EXCITATION STUDIES OF REACTIONS OCCURRING IN THE PROTON BOMBARDMENT OF ^{10}B†

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This note reports an investigation of the excitation functions for the reactions $^{10}B(p,\gamma)^{11}C$ and $^{10}B(p,\alpha)^{7}Be$ for proton energies of up to 775 keV. Curran, Dee, and Petržílka (1939) investigated the (p,γ) reaction by analysing the decay curve of activations produced in the bombardment of a thick boron target by 960 keV protons; they found no evidence for this reaction and quoted an upper limit of 10^{-13} ^{11}C nuclei formed per incident proton. Later, Walker (1950), using a magnetic pair spectrometer, observed a $(9\cdot 47 \pm 0\cdot 12)$ MeV γ-ray emitted in the bombardment of a thick separated ^{10}B target by 1200 keV protons, which was attributed to the reaction $^{10}B(p,\gamma)^{11}C$. The yield was $3\cdot 4 \times 10^{-10}$ γ-rays per proton.

The excitation function for the $9\cdot 5$ MeV γ-radiation has previously been measured, using NaI(Tl) single crystal spectrometers, by three groups. Krone and Seagondollar (1953) studied the proton energy region $0\cdot 6$–$1\cdot 4$ MeV, and found indications of a resonance at about 780 keV. Day and Huus (1954), studying the energy region $0\cdot 5$–$2\cdot 4$ MeV, failed to observe this resonance, but found one at $1\cdot 2$ MeV. Recent work by Hahn, Kern, and Farney (1955) supports the result of Day and Huus.

All of these (p,γ) excitation curve experiments suffer from a large background of 4, 12, and 16 MeV γ-rays produced from the reaction $^{11}B(p,\gamma)^{12}C$ due to residual ^{11}B impurity present even in the separated targets used. Because of this, it is difficult both to observe the spectrum of γ-rays from $^{10}B(p,\gamma)^{11}C$ and to separate its contribution to the γ-ray spectrum in an excitation curve measurement.

The method used in the present experiment was to measure the yield of ^{11}C nuclei formed in proton bombardment of a thick boron-containing target, as a function of proton energy. The ^{11}C nuclei were detected by means of their decay to ^{11}B with the emission of $0\cdot 98$ MeV positrons: half-life $20\cdot 4$ min (Ajzenberg and Lauritsen 1952). The presence of ^{11}B in the target is then of no consequence, and targets containing natural boron were used, their only disadvantage being the smaller percentage of ^{10}B which they contain. The use of such an activation method will in principle give all resonances in which ^{11}C is formed, irrespective of the type of γ-ray transition preceding the formation of ^{11}C in its ground state.

The (p,α) excitation curve was studied simultaneously with the (p,γ) curve by measurement of the yield of ^{7}Be as a function of proton energy, the ^{7}Be

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(53 day half-life) being detected by means of the $0\cdot478$ MeV γ-radiation emitted in the electron capture decay to ^{7}Li (Ajzenberg and Lauritsen 1952). The (p, α) curve has been previously studied, through observation of the α-particles emitted, by Burcham and Freeman (1949, 1950) who found no resonances in the region 200–800 keV. The (p,α) activation experiment reported here is of a confirmatory nature.

In each run of the present experiment a thick target of borax, prepared by melting about $0\cdot7$ g of anhydrous borax ($Na_2B_4O_7$) into a $\frac{3}{8}$ in. diameter nickel target cup, was bombarded for 40 min (about two half-lives of ^{11}C) by an analysed beam of protons from the 750 keV electrostatic generator at the University of Melbourne. The current received by the target passed first through an "ordinary" integrator to record the total charge received and then into a "leaky" integrator, of the type used by Snowdon (1950), having a decay time constant made equal to that for the ^{11}C decay. This recorded the effective charge for ^{11}C production allowing for the fact that the ^{11}C was decaying with a half-life comparable to the time of bombardment.

After bombardment the cup was extracted from the target holder and placed in fixed geometry in the activation counting apparatus. The relative amount of ^{11}C was measured by coincident detection of the two $0\cdot51$ MeV quanta produced by annihilation of the positrons in the surrounding material, using a pair of NaI(Tl) single crystal γ-ray spectrometers feeding into a coincidence circuit of $1\cdot0$ μsec resolving time. The quantity of ^{11}C was determined by analysis of the coincidence decay curve, taken over a period of about three half-lives after bombardment; division by the leaky integrator reading then gave the relative yield of ^{11}C (the background to be subtracted varied from run to run owing to a small contribution of coincidences arising from "double scattering" of $0\cdot478$ MeV γ-rays from ^{7}Be). The relative yield of ^{7}Be was given by the amount of long-lived γ-ray activation per proton, determined at a time when the ^{11}C had decayed to a negligible amount.

In addition to the usual procedures employed in order to obtain a quantitatively reliable excitation curve (suitable beam/target geometry, secondary electron suppression, stability of activation counting apparatus), the following special precautions had to be taken to keep the conditions of bombardment and counting constant from run to run. (i) It was found that the beam slowly bored a hole through the borax target material; this effect was minimized by the use of low beam currents (10–15 μA), and a sufficiently large thickness of borax was used. During each bombardment the target condition was checked every few minutes by means of a NaI(Tl) γ-ray monitor, with bias set at 3 MeV. This would detect any reduction of target thickness below that required to stop the incident protons completely; such an effect would appear as a drop in the prompt γ-ray yield from $^{11}B(p,\gamma)^{12}C$ and to a smaller extent from $^{23}Na(p,\gamma)^{24}Mg$ and $^{10}B(p,\gamma)^{11}C$. (ii) It was observed that some activated material was being evaporated, and so lost from the target, by the heating due to the beam and that this material condensed on the sides of the target cup; in order to correct this a lining of aluminium foil was placed around the sides of the cup during bombardment so as to collect this material; after bombardment the foil was crushed back on to the target, thus retaining all activation in a small volume for counting purposes.

Precautions were taken to eliminate any interference by unwanted activations due to primary proton reactions and secondary photodisintegration or slow neutron reactions with target material, cup, or counters. The most serious of these activations was ^{13}N, a positron emitter with 10 min half-life (Ajzenberg and Lauritsen 1952) produced by the reaction $^{12}C(p,\gamma)^{13}N$ in carbon deposited on the target from oil vapours in the system ; the use of a liquid oxygen trap, and the heating of the target to about 200 °C, reduced this to negligible amount.* Another activation to be guarded against was ^{128}I, which, it was observed, could be produced by the capture of slow neutrons by the iodine in the detecting crystals ; this could give β-γ coincidences with a 25 min half-life. The activation counting apparatus was therefore placed at some distance from the target ; experiments without the target in place in this apparatus, and the observed half-life of the activation (see Fig. 1), proved conclusively that the short-lived activation being detected was not due to this process.

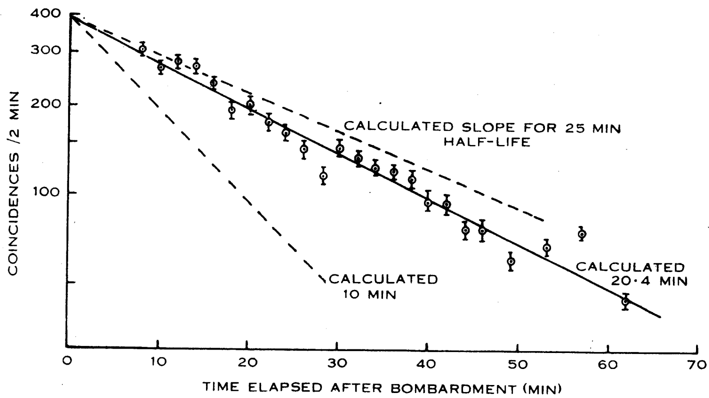

Fig. 1.—Typical coincidence decay curve obtained after proton bombardment of borax target (proton energy 750 keV), background subtracted.

A typical coincidence decay curve obtained in the experiment is shown in Figure 1, on which the calculated slopes for 10, 20·4, and 25 min half-lives have been drawn. Although the statistical fluctuations are large, it is clear that the activity measured arises from the decay of ^{11}C. A decay curve, taken over a period of weeks, for the intensity of γ-radiation from a bombarded target exhibited a half-life of 53 days as expected from ^{7}Be.

The excitation curves obtained are shown in Figure 2. Figure 2 (*a*) represents the prompt γ-ray yield mentioned above, and acts as a useful check on the target condition and the reliability of the current monitoring apparatus.

* At an early stage amorphous boron was tried as a target material but was found to contain a large proportion of carbon. There was also evidence that the effective percentage of ^{10}B in the surface layers of a target pressed from this material was changed by bombardment.

The excitation curve for $^{10}B(p,\alpha)^{7}Be$ is given in Figure 2 (*b*); within the limitations imposed by the fact that the ^{7}Be count is only of order one-tenth background this exhibits the smooth rise expected from the α-particle measurements of Burcham and Freeman. Figure 2 (*c*) is the thick target excitation function for $^{10}B(p,\gamma)^{11}C$; this is seen to have a smooth rise up to about 750 keV, with no observed resonances within the statistical accuracy of the measurements.

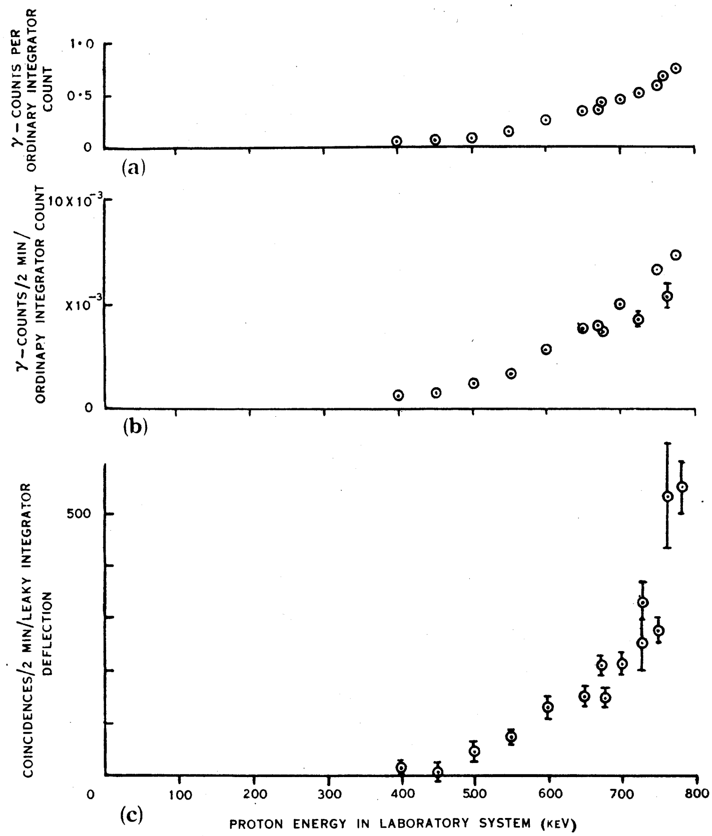

Fig. 2.—Thick target excitation functions for reactions of protons with borax target. (*a*) Prompt γ-rays$>$3 MeV; (*b*) $^{10}B(p,\alpha)^{7}Be$; (*c*) $^{10}B(p,\gamma)^{11}C$.

No attempt has been made at accurate measurement of absolute yields of ^{11}C and ^{7}Be, but rough estimates of counting efficiencies lead to thick borax target yields, at 700 keV, of 5×10^{-12} ^{11}C nuclei per proton and 3×10^{-8} ^{7}Be nuclei per proton.

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