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LOW-ENERGY SPECTRA OF ^{8}He AND ^{10}He STUDIED IN (t,p) TYPE REACTIONS IN INVERSE KINEMATICS*

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Missing mass spectra for ^{8}He and ^{10}He obtained in the reactions ^{3}H(^{6}He$,p)^{8}$He and ^{3}H(^{8}He$,p)^{10}$He, respectively, are presented.

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1. Introduction

^{8}He is the heaviest of the known bound He isotopes. Its ground state properties are well known, but information related to its excited states has been rather inconsistent. The energy of its first excited state is still defined with a large uncertainty $E = 2.7$–3.6 MeV [1]. Such uncertainty imposes serious limitations on the precision of the related theoretical studies.

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^{10}He has been one of the key nuclei in the shell model studies due to its maximal neutron to proton ratio ($N/Z = 4$) among the known nuclei and because it should have a double closed shell structure. It has been observed only twice until these days. At RIKEN the reactions ^{11}Li(d,^{10}He)X and ^{11}Li(^{12}C,^{10}He)X were investigated [2]. A state at energy (1.2 ± 0.3) MeV above the ^{10}He decay threshold with the width $\Gamma < 1.2$ MeV was observed and such state was accepted as the ground state of ^{10}He. The reaction ^{14}C(^{10}Be,^{14}O)^{10}He was investigated at HMI [3]. The observed state with energy $E = (1.07 \pm 0.07)$ MeV was assumed as the ^{10}He ground state and two excited states were also achieved. On the basis of information about the ^{9}He virtual state [4] Aoyama predicted maximum energy of the ^{10}He ground state as 0.05 MeV [5].

To study dripline nuclei with large neutron excess one can choose between the neutron transfer, proton removal or nucleon exchange. We decided to use the two-neutron transfer reactions ^{3}H(^{6}He,p)^{8}He and ^{3}H(^{8}He,p)^{10}He, for which the main advantage is the simplicity of their mechanism.

Our experiments were carried out in FLNR JINR in Dubna on the fragment separator ACCULINNA. Secondary ^{6}He and ^{8}He radioactive beams with energy ≈ 25 MeV and intensity of $\approx 10^{-4}$ s^{-1} fell on a target cell filled with tritium gas and reaction products were measured using two position sensitive Si telescopes and a scintillator detection wall. The annular telescope placed in front of the tritium target was designated for the detection of protons. The zero angle square telescope situated behind the experimental target was assigned for the heavy charged particles detection. An array of scintillation units of the TOF neutron spectrometer DEMON was installed downstream out of the experimental vacuum chamber. The experimental setup is described in [6] or [7] and references therein.

2. Results and interpretation

Both reactions were investigated at small angles (4°–10°) in the center-of-mass system. The ^{8}He and ^{10}He spectra were studied by the missing mass method using the measured proton energy. The experimental resolution was determined as 450 keV.

^{8}He missing mass spectrum is presented in Fig. 1. We observed the ground state (0^+) with a population cross-section (c.s.) ≈ 200 μb/sr, the 2^+ excited state at energy $\approx$ 3.6–3.9 MeV with c.s. 100–250 μb/sr, 1^+ excited state at energy ≈ 5.4 MeV with c.s. ≈ 100 μb/sr and some indication for a state at energy ≈ 7.5 MeV. Such results are in agreement with other experimental data (*e.g.* [8, 9]), however we noticed a well distinguishable steep rise on the left side of the 2^+ resonance peak. Such steep rise cannot be explained by a pure 2^+ state and we suggest to explain the observed behavior of the excited continuum as a mixture of the 2^+ state and E1 (1^-) excitation (the soft dipole mode) [7].

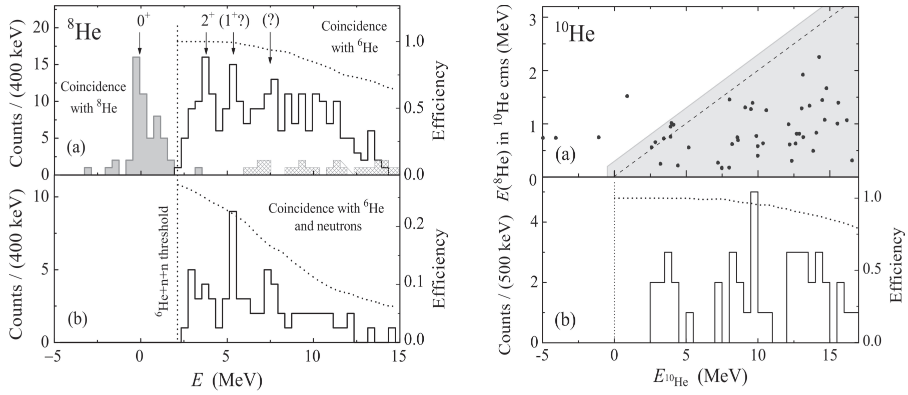

Fig. 1. Left: Missing mass spectrum of ^{8}He populated in the ^{3}H(^{6}He,p)^{8}He reaction. Right: Missing mass spectrum of ^{10}He populated in the ^{3}H(^{8}He, p)^{10}He reaction. The upper plot shows the kinetic energy of ^{8}He emitted at the decay of ^{10}He in center-of-mass system versus the energy of ^{10}He above the decay threshold. Dashed line depicts kinematical boundary line $E(^8\mathrm{He}) \leq (1/5)E(^{10}\mathrm{He})$, whereas the grey triangle represents the area with possible values of $E(^8\mathrm{He})$ taking into account the experimental resolution.

Energy spectrum of ^{10}He is presented in Fig. 1. There is a well recognizable group of ten events lying between 2.5 and 5.5 MeV in the spectrum. This group has a resonant c.s. ≈ 140 μb/sr and is well isolated from the rest of events.

The ratio of the expected cross-sections σ_{10}/σ_8 is estimated to be between 0.6 and 4.0 [6]. Here σ_{10} and σ_8 denote the c.s. values for the reactions ^{3}H(^{8}He, p)^{10}He and ^{3}H(^{6}He, p)^{8}He populating the ground states in ^{10}He and ^{8}He, respectively. At that, we assume that the ^{10}He ground state is either a pure $p_{1/2}$ or $s_{1/2}$. All together, this implies that as a minimum 8 events had to be observed in the ^{10}He missing mass spectrum at energy < 2.5 MeV if the ground state of this nucleus is at 1.0–1.2 MeV. We observed zero events in this energy region. Accidental probability for such result is $\approx 3 \times 10^{-4}$. This result implies a scattering length $a > 5$ fm for the ^{9}He virtual state.

3. Conclusion

We have to reassess the c.s. estimates for the 2^+ state in ^{8}He. In the case of a pure 2^+ state, its energy would be in agreement with the usually accepted position, *i.e.* ≈ 3.6 MeV and it would be populated with the c.s. ≈ 250 μb/sr. However, we suppose the presence of a soft dipole mode with low energy ≈ 3.0 MeV as an explanation of the peculiar form of the first excited state resonance. In this case, the population c.s. of the 2^+ state is ≈ 100 μb/sr and its resonance energy has to be shifted to ≈ 3.9 MeV. We assume 60% feeding to the 1^- continuum [7].

The group of ten events observed in energy region 2.5–5.5 MeV represents a resonance state at energy ≈ 3 MeV with population c.s. ≈ 140 μb/sr. This corresponds to the population of the $p_{1/2}$ structure in ^{10}He [6]. We suggest that this 3 MeV resonance and the peak observed at energy 1.2 MeV in Ref. [2] show the same ^{10}He 0^+ state. Due to the specific structure of ^{11}Li, the knock-out reaction ^{12}C(^{11}Li,^{10}He)X used in Ref. [2], would result in a shift to lower energy for the observed ground state resonance of ^{10}He. The theory of Ref. [10] is able to consistently explain the data of Ref. [2] and the 3 MeV peak of ^{10}He obtained in the present work and it cannot reconcile the result of [4]. The 3 MeV peak energy is consistent with the resonance properties inferred from the S-matrix in Ref. [10] and therefore the one-step two neutron transfer reaction gives better information about the resonance properties [6]. Further measurements with higher statistics would allow to finally resolve the intriguing issues outlined above.

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