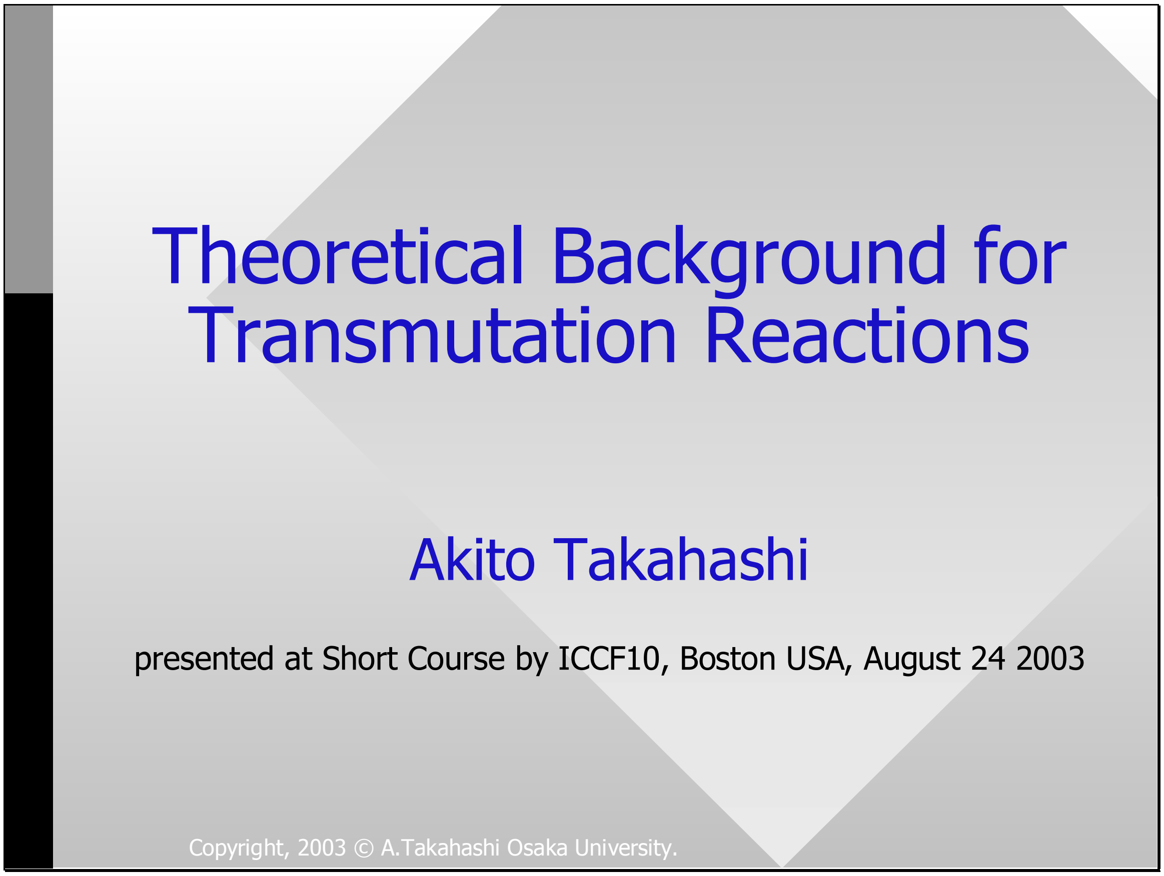
Takahashi, A. *Theoretical Background for Transmutation Reactions, PowerPoint slides*. in *Tenth International Conference on Cold Fusion*. 2003. Cambridge, MA: LENR-CANR.org.

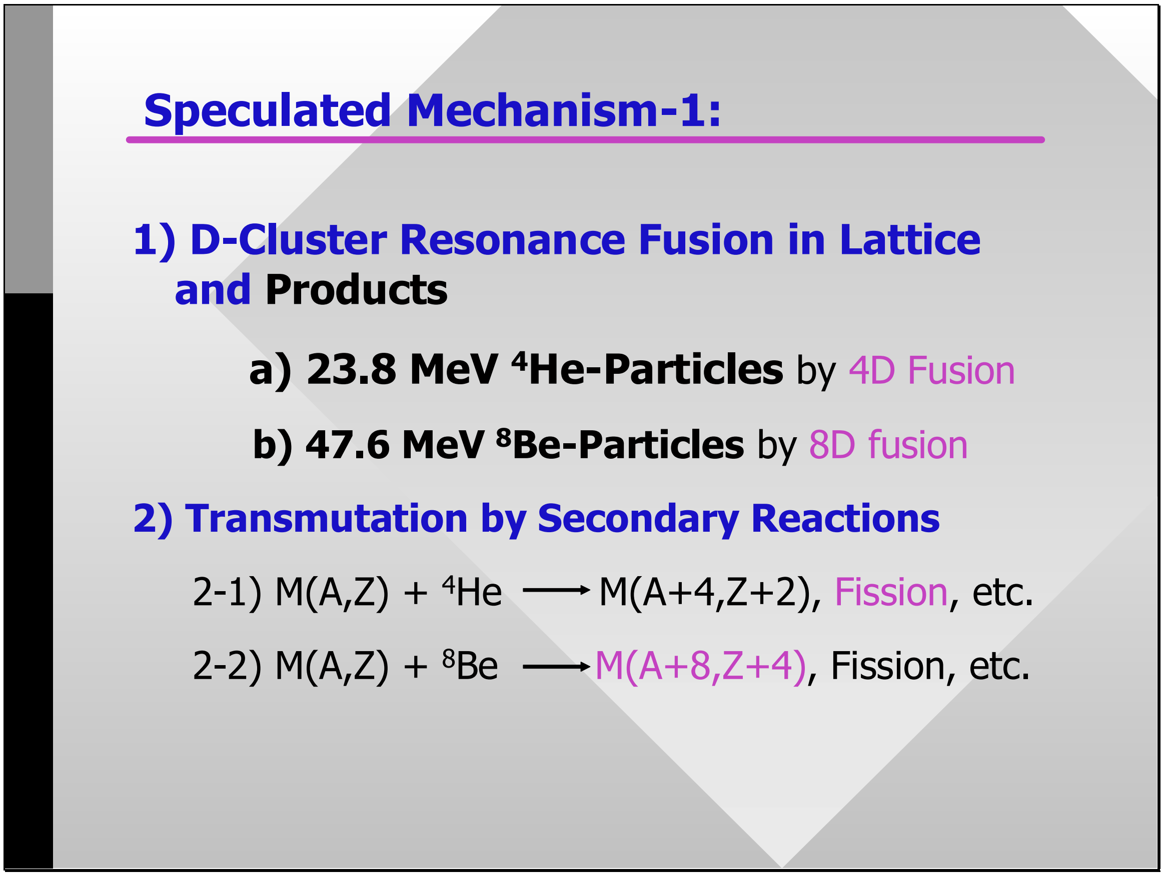
Slide 1



Theoretical Background for Transmutation Reactions

Akito Takahashi

presented at Short Course by ICCF10, Boston USA, August 24 2003



Speculated Mechanism-1:

1) D-Cluster Resonance Fusion in Lattice and Products

- **a) 23.8 MeV ^{4}He-Particles** by 4D Fusion
- **b) 47.6 MeV ^{8}Be-Particles** by 8D fusion

2) Transmutation by Secondary Reactions

2-1) M(A,Z) + ^{4}He $\longrightarrow$ M(A+4,Z+2), Fission, etc.

2-2) M(A,Z) + ^{8}Be $\longrightarrow$ M(A+8,Z+4), Fission, etc.

Speculated Mechanism-2 :

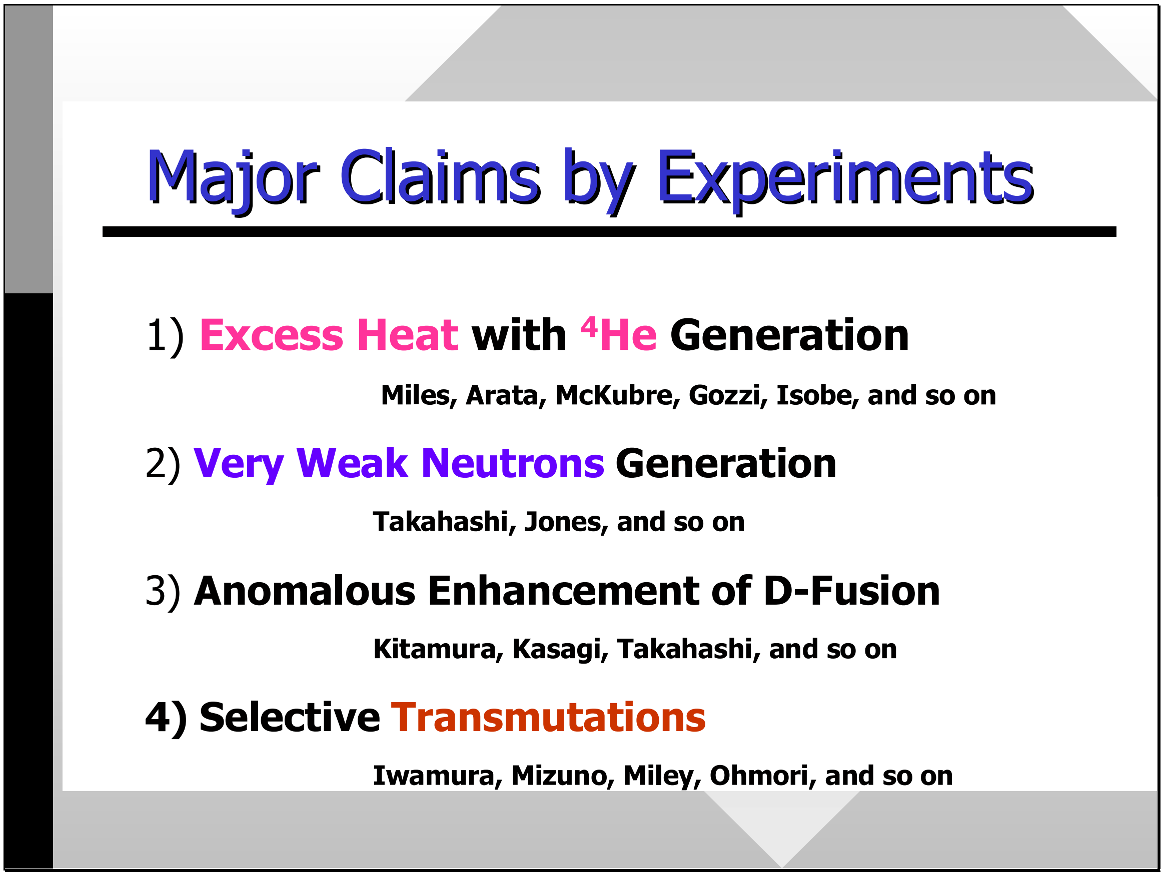
a) Selected Channel Fission Model

Model Check by ^{235}U + n Fission
Application to A<200 Nuclei
Pd, W, Au

b) Estimation for Fission Products

Mass Distribution
Element Distribution
Isotopic Ratios
Radioactivity
: Comparison with Claimed Experimental CF Data

Slide 4



Major Claims by Experiments

1) **Excess Heat with ^{4}He Generation**

Miles, Arata, McKubre, Gozzi, Isobe, and so on

2) **Very Weak Neutrons Generation**

Takahashi, Jones, and so on

3) **Anomalous Enhancement of D-Fusion**

Kitamura, Kasagi, Takahashi, and so on

4) Selective Transmutations

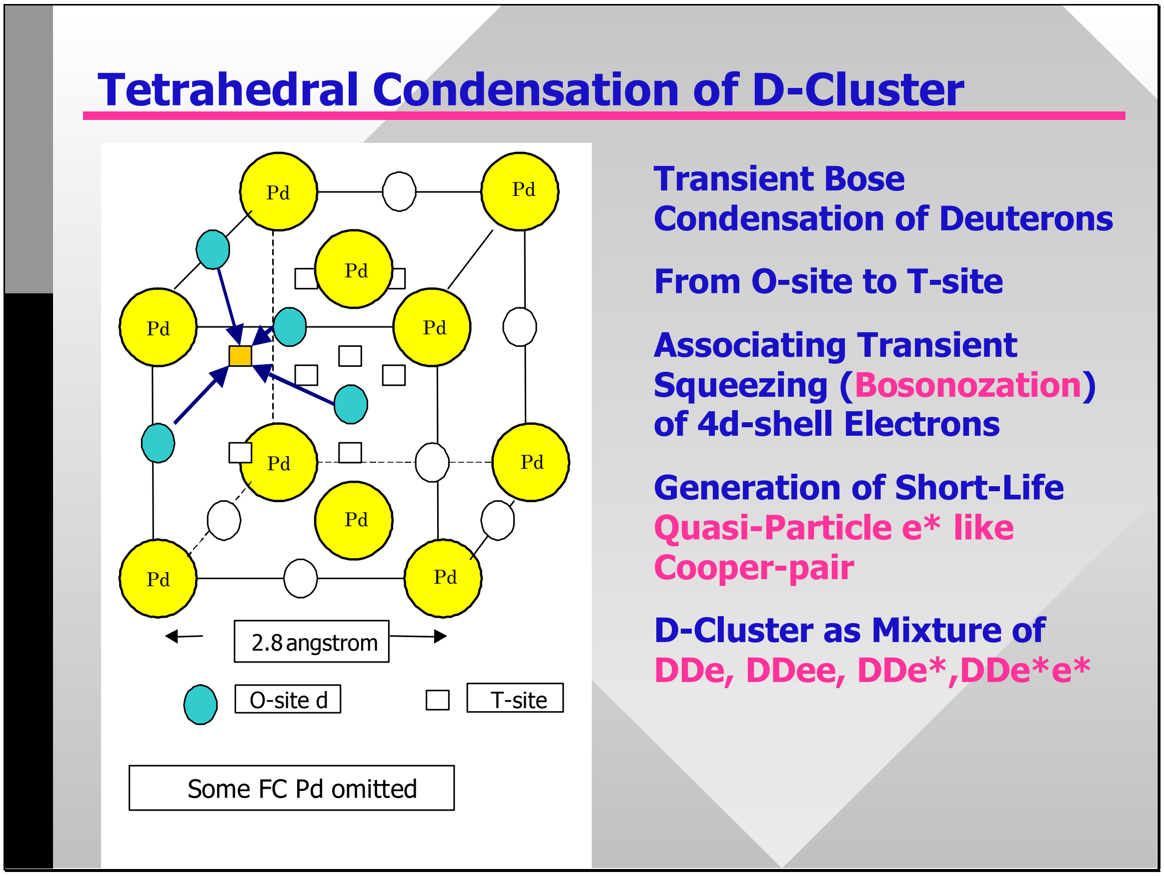
Iwamura, Mizuno, Miley, Ohmori, and so on

OUTLINE-1 : D-Cluster Fusion

Transient D-Cluster Condensation in PdDx Lattice

Transient Quasi-Particle State of Electrons (e*) and DDe* State Potentials to Realize Super-Screening for Fusion

Resonance Multi-Body Fusion: 3D, 4D, 8D to Produce ^{4}He and Mass-8 & Charge-4 Increased Transmutation



Tetrahedral Condensation of D-Cluster

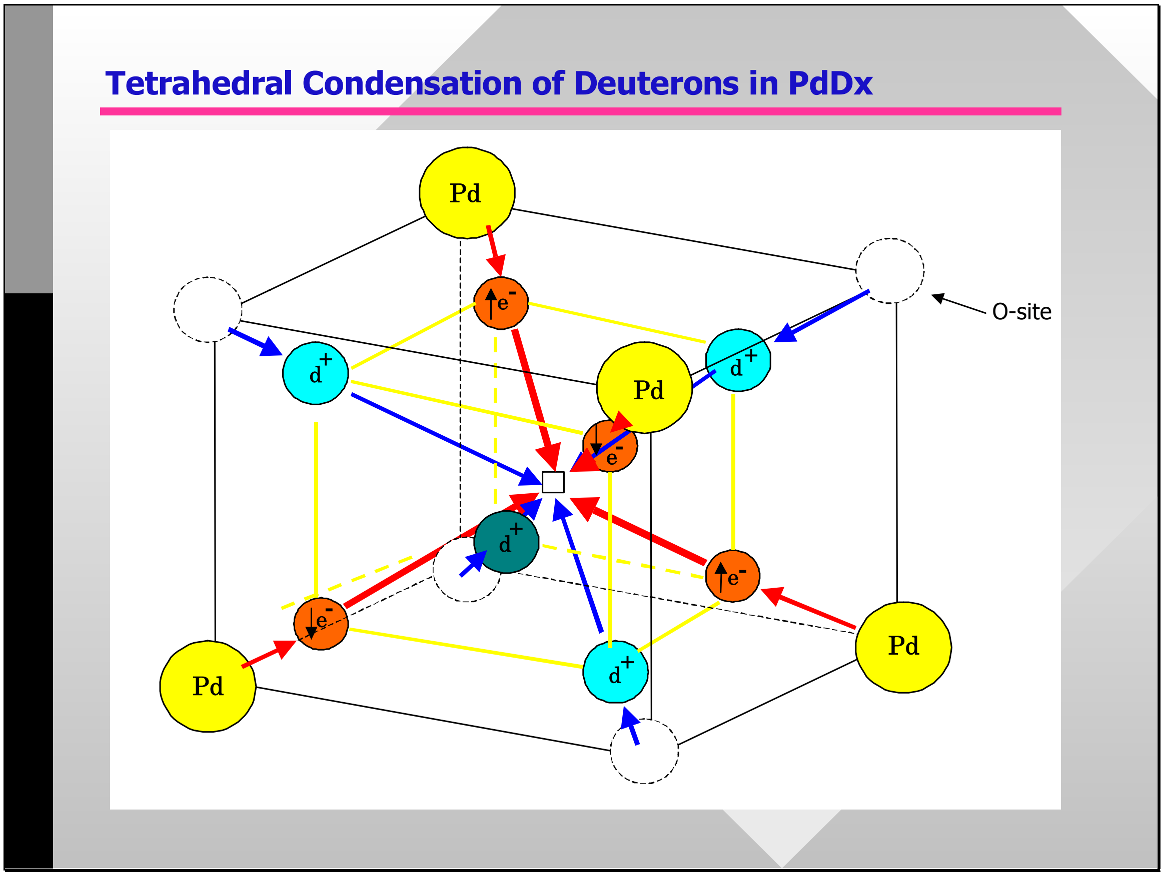
Transient Bose Condensation of Deuterons

From O-site to T-site

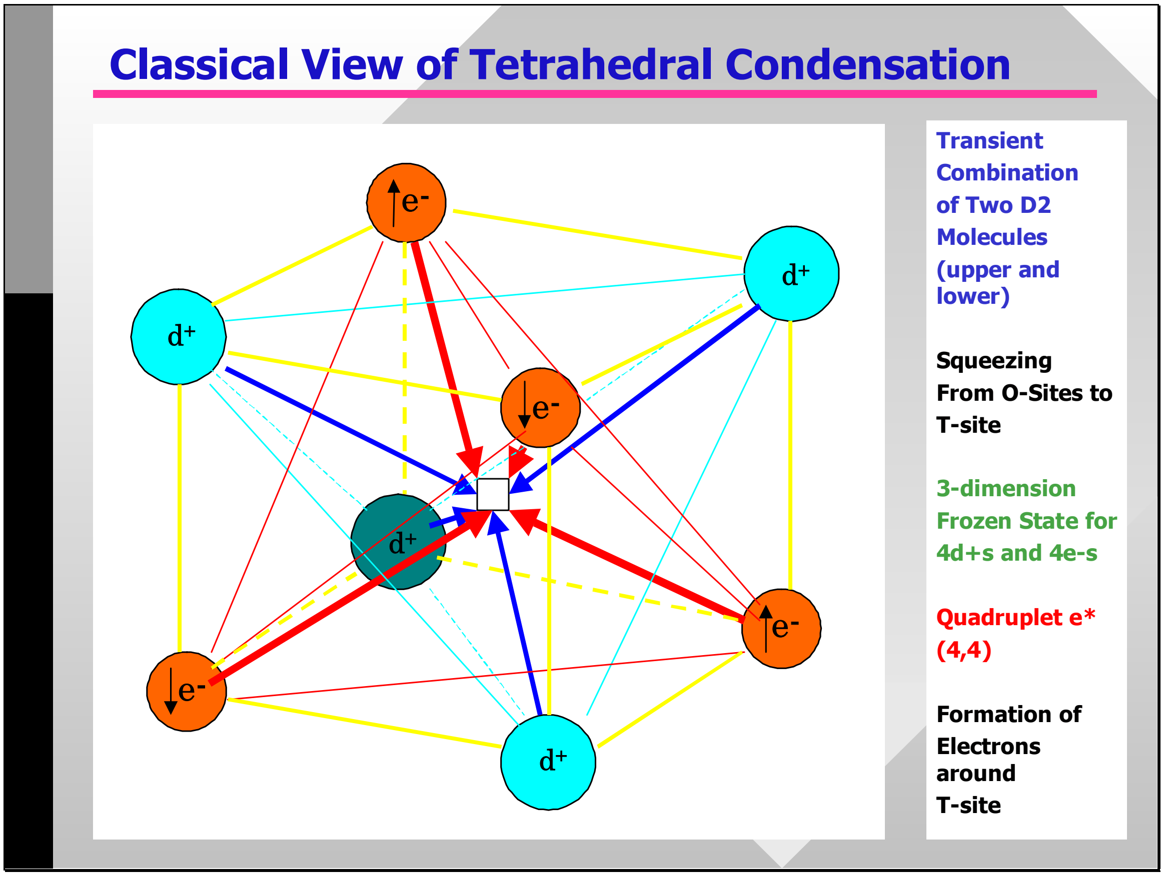
Associating Transient Squeezing (Bosonozation) of 4d-shell Electrons

Generation of Short-Life Quasi-Particle e* like Cooper-pair

D-Cluster as Mixture of DDe, DDee, DDe*,DDe*e*



Tetrahedral Condensation of Deuterons in PdDx



Classical View of Tetrahedral Condensation

Transient Combination of Two D2 Molecules (upper and lower)

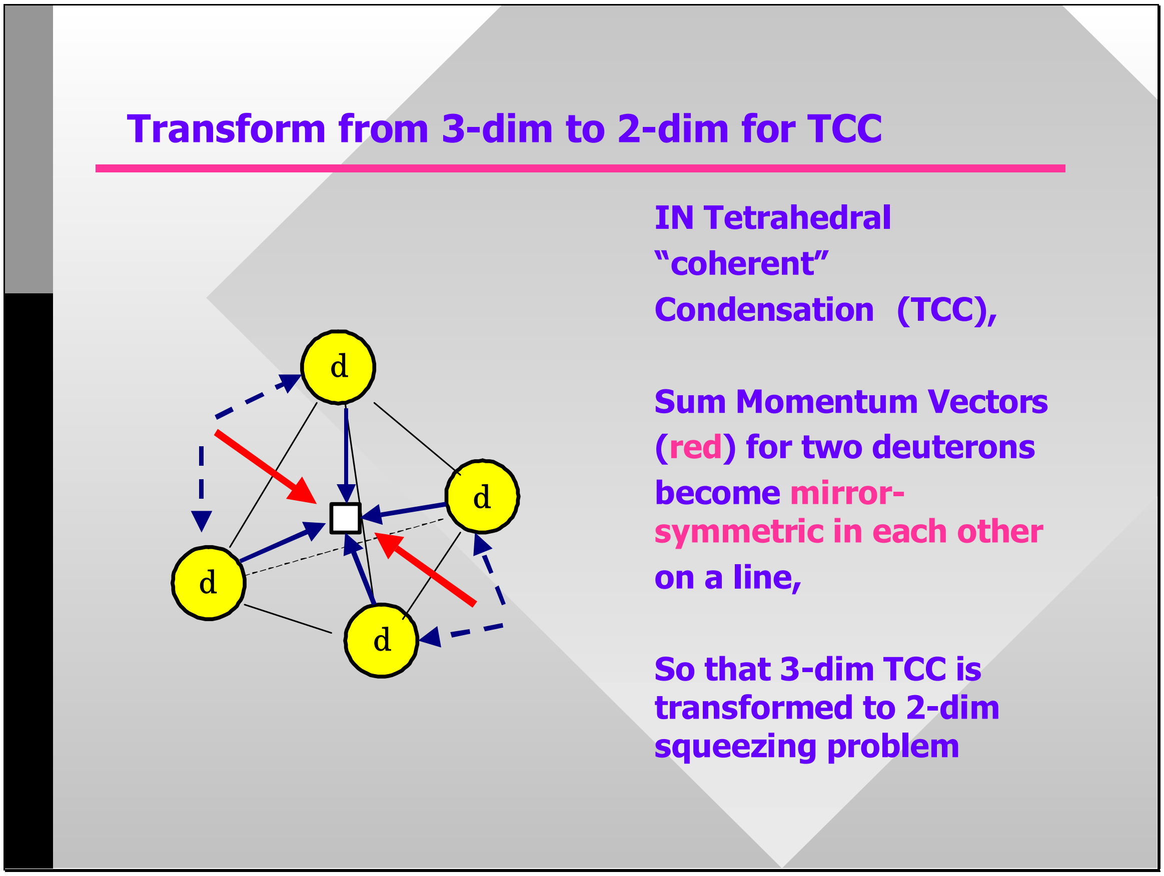
Squeezing From O-Sites to T-site

3-dimension Frozen State for 4d+s and 4e-s

Quadruplet e* (4,4)

Formation of Electrons around T-site

Slide 9

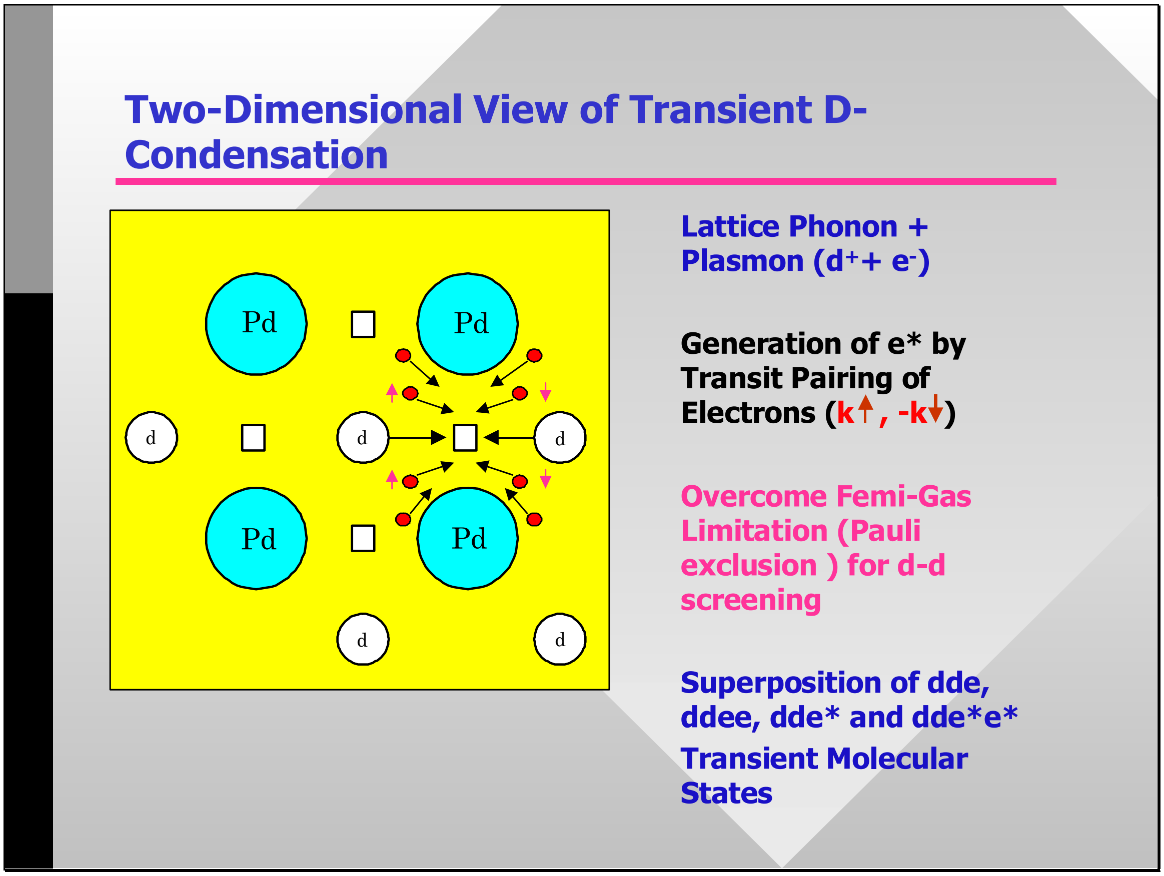


Transform from 3-dim to 2-dim for TCC

IN Tetrahedral
“coherent”
Condensation (TCC),

Sum Momentum Vectors (red) for two deuterons become mirror-symmetric in each other on a line,

So that 3-dim TCC is transformed to 2-dim squeezing problem



Two-Dimensional View of Transient D-Condensation

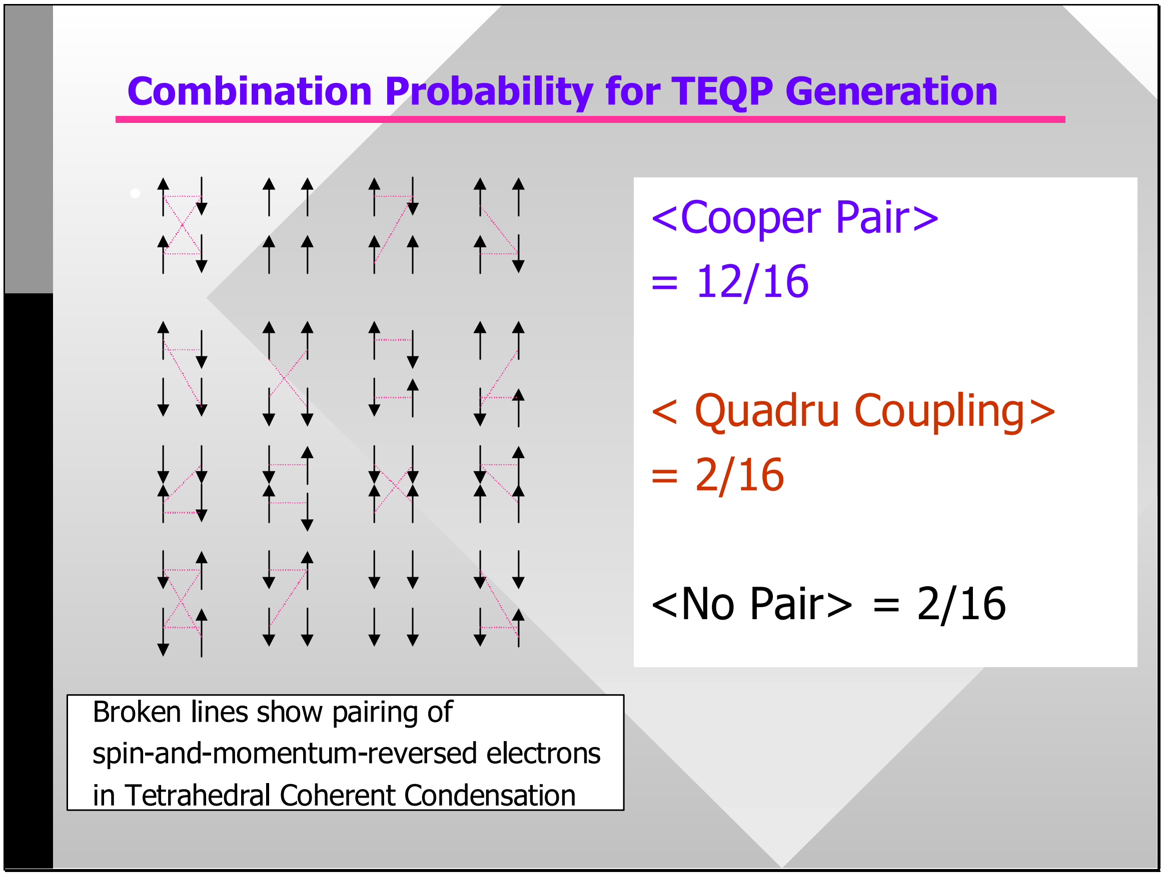
Lattice Phonon + Plasmon ($d^+ + e^-$)

Generation of e* by Transit Pairing of Electrons ($k\uparrow$, $-k\downarrow$)

Overcome Femi-Gas Limitation (Pauli exclusion) for d-d screening

Superposition of dde, ddee, dde* and dde*e*
Transient Molecular States

Slide 11



Combination Probability for TEQP Generation

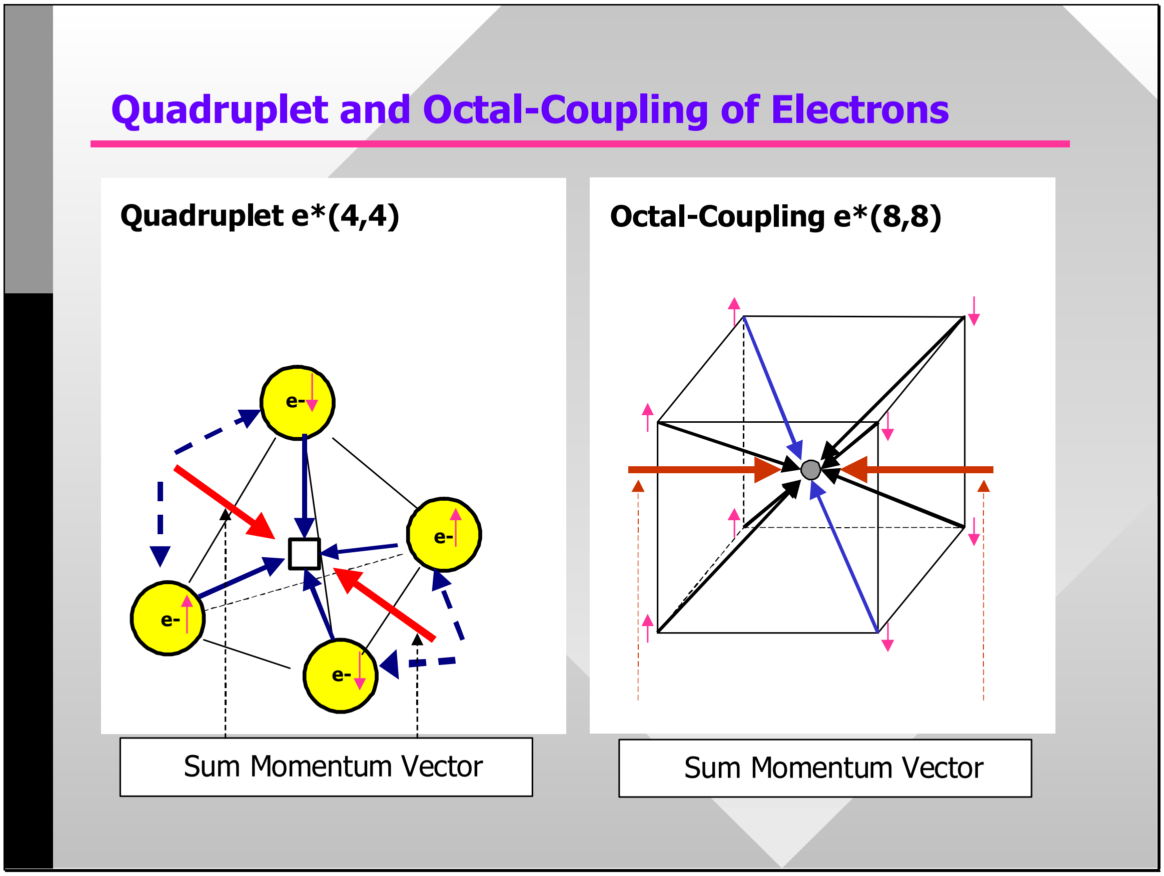
<Cooper Pair>
= 12/16

< Quadru Coupling>
= 2/16

<No Pair> = 2/16

Broken lines show pairing of spin-and-momentum-reversed electrons in Tetrahedral Coherent Condensation

Slide 12



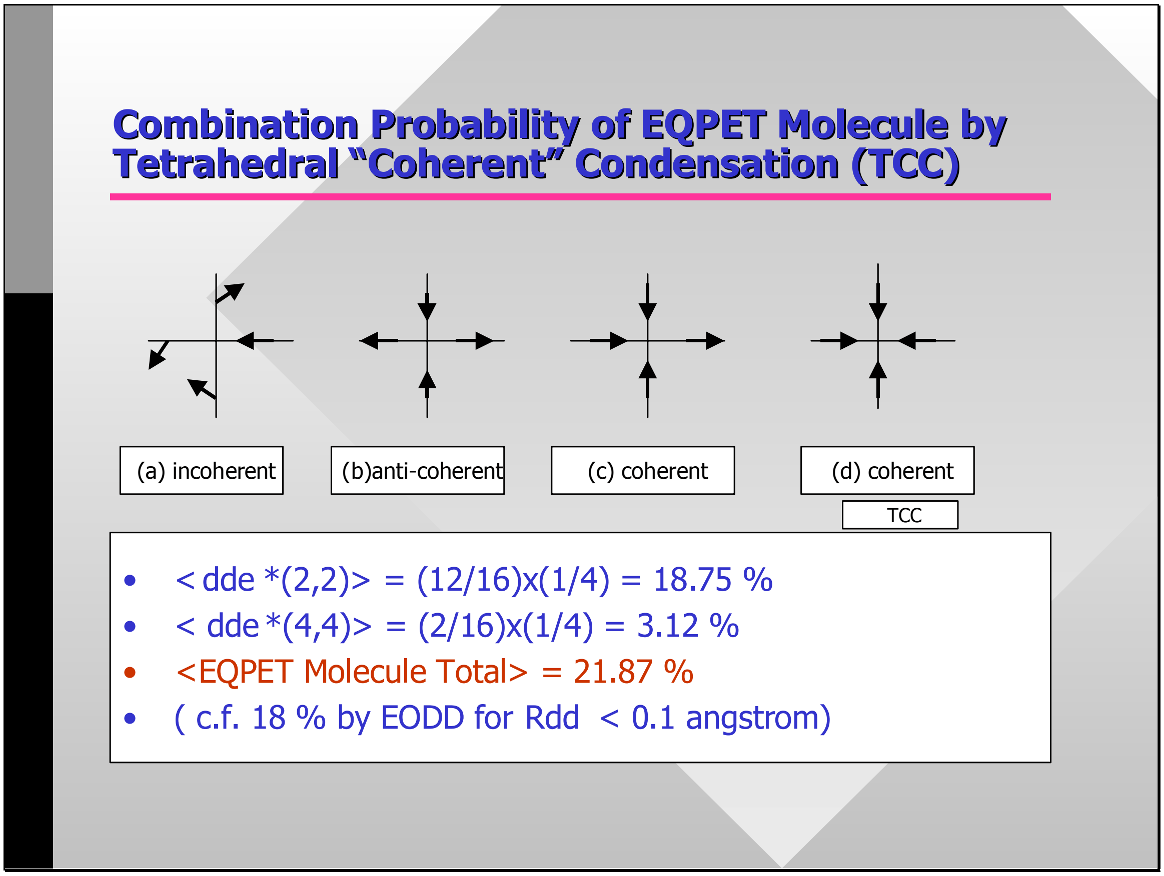
Quadruplet and Octal-Coupling of Electrons

Quadruplet e*(4,4)

Octal-Coupling e*(8,8)

Sum Momentum Vector

Sum Momentum Vector



Combination Probability of EQPET Molecule by Tetrahedral "Coherent" Condensation (TCC)

(a) incoherent

(b)anti-coherent

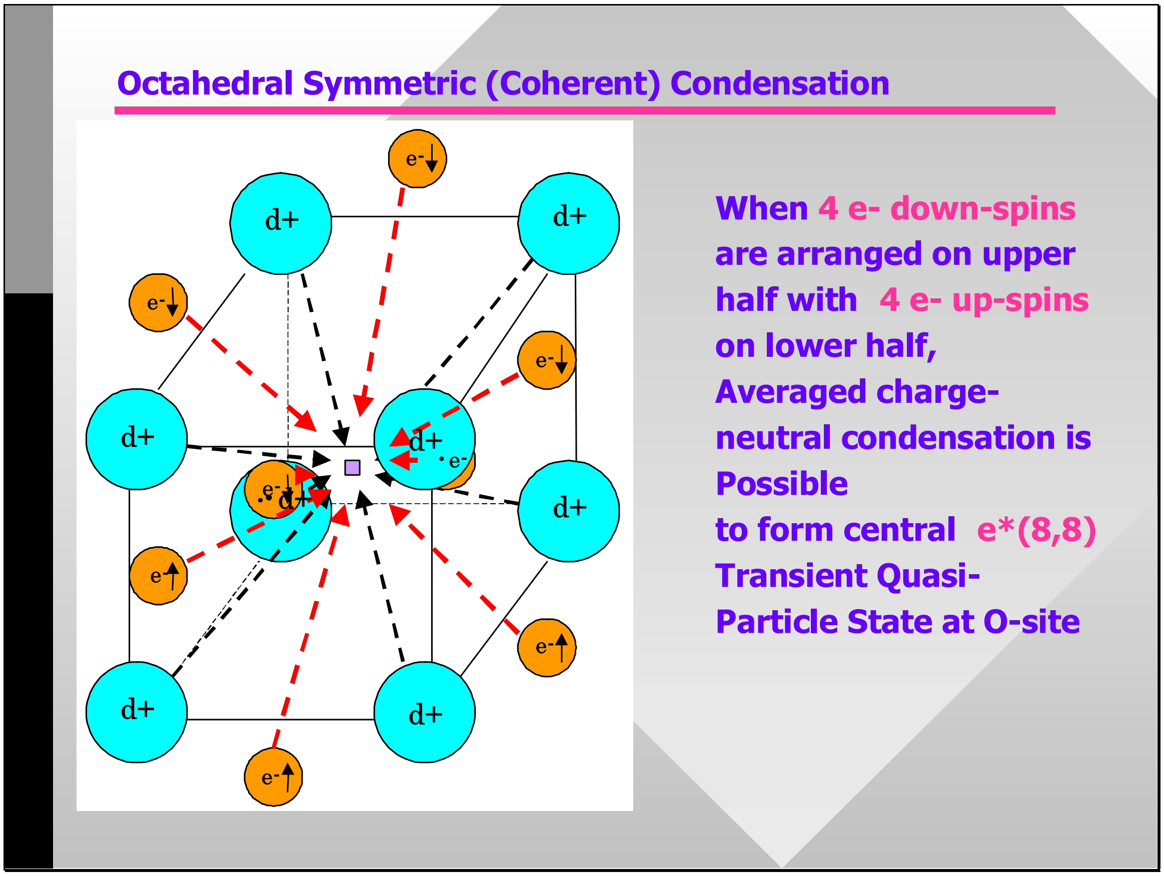
(c) coherent

(d) coherent

TCC

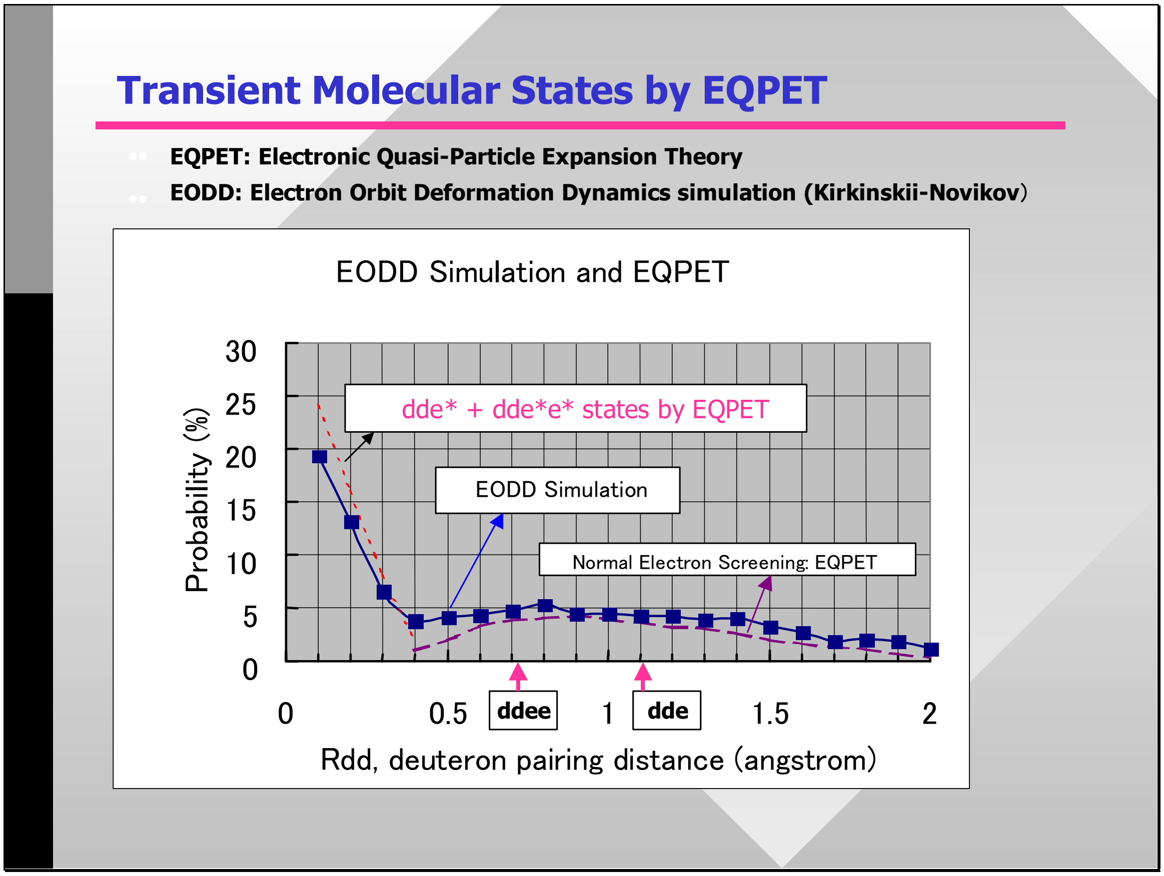
- < dde *(2,2)> = (12/16)x(1/4) = 18.75 %
- < dde *(4,4)> = (2/16)x(1/4) = 3.12 %
- <EQPET Molecule Total> = 21.87 %
- (c.f. 18 % by EODD for Rdd < 0.1 angstrom)

Slide 14



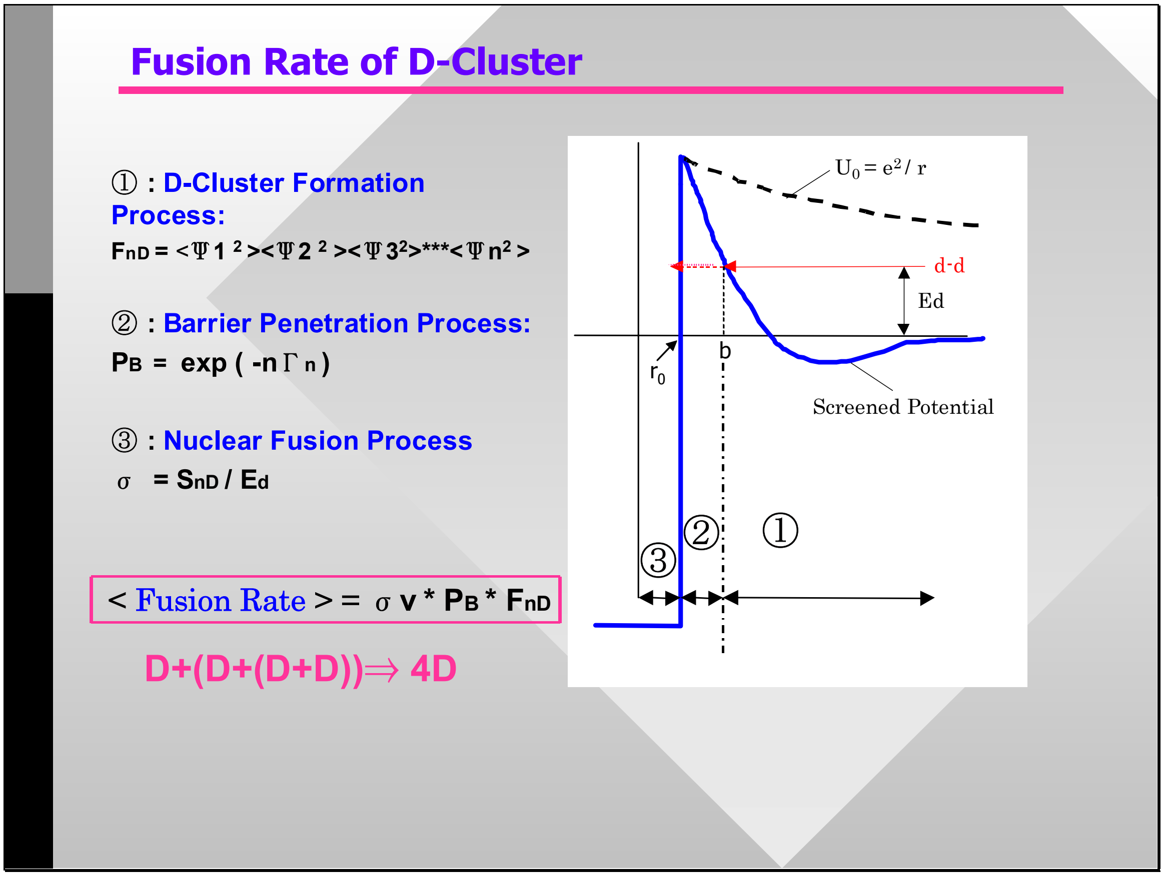
Octahedral Symmetric (Coherent) Condensation

When 4 e- down-spins are arranged on upper half with 4 e- up-spins on lower half,
Averaged charge-neutral condensation is Possible
to form central e*(8,8) Transient Quasi-Particle State at O-site



Transient Molecular States by EQPET

- **EQPET: Electronic Quasi-Particle Expansion Theory**
- **EODD: Electron Orbit Deformation Dynamics simulation (Kirkinskii-Novikov)**



Fusion Rate of D-Cluster

① : **D-Cluster Formation Process:**

$F_{nD} = <\Psi 1^{2}><\Psi 2^{2}><\Psi 3^{2}>***<\Psi n^{2}>$

② : **Barrier Penetration Process:**

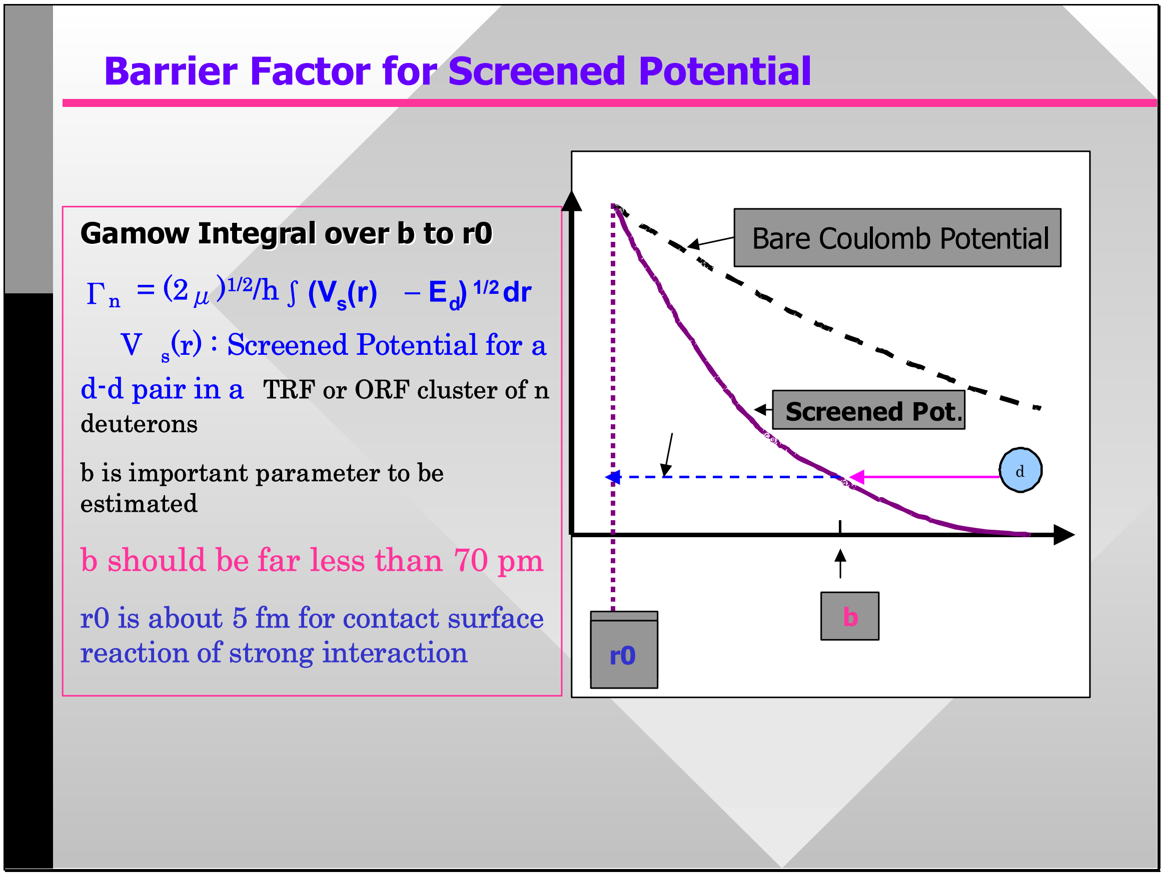
$P_B = \exp(-n\Gamma_n)$

③ : **Nuclear Fusion Process**

$\sigma = S_{nD} / E_d$

$< \text{Fusion Rate} > = \sigma v * P_B * F_{nD}$

D+(D+(D+D))⇒ 4D



Barrier Factor for Screened Potential

Gamow Integral over b to r0

$\Gamma_n = (2\mu)^{1/2}/h \int (V_s(r) - E_d)^{1/2} dr$

$V_s(r)$: Screened Potential for a d-d pair in a TRF or ORF cluster of n deuterons

b is important parameter to be estimated

b should be far less than 70 pm

r0 is about 5 fm for contact surface reaction of strong interaction

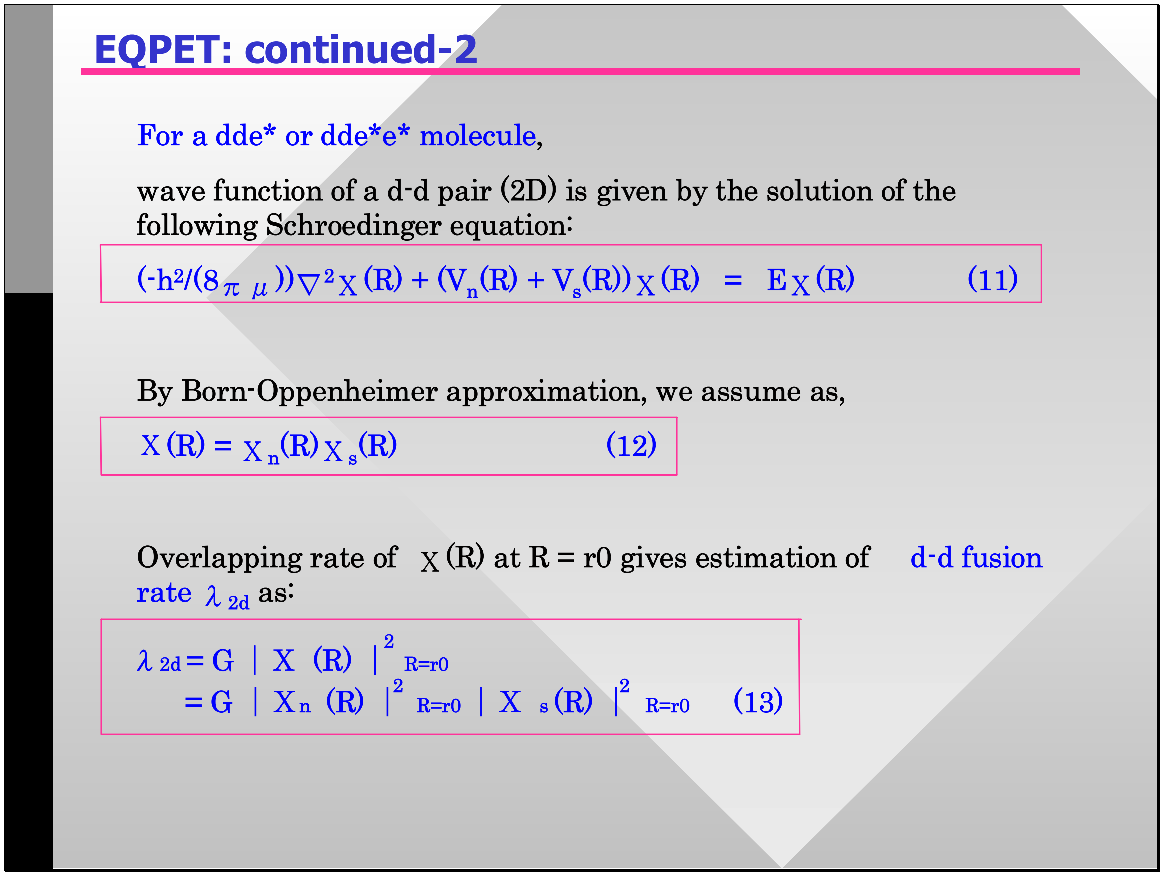
EQPET: continued-1

“Bosonized” electron wave function Ψ_N for N-electrons system in MDx lattice will be approximated by a linear combination of normal electron wave function $\Psi_{(1,1)G}$ and quasi-particle wave functions $\Psi_{(2,2)G}$ $\Psi_{(4,4)G}$ and $\Psi_{(8,8)G}$ as;

$$|\Psi_N> = a_1|\Psi_{(1,1)G}> + a_2|\Psi_{(2,2)G}> + a_4|\Psi_{(4,4)G}> + a_8|\Psi_{(8,8)G}> \qquad (3)$$

For the time-window of potential deep hole [1,2], effective (time-averaged) screening potential, for a d-d pair in a transient D-cluster of 4-8 deuterons for TRF and ORF condition [2], can be defined by a screened potential of quasi-particle complex;

$$V_s(R) = b_1V_{s(1,1)}(R) + b_2V_{s(2,2)}(R) + b_4V_{s(4,4)}(R) + b_8V_{s(8,8)}(R) \qquad (9)$$



EQPET: continued-2

For a dde* or dde*e* molecule,

wave function of a d-d pair (2D) is given by the solution of the following Schroedinger equation:

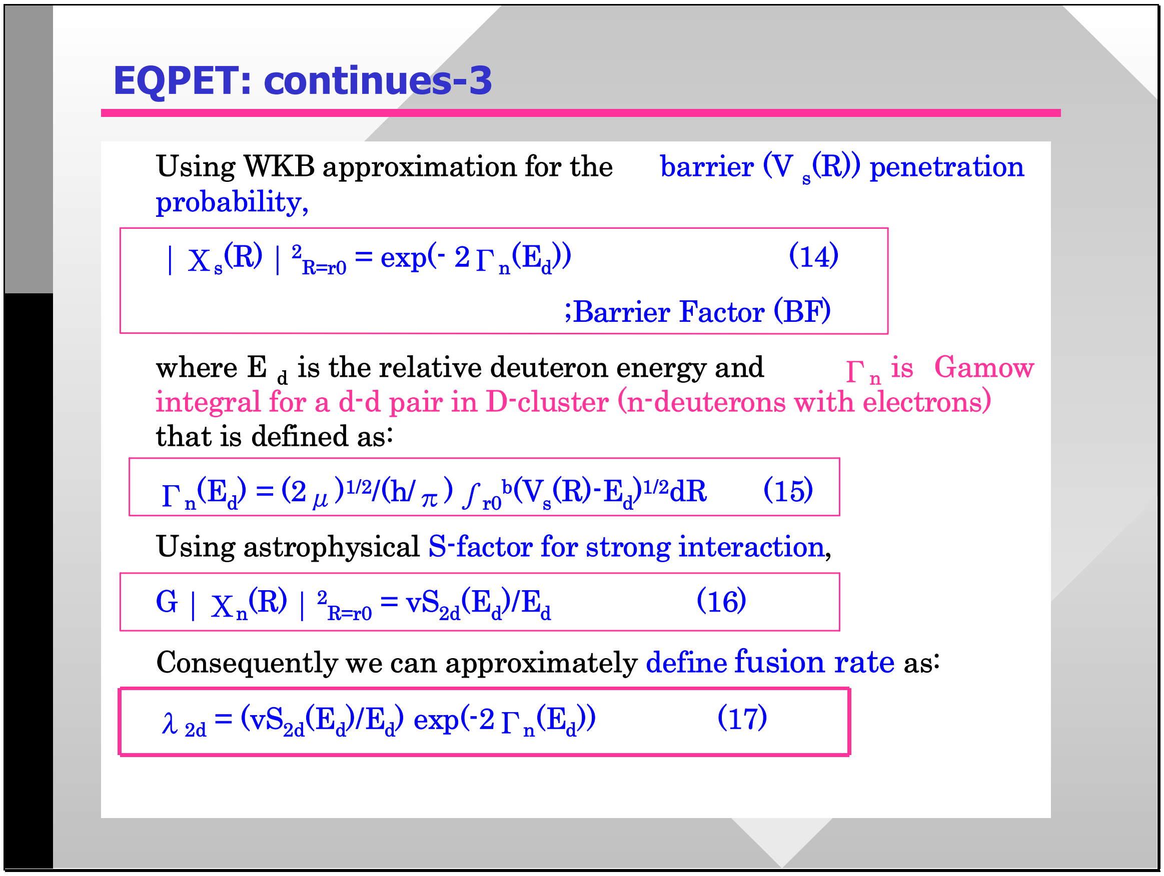
$$(-h^2/(8\pi\mu))\nabla^2\chi(R) + (V_n(R) + V_s(R))\chi(R) = E\chi(R) \qquad (11)$$

By Born-Oppenheimer approximation, we assume as,

$$\chi(R) = \chi_n(R)\chi_s(R) \qquad (12)$$

Overlapping rate of $\chi(R)$ at R = r0 gives estimation of d-d fusion rate λ_{2d} as:

$$\begin{aligned}\lambda_{2d} &= G\,|\chi(R)|^2_{R=r0}\\ &= G\,|\chi_n(R)|^2_{R=r0}\,|\chi_s(R)|^2_{R=r0} \qquad (13)\end{aligned}$$



EQPET: continues-3

Using WKB approximation for the barrier ($V_s(R)$) penetration probability,

$$|X_s(R)|^2_{R=r0} = \exp(-2\Gamma_n(E_d)) \qquad (14)$$

;Barrier Factor (BF)

where E_d is the relative deuteron energy and Γ_n is Gamow integral for a d-d pair in D-cluster (n-deuterons with electrons) that is defined as:

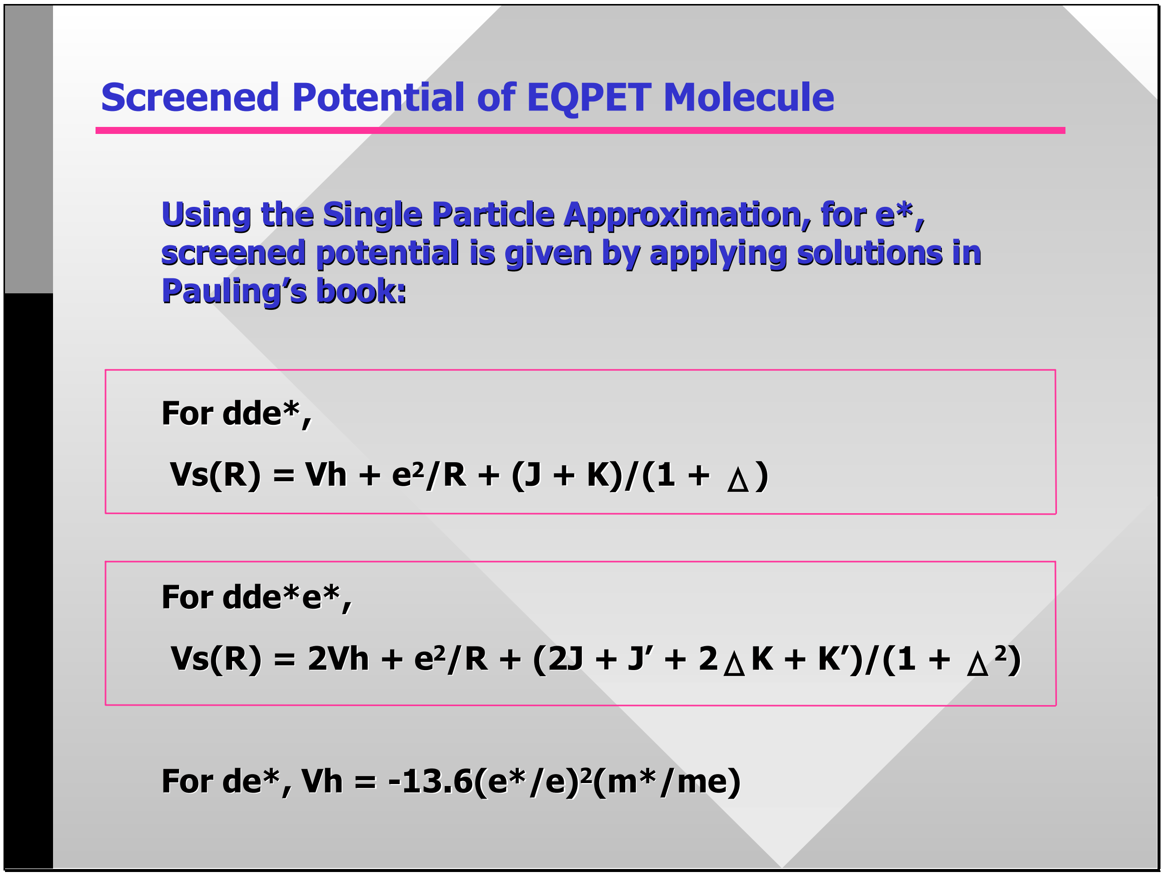
$$\Gamma_n(E_d) = (2\mu)^{1/2}/(h/\pi)\int_{r0}^{b}(V_s(R)-E_d)^{1/2}dR \qquad (15)$$

Using astrophysical S-factor for strong interaction,

$$G|X_n(R)|^2_{R=r0} = vS_{2d}(E_d)/E_d \qquad (16)$$

Consequently we can approximately define fusion rate as:

$$\lambda_{2d} = (vS_{2d}(E_d)/E_d)\exp(-2\Gamma_n(E_d)) \qquad (17)$$



Screened Potential of EQPET Molecule

Using the Single Particle Approximation, for e*, screened potential is given by applying solutions in Pauling's book:

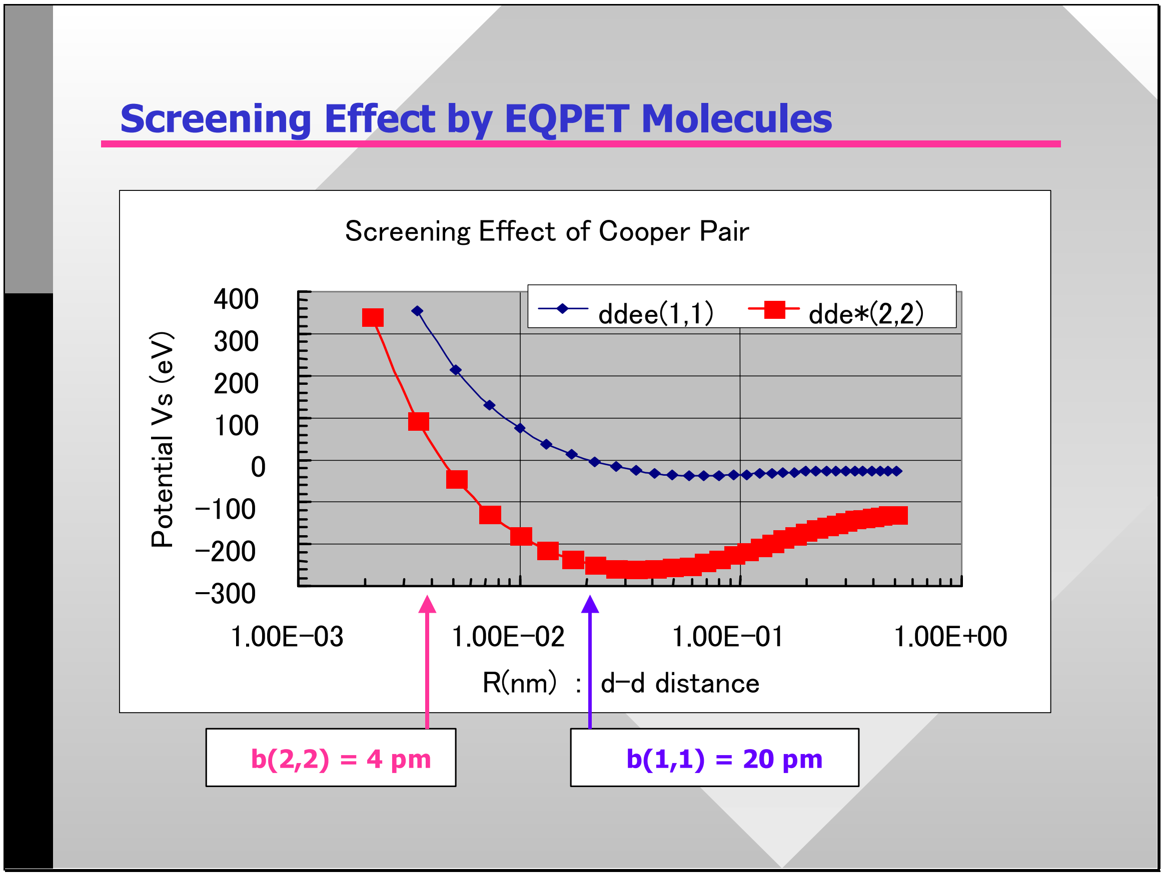
For dde*,

$$Vs(R) = Vh + e^2/R + (J + K)/(1 + \Delta)$$

For dde*e*,

$$Vs(R) = 2Vh + e^2/R + (2J + J' + 2\Delta K + K')/(1 + \Delta^2)$$

For de*, $Vh = -13.6(e^*/e)^2(m^*/me)$



Screening Effect by EQPET Molecules

b(2,2) = 4 pm

b(1,1) = 20 pm

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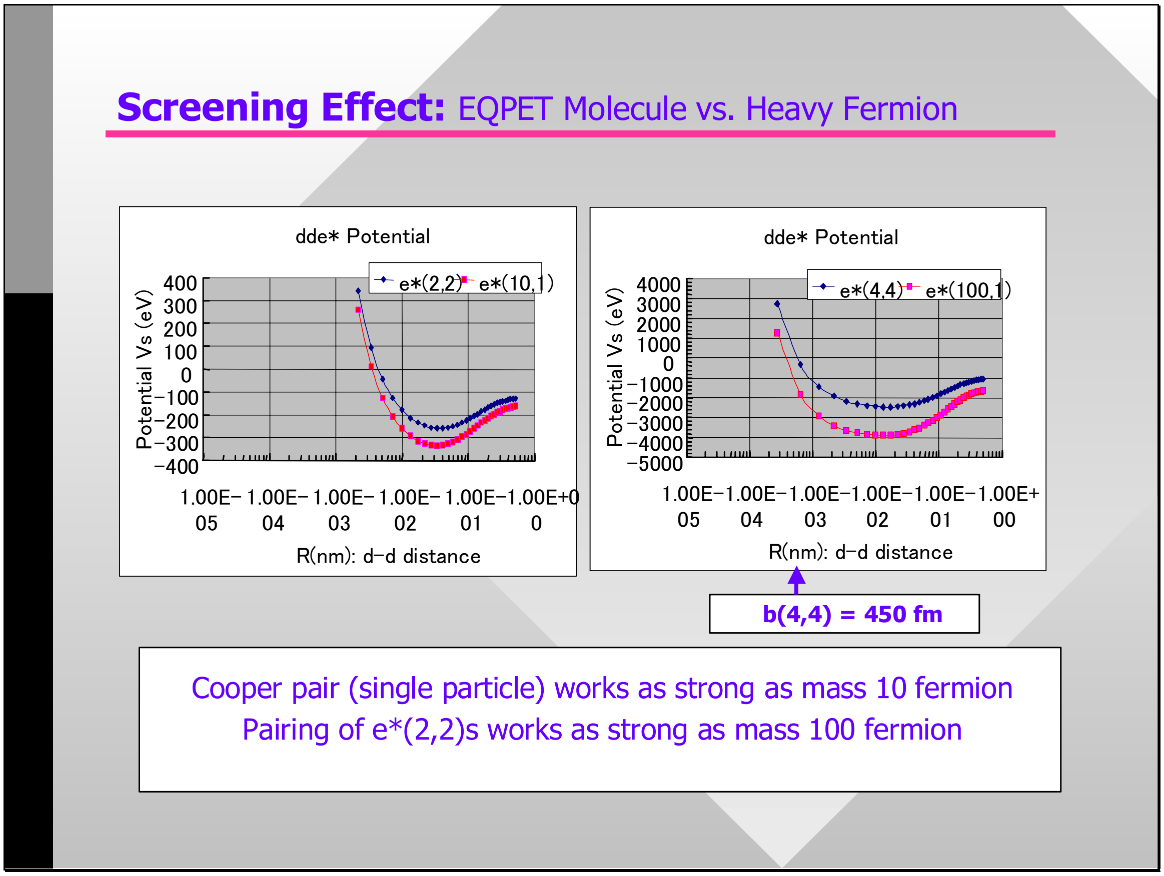
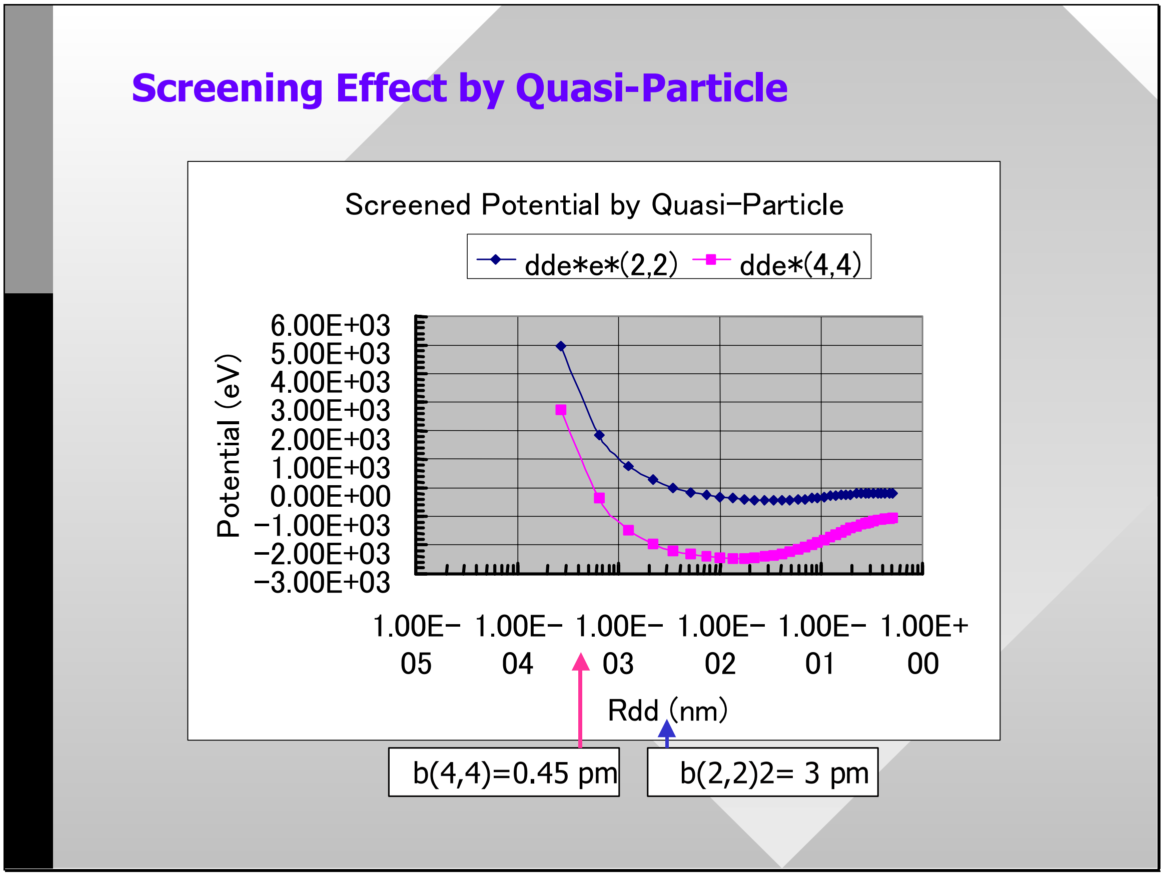


Screening Effect: EQPET Molecule vs. Heavy Fermion

b(4,4) = 450 fm

Cooper pair (single particle) works as strong as mass 10 fermion
Pairing of e*(2,2)s works as strong as mass 100 fermion



Screening Effect by Quasi-Particle

b(4,4)=0.45 pm

b(2,2)2= 3 pm

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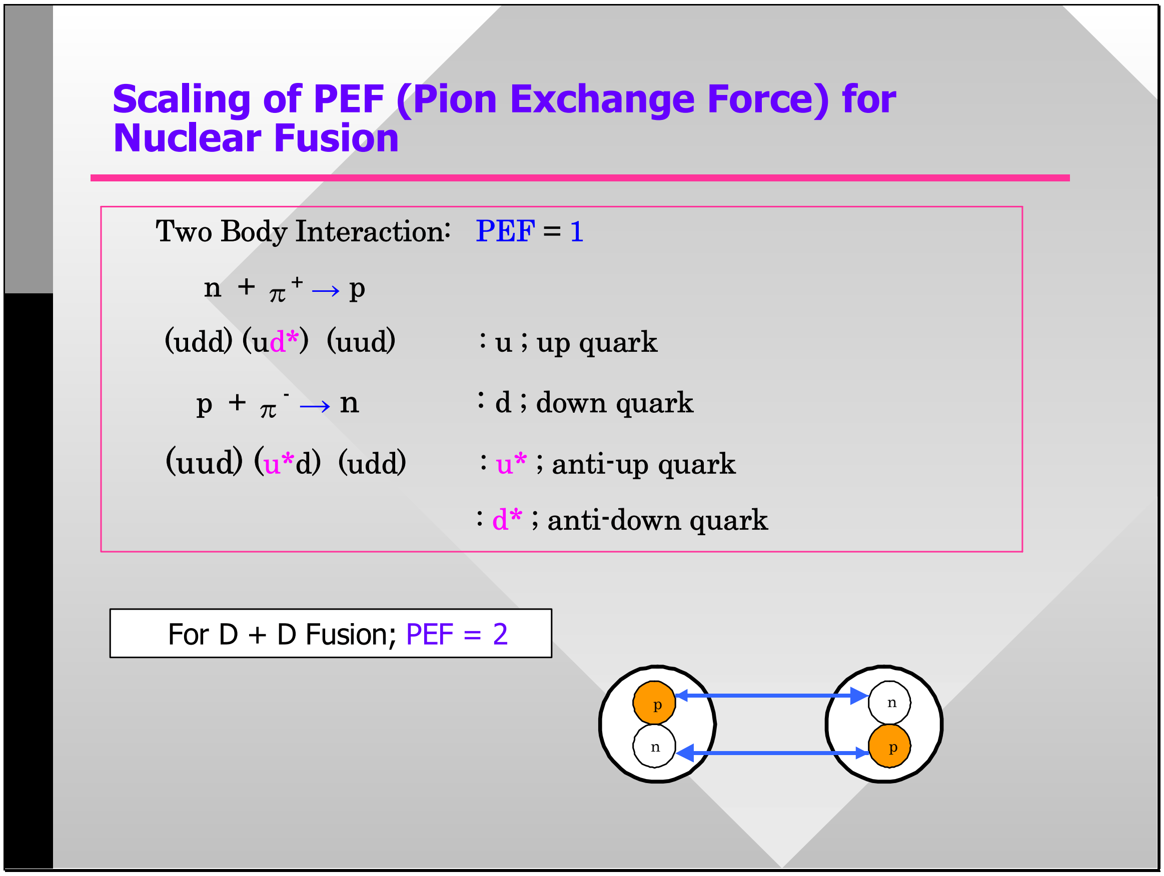


Scaling of PEF (Pion Exchange Force) for Nuclear Fusion

Two Body Interaction: PEF = 1

$n + \pi^{+} \rightarrow p$

(udd) (ud*) (uud)

$p + \pi^{-} \rightarrow n$

(uud) (u*d) (udd)

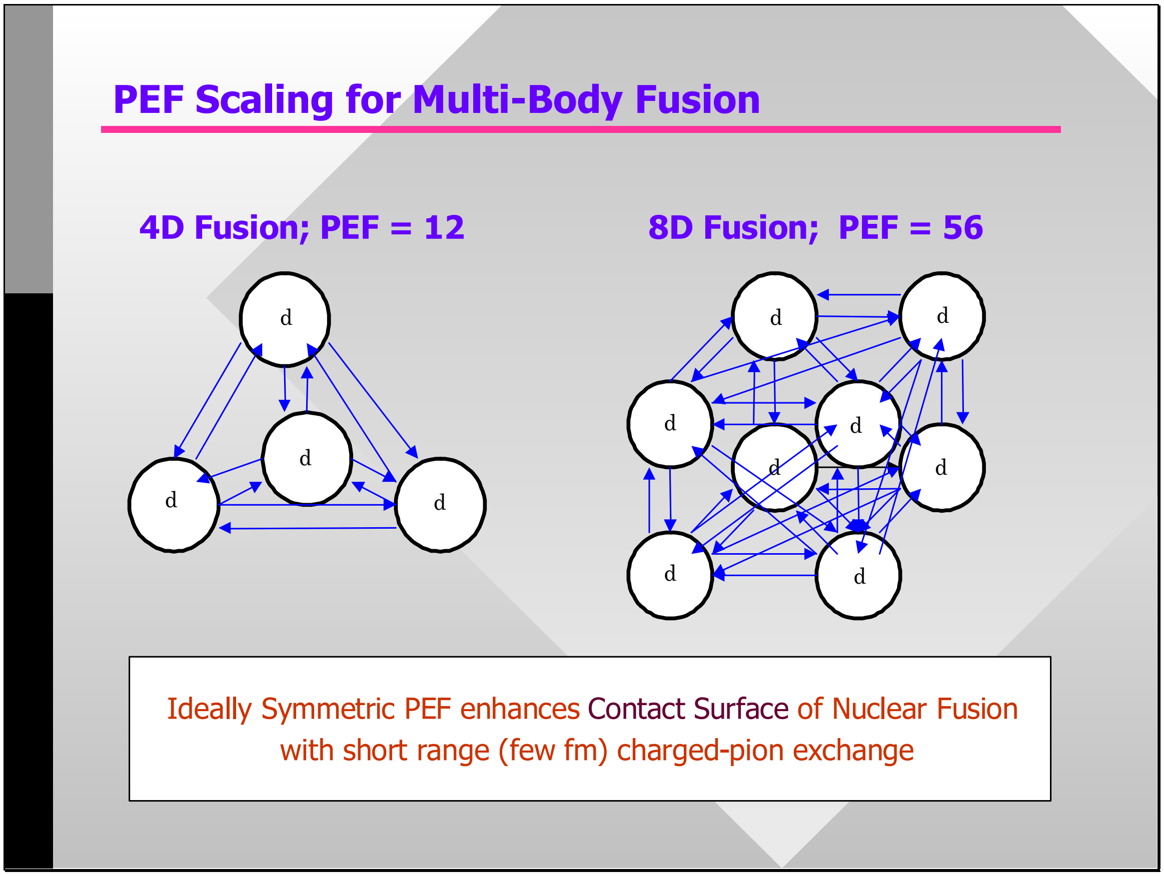
: u ; up quark

: d ; down quark

: u* ; anti-up quark

: d* ; anti-down quark

For D + D Fusion; PEF = 2

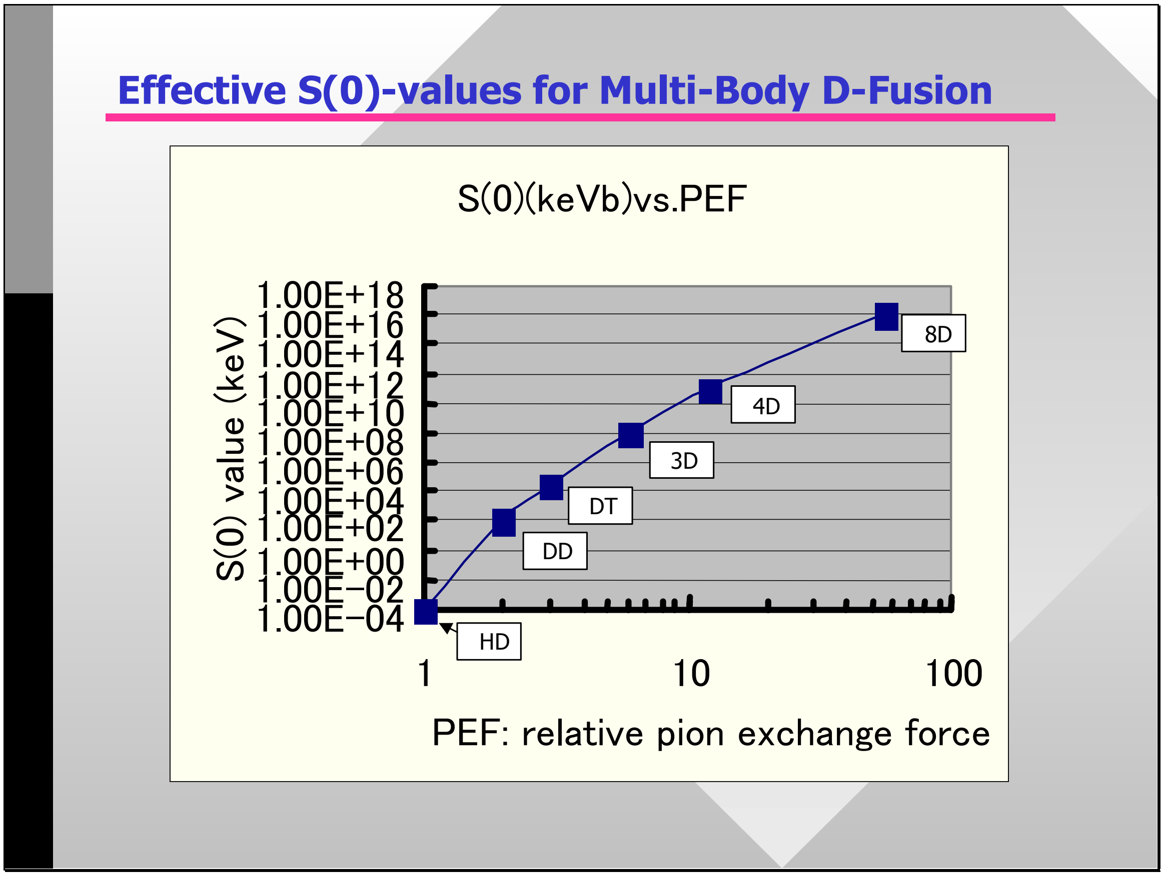


PEF Scaling for Multi-Body Fusion

4D Fusion; PEF = 12

8D Fusion; PEF = 56

Ideally Symmetric PEF enhances Contact Surface of Nuclear Fusion with short range (few fm) charged-pion exchange



Effective S(0)-values for Multi-Body D-Fusion

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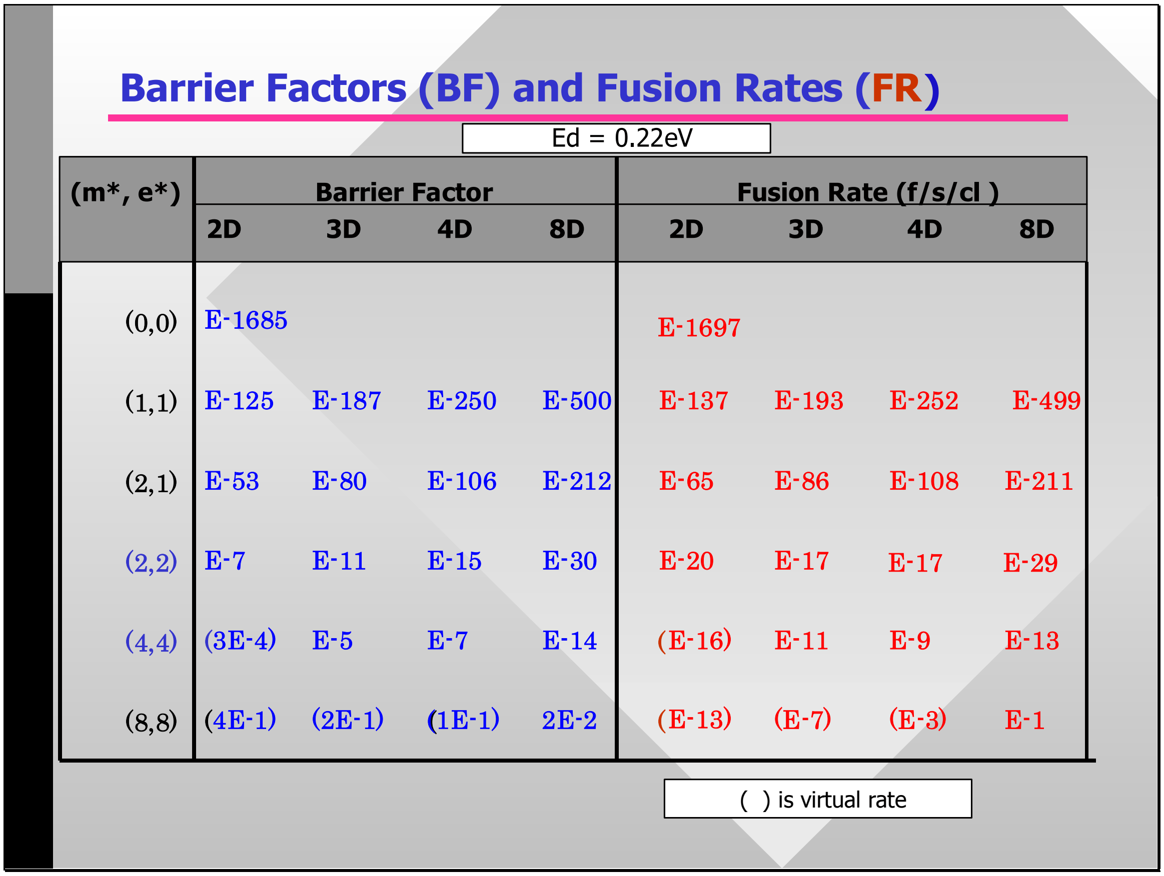

Barrier Factors (BF) and Fusion Rates (FR)

Ed = 0.22eV

(m*, e*)	Barrier Factor				Fusion Rate (f/s/cl)			
	2D	3D	4D	8D	2D	3D	4D	8D
(0,0)	E-1685				E-1697			
(1,1)	E-125	E-187	E-250	E-500	E-137	E-193	E-252	E-499
(2,1)	E-53	E-80	E-106	E-212	E-65	E-86	E-108	E-211
(2,2)	E-7	E-11	E-15	E-30	E-20	E-17	E-17	E-29
(4,4)	(3E-4)	E-5	E-7	E-14	(E-16)	E-11	E-9	E-13
(8,8)	(4E-1)	(2E-1)	(1E-1)	2E-2	(E-13)	(E-7)	(E-3)	E-1

( ) is virtual rate

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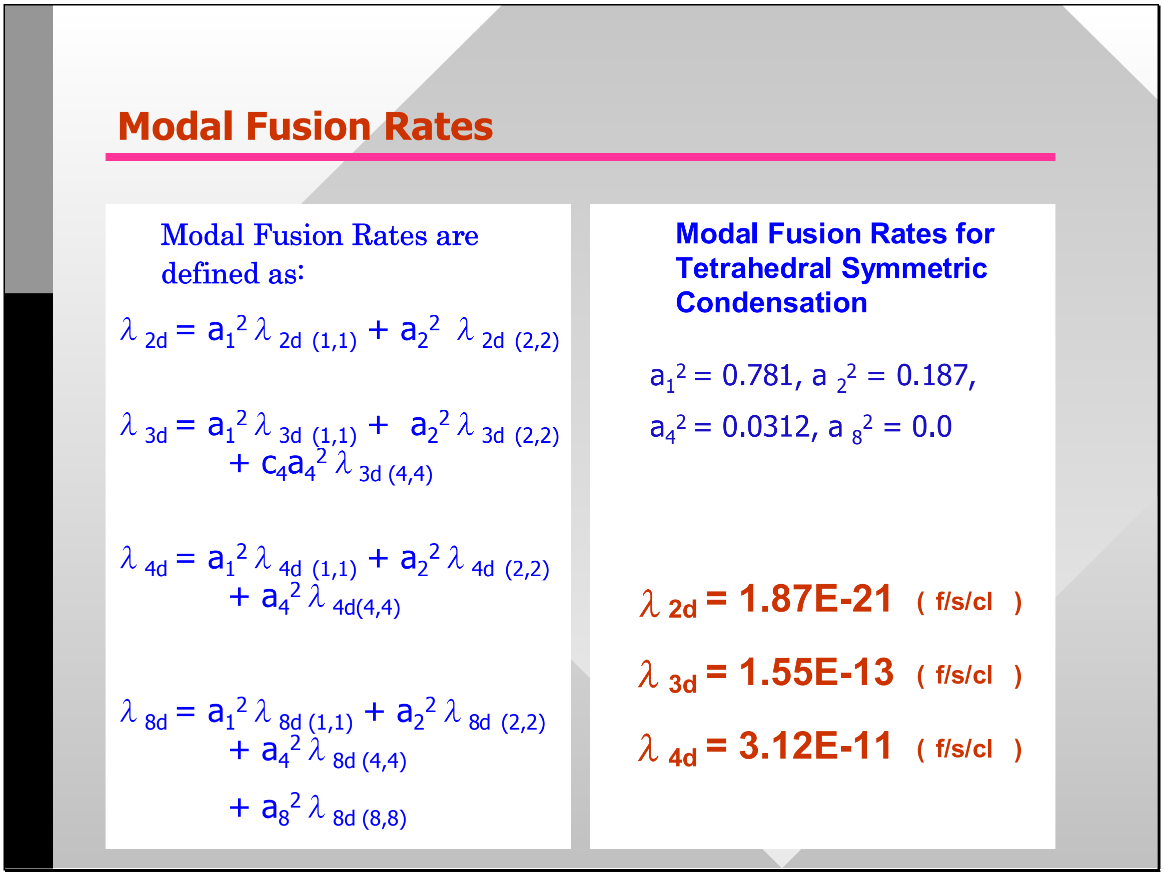


Modal Fusion Rates

Modal Fusion Rates are defined as:

$$\lambda_{2d} = a_1^2 \lambda_{2d\ (1,1)} + a_2^2\ \lambda_{2d\ (2,2)}$$

$$\lambda_{3d} = a_1^2 \lambda_{3d\ (1,1)} + a_2^2 \lambda_{3d\ (2,2)} + c_4 a_4^2 \lambda_{3d\ (4,4)}$$

$$\lambda_{4d} = a_1^2 \lambda_{4d\ (1,1)} + a_2^2 \lambda_{4d\ (2,2)} + a_4^2 \lambda_{4d(4,4)}$$

$$\lambda_{8d} = a_1^2 \lambda_{8d\ (1,1)} + a_2^2 \lambda_{8d\ (2,2)} + a_4^2 \lambda_{8d\ (4,4)} + a_8^2 \lambda_{8d\ (8,8)}$$

Modal Fusion Rates for Tetrahedral Symmetric Condensation

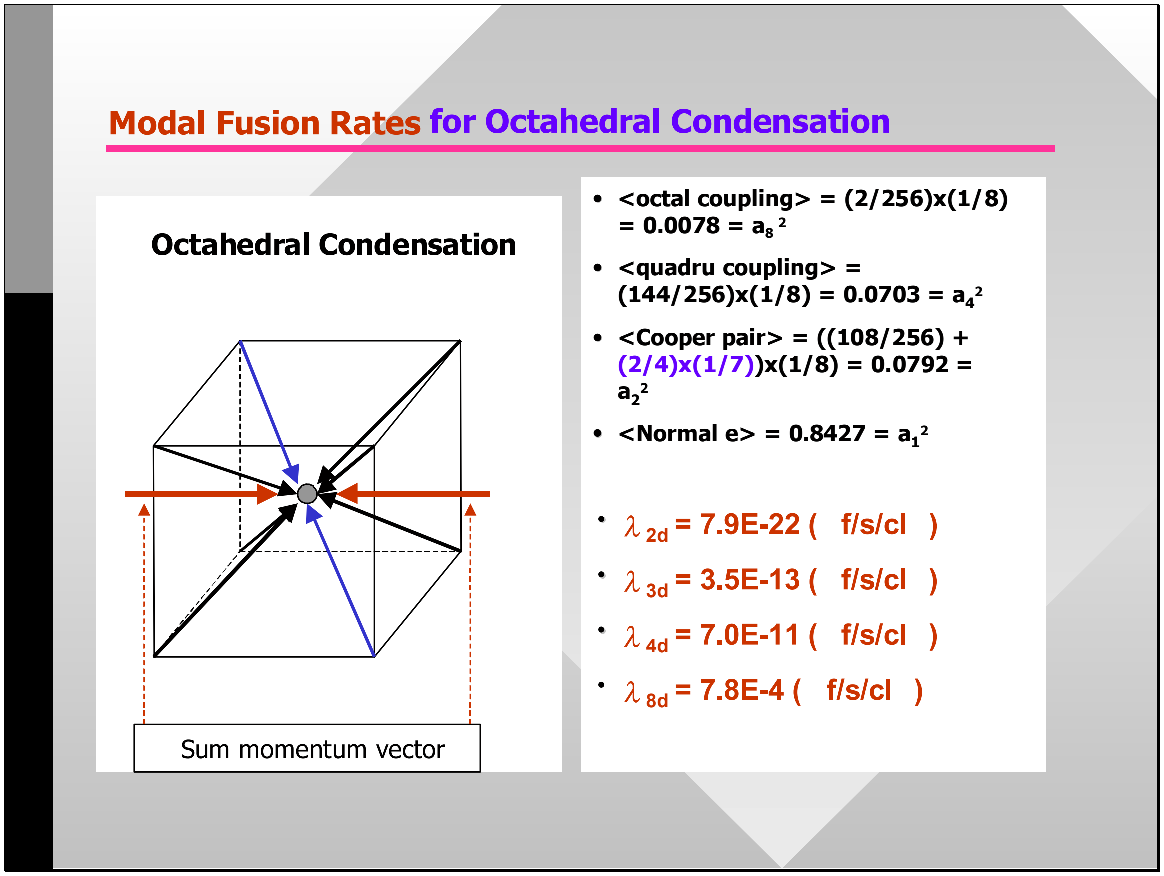
$a_1^2 = 0.781$, $a_2^2 = 0.187$,

$a_4^2 = 0.0312$, $a_8^2 = 0.0$

λ_{2d} **= 1.87E-21** (**f/s/cl**)

λ_{3d} **= 1.55E-13** (**f/s/cl**)

λ_{4d} **= 3.12E-11** (**f/s/cl**)



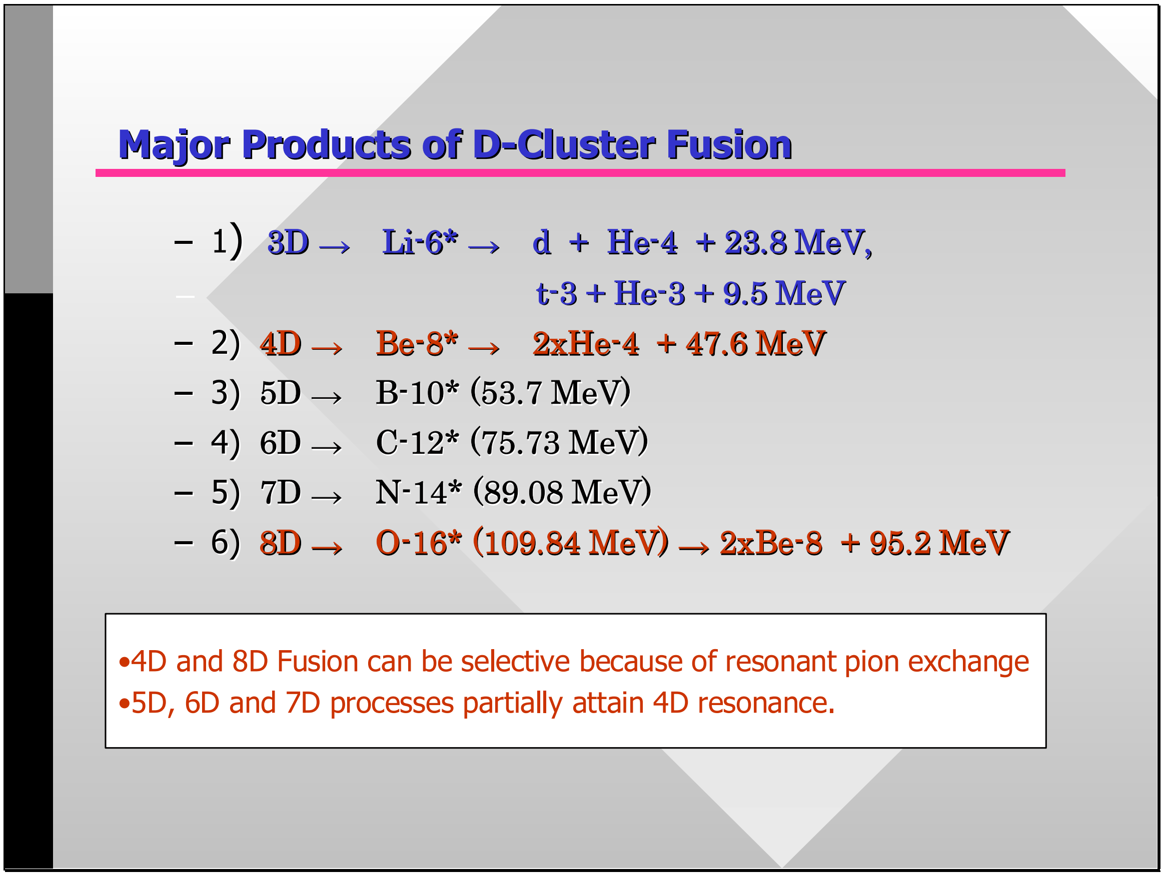
Modal Fusion Rates for Octahedral Condensation

Octahedral Condensation

Sum momentum vector

- **<octal coupling> = (2/256)x(1/8) = 0.0078 = a_8^2**
- **<quadru coupling> = (144/256)x(1/8) = 0.0703 = a_4^2**
- **<Cooper pair> = ((108/256) + (2/4)x(1/7))x(1/8) = 0.0792 = a_2^2**
- **<Normal e> = 0.8427 = a_1^2**

- λ_{2d} = 7.9E-22 (f/s/cl)
- λ_{3d} = 3.5E-13 (f/s/cl)
- λ_{4d} = 7.0E-11 (f/s/cl)
- λ_{8d} = 7.8E-4 (f/s/cl)

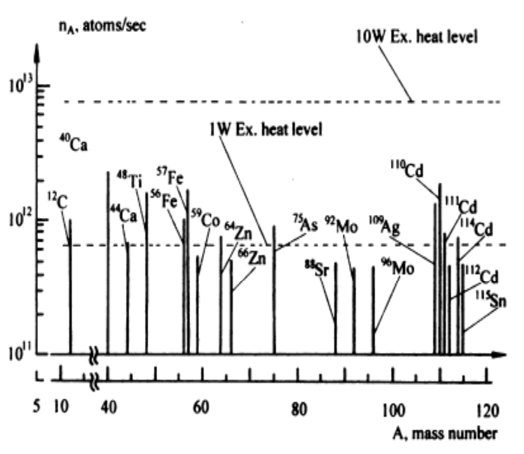


Major Products of D-Cluster Fusion

- 1) 3D → Li-6* → d + He-4 + 23.8 MeV,
- t-3 + He-3 + 9.5 MeV
- 2) 4D → Be-8* → 2xHe-4 + 47.6 MeV
- 3) 5D → B-10* (53.7 MeV)
- 4) 6D → C-12* (75.73 MeV)
- 5) 7D → N-14* (89.08 MeV)
- 6) 8D → O-16* (109.84 MeV) → 2xBe-8 + 95.2 MeV

- 4D and 8D Fusion can be selective because of resonant pion exchange
- 5D, 6D and 7D processes partially attain 4D resonance.

Karabut Data and Pd + ^{4}He Reactions



Impurity production rates in Pd cathode of D2 glow-discharge plus SIMS, by Karabut, Proc. ICCF9, 2002

- Secondary Reactions by 23.8MeV ^{4}He of 4D TRF
- ^{105}Pd + ^{4}He → ^{109}Cd*(1.27y)
- ^{106}Pd + ^{4}He → ^{110}Cd
- ^{108}Pd + ^{4}He → ^{112}Cd
- ^{110}Pd + ^{4}He → ^{114}Cd
- ^{107}Pd*(6.5x10^{6} y) + ^{4}He → ^{111}Cd

^{109}Ag might be ^{109}Cd ?

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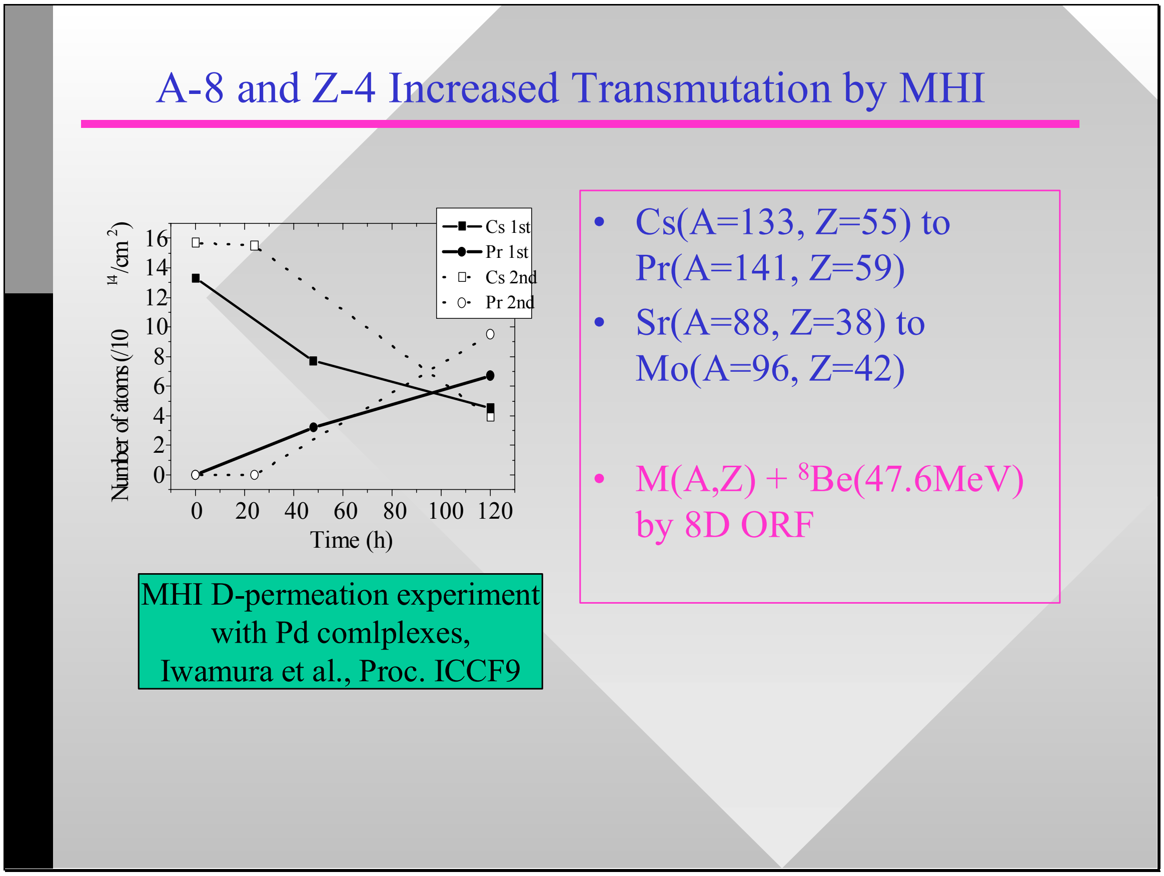

A-8 and Z-4 Increased Transmutation by MHI

MHI D-permeation experiment with Pd comlplexes, Iwamura et al., Proc. ICCF9

- Cs(A=133, Z=55) to Pr(A=141, Z=59)
- Sr(A=88, Z=38) to Mo(A=96, Z=42)

- M(A,Z) + ^{8}Be(47.6MeV) by 8D ORF

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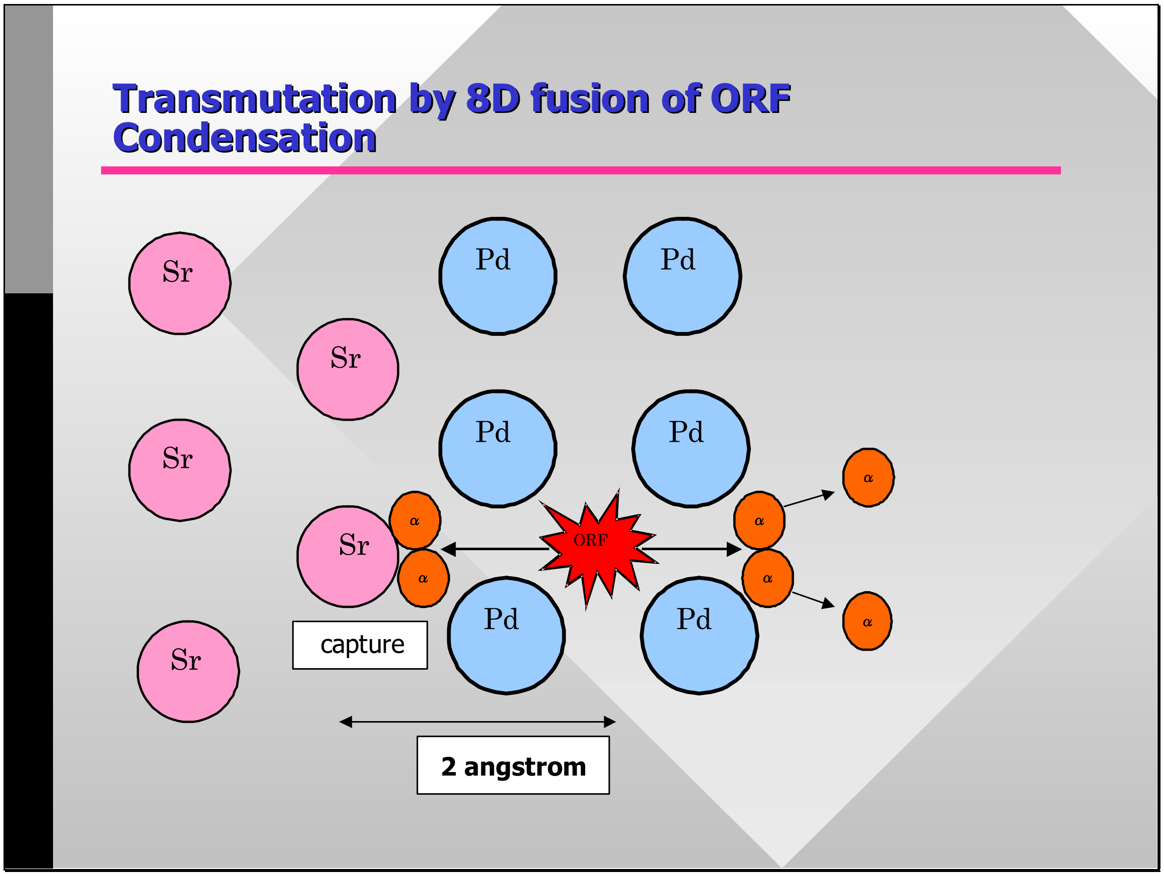
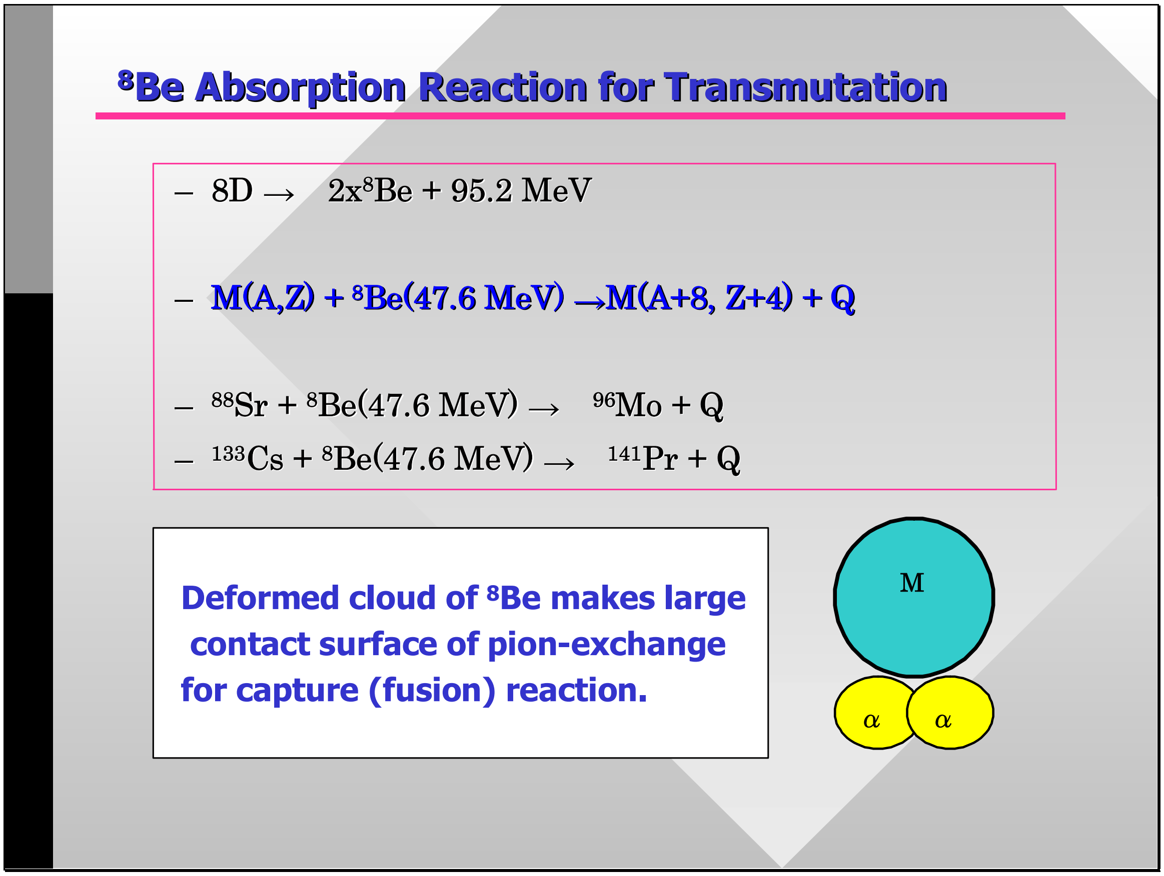


Transmutation by 8D fusion of ORF Condensation

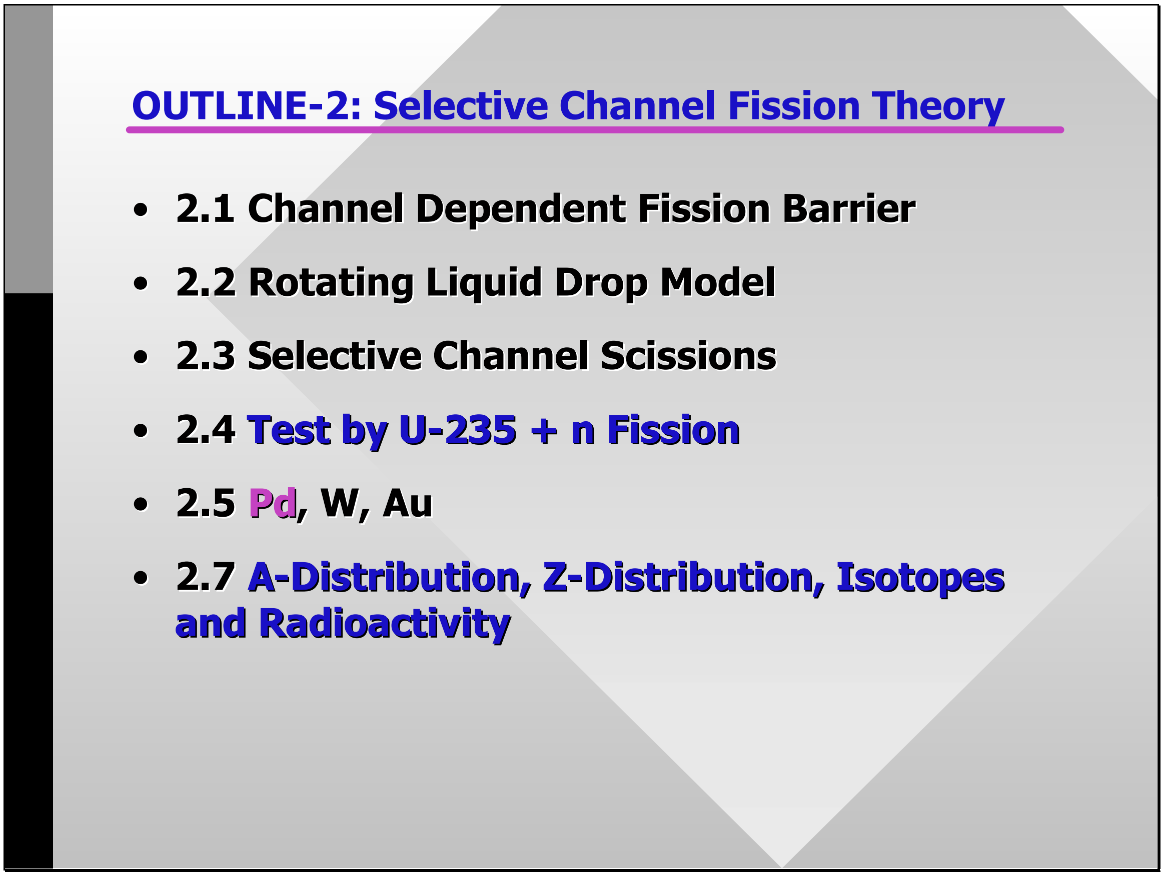
Slide 35



^{8}Be Absorption Reaction for Transmutation

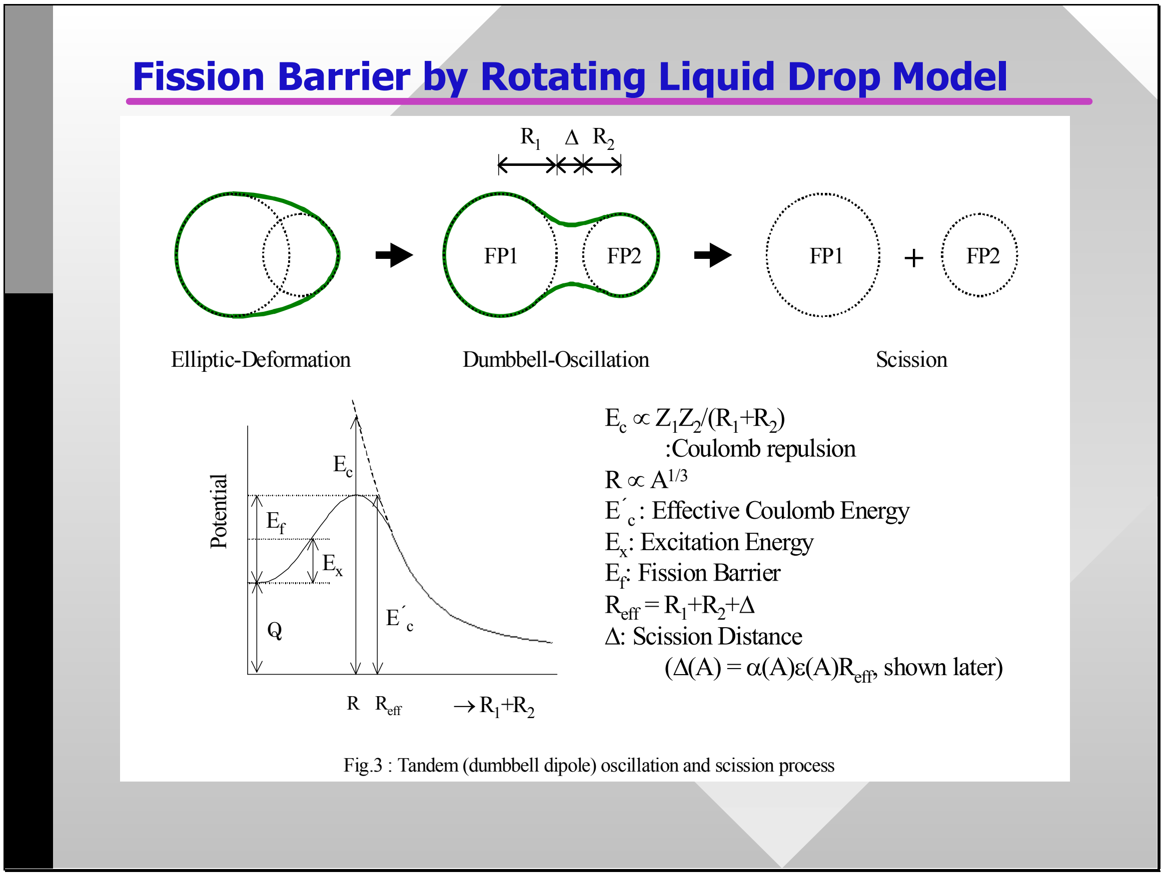
- $8D \rightarrow 2 \times {}^8Be + 95.2$ MeV
- **$M(A,Z) + {}^8Be(47.6\ \text{MeV}) \rightarrow M(A+8, Z+4) + Q$**
- ${}^{88}Sr + {}^8Be(47.6\ \text{MeV}) \rightarrow {}^{96}Mo + Q$
- ${}^{133}Cs + {}^8Be(47.6\ \text{MeV}) \rightarrow {}^{141}Pr + Q$

Deformed cloud of ^{8}Be makes large contact surface of pion-exchange for capture (fusion) reaction.



OUTLINE-2: Selective Channel Fission Theory

- **2.1 Channel Dependent Fission Barrier**
- **2.2 Rotating Liquid Drop Model**
- **2.3 Selective Channel Scissions**
- **2.4 Test by U-235 + n Fission**
- **2.5 Pd, W, Au**
- **2.7 A-Distribution, Z-Distribution, Isotopes and Radioactivity**



Fission Barrier by Rotating Liquid Drop Model

$E_c \propto Z_1Z_2/(R_1+R_2)$
:Coulomb repulsion
$R \propto A^{1/3}$
E'_c: Effective Coulomb Energy
E_x: Excitation Energy
E_f: Fission Barrier
$R_{eff} = R_1+R_2+\Delta$
Δ: Scission Distance
($\Delta(A) = \alpha(A)\varepsilon(A)R_{eff}$, shown later)

Fig.3 : Tandem (dumbbell dipole) oscillation and scission process

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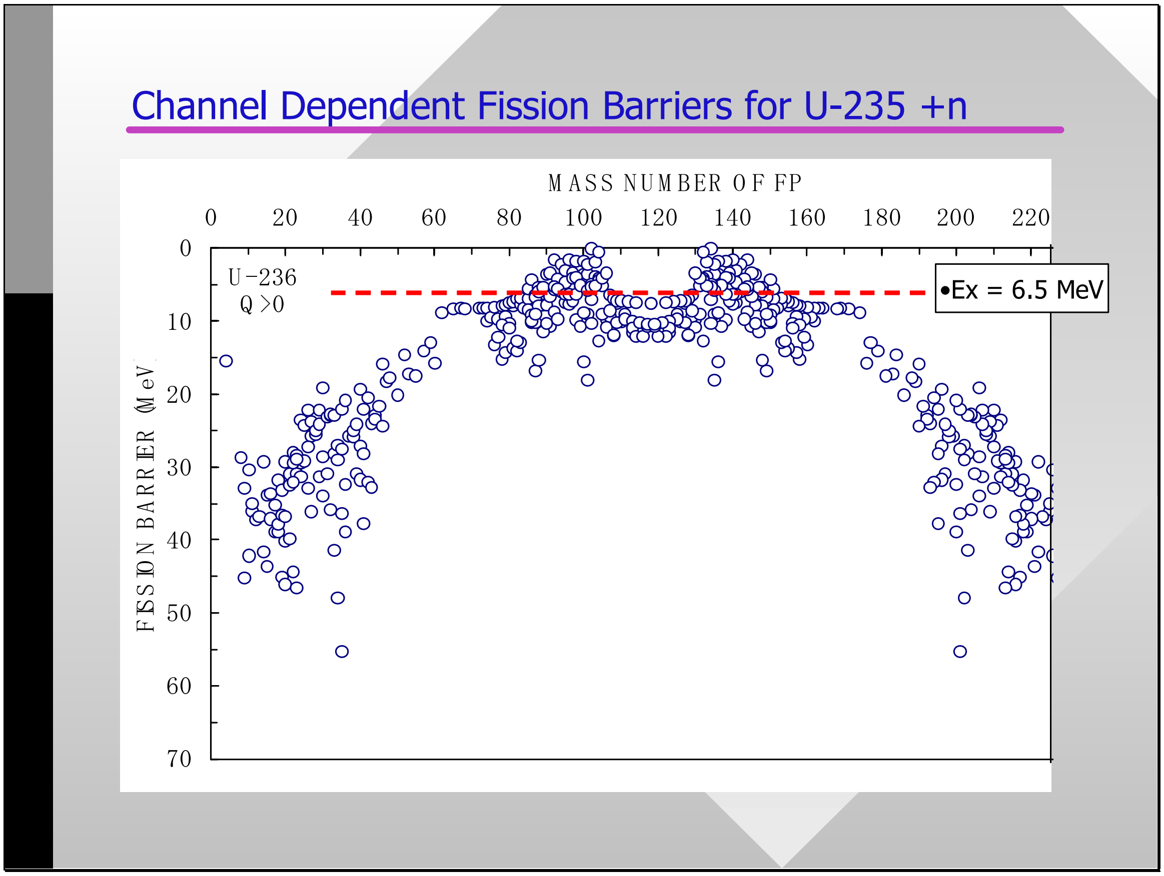
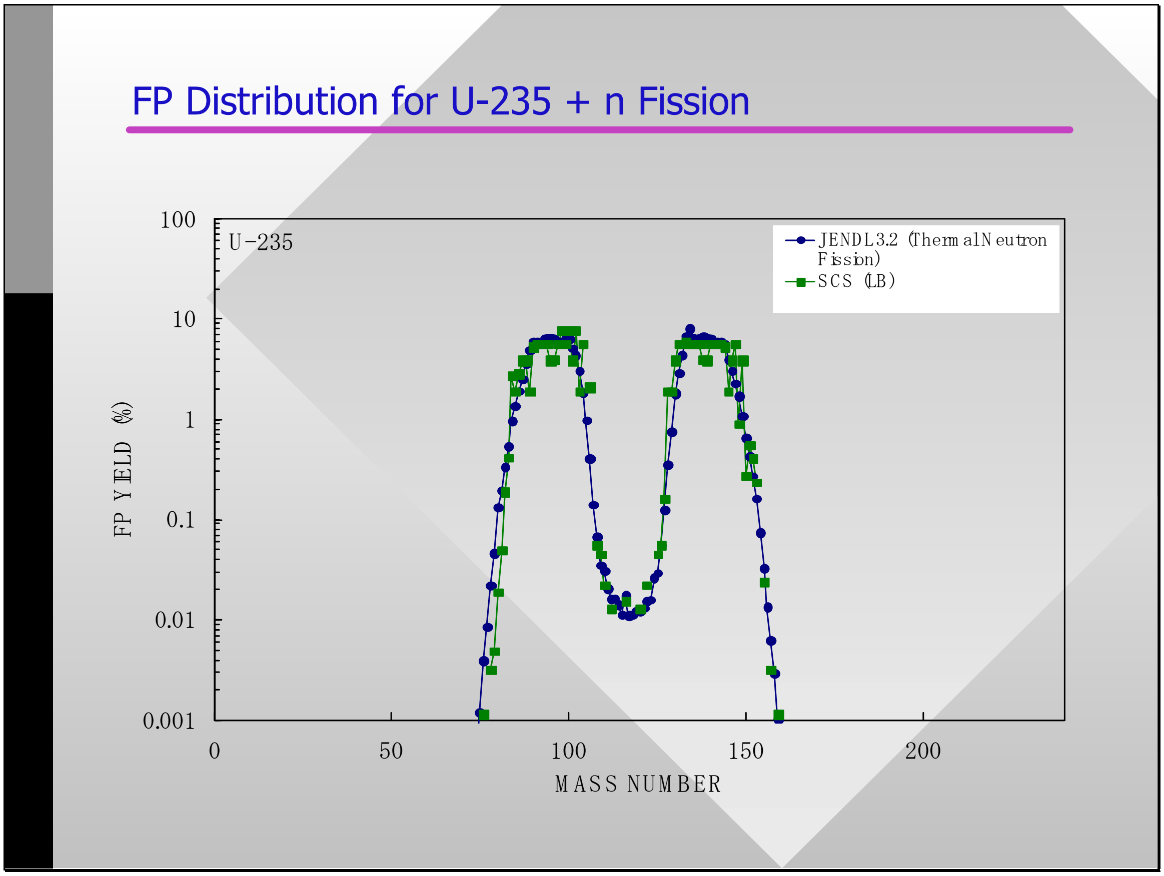
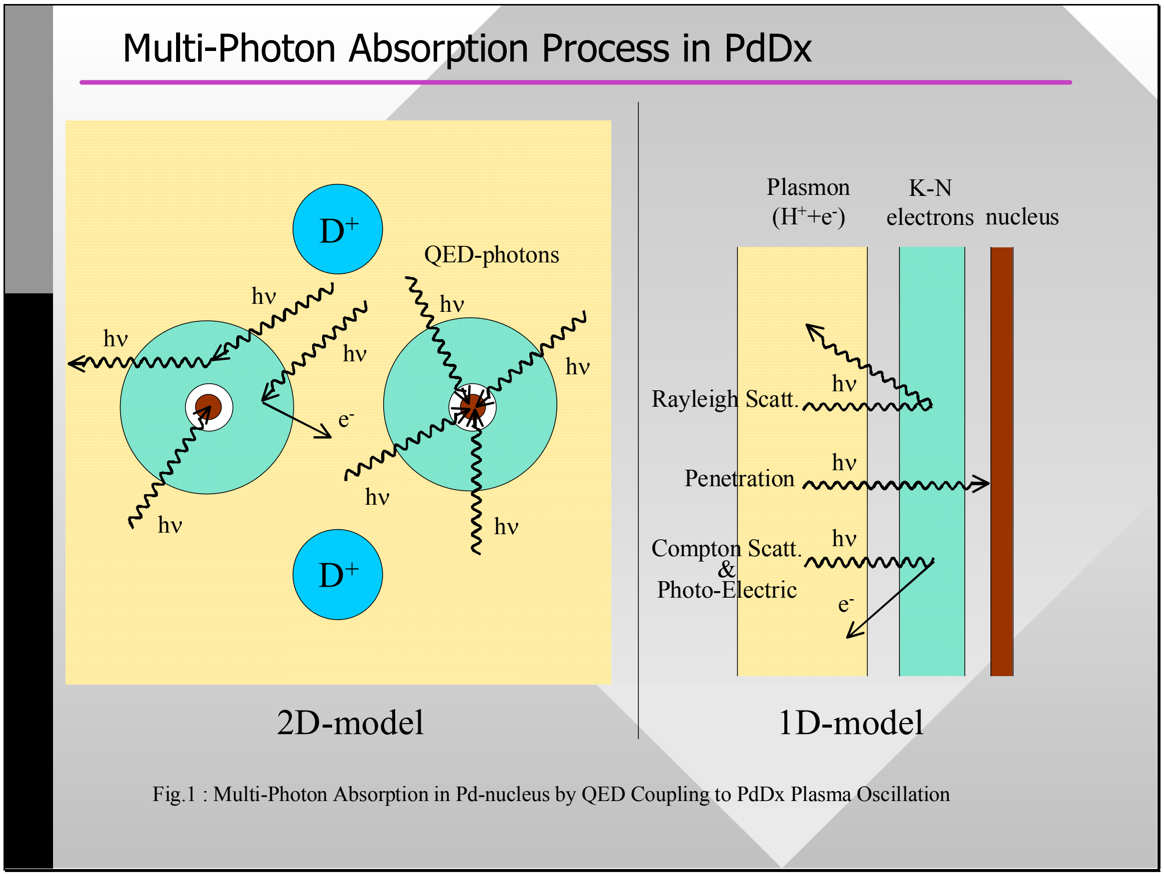


Channel Dependent Fission Barriers for U-235 +n



FP Distribution for U-235 + n Fission



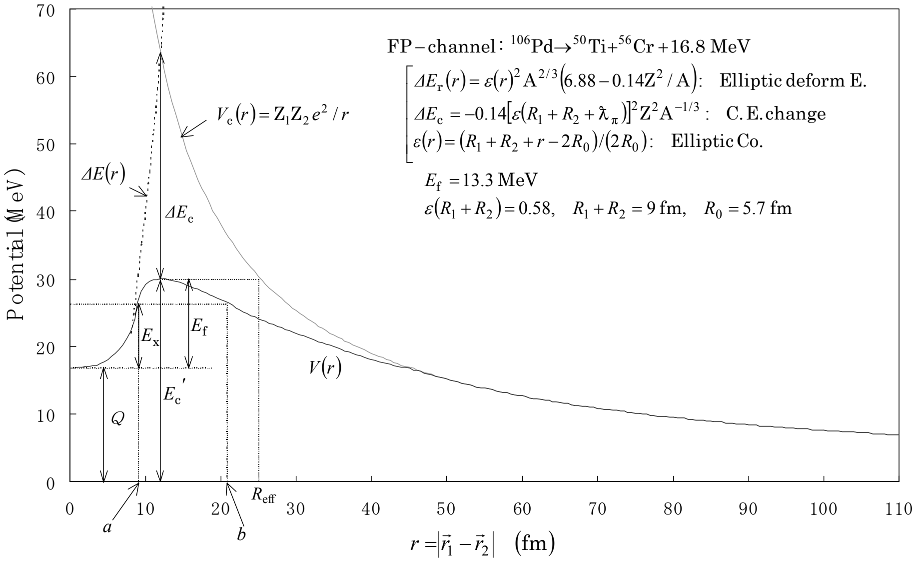
Multi-Photon Absorption Process in PdDx

2D-model

1D-model

Fig.1 : Multi-Photon Absorption in Pd-nucleus by QED Coupling to PdDx Plasma Oscillation

Determination of Fission Barrier Height for Pd



FP − channel : $^{106}\text{Pd} \rightarrow {}^{50}\text{Ti} + {}^{56}\text{Cr} + 16.8\ \text{MeV}$

$\Delta E_r(r) = \varepsilon(r)^2 A^{2/3}(6.88 - 0.14Z^2/A)$: Elliptic deform E.

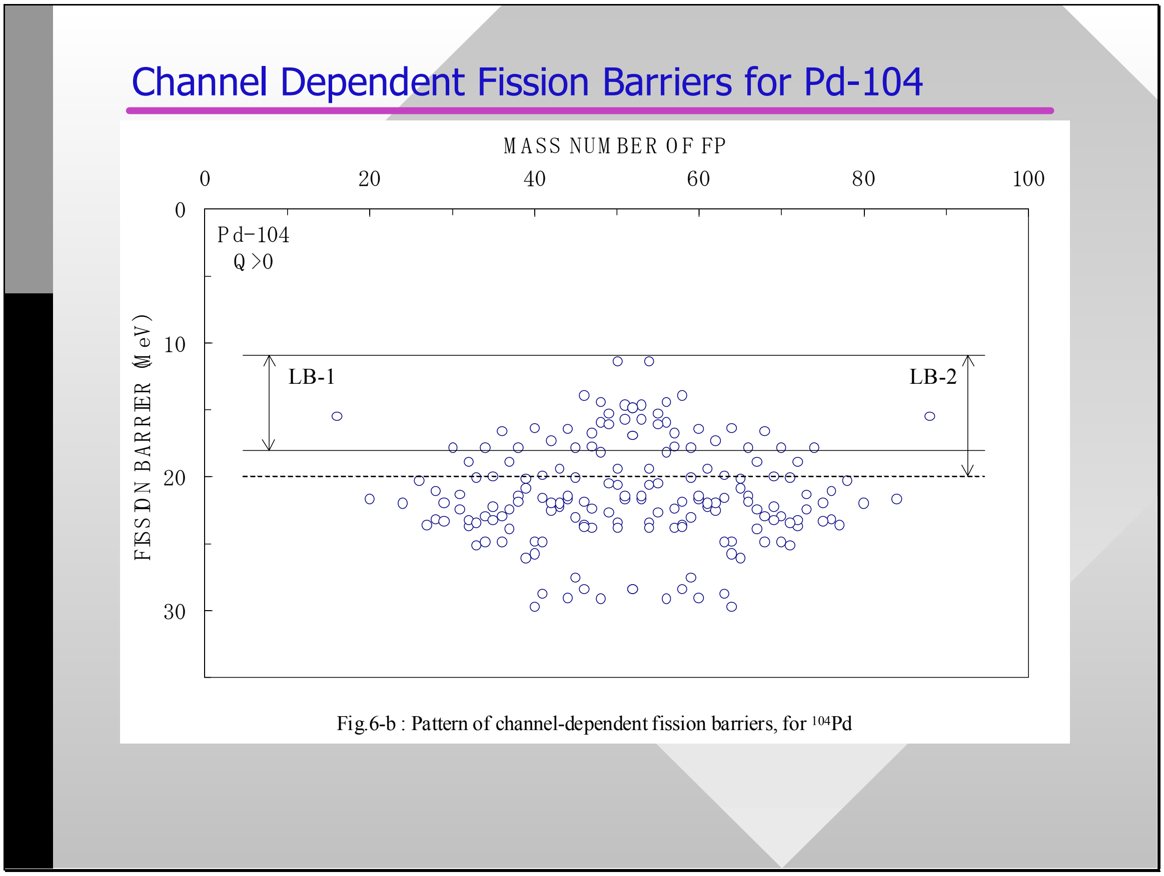
$\Delta E_c = -0.14[\varepsilon(R_1 + R_2 + ƛ_\pi)]^2 Z^2 A^{-1/3}$: C. E. change

$\varepsilon(r) = (R_1 + R_2 + r - 2R_0)/(2R_0)$: Elliptic Co.

$E_f = 13.3\ \text{MeV}$

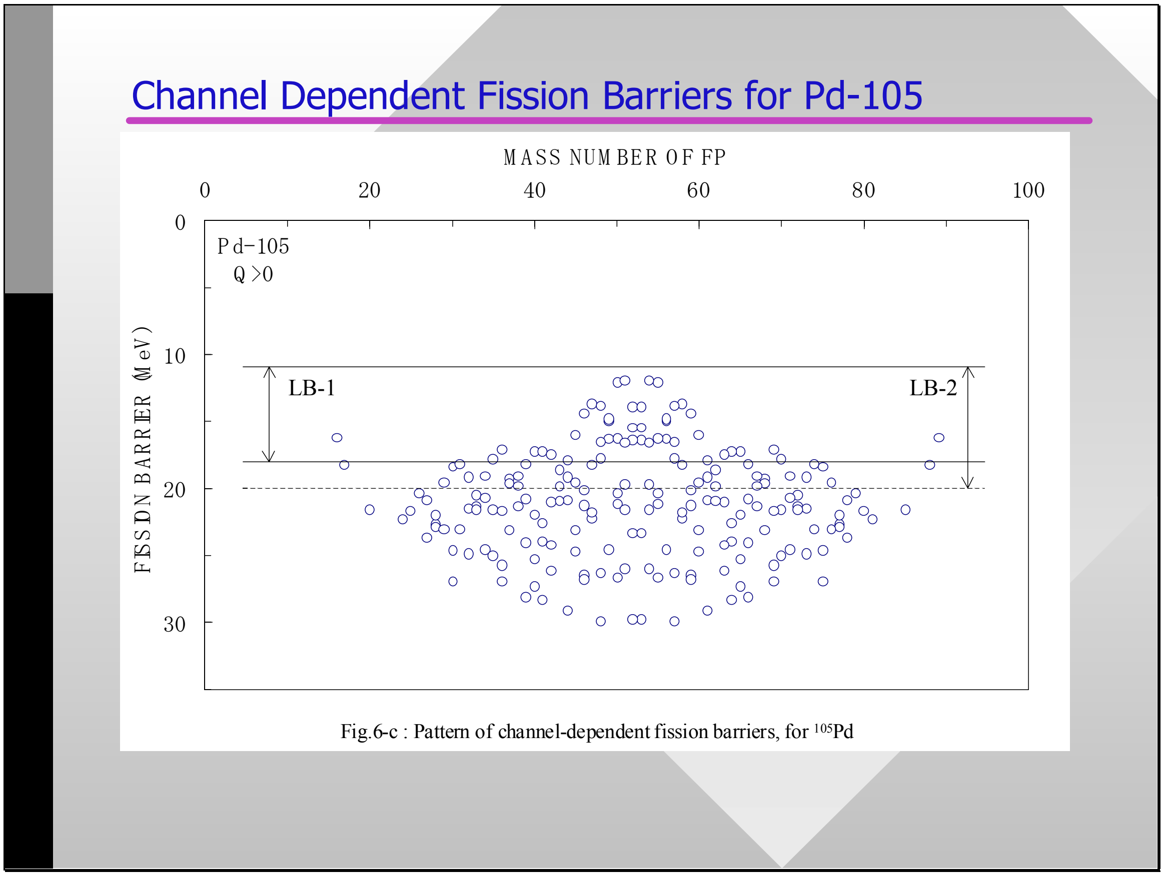
$\varepsilon(R_1 + R_2) = 0.58, \quad R_1 + R_2 = 9\ \text{fm}, \quad R_0 = 5.7\ \text{fm}$

Fig.4 : Fission potential for a scission channel of ^{106}Pd



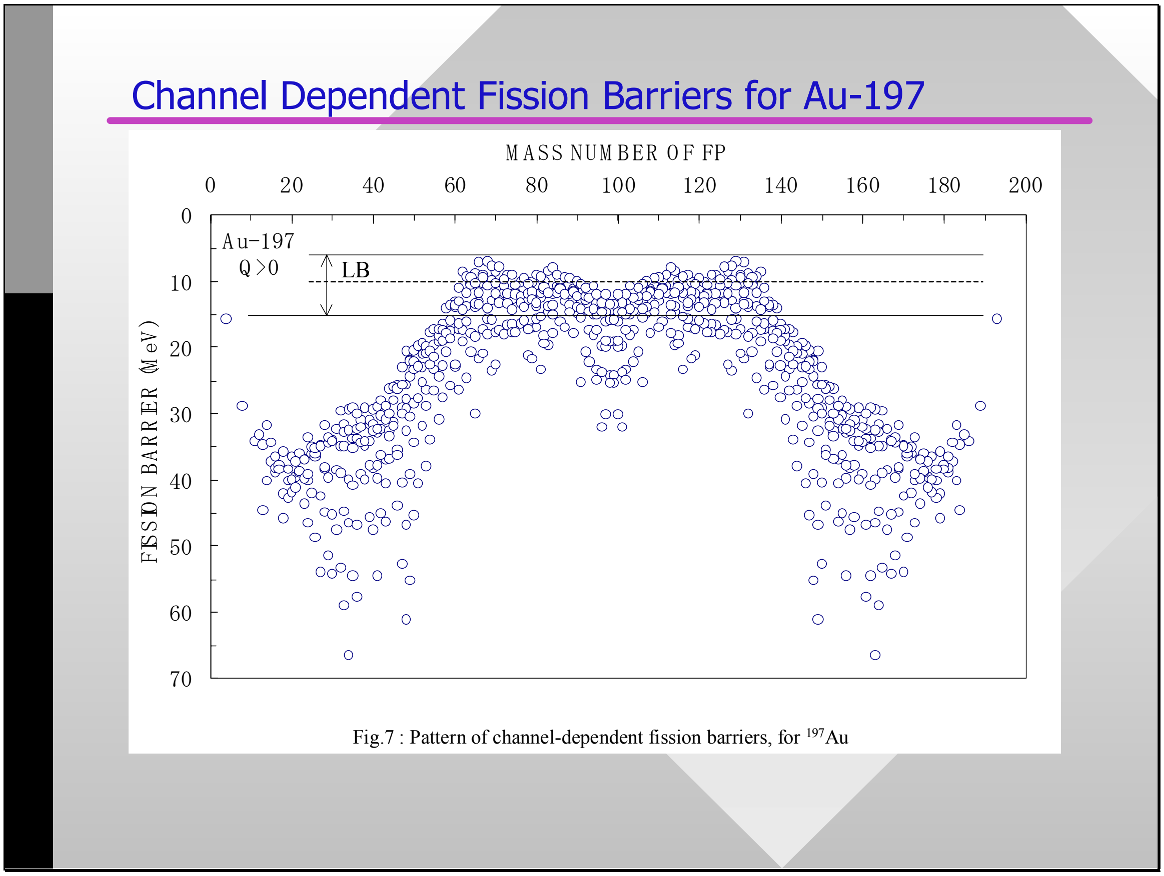
Channel Dependent Fission Barriers for Pd-104

Fig.6-b : Pattern of channel-dependent fission barriers, for ^{104}Pd



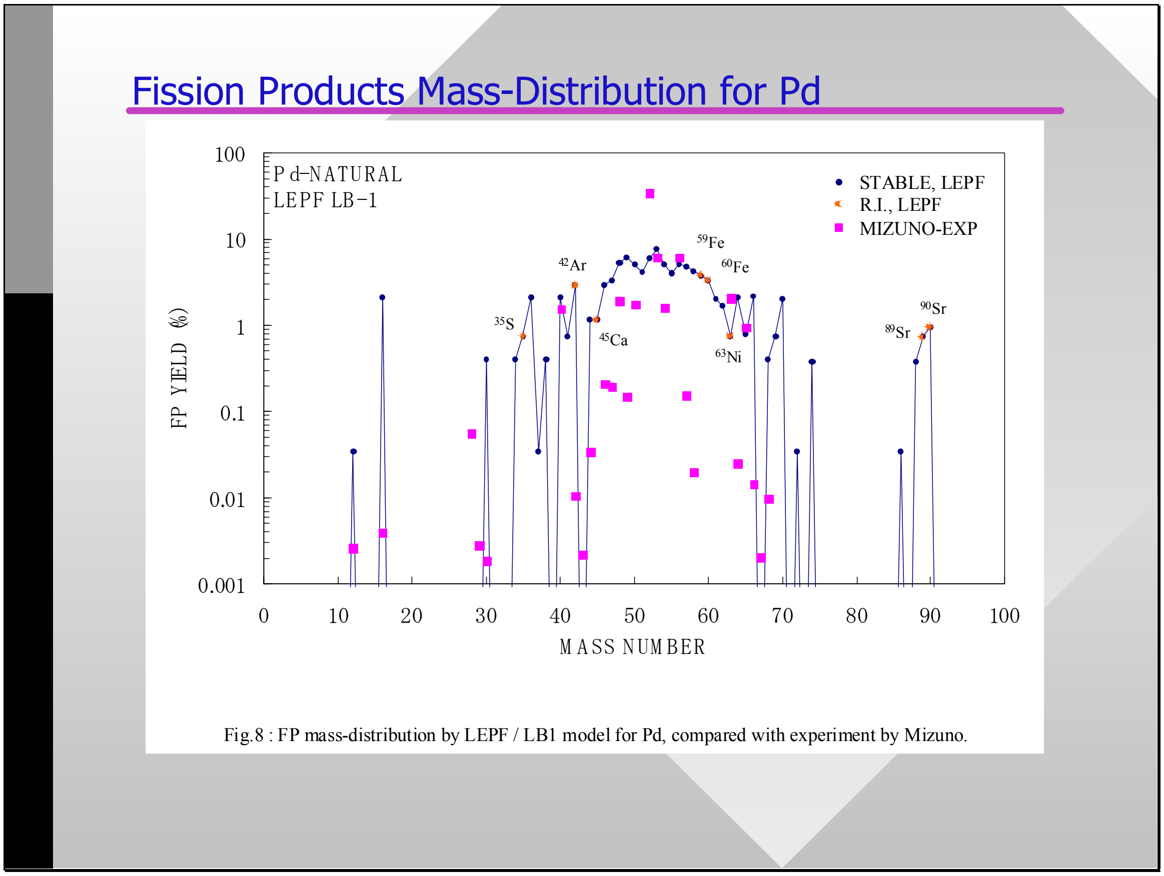
Channel Dependent Fission Barriers for Pd-105

Fig.6-c : Pattern of channel-dependent fission barriers, for ^{105}Pd



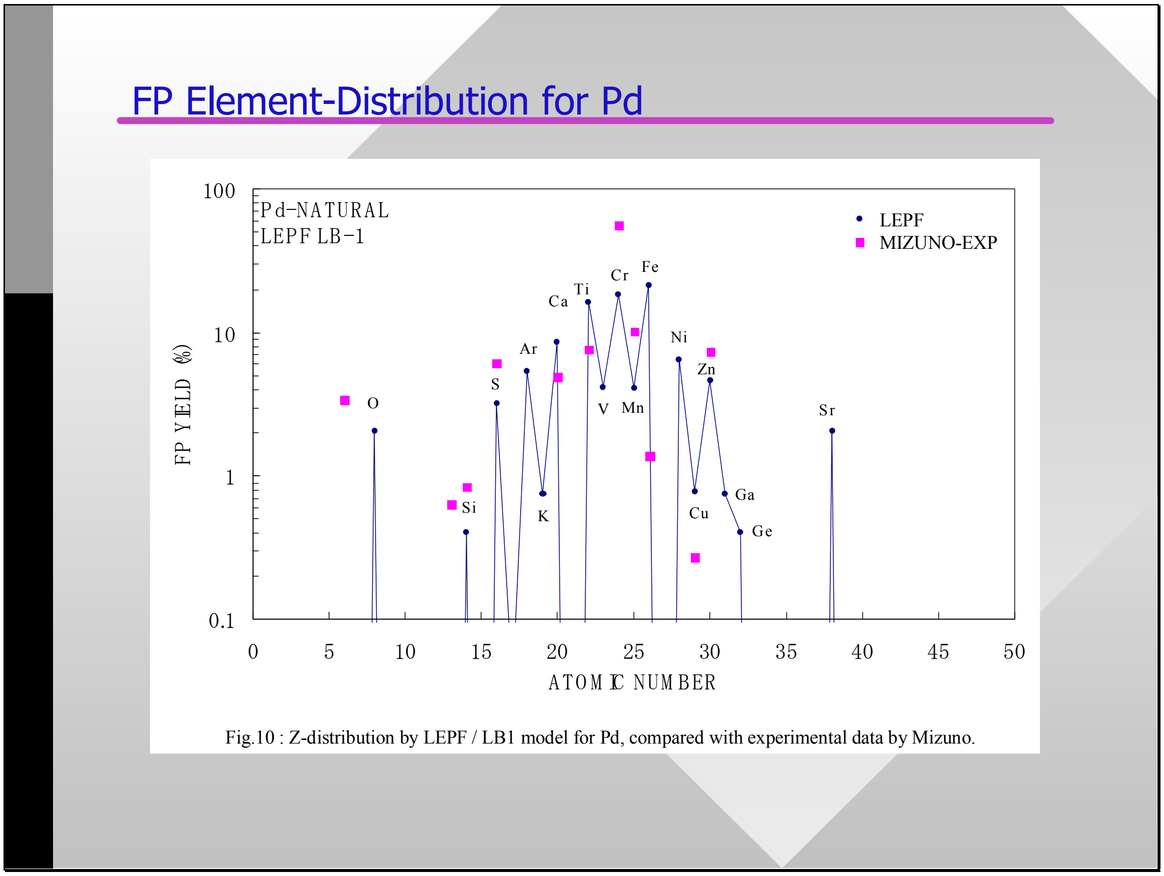
Channel Dependent Fission Barriers for Au-197

Fig.7 : Pattern of channel-dependent fission barriers, for ^{197}Au



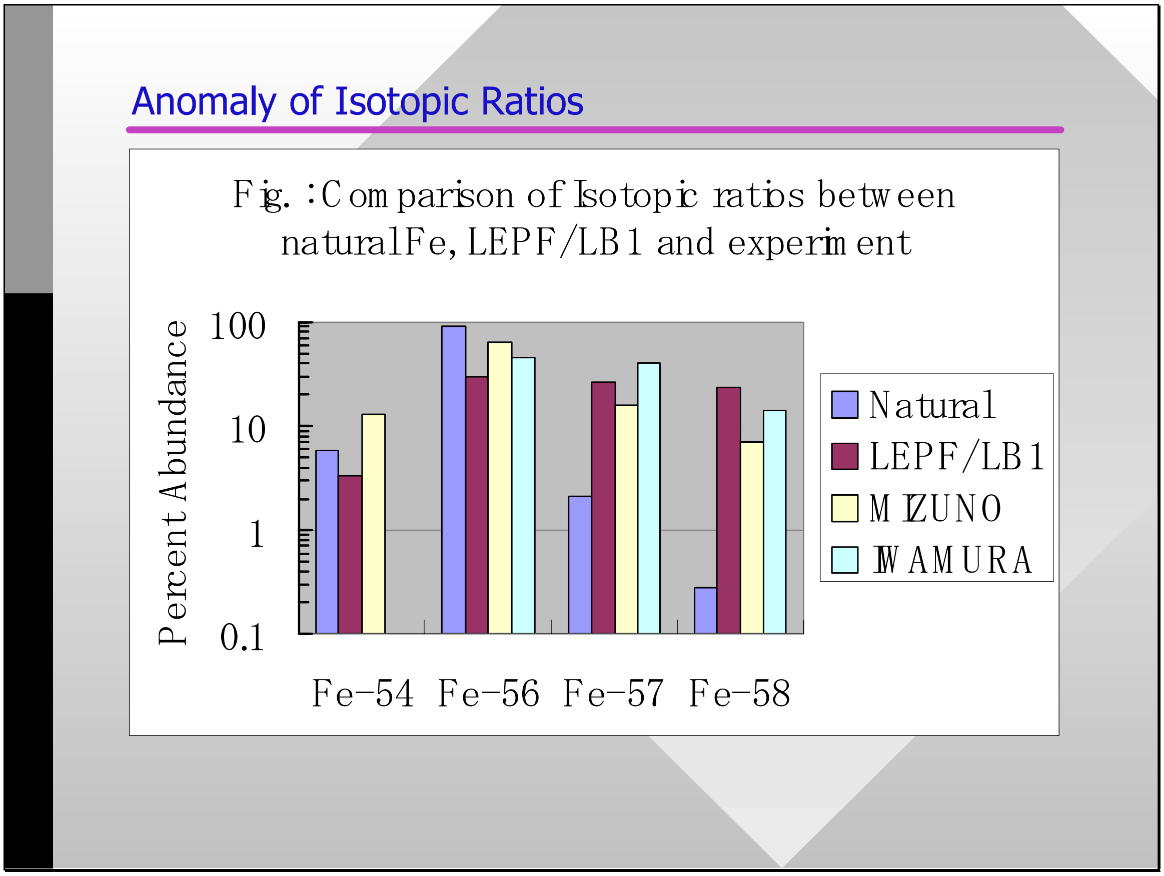
Fission Products Mass-Distribution for Pd

Fig.8 : FP mass-distribution by LEPF / LB1 model for Pd, compared with experiment by Mizuno.



FP Element-Distribution for Pd

Fig.10 : Z-distribution by LEPF / LB1 model for Pd, compared with experimental data by Mizuno.



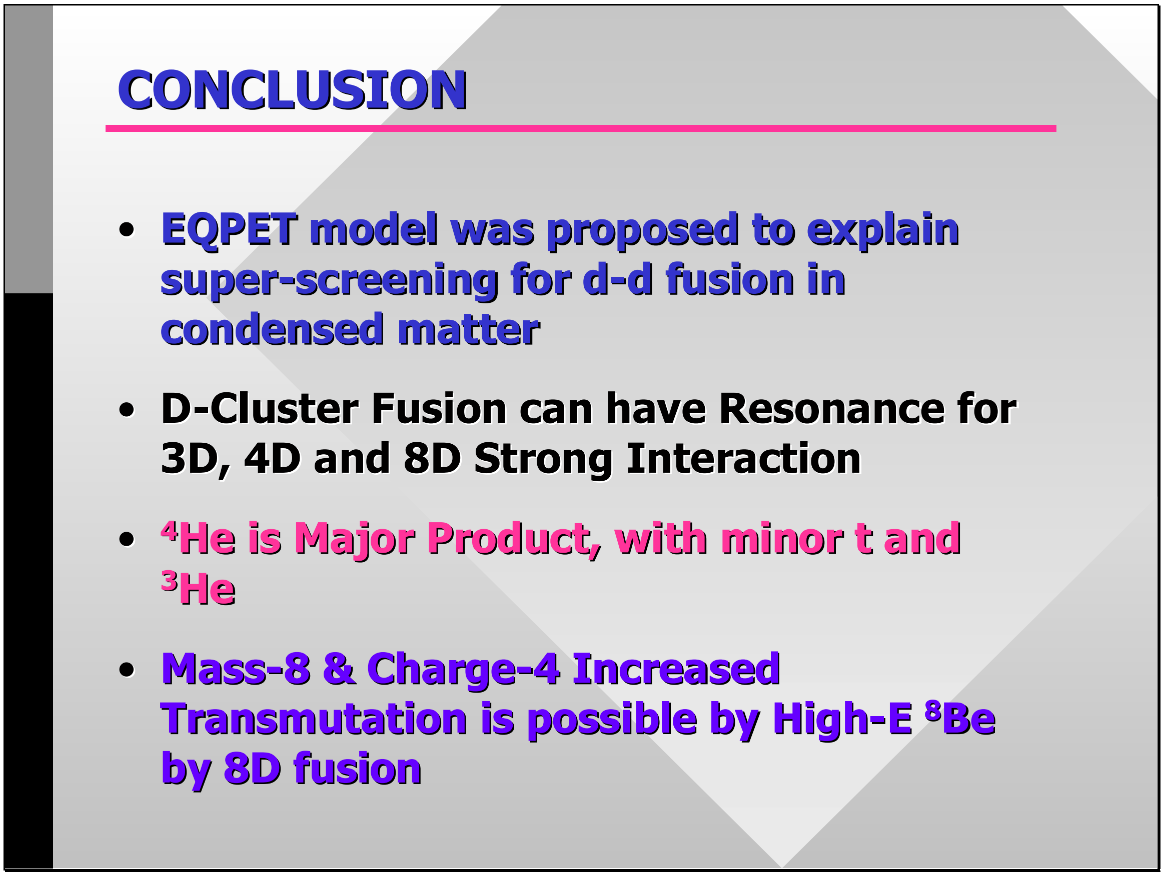
Anomaly of Isotopic Ratios

Fig.: Comparison of Isotopic ratios between natural Fe, LEPF/LB1 and experiment

Top 10 FP Channels for Pd Photo-Fission

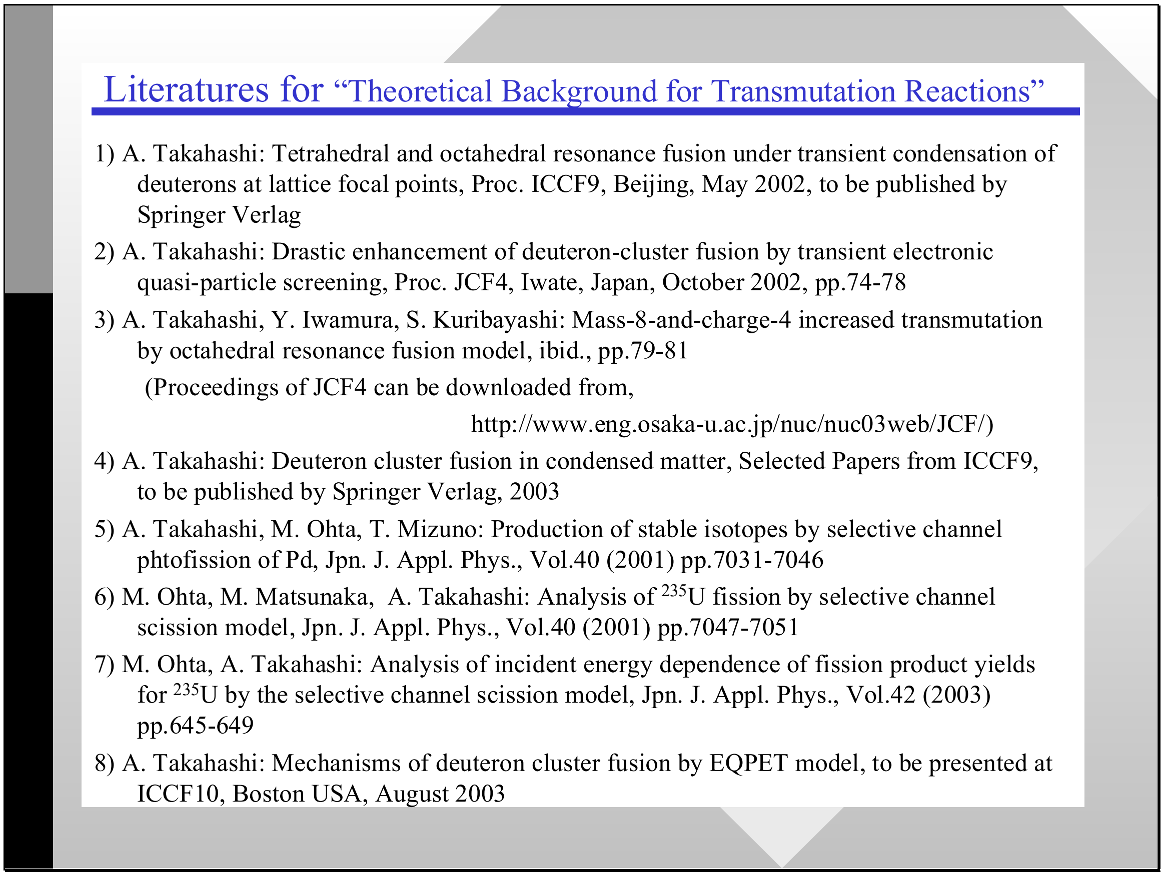
- (1) $^{104}\mathrm{Pd} \rightarrow {}^{50}\mathrm{Ti} + {}^{54}\mathrm{Cr}$ + 18.96 MeV (E_f = 11.36 MeV)
- (2) $^{102}\mathrm{Pd} \rightarrow {}^{50}\mathrm{Ti} + {}^{52}\mathrm{Cr}$ + 18.91 MeV (E_f = 11.60 MeV)
- (3) $^{105}\mathrm{Pd} \rightarrow {}^{51}\mathrm{Ti}$(5.8 m)$^{51}\mathrm{V} + {}^{54}\mathrm{Cr}$ + 18.24 MeV (E_f = 11.98 MeV)
- (4) $^{105}\mathrm{Pd} \rightarrow {}^{50}\mathrm{Ti} + {}^{55}\mathrm{Cr}$(3.5 m)$^{55}\mathrm{Mn}$ + 18.12 MeV (E_f = 12.11 MeV)
- (5) $^{102}\mathrm{Pd} \rightarrow {}^{48}\mathrm{Ti} + {}^{54}\mathrm{Cr}$ + 17.49 MeV (E_f = 13.03 MeV)
- (6) $^{106}\mathrm{Pd} \rightarrow {}^{48}\mathrm{Ca} + {}^{58}\mathrm{Fe}$ + 16.46 MeV (E_f = 13.23 MeV)
- (7) $^{106}\mathrm{Pd} \rightarrow {}^{50}\mathrm{Ti} + {}^{56}\mathrm{Cr}$(6 m)$^{56}\mathrm{Mn}$(2.6 h)$^{56}\mathrm{Fe}$ + 16.81 MeV
- (E_f = 13.32 MeV)
- (8) $^{108}\mathrm{Pd} \rightarrow {}^{48}\mathrm{Ca} + {}^{60}\mathrm{Fe}$(1.6x$10^6$ y)* + 16.10 MeV (E_f = 13.42 MeV)
- (9) $^{106}\mathrm{Pd} \rightarrow {}^{52}\mathrm{Ti}$(1.7 m)$^{52}\mathrm{V}$(3.7 m)$^{52}\mathrm{Cr} + {}^{54}\mathrm{Cr}$ + 16.49 MeV
- (E_f = 13.63 MeV)
- (10) $^{105}\mathrm{Pd} \rightarrow {}^{48}\mathrm{Ca} + {}^{57}\mathrm{Fe}$ + 15.98 MeV (E_f = 13.81 MeV)

Fission Products for A<200 become clean.



CONCLUSION

- EQPET model was proposed to explain super-screening for d-d fusion in condensed matter
- D-Cluster Fusion can have Resonance for 3D, 4D and 8D Strong Interaction
- ^{4}He is Major Product, with minor t and ^{3}He
- Mass-8 & Charge-4 Increased Transmutation is possible by High-E ^{8}Be by 8D fusion



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2) A. Takahashi: Drastic enhancement of deuteron-cluster fusion by transient electronic quasi-particle screening, Proc. JCF4, Iwate, Japan, October 2002, pp.74-78

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(Proceedings of JCF4 can be downloaded from, http://www.eng.osaka-u.ac.jp/nuc/nuc03web/JCF/)

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