Excitation of α-Cluster in ^{8}Be

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1. Introduction. - In cluster structure problems, it is very important to study a new aspect originating from distortion or excitation of the clusters. For example, there have been reported experimental evidences on the existence of the resonances with (α* + nucleon)-like structure,[1)] where α* represents the first excited 0_2^+ (20.1 MeV) state.

In the T=0 excited states of ^{8}Be observed by the α-α elastic scattering,[2)] the 0^+ (20.3 MeV), 2^+ (22.2 MeV), 4^+ (25.6 MeV) states show the level sequence like a rotational band whose "band head" is near the α-α* (0_2^+) threshold. It is analogous to the ground state rotational band which has been recognized as the well developed 2α-cluster structure. So in order to examine how well these resonances can be described as having (α+α* (0_2^+)) structure, we carry out (α-α)+(α-α*) coupled channel calculations.

2. The Second 0^+ State of ^{4}He. - The T=0 0_2^+ state of ^{4}He is usually treated as shell-model state of $2\hbar\omega$ excitation with orbital symmetry [f]=[4] or breathing-mode state, but its character is not so well established. The theoretical study using ATMS method[3)] indicates that T=0 negative parity states of ^{4}He have cluster-like structure such as p+^{3}H or n+^{3}He. Experimentally, the 0_2^+ state has excitation energy 20.1 MeV close to the threshold energies of p-^{3}H and n-^{3}He channels, and has large single nucleon width. So it is reasonable to expect that 0_2^+ has (3 bodies +1 body)-like structure (abbreviated as (3+1)). We solve the relative motion within the bound state approximation, using the generator coordinate method (GCM).

The GCM wave function is

$$\phi(0^+) = \int d\vec{e}\, F(e)\ Y_{00}(\hat{e})\, \mathcal{A}\{\phi^{int}_{(3+1)}\ \exp[-\lambda(\vec{r}-\vec{e})^2]\} \quad , \qquad (1)$$

with $\vec{r}$ being relative coordinate of 3 bodies and 1 body, and $\vec{\epsilon}$ being generator coordinate corresponding to $\vec{r}$. The function ϕ^{int} is internal function of (3+1) with channel spin S=0, T=0. As a two-body interaction we use Volkov No.1 force with m=0.56 and size parameter ν=0.25 fm^{-2}. Two 0^+ states are obtained, one is $(0S)^4$ compact shell-model ground state and another is the (3+1) cluster state which has large r.m.s. radius 2.70 fm with the 24.3 MeV excitation energies (Fig. 1). We also calculate the matrix element of E0 transition between two 0^+ states and get 2.37 fm^2 in good agreement with experimental value 2.02 ± 0.32 fm^2.

3. $(\alpha-\alpha)+(\alpha-\alpha^*)$ Coupled Channel Calculations. - We make $(\alpha-\alpha)+(\alpha-\alpha^*)$ coupled channel GCM calculations with the same interaction used in the α^*. As the α, we use $(0S)^4$ harmonic oscillator shell model wave function for simplicity. Two cases are considered for the α^*, the first is that throughout the collision time the α^* is always the same as the free α^*, and the second is that the α^* can change its structure in the interaction region. We introduce the generator coordinates d and d' corresponding to the relative coodinates of α-α and α-α^*, respectively. We calculate energy curves of α-α and α-α^* channels at the fixed d and d', as shown in Fig. 2. The dashed lines are in the case of the free α^*. The $(\alpha-\alpha)$ channel GCM wave function is

$$\Psi_L(\alpha\text{-}\alpha;\ d) = \int d\Omega_d\ Y_{LM}(\hat{d})\,\mathcal{A}\{\phi_\alpha^{int}\phi_\alpha^{int}\ \exp[-\mu(\vec{R}-\vec{d})^2]\} \quad , \qquad (2),$$

and $(\alpha-\alpha^*)$ channel GCM wave function is

$$\Psi_L(\alpha\text{-}\alpha^*;\ d') = \int d\Omega_{d'}\,Y_{LM}(\hat{d}')\,\mathcal{A}\{\phi_\alpha^{int}\phi_{\alpha^*}^{int}\exp[-\mu(\vec{R}-\vec{d}')^2]\} \quad , \qquad (3),$$

$\vec{R}$ being relative coordinate of α and α(or α^*). The functions ϕ_α^{int} and $\phi_{\alpha^*}^{int}$ are internal functions of α and α^*, respectively. As the $\Psi_L(\alpha\text{-}\alpha;\ d)$ and $\Psi_L(\alpha\text{-}\alpha^*;\ d')$ have large overlaps, we diagonalize the Hamiltonian with these two functions at the generator coordinates d=d'.

The solid lines correspond to the second case. The GCM wave function is (Fig. 3)

$$\Psi_L(d;\ e) = \int d\Omega_d \int d\Omega_e\ Y_{LM}(\hat{d})\ Y_{00}(\hat{e})\ \mathcal{A}\{\phi_{3+1}^{int}\ \phi_{\alpha}^{int}\ \exp[-\lambda(\vec{r}-\vec{e})^2-\mu(\vec{R}-\vec{d})^2]\}. \tag{4}$$

We diagonalize the Hamiltonian with $\Psi_L(d;\ e)$ of several e's and fixed d. The lowest solution corresponds to the α-α and the next one corresponds to the α-α*.

4. Conclusion. - In Fig. 2, we can see that L=0 energy curve has a different character from L=2 and L=4, and L=0 partial wave has possibility to form compound state in the region of small d'. Hackenbroich et al.[4] calculated (α-α)+(α-α*) coupled channel K matrix and showed that L=0 phase shift in α-α* channel is of the different character from other partial waves. Calculations of (α-α)+(α-α*) coupled channel S matrix for the two cases are now under investigation.

References

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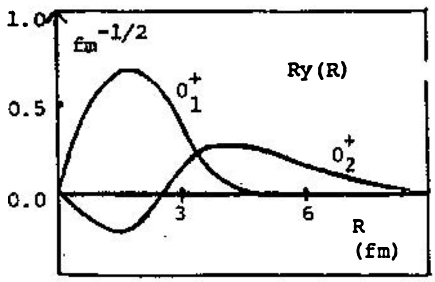

Fig. 1 Nucleon-reduced width amplitude of two 0^+ states of ^{4}He.

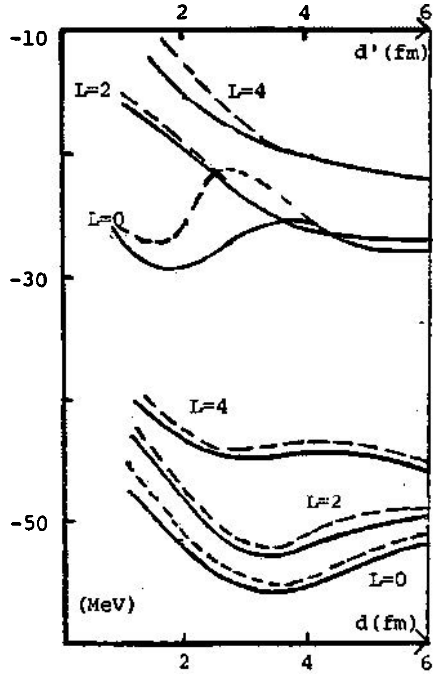

Fig. 2 Energy curves of α-α, α-α* channels.

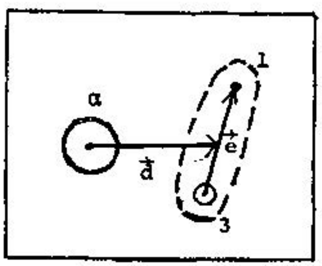

Fig. 3 Generator coordinates in ^{8}Be.