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^8He spectroscopy in stopped pion absorption by ^{11}B nuclei

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Abstract. Level structure of ^8He has been studied in the reaction of stopped pion absorption by ^{11}B nuclei $^{11}\text{B}(\pi^-, \text{pd})\text{X}$. The experiment was carried out at the LANL with a two-arm semiconductor spectrometer. The missing mass spectrum in the range $0 \text{ MeV} < \text{MM} < 50 \text{ MeV}$ has been described by the superposition of phase-space distributions and the six states of ^8He . Parameters of these states have been compared with data of other experimental and theoretical works.

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 ^8He has a record ratio of the neutron number to proton number: $N/Z = 3$. Valence nucleons in ^8He are bound stronger than in ^6He ($S_{2n}(^8\text{He}) = 2.14 \text{ MeV}$, $S_{2n}(^6\text{He}) = 0.973 \text{ MeV}$ [1]), therefore cluster structure of ^8He is a $^4\text{He}+n+n+n+n$ system and ^8He rms radius is smaller than ^6He one. The ground state of ^8He 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 ^8He 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: $E_x = 2.7 \div 3.6 \text{ MeV}$. 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 $E_x = 7.5 \text{ MeV}$ [8]. But these results can be considered only as indications on the existence of ^8He 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 $^{6,7}\text{He}$ [10-12]. In present work this method has been used for ^8He in the measurement of the reaction $^{11}\text{B}(\pi^-, \text{pd})\text{X}$.

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 ($\approx 24 \text{ mg}\cdot\text{cm}^{-2}$). The rate of pion stopping in targets was about $6 \times 10^4 \text{ s}^{-1}$. 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 resolution of missing mass (MM) during the registration of a pair of a singly charged was 1 MeV.

The spectrometer and experimental technique are described in more detail in [13–15].

3. Results and Discussion

A search for the ^8He excited states was performed on the peaks in the missing mass spectrum (MM) obtained in measurements of the reaction $^{11}\text{B}(\pi^-, \text{pd})\text{X}$. The measured spectrum is shown in figure 1. The mass of ^8He is taken as a reference point.

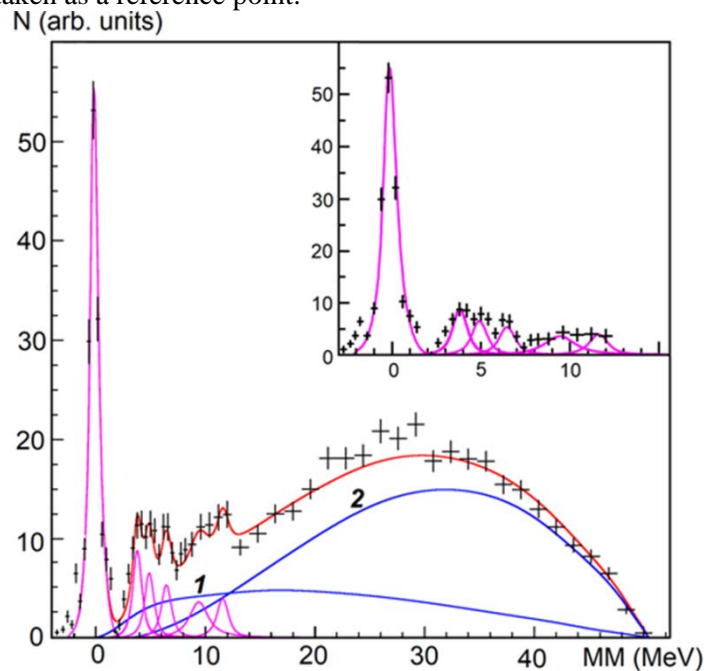


Figure 1. MM spectrum in the reaction $^{11}\text{B}(\pi^-, \text{pd})\text{X}$. Dots with error bars are the experimental data. Red line is full description; pink lines are ground and excited states of ^8He ; phase space distributions: $1 \pi^- + ^{11}\text{B} \rightarrow \text{p} + \text{d} + ^6\text{He} + \text{n}^2$, $2 \pi^- + ^{11}\text{B} \rightarrow \text{p} + \text{d} + ^6\text{He} + 2\text{n}$.

Peaks formed due to the appearance of the ground state and the excited states of ^8He are well seen. To determine 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 five excited states with parameters (E_x , Γ) presented in the Table 1. Also table 1 includes data of the compilation [1] and results of the later works.

It is seen that parameters of the first and second excited states obtained in the present work coincide with the last data in the limits of errors of the measurements. The states $E_x = 9.3$ and 11.5 have been observed in the first time.

Table 1. Excited states of ^8He

E_x , MeV	Γ , MeV	work
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$2.7 \div 3.6$	0.6 ± 0.2	[1]
3.62 ± 0.14	0.3 ± 0.2	[16]
$3.6 \div 3.9$	~ 0.5	[17]
3.9 ± 0.2	0.3 ± 0.1	[18], this work
4.36 ± 0.2	1.3 ± 0.5	[1]
4.6 ± 0.3	0.3 ± 0.1	[18], this work
5.4 ± 0.5	0.3 ± 0.5	[16]
$5.3 \div 5.5$		[17]
6.03 ± 0.10	0.15 ± 0.15	[1]
6.4 ± 0.2	0.6 ± 0.3	this work
7.16 ± 0.04	0.1 ± 0.1	[1]
9.3 ± 0.4	1.7 ± 0.3	this work
11.5 ± 0.3	0.8 ± 0.3	this work

4. Conclusion

Excited states of ^8He have been observed in the stopped pion absorption reaction by ^{11}B . The first two excited states agree with previous results. The states $E_x = 9.3$ and 11.5 have been observed in the first time.

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