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Recoil proton tagged knockout reaction for ^{8}He

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ABSTRACT

We report for the first time the discrimination of the core fragment knockout and valence nucleon knockout reaction mechanisms at medium energy range, by the use of the recoil proton tagging technique. Intense ^{8}He beams at 82.3 MeV/u were supplied by the RIPS beam line at RIKEN, and impinged on both hydrogen and carbon targets. Recoil protons were detected in coincidence with the forward moving core fragments and neutrons. The core fragment knockout mechanism is identified through the polar angle correlation and checked by various kinematics relations. This mechanism may be used to extract the cluster structure information of unstable nuclei. On the other hand, with the selection of the tagged valence nucleon knockout mechanism, a narrower peak of ^{7}He ground state is obtained. The extracted neutron spectroscopic factor $S_n = 0.512(18)$ is relatively smaller than the no-tagged one, and is in good agreement with the prediction of *ab initio* Green's function Monte Carlo calculations.

1. Introduction

Knockout reactions play an important role in probing the single-particle and cluster structure of stable nuclei [1,2]. Since the advent of fast radioactive nuclear beams, knockout reactions with inverse kinematics have been developed into a powerful tool for spectroscopic investigation of the exotic properties of unstable nuclei [3]. As indicated in many occasions (Ref. [4] for instance), applicability of reaction tools to extract nuclear structure information depends sensitively on the precise handling of the reaction mechanisms. Recently it was reported that, for nuclei with large neutron–proton asymmetry, the spectroscopic factors (SF) obtained from knockout reactions deviate systematically from those obtained from transfer reactions [5,6]. Some non-direct reaction processes were proposed to account for this discrepancy [7]. Also a suspicious resonance peak at around 0.6 MeV above the ground state of ^{7}He was reported from a knockout reaction experiment using a carbon target [8,9], but cannot be confirmed by some other experiments (see Ref. [10] for a summary) including a similar knockout reaction experiment but using a hydrogen target [11]. It seems better to use "a clean structure-less probe" like proton target in order to avoid the possible complex reaction processes [11]. But even for a proton target various reaction mechanisms together with their sensitivities to particular structure configurations still need to be clarified.

^{8}He is an exotic nucleus with the largest neutron to proton ratio for any known particle-stable nucleus, and has attracted continuous attention experimentally as well as theoretically [12]. Based on the already established important properties [8,10–12], ^{8}He provides an excellent test case to evaluate the reaction mechanisms. Early in 1990s the breakup reaction mechanisms of a fast moving Borromean type projectile was classified as [13,14]: (A) sudden breakup of the projectile nucleus in the field provided by the target nucleus (diffractive breakup); (B) knockout of a valence nucleon (stripping) followed by sudden breakup of the spectator fragment; (C) knockout of a valence nucleon followed by strong final state interaction (FSI or resonance decay), and (D) knockout of the core fragment followed by emission of valence nucleons. In the subsequent studies using knockout reactions it was realized that, for a Borromean nucleus, the mechanism (C) dominates over (B) [15]. In the mean time the process (D) was often ignored based on the strong absorption assumption for experiments employing composite targets [3]. This assumption, which neglects the effect of the complex core–target interactions, is necessary to validate

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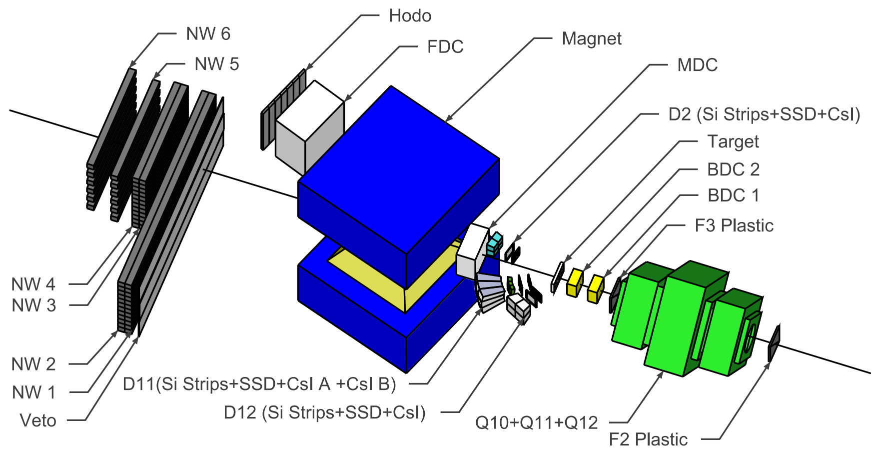

Fig. 1. Schematic view of the experimental setup at RIKEN-RIPS. Beams were injected from the lower left corner.

the inclusive experiment measuring the spectator core fragments at forward angles (some times in coincidence with the in-beam γ-rays). But in the case of proton target this strong absorption assumption is obviously not valid and the explicit treatment of the process (D) is needed. We note that an important step towards the isolation of a typical reaction process was reported based on the exclusive measurement of the two breakup components of a proton-rich projectile [16]. But the purpose of that experiment was to separate the diffractive breakup (process (A)) from the stripping (process (B) or (C)), without touching process (D) due to the application of an absorptive ^{9}Be target.

As demonstrated in a quasi-free scattering (QFS) experiment with ^{6,8}He beams impinging on a hydrogen target [17], the core fragment knockout process (process (D)) can be isolated through the exclusive measurement of the recoil target protons in coincidence with the forward moving core fragments. In addition the SF of the cluster structure of the projectile in its ground state can be extracted from this core knockout process. This is of great importance since clustering structure seems growing in the vicinity of the neutron drip-line and spectroscopic investigation of this new degree of freedom is very demanding [18]. The reported experiment was carried out at very high energies (671 MeV/u for ^{8}He) and did not employ neutron detection [17]. It would be interesting to investigate the separability and applicability of these reaction mechanisms at energies around 100 MeV/u where most knockout experiments for unstable nuclei have been performed and a lot of spectroscopic information has been accumulated [6].

2. Description of the experiment

A detailed description of the experiment was given in a recent article reporting the results of quasi-elastic scattering of ^{6}He [19], and only a brief outline relevant to the knockout reaction is presented here. The experiment was carried out at the RIKEN-RIPS beam line [20]. The secondary beam of ^{8}He at 82.3 MeV/u was produced by a 115 MeV/u ^{13}C primary beam impinged on a thick ^{9}Be target. The secondary beam intensity amounts to 2.5×10^5 pps with a purity of about 70% for ^{8}He. A schematic view of the detection setup is given in Fig. 1. A CH_2 foil (83.0 mg/cm^2) and a carbon film (133.9 mg/cm^2) were mounted as the physics targets, together with an empty target used for background measurement. Drift chambers (BDC1, BDC2 and MDC) were used upstream and downstream from the target to determine the particle tracks event by event, with an angular resolution of less than 0.1°. A deflection magnet was installed downstream from the target in order to keep the forward neutron wall away from being exposed to the direct beam. Another drift chamber (FDC) was installed down stream from the magnet to measure the deflected tracks of the charged fragments. An hodoscope wall composed of seven plastic scintillation bars (HODO) was placed behind the Magnet + FDC system to measure the time of flight (TOF) and energy loss of the fragments. Neutron walls composed of 60 scintillation bars were mounted at about 5 meters downstream from the target around the 0° axis (beam direction). Two specially designed telescopes (D11 and D12) were installed, covering an angular range between 15° and 75° (for two setups) relative to the beam axis, to detect the recoil protons [21]. Another telescope D2 was installed beside the magnet acceptance, covering forward angles from 6° to 21°. Each of these telescopes is composed of one double-sided silicon strip detector (DSSD) of 1 mm in thickness and 64×64 mm^2 in area, one large surface silicon detector of 1.5 mm in thickness, and one or two layers of thick CsI(Tl) crystals. The strip width of the DSSD is 2 mm at both X and Y directions.

3. Results and discussion

3.1. *Knockout of the core fragment*

Plotted in Fig. 2(a) and (b) are polar angle correlations between the recoil protons and the forward moving ^{6}He fragments, for CH_2 and carbon targets, respectively. For ease of comparison Fig. 2(a) and (b) are drawn with comparable number of incident particles and target thickness. At the upper right part of Fig. 2(a) a component (in the frame F) arises clearly with relatively large proton and ^{6}He polar angles and follows quite well the ^{6}He + p free scattering kinematics as displayed by the solid curve. The angular spreading (and the width of the frame) of this component is mainly determined by the transverse momentum distribution of the ^{6}He core fragment [17]. According to earlier studies [17] this component corresponds to the core fragment knockout mechanism, whereas the component at very small ^{6}He angles (in the frame N) is related to the valence nucleon knockout mechanism. For the core knockout component (frame F) the upper limit of the proton angle is due to the angular coverage of the D2 telescope as specified above, whereas the lower limit at about 35° is due to the rapid decrease of the knockout cross section as illustrated below. We note that the medium energy range of 50–100 MeV/u is already at the fringe of the quasi-free knockout reaction domain. At these energies the proton detection angular window must be selected carefully in order to observe the core fragment knockout component, as illustrated in Fig. 2(a).