HELIUM CLUSTERING IN NEUTRON-RICH Be ISOTOPES*

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The experimental study of the helium decays of the ^{10}Be and ^{12}Be excited states was performed at TRIUMF, Vancouver, using the transfer reactions of the ^{9}Li beam on the LiF target and resonant particle spectroscopy technique. Part of the results from the full dataset are presented here, for the ^{4}He+^{6}He (0^+; 1.8 MeV, 2^+), ^{6}He+^{6}He (0^+; 1.8 MeV, 2^+), and ^{4}He+^{8}He decays of the ^{10}Be and ^{12}Be excited states, respectively. The ^{6}He+^{6}He (1.8 MeV, 2^+) decay channel was observed for the first time in the present experiment, while for the ^{4}He+^{6}He (1.8 MeV, 2^+) decay channel, there was previously only one measurement available, which present results agree with. New highly excited states were observed in all decay channels studied. Although branching ratios and the spins of the states were not determined, important spectroscopic information is obtained and present results are in good agreement with the proposed α–Xn–α molecular structure of these isotopes, based on the comparison with previously published results.

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1. Introduction

Evolution of the clustering with addition of valence neutrons in beryllium isotopes presents an important benchmark to our understanding of the nuclear structure and underlying force from which the cluster structure emerges [1]. Rotational bands with the molecular α–$2n$–α structure have been identified in the ^{10}Be nucleus, but there is still a question whether the

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strong α–α clustering persists when the spin–orbit force is increased. There is no firm agreement on the existence of the 4^+ member of the ground-state rotational band [2], and there is the ongoing search for the 6^+ member of the deformed molecular band with ${0_2}^+$ 6.2 MeV band head, built on σ valence neutrons structure. Contrary to the previous observations, the latest dedicated experimental measurement found no evidence for such a state in the 13–15 MeV energy region [3]. With additional two valence neutrons in ^{12}Be, even more complex and rich structural phenomena are expected in the excited states. Rotational bands, built on the ^{6}He+^{6}He and ^{4}He+^{8}He clustering and underlying molecular α–$4n$–α structure are proposed to exist in the excited states of ^{12}Be [4], with recent results finding states close to respective particle decay thresholds which agree well with the proposed rotational bands [5]. There is still a need for the confirmation of these results at higher excitation energies, as there were contradicting results in the past [6].

To examine the clustering in the excited states of these and other neutron-rich light nuclei, an experiment was performed at the ISAC-II accelerator facility at TRIUMF, Vancouver. Transfer reactions of the ^{9}Li beam of 74.8 MeV energy on the ≈ 1 mg/cm^2 thick LiF target were used to populate the excited states of ^{10}Be and ^{12}Be nuclei, which could have been produced by either p or t transfer to the ^{9}Li beam, respectively, alongside more complex processes like fusion to compound nucleus followed by the sequential decay.

2. Experimental setup and analysis

A large solid angle detector array, comprised of six wedge shaped telescopes, each having 65 μm thick ΔE and 1.5 mm thick E detector, both single-sided silicon strip detectors (SSSSD), arranged in "lampshade" geometry, was used and the reaction products were identified using the standard ΔE–E method. A thorough analysis was performed for every combination of detected reaction products and telescope segments separately, as the particles could have been detected in the same (d$T = 0$), neighbouring (d$T = 1$), separated by one (d$T = 2$) and opposite (d$T = 3$) telescopes, to identify and correctly select the data from the particular reaction exit channel. For this, the Q-value conditions, graphical cuts on the Catania plots, and additional correlation spectra, when required, were used. Due to the large uncertainty in the nominal $\Delta\phi$ angle between detected reaction products, after the initial data selection, the relative azimuthal angle was reconstructed from the conservation laws, restoring the part of the resolution in the excitation energy spectra. Due to the large systematical uncertainty of the present data and low statistics obtained in most of the spectra, binning of 320 keV was used to match the experimental resolution. All spectra were fitted with Gaussian functions on top of the smooth background to extract the position of the peaks which were candidates for the states. Only if the peak was observed clearly in two separate datasets it is considered to be a real state, or a tentative assignment is made for peaks with less statistics and certainty. Details on the experimental setup, analysis performed, and results obtained for the decays of the ^{12}Be excited states can be found in [7].

3. Results

An example of the data selection and two-dimensional excitation energy spectrum for the ^{7}Li(^{9}Li,^{6}He^{6}He)^{4}He reaction, identified from the ^{6}He+^{6}He coincident events in the d$T = 3$ telescope combination, is presented in Fig. 1. In the excitation energy spectrum of ^{10}Be$_{13}$ *versus* ^{10}Be$_{23}$ in Fig. 1 (right), where the subscript indicates a combination of nuclei in the reaction exit channel, with "3" being undetected nucleus ^{4}He, peaks at 9.6 MeV (2^+), 10.2 MeV (4^+), and 11.8 MeV (4^+) are labeled with dashed lines. Observation of these states is a valuable quality test of the procedures used in the analysis and the data selection. The same states are observed in the ^{4}He+^{6}He* (1.8 MeV, 2^+) decay channel, which confirms the only available result for this channel [8]. The obtained results for the decays of the ^{10}Be excited states will be presented in more detail in a separate publication.

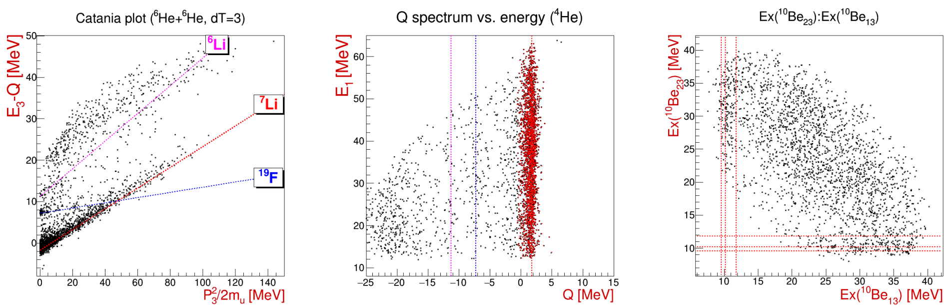

Fig. 1. (Color online) Catania plot, Q-value spectrum, and two-dimensional excitation energy spectrum for the ^{10}Be$_{13}$ *versus* ^{10}Be$_{23}$, from the ^{7}Li(^{9}Li,^{6}He^{6}He)^{4}He reaction (red, $Q = 2.24$ MeV).

For the decays of the ^{12}Be excited states, an example of combined spectra for the decays to the ^{6}He+^{6}He and ^{4}He+^{8}He channels is shown in Fig. 2. Even though the quality, *i.e.* resolution and statistics of any individual spectrum is limited, observation of the same peaks in at least two different datasets for different nuclei and telescope combinations in the exit channel led to the conclusion that these are indeed real states, and results generally agree with those of [4] and with more recent ones [5]. For the first time in present experimental data, the decay to the ^{6}He+^{6}He* (1.8 MeV, 2^+)

channel is observed [7]. Most of the states observed in that channel decay to either ^{4}He+^{8}He or ^{6}He+^{6}He channel, which is indicative of their special cluster structure. More results and detailed discussion can be found in [7].

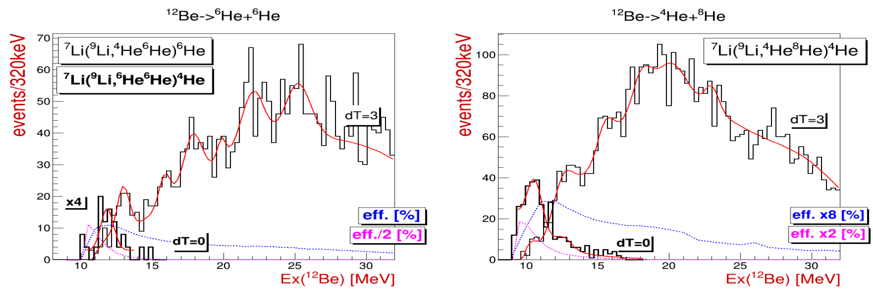

Fig. 2. Excitation energy spectra for the decays of the ^{12}Be excited states to the ^{6}He+^{6}He and ^{4}He+^{8}He channels, from two datasets each, are presented.

Although spin and parity of the states were not determined in the present experiment, the observation of the number of helium decaying states well above the neutron decay thresholds, combined with the previous knowledge on spin, parity, and branching ratios for these states, agrees well with the existence of strong clustering and proposed molecular α–Xn–α structure in the ^{10,12}Be nuclei.

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