The Q value was computed relativistically using the atomic mass[5] for B^{10} and subtracting the mass of the missing electrons from $(He^3)^{++}$ and $(N^{12})^{5+}$. Our result for the $B^{10}(He^3,N^{12})n$ Q-value measurement at 1.73° is 1.580 ± 0.025 MeV. The major contributions to the uncertainty are ±17 from the uncertainty in the location of the step in Fig. 2 at 5.3309 ± 0.0036 MeV and ±15 keV due to the finite resolution of the beam energy analyzer. The angle of observation is known to within $\pm0.1°$ if we assume that the angular distribution of the reaction does not vary significantly over the angular spread between 1.1° and 2.8°.

As a test of the reliability of our method of measuring a Q value, we have observed $B^{10(5+)}$ ions from $B^{10}(He^3,B^{10})He^3$ in the same geometry. Our measured Q value for this elastic scattering is -1.2 keV, well within the limits of error.

Because the measured Q value at 1.73° differs considerably from the value 1.46 ± 0.06 MeV obtained from neutron spectroscopy,[3] the measurement was repeated at an angle of 7.02°. This measurement was more difficult because of the much greater variation in N^{12} energy with angle at 7° which made it necessary to use a smaller entrance aperture and longer measuring periods. The average value taken from two independent measurements at 7.02° is $Q=1.560\pm0.025$ MeV, in satisfactory agreement with the measurement at 1.73°. We therefore adopt as our final value $Q=1.570\pm0.025$ MeV.

The end point energy for the N^{12} beta decay calculated from our Q-value measurement is 16.320 ± 0.025 MeV. This is to be compared with the previously accepted value of 16.43 ± 0.06 MeV, and a directly measured value of 16.384 ± 0.015 MeV.[1] When our value for the end point energy is used, the ft value of 1.33×10^4 quoted in Ref. (2) is lowered to $(1.29\pm0.02)\times10^4$. The ratio $ft(N^{12})/ft(B^{12})$ is lowered from 1.14 ± 0.025 to 1.10 ± 0.02. Though our present Q-value measurement tends to bring these ft values into closer agreement, a real discrepancy still exists.

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[5] F. Everling, L. A. Koenig, J. H. E. Mattauch, and A. H. Wapstra, Nucl. Phys. **15**, 342 (1960).

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Q Values for $B^{10}(He^3,n)N^{12}$ and N^{12*} †

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Using the reaction $Si^{28}(n,\alpha)Mg^{25}$ in a surface-barrier detector as a neutron spectrometer, a comparison measurement is made of the energies of neutron groups from the reaction $B^{10}(He^3,n)N^{12}$ with $B^{10}(\alpha,n)N^{13}$ as a calibration standard. A ground-state Q value, $Q_0=1.561\pm0.009$ MeV, is found for $B^{10}(He^3,n)N^{12}$, and two states of N^{12} are located at excitation energies 0.994 ± 0.020 and 1.22 ± 0.03 MeV.

I. INTRODUCTION

The preceding paper[1] has described a determination of the Q value of the reaction $B^{10}+He^3\rightarrow N^{12}+n$ through measurement of the energy of the recoil N^{12} ion in a magnetic spectrometer. The result, $Q_0=1.570\pm0.025$ MeV, is applied to calculate, with accuracy improved over previous values, the ft values of the N^{12} beta decays to states of C^{12}; in particular, the existence of a 9% discrepancy between the N^{12} and B^{12} ground-state mirror decays is confirmed.

Described in the present report is a measurement of the same Q value, in this case by exploiting the properties of a silicon surface barrier detector as a precision neutron spectrometer,[2,3] in order to make a direct comparison of the Q of $B^{10}(He^3,n)N^{12}$ with the well-known value[4] $Q=1.0602\pm0.0015$ MeV for $B^{10}(\alpha,n)N^{13}$. In addition, excited states of N^{12} are found at 0.994 ± 0.020 and 1.22 ± 0.03 MeV.

II. METHOD

When a silicon detector is exposed to a beam of monoenergetic neutrons, the most prominent pulses result from six reactions[5]:

$$Si^{28}(n,\alpha)Mg^{25},\quad Q_0=-2.655\pm0.003\text{ MeV}\qquad(1)$$

$$Si^{28}(n,p)Al^{28},\quad Q_0=-3.857\pm0.004\qquad(2)$$

$$Si^{29}(n,\alpha)Mg^{26},\quad Q_0=-0.036\pm0.004\qquad(3)$$

$$Si^{29}(n,p)Al^{29},\quad Q_0=-2.898\pm0.007\qquad(4)$$

$$Si^{30}(n,\alpha)Mg^{27},\quad Q_0=-4.213\pm0.005\qquad(5)$$

$$Si^{30}(n,p)Al^{30},\quad Q_0=-6.51\pm0.25.\qquad(6)$$

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[1] T. R. Fisher and W. Whaling, Phys. Rev. **133**, B1502 (1964), preceding paper.

[2] G. Dearnaley and A. T. G. Ferguson, Phys. Letters **1**, 196 (1962); M. G. Marcazzan, F. Merzari, and F. Tonelini, IRE Trans. Nucl. Sci. **NS-9**, 234 (June 1962).

[3] M. Birk, G. Goldring, and P. Hillman, Nucl. Instr. Methods **21**, 197 (1963).

[4] *1960 Nuclear Data Tables* (U. S. Government Printing Office, Washington, D. C., 1960), Part 1.

[5] P. M. Endt and C. Van der Leun, Nucl. Phys. **34**, 1 (1962).

Of these, the last four can often be neglected because of the small isotopic abundances of Si^{29} (4.7%) and Si^{30} (3.1%). Except for edge effects due to finite size of the depletion region in the detector, *all* of the kinetic energy of both final-state particles in each reaction is deposited in the detector, and thus ideally for each reaction a pulse of fixed magnitude occurs, independent of the angular distribution of the outgoing particles. The pulse-height spectrum is very complicated, however, since for each reaction many gamma-emitting excited states of the final nucleus[5] are formed, and the gamma-ray energy is rarely retained in the detector. The spectrum is then a series of lines, broadened in practice by detector noise, inhomogeneity, and fluctuating ion-pair recombination due both to varying location of the primary events and to the distribution of energy partition between the outgoing primary ions with consequent variation in mean specific ionization. The relative intensities of the various lines are, of course, functions of the energy of the incident neutron, and barrier penetration effects in the outgoing channel reduce the total efficiency exponentially for neutron energies below a few MeV. For neutron energies of about 10 MeV, a cross section for (1) of the order of 0.04 b obtains, for which a detector 5 mm thick has an efficiency of 0.001.

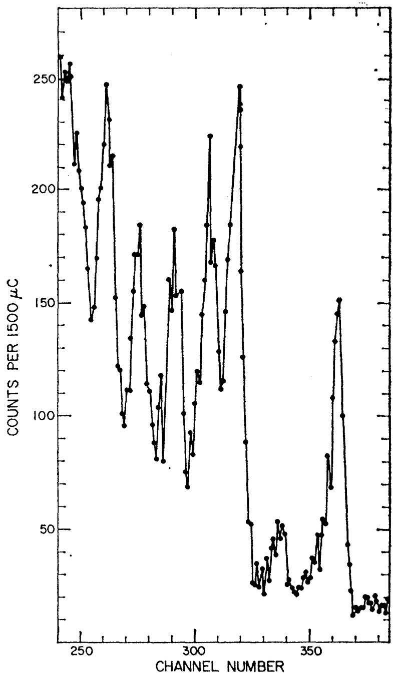

FIG. 2. Pulse-height spectrum from $B^{10}(He^3,n)N^{12}$ at $E_{He^3}=10.056$ MeV. Compare Fig. 1.

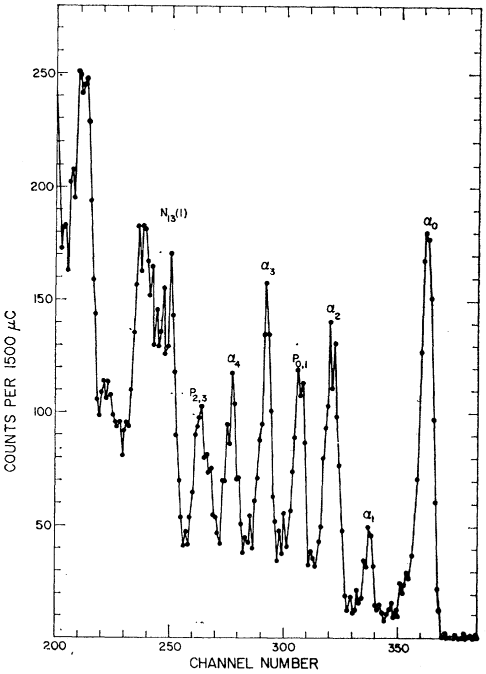

FIG. 1. Pulse-height spectrum due to neutrons from $B^{10}(He^4,n)N^{13}$ reacting in the silicon detector. The peaks above channel 260 are due to various reactions involving the 11.242-MeV ground-state neutron group, as described in the text. The abscissa energy scale is about 23.6 keV per channel. $E_{He^4}=11.000$ MeV.

The measurements were made with a lithium-drifted detector,[6] gold-surface-barrier type, 10 mm in diameter by 5 mm thick, operated at 500-V bias at atmospheric pressure. The temperature was reduced by mounting the detector on an aluminum bar, the other end of which was immersed in liquid nitrogen. To prevent moisture condensation, the chilled detector and connectors were enclosed with a drying agent. In this configuration, the photopeak of 661-keV gamma rays was observed with a width less than 15 keV.

A target, consisting of 75 $\mu g/cm^2$ of B^{10} (96%) on tantalum backing, was placed at 50° to the incident beam, and bombarded either with 11.000-MeV He^4 or 10.056-MeV He^3 ions from the ONR-CIT Tandem accelerator. The beam energies were defined by magnetic analysis to an estimated relative precision of ±7 keV. (Note that only the relative accuracy of the two beam energies enters into the final calculations.) With these bombarding energies, the neutrons from the two reactions $B^{10}(He^4,n)N^{13}$ and $B^{10}(He^3,n)N^{12}$ have very nearly the same energy, facilitating the comparison measurement. The target thickness corresponds to an energy loss in the two cases of 52 and 43 keV, respectively. The distance from target to detector was 37 mm, for which the maximum energy spreads due to kinematics were 33 and 29 keV, respectively.

III. RESULTS

Typical spectra obtained in the two cases are shown in Figs. 1 and 2. In the first, for $B^{10}(He^4,n)N^{13}$, the seven highest energy prominent peaks are all attributed

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[6] Manufactured by Technical Measurements Corporation, San Mateo, California.

to reactions (1) and (2) with the ground-state neutron group, and are accordingly labeled with the outgoing light particle; the subscripts denote the states of the outgoing nuclei Mg^{25} and Al^{28} produced in the reactions. Small contributions from reactions (3) and (4) may be seen at about channel 350, due to $Si^{29}(n,\alpha_2)$ and $Si^{29}(n,p_0)$. The neutrons produced when N^{13} is formed in its first excited state should spawn a new series of such peaks, with the highest at channel 250 as indicated. Although it is not significant for the Q-value measurements, it should be noted that the pulse heights corresponding to reaction (2) appear consistently lower by about 100 keV than those for the same energy released in reaction (1).

In Fig. 2, for $B^{10}(He^3,n)N^{12}$, the spectrum is essentially the same as in Fig. 1 above channel 325, except for a small background extending to higher pulse heights, which is presumed to be due to the B^{11} (4%) in the target. In seven spectra like Fig. 1 and six like Fig. 2, the centroids of the highest peaks were found in a systematic way, and used to determine the difference in the neutron energies for the two reactions. The result and its standard deviation is $\Delta E_n = 1 \pm 6$ keV. From this and the bombarding energies, the ground-state Q value for $B^{10}(He^3,n)N^{12}$ is 1.561 ± 0.009 MeV. Included is a -6-keV correction for differences in target thickness and kinematic energy spreads. Since great stability is obviously required for these measurements, the electronic gain was determined to $\pm 0.04\%$ by monitoring with a pulser with standard cell reference during the runs.

Below channel 325, two peaks appear, which, by comparison with intensities in Fig. 1, are attributed (in part) to two additional neutron groups from $B^{10}(He^3,n)$. Their positions were determined from plots of differences of (He^3,n) and (He^4,n) spectra, which is equivalent to subtracting the contribution of the (He^3,n) ground-state group. The results, expressed as excitation of the corresponding states in N^{12}, are $E_{x1} = 0.994 \pm 0.020$ MeV and $E_{x2} = 1.22 \pm 0.03$ MeV. The presumably analogous excited states in the mirror nucleus B^{12} are at 0.947 and 1.67 MeV, and the corresponding energy separations of $T=1$ states in C^{12} are 1.00 and 1.47 MeV.

Combining the Q_0 value from this measurement with that of Fisher and Whaling gives $Q_0 = 1.563 \pm 0.009$ MeV and an end-point energy for the N^{12} positron decay of 16.327 ± 0.009 MeV. With this and data on the half-lives and branching ratios summarized by Fisher,[7] we find[8] $ft(B^{12}) = (1.180 \pm 0.007) \times 10^4$ sec, $ft(N^{12}) = (1.306 \pm 0.009) \times 10^4$ sec, and $ft(N^{12})/ft(B^{12}) = 1.11 \pm 0.01$.

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[7] T. R. Fisher, Phys. Rev. **130**, 2388 (1963).

[8] National Bureau of Standards AMS 13, 1952 (unpublished).