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^{8}He spectroscopy in stopped pion absorption by ^{9}Be

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Abstract

Level structure of ^{8}He has been studied in the reaction of stopped pion absorption by ^{9}Be nuclei. The missing mass spectrum in the range 0 MeV $\leq MM \leq$ 10 MeV has been described by the superposition of phase-space distributions and the three states of ^{8}He. Parameters of these states have been compared with data of other experimental and theoretical works.

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

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1. Introduction

The light neutron-rich nuclei lying in the vicinity of the drip line are interesting for the study of structure and properties of exotic nuclear states. The properties of these states are important for the development of nuclear models and refinement of the nucleon-nucleon potentials.

Among nucleon-stable isotopes the ^{8}He has a record ratio of the neutron number to proton number: N/Z = 3. Valence nucleons in ^{8}He are bound stronger than in ^{6}He ($S_{2n}(^{8}$He) = 2.14 MeV, $S_{2n}(^{6}$He) = 0.973 MeV [1]), therefore cluster structure of ^{8}He is a ^{4}He+n+n+n+n system and ^{8}He rms radius is smaller than ^{6}He one. The ground state of ^{8}He was previously considered as a system consisting of an inert α-particle core, surrounded by four valence neutrons, occupying the $p_{3/2}$ shell [2]. However, it was shown experimentally [3, 4] and theoretically [5, 6], that along with the $(p_{3/2})^4$ component the wave function of the ground state, can contain a noticeable admixture of other components – $(p_{3/2})^2(s_{1/2})^2$, $(p_{3/2})^2(d_{3/2})^2$ and $(p_{3/2})^2(p_{1/2})^2$.

Excitation levels ^{8}He were observed in several experiments (see compilation of world data [1] and review [7]), however, the statistical reliability of the data is low.

Probably this is the main reason of considerable uncertainty in the energy of the first excited state: E_x = 2.7 ÷ 3.6 MeV. Another reason may be due to the fact that the peak observed in the experiments is a superposition of two states – 2^+ resonance and a soft dipole resonance with $J^P = 1^-$ [8]. Therefore, the difference in the results may be due to the different population of these channels. However, evidence of this assumption requires better statistics of measurements. In several works [1, 4, 8, 9] higher excitations were observed. The observed spectrum is limited to the E_x = 7.5 MeV [8]. But these results can be considered only as indications on the existence of ^{8}He states due to low statistics.

Use of the reaction of stopped pion absorption by light nuclei was successful in the study of the level structures of heavy helium isotopes ^{6,7}He [10–12]. In present work this method has been used for ^{8}He in the measurement of the reaction ^{9}Be(π^-, p)X.

2. Experiment

The experiment was performed in the low energy pion beam of meson factory LANL using the two arm semiconductor spectrometer [13].

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}. The measurements were carried out on the isotope-pure target ^{9}Be. The contribution of uncontrolled impurities was ≤ 1%. Charged particles, emitted after pion absorption in the target 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 in the whole energy range up to the kinematic limits of the reaction [14]. The error of absolute energy calibration did not exceed 100 keV [14].

The spectrometer and experimental technique are described in more detail in [13, 14].

3. Results and Discussion

A search for the ^{8}He excited states was performed on the peaks in the missing mass spectrum (*MM*) obtained in inclusive measurements of the reaction ^{9}Be(π^-,p)X. The measured spectrum is shown in fig. The mass of ^{8}He is taken as a reference point.

Peaks formed due to the appearance of the ground state and the excited states of ^{8}He in the two-body reaction channels are well seen. To determined these states

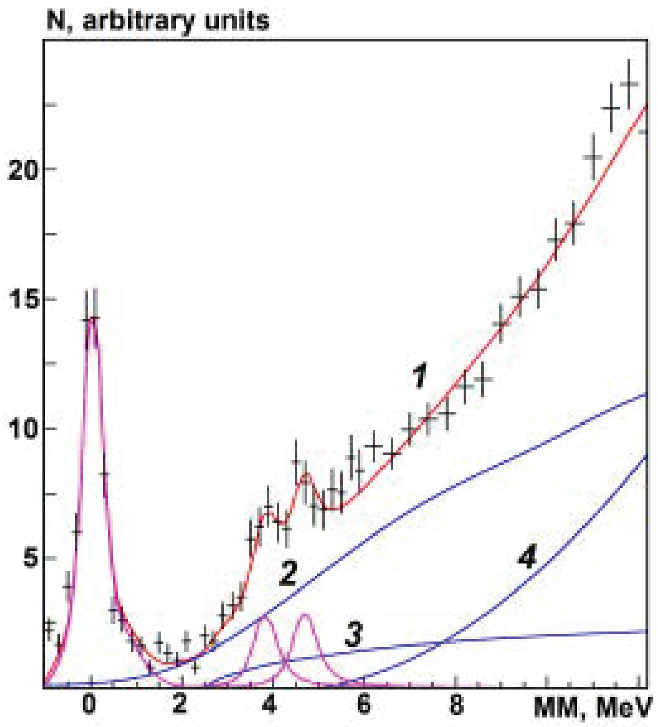

Figure 1: *MM* spectrum in the reaction ^{9}Be(π^{-},p)X. Dots with error bars are the experimental data. 1 is full description; pink lines are ground and excited states of ^{8}He; phase space distributions: 2 $-\pi^{-}$ + ^{9}Be → p+^{6}He+n^{2}, 3 $-\pi^{-}$ + ^{9}Be → p+^{7}He+n, 4 $-\pi^{-}$ + ^{9}Be → p+^{6}He*(1.797)+2n.

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 two excited states of ^{8}He with parameters (E_x, Γ) presented in the Table. Also table includes data of the compilation [1] and results of the later works.

It is seen that parameters of the first excited state obtained in the present work coincide with the last data in the limits of errors of the measurements. The small width level is hardly compatible with the assumption that the observed peak is a superposition of two states. At the same time, the position of the second excited level coincides with the results of earlier works [1]. However, the level observed us is significantly narrow in comparison with data from [1].

The position of the first excited level is consistent with the predictions of theoretical works [17–19]. At the same time, we found no theoretical predictions the second level, which coincides with our result.

Table 1: Excited states of ^{8}He (E_x < 6 MeV).

	E_{x1}, MeV	Γ_1, MeV	E_{x1}, MeV	Γ_2,MeV
[1], compilation	2.7÷3.6	0.6±0.2	4.36±0.20	1.3±0.5
[15] ^{8}He(p, p′)X	3.62 ± 0.14	0.3 ± 0.2	5.4 ± 0.5	0.3±0.5
[16], ^{3}H(^{6}He, p)^{8}He	3.6 ÷ 3.9	~0.5	5.3 ÷ 5.5	
this work, π^-(^{9}Be, p) X	3.8 ± 0.2	0.3±0.1	4.6 ± 0.3	0.3±0.1

4. Conclusion

The excited states of heavy helium isotopes ^{8}He were studied in reaction ^{9}Be(π^-,p)X. The state of ^{8}He with E = 4.6(3) MeV and Γ = 0.3(1) MeV has been observed in the first time.

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