Molecular-like Structure in Light Neutron-rich Nuclei

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The survey of the molecule-like structure is one of the most challenging subjects in light neutron-rich nuclei. In Be isotopes, recently, decay into fragments of He isotopes (^{4}He, ^{6}He, ^{8}He) has been observed from the excited states of ^{10}Be and ^{12}Be, and the presence of two-center configuration is suggested.

As for the multi-cluster configurations in light α-nuclei beyond the two-center systems, the existence of $N\alpha$ states has been predicted around the threshold energy in the so-called Ikeda diagram. For example, it has been suggested that the second 0^+ state of ^{12}C has 3α-like molecular configuration. However, according to a lot of theoretical analyses the state is not necessary to have a linear-chain of 3α, but is described as a weak-coupling state with triangular shape or ^{8}Be+α configuration.

Recently, the discussions of the well-developed cluster structure are extended to the neutron-rich nuclei, and the role of valence neutrons which stabilize the linear-chain structure has been pointed out. For example, von Oertzen has extended his analyses for the molecular structure in Be isotopes [1] to C isotopes, and the linear-chain state consisting of 3α and valence neurons around it has been speculated. Even if the 3α-system without valence neutrons (^{12}C) does not have a linear-chain structure, the valence neutrons around it are expected to increase the binding energy and stabilize the linear-chain state.

Here, we perform a microscopic calculation for the Be isotopes and the C isotopes and study these well-developed molecular-like states. The appearance of prolonged structure with the α-α core in ^{10}Be [2] and ^{12}Be [3] is shown to be successfully described by the α+α+n+n+$\cdots$ model, where the orbits for the valence neutrons are classified based on the molecular-orbit (MO) model. In MO, the orbit of the valence neutron perpendicular to the α-α axis (z-axis) is called π-orbit, and one along the axis is called σ-orbit. The antisymmetrization imposes the forbidden space for the valence neutrons; the π-orbit must have at least one node perpendicular to the axis, and the σ-orbit must have at least two nodes since two α-clusters along the z-axis already occupy the orbitals with $n_z = 0, 1$.

In ^{10}Be, all of the observed positive-parity bands and the negative-parity bands are described within the model. The second 0^+ state of ^{10}Be has a large α-α structure with a $(1/2^+)^2$ configuration (the σ-orbit for the two valence neutrons). An enlargement of the α-α distance due to two-valence neutrons along the α-α axis makes their wave function smooth and reduces the kinetic energy drastically. A large E2 transition probability between states which belong to a rotational band (0_2^+, 2_3^+, 4_2^+) is a signature for the presence of such states. ^{12}Be is also investigated using α+α+$4n$ model, in which four valence neutrons are considered to occupy the $(3/2^-)^2(1/2^+)^2$ configuration. The energy surface of ^{12}Be is shown to exhibit similar characteristics, that the remarkable α clustering makes the binding of the state with $(3/2^-)^2(1/2^+)^2$ configuration properly stronger in comparison with the closed p-shell $(3/2^-)^2(1/2^-)^2$ configuration. This effect is suggested to play a crucial role in accounting for the dissipation of the $N = 8$ magic number in ^{12}Be.

The molecule-like structure of the C isotopes is investigated using a microscopic α+α+α+n+n+$\cdots$ model, where both π-orbit and σ-orbit are introduced around three α-clusters. The valence neutrons which occupy the π-orbit increase the binding energy and stabilize the linear-chain of 3α against the breathing-like break-up. However, ^{14}C with the π-orbit does not show clear minimal energy against the bending-like path. The combination of the valence neutrons in the π- and the σ-orbit is promising to stabilize the linear-chain state against the breathing- and bending- modes, and it is found that the excited states of ^{16}C is one of the most promising candidates for such structure.

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