He cluster formation in light neutron-rich nuclei†

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Recently, a negative correlation between the neutron number and ^{4}He cluster formation probability on the nuclear surface was experimentally reported for Sn isotopes.[1)] A similar trend was theoretically observed for C isotopes.[2)] However, this trend contradicts to the previous expectation; ^{4}He clustering develops toward the neutron drip-line of Be and B isotopes.[3)] To understand these ambiguous results, we have quantitatively evaluated the ^{4}He cluster formation probability based on the antisymmetrized molecular dynamics (AMD).

Figure 1 shows the calculated intrinsic proton density distributions of the ground states.[4)] Except for ^{11}B, the distributions exhibit two peaks, indicating the formation of He + He and He + He clusters in Be and B isotopes, respectively. The development of clusters can be estimated from the distance between the clusters (distance between two peaks), which is shown in the lower panel of Fig. 1. It suggests a gradual growth of clusters toward the drip line, which is qualitatively consistent with the previous expectation.[3)]

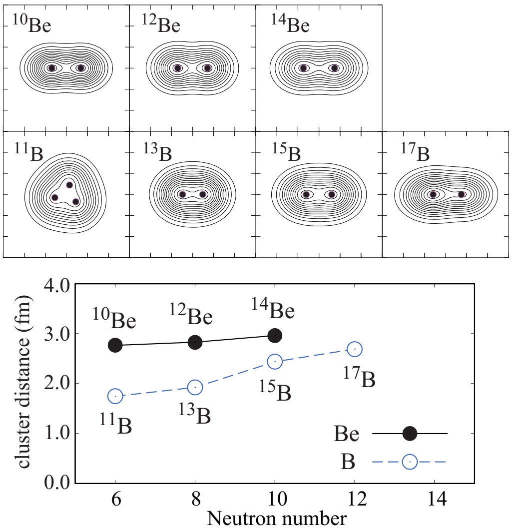

Fig. 1. Upper panels show the intrinsic proton density distribution where peaks of the density distribution are plotted by filled circles. Lower panel shows the distance between cluster centroids, *i.e.* inter-cluster distance.

To quantitatively evaluate He cluster formation and relate it to ^{4}He knockout reaction, we calculated the reduced width amplitude (RWA).

$$r\mathcal{Y}(r) = \sqrt{\binom{A}{A'}}\,\langle \delta(x-r)\,\Phi_{\mathrm{He}}\Phi_{A'}Y_{l=0}(\hat{x})]_0|\,\Phi_{\mathrm{A}}\rangle\,, \tag{1}$$

where Φ_{He}, $\Phi_{A'}$ and Φ_A denote the wave functions of the He cluster, daughter, and target nuclei. RWA is the probability amplitude to determine the He cluster at distance r from the daughter nucleus. Hence, its square integral (herein referred to as S-factor) defines the cluster formation probability.

The results are denoted by solid lines in Fig. 2. Unexpectedly, the S-factor decreases as neutron number increases. This contradicts the results illustrated in Fig. 1 and previous expectation;[3)] however, this trend remains consistent in Sn isotopes.[1)] To resolve this issue, we investigated the formation probabilities of ^{6}He and ^{8}He clusters (Fig. 2). The ^{6}He and ^{8}He clusters dominate over the ^{4}He cluster as neutron number increases. Considering the sum of the formation probabilities of He isotopes, we observe an increasing trend, as shown in Fig. 1.

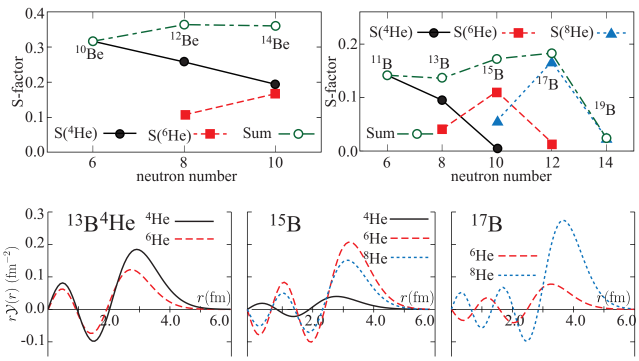

Fig. 2. Upper panels show the ^{4}He, ^{6}He and ^{8}He cluster formation probabilities. The lower panels show the RWA of the ^{4}He, ^{6}He and ^{8}He clusters in B isotopes.

The aforementioned results may be summarized as follows: In neutron-rich Be and B isotopes, ^{4}He is formed as a cluster core; however, but it is always accompanied by excess neutrons. As a result, we should sum up the ^{4}He clusters and ^{6,8}He clusters to accurately evaluate the cluster formation probability. We believe that this new insight is important for future studies to understand the relationship between clustering and excess neutrons.

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