Abstract of Doctoral Dissertation

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Gas-like Bosonic states formed around ^{16}O core nucleus close to the 2α decay threshold energy
（2α崩壊しきい値近傍の ^{16}0 コア核のまわりに形成されるガス的ボソン状態の研究）

Nuclear clustering is the most unique and interesting phenomena observed in various physical aspects. In studies of nuclear clustering phenomena, the Hoyle state, an excited state of ^{12}C located at 7.65MeV, is the representative example of carbon production in a stellar environment through the triple-alpha process. In recent years, it has been suggested that the Hoyle state exhibits characteristics of a Bose-Einstein Condensate (BEC), attracting considerable interest from both theoretical and experimental perspectives. What is the maximum number of α clusters for multi-alpha condensation and how can these multi-clusters system overcome the inherent instabilities present in heavier nuclei.

In multi-alpha condensed system, theoretical studies have reported that the maximum number of α particles is limited to approximately ten. A reasonable solution to this instability problem is the assuming the presence of the Core nucleus that provides an additional attractive potential. Exploring the possibility of α condensation around a core nucleus represents a new and intriguing class of nuclear clustering. Previous theoretical investigations, Ichikawa et al, have predicted the plausible ^{16}O+2α condensed states based on interesting idea. However, the strong mixing with physically unimportant configurations (non-resonant states) in their result, made the identification of true resonant states non-trivial.

To address this issue, we aim to provide a more robust theoretical verification of the ^{16}O+2α condensation. Our objective is to clearly identify the resonant states in which α particles condense around an inert core nucleus by extending the limitation of previous study. Furthermore, we attempt to predict the properties of resonant candidates, such as the resonance energies and α-decay widths.

As numerical methods, the real-time evolution method (REM) and the analytical continuation in the coupling constant (ACCC) method were applied in our calculations. REM method has a good opportunity for investigating the ground and excited cluster states of atomic nuclei. We employ the real-time evolution method (REM), which generates physically important basis states using the equation of motion, minimizing contamination from the continuum (physically unimportant configurations). The analytical continuation in the coupling constant (ACCC) method also includes a simple calculation method and it was used to estimate the characteristics of the resonance states (the α-decay widths).

Our REM calculations yield significantly improved and stable results than previous research and identify resonance states clearly. The numerical results show reasonable agreement with previous studied results by Ichikawa et al. and firmly establish the candidates for the ^{16}O+2α condensed state. The 0_3^+ and 0_4^+ eigenstates were identified as strong candidates of resonance states. They exhibit remarkably strong isoscalar monopole transition strengths from the ground state to the respective excited states, strongly supporting their nature as spatially extended ^{16}O+2α condensate. These findings are consistent with the predictions of Ichikawa et al. The root-mean-square radii of these two eigenstates are approximately 3.0fm, also in good agreement with the Ichikawa et al. Although, these radii appear smaller than that of the Hoyle state of ^{12}C (3.7 fm). For this reason, the distribution of valence 2α in the 0_3^+ and 0_4^+ eigenstates are calculated. It suggests that the α particles trapped between the surface of the core nucleus and the Coulomb barrier. Furthermore, the calculated α-decay widths of these states are small, indicating that experimental observation appears feasible.

Finally, we performed a theoretical investigation of core nucleus plus 2 alpha condensates, representing a novel type of α clustering. By reducing the substantial mixing with continuum, we achieved the clear identification of real resonances. Our results show the reasonably agreement with previous work and firmly establishing the 0_3^+ and 0_4^+ states approximately 5 and 1 MeV below the ^{16}O+2α threshold as candidates for the 2α condensation around the ^{16}O core. The real-time evolution method (REM) demonstrated its effectiveness in identifying these gas-like bosonic states of 2α condensation around the core nucleus ^{16}O.