Neutrons from the Proton Bombardment of B^{11}†

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A thin target of isotopic boron has been bombarded with 7.03-Mev protons. The neutrons from the $B^{11}(p,n)C^{11}$ reaction, studied by means of nuclear emulsions, indicate an excited state of C^{11} at 2.01 ± 0.06 Mev.

THE location of the bound excited states of B^{11} is very accurately known, primarily because of the magnetic analysis of the proton groups from the $B^{10}(d,p)B^{11}$ reaction by Buechner and his collaborators.[1,2] In particular, the first excited state of B^{11} is found to be at 2.138 ± 0.009 Mev. In the corresponding region of the mirror nucleus, C^{11}, the locations of the excited states are based on studies of the neutrons[3–5] and γ rays[3,6] from $B^{10}(d,n)C^{11}$. An excitation energy of 1.85 ± 0.06 Mev for the first excited state is given by Johnson.[4] However, this value, because of the relatively small number of proton recoil tracks due to high-energy neutrons, was based on the measurement of a total of less than 50 tracks on four different plates. Gibson,[5] in an earlier paper, found the excitation energy to be 2.02 ± 0.1 Mev. This result was based on roughly 50 tracks measured at one angle. Since these measurements are the only direct evidence on the existence of the 2-Mev state of C^{11}, we felt that it would be of interest to attempt a more accurate measurement of its excitation energy.

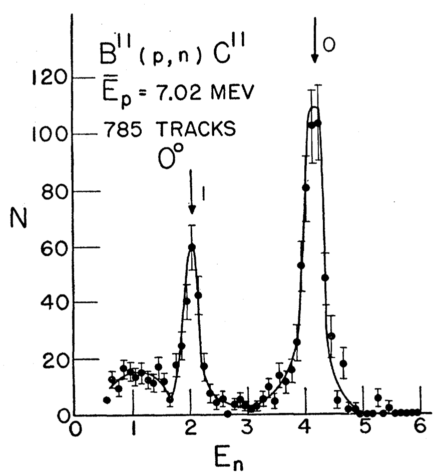

FIG. 1. The 0° data. N is the relative number of neutrons/100-kev interval. 0 and 1 indicate, respectively, the positions of the neutrons to the ground state and the first excited state of C^{11}.

A thin target of isotopic boron powder, painted on a tantalum backing, was bombarded by 7.03-Mev protons from the M.I.T.–O.N.R. Van de Graaff generator. The neutrons were detected by means of Ilford C-2 nuclear emulsions, 400 μ thick, placed 4 inches from the target and at several angles to the incident proton beam in a manner described earlier.[7] The exposure was 1500 microcoulombs. The plate processing procedure was very similar to that discussed by Allred, Armstrong, and Rosen.[8] The range-energy relation used was that derived by Rotblat.[9] The data shown on Figs. 1 to 4 have been corrected for geometry[10] and for variation of the n-p scattering cross section.[11]

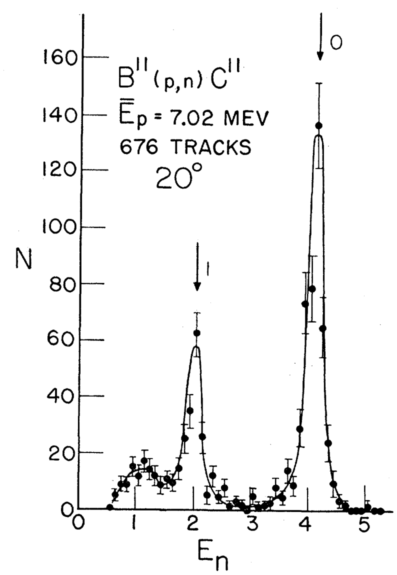

FIG. 2. The 20° data.

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Figures 1–4 show our results at 0°, 20°, 45°, and 60° to the incident beam. The neutron groups corresponding to the ground state of C^{11} are indicated as 0. Those corresponding to the first excited state are indicated as 1. On the basis of these data, we find $Q_0 = -2.83_{-0.05}^{+0.08}$ Mev,[12] and $Q_1 = -4.84_{-0.05}^{+0.08}$ Mev, with an excitation energy, E_x, of 2.01 ± 0.06 Mev for the first excited state of C^{11}. Lack of precise knowledge of $\bar{E}_p$, due to uncertainty in the measurement of the target thickness, leads to the rather large quoted errors in our Q-value measurements. However, $Q_0 - Q_1 = E_x$ does not depend on a precise knowledge of $\bar{E}_p$ and is believed to be more accurately determined.

The intensities (in the center-of-mass system) of the neutron groups to the ground state are approximately 2.5 times greater than the intensities of the groups to the 2.01-Mev excited state at all four angles scanned. The angular distributions of both neutron groups are peaked at 0°: $I_{0°}/I_{20°} \simeq 2.5$ for both groups.‡

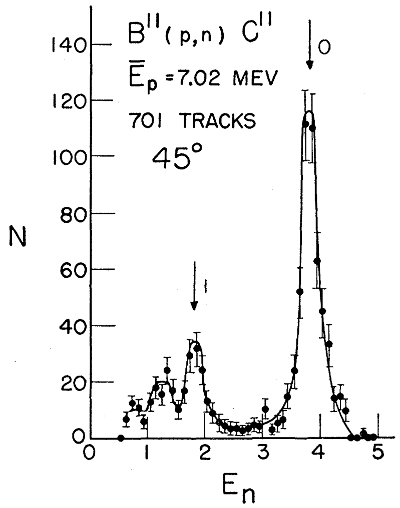

FIG. 3. The 45° data.

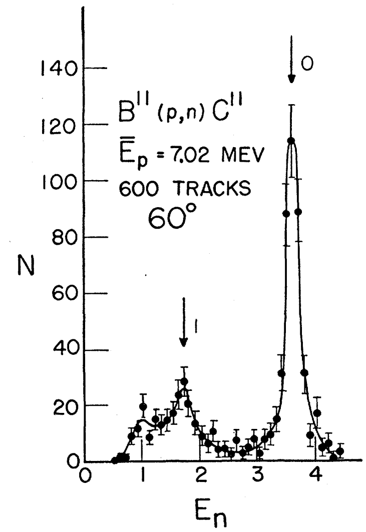

FIG. 4. The 60° data.

The appreciable number of low-energy neutrons ($E_n \lesssim 1.5$ Mev) cannot be explained as being due to transitions to a single excited state of C^{11}. The possibility that the neutrons were due to the $Si^{29}(p,n)P^{29}$ reaction was considered since the target used was found, on spectrochemical analysis, to contain ~11% of silicon and, therefore, ~0.7% Si^{29}. A second exposure was made at the same energy but with a boron target containing less than $\frac{1}{10}$ the amount of silicon in the first target. The relative number of low-energy neutrons was found to be the same within statistics. 800 tracks were scanned on the second set of plates at 0° and at 45° to the incident beam. The possibility that the neutrons were due to $C^{13}(p,n)N^{13*}$ was also considered. However, the amount of carbon in either target was <1% and therefore the amount of C^{13} was negligible. The "room" background is known from previous experiments to be extremely low. Therefore, at this time, no explanation can be offered for the low-energy neutrons.

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[12] To be compared with the very accurate threshold measurement of Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950), which gave $Q_0 = -2.762 \pm 0.003$ Mev.

‡ *Note added in proof.*—The differential cross section for the formation of the ground state of C^{11} at 0° is 13_{-7}^{+13} mb/sterad. The calculation was carried out in the manner described by L. Rosen, Nucleonics **11**, No. 8, 39 (1953). We are greatly indebted to Dr. Rosen for an illuminating discussion of the calculation.