^{8}He cluster structure studied by recoil proton tagged knockout reaction

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Abstract. Knockout reaction experiment for ^{8}He at 82.3 MeV/u on Hydrogen target was carried out at the RIPS beam line in RIKEN. Recoil protons were detected in coincidence with the forward moving core fragments and neutrons. The quasi-free knockout mechanism is identified through the polar angle correlation and checked by various kinematics conditions. The absolute differential cross sections for ^{6}He core cluster are obtained and compared with the simple Glauber model calculations. The extracted spectroscopic factor is close to unity and a shrinking of the cluster size is evidenced.

1. Introduction

Knockout reactions play an important role in studying 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 used intensively for spectroscopic investigation of the exotic properties of unstable nuclei [3]. As indicated in many occasions, applicability of reaction tools to extract nuclear structure information depends sensitively on the handling of the reaction mechanisms [4, 5, 6]. It was suggested to use "a clean structure-less probe" like proton target in order to avoid the possible complex reaction processes [7].

^{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 [8]. Based on the already established important properties ^{8}He provides an excellent test case to evaluate the reaction mechanisms. As demonstrated in a quasi-free scattering (QFS) experiment with ^{6,8}He beams impinging on a Hydrogen target [9], the core cluster knockout process can be isolated through the exclusive measurement of the recoil target protons in coincidence with the forward moving core fragments. 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 [10]. The reported experiment was carried out at very high energies and did not employ neutron detection [9]. It would be interesting to see if these

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reaction mechanisms could identified and applied at energies around 100 MeV/u where most knockout experiments for unstable nuclei have been performed.

2. The experiment

A detailed description of the experiment was given in Refs. [11, 12, 13]. The experiment was carried out at the RIKEN-RIPS beam line. In addition to the deflection magnet and neutron wall systems, 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. 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, 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

In Fig. 1 the polar angle correlation between the recoil protons and the forward moving ^{6}He fragments, for CH_2 target is plotted. At the upper right part of this figure, a component (in the frame F) appears clearly with relatively large proton and ^{6}He polar angles and follows very well the ^{6}He + p free scattering kinematics as described by the solid curve. It should be noted that this component does not exist for Carbon target [13]. According to earlier studies [9] this component arises from the core fragment knockout mechanism. For this component the upper limit of the proton angle is due to the angular coverage limit of the D2 telescope, whereas the lower limit at about 35° is due to the rapid decrease of the knockout cross section as demonstrated below.

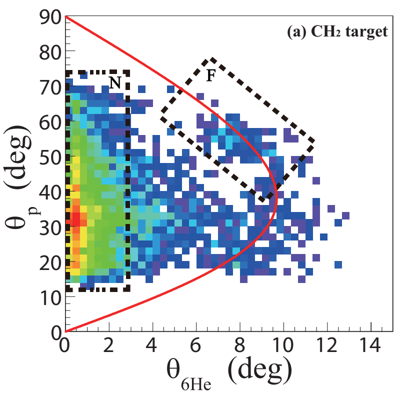

Figure 1. Polar angle correlations between the recoil protons and the forward moving ^{6}He fragments for CH_2 target. See the text for details.

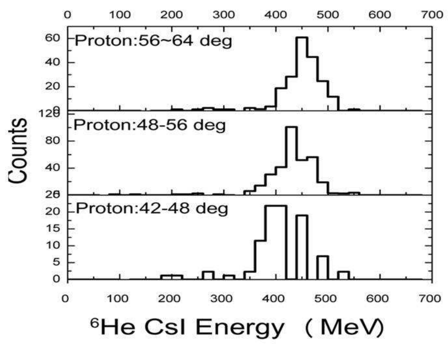

Figure 2. Energy distributions of the ^{6}He fragments in coincidence with the recoil protons in various angular bins.

The relation between the ^{6}He energy and its emission angle was further checked against the free scattering kinematics. It turns out that for each proton angular bin the energy distribution of the coincident ^{6}He fragments is well peaked and the peak moves as a function of the proton angle according to approximately the free scattering kinematics, as shown in Fig. 2. The azimuthal angle correlation between the core fragments and the recoil protons also satisfies well the free scattering condition. The quasi-free scattering mechanism between the ^{6}He core and the proton target is therefore well established for ^{8}He + p collision at about 80 MeV/u.

Based on the quasi-free scattering mechanism for ^{6}He core fragment, the absolute differential cross sections can be deduced accordingly. The solid angle for the coincident detection was determined by Monte Carlo simulation taking into account the two-body scattering kinematics, the realistic incident particle momentum distribution and the actual detector setup and efficiency. The results are shown in Fig. 3. Fig. 4 shows the differential cross sections for the knockout ^{6}He core fragments (filled diamonds) compared with the ^{6}He elastic scattering data (open circles) reported earlier [14]. A simple and approximate way to extract the SF for a cluster configuration is to compare the measured cluster knockout cross sections to the calculated elastic scattering ones [9]. As displayed in Fig. 4 by the dashed line, Glauber model calculations were performed for ^{6}He + p elastic scattering with the matter radii of ^{6}He to be 2.8 fm. A good description (solid curve) for the knockout data can also be obtained by just reducing the matter radii of ^{6}He to 2.2 fm. The shrinking of the the ^{6}He core cluster inside a ^{8}He nucleus was also find previously [9]. Since there is no need to substantially shift the absolute value of the calculated cross section to meet the experimental data, the SF of ^{6}He cluster configuration in ^{8}He should be close to 1.0. This is consist with previously reported result [9].

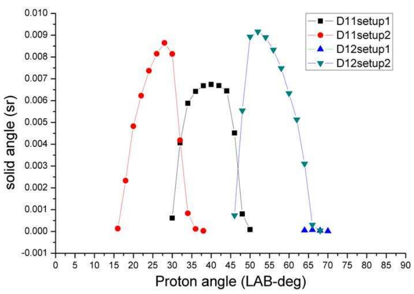

Figure 3. Absolute angular acceptance for ^{6}He + p free scattering, obtained from the simulation taken into account the real experimental setup.

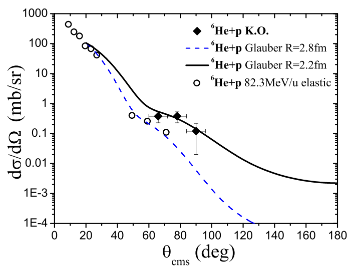

Figure 4. Differential cross sections of ^{6}He fragments from experiment at 82.3 MeV/u. See the text for details.

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