Gamma Rays from Proton Bombardment of B^{10}†

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The γ-ray spectrum resulting from the radiative decay of C^{11}, produced by the proton bombardment of B^{10}, has been investigated using thick and thin targets. Observations were made for proton energies ranging from 500 kev to 1.7 Mev. A broad resonance with a maximum at 780 kev appears well established. The compound nucleus decays in a one-step transition to the ground state of C^{11} with the emission of a γ ray of energy approximately equal to 9 Mev. The existence of two other resonances, observed for proton energies of 0.95 and 1.33 Mev, is less certain.

INTRODUCTION

IN a recent publication Walker[1] has reported that a high-energy γ ray is observed when thick B^{10} targets are bombarded with protons of 1.2 Mev. This γ ray has been attributed to the radiative decay from a highly excited compound state in C^{11}. The low intensity of this radiation, and the large background from the 12- and 16-Mev γ rays from $B^{11}(p,\gamma)$ make it awkward to observe this process by the technique commonly utilized for (p,γ) experiments. This undoubtedly accounts for the failure to detect this γ ray in earlier experiments. Inasmuch as the results of Walker were obtained with a proton beam of just a single energy, it appeared of interest to make a more detailed study of this reaction.

EXPERIMENTAL PROCEDURE

A beam of monoenergetic protons is available from the University of Kansas electrostatic generator.[2] The analyzed beam enters the target chamber shown in Fig. 1 which has been designed so that either thin or thick targets may be used. An RCA 5819 photomultiplier tube, on which is mounted a $1\frac{1}{2}$ in. long NaI(Tl) crystal, serves as the detector of the γ rays. With the arrangement used, the scintillation detector can be placed to within $\frac{3}{8}$-inch of the target. Because of the small cross section of the reaction it is essential to bring the detector as close as possible to the target to have a counting rate significantly larger than the background.

Measurements were made with both thick and thin targets. The thick targets were prepared by pressing enriched B^{10} into a molybdenum cup. A background run taken with the empty cup in place revealed no significant background of γ radiation having energy greater than 5 Mev. Two thin B^{10} targets, evaporated on a 1-inch diameter tantalum disk, were available. The thickness of these targets was approximately 40 $\mu g/cm^2$. Both of these targets exhibited contamination of fluorine and sodium. The sharp resonance peaks of both contaminants were readily detectable but could always be distinguished from the B^{10} γ rays by a careful analysis of γ-ray energies.

The observation of the capture radiation resulting from B^{10} is awkward for the following reason. Even with enriched targets, the background from the $B^{11}(p,\gamma)$ reaction is sufficiently large to mask the much lower intensity γ rays resulting from B^{10}. Recent experiments[3,4] have shown the existence of two broad resonance states in C^{12}. These states correspond to maxima in the γ-ray yield for bombarding energies 680 kev and 1.38 Mev. Two high-energy γ rays having energy of 12 Mev and 16 Mev are observed in the resultant decay. These two γ rays produce in the scintillation detector not only the usual peak, corresponding to the production of an electron-positron pair, but also a continuous distribution of pulses which tends to mask those pulses arising from a 9-Mev γ ray expected from the B^{10} reaction. Since this distribution depends on the dimensions of the crystal and the material surrounding it, it may not readily be computed. The usual technique of counting all the pulses produced, as a function of bombarding energy, leads therefore to no significant results, as long as there are no rapid fluctuations in the yield corresponding to well-defined resonances in the compound nucleus.

A more promising, though more qualitative, procedure consists of photographing the pulse-height distribution appearing on an oscilloscope for various bombarding energies. This method is equivalent to pulse-height analysis with a single-channel discriminator. The latter method has the advantage of allowing quantitative comparison of the peaks at various energies. Because of the extremely low counting rates available, this advantage is offset by the statistical uncertainties of the data so obtained. Experience has shown that with the proton currents available (2 microamperes or less) no significant results could be obtained with thin targets for runs lasting less than one hour. Because of the danger of carbon deposits on the target and possible drifting of the electronic circuits, no pulse-height analysis with discriminating circuits was at-

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[1] W. D. Walker, Phys. Rev. **79**, 172 (1950).

[2] A detailed description of the Van de Graaff generator, its method of control, and energy stability will be published elsewhere.

[3] Cochran, Ryan, Givin, Kern, and Hahn, Phys. Rev. **87**, 672 (1952).

[4] T. Huus and R. B. Day, Phys. Rev. **85**, 761 (1952).

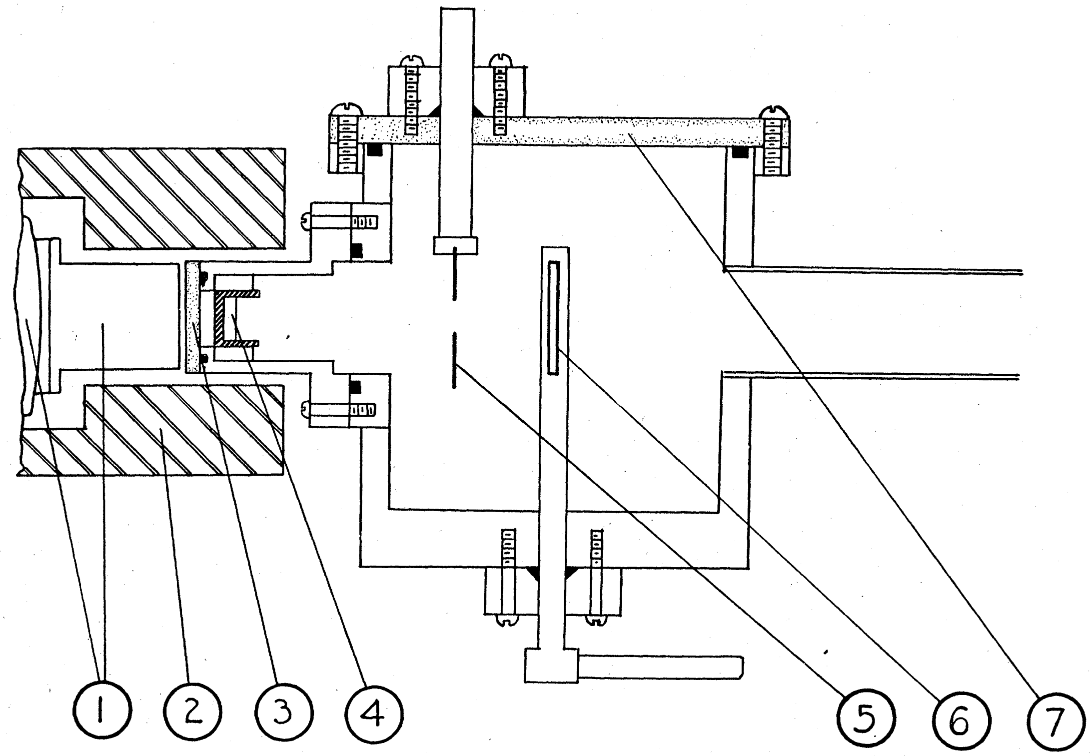


FIG. 1. Target chamber used for (p,γ) experiments. 1. NaI(Tl) crystal mounted on a RCA 5819 photomultiplier tube; 2. lead shield; 3. lucite window; 4. thick target assembly consisting of a molybdenum cup which is held in place by brass ring. For thin target observations the cup is removed and the thin target inserted between the brass ring and the end wall of the chamber; 5. tantalum disk with $\frac{1}{4}$-inch hole serving as an aperture. The disk is electrically insulated from the remainder of the target chamber; 6. rotating quartz window; 7. lucite cover.

tempted, except with thick targets for which the counting rate was very much larger.

RESULTS

Data have been taken using bombarding energies ranging between 520 kev and 1.7 Mev. As a general rule this energy region was scanned in steps of 40 kev.

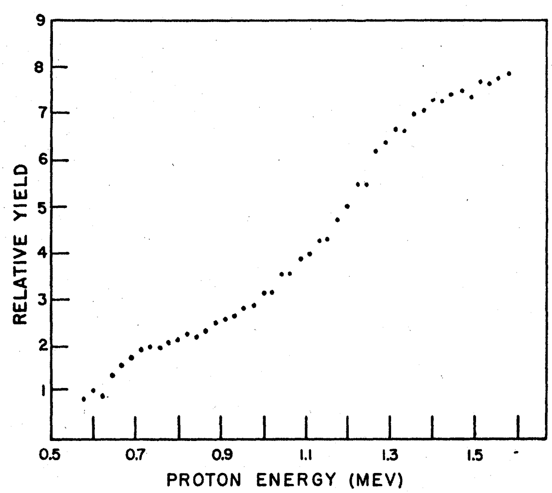


FIG. 2. Thick target yield as a function of proton bombarding energy obtained with enriched B^{10}. This curve was obtained by counting all γ rays greater than 6 Mev.

Much more detailed data were obtained with a thin target between 0.9 and 1.3 Mev to ascertain the possible existence of a well-defined resonance state in the neighborhood of 1.16 Mev in conformity with the results of Walker. A sharp resonance was observed at 1.162 Mev and others at 1.210, 1.254, and 1.281 Mev. A careful check showed, however, that all these peaks were due to sodium contamination of the target.

The results of a typical thick target run, with the discriminator bias adjusted to accept only pulses corresponding to γ rays of energy greater than 6 Mev, are shown in Fig. 2. The shape of this curve may be understood by assuming the existence of two very broad resonances, the maximum of one corresponding to a proton bombarding energy of approximately 700 kev, that of the other to an energy of approximately 1.35 Mev. This is precisely what would be expected from the $B^{11}(p,\gamma)$ process. Any resonances arising from the $B^{10}(p,\gamma)$ reaction must, therefore, be very much weaker in intensity, unless they occur at approximately the same bombarding energies as those of the competing process.

Pulse-height distributions were obtained with thick targets over the entire energy range. The system was calibrated by recording the pair peaks resulting from the γ rays of $Li^7(p,\gamma)$ and $F^{19}(p,\gamma)$. The results indicate the existence of a γ ray of approximately 9 Mev which must be ascribed to the $B^{10}(p,\gamma)$ reaction. These data also show the 4.4- and 12-Mev γ rays from the $B^{11}(p,\gamma)$ process, and at higher energies the 16-Mev γ ray from that same reaction. A comparison run taken with a thick target of elemental boron confirms this conclusion by the absence of the 9-Mev radiation. Figure 3 shows two photographs comparing a typical pulse-height distribution of B^{10} and elemental boron. The bombarding energies for both of these runs was 1.07 Mev. Figure 4 shows the identical pulse-height distribution of B^{10} as obtained with a single-channel pulse-height discriminator. A careful examination of a series of such pulse-height distributions indicates the gradual appearance of the 9-Mev radiation beginning at a bombarding energy of approximately 650 kev. An attempt has been made to obtain from these data the usual thick target yield curve by plotting the number of counts above the continuous distribution as a function of bombarding energy. The results of this analysis, plotted in Fig. 5, show the yield rapidly increasing above bombarding energies of 670 kev and leveling off above 900 kev, as would be expected from a broad resonance level. This indicates that the low-energy resonance apparent in Fig. 2 is really the result of two processes; the 680-kev resonance due to the $B^{11}(p,\gamma)$ reaction, as well as another due to $B^{10}(p,\gamma)$ at somewhat higher energy.

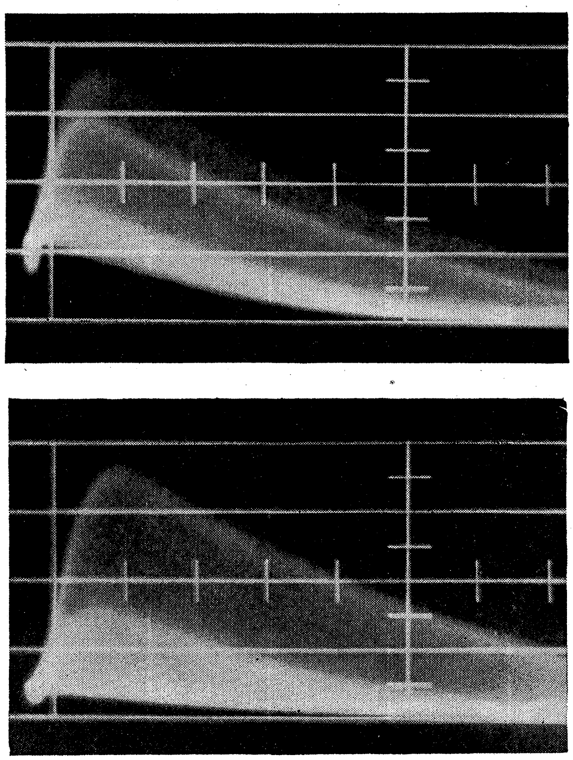


FIG. 3. Thick target pulse-height distributions resulting at proton bombarding energy of 1.07 Mev. The photograph on top was obtained with an enriched B^{10} target. The photograph below was obtained under identical conditions with an elemental boron target.

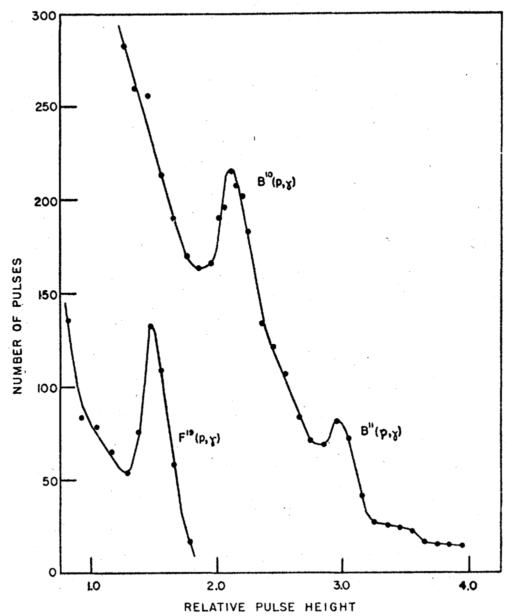


FIG. 4. Thick target pulse-height distribution of the γ rays resulting from $B^{10}(p,\gamma)$ at proton bombarding energy of 1.07 Mev. The curve at the lower left shows the peak from the $F^{19}(p,\gamma)$ reaction which has been used as a calibration for the single channel pulse-height analyzer.

Pulse-height distributions obtained by photographic means with thin targets confirm the existence of a broad resonance with a maximum at approximately 780 kev. At higher energies the 9-Mev radiation decreases in intensity but remains detectable to 1.5 Mev.

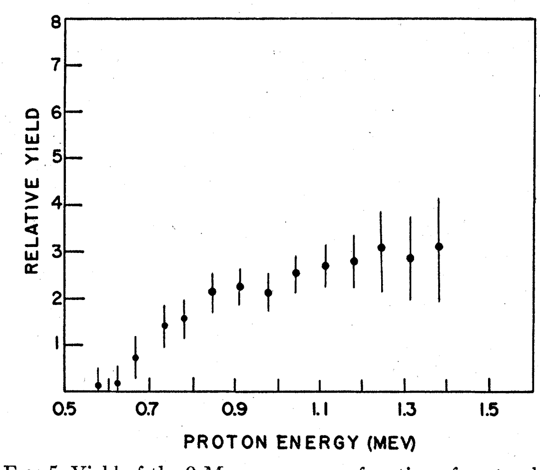
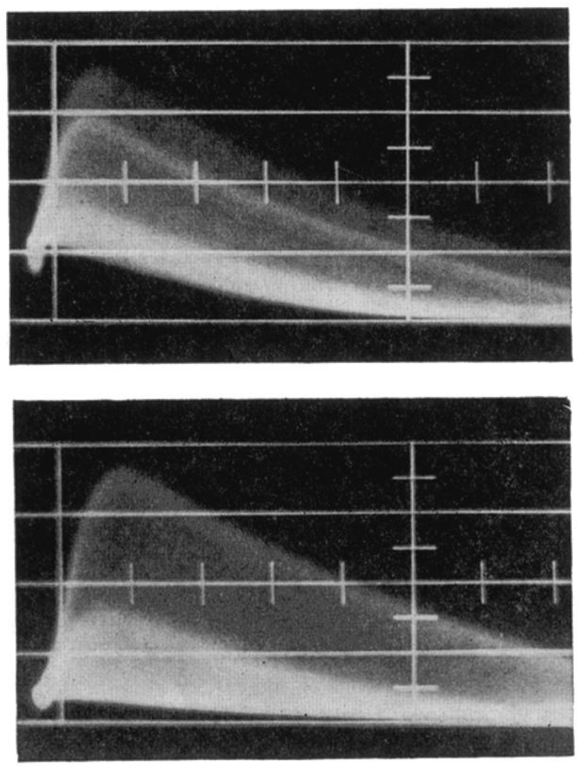


FIG. 5. Yield of the 9-Mev γ rays as a function of proton bombarding energy obtained with a thick target of B^{10}. The data for this graph were obtained by taking pulse-height distributions for a series of bombarding energies, and calculating the number of counts above the continuous distribution.

The photographic records of the distributions indicate two peaks in this range of energies having their respective maxima at 0.95 and 1.33 Mev. Of these, the first is the better established. These variations in the yield are too small to be detectable with thick targets. They should therefore be considered as questionable.



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