Low-lying energy levels of $^{10}B_5$ (populated in $^{9}Be(d,n)^{10}B$)

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Low-lying energy levels of $^{10}B_5$

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Abstract. The nuclear emulsion method has been used to examine neutrons from ^{9}Be(d, n)^{10}B reaction at a deuteron energy of 600 KeV on a ^{9}Be target of 4 mm thickness.

The well known energy levels of ^{10}B have been verified but our data strongly suggest that the 2·9 MeV level, which is the subject of some dispute, is composed of two levels, one at 2·75 MeV and the other at 3·17 MeV.

1. Introduction

The energy spectrum of neutrons from ^{9}Be(d,n)^{10}B has been investigated by many workers. Low-lying energy levels of ^{10}B at 0·72, 1·74, 2·15 and 3·59 MeV besides the ground state are well established.

On the other hand, using the ^{9}Be(d,n)^{10}B reaction, first Bonner and Brubaker (1936), then Staub and Stephens (1939), Dyer and Bird (1953), Reid (1954), Génine (1958), Hjalmar and Stätis (1961), Galloway and Sillitto (1961), Coombe and Walker (1962), Srivastava and Sah (1970, 1971, 1972) claimed the presence of another energy level in ^{10}B at around 2·9 MeV. Coombe and Walker proposed that this level could probably be composed of two levels, one at 2·7 MeV and the other at 3·1 MeV energy. Good (1960) indicated an energy level between the 2·21 and 3·6 MeV levels in his flight time spectrum of the ^{9}Be(d,n)^{10}B reaction but he did not make any comment on it. On the other hand, Powell (1943), Whitehead and Mandeville (1950), Ajzenberg (1952), Pruitt *et al* (1953), Green *et al* (1955), Shpetnyi (1957), Neilson *et al* (1958), Morisson *et al* (1961), Riley *et al* (1963), Maydan and Vass (1965) also used the same reaction and they did not have evidence for such levels. The earlier work was done mostly using the emulsion method and the later work (Neilson *et al* 1958, Morisson *et al* 1961, Riley *et al* 1963, Maydan and Vass 1965) using the flight time method. However, a critical survey of their spectra shows higher background in the area between the 2·15 MeV and 3·6 MeV levels than in the other parts of the spectrum.

2.. Experimental procedure

In this work, neutron spectra of the ^{9}Be(d,n)^{10}B reaction were investigated using the nuclear emulsion method. A ^{9}Be target of 4 mm thickness was bombarded with 600 keV ($\pm$3 keV) deuterons and the exposure was 100 μA h. The neutron yield was monitored using a plastic (pamelon) scintillator with an efficiency of 10^{-6} per neutron. For each 100 s, counts were constant within statistical error limits. Ilford C2 plates of 400 μm thickness were used as the neutron detector.

Plates were put at 0°, 30°, 60°, 90°, 120° and 150° laboratory angles to the deuteron beam and the emulsion surfaces were tilted by 2° to the incoming neutron direction. The centres of the plates were placed 17 cm away from the target's centre. After irradiation, the plates were processed by the temperature development method. Recoil proton tracks were examined by an M4000 Cooke, Troughton and Simms nuclear research microscope. Observations were made with an oil immersion objective with a 2·2 mm focal distance and 1·32 numerical aperture in combination with a 15 × Kellner eyepiece. The emulsion was treated with glycerin in order to reduce its shrinkage after development. For recoil track measurements, the angle of acceptance was ±5° in depth and ±5° radially. This sampling criterion introduces an overall 0·5 % reduction in neutron energies. Track measurements were carried out by measuring the length of each straight portion of the tracks taking the coordinates of their end points; thus, genuine lengths of

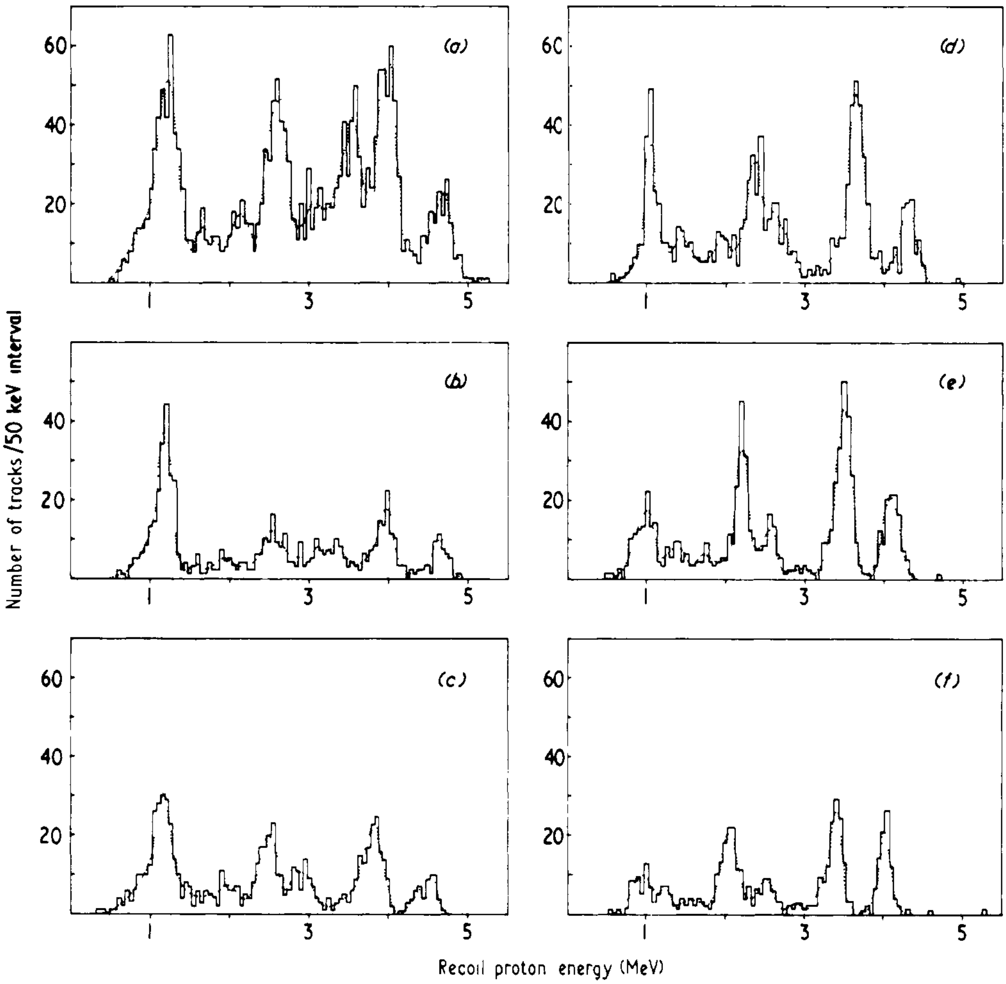

Figure 1. Energy histograms with 50 keV intervals without any correction. Dotted curves are smoothed curves. Values of θ_L (deg), the number of tracks and the scanned volume (mm^3) for each part are given respectively by: (*a*) 0, 2000, 1·96; (*b*) 30, 604, 0·43; (*c*) 60, 750, 0·63; (*d*) 90, 1000, 0·73; (*e*) 120, 750, 0·43; (*f*) 150, 500, 0·35.

each track were worked out. In order to eliminate corrections for the escaped recoil tracks, recoil protons originating in the upper 40 μm and bottom 40 μm depths were not measured. Only, in the central part of the plates, at 320 μm depth, was the emulsion scanned. Scanned volumes of each plate were carefully measured.

According to our sampling criteria, recoil proton energies were taken as neutron energies. Energy histograms were constructed with 50 keV intervals without any correction. Histograms were smoothed using the second-order seven-terms Spencer

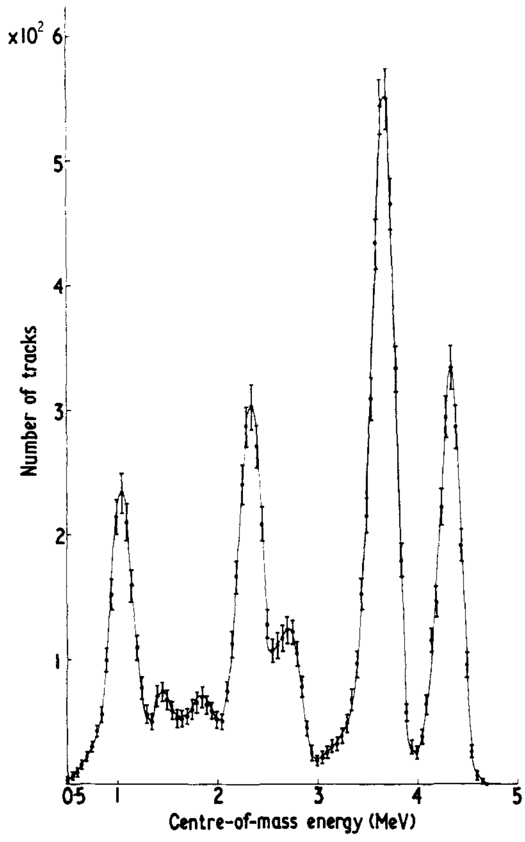

Figure 2. Centre-of-mass spectrum, the sum of the six spectra.

Table 1. Excited levels of ^{10}B

The results of the present experiment (MeV)	Accepted levels (MeV)	Sah's results (MeV)	Coombe's and Walker's results (MeV)
0·72 ± 0·01	0·717	0·73	0·72
1·76 ± 0·03	1·740	1·76	1·74
2·21 ± 0·02	2·154	2·19	2·15
2·75 ± 0·03	—	2·85	?2·7 ± 0·1 2·9 ± 0·2
3·17 ± 0·02	—		?3·1 ± 0·1
3·65 ± 0·02	3·59	3·69	They did not measure this group

formula (Whittaker and Robinson 1954). Wilkins' (1951) range–energy relations were used to calculate recoil proton energies. Each spectrum was normalized to the minimum scanned volume which corresponds to the scanned volume of $\theta_L = 150°$, they were then corrected for the change of the neutron–proton elastic scattering cross section using Adair's data (Adair 1950). Carrying out a graphical lineshape analysis, taking the ground state lineshape as the true lineshape at $\theta_L = 0°$, D–D neutrons were estimated using the angular distribution of Livesey and Wilkinson (1948–49). Therefore, D–D neutrons in each spectrum were estimated. After subtracting D–D neutrons, the six spectra in a centre-of-mass spectrum were summed in order to calculate the Q values of the levels.

3. Results

In figure 1 uncorrected recoil proton energy histograms are given. Smooth curves also given on each histogram by the dotted curves. The sum of the spectra in the centre-of-mass system is shown in figure 2.

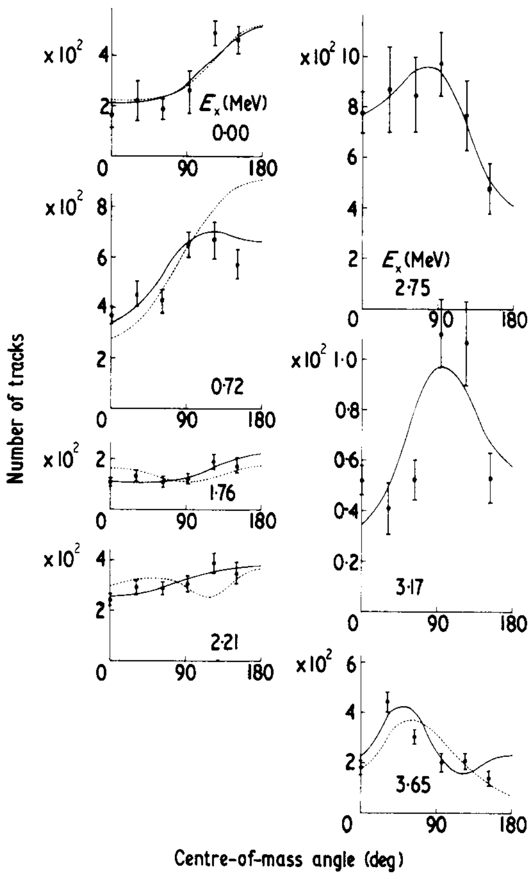

Figure 3. Angular distributions in arbitrary units. Broken curves are the best fits of Green *et al.* Full curves are our fits. The discrepancy between the two fittings may be attributed to the difference of deuteron beam energies in the two experiments.

In all the spectra, neutron groups are well resolved, and besides the accepted levels at 0·72, 1·74, 2·15 and 3·59 MeV, two other levels at 2·75 and 3·17 MeV are clearly resolved.

The deuteron beam energy was 600 keV, but since a very thick ^{9}Be target was used, the effective beam energy, estimated using the excitation function of the ^{9}Be(d,n) ^{10}B reaction, is 530 keV, and the Q value of the reaction calculated from our spectrum is 4·359 MeV, in very good agreement with the Q value calculated from masses.

The results of this measurement are summarized and compared with others in table 1, and angular distributions are given in figure 3.

4. Conclusions

This work provides strong evidence that the disputed 2·9 MeV level in $^{10}B_5$ is composed of two levels with 2·75 MeV and 3·17 MeV excitation energies. These values are identical, within experimental error limits, with the results of Coombe and Walker.

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