1. INTRODUCTION

The $^7$He nucleus has been repeatedly studied for 30 years, and its well-known ground-state resonance decaying into $n + ^6$He has been obtained in many reactions (see [1]). However, excited states ($E^* < 10$ MeV, $\Gamma < 2$ MeV) were not found in this nucleus until very recent time. Particularly, a negative conclusion has been drawn from the energy spectra of $^6$He and $^8$Be obtained, respectively, in the reactions $^7$Li($^7$Li, $^7$Be)$^7$He and $^9$Be($^6$Li, $^8$B)$^7$He [2]. More recent experiments that employed transfer reactions with stable heavy-ion beams also yielded negative results in what is concerned with excited states in $^7$He [3–5].

It is evident that radioactive nuclear beams provide the best conditions for studying nuclei with a high neutron excess, such as $^7$He. As reactions that are induced by neutron-rich projectiles and which lead to $^7$He become simpler, their cross sections grow, while physical backgrounds decrease. These observations were justified in [6], where a $^7$He nucleus was obtained in the reaction $p(^8$He, $d)^7$He at a $^8$He beam energy of 50 MeV per projectile nucleon. The detection of deuterons in correlation with other particles emitted in the decay of $^7$He allowed the authors to obtain, for the first time, an excited state of $^7$He at $3.3 \pm 0.3$ MeV above the $n + ^6$He threshold. The width of this resonance state is $\Gamma = 2.2 \pm 0.3$ MeV. It decays predominantly into $3n + ^4$He, though the energy of its $n + ^6$He decay is higher. One can put forth arguments in favor of the assumption [6] that, most likely, this state has a structure with a neutron in the $p_{1/2}$ state coupled to the $^6$He core, which itself is in the excited $2^+$ state. A tentative spin–parity assignment for this state is $J^p = 5/2^-$. To all appearance, $^8$He is a “suitable” projectile for populating this excited state in $^7$He after one-neutron stripping because, as is expected (see [6, 7]), the ground state of $^8$He contains mainly a $^6$He subsystem in the excited $2^+$ state.

In this connection, the question of whether there are excited states in $^7$He with a single–particle structure is still open, despite the fact that this problem remains persistently interesting. It was expected that $^7$He could have an excited $1/2^-$ state of this nature. The observation of such a state in $^7$He could shed light upon spin–orbit interaction in neutron–halo nuclei. Theoretical predictions (see [8] and references
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The reaction \(p(6\text{He}, 7\text{He})d\) was employed in experiments devoted to the superheavy hydrogen isotope \(5\text{H}\). The presented notation underlines that an analog of the missing-mass method where a recoil particle \(d\) from a reaction \(a(b, c)d\) is unstable (the virtual state of \(2\text{He}\)), and this particle is detected by measuring the characteristics of its decay products.

The experiments were carried out at the U-400M cyclotron of the Flerov Laboratory of Nuclear Reactions (JINR, Dubna). The experimental setup is shown schematically in Fig. 1. A primary beam of \(11\text{B}\) ions with an energy of 42 MeV per projectile nucleon was used to obtain a secondary \(6\text{He}\) beam of energy 37 MeV per nucleon in the focal plane of the ACCULINNA separator [17]. In long-term experimental runs, the average intensity of the \(6\text{He}\) beam on the target was \(5 \times 10^4\) s\(^{-1}\). Of the total beam flux hitting the target, tritons and \(8\text{Li}\) ions comprised, respectively, \(\sim 55\%\) and < 1\%. While the energy spread of the beam ions amounted to 5\% (FWHM), the energy of individual \(6\text{He}\) ions was defined with an accuracy of \(\Delta E/E \leq 2\%\) by means of time-of-flight (TOF) measurements. For each event associated with the detection of reaction products, the measured time of flight and the energy loss in the second TOF plastic (plastic 3 in Fig. 1) allowed us to identify unambiguously the incoming ion that had generated the reaction products. Two multiwire proportional chambers (positions 4 and 5 in Fig. 1) were used for tracking individual beam ions.

The GANIL gas target filled with pure hydrogen isotopes was employed in these experiments. The length of the target cell along the beam axis was 10 mm, its entrance and exit window diameters being 15 mm. In the case where the reaction \(d(6\text{He}, 7\text{He})p\) was studied, the target filling was 3 atm of pure deuterium gas cooled down to 40 K. The target windows were 10-\(\mu\)m stainless steel foils. In the case of the reaction \(p(6\text{He}, 5\text{H})\)\(\cdot\)\(\text{He}\), the target cell having 20-\(\mu\)m stainless-steel windows was filled with a pure hydrogen gas at a pressure of 11 atm. The gas was cooled down to 35 K.

An array of three annular Si-strip detectors from the RIKEN telescope [6] was employed to observe protons originating from the reaction \(d(6\text{He}, 7\text{He})p\). Covering an angular range between 170.8\(^\circ\) and 154.3\(^\circ\) in the laboratory frame (see Fig. 1, position 7), this array was intended for detecting low-energy \((E = 2.5–6.0\) MeV\)) protons emitted at small c.m.

2. EXPERIMENTAL LAYOUT

We used the pickup reaction \(d(6\text{He}, 7\text{He})p\) to carry out searches for new excited states in the \(7\text{He}\) nucleus. One could anticipate a relatively high population probability for a single-particle 1/2\(^+\) state in this reaction, which would be a single-step transfer in contrast to the stripping reaction \(p(8\text{He}, 7\text{He})d\), where a two-step process is required, if one assumes, for \(8\text{He}\), the structure [6, 7] mentioned above.

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