Unified studies of the structure changes and the nuclear reactions in $^{10}$Be

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Introduction

Light stable nuclei
Cluster Correlation is strong. \[ ^8\text{Be}=\alpha+\alpha,\ 20\text{Ne}=\alpha+^{16}\text{O},\ \text{etc} \]

Light N-rich nuclei (Be, Ne etc …) W. von Oertzen, N. Itagki etc…
Cluster Cores + valence Neutrons ? Various Structures

Our interests
Various structures
Enhancements
Unified treatment is important.
Probes
Reaction mechanism
Coexistence ??
Molecular Orbitals
Valence Bond ??
G.S. Ex.
Be isotope \((\alpha + \alpha + N + N + \ldots)\)

Present study

We study the structural change as well as reaction mechanism of \(^{10}\text{Be}\).

Molecular orbital

\[ \pi^- \alpha \alpha \]

\[ \sigma^+ \alpha \alpha \]

Low-lying States
Theory by Itagaki, Enyo, Arai...

High-lying States
Frer et al., Shimoura et al.

\[ \text{Breakup reaction} \]

\[ \text{Generalized Two-center Cluster model (PLB588)} \]

Should be treated in a unified manner!!

\[ \text{Scattering} \]

\[ \alpha + ^6\text{He} \]

\[ ^{10}\text{Be}_{\text{g.s.}} \]
Generalized Two-center Cluster Model (PLB588)

Microscopic cluster model

$^{10}\text{Be} = \alpha + \alpha + N + N : J^\pi = 0^+$

Total wave function

$$\Psi^{J\pi} = P^{J\pi} A \sum C_i \Phi_i$$

Basis : Atomic orbital (A.O.)

$\alpha : (0s)^4$

$$\Phi_i = \{ \alpha + 6\text{He}(0^+) \}$$

$0p_i$ A.O. ($i=x,y,z$)

Red Dots : [ $\alpha + 6\text{He} (1) \}$ LJ

Blue Dots : [ $5\text{He}(l_1) + 5\text{He} (l_2) \}$ LJ

Adiabatic energy surfaces ($J^\pi = 0^+$)

Excitation Energy (MeV)

Weak Coupling

$\alpha + 6\text{He}_2$.
Adiabatic surfaces \((J^\pi = 0^+)\)

Energy spectra \((J^\pi = 0^+)\)
Coexistence of atomic and molecular orbitals in $^{10}\text{Be}$

$J^\pi = 0^+$

- $(\pi)^2$
- $2^+$
- $\alpha + ^6\text{He}(2^+)$
- $\alpha + ^6\text{He}_{g.s.}$
- $0_2^+$
- $0_3^+$
- $0_4^+$

$J^\pi = 1^-$

- $(\pi\sigma^+)$
- $1_2^-$
- Continuum
- Inversion Doublet of $\alpha + ^6\text{He}_{g.s.}$
- $1_1^-$

$J^\pi = 1^-$
Enhancements in inelastic scattering of $\alpha + ^6\text{He}$

$J^{\pi} = 0^+$ Resonance Poles

$\alpha + ^6\text{He}(0^+) \ ? \ \alpha + ^6\text{He}(2^+)$

$J^{\pi} = 1^-$ L-Z level crossing

$\alpha + ^6\text{He}(0^+) \ ? \ \alpha + ^6\text{He}(2^+)$

(- parity)

Doublet

(+ parity)

$L-Z$ level crossing
CDCC calculation of Nuclear breakup of $^{10}\text{Be}$

$^{10}\text{Be} + ^{12}\text{C} \rightarrow (^{4}\text{He} + ^{6}\text{He})^0 + ^{12}\text{C}$ (E/A = 30 MeV)

Cross sections of Breakup

Energy spectrum in $^{10}\text{Be}$ (0$^{-}$)

Importance of atomic degree of freedom in reactions

$J^\pi = 0^+$

$J^\pi = 1^-$

$\alpha$ $\rightarrow$ $^6\text{He}_{g.s.}$

Low-E Scattering

Pole

L-Z. Tr.

Continuum

Nuclear Breakup

Atomic degree of freedoms play very important roles in reaction process.
Summary and conclusion

1. Studies on light N-rich nuclei
   It is very important and interesting to study the nuclear structures as well as the nuclear reactions in light N-rich systems.

2. Our approach
   Generalized Two-center Cluster Model makes possible to do such unified studies. (AMD and Mol. orbital models are difficult !!)

3. Application to $^{10}$Be
   Structures: Atomic and molecular orbitals coexist in this system.
   Reactions: Atomic states are important in scattering and breakup.

Future plan

Extension to $^{12}$Be = $\alpha + \alpha + 4N$ is very important.

$^{12}$Be ? $^6$He + $^6$He by M. Freer et al. (PRL99) and A. Saito at CNS.