Monopole Transitions in Light Unstable Nuclei

Makoto Ito[1,2]

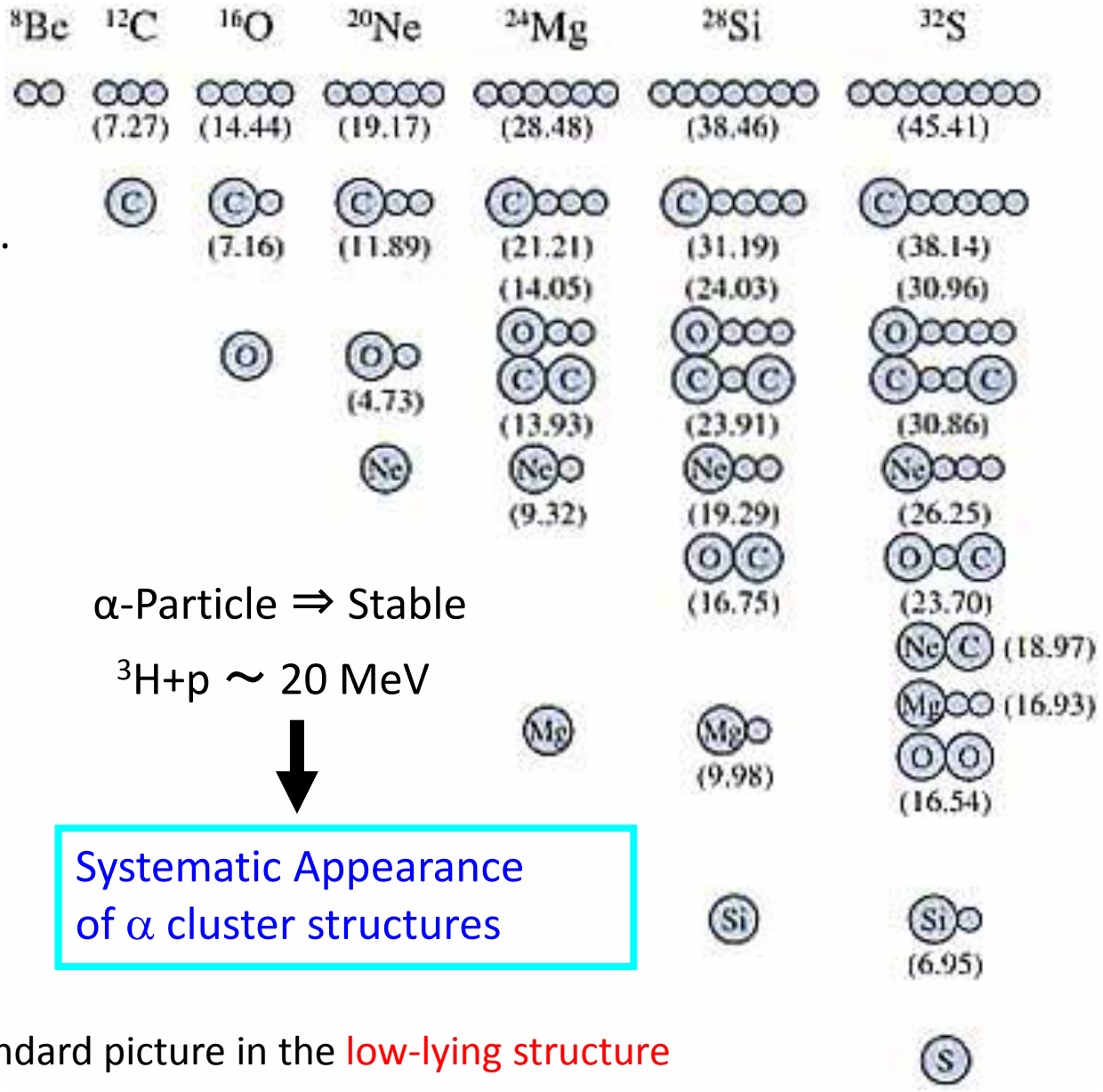
[1]Department of Pure and Applied Physics, Kansai University

[2]Rsearch Center of Nuclear Physics (RCNP), Osaka University

Contents

Cluster structures in 4N nuclei

IKEDA Diagram

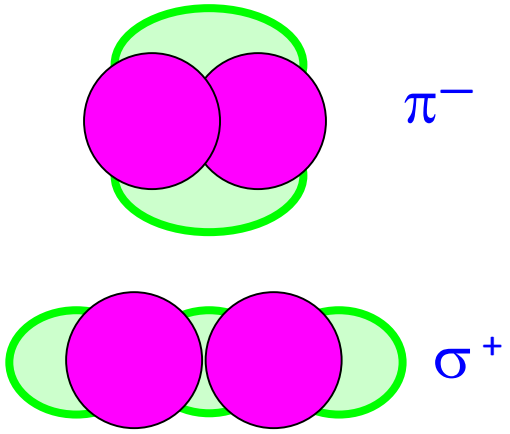


[Ikeda's Threshold rules](#)

Molecular structures will appear close to the respective cluster threshold.

Be isotopes

Molecular Orbital (MO) picture



α-Particle ⇒ Stable

^{3}H+p ~ 20 MeV

Systematic Appearance of α cluster structures

The MO model gives one of standard picture in the low-lying structure

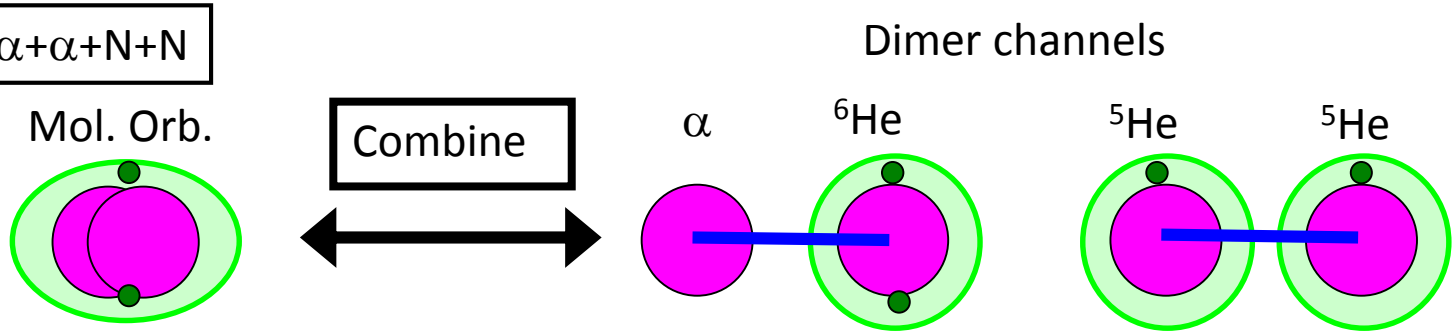
Extension of the MO model

Research subject: Structure changes beyond MO in the highly excited states

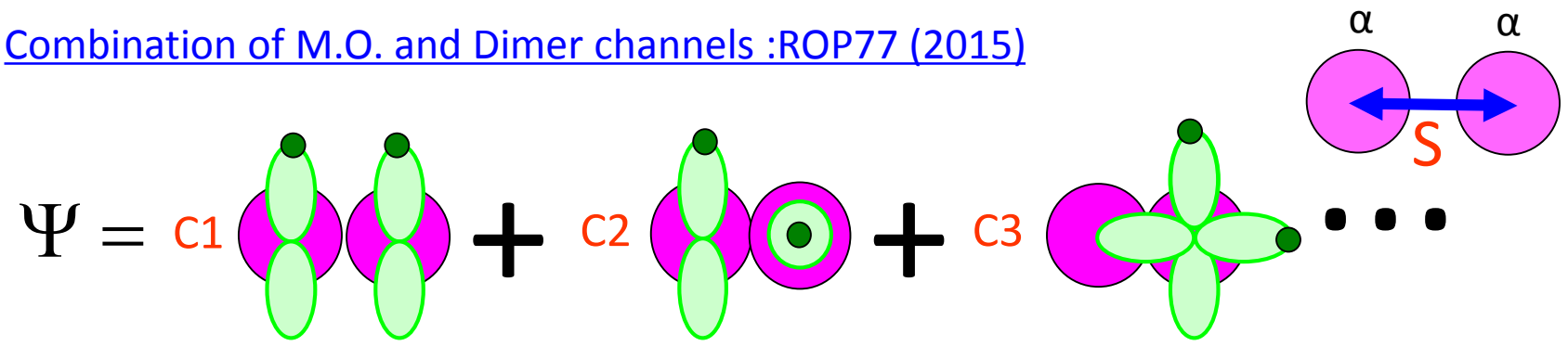
→ Extension of the MO model is important on the wide structure changes

Generalized Two-center Cluster Model (Example of ^{10}Be)

^{10}Be=α+α+N+N



Combination of M.O. and Dimer channels :ROP77 (2015)



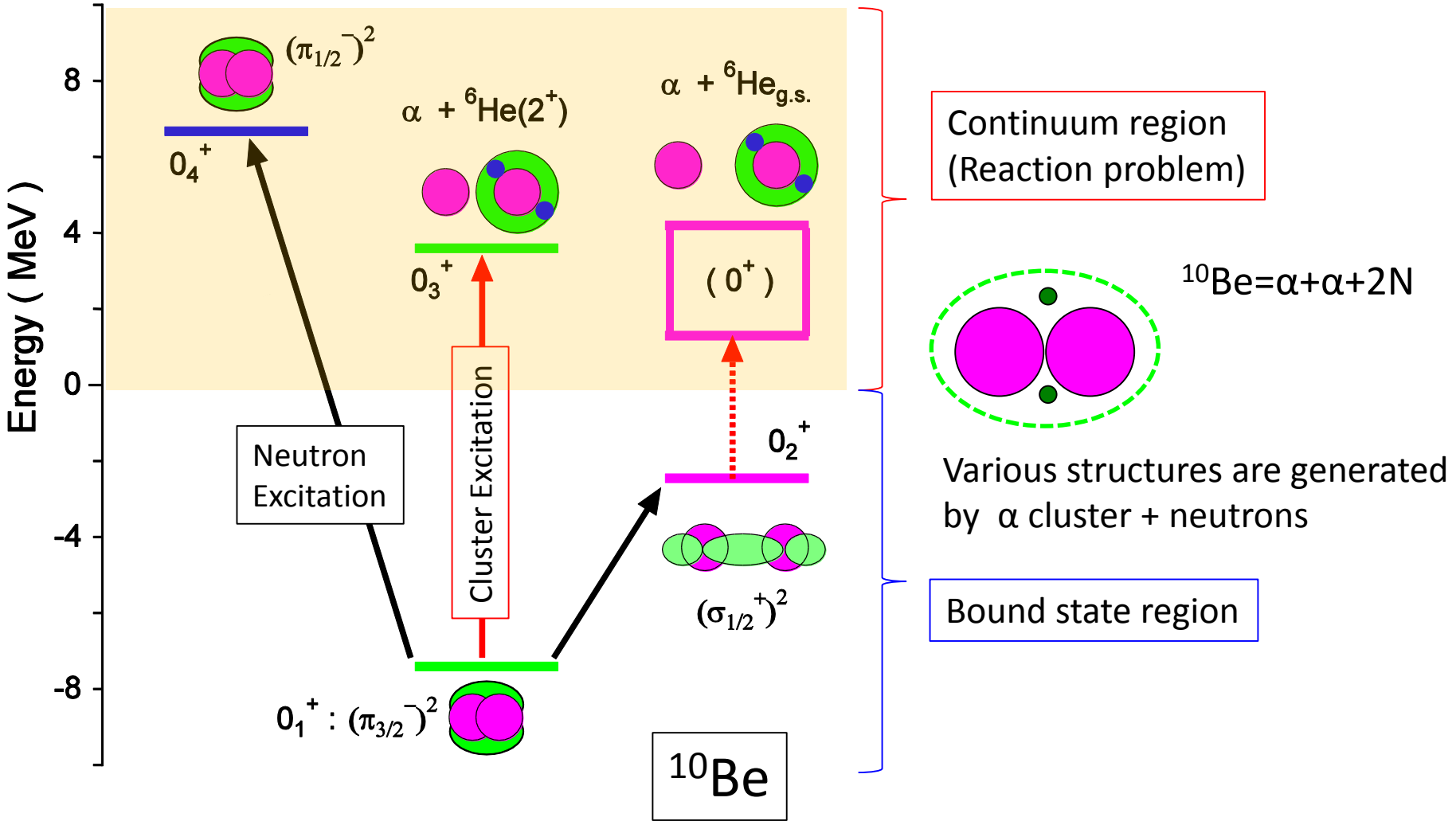
0Pi (i=x,y,z) Atomic Orbit at Left or Right side center

S, Ci : Variational PRM.

Previous studies

M. Ito and K. Ikeda, Report on Progress in Physics 77 (2014)

We have performed the unified studies of the chemical-bonding structure and reaction mechanism in even Be isotopes (A=10,12,14,16)



Monopole excitation and cluster structures

Enhancement of the monopole transition is a sign of the development of the cluster structure in final states

$$M(E0, IS) = \left\langle 0_1^+ \left| \sum_{i=1}^{A} r_i^2 \right| 0_{ex}^+ \right\rangle$$

← Cluster structure

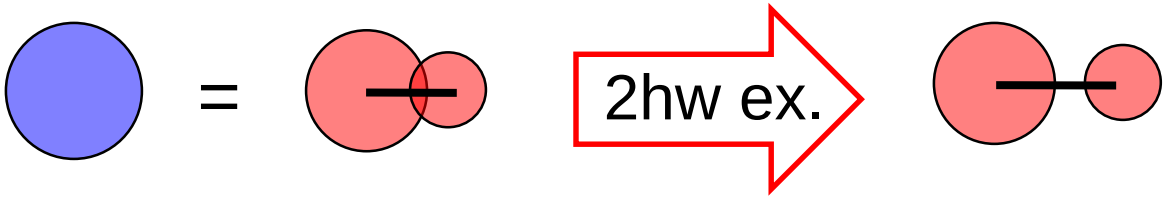
Monopole and Clusters

2hw excitation of the clusters' rel. motion

$$M(IS) \approx \langle G.S. | A_{rel}^+(2\hbar\omega) | Cluster \rangle$$

Shell model = Melted Cluster

Developed cluster



Monopole operator induces 2hw Ex. for the clusters in G.S.

Bayman-Bohr Theorem

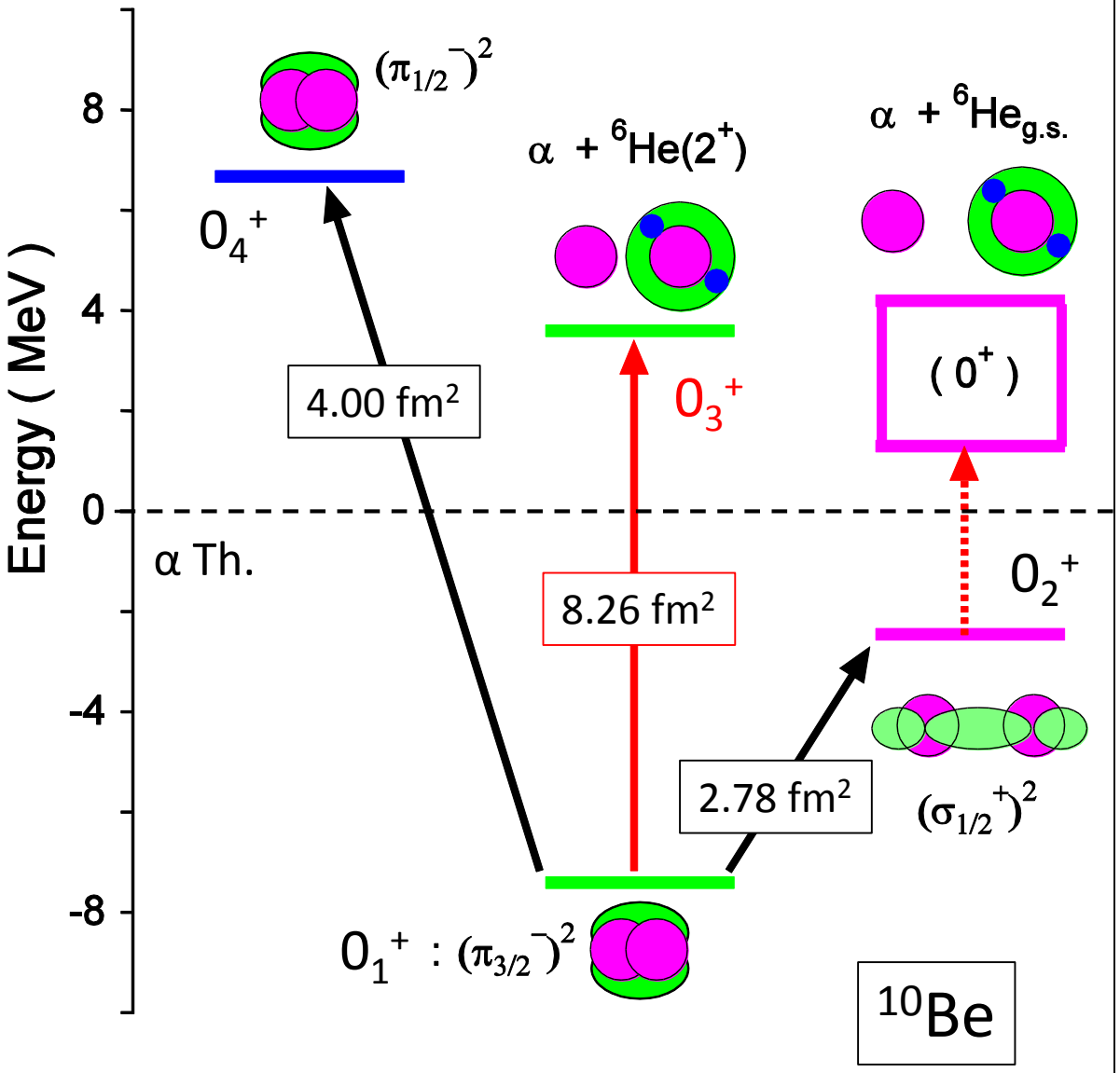
T. Yamada et al., PTP120 (08)

Strength in Ex < 15 MeV is possible

(Lower strength is difficult in shell model)

Isoscalar Monopole Transition in ^{10}Be

$$M(IS) = \left\langle 0_1^+ \left| \sum_{i=1}^{A} r_i^2 \right| 0_{ex}^+ \right\rangle$$

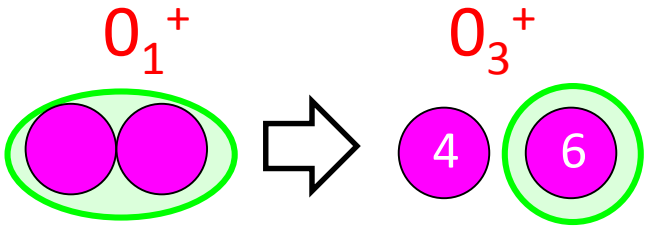


Strengths are comparable to $M(IS)_{S.P.}$ = 3.37 fm^2

$$M(IS)_{s.p.} = \langle 1p | r^2 | 0p \rangle$$

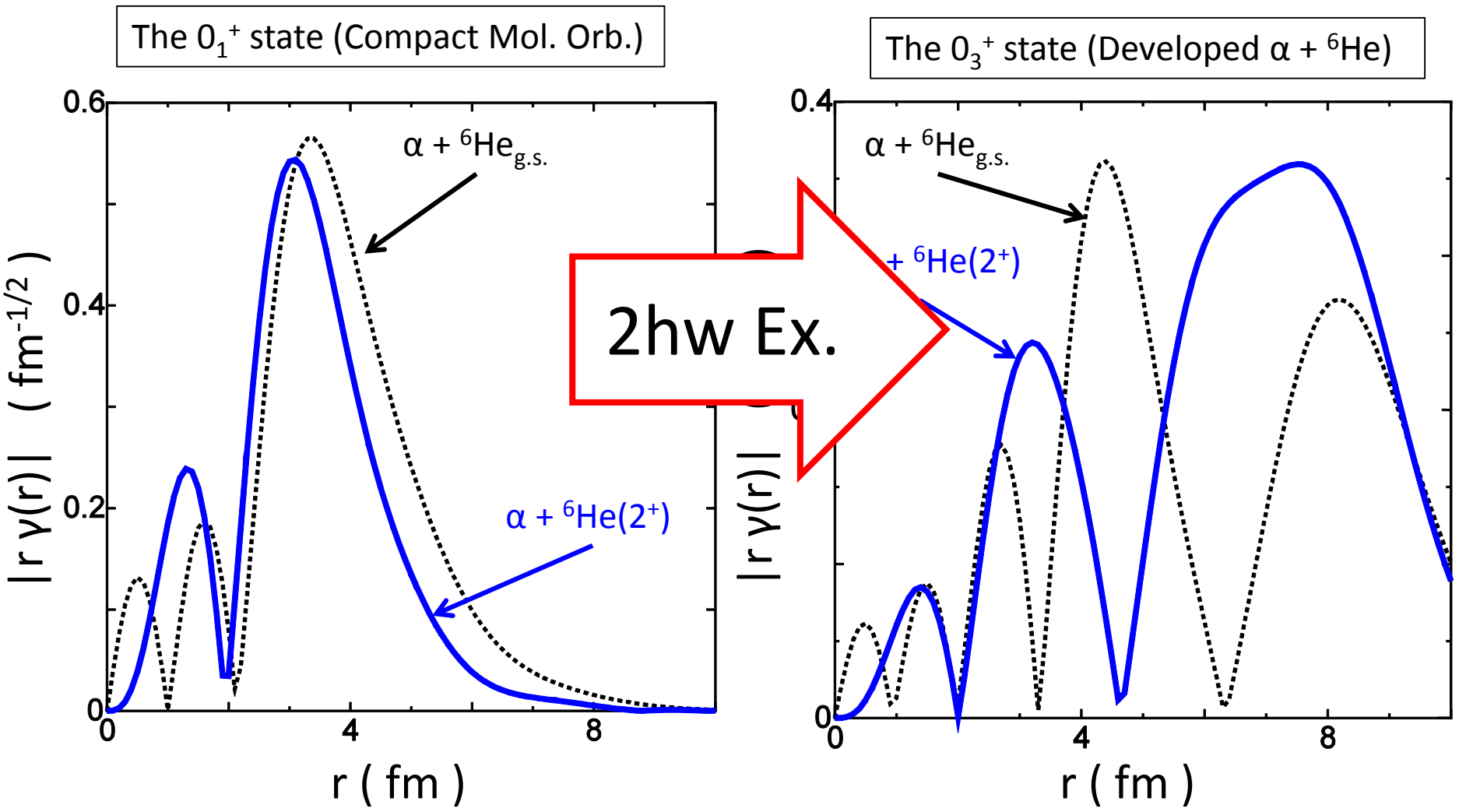
M(IS) is prominently enhanced for $0_1^+ \Rightarrow 0_3^+$

$\Rightarrow$ Cluster's relative EX.



2hw Cluster ex.

He-He Relative wave functions (Reduced width)



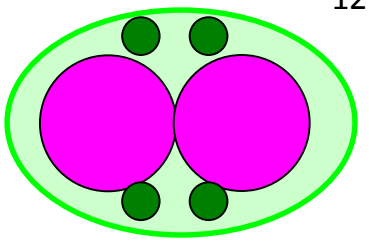
Radial excitation of the relative wave function occurs in $0_1^+ \Rightarrow 0_3^+$

$0_1^+ \Rightarrow 0_3^+$ are connected by the monopole (2hw ex.) operator

Variety of Nuclear Chemical Clusters

Question

What is a variation in replacing α core or valence neutrons ?

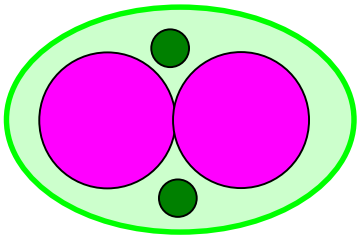


$^{12}Be = \alpha + \alpha + 4N$

Structure is abundant
Degenerate M(IS) strength appear at Ex. < 15 MeV

ROP 77 096301 (2014)

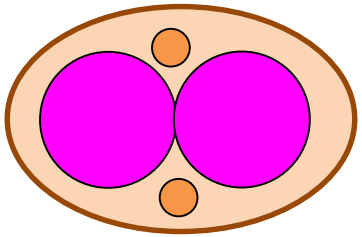
+ 2N



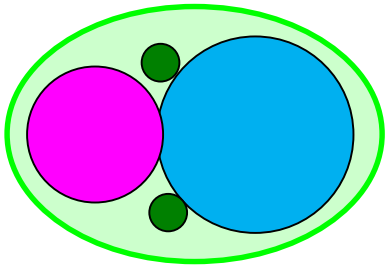
$^{10}Be = \alpha + \alpha + 2N$

2N ⇒ 2P

α ⇒ ^{12}C

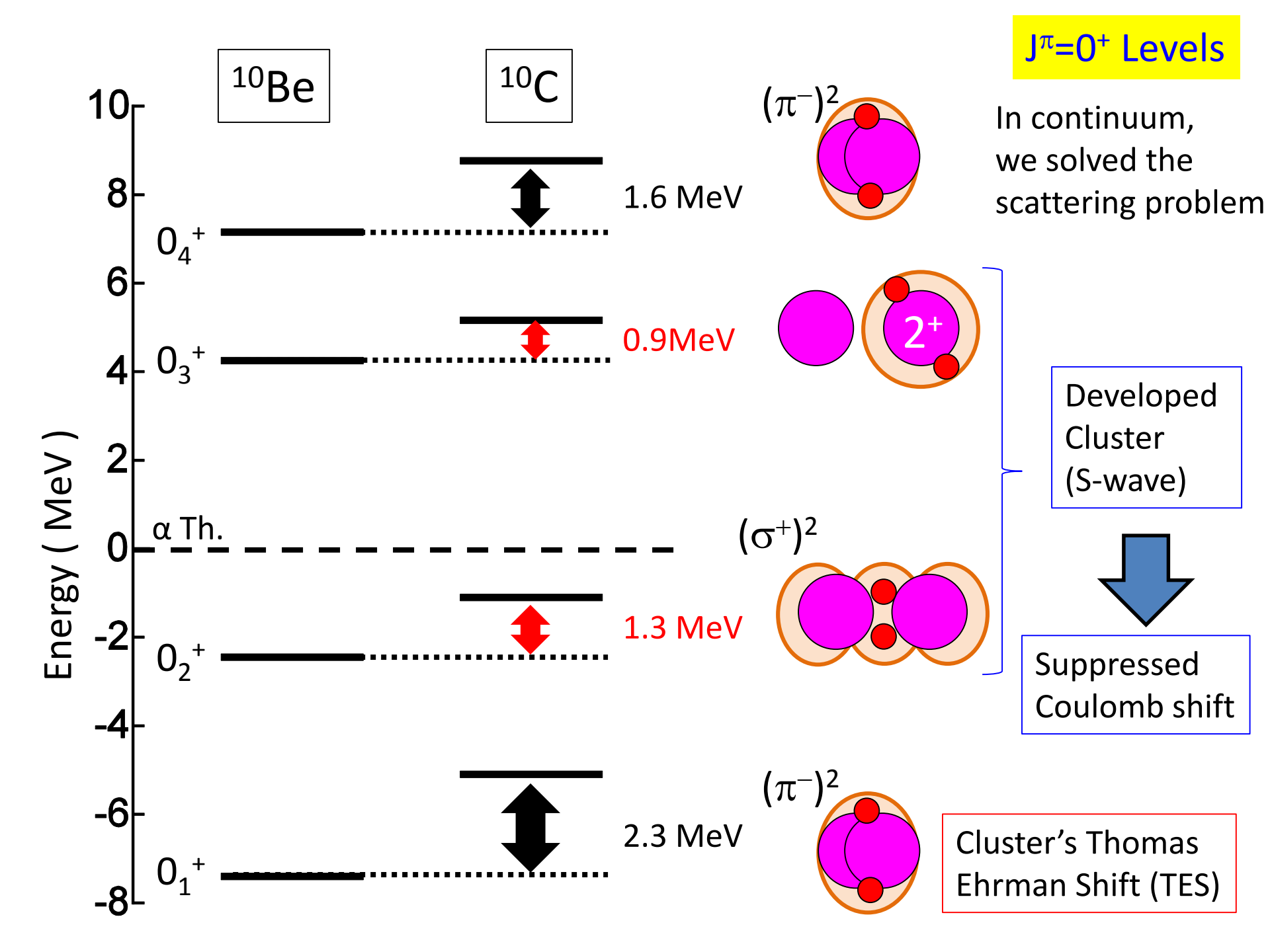


Coulomb Effect
(Thomas-Ehrman Shift)

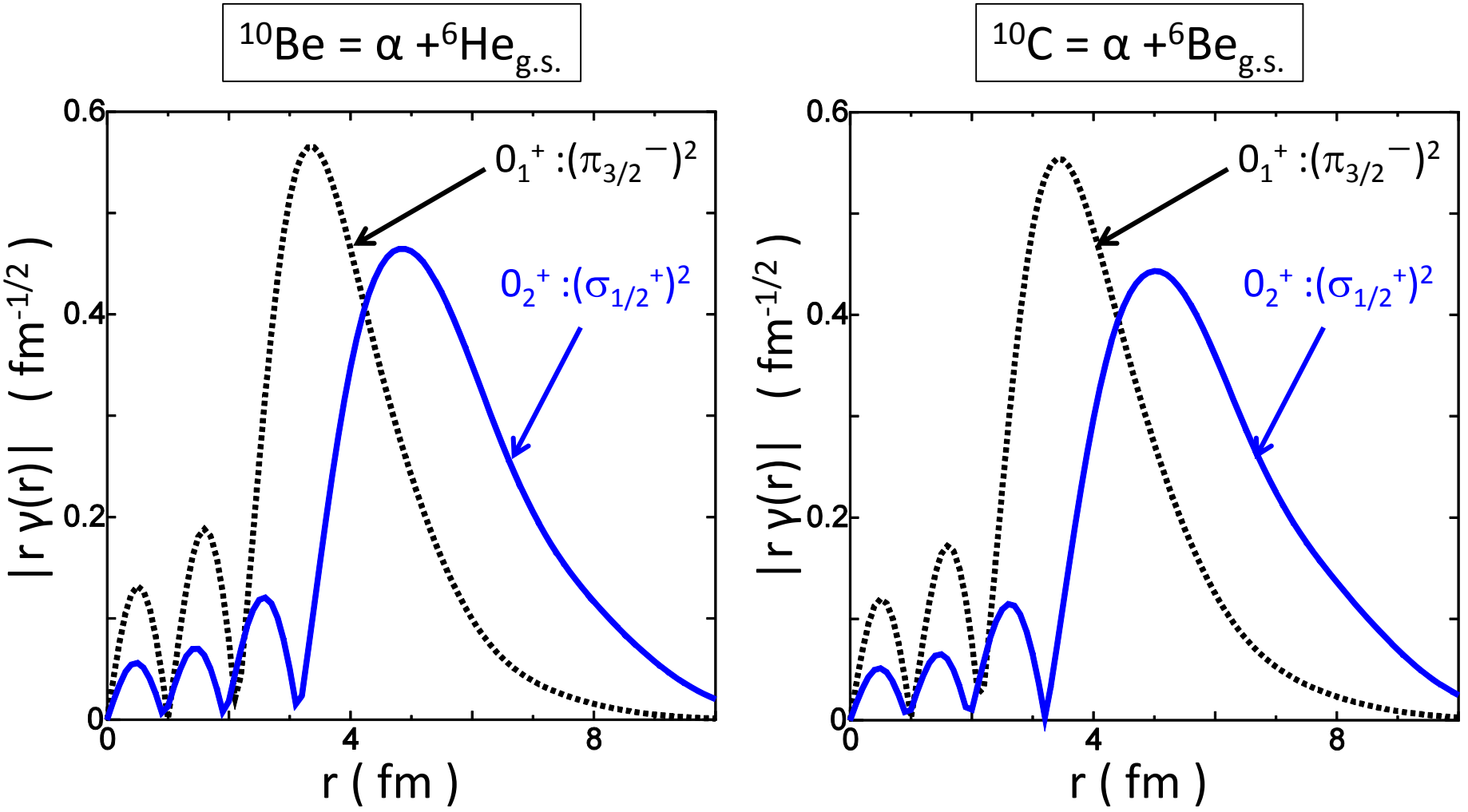


$^{10}C = \alpha + \alpha + 2P$

$^{18}O = \alpha + {}^{12}C + 2N$


$J^\pi=0^+$ Levels
^{10}Be
^{10}C
10
8
6
4
2
0
-2
-4
-6
-8
Energy (MeV)
0_4^+
0_3^+
0_2^+
0_1^+
α Th.
1.6 MeV
0.9MeV
1.3 MeV
2.3 MeV
$(\pi^-)^2$
$(\sigma^+)^2$
$(\pi^-)^2$
2^+
In continuum, we solved the scattering problem
Developed Cluster (S-wave)
Suppressed Coulomb shift
Cluster's Thomas Ehrman Shift (TES)

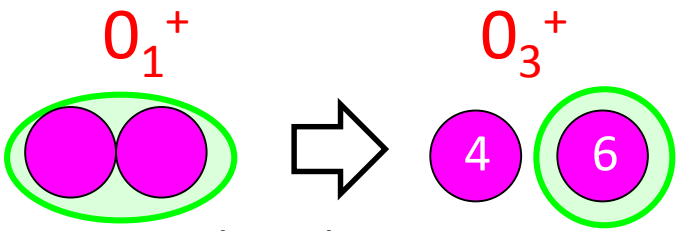
$^{10}Be = \alpha + {}^{6}He$ and $^{10}C = \alpha + {}^{6}Be$ wave function



W.F. of 0_2^+ is more extended than W.F. of 0_1^+

$\Rightarrow$ Coulomb repulsion is suppressed for the 0_2^+ state

Monopole transition in ^{10}C and ^{10}Be



2hw Cluster ex.

Theoretical Prediction of M(IS)

	r.m.s. (fm)	E(0_2^+) (MeV) Theory	M(IS) (fm^2) $0_1^+ \Rightarrow 0_2^+$	M(IS) (fm^2) $0_1^+ \Rightarrow 0_3^+$	M(IS) (fm^2) $0_1^+ \Rightarrow 0_4^+$
^{10}Be	2.66	4.90	2.78	8.26	4.00
^{10}C	2.73	4.00	5.27	7.55	2.90
			MO EX.	Cluster EX.	MO EX.

1. All the strengths are comparable to or larger than $M(IS)_{S.P.} = 3.37$ fm^2
   ⇒ M(IS) is prominently enhanced for the clusters' relative excitation.

2. M(IS) of $0_1^+ \Rightarrow 0_2^+$ is not charge-symmetric in ^{10}Be and ^{10}C
   ⇒ Due to the Cluster TES (ΔE=0.9 MeV) appearing n ^{10}C.

Summary

M. Ito and K. Ikeda, Rep. on Prog. in Phys., 77 096301 (2014)

We have investigated the structure changes of the two-center systems and the enhancement of the IS monopole transition.

Results

1. Chemical bonding structure and M(IS) transition in ^{10}Be

① Wide variety appears by the combination of cluster-core and excess-nucleons

② IS monopole transition has a strong responsibility for the cluster excitation

2. Analysis of the mirror system, ^{10}Be and ^{10}C

① Suppression of the Coulomb shift

⇒ Suppression occur in the cluster state (Spatially extended structure)

② Monopole transition

⇒ Asymmetry in the $0_1^+ \Rightarrow 0_2^+$ transition is predicted

Analysis of the mirror system will give an important information on the spatially extended cluster structure in the excited state

cf. ^{8}C-^{8}He, by T. Myo and K. Kato,PTEP2014,083D01