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A new experimental study of the ^{12}Be cluster structure

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Abstract. We have carried out a new experiment with ^{12}Be secondary beam at 29MeV/u. The molecular resonant states were reconstructed from ^{4}He-^{8}He and ^{6}He-^{6}He decaying channels. These states agree well with previously reported results by Freer et al., and therefore support the highly disputed clustering structure of ^{12}Be. Cross sections for these two breakup channels were also deduced.

1 Introduction

Many theoretical and experimental studies have been devoted to the cluster structure in nuclei in the past decades[1–4]. For stable nuclei, the cluster structure is generally developed at excited states close to the corresponding particle decay threshold as illustrated in the Ikeda diagram [5]. Nevertheless, when approaching the neutron drip line some compact cluster cores may be favored in exotic nuclei even in the ground state[1, 6, 7], which has been indicated in the Anti-symmetrized Molecular Dynamics(AMD) calculations for neutron rich Be isotopes [8].

The N=8 shell closure was found quenching in ^{12}Be[9–12], which may be related to the α-clustering[13, 14]. One possible method to probe the Molecular-Resonance(MR) states is to apply the inelastic excitation followed by coincidently recording the decay products [15, 16, 19]. So far, there have been some inconsistence in the rather limited experimental results. Some MR cluster states were reported in the work of Freer et al., from which a ^{6}He+^{6}He rotational band was constructed in accordance with an α-4n-α cluster configuration[15]. However, most of these resonances were not observed in a later experiment by Charity et al. with significantly better statistics[16]. This brings in severe disputation on the description of molecular states in ^{12}Be. So, more measurements are necessary to check the existence of these MR states and related α-4n-α cluster structure in ^{12}Be. Here we present experimental data for the breakup of ^{12}Be into 2 helium fragments via inelastic scattering off carbon target at 29MeV/u.

2 Description of the experiment

The experiment was carried out at the Radioactive Ion Beam Line in Lanzhou(RIBLL)[17]. The secondary beam of ^{12}Be at 29MeV/u was tracked onto a 100mg/cm^2 carbon target by two PPACs with a position resolution(FWHM) of about 1mm. The fragmentation products were recorded by a downstream zero-degree telescope consisting of a 300μm-thick double-sided silicon strip detector(DSSD)

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and a 4*4 CsI scintillator array. The DSSD detector has an active area of 6.4*6.4cm^2 with front and back faces devided into 32 strips, providing a position resolution of 2mm equal to the width of the strips. It was placed at 15.5cm from the target, covering an angular range of 0^o-10^o. The CsI array was situated at 32.3cm from the target so as to cover the same angular range of the DSSD. The energy resolution of the CsI scintillators was about 3% for 50MeV/u ^{4}He, while that of the DSSD was 35KeV for a ^{241}Am alpha source.

In the present work, only events with two helium fragments were analyzed. The excitation energy(E_x) of the inelastically scattered ^{12}Be was reconstructed from the kinetic energies(T_a,T_b) and the opening angle(θ) of the two decaying fragments according to the invariant mass method as used in our previous work for ^{8}He[18]. Monte Carlo simulations were performed to estimate the resolution of the reconstructed excitation energy and the detection efficiency for 2-^{X}He events. The resolution(FWHM) is determined to be around 0.4MeV at a relative energy(E_{rel}) of 1MeV and increases to about 0.8MeV at E_{rel} of 4MeV as shown in Fig 1(a). The small size of the CsI scintillators and the angular coverage of the telescope from 0^o offered higher sensitivity in case of small relative energies compared to detector systems of Freer et al.[15] and Charity et al.[16]. The detection efficiency for ^{12}Be decaying into 2-^{X}He fragments is thus determined to be around 40% in average, as shown in Fig 1(b) for ^{12}*Be* decaying into ^{4}He+^{8}He. Great improvements of the efficiency for small relative energies can be clearly seen, compared to that taken from the reference[19].

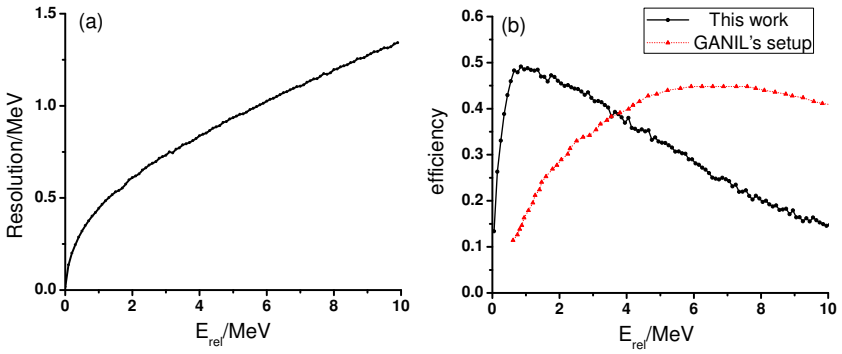

Figure 1. Resolution(FWHM) of E_{rel} (a) and detection efficiency (b) for ^{12}Be decaying into ^{4}He+^{8}He. Similar results are also obtained for ^{12}Be decaying into ^{6}He+^{6}He. And for comparison, the efficiency obtained from the reference[19] was also shown.

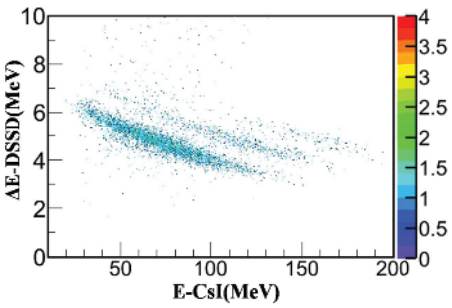

Figure 2. Particle identification(PID) spectrum for ^{12}Be.

3 Results and disscusion

The particle identification(PID) spectrum is shown in Fig 2, where ^{4}He, ^{6}He, ^{8}He isotopes are clearly resolved. Target-out measurements were also performed and the background for the current coincident measurement was demonstrated to be negligible. The reconstructed ^{12}Be excitation energy spectra(not corrected for the detection efficiency) for ^{6}He+^{6}He and ^{4}He+^{8}He are displayed in Fig 3(a) and (b), respectively.

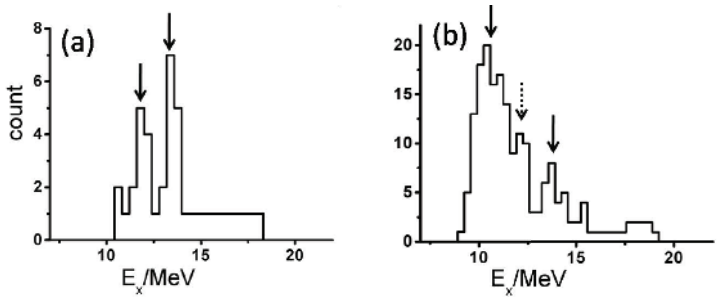

Figure 3. Reconstructed excitation energy spectra of ^{12}Be for decaying channels of ^{6}He+^{6}He(a) and ^{4}He+^{8}He(b).

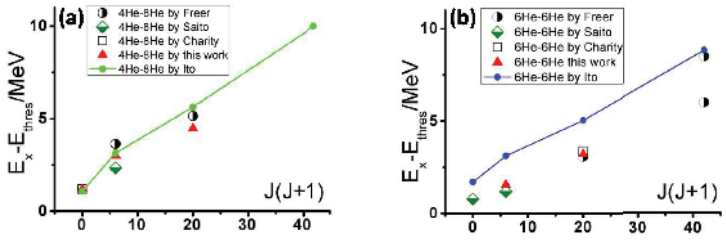

Figure 4. Comparison of the observed resonance states to the GTCM calculation for ^{12}Be decaying into ^{6}He+^{6}He(a) and ^{4}He+^{8}He(b). The experimental data are from [15, 16, 22] and the results of this work, while the GTCM calculation is from [21].

For the ^{6}He+^{6}He decaying channel, two excited states located at 11.7MeV and 13.3MeV are observed. The 13.3MeV state corresponds to the 13.2MeV state reported by Freer et al.[15], while the 11.7MeV peak was not seen in the two previous experiments due to the limited acceptance of their detector systems at low excitation energy side(Fig 1(b)).In case of the ^{4}He+^{8}He coincident events, two peaks at 10.2MeV, and 13.4MeV can be identified. There might be a peak at ~12.0MeV. As a matter of fact, the Generator Coordinate Method(GCM) calculation located the 2^{+} member of this molecular band very close to our measured energy[20].

In the present work, it was found that angular distributions for the inelastic scattering of ^{12}Be to the 13.3MeV state of the ^{6}He+^{6}He decaying channel and the 13.4MeV state of the ^{4}He+^{8}He decaying channel are consistent with the Distorted Wave Born Approximation (DWBA) calculations for an excited state with spin-parity assignment of 4^{+}.

We compared our results with the generalized two-center cluster Model(GTCM) calculation by Ito[21] in Fig 4, together with resonances reported by Freer et al.[15], Saito et.al[22] and Charity

et al.[16]. Good agreements with the GTCM calculation and previously reported data was achieved, although an overall shift of about 1.5MeV from the experimental results to the GTCM calculation was observed for the ^{6}He-^{6}He band. This discrepancy is approximately equal to the difference of 1.7MeV between the experimental threshold energy and that from GTCM calculation, and may be attributed to the adopted interaction strength in the calculation [23]. In the GTCM calculation, ^{12}Be is described as two alpha cores plus 4 valence neutrons[21]. The obtained good agreement between the experimental data and the GTCM calculation for both ^{4}He-^{8}He and ^{6}He-^{6}He molecular bands strongly supports a highly clustered α-4n-α configuration in ^{12}Be.

Cross sections were deduced to be 0.14±0.03 mb and 0.65±0.10 mb for the ^{6}He+^{6}He and ^{4}He+^{8}He decaying channels, respectively, which are reasonably consistent with previous results at 42MeV/u by Ashwood et al.[24] with a similar detector system.

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