Eur. Phys. J. A **25**, s01, 325–326 (2005)
DOI: 10.1140/epjad/i2005-06-139-4

EPJ A direct
electronic only

Breakup reactions of halo nuclei

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Received: 19 January 2005 /
Published online: 10 August 2005 –

Abstract. Coulomb and nuclear breakup of halo nuclei have been studied at RIKEN. In this contribution, we focus on the cases of Coulomb breakup of the one-neutron halo nucleus ^{11}Be at 69 MeV/nucleon with a lead target and the nuclear breakup of ^{11}Be at 67 MeV/nucleon with a carbon target. In these studies, we have extracted the angular distributions of ^{10}Be + n c.m. system (inelastic scattering) as well as the relative energy spectra. The angular distributions have been found very important to extract the pure $E1$ component in the breakup with Pb target, while it has been used to specify the angular momentum of two discrete levels observed for the breakup with C target. We also present preliminary results of Coulomb breakup of the two-neutron halo nucleus ^{11}Li.

PACS. 25.60.-t Reactions induced by unstable nuclei – 21.45.+v Few-body systems

1 Coulomb breakup of the one-neutron halo nucleus ^{11}Be

Breakup reactions have played an important role in the study of halo structures. Coulomb breakup of halo nuclei is characterized by its large cross-section of the order of 1 barn due to strong $E1$ excitation to the low-lying continuum just above the neutron-decay threshold. Our previous Coulomb breakup experiment on ^{11}Be [1] and ^{19}C [2] clearly showed that this large $E1$ strength is attributed to the direct breakup mechanism. Owing to this simple picture, the Coulomb dissociation of the halo nucleus can become a powerful tool to probe exclusively the halo ground state, whose wave function is related directly to the $B(E1)$ spectrum. However, this simple reaction mechanism may require a revision due to the possible higher-order effects and the contribution of the nuclear breakup as pointed out by many theoretical papers [3,4,5,6,7,8,9,10,11]. In order to resolve these problems, we have recently revisited the Coulomb dissociation of ^{11}Be at 69 MeV/nucleon with about 30 times more statistics than the previous experiment [1]. In this study, we have adopted the analysis using the angle θ of ^{10}Be + n center-of-mass (c.m.) system, namely, that of the inelastic scattering. In the semi-classical Coulomb breakup picture, this angle θ is directly related to the impact parameter b as $b = a\cot(\theta/2) \simeq 2a/\theta$, where a represents half the distance of the closest approach in the classical Coulomb head-on collision. Since the Coulomb breakup occurs at large impact parameters, selection of data at forward angular regions is expected to be effective to extract the pure $E1$ Coulomb breakup component.

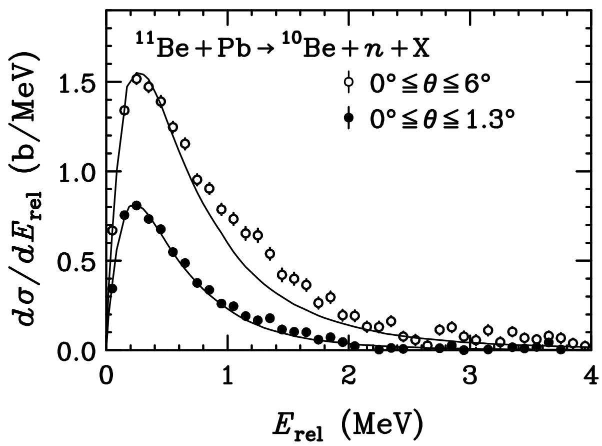

Fig. 1. Relative energy spectra for ^{11}Be + Pb at 69 MeV/nucleon for the whole acceptance region (open points), and for the selected forward angles (solid points). The data points are compared to the pure $E1$ direct breakup model calculation obtained with the ECIS code [12] with α^2 (spectroscopic factor for the halo configuration) of 0.72 (solid lines).

Figure 1 shows the relative energy spectra for ^{11}Be on the Pb target for the whole acceptance (open points), and the data selected for $\theta \leq 1.3°$ (solid points) corresponding to $b \geq 30$ fm in the semi-classical approximation. Here no subtraction for the nuclear breakup contribution is made.

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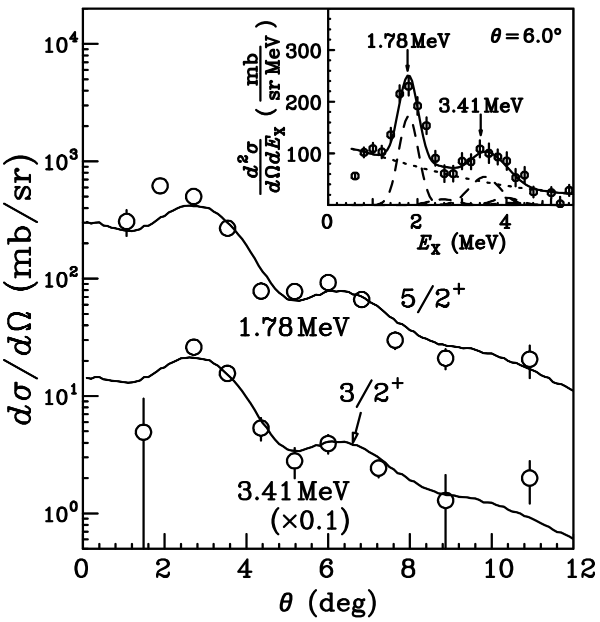

Fig. 2. Angular distributions of ^{11}Be into $E_x = 1.79$ MeV and 3.41 MeV states observed in the breakup reaction of ^{11}Be on C target. The angles are taken in the center-of-mass frame of the projectile and the target. Solid lines show calculations by the ECIS code for $L = 2$ transitions. Inset: excitation energy spectrum of ^{11}Be at $\theta = 6°$ in this reaction.

We can see clearly an excellent agreement with the first-order perturbation theory with the direct breakup model when selecting the most forward angles (solid curve). The spectroscopic factor is thus extracted to be 0.72(4), which is consistent with the previous experiment.

We have found that the higher-order effects can be well controlled by selecting the forward scattering angle, and that this effect is, in fact, very small. We could extract the spectroscopic factor of the ground state of ^{11}Be more precisely by this method. The details of the experiments and related discussions are seen in ref. [13].

2 Nuclear breakup of one-neutron halo nucleus ^{11}Be

As seen in the previous section, the Coulomb breakup of halo nuclei is dominated by a strong direct breakup cross-section, which is suitable for extracting the information of halo structure in the ground state. However, this implies that the discrete states above the neutron decay threshold are hidden by the direct breakup component. Breakup reaction of halo nuclei on a light target is thus very important to observe such discrete states.

The inset of fig. 2 shows the excitation energy spectrum for ^{11}Be on the carbon target at 67A MeV at $\theta = 6°$. As clearly seen in the figure, we have observed two discrete peaks corresponding to the known excited state at $E_x = 1.79$ MeV and $E_x = 3.41$ MeV. The angular distributions corresponding to these peaks are shown in fig. 2, where backgrounds were estimated as in the inset and were subtracted. The angles are defined in the center-of-mass frame of the projectile and the target. From the comparison with the DWBA calculation (ECIS [12], solid curves), these two transitions were found to have both $L = 2$ property, which is consistent with the assignment of $5/2^+$ and $3/2^+$, respectively, for these states predicted by the shell model. The detailed analysis and discussions are described in ref. [13].

3 Coulomb breakup of the two-neutron halo nucleus ^{11}Li

As shown in sect. 1, Coulomb breakup for the one neutron halo nucleus is now well established. On the other hand, that for the two-neutron halo case as in ^{11}Li has not been well understood, mainly due to discrepancies among previous three experimental results on the Coulomb dissociation obtained at MSU [14], RIKEN [15], and GSI [16]. We have thus studied the Coulomb dissociation of ^{11}Li on a Pb target at an incident energy of approximately 70 MeV/nucleon to obtain the data with much higher statistics and with much less ambiguities caused by cross talk events in detecting two neutrons.

In the preliminary spectrum of the relative energy (E_{rel}) of the three outgoing particles, ^{9}Li and two neutrons, we have observed a huge bump with an asymmetric shape as in ^{11}Be. This bump peaks at $E_{\mathrm{rel}} \sim 0.3$ MeV and its width is about 0.6 MeV (FWHM). The integrated cross-section at low relative energies amounts to 2.74±0.07 (stat.) barns for $E_{\mathrm{rel}} \leq 3$ MeV (preliminary). The $B(E1)$ strengths have then been obtained to be $1.5 \pm 0.1\, e^2\,\mathrm{fm}^2$ for $E_{\mathrm{rel}} \leq 3$ MeV using the conventional equivalent photon method. Further analysis is now in progress.

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