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Exotic clusters in an unbound region of light neutron-rich systems

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In light neutron-rich systems, many kinds of molecular structures are discussed from the view point of the clustering phenomena.In particular, much attention has been concentrated on Be isotopes. The molecular orbital (MO), such as π^- and σ^+ associated with the covalent binding of atomic molecules, have been shown to give a good description for the low-lying states of these isotopes. In their highly-excited states, furthermore, recent experiments revealed the existence of the interesting resonant states which dominantly decay to the ^{6,8}He fragments. In this report, we show the unified study of the exotic structures of ^{12}Be=α+α+4N in an unbound region and the α+^{6,8}He resonant scattering. We applied the generalized two-center cluster model in which the covalent MO and the atomic orbital (AO) configurations with ^{x}He+^{y}He could be described in a unified manner. First, we calculated the energy spectra below an α decay-threshold. The $(\pi^-_{3/2})^2(\sigma^+_{1/2})^2$ configuration corresponding to $\nu(0\mathrm{p})^4(\mathrm{sd})^2$ becomes the ground state, while $(\pi^-_{3/2})^2(\pi^-_{1/2})^2$ having a large overlap with $\nu(0\mathrm{p})^6$ appears as the first excited state. The rotational band of the ground state reaches to the maximum spin of J$^\pi$ = 8$^+$. This result means that the magicity of N=8 is broken in ^{12}Be due to the formation of $(\pi^-_{3/2})^2(\sigma^+_{1/2})^2$. Next, we solved the scattering problem of α+^{8}He and identified the several resonance poles. In the continuum region, we found the rotational bands having the AO configurations of α+^{8}He, ^{6}He+^{6}He, and ^{5}He+^{7}He. Furthermore, a much more exotic band appears in the same energy region. In this band, two valence neutrons are localized at individual α-cores (the ^{5}He+^{5}He cluster), while the other two neutrons form the covalent σ^+- bonding between two ^{5}He clusters; hence, it has a "hybrid structure" between the MO configuration and the AO one. In the J$^\pi$=0$^+$ state, it is strongly excited by the two-neutron transfer reaction, α+^{8}He$\rightarrow$^{6}He+^{6}He. We also calculated the matrix elements of isoscalar monopole transition (MTR), $|<0^+_f|\sum_i^{12} r_i^2|0^+_1>|^2$. The MTR matrix element going to the AO state of α+^{8}He is the largest in all the excited states, although an certain enhancement also occur in the transition to the first excited 0 $^+$, which seems to be consistent to the observed electric MTR. Therefore, this result strongly suggests that the monopole transition is enhanced when the final state have a developed cluster (AO) structure. In order to analyze the enhancement of MTR in the realistic reaction process, we also performed the calculation of the continuum discretized coupled-channels (CDCC) for the monopole breakup of ^{10}Be into α+^{6}He by a ^{12}C target. This breakup reaction is mainly induced by a nuclear interaction from the ^{12}C target, and the multi-step of the continuum-continuum coupling is quite strong. We confirmed the strong enhancement in the transition of $0^+_1 \rightarrow 0\,^+_3$, which have an AO configuration of α+^{6}He($2\,^+_1$). Therefore, the cluster state is strongly excited in the nuclear breakup reaction, which is consistent to the result in the analysis of MTR for ^{12}Be. Similar studies of even Be isotopes and future perspectives will also be presented.