the heavy fragment). On this basis it is reasonable that the two-neutron difference in the compound system be shared between the very asymmetric fragments, as is observed.

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Q Value for the $B^{10}(He^3,N^{12})n$ Reaction by Magnetic Analysis*

T. R. Fisher† and W. Whaling
California Institute of Technology, Pasadena, California
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The Q value for the reaction $B^{10}(He^3,N^{12})n$ has been measured by observing the $(N^{12})^{5+}$ recoil ions in a magnetic spectrometer at 10-MeV bombarding energy. Observations at 1.7° and 7.0° laboratory angle yield $Q=1.570\pm0.025$ MeV, based on the ThC′ alpha line at 8.7841 MeV. The N^{12}-C^{12} mass difference computed from this Q value corresponds to an endpoint energy of 16.320 MeV for the N^{12} beta decay and a ft value of $(1.29\pm0.02)\times10^4$. The ratio $ft(N^{12})/ft(B^{12})$ becomes 1.10 ± 0.02.

I. INTRODUCTION

RECENT interest in the beta spectra of B^{12} and N^{12} has stimulated remeasurements of the ft values for these decays.[1,2] Our knowledge of the ft value for N^{12} is limited by the uncertainty in the end point energy of this decay, which can be calculated from the N^{12}-C^{12} mass difference. This mass difference is determined from a cycle of nuclear reaction energies, in which the least certain link is the $B^{10}(He^3,n)N^{12}$ Q value determined by neutron energy measurements in emulsions.[3] We have remeasured this Q value using a magnetic spectrometer to measure the energy of the recoil N^{12} ions.

II. EXPERIMENTAL METHOD

The ONR-CIT tandem accelerator provided a $(He^3)^{++}$ beam of energy 10.009 ± 0.006 MeV. The uncertainty in the beam energy arises from the width of the entrance and exit slits, both of 0.2032-cm full width, on the 90° beam analyzing magnet of 86.36-cm radius. The beam from the tandem was passed through crossed electric and magnetic fields to filter out a weak heavy ion contaminant in the He^3 beam.

The B^{10} target was an unsupported foil of metal enriched to 94% B^{10}. To prepare these foils, a 400-Å layer of $BaCl_2$ was evaporated onto a clean glass microscope slide, and a layer of boron was deposited on this substrate by vacuum evaporation from a W boat. The boron foils were floated off on water and picked up on tantalum frames to expose an unsupported area of 0.6350-cm diameter. Analysis of the target composition by elastic proton scattering shows these foils to contain about 75% B atoms by number, with carbon and oxygen the principal contaminants.

Only trace amounts of tungsten, less than 0.5% by number of atoms, were evaporated along with the boron. The 5.3-MeV N^{12} ions were observed to lose 114 keV in passing through the foil used in the Q-value measurement, from which we estimate the energy loss of the 10-MeV He^3 beam in the foil to be 4.4 keV.

The 180° double-focusing magnetic spectrometer of 60.96-cm radius was set at 0° to observe the recoil N^{12} ions. Horizontal and vertical slits at the entrance of the spectrometer defined a square aperture with sides displaced 2.0° from the beam axis, and a square beam catcher with sides 1.1° off the beam axis prevented the He^3 beam from entering the spectrometer and permitted the usual integration of the beam current. The average angle of observation computed for this entrance aperture between the square at 1.1° and square at 2.0° is 1.73°.

The particle groups emerging from the spectrometer were detected in a Au-Si surface barrier counter located behind a 0.3175-cm slit in the focal plane. The detector output was fed into a 100-channel pulse-height analyzer, and a typical pulse spectrum is shown in Fig. 1. The energy of a particle group, determined to better than 4% from the pulse height in Fig. 1, together with the magnetic rigidity fixed by the spectrometer, provides

* Supported by the U. S. Office of Naval Research.
† Present address: Physics Department, Stanford University, Stanford, California.
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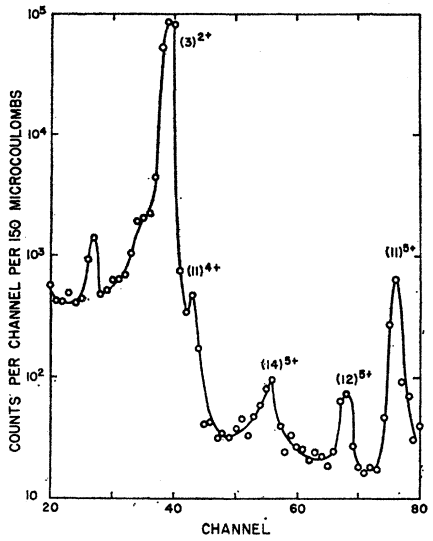

FIG. 1. Pulse-height spectrum at a spectrometer field corresponding to $AE/Q^2=2.512$ MeV, where E is the energy of ion $(A)^{Q+}$. The strong He^3 group comes from small angle scattering in the target of low-energy He^3 ions which are present in the incident beam as a result of slit scattering. The spectrometer angle is 1.73°.

an unambiguous identification of the group in channel 68 as a mass 12 ion in the charge state 5+. We cannot distinguish C^{12} from N^{12} by detector response nor by variation of particle energy with angle. However, if one assumes that the $(12)^{5+}$ ions are C^{12} particles from the reaction $B^{10}(He^3,p)C^{12}$, our Q-value measurement requires a narrow state in C^{12} at 18.108-MeV excitation energy which decays by gamma emission. No such state is known and we conclude that this group is due solely to N^{12} in the charge state 5+ coming from the reaction $B^{10}(He^3,n)N^{12}$.

The magnetic field in the spectrometer was measured with a proton moment magnetometer designed for use in nonuniform magnetic fields and located in a part of the field not traversed by the deflected particles. The magnetometer was calibrated with the alpha line[4] at 8.7841±0.0028 MeV from a ThC′ source deposited from thoron gas on a highly polished stainless steel surface. The spectrometer was calibrated with the same entrance aperture used to observe the N^{12} ions in order to avoid errors arising from aberrations. The magnetic beam analyzer of the tandem was then calibrated by setting the spectrometer at the field corresponding to the ThC′ alpha line and sending the $(He^3)^{++}$ beam directly into the spectrometer through a 0.2-mm aperture located at the target position. Since the 90° beam analyzer is a uniform field magnet with a proton moment magnetometer, perfect linearity was assumed between magnetometer reading and particle rigidity. This assumption was checked experimentally using a He^4 beam and found good to 1 part in 3000 over a range of field settings corresponding to a range of 2.5 to 10 MeV in alpha-particle energy. For the double-focusing magnetic spectrometer the relation between measured field and particle momentum is not perfectly linear, and the calibration figure obtained for the beam analyzing magnet was used to calibrate the spectrometer at the field setting corresponding to the 5.3-MeV N^{12} 5+ ions, again by sending the beam directly into the spectrometer. By using this calibration procedure, the energy of both the incident He^3 beam and the N^{12} ions is measured in terms of the ThC′ energy, which therefore appears as a factor in the final Q value. The uncertainty introduced into the Q-value measurement due to the uncertainty in the calibration of the 90° magnet and the spectrometer was negligible in comparison with the statistical uncertainty in locating the position of the step in Fig. 2.

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III. RESULTS

The N^{12} momentum spectrum is shown in Fig. 2. The width of the step at 5.3 MeV arises from the finite width of the collecting slit and beam spot, the energy spread in the He^3 beam, and the variation in N^{12} energy with angle over the aperture of the spectrometer. The energy spread contributed by each of these is shown in the figure. The distance between the half-height points of the front and back edges of the group in Fig. 2 is a measure of the energy loss of the N^{12} ions in the target. The N^{12} ions of highest energy are those that come from the back of the target. Consequently, we subtract the 4.4 keV lost by the He^3 in passing through the target from the beam energy before computing the Q value.

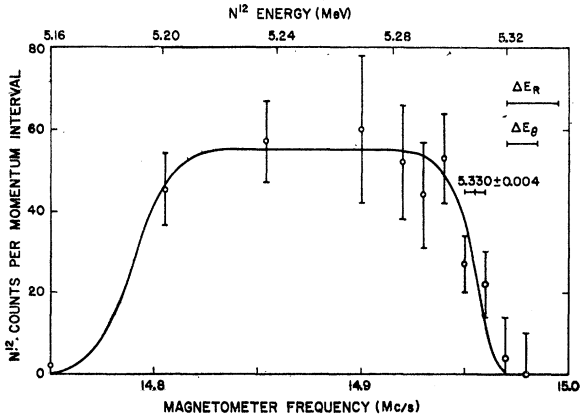

FIG. 2. Momentum spectrum of $(N^{12})^{5+}$ from $B^{10}(He^3,n)N^{12}$ at 10-MeV bombarding energy, 1.73° laboratory angle. The magnetometer frequency is proportional to particle momentum, and the momentum interval is $P/720$. The width of this group indicates the energy loss ΔE_T of N ions passing through the target, and the midpoint of the leading edge of the step corresponds to ions coming from the back surface of the target. The uncertainty assigned to the position of this step, shown by the error bars, contributes an uncertainty of ±17 keV to the Q value. Factors contributing to the shape of the leading edge are shown: ΔE_R from the finite size of the collecting slit and beam spot size, and ΔE_θ from the variation of N^{12} energy with angle over the entrance aperture of the spectrometer.

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 ±0.1° 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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Q Values for $B^{10}(He^3,n)N^{12}$ and N^{12*} †

R. W. KAVANAGH
California Institute of Technology, Pasadena, California
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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]:

$$Si^{28}(n,\alpha)Mg^{25},\quad Q_0=-2.655\pm0.003\text{ MeV} \quad (1)$$
$$Si^{28}(n,p)Al^{28},\quad Q_0=-3.857\pm0.004 \quad (2)$$
$$Si^{29}(n,\alpha)Mg^{26},\quad Q_0=-0.036\pm0.004 \quad (3)$$
$$Si^{29}(n,p)Al^{29},\quad Q_0=-2.898\pm0.007 \quad (4)$$
$$Si^{30}(n,\alpha)Mg^{27},\quad Q_0=-4.213\pm0.005 \quad (5)$$
$$Si^{30}(n,p)Al^{30},\quad Q_0=-6.51\pm0.25. \quad (6)$$

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