FIZIKA 10 (1978) 273—278 YU ISSN 0015 - 3206

EVIDENCE FOR A LEVEL IN ^{9}B AT 17.11 MeV MEMBER OF THE SECOND T = 3/2 QUADRUPLET

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Received 21 July 1978

Abstract: The reactions $^{6}Li\,(^{3}He, \gamma)\,^{9}B$ and $^{6}Li\,(^{3}He, p)\,^{8}Be_{16.6}\,(2\alpha)$ have been investigated searching for the existence of a second T = 3/2 level in ^{9}B. Both experiments resulted in the evidence on the existence of a level of ^{9}B. at 17.11 MeV. To this level T = 3/2 value is assigned, because it appears only in two reactions which are isospin allowed and does not appear in any of those reactions which are isospin forbidden if it is a T = 3/2 state. This state in ^{9}B and the states in ^{9}Be and ^{9}Li with excitation energies of 16.97 and 2.69 MeV, respectively, as well as a nonidentified state in ^{9}C, form the second isospin quadruplet of nuclei with A = 9.

1. Introduction

It is well-known[1] that the ground state of ^{9}Li, 14.39 MeV state of ^{9}B, 14.67 MeV state of ^{9}B and the ground state of ^{9}C do constitute the first T = 3/2 quadruplet in the family of A = 9 nuclei. However, only 2.69 MeV state of ^{9}Li and 16.97 MeV state of ^{9}Be were experimentally identified[2,3] as the members of a possible second T = 3/2 quadruplet, while any identification of the corresponding states in ^{9}B or ^{9}C was missing.

We have been interested earlier[4,5] in the reactions initiated by the collission of lithium isotopes with ^{3}He, so we have investigated also the reactions $^{6}Li\,(^{3}He,d)\,^{7}Be$ and $^{6}Li\,(^{3}He, p)^{8}Be$. In the ^{3}He energy region from 0.5 to 1.3 MeV, which coresponds to ^{9}B excitation from 16.93 to 17.46 MeV, the level of ^{9}B at 17.20 MeV with the width $\Gamma = 110 \pm 30$ keV was the only one which we identified

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and we thought, similarily as others[6], that the second T = 3/2 state of ^{9}B is probably admixed to the known broad T = 1/2 state at 17.20 MeV. However, a careful search for gamma-rays resulting from $^{6}Li\,(^{3}He, \gamma)^{9}B$ reaction led us to the identification of a narrow (less than 5 keV wide) resonance at 765 keV ^{3}He beam energy, which coresponds to 17.111 Me V excitation of ^{9}B. In Section 2 the description and results of experiment 1 are given, and also we describe experiment 2, i. e. $^{6}Li\,(^{3}He.\ p)^{8}Be_{16.6}$ (2α) in which alpha particles were detected and which, independently, has shown the same resonance. In Section 3 the discussion of results leads to T = 3/2 ascription for 17.111 Me V state of ^{9}B, establishing so the parameters of the second T = 3/2 quadruplet in A = 9 nuclei, which offers the possibility for the further discussion on Coulomb energy in these nuclei.

2. *Experimental methods and results*

Two reaction were studied: $^{6}Li\,(^{3}He, \gamma)^{9}B$ and $^{6}Li\,(^{3}He, p)^{8}Be_{16.6}$ (2α). In both cases the Cockcroft-Walton 1.5 Me V accelerator of the »Boris Kidrič« Institute was used to accelerate ^{3}He ions. The ^{3}He beam was deflected and analyzed first by a magnetic deflector and then by a electrostatic deflector. Before and after the experiments, the energy calibration was done by using well-known[7] procedure with (p, γ) resonances in ^{7}Li and ^{27}Al.

$^{6}Li\,(^{3}He, \gamma)^{9}B$ reaction (experiment 1). This reaction was investigated in the energy range of ^{3}He from 0.6 to 1.2 MeV. The ^{3}He beam energy spread was less than ± 3 keV. The target of 90% enriched ^{6}Li as well as the »background targets« of natural Li were prepared by evaporation on Al foils; both of these targets were made in series with thicknesses: 20 keV, 10keV, 5 keV and 2 keV approximately. As the control for selection of targets, apart from classical weighting, the measurement of the yield of 431 keV gamma-ray following $^{6}Li\,(^{3}He, d_{1})\,^{7}Be_{431}$ keV reaction were made also, at a standard ^{3}He energy with standard ^{3}He current. The thickness of »natural Li targets« was measured also using (p, γ) reaction on ^{7}Li around known[7] resonance at 440 keV, determining its experimental width. In a target chamber four targets (two of ^{6}Li with different thicknesses, one natural Li, one blank Al foil) were placed during one experimental series and they were interchangable at the beam position.

The gamma-rays were detected by a 5 in × 6 in NaJ(Tl) detector, followed by a TMC 256- channel analyser. The energy calibration was done using the position of well-known[8] peaks from $^{7}Li\,(^{3}He, \gamma)^{10}B$ reaction. Only the energy region from 10 to 20 MeV was analyzed.

The standard measuring procedure consisted of the first measurement with ^{6}Li target and the second measurement with natural Li target, since the reaction of ^{3}He with ^{7}Li is, by far, the largets source of background while bombarding a ^{6}Li target. Before these experiments the ratio of ^{6}Li to ^{7}Li on both »^{6}Li target« and »natural Li target« was determined by analyzing the yield of the most prominent proton peaks from well-known[4,5] reactions $^{6}Li\,(^{3}He, p)^{8}Be$ and $^{7}Li\,(^{3}He, p)$ ^{9}Be. These ratios of ^{6}Li to ^{7}Li in both targets were used in the normalization of »background« determined from »natural Li target« runs, which was always subtracted from »^{6}Li target« measurements.

In Fig. 1 the normalized spectra of gamma-rays from ^6Li (^3He, γ)^9B and ^7Li (^3He, γ)^{10}B reactions are given, for $E_{^3He} = 765$ keV and averaged for each 10 channels. It is seen that, at the position of strong 14.8 MeV peak (located around channel 60) from ^7Li (^3He, γ)^{10}B reaction, both spectra almost coincide, which is an additional test that the normalization of background was done properly. We

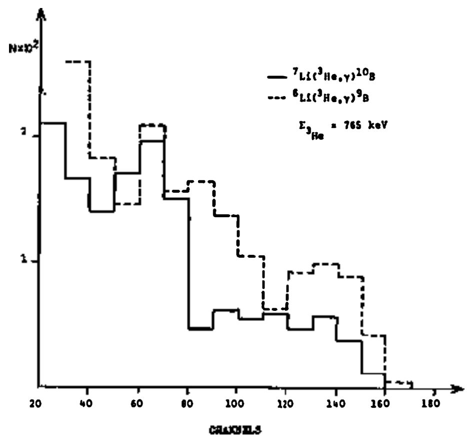

Fig. 1. The high energy part of gamma spectra with natural Li (— — —) and ^{6}Li (—) targets.

note the existence of two broad peaks in the substracted spectrum which correspond to the gamma-ray transitions in ^9B from the state on 17.11 MeV to the ground state and the 2.33 MeV state. These two γ-rays are located around channels 130 and 90 of the spectrum from Fig. 1.

We started the measurements with 20 keV and 10 keV thick targets, with 10 keV steps in changing the beam energy. After these runs we concentrated at the region around 765 keV, suspecting here a weak resonance. All other measurements, done with 5 keV targets resulted in establishing the evidence on the existence of a resonance at 765 ± 5 keV, which corresponds to (17.111 ± 0.005 MeV state of ^9B.

In Fig. 2 the energy dependence of the yield of gamma-rays which go to the ground state in ^9B from ^6Li (^3He, γ)^9B is given in the region of that resonance. This yield was obtained by subtracting before-mentioned background (»natural Li target«) from »^{6}Li target« run, in a way illustrated in Fig. 1. In Fig. 3 the energy depedence of the yield of gamma-rays which go to 2.33 MeV level in ^9B is given; the errors shown at experimental points are total statistical errors for both measurements with »^{6}Li target« and »natural Li target«. The cross-sections indicated in Figs. 2 and 3 are obtained by normalization to the known cross-section of ^7Li (^3He, γ) $^{10}B_{4.77}$ at 800 keV.

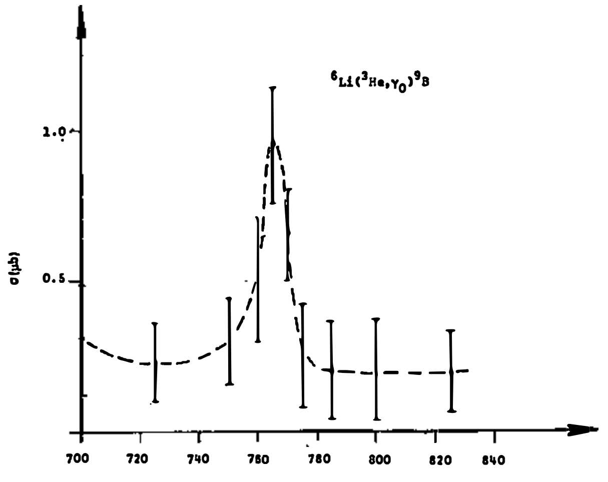

Fig. 2. The resonance at E (^{3}He) = 765 keV from ^{6}Li (^{3}He, γ_0)^{9}B$_{g.s.}$ reaction.

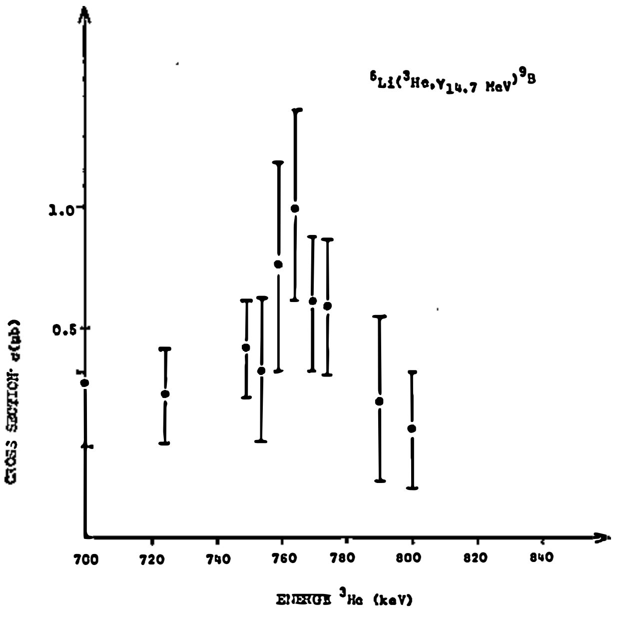

Fig. 3. The resonance at E (^{3}He) = 765 keV from ^{6}Li (^{3}He, γ)^{9}B$_{st.s.}$ reaction.

^{6}Li (^{3}He, p)^{8}Be 16.6 MeV (2a) reaction (experiment 2). This reaction was used for obtaining an independent evidence on 17.11 MeV state of ^{9}B, since this state, if it is a $T = \frac{3}{2}$ state, could decay by low-energy proton emission leaving ^{8}Be in 16.6 MeV state. Since the detection of low-energy protons (about 0.5 MeV)

is rather difficult in our experimental arrangement, we decided to detect two coincident alpha-particles resulting from the decay of the $^{8}Be_{16.6}$ MeV state.

The experiment was performed in a scattering chamber[5)] where two Si-detectors (followed by multichannel analysis) were located at angles where one could expect these two coincident alphas by kinematics (one at $\Theta = 90°$, $\Phi = 0°$, second at $\Theta = 80°$, $\Phi = 180°$). The appearence of such coincident alphas is not connected with 765 keV $\left(\text{supposedly } T = \frac{3}{2}\right)$ resonance only, since also any $T = \frac{1}{2}$ state in ^{9}B would be allowed to decay to the 16.6 MeV ^{8}Be state because of its mixed T character. This enabled us to set our experimental technique properly, without respect to the existance of a resonance at 765 keV.

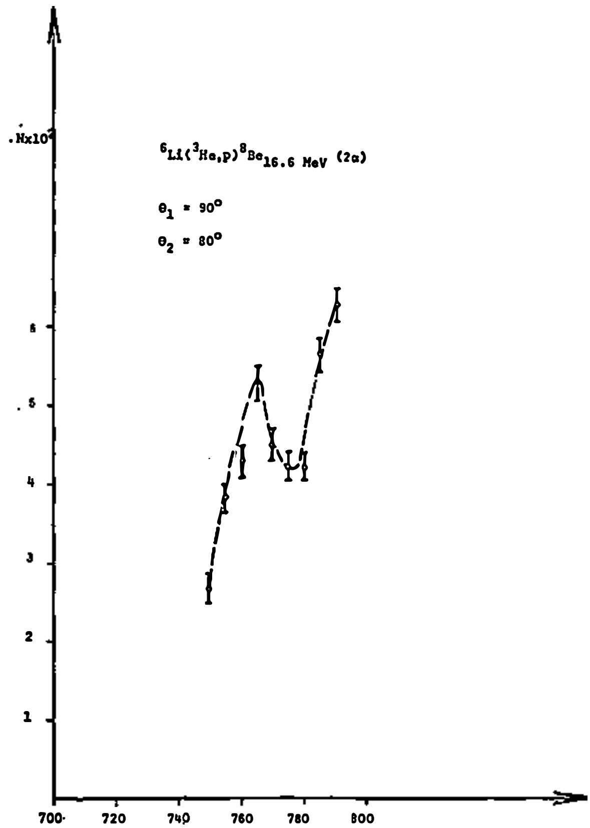

Fig. 4. The resonance at E (^{3}He) = 765 keV from $^{6}Li\,(^{3}He, p)^{8}Be_{16.6}\,(2\alpha)$ reaction.

In Fig. 4. the excitation function of $^{6}Li\,(^{3}He, p)^{8}Be16.6\,(2\alpha)$ reaction, measured by the technique of two coincident alpha-particles, is shown for the region from 750 keV to 780 keV. It is seen that the 765 keV resonance is evident. However same as in experiment 1, this effect is very weak and it took many carefully performed experimental runs to establish such evidence.

3. Discussion

Both experiments 1 and 2, as shown in Figs. 2—4, resulted in the evidence for the existence of (17.111 $\pm$ 0.005 MeV) level in ^{9}B. To this level $T = \frac{3}{2}$ value should be assigned, because it appears only in two reactions which are isospin allowed, and it does not appear in any of those reactions which are isospin forbidden if it were a $T = \frac{3}{2}$ state. The fact that its width is less than 5 keV, which is the experimental resolution, as seen from Figs. 2 and 3, also works in favour of $T = \frac{3}{2}$ assignement.

This state in ^{9}B along with the states in ^{9}Be and ^{9}Li with excitation energies of 16.97 and 2.69 MeV, respectively, as well as the non-identified state in ^{6}C, form the second isospin quadruplet of nuclei with A = 9. By the analysis of this isospin quadruplet, employing the isobaric mass formula[9] and using our experimental results, as well as the values[2,3] for the states in ^{9}Li and ^{9}Be, it is possible to define the mass formula constants. The values obtained are: $a = 28866 \pm 13.7$ keV, $b = 1206 \pm 8.2$ keV and $c = 269 \pm 41.6$ keV. The errors of these coefficients include the total calculated errors of particular levels' excitation energies.

The excitation energy of the second $T = \frac{3}{2}$ state in ^{9}B belonging to second isospin quadruplet of nuclei with A = 9, can be predicted using the isobaric mass formula — its value is (2.28 $\pm$ 0.22) MeV.

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DOKAZ POSTOJANJA NIVOA NA 17.11 MeV U ^{9}B KAO ČLANA DRUGOG T = 3/2 KVADRUPLETA KOD A = 9 JEZGARA

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Sadržaj

Eksperimentalno su ispitane ^{6}Li (^{3}He, γ)^{9}B i ^{6}Li (^{3}He p) $^{8}Be_{16.6\,MeV}$ (2 α) reakcije u cilju nalaženja drugog oivoa sa T = 3/2 kod ^{9}B. Oba eksperimenta su dokazala postojanje nivoa na 17.11 meV u ^{9}B. Sa vrednošću izospina T = 3/2. Ovo stanje u ^{8}B zajedno sa stanjima na 16.97 u ^{9}Be i 2.69 MeV u ^{9}Li kao i stanje na 2.28 MeV u ^{9}C, koje se na osnovu pomenuta tri stanja dobija iz kvadrupletne formule, čine drugi izospinski kvadruplet kod A = 9 jezgara.