Single-α orbits and α condensation in ^{12}C and ^{11}B

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Four-nucleon correlation of the α-cluster type play an important role in nuclei. The idea of alpha-particle condensation in nuclei has attracted much interest theoretically and experimentally to clarify the exotic structure. The study of bosonic properties of α particles such as single-α orbits and occupation numbers in nuclei provide with a good tool to decide theoretically whether nuclear state is of alpha-particle condensate or not. In this paper bosonic properties of α particles in the 0_2^+ state of ^{12}C at E_x=7.65 MeV (Hoyle state) as well as the ground state (0_1^+) are investigated with the semi-microscopic 3α cluster model, 3α Orthogonality Condition Model (OCM) [1]. They can be evaluated by solving the eigenvalue equation of the one-particle density matrix $\rho(r, r')$ derived from the total wave function of ^{12}C.

The Hoyle state is found to have a dilute 3α structure characterized by the nuclear radius as large as about 4 fm, in which the α particle is occupied in a single S orbit with about 70% probability, and the radial behavior of the S orbit is similar to the S-wave Gaussian wave function with a very long tail. The momentum distribution of the α particle illustrates the δ-function-like behavior, similar to the momentum distribution of dilute neutral atomic condensate states at very low temperature, a feature which eventually can be measured experimentally. These results give more theoretical evidence that the 0_2^+ state is a dilute 3α condensate [2]. On the other hand, the 0_1^+ state has a compact structure with a nuclear radius of 2.44 fm. The occupation probabilities of the α particles spread out over the S, D, and G orbits, amounting to about 30%, each, the results of which comes from the fact that the 0_1^+ state is characterized by the nuclear SU(3) wave function, $[f](\lambda\mu)$=[444](04). The feature is much in contract with that of the 0_2^+ state.

It is interesting to explore a dilute cluster condensed state in ^{11}B. The recent experimental analysis of the ^{11}B(d,d') reaction showed that the third $3/2^-$ state at E_x=8.56 MeV has a $\alpha+\alpha+t$ cluster structure [3]. The $\alpha+\alpha+t$ OCM with the Gaussian basis was applied to study the structure of ^{11}B. It is found that the state has a loosely-coupled $\alpha+\alpha+t$ cluster structure with R_{ms}=3.44 fm, which is larger than that of the ground state (R_{ms}=2.32 fm). However, there is no significant concentration of the occupation number in single-α or single-t orbits like the 0_2^+ state of ^{12}C. This is due to the fact that all of the relative orbital angular momentum between any two clusters in the $\alpha+\alpha+t$ system with $3/2^-$ is not S-wave. We found that the $1/2^+$ state around the $\alpha+\alpha+t$ threshold has a dilute $\alpha+\alpha+t$ structure with R_{ms}=5.4 fm, in which the alpha and triton particles are occupied in S-orbit with about 60% and 90% occupancies, respectively. Thus, the results indicate that the $1/2^+$ state is a counterpart of the Hoyle state of ^{12}C. Recently, Sonic et al. [4] suggested in the ^{7}Li(^{9}Be,α^7Li)^{5}He experiment that the $1/2^+$ state at E_x=12.5 MeV (just above $\alpha+\alpha+t$ threshold) has a $\alpha+\alpha+t$ cluster structure with isospin $T=1/2$. The state might correspond to our present state.

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