Conference Paper

Spectroscopy of helium isotope ^{6}He

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Abstract

The excited states of heavy helium isotope ^{6}He were studied in stopped pion absorption in the reactions ^{9}Be(π^-,t)X, ^{12}C(π^-,d^4He)X and ^{12}C(π^-,t^3He)X. The experiment was carried out on LANL accelerator using two-arm multilayer semiconductor spectrometer of charged particles. Search for states of the ^{6}He was performed in missing mass spectra in inclusive and correlation measurements. New state of ^{6}He with E = 4.8(2) MeV and Γ = 2.9(2) MeV has been observed in the ^{9}Be(π^-,t)X reaction. Excitation energies and widths observed states are compared with results obtained in stopped pion absorption by boron isotopes ^{10,11}B.

Keywords: Heavy Helium Isotopes, Pion Absorption, Energy Level, Semiconductor Spectrometer.

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Received: 25 December 2017
Accepted: 2 February 2018
Published: 9 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICPPA Conference Committee.

1. Introduction

Studies of heavy helium isotopes are currently in the center of experimental activity [1]. The characteristics of these exotic nuclei allow us to extend our understanding of the properties of nuclear matter under conditions of anomalously high N/Z ratios. A relatively small number of nucleons in heavy helium isotopes makes it possible to describe microscopically their properties and, as consequence, to test nuclear models and nucleon–nucleon potentials.

The ground state of ^{6}He (J^π = 0$^+$) is the nucleon-stable and is bound to decay into an α-particle and two neutrons at 0.973 MeV [2]. ^{6}He is the lightest nucleus that possesses a neutron halo. Also reliable established the existence of narrow first excited state with E_x = 1.797 (25) MeV, Γ = 113 (20) keV (J^π = 2$^+$), which decays into α + 2n [2]. Experimental information on higher excitation states is less certain. In the region of excitation energies E_x = 2 ÷ 10 MeV levels were found in the several works ([3, 4], the results of earlier works were presented in the compilation [2]). However, the results of various works poorly agree with each other.

In high-energy excitations it is possible to allocate three regions. Near the threshold of the decay of ^{6}He* → t + t (12.3 MeV) several states have been observed in the works [2, 3, 5, 6].

The second group of wide states (Γ≥ 4 MeV) was found at E_x ≈ 24 MeV [2, 3]. The third region is above the threshold of decay ^{6}He on free nucleons. The indication on two relatively narrow (Γ≤ 2 MeV) resonances at E_x = 32 and 36 MeV were obtained in the reaction ^{7}Li(^{3}He, p^{3}He)^{6}He [7].

This paper presents an overview of the results on the level structure of ^{6}He obtained in our studies of the stopped pion absorption by light nuclei. Part of this information obtained in the reactions ^{9}Be(π^-, *tt*)*t*, ^{10}B(π^-, *dd*)X, ^{10}B(π^-, *pt*)X and ^{11}B(π^-, *dt*)X was presented in the works [8, 9]. Results of the measurements of the reactions ^{9}Be(π$^-$, *t*)X, ^{12}C(π$^-$, d^{4}He)X and ^{12}C(π$^-$, d^{4}He)X are presented in the first time.

2. Experiment

The experiment was performed in the low energy pion beam of meson factory LANL using the two arm semiconductor spectrometer [10].

A beam of 30 MeV negatively charged pions traversed a beryllium moderator and stopped in the thin target (≈ 24 mg.cm^{-2}). The rate of pion stopping in targets was about 6 × 10^{4} s^{-1}. In one experimental run the measurements were carried out on the isotope-pure targets ^{9}Be and ^{12}C, targets ^{10}B (contribution of the ^{11}B impurity was 15%), ^{11}B (contribution of the ^{12}C impurity was 8%) and ^{14}C "radioactive" target (76% is ^{14}C, 23% is ^{12}C). The contribution of uncontrolled impurities in all targets was ≤ 1%. This set of targets enables the correct estimation of the contribution of the impurities in the measured spectra.

Charged particles, including the hydrogen isotopes *p*, *d*, and *t* and the helium isotopes ^{3,4}He, emitted after pion absorption in the targets were detected by two semiconductor telescopes arranged at an angle of 180∘ with respect to each other. The energy resolution (*FWHM*) for single-charged particles (*p, d, t*) was better than 0.5 MeV and 2 MeV for doubly charged particles (^{3,4}He) [10]. The error of absolute energy calibration did not exceed 100 keV [11].

A search for the ^{6}He excited states was carried out on the peaks in the missing mass spectrum (*MM*). In the measurements of any pairs of singly charged particles the *MM* resolution was ≈ 1 MeV [11]. In the measurements of pairs of single and double charged particles the *MM* resolution was ≈ 3 MeV The error of the *MM* absolute calibration

(δMM) did not exceed 100 keV for pairs of singly charged particles and 200 keV for other pairs [11].

The spectrometer and experimental technique are described in more detail in [10, 11].

3. Results and Discussion

In inclusive measurements search for excited states of ^{6}He was carried out in the reaction ^{9}Be(π^-,t)X. The MM spectrum obtained in this reaction is shown in fig. 1.

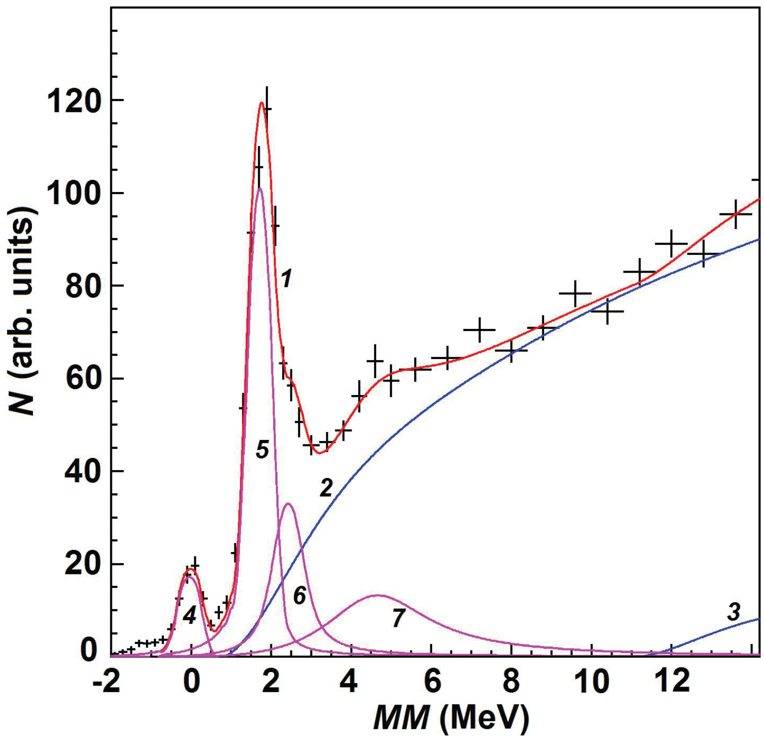

Figure 1: MM spectrum in the reaction ^{9}Be(π^-,t)X. Dots with error bars are the experimental data. 1 – full description; phase space distributions: 2 – π^- + ^{9}Be → t+^{5}He+n, 3 – π^- + ^{9}Be → t+t+t; 4 – ^{6}He ground state; the Breit–Wigner distributions for excited states 5 – 7.

Peaks formed due to the appearance of the ground state and the excited states of ^{6}He in the two-body reaction channels are well seen. To resolve these states we used the method of least squares in describing the experimental spectra by the sum of n–particle distributions over phase space ($n \geq 3$) and Breit–Wigner distributions for excited states. A statistically satisfactory description of the experimental spectrum can be obtained by introducing the ground state and three excited states of ^{6}He with following parameters (E_x, Γ): (1.80(3) MeV, 0.11(2) MeV), (2.5(2) MeV, 0.5(2) MeV) and (4.8(2) MeV, 2.9(2) MeV). Note that the contribution to the measured spectrum the reaction channel π^- + ^{9}Be → t+^{4}He+n+n is negligible.

The energy of the second excited state coincides with the data obtained in [4], but the width in our measurements is considerably less. The level with E_x = 4.8(2) MeV is observed for the first time and lies below the level with E_x = 5.5(3) MeV, which was observed in this region of excitations previously [3, 4]. We have not received indications on the existence of the level with E_x =3.5(2) MeV, which was observed in reactions of stopped pion absorption by boron isotopes [9]. Perhaps this is due to the difference in the structures of the absorbing nuclei.

We do not observed high excitation states in the measurements of ^{9}Be(π^-,t)X reaction. This is caused to the rapid increase of the physical background in inclusive measurements, due to many-particle channels of reaction.

The results obtained in measurements on carbon target are presented in fig. 2. In these measurements *MM* resolution becomes worse (FWHM ≈ 3 MeV). Also in these channels the statistics is not high enough. Therefore in these measurements we observed only the ground state of ^{6}He and possibly the first excited state in the reaction ^{12}C(π^-,t^3He)X. The inset in the fig. 2 shows the spectrum obtained after subtraction of the sum of the phase-space distributions. It is seen that first excited state allows us to describe the shoulder observed in the peak.

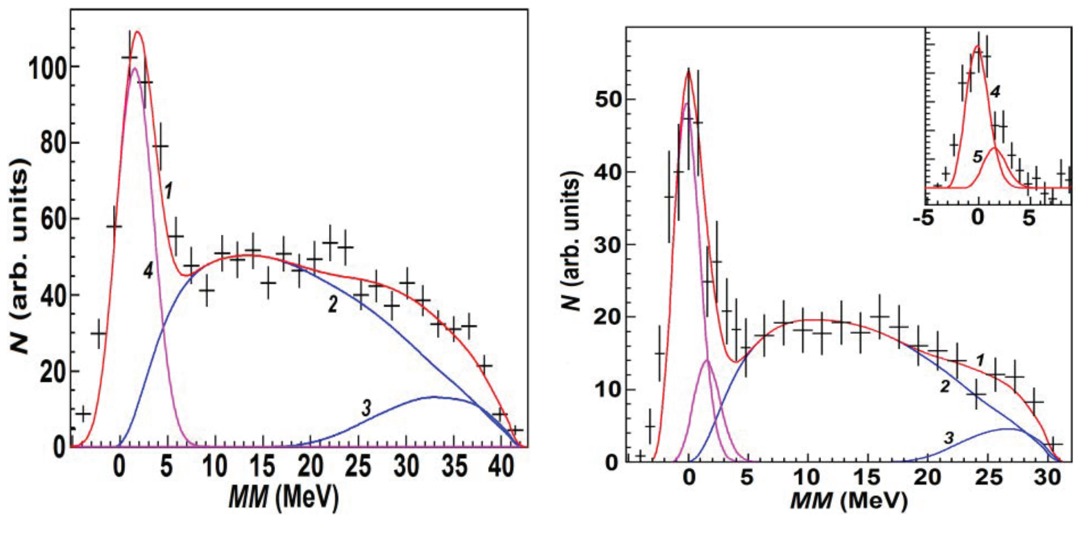

Figure 2: Missing mass spectrum for the reactions ^{12}C(π^-,d^4He)X (left) and ^{12}C(π^-,t^3He)X (right). Dots with error bars are the experimental data. 1 – full description; phase space distributions: 2 –π^- + ^{12}C → d+^{5}He+^{4}He+n, 3 –π^- + ^{12}C → d+^{4}He+d+t+n (left); 2 –π^- + ^{12}C → t+^{5}He+^{3}He+n, 3 –π^- + ^{12}C → t+^{3}He+d+t+n (right); 4 –^{6}He ground state; 5 – the Breit-Wigner distributions for first excited states.

The data obtained in the reactions ^{9}Be(π^-,t)X, ^{12}C(π^-,d^4He)X and ^{12}C(π^-,t^3He)X complement information on the region of low excitation energies, which were obtained us in the reaction on boron isotopes: ^{10}B(π^-, dd)X, ^{10}B(π^-, pt)X and ^{11}B(π^-, dt)X [9]. However, due to reasons mainly related to reaction mechanisms, we have not obtained new results on the high-energy excitations.

Summarize the main results for high excitations of ^{6}He, which were obtained in the reaction ^{9}Be(π^-, tt)t [8], and reactions on boron isotopes [9]. High excited states ($E >$ 12.3 MeV) were observed in several reaction channels. Some of them were identified as cluster resonances in a system of two tritons. In the reactions ^{10}B(π^-, pt)^{6}He and ^{9}B(π^-, tt)t there were observed two states with excitation energy lying above the threshold of decay into free nucleons.

4. Conclusion

The excited states of heavy helium isotopes ^{6}He were studied in stopped pion absorption by nuclei. Three reactions ^{9}Be(π^-,t)X, ^{12}C(π^-,d^4He)X and ^{12}C(π^-,t^3He)Xwere studied for the first time. New state of ^{6}He with E = 4.8(2) MeV and Γ = 2.9(2) MeV has been observed in the ^{9}Be(π^-,t)X reaction. At high excitations levels of ^{6}He have been found in the reactions ^{9}Be(π^-, tt)t, ^{10}B(π^-, dd)X, ^{10}B(π^-, pt)X and ^{11}B(π^-, dt)X.

Acknowledgments

This work was supported by the Russian Ministry of Education and Science grant N3.4911.2017/6.7 and by program of increasing the competitive ability of National Research Nuclear University MEPhI (agreement with the Ministry of Education and Science of the Russian Federation of August 27, 2013, project no. 02.a03.21.0005).

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