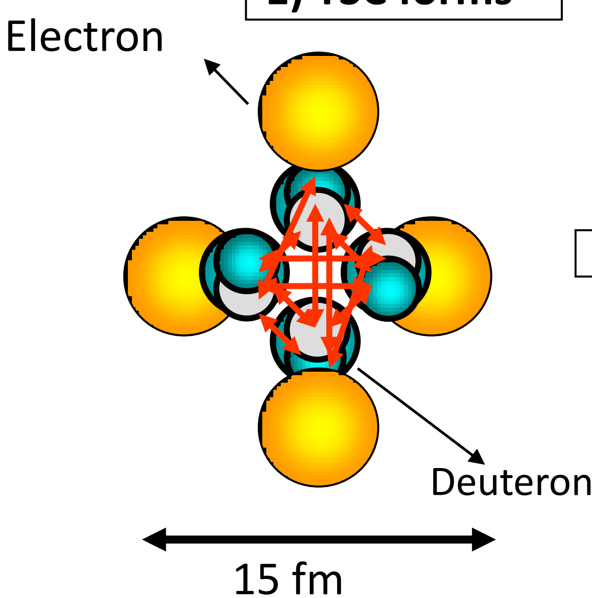
1) TSC forms

1.4007 fs



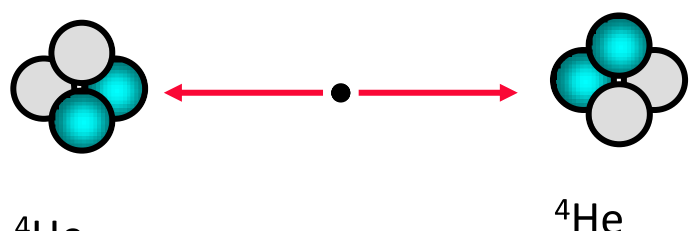
2) Minimum TSC reaches strong interaction range for fusion

100 % in $2x10^{-20}$ s



3) ^{8}Be* formation (PEF = 12)

Halo?



4) Break up to two ^{4}He's via complex final states; 0.04-5MeV α

Skip

Definition of η(t) : **Binding-E + Alpha**: Time-Dependent Sorption Energy per D(H)-atom

- L(t) : Evolution of Loading Rate (Convertible to D(H)/M)
- W(t) : Heat-Power Level in watt
- E(t) : Evolution of Released Heat

τ : Time Resolution of Calorimetry (5.2 min in Kobe Exp.)

$$E(t) = \int_0^t W(t)dt$$

$$\eta(t) = \frac{\overline{(\mathrm{d}E/\mathrm{d}t)}}{\overline{(\mathrm{d}L/\mathrm{d}t)}} = \left(\int_t^{t+\tau} \frac{\mathrm{d}E}{\mathrm{d}t}\mathrm{d}t \Big/ \tau\right) \Big/ \left(\int_t^{t+\tau} \frac{\mathrm{d}L}{\mathrm{d}t}\mathrm{d}t \Big/ \tau\right) = \int_t^{t+\tau} \mathrm{d}E \Big/ \int_t^{t+\tau} \mathrm{d}L$$

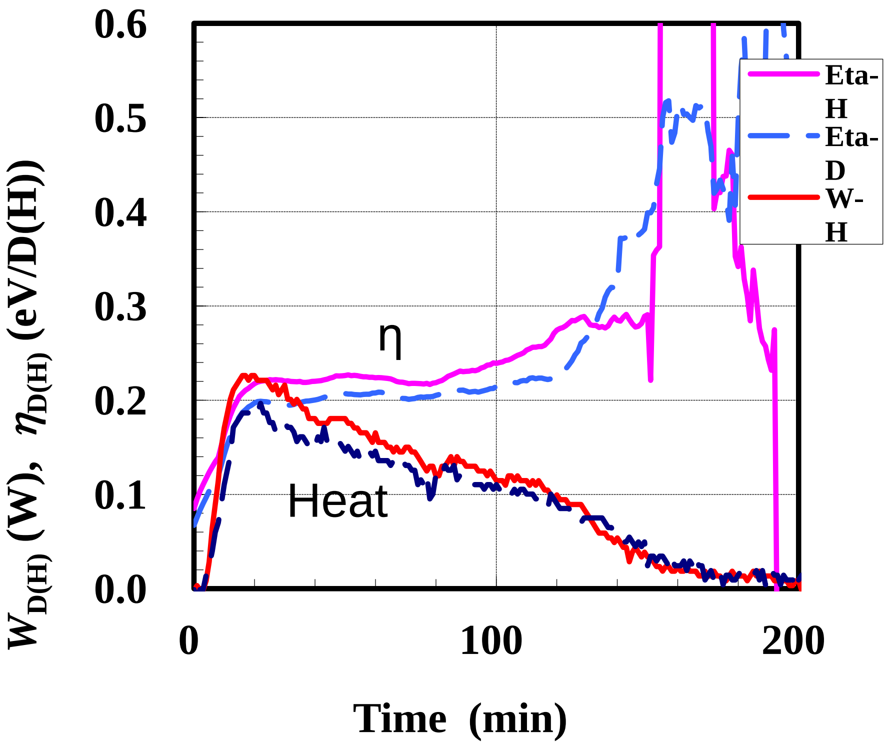
$$= \frac{\Delta E(t, t+\tau)}{\Delta L(t, t+\tau)} = \frac{E(t+\tau) - E(t)}{L(t+\tau) - L(t)}$$

PP3,4 #1(left) and #3(right) (100-nmϕ Pd):
PdO layer makes large effect (Ia phase)

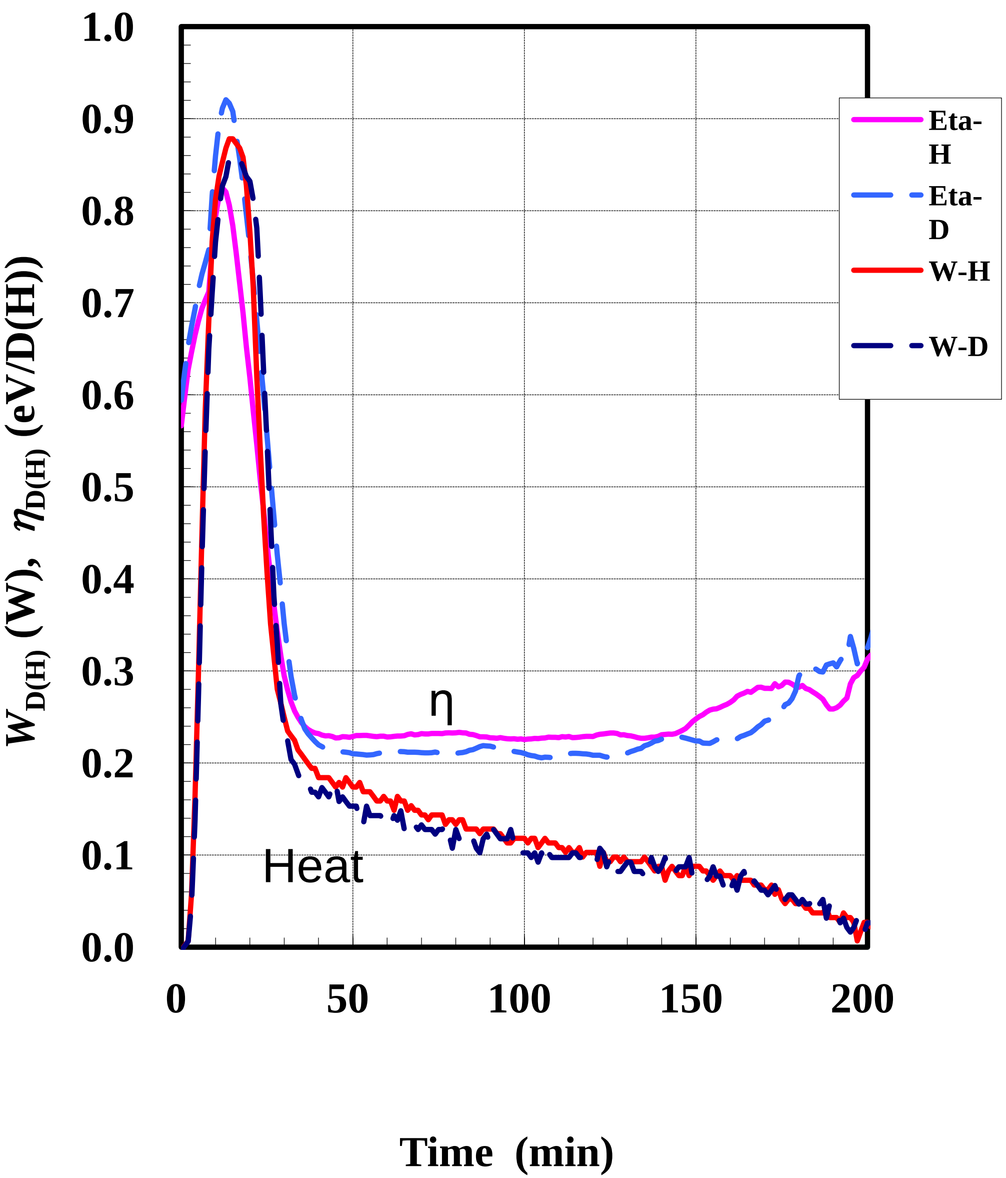
Skip

Comparison to bulk Pd:
η = 0.2

PP3,4#1: Virgin run



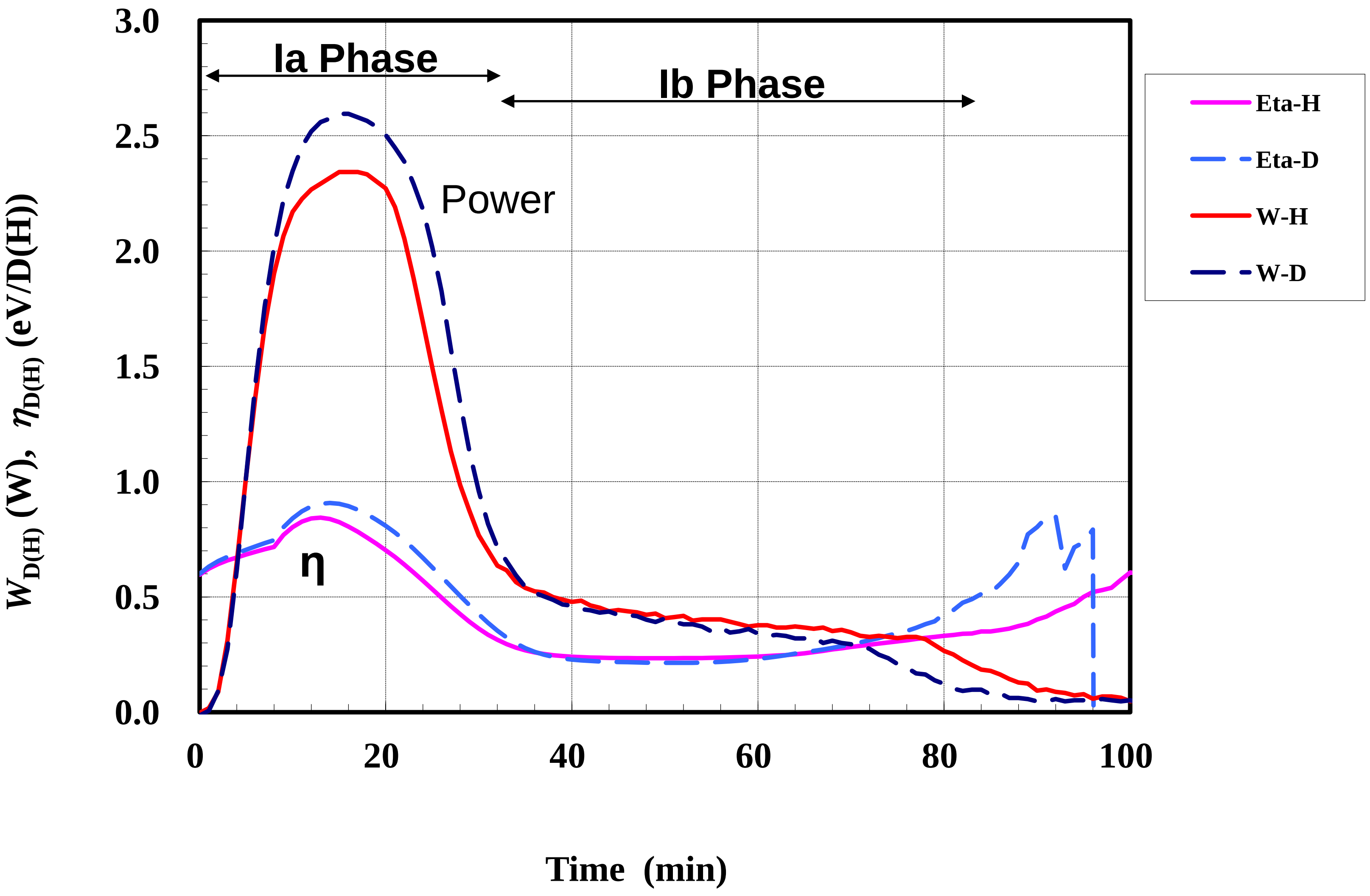
PP3,4#3: After 1.9(1.7)% PdO/Pd



Oxidization of Pd-Black makes large heat（Ia-Phase）

Skip

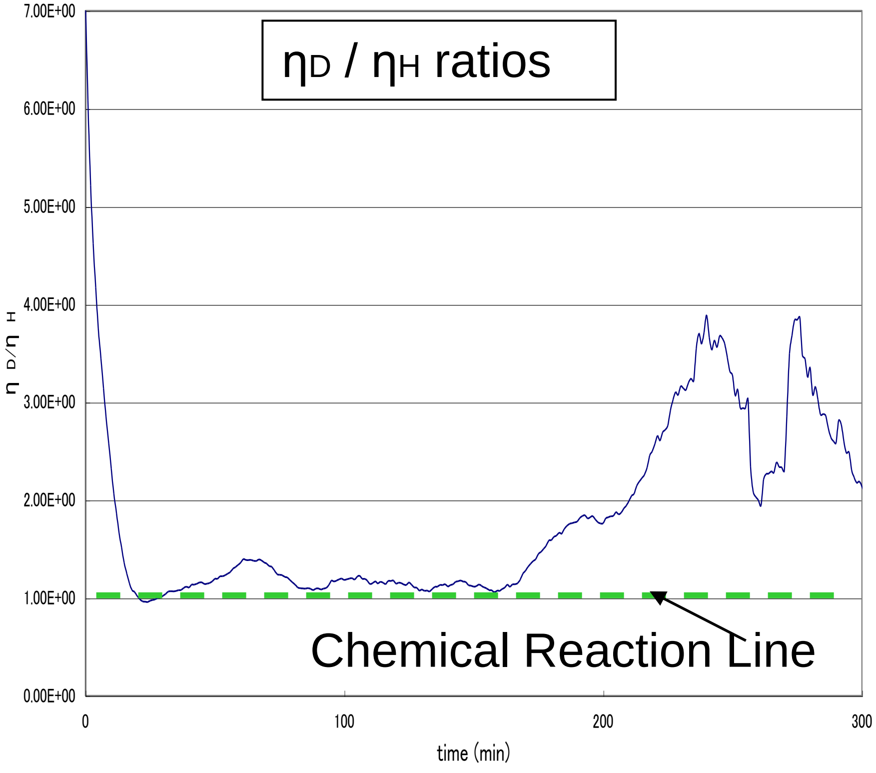
PB5,6#3 η vs. Power: After Forced Oxidization (20-17%)

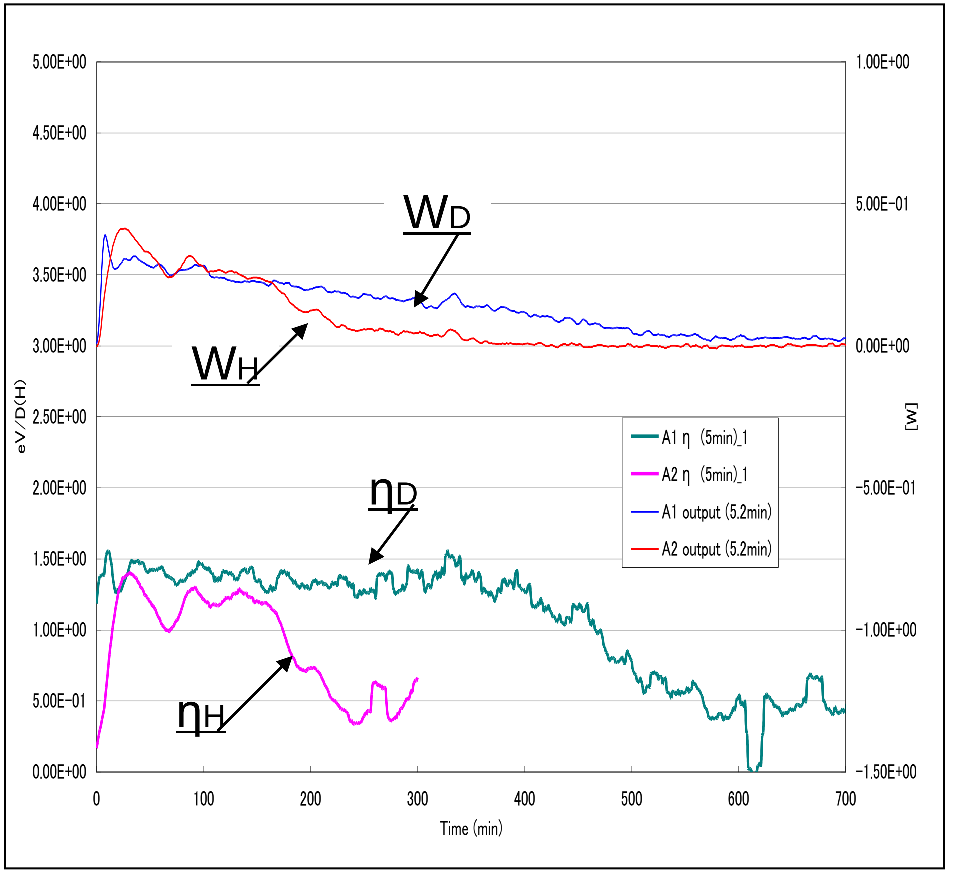


show

D/H Isotopic Effect in Heat-power (W); energy per D(H) sorption = η,
η_D / η_H Ratio had local very large values Beyond Chemical Explanation.
:D-**PZ**11#3 vs. H-**PZ**12#3: after forced oxidization **(50-80% PdO/Pd)**

Nano-Pd/ZrO_2

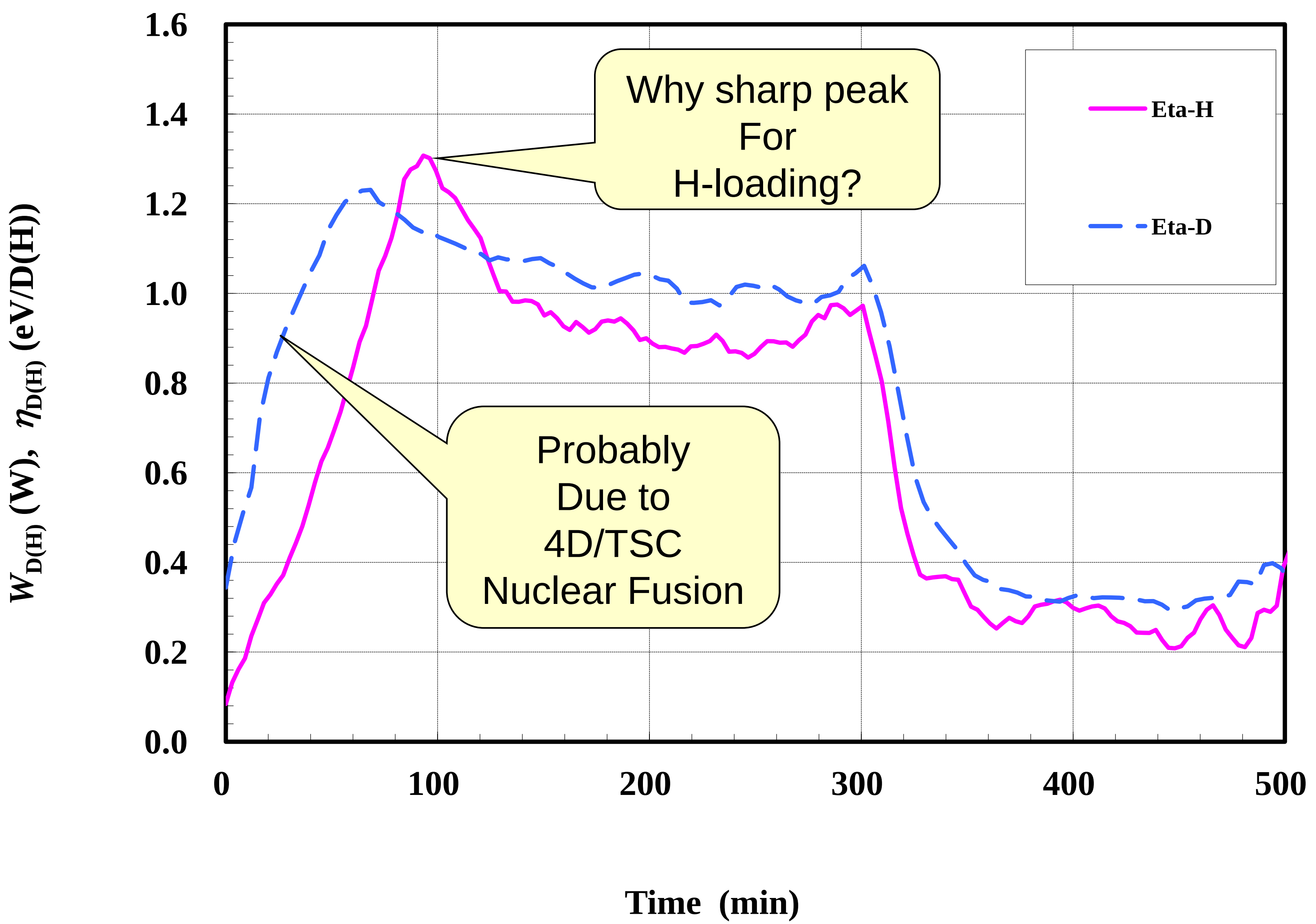




η_D / η_H >> 1.0;
By Nuclear Heat (?)

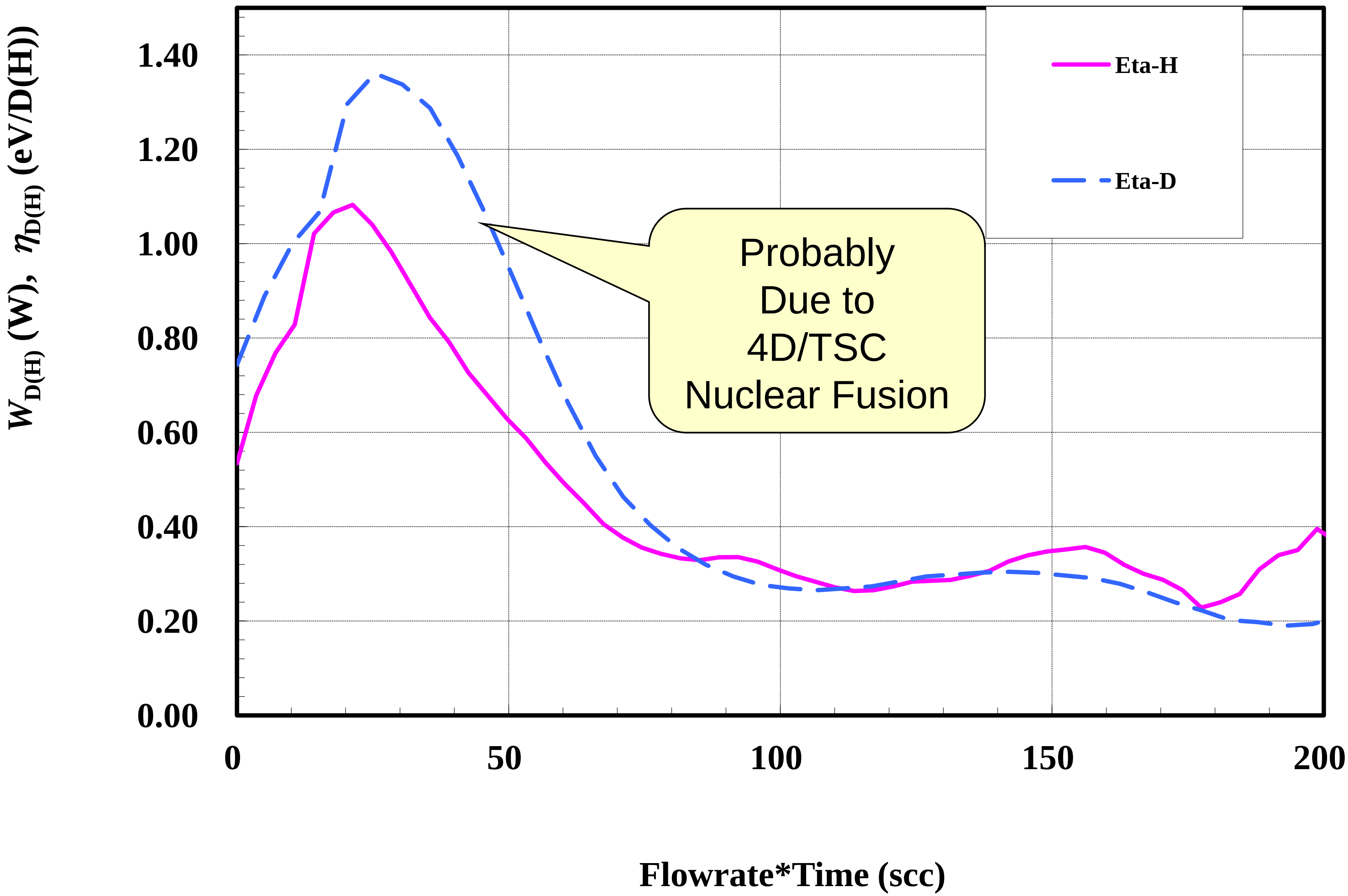
show

NanoPd/SiO2:PSII3,4#1:Virgin; η



PSII3,4#3_4(A1(D):28.72%,A2(H):34.19%); η

Skip



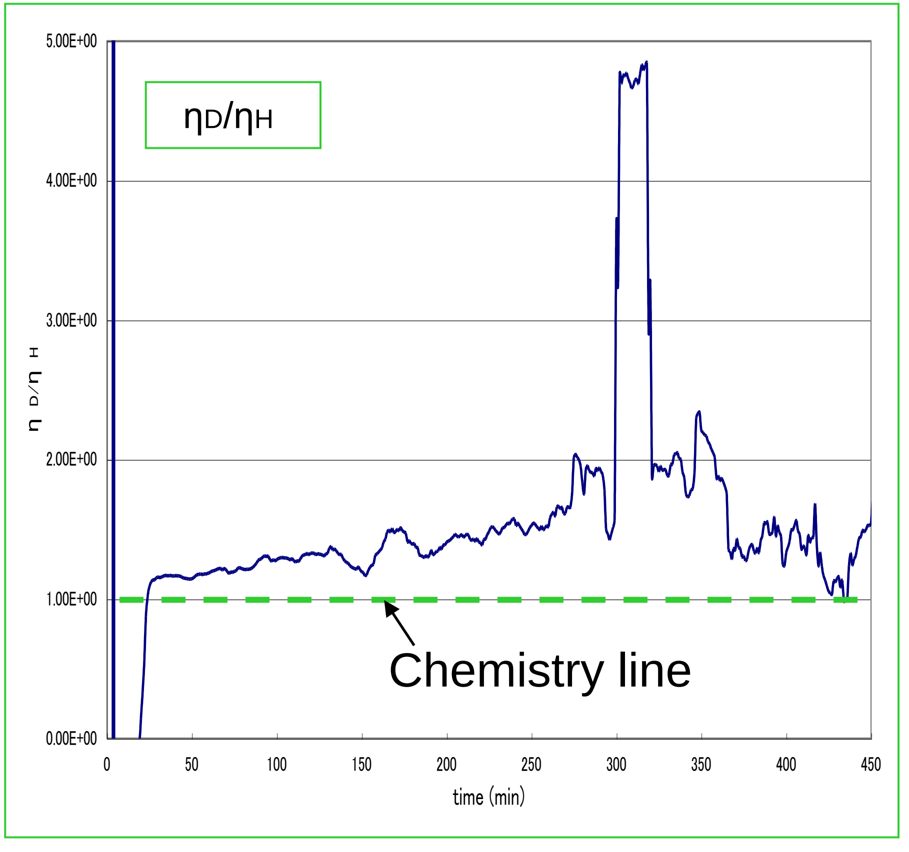
show

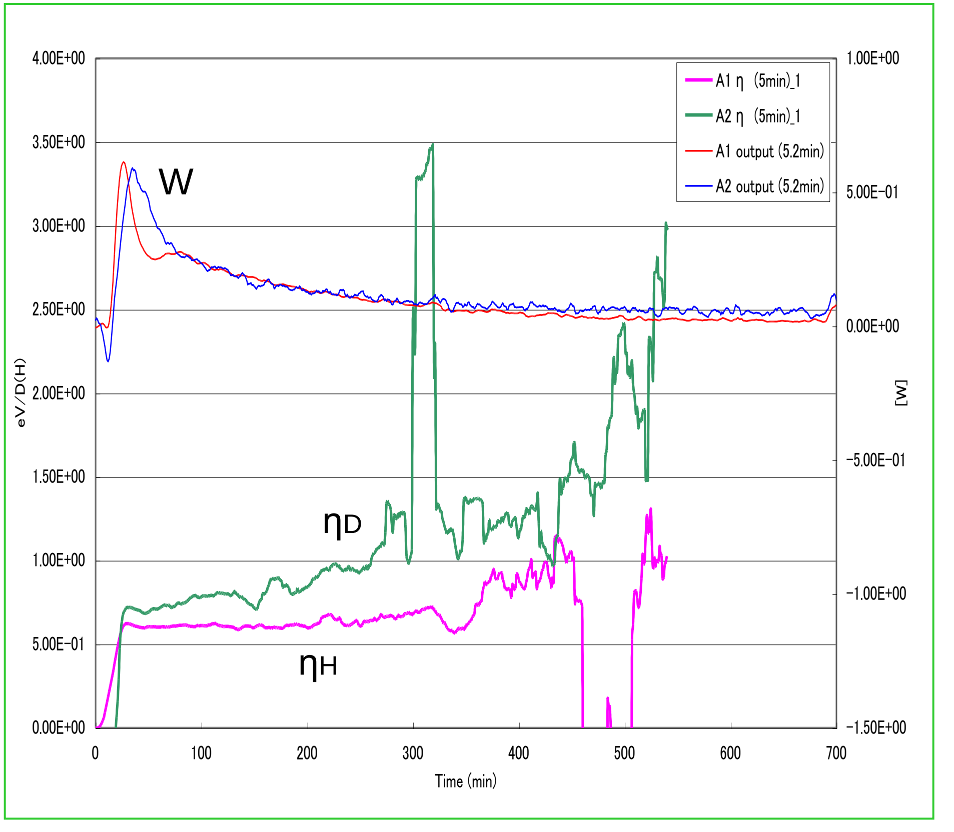
PNZ2B After Forced Oxidization（80%MO/M)

: Heat-Power (W), Energy per D(H)-sorption (η) and η_D/η_H

Nuclear Effect for η_D/η_H >> 1.0 !(?)

<u>Pd_1Ni_7/ZrO_2</u>

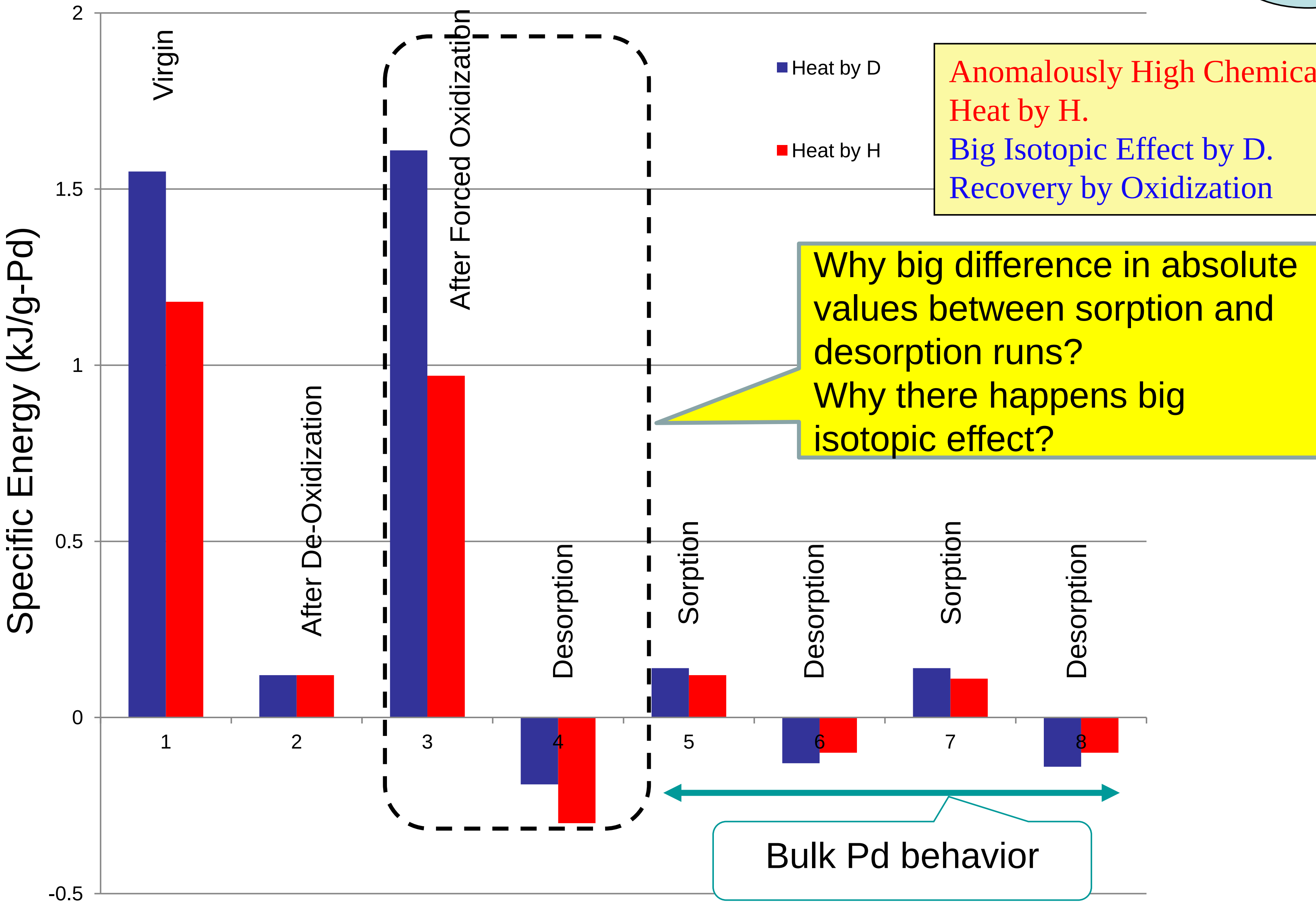




Integrated Heat Data (Phase-I) for PZ11 and PZ12

8nm diameter Pd

Skip



Anomalously High Chemical Heat by H.
Big Isotopic Effect by D.
Recovery by Oxidization

Kobe Results : Tested Metal/Ceramics Powders and Results

Skip

	Pd	Ni	Zr	O	Supplier	**Anomalies observed?**
100nmϕ-Pd **PP**	995%, 100nmϕ	---	---	---	Nilaco Corp.	[1],[2] No, bulk metal data, but PdO
Pd-black **PB**	99.9%, 300mesh	---	---	---	Nilaco Corp.	[1],[2] Yes, a little large heat & D/Pd
8-10nmϕ-*Pd* **PZ**	0.346	---	0.654	(1.64)	Santoku Corp.	[1],[2],[3], discussed **Yes**, Heat and D/Pd reproducible
mixed oxide **NZ**	---	0.358	0.642	(1.64)	Santoku Corp.	[2] No heat and loading
mixed oxide **PNZ**	0.105	0.253	0.642	(1.64)	Santoku Corp.	[2] Yes, but weak
2nmϕ-*PdNi* **PNZ2B**	0.04	0.29	0.67	(1.67)	Dr. B. Ahern	**Yes**, very large heat and D(H)/M, reproducible

Drastic change happens! **Why?**

[1] Phys. Lett. A, 373 (2009) 3109-3112.
[2] ***Low Eergy Nuclear Reactions***, (AIP Conf. Proc. 1273, ed. Jan Marwan, 2010).
[3] ***LENR Source Book 3***, (ed. Jan Marwan, ACS) to be published.

Phenomenological Model for PdO-coated Pd-nano-particle and Pd-Ni binary shell-core nano-particle as "Mesoscopic Catalyst"

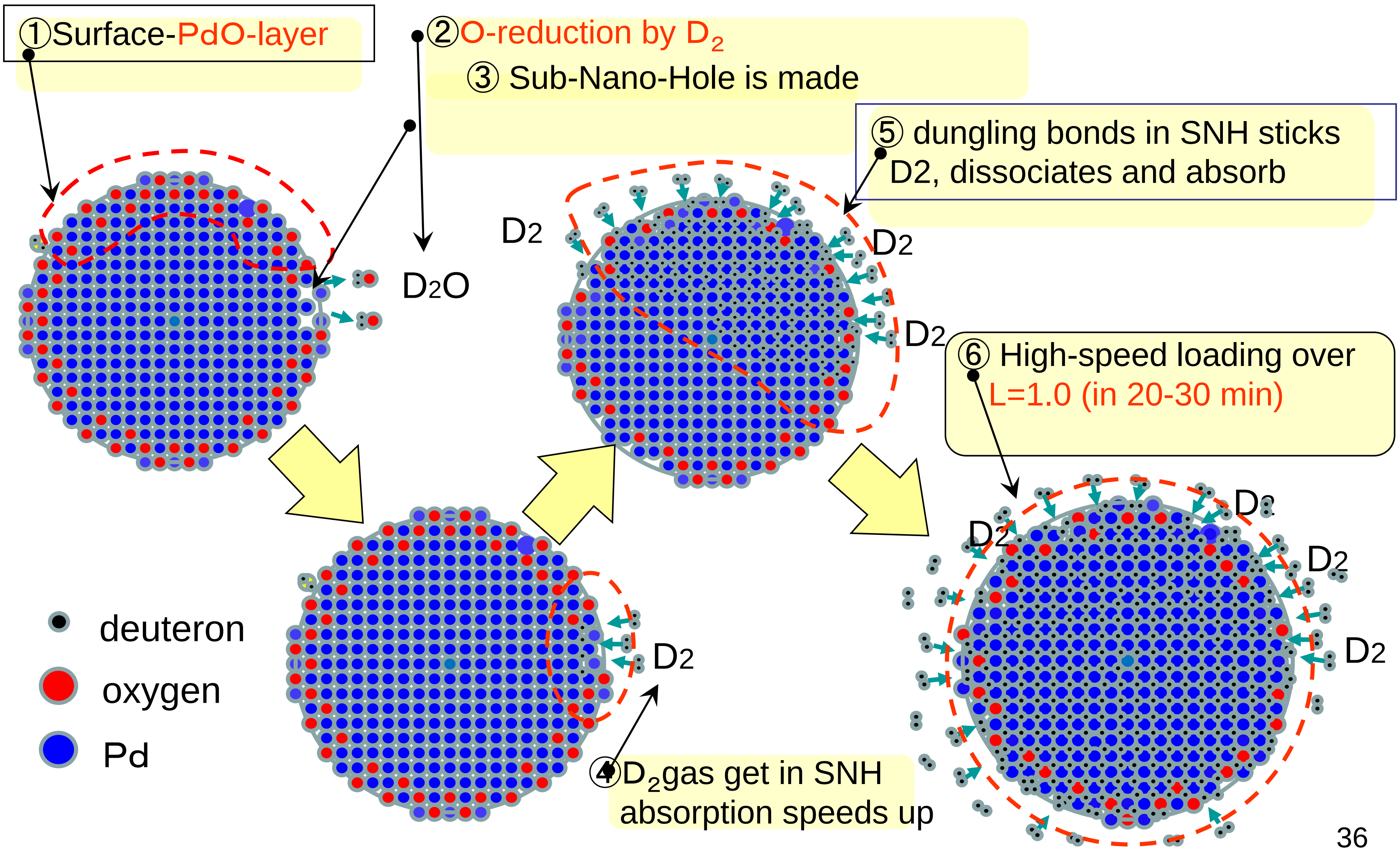
Skip

- PdO surface coating for few atomic layers (Pd ad-atoms on Ni core)
- Reduction of PdO by incoming D(H)-gas
- De-sorption of D(H)2O into vacuum
- "Sub-Nano Hole", SNH with active chemical dangling bonds
- Rapid adsorption of D(H) in SNHs
- 4D/TSC, cluster formation at SNHs
- Rapid lattice absorption (PdD(H) formation) through surface nano-holes, reaching to over-loaded x>1 state
- Formation of Collective Mesoscopic Potential Well
- Non-linear coupled oscillation of "long"- and "short"-pendulum state (PdD or NiD_3 local lattice)
- 4D/TSC cluster formation under non-linear oscillation

35

Skip

Modeling of H(D) Loading for PZ, PS Samples

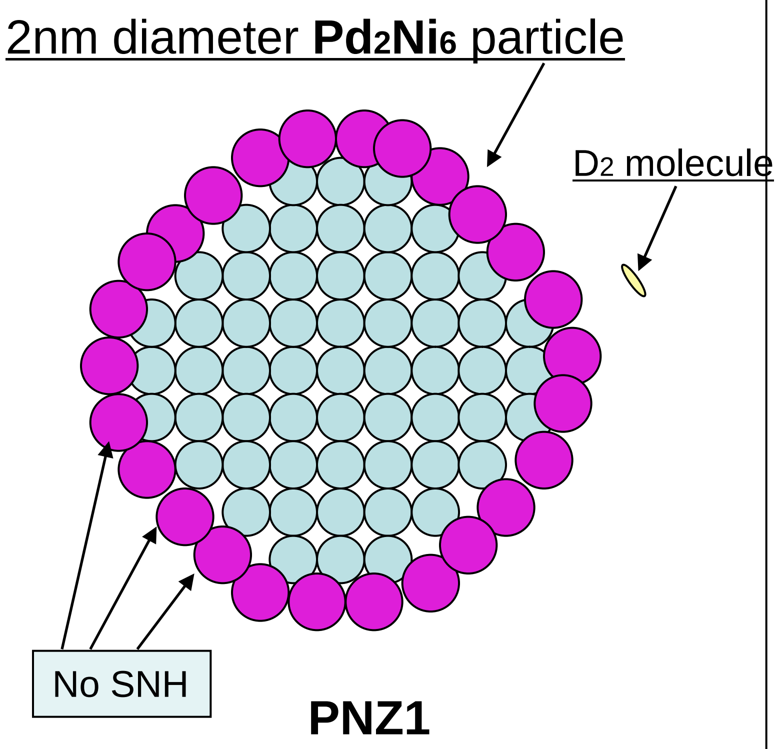


Binary Alloy Metal Nano-Particle Catalyst ;Model for Pd_xNi_y

a) Complete-Pd-shell/Ni-core

Ni-atom; r_0 = 0.138 nm

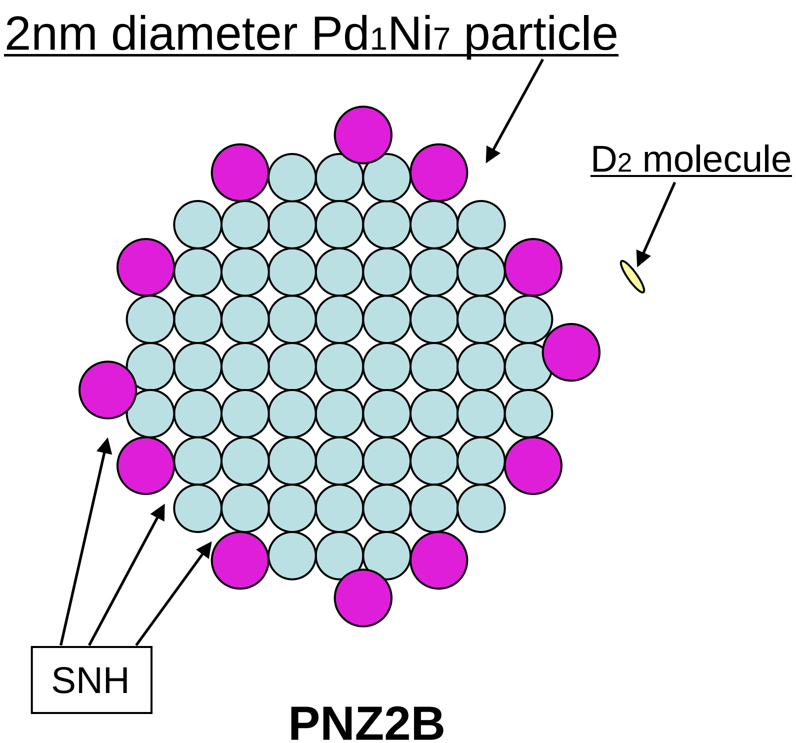
Pd-atom; r_0 =0.152 nm



b) Incomplete-Pd-shell/Ni-core

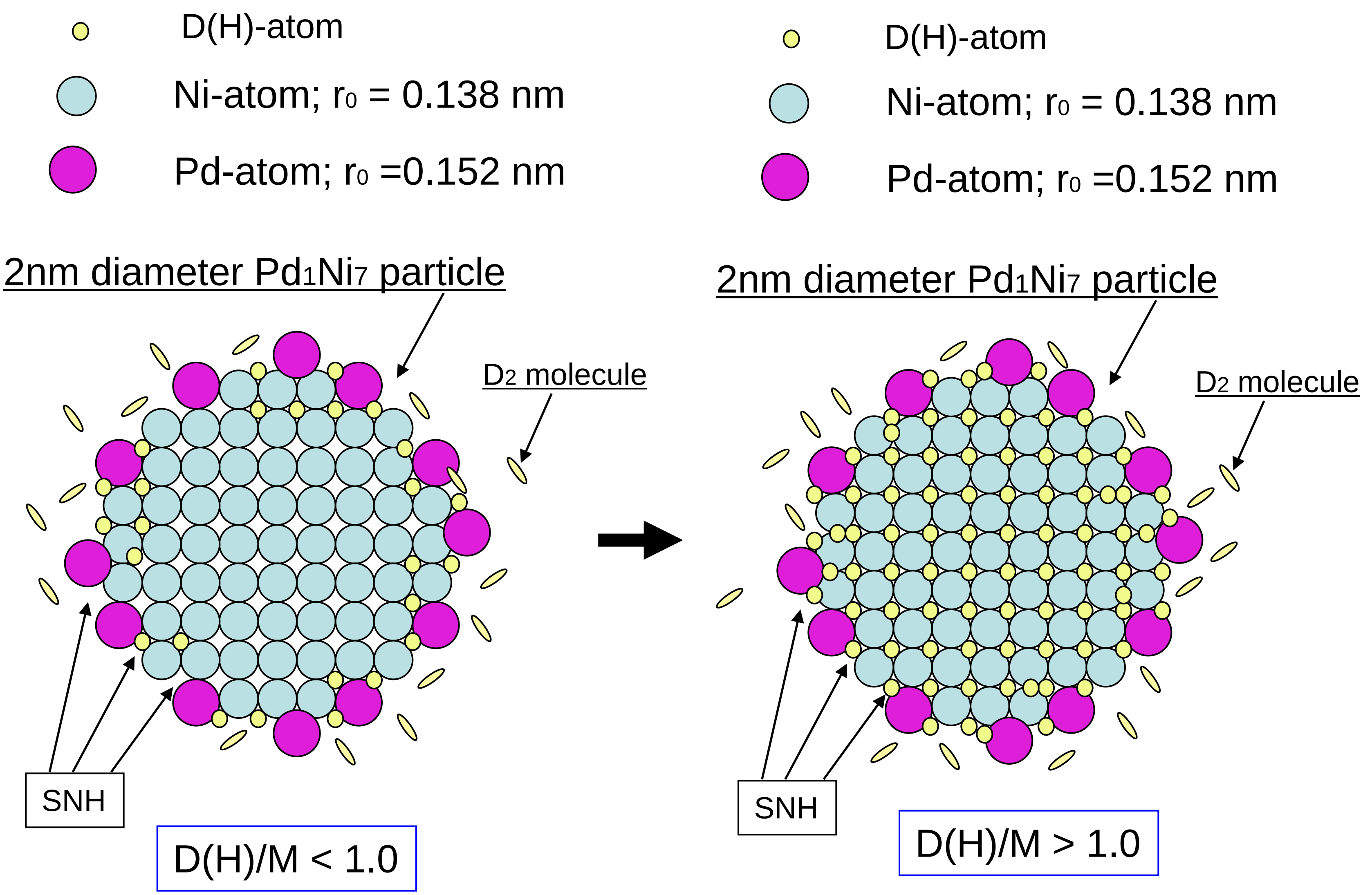
Ni-atom; r_0 = 0.138 nm

Pd-atom; r_0 =0.152 nm



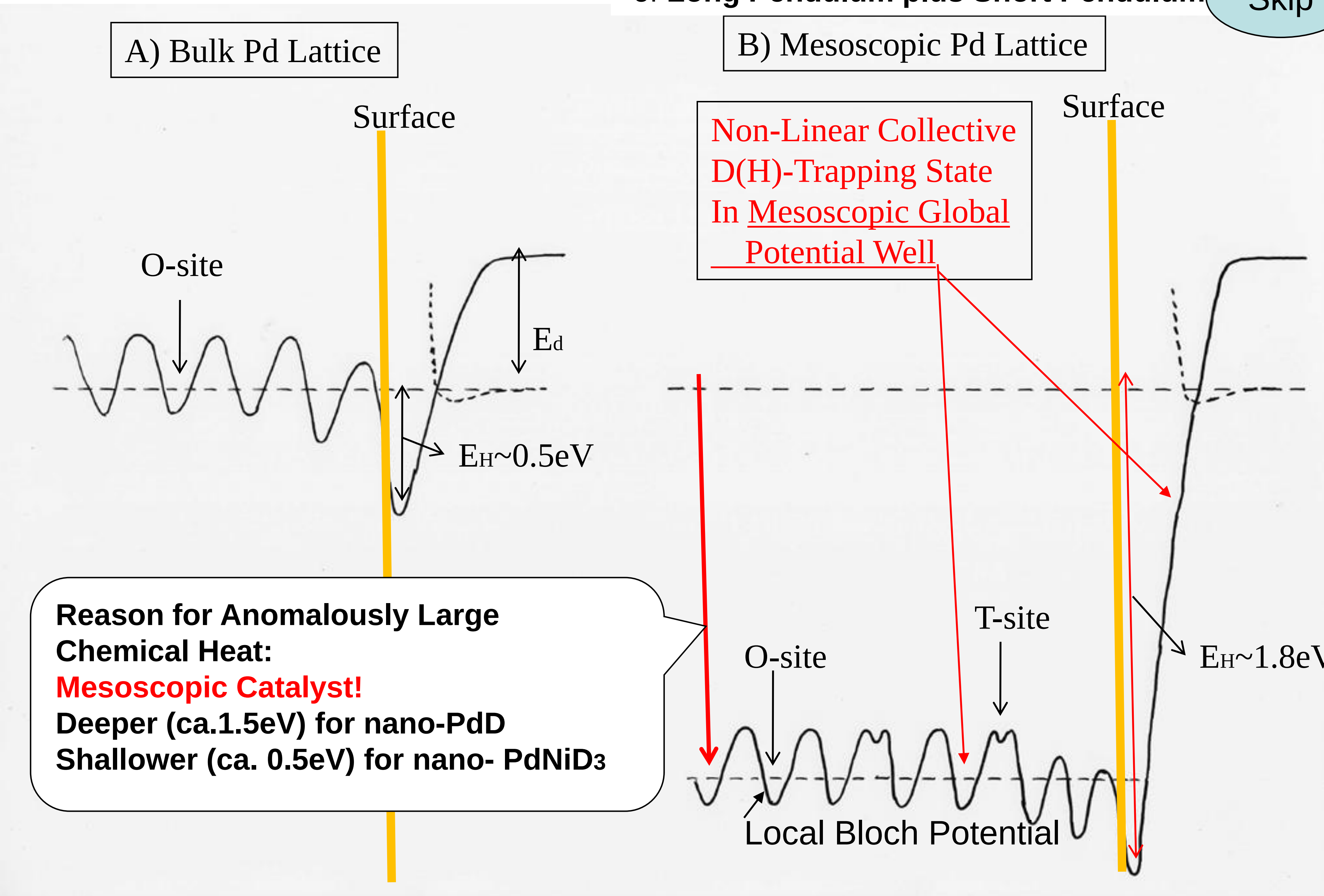
SNHs are prepared by O-reduction to start D(H) absorption (left)
And D(H)/M loading ratio exceeds 1.0 level (right)

Skip



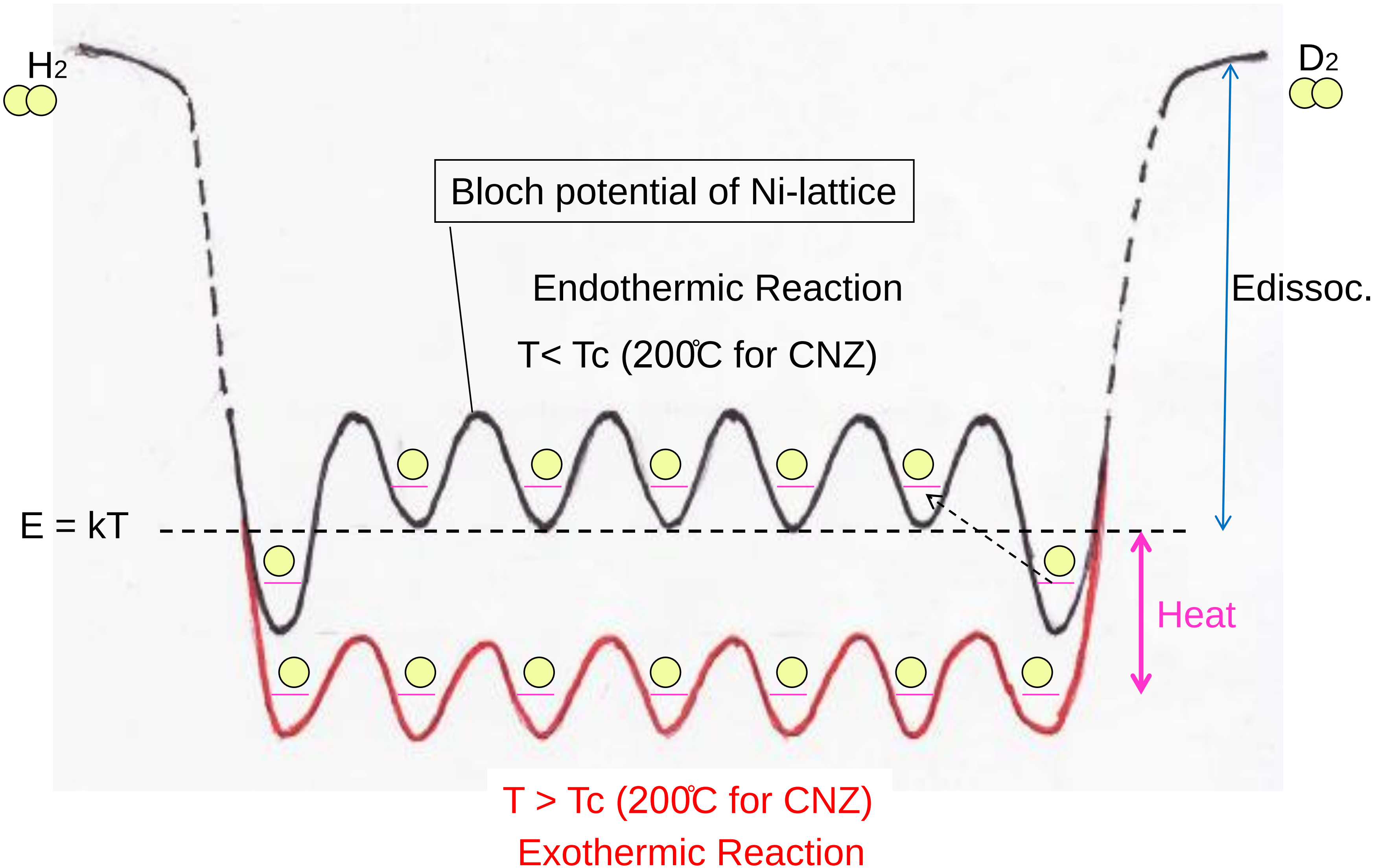
Quasi-free D-motion in coupled oscillation of **Long Pendulum plus Short Pendulum**

Skip



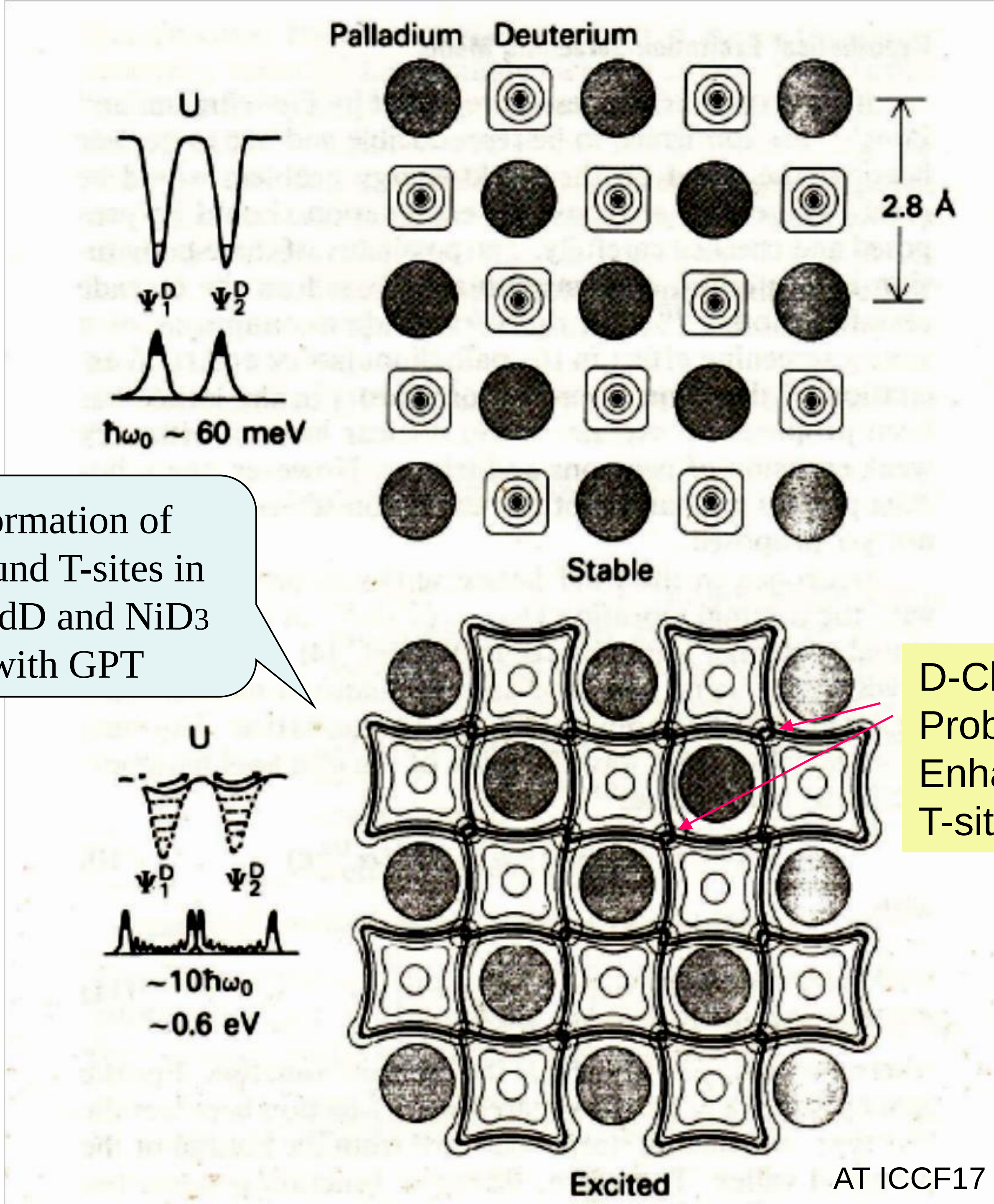
Skip

Speculative image of GMPW (Global Mesoscopic Potential Well)
For CNZ (Cu-Ni-ZrO2) nanocomposite powder + D(H) absorption



FT91

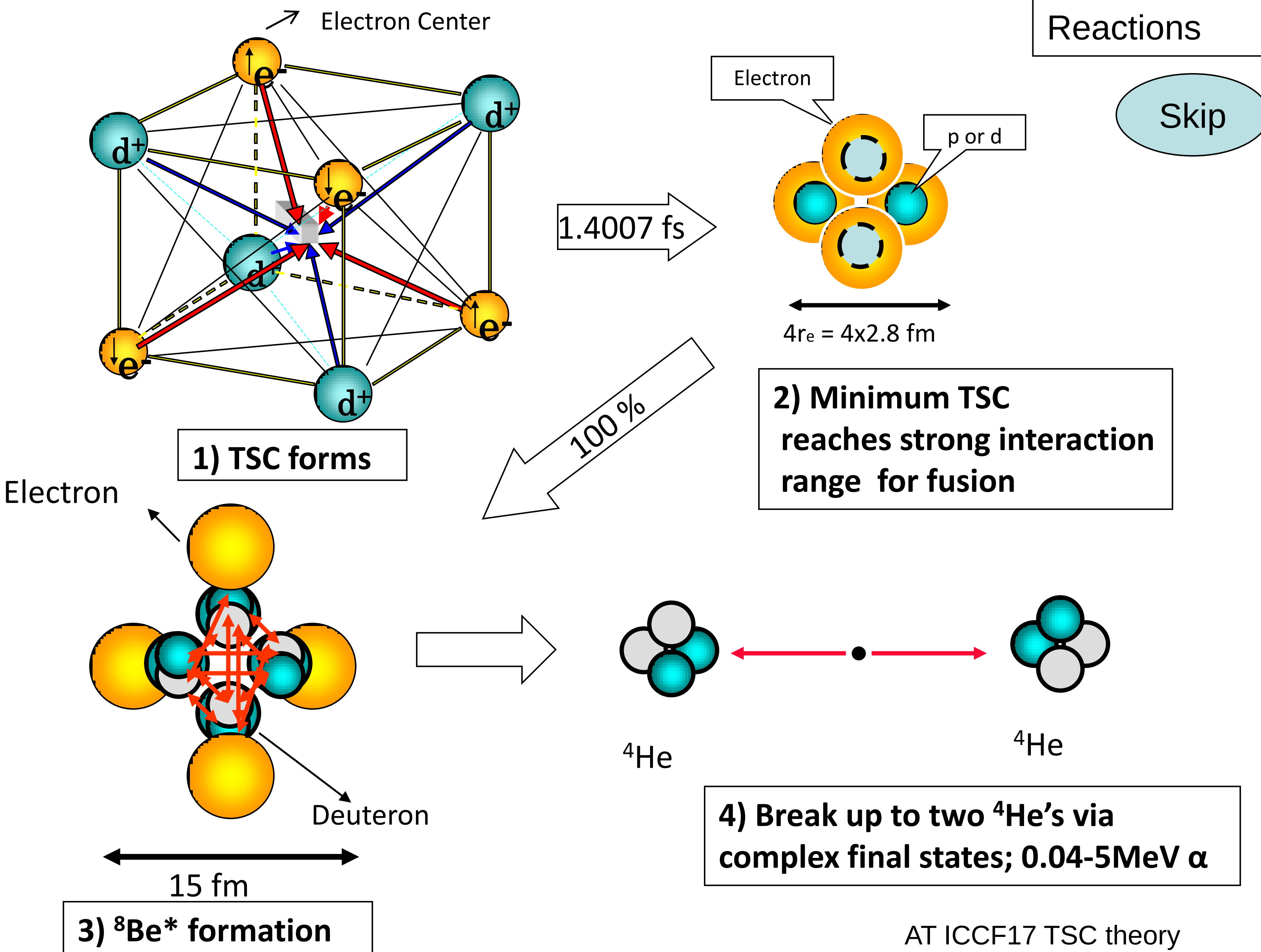
Skip



Transient formation of 4D/TSCs around T-sites in Mesoscopic PdD and NiD3 Particles with GPT

D-Cluster Formation Probability will be Enhanced at around T-sites.

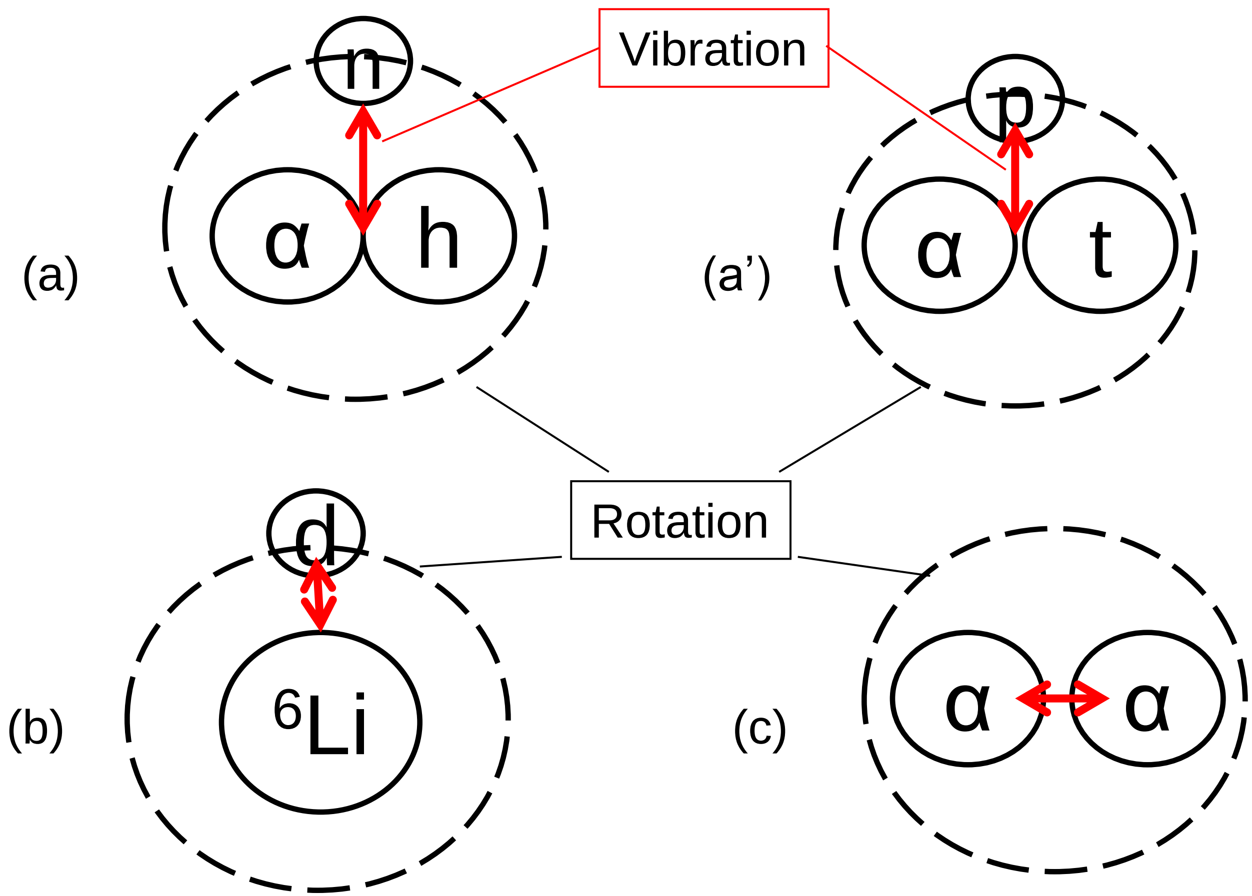
4D/TSC
Condensation Reactions



AT ICCF17 TSC theory

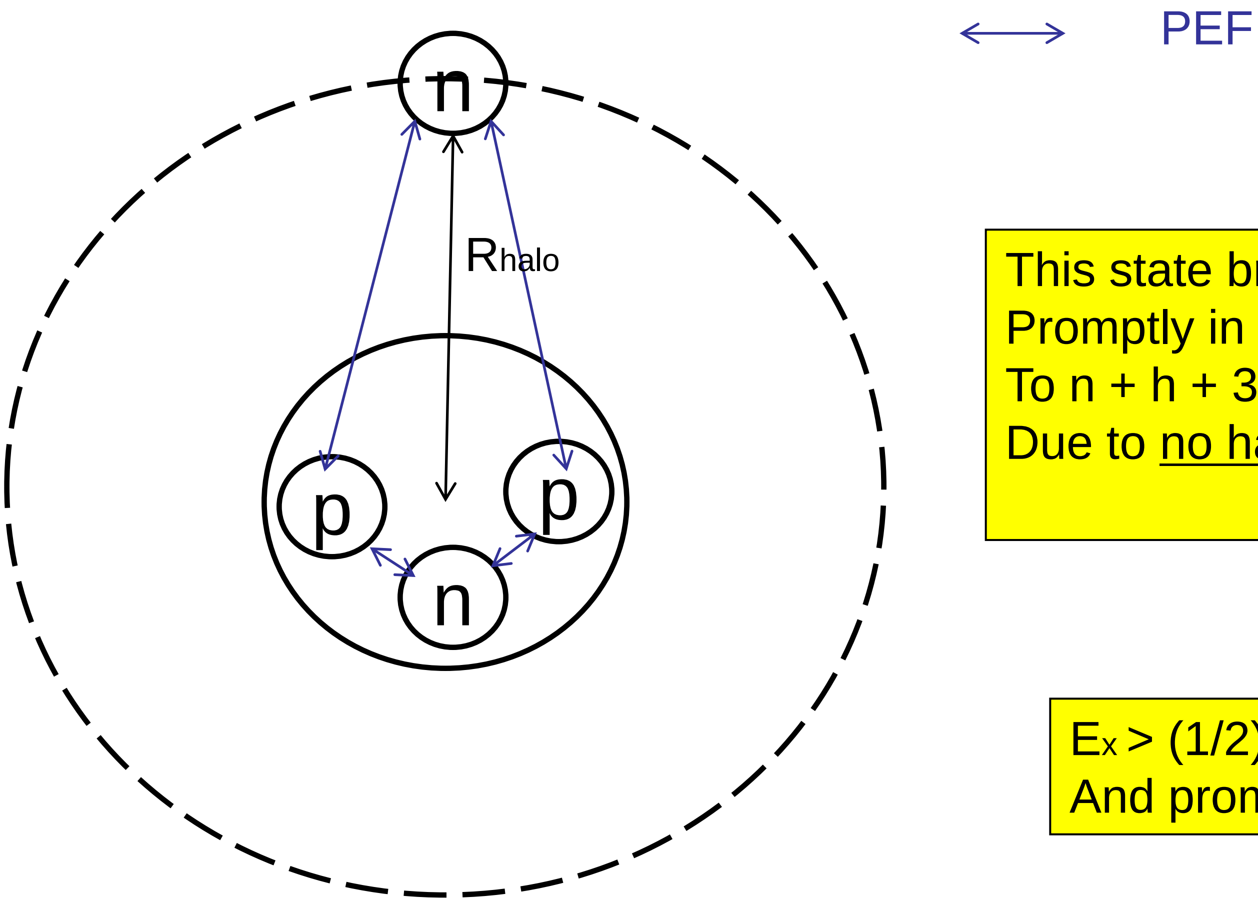
Nucleon Halo Model of $^{8}Be^{*}$(Ex=47.6 MeV: J^{π})
Vibration/Rotation Band Levels are narrow spaced for Long Life
Low Energy EM Transition Photons: a few keV: to ^{8}Be (g.s.)

Skip



Skip

Nucleon Halo Model of $^{4}He^{*}(Ex=23.8\ MeV: J^{\pi})$
Excitation with 2 PEFs spring



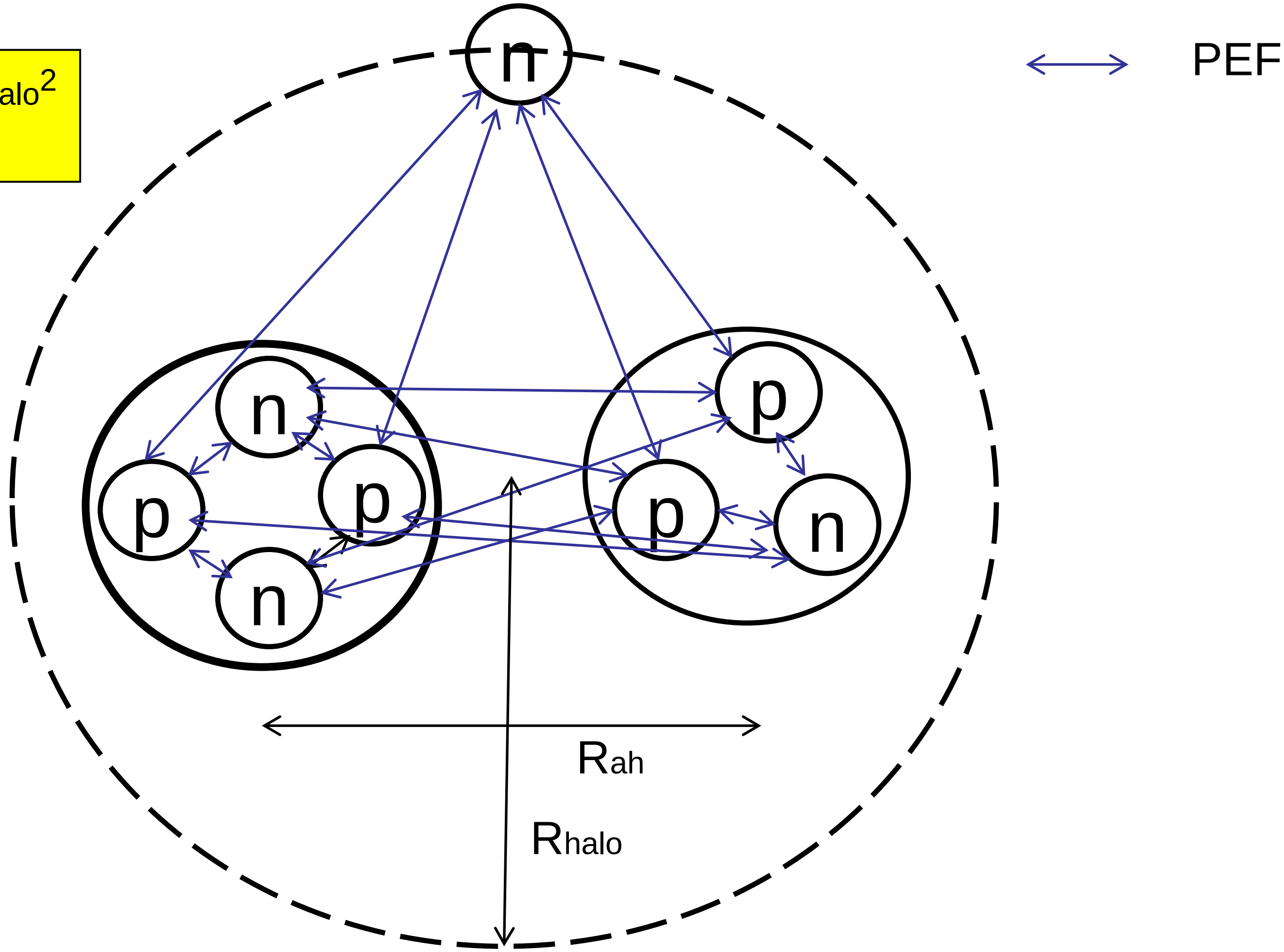
This state breaks up
Promptly in 10^{-22}s
To n + h + 3.25 MeV
Due to no hard alpha-core?

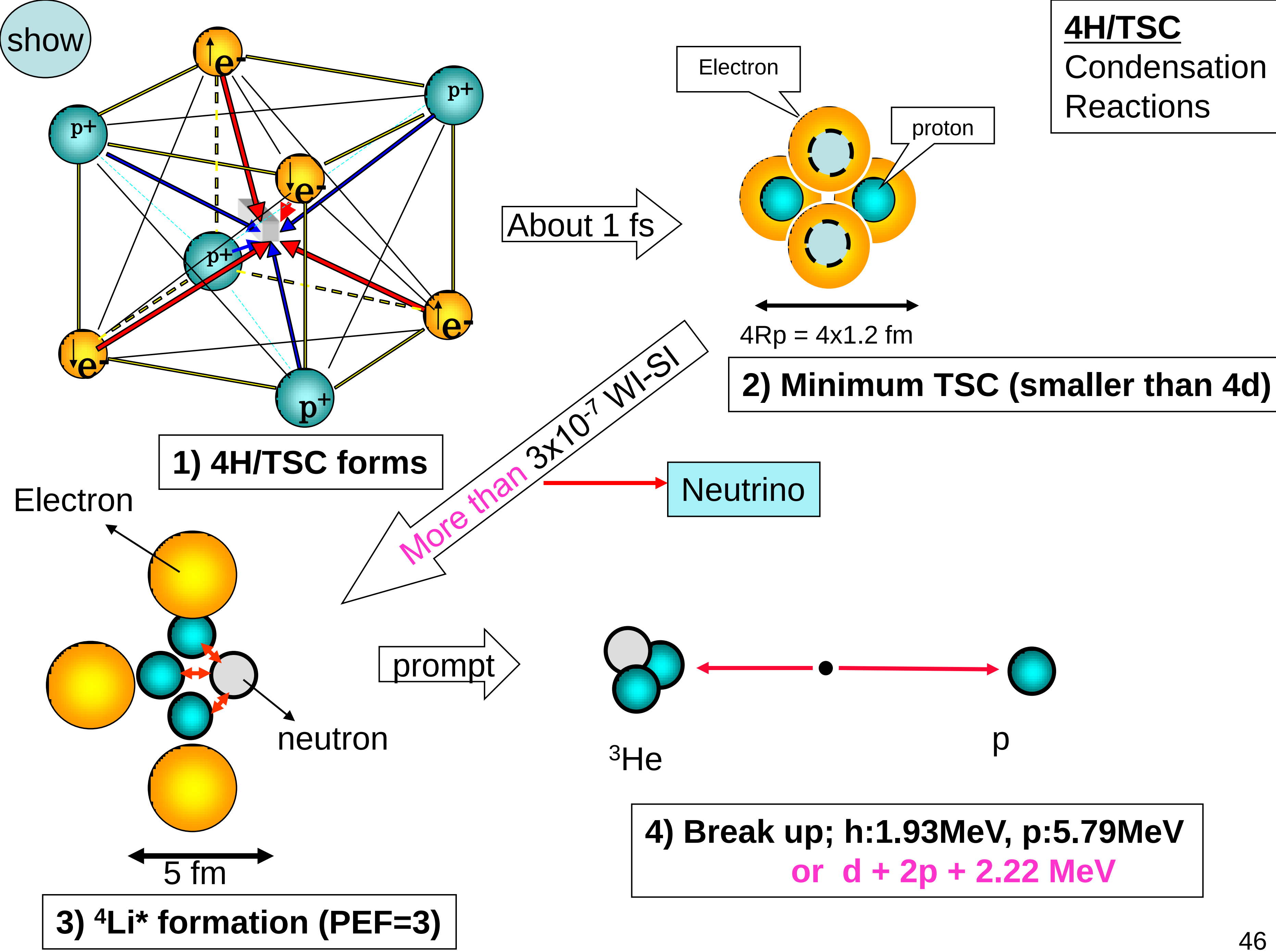
$E_x > (1/2)K_2 R_{halo}^2$
And prompt break-up

Nucleon Halo Model of ^{8}Be*(Ex=47.6 MeV: J^π): Excitation with 4 PEFs spring
Vibration/Rotation Band Levels are narrow spaced for Long Life
Low Energy EM Transition Photons: a few keV: to ^{8}Be (g.s.),
due to hard alpha-core?

Skip

$E_x < (1/2)K_4 R_{halo}^2 + (1/2)K_6 R_{ah}^2$

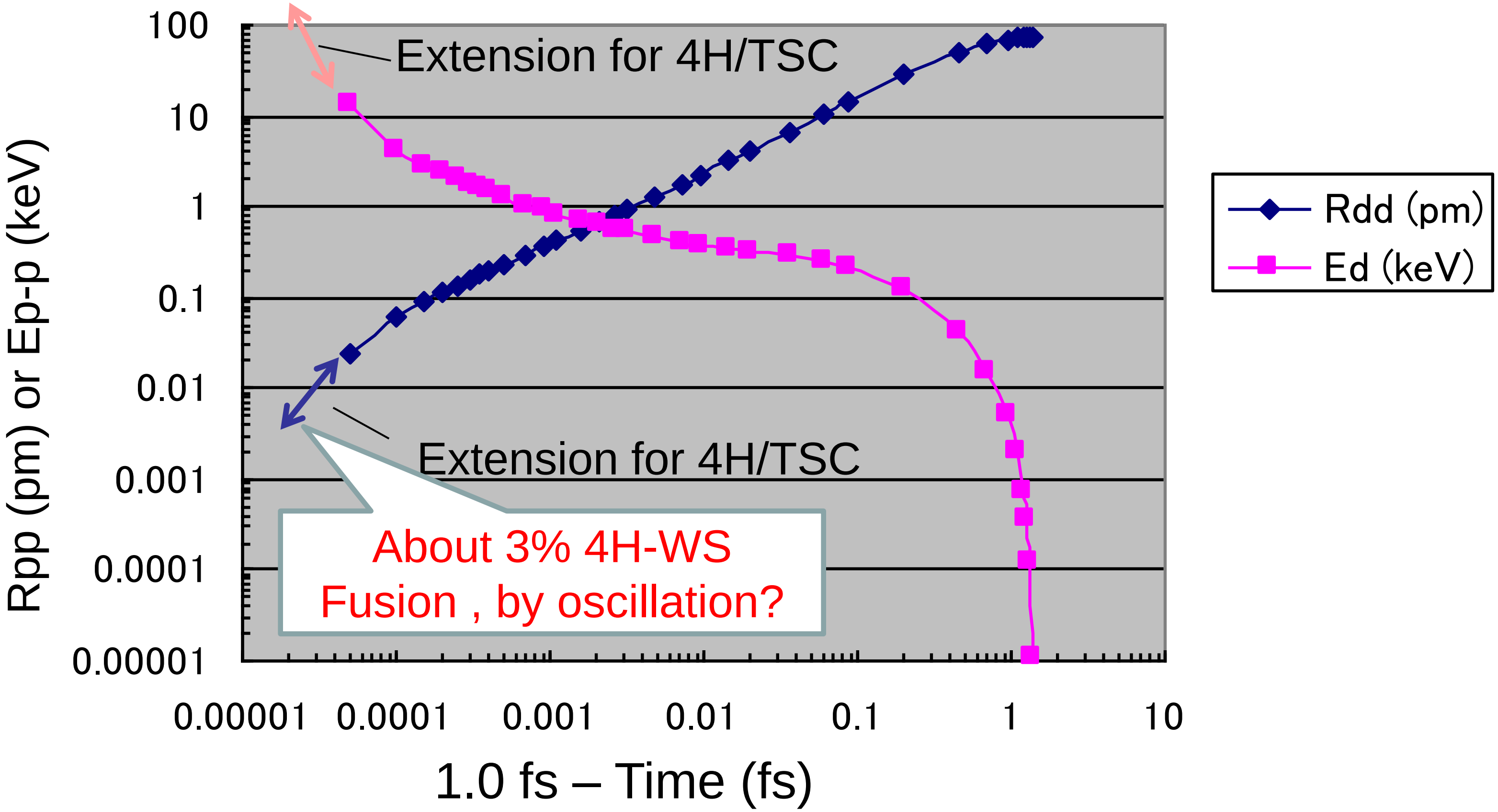




show
4H/TSC
Condensation Reactions
p+
e-
About 1 fs
Electron
proton
4Rp = 4x1.2 fm
2) Minimum TSC (smaller than 4d)
1) 4H/TSC forms
More than 3x10-7 WI-SI
Neutrino
Electron
neutron
5 fm
prompt
3He
p
3) 4Li* formation (PEF=3)
4) Break up; h:1.93MeV, p:5.79MeV
or d + 2p + 2.22 MeV

show

TSC Condensation Motion; by the Langevin Eq.:
Condensation Time = 1.4 fs for 4D and 1.0 fs for 4H
Proton Kinetic Energy INCREASES as Rpp decreases.



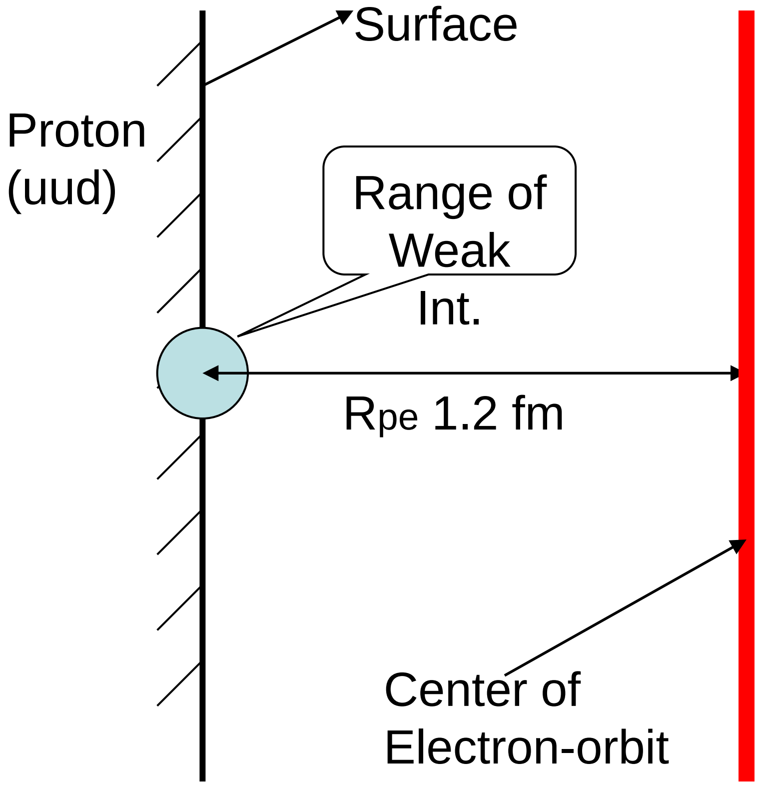
Ep = 100 keV at Rpp = 2.4 fm, Vtrap = - 1.2-2 MeV

Electrons Mean KE : 0.6-1MeV

show

Weak Interaction at 4H/TSC-min

[We assume WI happens at proton surface with W-boson wave length (2.5×10^{-3} fm)]



- E_{ke} = 600-1000 kev exceeds threshold (272 keV) of p + e^- to n + v interaction.
- p + e^- + $E_{ke} \rightarrow$ n + v + (E_{ke} – 272 keV)

Effective Volume for WI:

$$\Delta V_W = 4\pi R_p^2 \lambda_W = 4\pi \cdot (1.2\,fm)^2 \cdot 2.5 \times 10^{-3} = 4.5 \times 10^{-2} (fm)^3$$

We assume 1S-type electron wave function for "diminished Bohr radius" = $2R_{pe}$=2.4fm

$$\Psi_e(r) = (\pi a^3)^{-1} \exp(-r/a)$$

Weak Interaction at 4H/TSC-min

Skip

- p + e^- + E_{ke} (800keV)→ n + v + 528 keV
- Neutrino carries away most of 528 keV.
- **Produced n makes immediately strong interaction with remained 3p of TSC.**

$$<WIrate> = (4\pi / h) <W>_w \langle \Psi_e(r_w) \rangle^2$$

$\langle \Psi_e(r_w) \rangle^2$ ~ $\Psi e(R_p)^2 \Delta V_W$ = (0.6/(3.14x2.4^3))x4.5x10^{-2} = **5.9x10^{-5}**

4π/h

$$(4\pi / h) <W>_w = |M_{fi}|_F = (G_F / V) c_V \cos\theta_c$$

$$G_F = 1.16x10^{-5} GeV^{-2} (\hbar c)^3 = 89 eV (fm)^3$$

$\cos\theta_c = 0.88$: Weinberg angle, and We set c_V=1 and V=1

$<W>_w = 78eV$

<Real WIrate>=<WIrate><Δt-tsc-min> =2.37x10^{17}x5.9x10^{-5}x2x10^{-20}= **2.8x10^{-7}** (1/cluster)

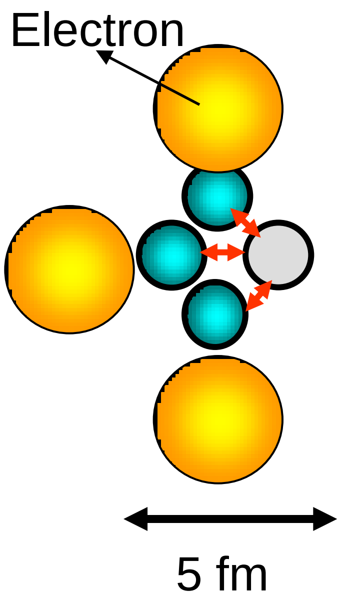
show

Rate of Strong Interaction for n-3p Cluster

Skip

: Immediate strong reaction with “n” by WI

Gauge boson propagation time per fm = 1 fm/c = $3x10^{-24}$ s →
Simultaneous 4-body reaction possible (100%) within Δt-tsc-min = $2x10^{-20}$ s



$$<SIrate> = (4\pi / h) <W>_s (\Delta t - tsc - \min)$$

$$PEF = 3$$

$$<W>_S = 0.115 MeV$$

It means 1.0 (100% fusion)

$$<SIrate> = 3.04x10^{21} x0.115x2x10^{-20} = 7.0(1/cluster)$$

<4H/TSC Fusion Rate>=<WIrate><SIrate>
=$2.8x10^{-7}$x1.0= $2.8x10^{-7}$ **(1/cluster)** →

By gas loading experiment with 2nm diam Ni(+Pd or Cu) particle,
one TSC per particle per sec was speculated: 1/10,000 per s per nano-p.

Supposing TSC production rate per s per mol-metal (Ni): $6.023x10^{23}$/**10^4** ~$6x10^{19}$

<Macroscopic 4H/TSC Fusion rate> = $2.8x10^{-7}$x$6x10^{19}$= **$1.7x10^{13}$** **(f/s/mol)**

About 20W

AT ICCF17 TSC theory

show

Products of 4H/TSC W-S Fusion

- $3p + n \rightarrow {}^{4}Li^{*}(4.62MeV)$
- ${}^{4}Li^{*}(4.62MeV) \rightarrow$ **${}^{3}He$** $+ p + 7.72MeV$

  (1.93) (5.79)
- ${}^{4}Li^{*}(4.62MeV) \rightarrow$ **d** $+ 2p + 2.22MeV$

  (~1MeV)
- 5.79MeV proton produces PIXE:

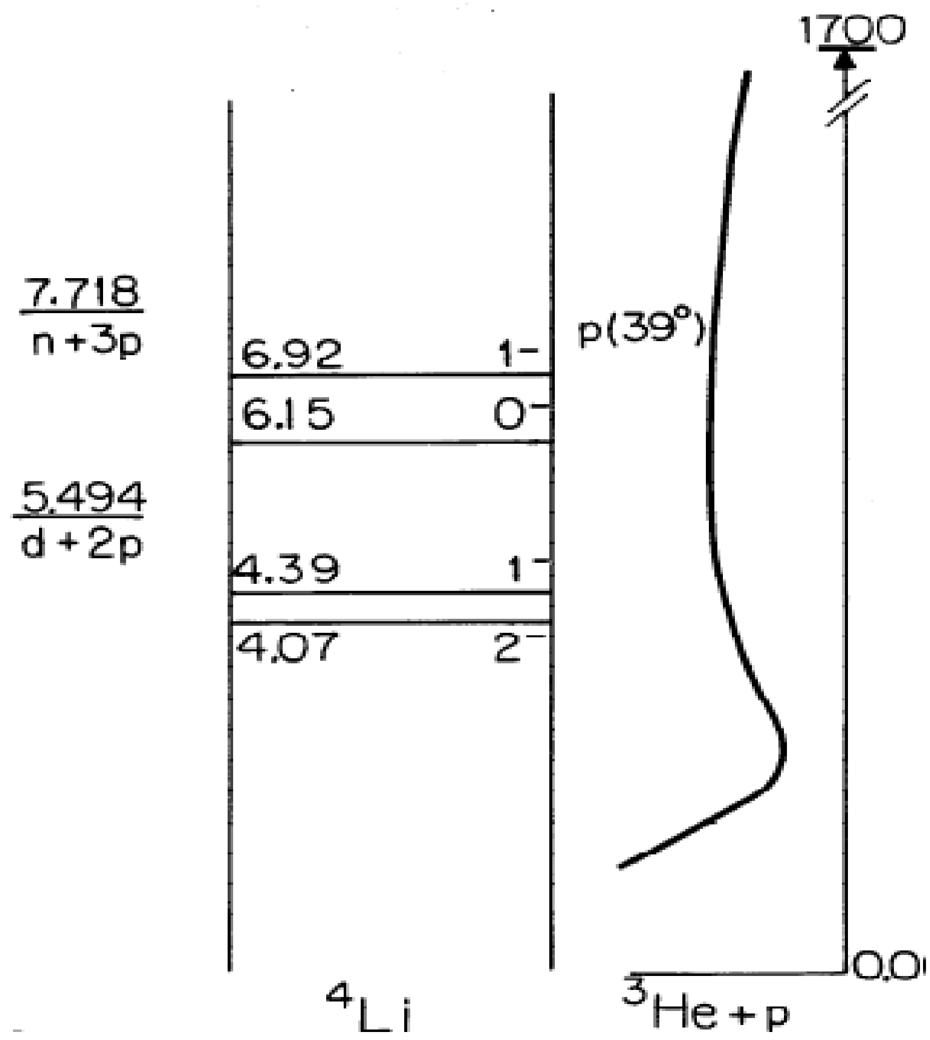
  ca. 8keV for Ni
- 5.79MeV proton energy is smaller than neutron emission threshold for ${}^{58}Ni$ (9.5MeV) and ${}^{60}Ni$(6.9MeV), but larger than those for ${}^{61}Ni$(3MeV), ${}^{62}Ni$(4.5MeV) and ${}^{64}Ni$(2.5MeV) . (So, see the slide after the next one.)

Main branch
See next slide
OR

Skip

From TUNL library

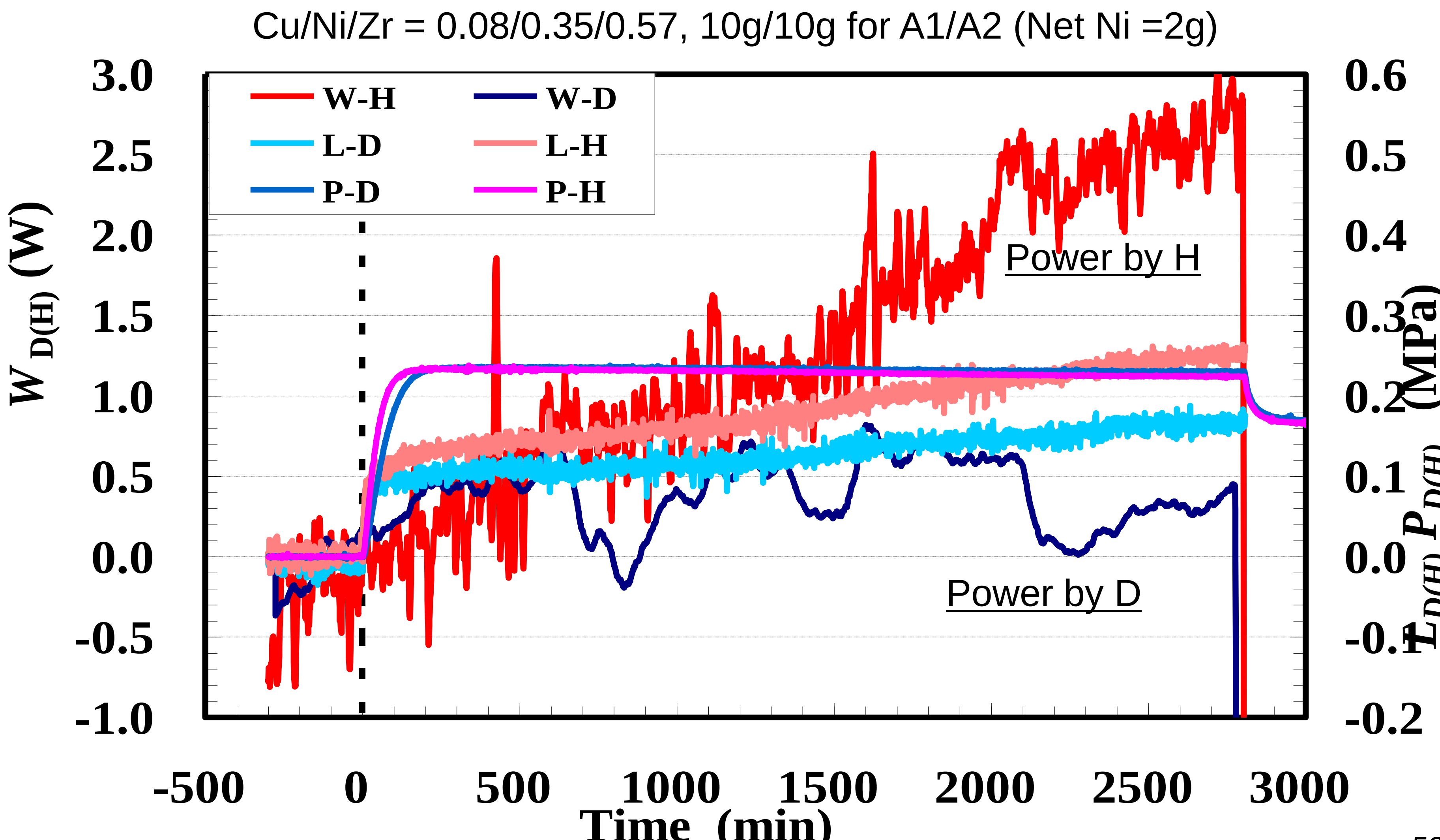
4.62 MeV →



show

CNZ3,4#5_513ºK Second Run; 0～3000min

Why H-gas charging produced larger heat-power than D-gas ?



show

Discussions

- Life Time: At $R_{pp}=2xR_p=2.4fm$, 4H/TSC condition will be distorted due to limited space for electron rotation. $R_{pp}=2x2^{1/2}R_p=3.4fm$ might be the final point, around which TSC would **oscillate** to have some enhanced life time (1 fs ?). We need further study on "how much life time". If so 4H/TSC WS fusion rate drastically increase!
- 4D/TSC fusion (47.6MeV/f) event makes much stronger damage than 4H/TSC WS fusion (ca. 4MeV av.), so that self-recovery of nano-particle works better for Ni-H system than Ni-D system (ca. 4hrs vs. 1hr of full Ni-lattice atoms displacement by one watt/g level heat-power.)
- Gamma rays: 5.79MeV proton will make Ni(p, γ) reaction with about 100 times the n emission rate, because it happens mainly for ^{58}Ni and ^{60}Ni of high abundance.

4)TSC-Induced Ni Fission

- The 4H/TSC + Ni-isotope capture-and-fission process, previously proposed, is another plausible scenario. The 4H/TSC-min state may have much longer life than 4D/TSC-min, and Ni has larger K-shell e-cloud radius than Pd. Ni + 4H capture will be enhanced significantly.
- Ni + 4p goes to fission to result in generation of clean fission products in A<100 mass region.

After A. Takahashi: JCMNS, vol.1,

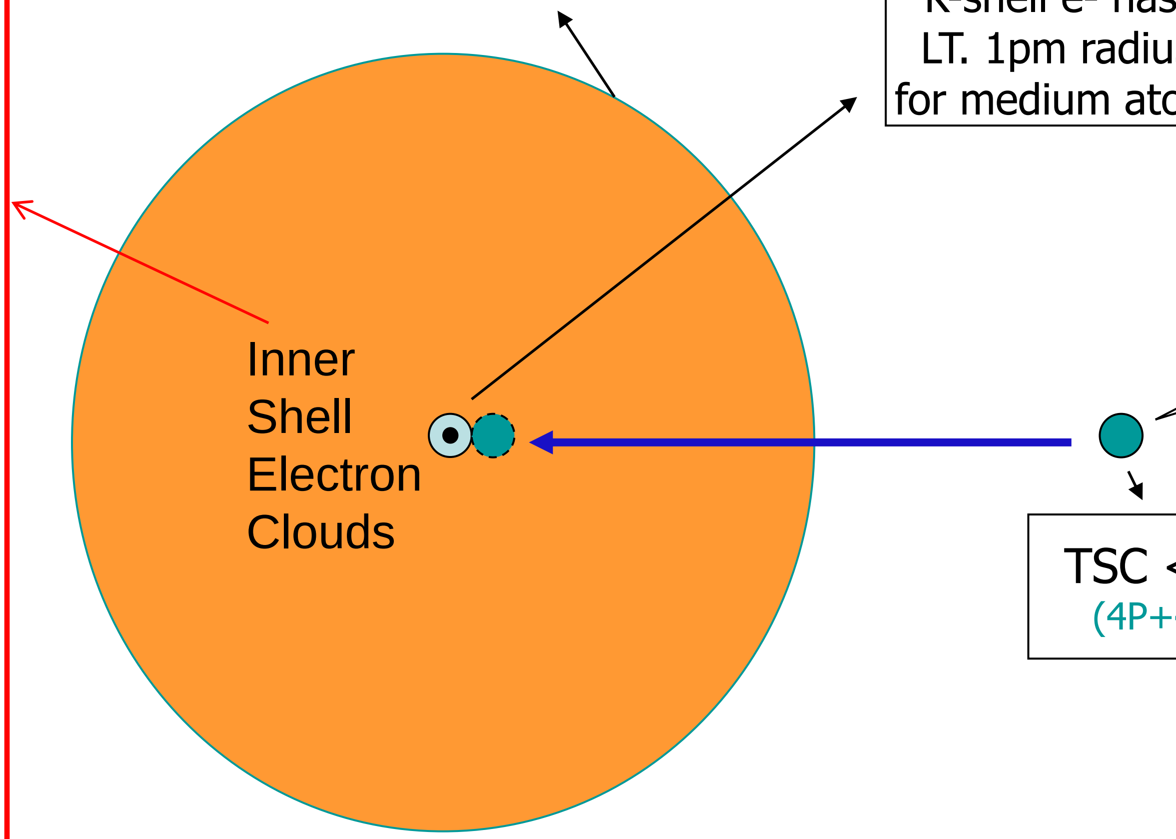
Skip

Ni(28)	Pd(46)
1s:2	1s:2
2s:2	2s:2
2p:6	2p:6
3s:2	3s:2
3p:6	3p:6
3d:8	3d:10
4s:2	4s:2
	4p:6
	4d:10

Target Atom Outer-Most Electron Cloud (ca. 100 pm radius)

K-shell e- has LT. 1pm radius for medium atom

Larger Radius For lighter atom



Neutral Pseudo-Particle (ca. 10fm for TSC)

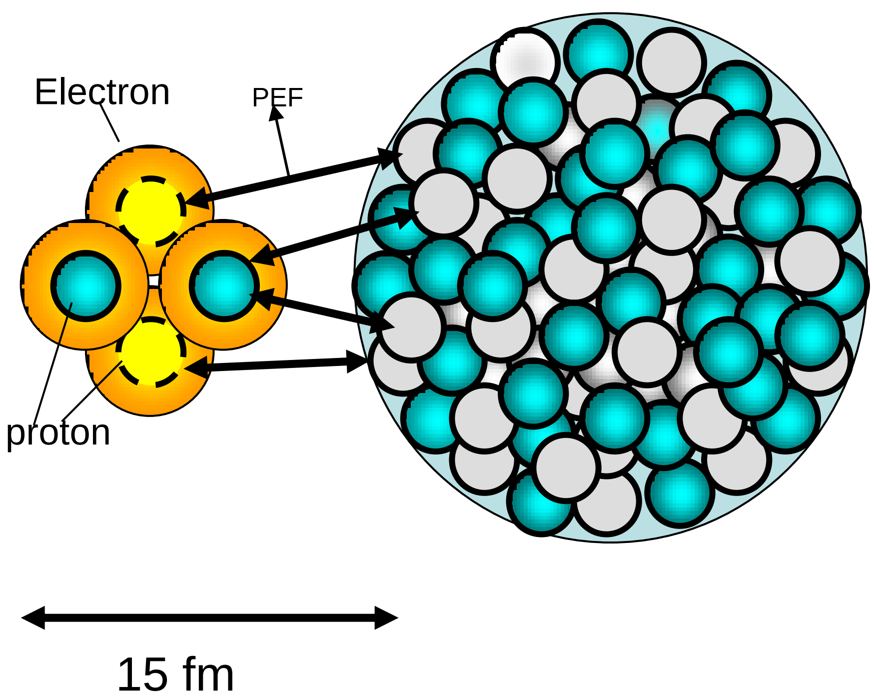
TSC < <0.1 pm
(4P+4e): neutral

TSC-min can penetrate through all shell-e-clouds!

After A. Takahashi: JCMNS, vol.1,

Skip

M + 4p/TSC Nuclear Interaction Mechanism



- Topological condition for Pion-Exchange (PEF): 4p's are within pion ranges.
- <u>Selection of simultaneous pick-up of 4p looks dominant.</u>
- M + 4p capture reaction.

Major Fission Channels from Ni + 4p (2)

Skip

- $^{62}Ni(3.6\%) + 4p \rightarrow {}^{66}Ge(Ex=24.0MeV)$
  $[^{58}Ni + 4d \rightarrow {}^{66}Ge(Ex=53.937MeV)]$

$\rightarrow$ 11.0MeV + n + $^{65}Ge(EC)^{65}Ga(EC)^{65}Zn$
$\rightarrow$ 21.4MeV + ^{4}He + $^{62}Zn(EC)^{62}Cu(EC)^{62}Ni$
$\rightarrow$ 11.5MeV + ^{8}Be + ^{58}Ni
$\rightarrow$ 18.9MeV + ^{12}C + ^{54}Fe
$\rightarrow$ 10.5MeV + ^{14}N + $^{52}Mn(EC)^{52}Cr$
$\rightarrow$ 8.2MeV + ^{16}O + ^{50}Cr
$\rightarrow$ 13.9MeV + ^{20}Ne + ^{46}Ti
$\rightarrow$ 15.2MeV + ^{24}Mg + ^{42}Ca
$\rightarrow$ 13.7MeV + ^{27}Al + ^{39}K
$\rightarrow$ 18.9MeV + ^{28}Si + ^{38}Ar
$\rightarrow$ 18.6MeV + ^{32}S + ^{34}S

Near Symmetric Fragmentation

- Neutron emission channel may open!
- S-values for higher mass Ni may be larger than Ni-58 and Ni-60, due to more p-n PEF interaction.

- $^{64}Ni(0.93\%) + 4P \rightarrow {}^{68}Ge(Ex=29MeV)$
  $[^{60}Ni + 4d \rightarrow {}^{68}Ge(Ex=55.049MeV)]$

$\rightarrow$ 16.7MeV + n + $^{67}Ge(EC)^{67}Ga(EC)^{67}Zn$
$\rightarrow$ 25.6Mev + ^{4}He + ^{64}Zn
$\rightarrow$ 10.0MeV + ^{6}Li + $^{61}Cu(EC)^{61}Ni$
$\rightarrow$ 13.2MeV + ^{8}Be + $^{57}Ni(EC)^{57}Co(EC)^{57}Fe$
$\rightarrow$ 10.9MeV + ^{9}Be + $^{59}Ni(EC)^{59}Co$
$\rightarrow$ 9.9MeV + ^{10}B + $^{58}Co(EC)^{58}Fe$
$\rightarrow$ 22.7MeV + ^{12}C + ^{56}Fe
$\rightarrow$ 14.8MeV + ^{14}N + $^{54}Mn(EC)^{54}Cr$
$\rightarrow$ 12.7MeV + ^{16}O + ^{52}Cr
$\rightarrow$ 17.6MeV + ^{20}Ne + ^{48}Ti
$\rightarrow$ 12.7MeV + ^{23}Na + ^{45}Sc
$\rightarrow$ 17.5MeV + ^{24}Mg + ^{44}Ca
$\rightarrow$ 14.8MeV + ^{27}Al + ^{41}K
$\rightarrow$ 18.7MeV + ^{28}Si + ^{40}Ar
$\rightarrow$ 18.7MeV + ^{32}S + ^{36}S

Near Symmetric Fragmentation

Skip

TSC-Induced Fission Products

- FPs can be Mostly Stable Isotopes for A<100 M-targets (Clean Fission) by Near Symmetric Fragmentation (If dominantly selected scission channels).

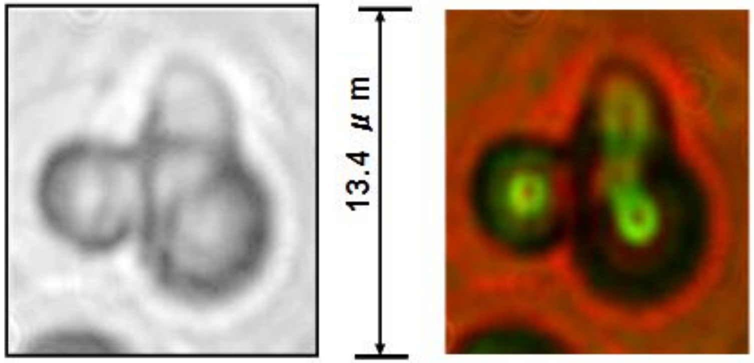
  It is likely, but precise FP analysis is needed.

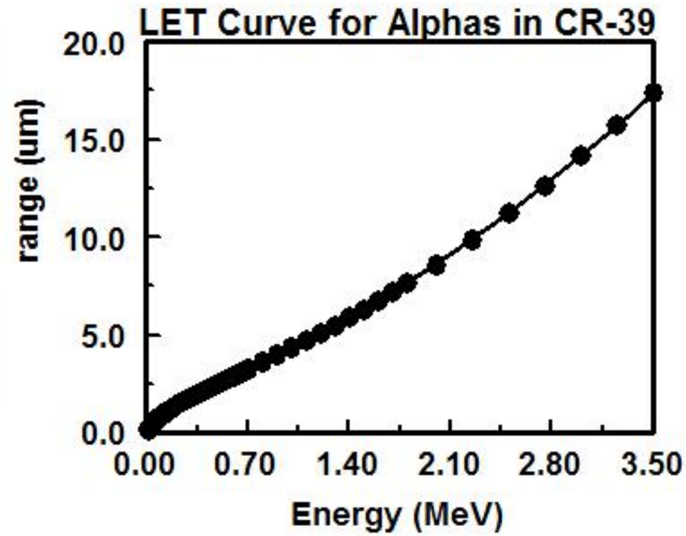
- Minor FPs are short-lived decay RIs by EC (K-electron capture process and /or positron decay), for A>50 M-target
- Significant gamma-peaks (prompt and annihilation) should appear for M + 4H/TSC with A<20 M-target

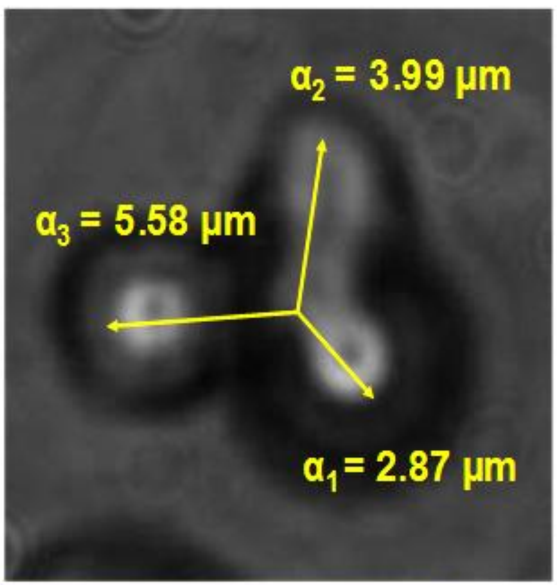
Skip

Calculation of the Energy of the Neutron that Created the Triple Track

SPAWAR Systems Center PACIFIC







$$E_n = E_{th} + E_{\alpha 1} + E_{\alpha 2} + E_{\alpha 3}$$

$$E_n = (9.6 + 0.59 + 0.91 + 1.23)\ \text{MeV}$$

$$E_n = 12.33\ \text{MeV}$$

En = En' + 7.245MeV + Ea1 + Ea2 + Ea3

En - En' = 9.98MeV

$^{12}C(n,n')3\alpha$

Generation of neutron over 10 MeV

高橋:気相常温核融合

Triton Production and DT neutron by Minor Branch of 4D Fusion

Skip

Channels for CP Generation by 4D

I. Symmetric Fragmentation

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

- 1-1) Ex=0;

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

- 1-2) Ex=20.21MeV (1st excited state of ${}^{4}He$);

  ${}^{4}He^{*}(20.21MeV;0^{+},0)$ $\rightarrow$p(0.6-2.2MeV)+**t(1.8-3.4MeV)**

  + (Ex-19.815=0.4MeV) + (3.6MeV; moving ${}^{4}He^{*}$)

  ; this **triton** makes secondary d+t reaction to **emit 10-17MeV neutrons**

Skip

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)

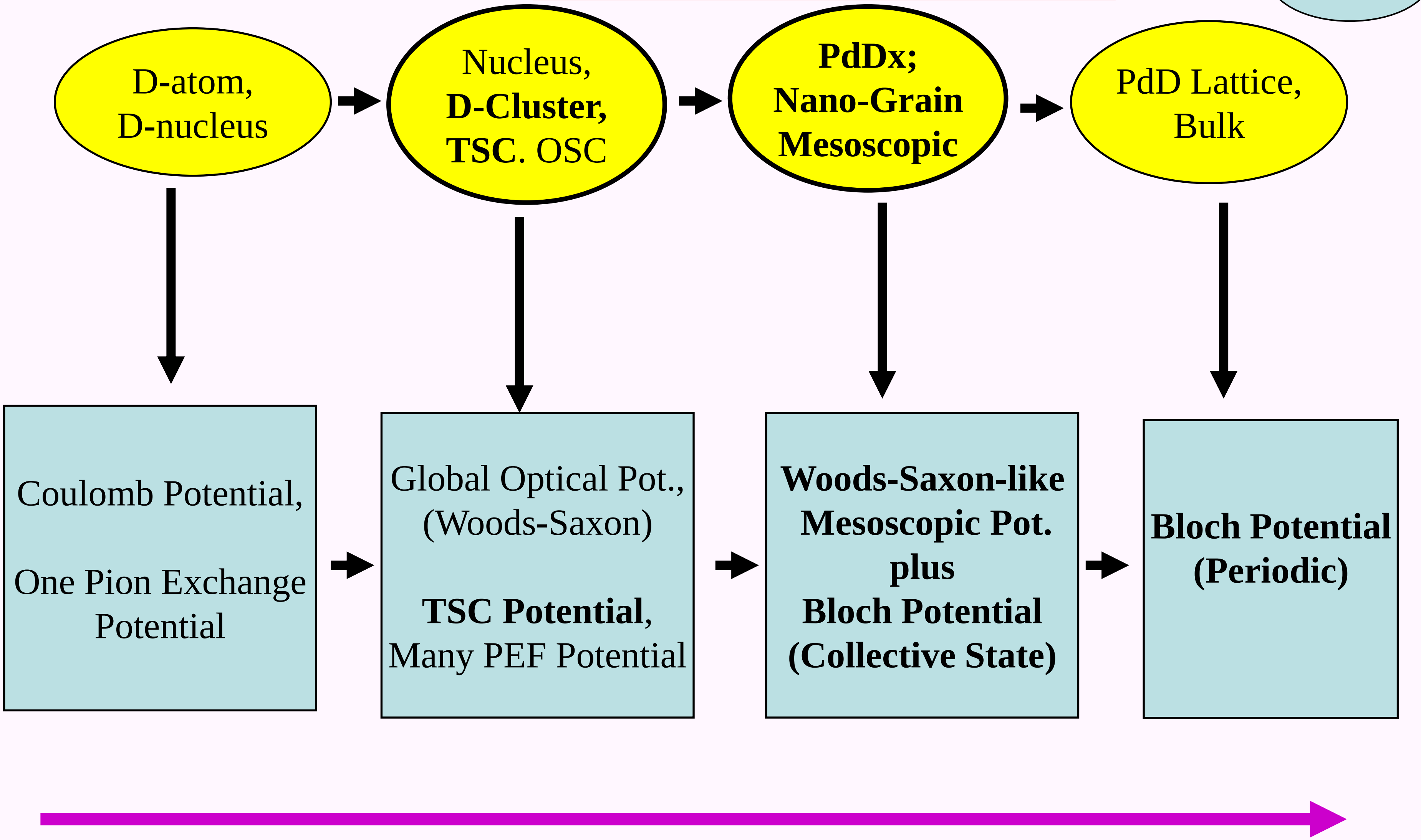
Purple values are by odd spin-parity of

^{8}Be*(Ex=47.6MeV)

Others are S-wave Transitions

D-Cluster Fusion

Skip



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

show

Conclusion

- **Cold Fusion in/on condensed matter requires the confinement of relatively high kinetic energy deuterons in a cluster within a very small (microscopic as 20 fm diameter) domain.**
- **4D/TSC** is a mechanism of Transitory BEC (Bose-Einstein Condensate) for realizing large heat level 4D fusions with ^{4}He ash, in/on the nano-catalytic condensed matter under the ordering/constraint condition of symmetric D-cluster formation.
- **4H/TSC** induced weak/strong self-fusion (^{3}He and D are ash) and metal fission are candidate models for Ni-H system's anomalous phenomena.

Appendix

- Fusion Rate Formula by Fermi's Golden Rule
- QM wave density flow in the strong field
- Inter-nuclear fusion rate
- Wave function in outer electro-magnetic field
- Adiabatic Equation of Fusion Rate by Born-Oppenheimer approximation
- The effective interaction domain of nuclear reaction

Mean Free Path in Strong Field (1)

- Forward Equation:

$$i\hbar\frac{\partial\Psi}{\partial t}=\left[-\frac{\hbar^2}{2M}\nabla^2+V+iW\right]\Psi \qquad (1)$$

- Adjoint Equation:

$$-i\hbar\frac{\partial\Psi^*}{\partial t}=\left[-\frac{\hbar^2}{2M}\nabla^2+V-iW\right]\Psi^* \qquad (2)$$

- Ψ*x(1) – Ψx(2):

$$i\hbar\left(\Psi^*\frac{\partial\Psi}{\partial t}+\Psi\frac{\partial\Psi^*}{\partial t}\right)=i\hbar\frac{\partial\Psi\Psi^*}{\partial t}=i\hbar\frac{\partial\rho}{\partial t}$$

$$i\hbar\frac{\partial\rho}{\partial t}=-\frac{\hbar^2}{2M}\left[\Psi^*\nabla^2\Psi-\Psi\nabla^2\Psi^*\right]+i\left[2W\rho\right]=-i\hbar div\vec{j}+i\left[2W\rho\right]$$

Quantum Mechanical Current Density

$$\vec{j} = \frac{\hbar}{2im}(\Psi * \vec{\nabla}\Psi + \Psi\vec{\nabla} * \Psi*)$$

$$= \frac{\hbar}{2im}(\Psi * \vec{\nabla}\Psi - \Psi\vec{\nabla}\Psi*)$$

$$div\vec{j} = \frac{\hbar}{2im}(\vec{\nabla}(\Psi * \vec{\nabla}\Psi) - \vec{\nabla}(\Psi\vec{\nabla}\Psi*))$$

$$= \frac{\hbar}{2im}(\Psi * \nabla^2\Psi + (\vec{\nabla}\Psi*)(\vec{\nabla}\Psi) - \Psi\nabla^2\Psi * -(\vec{\nabla}\Psi)(\vec{\nabla}\Psi*))$$

$$= \frac{\hbar}{2im}(\Psi * \nabla^2\Psi - \Psi\nabla^2\Psi*)$$

Mean Free Path in Strong Field (2)

- We get balance equation of QM density flow:

$$\partial\rho/\partial t = -\mathrm{div}(\mathbf{j}) + (4\pi/h)W(r)\rho(r,t) \qquad (3)$$

Here $\rho(r,t) = \Psi\Psi^*$: particle density and the 2^{nd} right hand side term shows absorption rate for negative W(r).

(Inter-Nuclear Fusion Rate)

- Mean free path:

$$\Lambda = (h/4\pi)v/W(r) \qquad (4)$$

= (velocity)x(life time)

Fusion Rate Formula by Fermi's Golden Rule

$$< FusionRate >= \frac{2}{\hbar}\left\langle \Psi_f \middle| W(r) \middle| \Psi_i \right\rangle$$

$$-\frac{\hbar^2}{2m}\nabla^2\Psi + [V_{nr}(r) + iW(r)]\Psi + V_c(r)\Psi = E\Psi$$

Nuclear Potential

Coulomb Potential

$$\Psi(r) = \Psi_n(r) \cdot \Psi_c(r)$$

Inter-nuclear wave function

EM Field wave function

Born-Oppenheimer Approximation

Adiabatic QM Equations

Inter-Nuclear QM Schroedinger Equation:

$$-\frac{\hbar^2}{2m}\nabla^2\Psi_n(r)+[V_{nr}(r)+iW(r)]\Psi_n(r)=E_n\Psi_n(r)$$

Outer-Nuclear QM Schroedinger Equation for Electro-Magnetic Field:

$$-\frac{\hbar^2}{2m}\nabla^2\Psi_c(r)+V_c(r)\Psi_c(r)=E_c\Psi_c(r)$$

Fusion Rate Formula by Born-Oppenheimer Approximation

$$< FusionRate >= \frac{2}{\hbar} \left\langle \Psi_{nf} \middle| W(r) \middle| \Psi_{ni} \right\rangle_{Vn} \cdot \left\langle \Psi_{cf} \middle| \Psi_{ci} \right\rangle_{Vn}$$

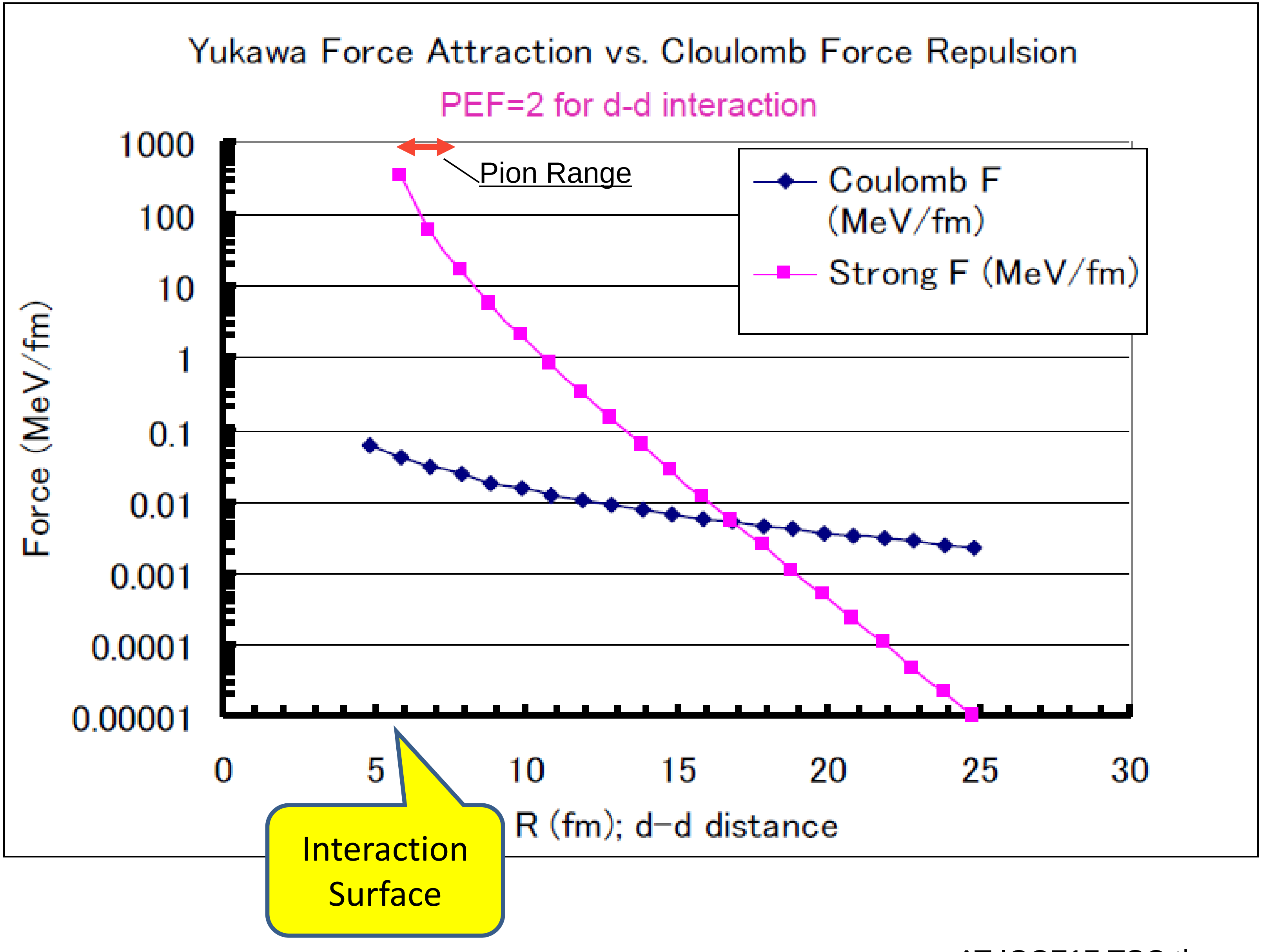
$$Vn \approx 4\pi R_n^{\ 2} \lambda\!\!\!^{-}_{\pi}$$

: Effective Volume of Nuclear Strong (Weak) Interaction Domain

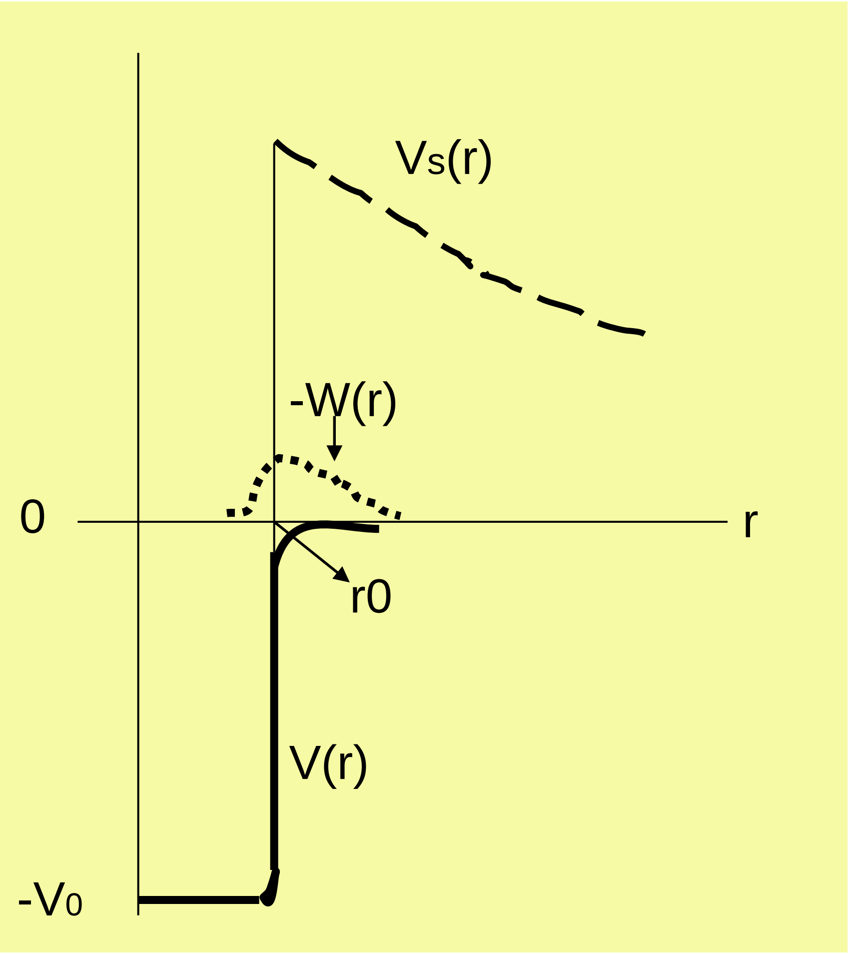
$\lambda\!\!\!^{-}_{\pi}$: Compton wave length of pion (1.4 fm) (weak boson: 2.5 am)

Rn : Radius of Interaction surface of strong (weak) force exchange

D-D Fusion: Strong Force vs. Coulomb Force



Optical Potential for Strong Interaction



- **$U(r) = V(r) + iW(r)$**
- $V(r)$ ~ -25 to -50 MeV
- $W(r)$ ~ -0.1 to -5 MeV
- For fusion by surface sticking force:

  $W(r) \sim W_0 \delta(r - r0)$

- $V_s(r)$: screened Coulomb potential

AT ICCF17 TSC theory