Structure and spectroscopy of the exotic nucleus ^{8}He via direct reactions

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Abstract

The structure of the light exotic nucleus ^{8}He was investigated using direct reactions of the ^{8}He SPIRAL beam on a proton-rich target. The (p,p') scattering to the 2_1^+ state, the (p,d)^{7}He and (p,t)^{6}He transfer reactions, were measured at the energy E_{lab} = 15.7 A.MeV. The excitation spectrum of ^{8}He was extracted. Above the known 2_1^+ excited state at 3.6 MeV, a second resonance was found around 5.4 MeV. The cross sections were analyzed within the coupled-reaction channels framework. It is inferred that the ^{8}He ground state has a different neutron-skin structure from the one suggested by previous $\alpha + 4n$ models assuming a pure $(1p_{3/2})^4$ configuration.

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1. Goals

In order to test the validity of the nuclear models and to improve their predictive power, the properties of the exotic nuclei are experimentally investigated using radioactive ion beams. In this scope we have studied the ^{8}He exotic nucleus, to clarify the correlations producing this weakly-bound structure at the drip line. This nucleus has the largest known N/Z ratio. It is expected to develop a 4-neutron skin structure [1]. Our goals were to explore the structure and to obtain the low-lying resonant states.

2. Experimental set-up

The direct reactions of ^{8}He on a proton-rich target of polypropylene foil were measured at GANIL using the SPIRAL ^{8}He beam accelerated at the incident energy of 15.7 A.MeV. We used the dedicated tools to study direct reactions induced by radioactive beams: the beam tracking detectors CATS [2], and the Si-strip position-sensitive particle detector MUST [3]. The emitted light charged particles, proton, deuteron or triton were detected by the wall of 8 MUST modules, in coincidence with the heavy ejectile detected at forward angles in a plastic scintillator. Mean intensity during the experiment was 5000/s (maximum was 10^4 /s). We obtained an angular resolution of 0.4° in the lab. frame. In the excitation spectrum measured from proton scattering, using the thin (1.48 mg/cm^2) target to measure the angles below $40^{\circ}_{c.m}$, and the thick one (8.25 mg/cm^2), the energy resolution is ranging from 600 keV to 1.2 MeV.

3. Results

Elastic, inelastic and transfer reaction cross-sections were extracted from the ^{8}He+p data and compared to theoretical calculations [4,5]. The ^{8}He(p,d) cross sections were found as large as the elastic ones in the angular range from 30 to $60^{\circ}_{c.m}$, showing strong coupled-channel (CC) effects [4]. Therefore, the data were analyzed using the coupled-reaction-channel (CRC) method. The entrance channel potential was calculated with the microscopic complex JLM [6] nucleon-nucleus potential, using the no-core shell model (NCSM) ^{8}He ground state (gs) densities [7]. With an explicit coupling to the (p,d) and (p,t) channels it was possible to reproduce both elastic and (p,d), (p,t) data (Fig. 1). Through the improved continuum discretized CC analysis, the best fit for the spectroscopic factor of the ^{8}He$_{gs}$ respected to ^{7}He$_{gs}$ was C^{2}S =3.3 [4]. To carry out a consistent analysis, not only of our complete data set but also of the previous measurements [8], we found that the ^{8}He gs was built on a mixing between the $(1p_{3/2})^4_\nu$ and the $(1p_{3/2})^2_\nu$ $(1p_{1/2})^2_\nu$ configurations [5]. We obtained a neutron-skin structure close to the one given by the NCSM model [9], but it differs from the COSMA model [1] which assumes a a pure $(1p_{3/2})^4_\nu$.

From the (p,p') reactions [10], the first 2 resonant excited states were extracted: the first 2^+ is obtained at 3.62±0.14MeV (width 0.3±0.2MeV), and a second state was found at 5.4 ±0.5MeV (width 0.3±0.5MeV) [10]. The values for the first 2^+ state are consistent with the previous data obtained by (p,p') [11], by multi-nucleon transfer [12,13] or break-up [14] reactions, and in contrast with the data in [15]. The resonances predicted by various theories, like the ab-initio calculations [16] or the ab-initio NCSM [9] overestimate

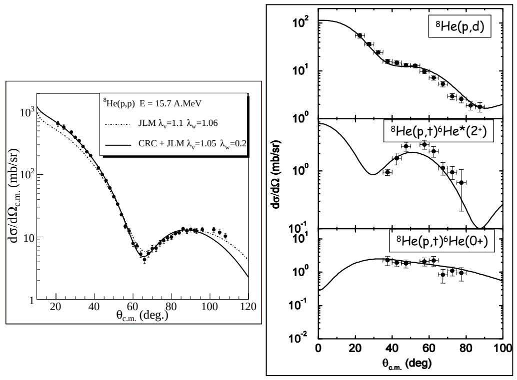

Fig. 1. *Experimental and calculated cross sections for ^{8}He(p,p) and ^{8}He(p,d) at 15.7 A.MeV [4,5]. See details in the text.*

our results. In models including the particle continuum effects, like the continuum shell model [17], the predictions for the 2 resonant states are consistent with our data.

4. Conclusions and prospective

The results obtained in the case of ^{8}He demonstrate the need for a complete data set of direct reactions in order to understand the CC effects between elastic, inelastic and transfer reactions. The same features can be expected throughout the nuclear chart, and particularly for neutron-rich nuclei with low particle threshold and continuum states close to the gs. The RIKEN/RIBF facility or the future SPIRAL2 or FAIR accelerators will offer the opportunity to extend the systematics of the low-lying resonances in the neutron-rich nuclei; the results will be used as new benchmarks for the theories including explicitly the continuum-coupling effects.

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