\( \alpha + ^{6,8}\text{He} \) resonant scattering and exotic structures in \(^{10,12}\text{Be}\)

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Structures and Reactions in N > Z systems

Reaction of N-rich systems is quite important in r-process. Example: $\alpha(2n,\gamma)^6\text{He}(\alpha,n)^9\text{Be}$ (Bridge the gap of A=5,8 ?)

**N≈Z case**

Active valence neutrons

$$(A+B)+(C+D) \Rightarrow \text{insufficient}!!$$

We should combine $(A+B) + (C+D) + \text{MO}$. Coupled channels with many configurations

**Strongly Polarized states**

MO ??

Excitation

Molecular Orbital (MO) $\pi^-, \sigma^+$, etc.

Bound (ground) states

$^{10,12}\text{Be} = \alpha + ^6,^8\text{He}$
Formulation: $^{10}\text{Be} = \alpha + \alpha + N + N$

Linear Combination of Atomic Orbital (LCAO)

\[(\sigma^+)^2 = \left( P_z(L) - P_z(R) \right)^2 \quad (P: 0p\text{-orbital})\]

\[= P_z(L) \cdot P_z(L) + P_z(R) \cdot P_z(R) - 2P_z(L) \cdot P_z(R)\]

$^6\text{He} + \alpha \quad \alpha + ^6\text{He} \quad ^5\text{He} + ^5\text{He}$

\[= P_x(R) \cdot P_x(R) + P_y(R) \cdot P_y(R) + P_z(R) \cdot P_z(R)\]

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

Total wave function

\[\Psi = \sum_{\beta, S} C(\beta, S) P_m(a) \cdot P_n(b)\]

\[\beta \equiv (m, n, a, b)\]
Adiabatic energy surfaces: NN int. ⇒ Volkov No.2 + G3RS

\( ^{10}\text{Be} = \alpha + \alpha + n + n \; (J^π = 0^+ ) \)

\( \sigma_{1/2}^+ \)^2sd-orbital

\( \pi^- \)^20p-orbital

\( \pi_{1/2}^- \)^2

Excitation Energy (MeV)

\( \alpha - \alpha \) Distance (fm)

Blue Dots

\( ^5\text{He} (I_1) + ^5\text{He} (I_2) \) L

\( ^{10}\text{Be} = \alpha + ^{\alpha} + ^{n} + ^{n} \; (J^{π} = 0^{+}) \)

\( ^{4}\text{He} + ^{6}\text{He}_{g.s.} \)

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\( ^{4}\text{He} + ^{6}\text{He}_{g.s.} \)

Weak Coupling

\( ^{10}\text{Be} = ^{\alpha} + ^{\alpha} + ^{n} + ^{n} \; (J^{π} = 0^{+}) \)

\( ^{4}\text{He} + ^{6}\text{He}_{g.s.} \)

\( ^{10}\text{Be} = ^{\alpha} + ^{\alpha} + ^{n} + ^{n} \; (J^{π} = 0^{+}) \)

\( ^{4}\text{He} + ^{6}\text{He}_{g.s.} \)
Adiabatic surfaces ($J^{\pi} = 0^+$)  

Energy spectra ( $J^{\pi} = 0^+$)
Enhancements in $\alpha+^6\text{He}$ inelastic scattering


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

$\alpha+^6\text{He}(0^+_1) \rightarrow \alpha+^6\text{He}(2^+_1)$

Adiabatic energy surfaces ($J^P = 0^+$)

$\alpha+^6\text{He}(0^+_1) \rightarrow \alpha+^6\text{He}(2^+_1)$

$\alpha+^6\text{He}(0^+_1) \rightarrow \alpha+^6\text{He}(2^+_1)$

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

$\alpha+^6\text{He}(0^+_1) \rightarrow \alpha+^6\text{He}(2^+_1)$

( - parity)

Doublet

(+ parity)
Effect of molecular-orbital configurations in $\alpha^+{}^8\text{He} \Rightarrow {}^6\text{He}{}^6\text{He}$

\[ \Psi = \phi(\alpha^+{}^8\text{He}) + \phi(\text{}^6\text{He}{}^6\text{He}) + \Omega(\text{Mol.Orb.}) \]

Dotted curves (Open)

Red circles (Closed)

Solid curves

Coupling with MO is important!!
1. General Remark

Unified treatment of nuclear structures and nuclear reactions is quite important in studies on nucleosynthesis.

2. Structures and Reactions in light neutron-rich systems

Simple coupled-channel (initial + final channels) is insufficient. Asymptotic cluster and molecular orbital configurations should be combined.

⇒ Our model makes possible to describe the structures and reactions in exotic systems, light N-rich nuclei.

In the present report, we showed some applications to $^{10,12}$Be

3. Results of the present applications

$^{10}$Be : Strong enhancements will be observed in the $\alpha+^6$He inelastic scattering

Positive parity : Resonance  Negative parity : Level crossing

$^{12}$Be : In the $\alpha+^8$He reaction, the coupling of the molecular orbital configurations strongly affects the cross section at extremely low energy.