Excited States of B^{13}

G. C. MORRISON AND J. A. GALEY
Enrico Fermi Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
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The energy levels in B^{13} up to an excitation energy of 6 Mev have been investigated by means of the reaction $Li^7(Li^7,p)B^{13}$ at an energy of 2 Mev for the incident Li^7 ions. Selection and identification of the outgoing protons in the presence of deuterons, tritons, and alpha particles emitted in competing reactions is achieved with a proportional counter-CsI(Tl) scintillation counter telescope system which gives a measure of the dE/dx and E of the emitted particle. From the observed energy spectrum of protons emitted at 90°, the Q-value of the reaction leading to the ground state of B^{13} was determined to be 5.97 ± 0.05 Mev in agreement with a previous measurement by Norbeck, and the energy of excitation of the first four levels in B^{13} were determined to be 3.70 ± 0.05 Mev, 4.16 ± 0.05 Mev, 5.05 ± 0.08 Mev, and 5.5 ± 0.1 Mev. At 90° in the laboratory system the relative intensities of the proton groups leading to the ground state and first four excited states are in the ratios of 1.0:2.6:0.8:1.6:1.0, respectively.

THIS is a report[1] of results obtained as part of a detailed study of the nuclear reaction products emitted in the bombardment of lithium targets with Li^6 and Li^7 ions. In view of the many exothermic nuclear reactions possible when two lithium nuclei interact, experimental difficulties are encountered in separating out for study a single particle group with the low-resolving power methods necessitated by the small yields at bombarding energies of 2 Mev. The development of a particle selector system has to a large extent obviated this difficulty and we are able to present the energies of some of the excited states of B^{13} from a study of the shorter range proton groups from the reaction $Li^7(Li^7,p)B^{13}$. In previous work from this laboratory the reaction leading to the ground state of B^{13} has been observed and the Q-value of the reaction established at 5.97 Mev.[2]

In the present work the reaction products emitted when the lithium ion beam from the Chicago 2-Mev Van de Graaff accelerator strikes the target are observed at 90°. The detection apparatus[3] is separated from the target chamber by a 6.4×10^{-4}-cm thick Mylar window. The reaction products traverse a methane-filled proportional counter and stop in a thin, 1 mm, CsI(Tl) crystal, giving a measure of the dE/dx and the E of the emitted particles, respectively. The gas pressure in the proportional counter has been kept as low as possible to minimize the energy lost by a particle before entering the CsI(Tl) crystal, thereby allowing the energy spectrum of the emitted particles to be observed down to low energies and reducing straggling in the particle energy before entering the crystal.

In the particle selection system used, the dE/dx and E pulses for each individual particle after suitable amplification and shaping are displayed as vertical and horizontal deflections on an oscilloscope screen. A gate pulse corresponding to the particle type of interest is obtained from a photomultiplier viewing the oscilloscope screen which is appropriately masked to discriminate against all other particle types.

Using the selection system with the mask appropriate to provide gate pulses for protons, the energy spectrum of protons emitted in the reaction $Li^7(Li^7,p)B^{13}$ has been obtained at an energy of 2 Mev for the incident Li^7 ions. Before and after each gated run, a run was made during which a time exposure photograph of the masked screen was taken to ensure that only protons were being selected. In Fig. 1 the summed pulse-height spectrum obtained from a series of gated runs is shown as displayed on an RCL 256-channel analyzer. The highest energy group corresponds to the ground state of B^{13} and the four lower groups to protons leading to excited states in B^{13}.

To calibrate the energy scale of the pulse-height analyzer the reaction $Li^6(Li^7,p)B^{12}$ with $Q=8.33$ Mev was used. However, the excited states of B^{12} are not known above 6 Mev, so that the reaction serves only to calibrate the CsI crystal for protons above an energy of 3 Mev. For this reason the deuteron groups from the reaction $Li^6(Li^7,d)B^{11}$, $Q=7.19$ Mev, were also used.

In Fig. 2 is shown the pulse-height spectrum of protons and deuterons emitted at 90° in the bombardment of Li^6 by Li^7 when the mask is chosen to select all $Z=1$ particles. Although there is an exothermic triton-pro-

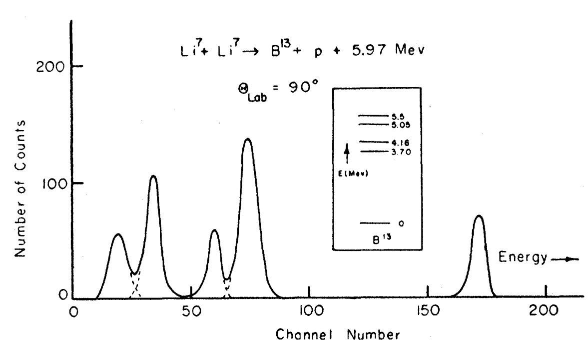

FIG. 1. Proton groups from $Li^7(Li^7,p)B^{13}$ as displayed on a pulse-height analyzer. The insert to the figure shows the portion of the energy level diagram of B^{13} which follows from the observed groups.

[1] This work was supported in part by the U. S. Atomic Energy Commission.
[2] E. Norbeck, Jr., Phys. Rev. **105**, 204 (1957).
[3] P. G. Murphy, Phys. Rev. **108**, 421 (1957). See Fig. 1.

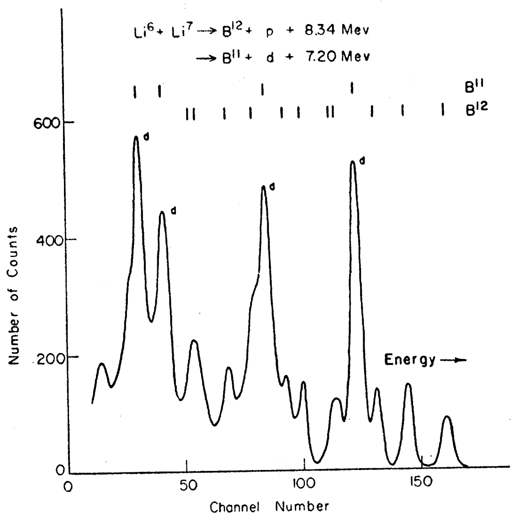

FIG. 2. Protons and deuterons from the bombardment of Li^6 by Li^7. The particle selector system is set to reject pulses for particles of Z greater than 1. The locations of groups to be expected from known excited states of B^{11} and B^{12} are shown above.

ducing reaction, the triton energy is too low for them to appear in the range shown. From the kinematics of these reactions the expected energies of the protons and deuterons emitted at 90° can be calculated. The observed proton and deuteron groups can then be related to the known energy levels in B^{12} and B^{11} and their positions are shown above the spectrum. From a plot of proton and deuteron pulse heights *versus* energy, the energy as measured in the crystal of the unknown proton groups emitted in the Li^7+Li^7 reaction was determined, and, in so far as the plot was fitted by the same straight line passing through the origin, served to establish the correctness of the assumed equivalent absorber thickness between the target and surface of the crystal. A further and more sensitive check on the assumed equivalent absorber thickness was obtained from a plot of pulse height *versus* energy for alpha particles emitted in various lithium-induced reactions, which also was fitted at energies less than 8 Mev by a straight line passing through the origin.

On this basis the energy of the proton groups emitted at 90° in the reaction $Li^7(Li^7,p)B^{13}$ was determined and hence the Q-value of the reaction and the energy of excitation of the levels in B^{13}.

The Q-value of the reaction is in agreement with that previously measured by Norbeck[2] where Al absorbers were used to remove all particles other than the ground-state protons. The results are displayed in Table I, and

TABLE I. Proton groups from $Li^7(Li^7,p)B^{13}$.

Energy of proton group (Mev)[a]	Relative intensity of group (90°)	Excitation energy of B^{13} (Mev)
6.40±0.05	1.0	0
2.96±0.05	2.6	3.70±0.05
2.53±0.05	0.8	4.16±0.05
1.71±0.08	1.6	5.05±0.08
1.29±0.1	1.0	5.5±0.1

[a] 90° in the laboratory; 2.00-Mev Li^7 bombardment.

the deduced energy levels of B^{13} are shown in an insert in Fig. 1. The quoted errors combine the uncertainty in locating the position of the center of the peak corresponding to each proton group and the uncertainty in the value assumed for the equivalent absorber thickness. The relative intensities of the groups as given in Table I have an uncertainty of about 8% arising from counting statistics only. No attempt was made to improve the statistics, considering the fact that the outgoing protons are observed at only one angle.

As a further check on the position of the excited states given here and in an attempt to obtain level parameters, it is intended in future work to study the de-excitation gamma rays emitted in coincidence with the observed proton groups.

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