Di-dineutron correlation in ^{8}He[†]

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The four-neutron correlation in nuclei has attracted much attention as it describes the extreme state of neutron-rich systems. However, strengthening the four-neutron correlation is not as simple as strengthening the dineutron correlation in nuclear systems because the lowest energy states of four neutrons in a vacuum cannot all occupy the s orbits, and the two neutrons must be in the p orbits due to the Pauli principle. As a result, four neutrons are split into two positive-parity and two negative-parity orbits, resulting in insufficient four-neutron correlations to form a bound state. Is there a situation in which the four-neutron correlation in nuclei is strengthened? Let us consider a four-neutron system moving around a core nucleus (closed shell configuration). In such a case, since the lowest energy state is already occupied by the nucleons in the core nucleus, all the valence four neutrons can occupy the same orbit. The four-neutron correlation is therefore expected to be stronger than that in a vacuum.

In this study, the four-neutron correlation in such a bound nucleus is investigated for a ^{8}He nucleus, which exhibits the simplest core+four-neutron (n) structure. The ground-state wave function is described by the microscopic ^{4}He$+n+n+n+n$ cluster model. The Hamiltonian consists of the kinetic energy and the two-body effective nucleon-nucleon potential terms. The potential includes the central and spin-orbit terms whose parameters are tuned to reproduce important properties of the subsystems: the binding energy of ^{4}He and the low-energy phase shifts of the proton+^{4}He and ^{4}He-^{4}He scattering. With this Hamiltonian, the parity and angular momentum projected wave function is obtained by superposing many valence neutron configurations, including explicit dineutron-dineutron correlations. As each nucleon wave function is given by a Gaussian wave packet, the ^{4}He and dineutron clusters are represented by spin- and isospin-saturated four nucleons and two neutrons with spin up and down sharing the same Gaussian center, respectively. In addition to randomly generated four-neutron configurations around ^{4}He, we explicitly include various ^{4}He $+ 2n + 2n$ configurations with isosceles triangles, where two sides of the ^{4}He-$2n$ distance D are taken from 1 to 6 fm, and their opening angle Θ is taken from 30° to 150°.

The calculated binding energy for the ground state of ^{8}He is -3.14 MeV from the ^{4}He + $4n$ threshold, which agrees with the experimental data of -3.10 MeV.[1)] The calculated root-mean-square point proton radius is 1.82 fm and is also in good agreement with the experimental one derived from the charge radius, 1.80(3) fm.[2)] As a measure of the validity of the neutron density distribution, we evaluate the total reaction cross section on a carbon target using the Glauber model. The calculated cross section is 798 mb at 800 MeV/nucleon, which is in good agreement with the experimental interaction cross section value 817 ± 6 mb at 790 MeV/nucleon.[3)] These comparisons confirm the validity of our ^{8}He wave function.

Figure 1 plots the squared overlap between the ground-state wave functions of ^{8}He and the ^{4}He + $2n + 2n$ cluster configurations as a function of Θ. We find that the largest overlap value 0.45 is obtained at $D = 3$ fm and $\Theta \approx 80°$. The ^{8}He wave function contains a sizeable two-$2n$ component with a large D value, a component of the correlated dineutron-dineutron pair. Exploring such a di-dineutron correlation in other neutron-rich nuclei would aid the universal understanding of the four-neutron correlation.

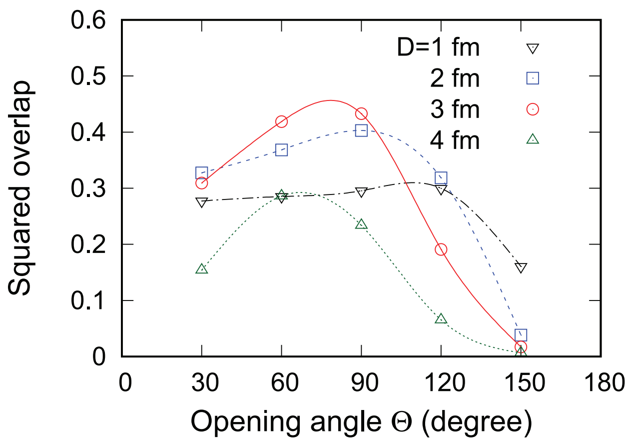

Fig. 1. Squared overlap between the ground-state wave function and ^{4}He $+ 2n + 2n$ configurations.

References
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