Half-Lives of N^{12} and B^{12}†

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The half-lives of N^{12} and B^{12} have been measured with high precision because of recent interest in the spectrum shape of these two beta emitters. The N^{12} and B^{12} activities were made in the reactions $B^{10}(He^3, n)N^{12}$ and $B^{11}(d,p)B^{12}$ by bombarding boron targets with He^3 ions and deuterons. The beam was obtained from the 3-MeV electrostatic accelerator at the Kellogg Radiation Laboratory, and was pulsed on for 20 msec and off for 180 msec. During the "beam-off" period, the counts from the N^{12} or B^{12} activity were recorded as a function of time using a 400-channel time interval analyzer. The measured values for the half-lives are $t_{1/2}(N^{12})=10.95\pm0.05$ msec and $t_{1/2}(B^{12})=20.3\pm0.1$ msec. Using these values, the ft values for the decays of N^{12} and B^{12} to the ground state of C^{12} are $ft(N^{12})=(1.33\pm0.027)\times10^4$ and $ft(B^{12})=(1.17\pm0.012)\times10^4$. The uncertainties quoted for the ft values include the uncertainties in the branching ratios and end-point energies for the two decays.

I. INTRODUCTION

OUR primary objective has been to compare the ft values for the decay of N^{12} and B^{12} to the ground state of C^{12}. From conservation of isotopic spin, one expects these two ft values to be identical except for possible small differences due to Coulomb effects on the nuclear matrix elements. Previous measurements of the N^{12} and B^{12} half-lives, which are listed in Table I,

TABLE I. Previous measurements of B^{12} and N^{12} half-lives

	$t_{1/2}$ in msec	Reference
B^{12}	22±2	[a]
	27±2	[b]
	22±1	[c]
	$18_{-1.3}^{+1.5}$	[d]
	18.5 ±1	[e]
	20.4 ±0.4	[f]
	20.2 ±0.2	[g]
	20.3 ±0.1	This experiment
N^{12}	12.5 ±1	[h]
	11.2 ±0.4	[f]
	11.0 ±0.1	[g]
	10.95±0.05	This experiment

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[f] B. J. Farmer and C. M. Class, Bull. Am. Phys. Soc. **4**, 278 (1959).
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show some discrepancies and we have therefore remeasured these half-lives.

II. EXPERIMENTAL PROCEDURE

Enriched (96% B^{10}) and natural boron targets were produced by thermal decomposition of diborane[1] and bombarded with a He^3 or D^2 beam to produce N^{12} or B^{12} in the reactions $B^{10}(He^3,n)N^{12}$ and $B^{11}(d,p)B^{12}$. The beam was interrupted periodically, and the decay of the activity as a function of time was observed with the beam off.

Beta particles were detected in an anthracene crystal scintillator, 0.375 in. thick by 1.5-in. diam, mounted on the face of a 6292 Dupont photomultiplier tube. The front face of the crystal was located 0.75 in. from the target, with a 0.150-in. aluminum barrier between the target and the crystal to stop beta particles of energy less than 2 MeV. High-energy beta particles (E_{max} =16.43 MeV for N^{12}, 13.369 MeV for B^{12}) lose only about 2 MeV in passing through the crystal, and the pulse-height spectrum shown in Fig. 1 has a peak corresponding to this energy loss. An integral pulse-height discriminator biased at channel 60 in Fig. 1 was used to bias out the low-level noise.

The beam was chopped by applying a negative 300 V to the grid of the radio-frequency oscillator in the ion source to extinguish the discharge. A beam pulse lasted for 20 msec with an interval of 180 msec between pulses. After leaving the accelerator, the beam passed near an insulated beam sensing electrode, and the voltage signal induced on this electrode was used to synchronize the operation of gating and control circuits with the beam pulses.

A 400-channel differential pulse-height analyzer manufactured by Radiation Instrument Development Laboratories was used to record beta-particle counts as a function of time. The analyzer was operated in the time mode. In this mode of operation, the pulses of

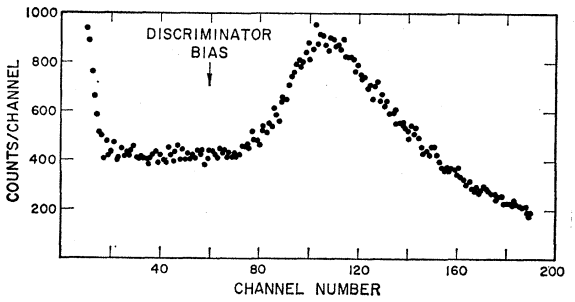

FIG. 1. Spectrum of beta particles from B^{12} obtained with anthracene crystal. The peak in the figure corresponds to an energy loss of about 2 MeV in the crystal. The spectrum of beta particles from N^{12} was almost identical to the B^{12} spectrum.

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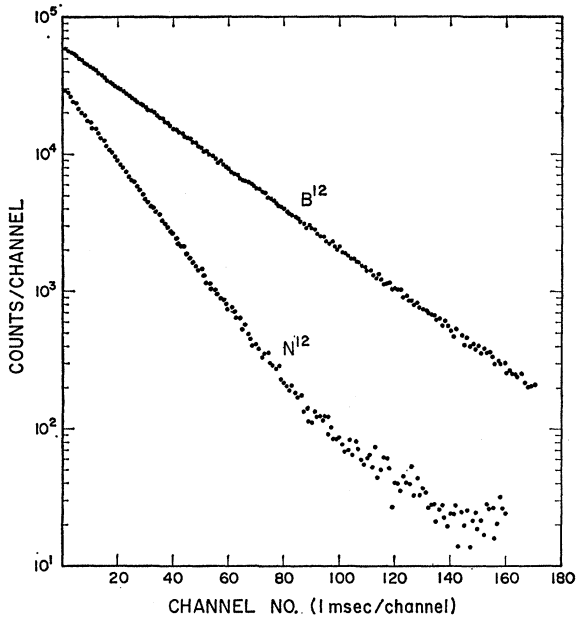

FIG. 2. Decay curves of N^{12} and B^{12}, uncorrected for experimental errors.

constant amplitude from the integral discriminator were fed into the analyzer and all pulses were stored in channel N until an external timing signal advanced the storage address to channel $N+1$. With a series of equally spaced timing pulses, the number of counts per channel as a function of channel number was proportional to the number of decays as a function of time. Timing pulses of 2-μsec duration with a 1-kc/sec repetition rate were obtained by scaling down the output of a 100.000-kc/sec crystal-controlled oscillator by a factor of 100 and shaping the output pulse. The analyzer storage was reset to channel zero at the end of each beam pulse by the signal from the beam-sensing electrode.

III. B^{12} HALF-LIFE

The decay curve for B^{12}, uncorrected for experimental errors, is shown in Fig. 2. The total running time for this measurement was approximately one hour. In determining the B^{12} half-life from Fig. 2, the following three sources of experimental error were considered:

1. Constant Background

Other beta emitters which can be produced in the target have half-lives at least 200 times as long as that of B^{12}. We, therefore, assume that any background present is constant in time. This constant background was estimated by comparing the slope of the last portion of the decay curve (channels 130 to 150) with the slope of the central portion (channels 20 to 130). The estimated background was 17 ± 17 counts per channel.

2. Dead Time

The approximate duration of a beta pulse was 2 μsec and the recovery time of the integral discriminator was 2 μsec. Since the counting rate in channel 1 of Fig. 2 was approximately 4000 counts/sec for the B^{12} measurement, the percent dead time in channel 1 was estimated to be 0.8%. The correction for dead time led to a reduction of 0.1% in our final value for the B^{12} half-life.

3. Change in Photomultiplier Gain with Counting Rate

At high counting rates, additional currents flow between the phototube dynodes, and the dynode bias and gain per stage is altered. A careful comparison of the beta-particle pulse-height spectra taken at different counting rates showed a gain change of less than 4% for counting rates up to 4000 counts/sec. It was possible to show that a gain change of this magnitude could not introduce any significant error into our final value for the B^{12} half-life.

The B^{12} decay curve was divided into three sections: (a) channels 1 to 20, (b) channels 20 to 130, and (c) channels 130 to 150. The three sections were each fitted by least squares to give a value for the B^{12} half-life. The values obtained were 20.30 ± 0.1, 20.40 ± 0.03, and 20.70 ± 1.0 msec, respectively. The values for sections (b) and (c) were compared to obtain the estimate of 17 ± 17 counts per channel for the constant background. Section (b) was then corrected for this constant background and for dead time and the least-squares fit was repeated. This gave the value 20.30 ± 0.1 msec for the B^{12} half-life which we take as our final value. The additional uncertainty in this figure is due to the uncertainty in the background correction.

IV. N^{12} HALF-LIFE

The decay curve for N^{12}, uncorrected for experimental errors, is shown in Fig. 2. The total running time for this measurement was approximately one hour. The same sources of experimental error were considered as in the analysis of the B^{12} decay curve. The constant background was estimated from the counting rates in channels 140 to 160 of Fig. 2 to be 20 ± 5 counts per channel. Corrections for dead time and phototube gain change were negligible.

In the analysis of the N^{12} decay curve, it was necessary to consider two additional sources of error:

(1) B^{12} Background. Due to the presence of an HD component in the He^3 beam, some B^{12} is produced in the target in the reaction $B^{11}(d,p)B^{12}$, and this background cannot be treated as constant in time. A correction can be made for B^{12} background if we know the initial ratio of B^{12} activity to N^{12} activity at time $t=0$ (channel 1 of Fig. 2). The measurement in Fig. 2 was made with an enriched B^{10} target (96% B^{10}, 4% B^{11}).

To estimate the "initial" ratio of B^{12} to N^{12}, a similar measurement was made with a natural boron target (19% B^{10}, 81% B^{11}). Since the ratio of B^{11} to B^{10} was increased by a factor of 87 by the substitution of the natural boron target, the initial ratio of B^{12} to N^{12} was increased by a factor of 87 over that in Fig. 2. Under these conditions, the presence of B^{12} showed up clearly as "gradual curvature in the decay plot and the ratio B^{12}/N^{12} ($t=0$) could be estimated. With the natural boron target, we obtained B^{12}/N^{12} ($t=0$)$=0.50\pm0.07$. Dividing this by 87 gave B^{12}/N^{12} ($t=0$)$=0.0057\pm0.008$ for the measurement in Fig. 2.

(2) Loss of Nitrogen from Target. Since nitrogen is normally a gas, it was necessary to show that the half-life measurement was not significantly affected by loss of N^{12} from the target. To check this point, the half-life of N^{13} was measured making use of the reaction $B^{11}(He^3,n)N^{13}$ to produce the N^{13}. We obtained the value 10 ± 1 min for the half-life, in good agreement with the accepted value of 10.05 min. Since the half-life of N^{12} is some 60 000 times shorter than this, we assume that loss of nitrogen from the target could not occur rapidly enough to affect the N^{12} half-life measurement significantly.

The N^{12} decay curve in Fig. 2 was corrected for constant background and B^{12} background and the central portion (channels 10 to 90) was fitted by least squares to give the N^{12} half-life. Our final value is 10.95 ± 0.05 msec. The uncertainty in this figure includes the statistical uncertainty and the uncertainty in the background corrections. As a check on this result, channels 1 to 10 and channels 90 to 110, corrected for background, were also fitted by least squares. The results (10.95 ± 0.13 and 11.82 ± 1.1 msec) were consistent with the value 10.95 ± 0.05 msec obtained by fitting channels 11 to 90.

V. *ft* VALUES

Using our values of 20.30 ± 0.1 and 10.95 ± 0.05 msec for the half-lives of B^{12} and N^{12} we have calculated the *ft* values for the decays to the C^{12} ground state. The end-point energies and branching ratios were taken from the work of other investigators as given in Table II. The *f* values were calculated by numerical integration using the tables of the National Bureau of Standards.[2] The calculated value for the ratio $(ft\,N^{12})/(ft\,B^{12})$ is 1.14 ± 0.025. The uncertainty in this figure is due mainly to the uncertainty in the end-point energy of the N^{12} decay. There are no known corrections to the *f* values, such as the inclusion of the effects of second forbidden terms, etc., which appear capable of changing this ratio by much more than a percent. It also seems unlikely that the large difference of 14% is due to experimental errors. It is then necessary to explain a difference of 14% in the nuclear matrix elements for the two decays.

TABLE II. Experimental data used in the calculation of *ft* values for the decays of B^{12} and N^{12} to the C^{12} ground state.

			Reference
B^{12}	Half-life	20.30 ± 0.1 msec	Present experiment
	E_β(max)	13.369 ± 0.001 MeV	[a]
	Branch to 4.4-MeV state of C^{12}	$1.3\pm0.1\%$	[b]
	Branch to 7.65-MeV state of C^{12}	$1.3\pm0.4\%$	[c]
	Branch to 10.1-MeV state of C^{12}	$0.13\pm0.04\%$	[c]
N^{12}	Half-life	10.95 ± 0.05 msec	Present experiment
	E_β(max)	16.43 ± 0.06 MeV	[d]
	Branch to 4.4-MeV state of C^{12}	$2.4\pm0.2\%$	[b]
	Branch to 7.65-MeV state of C^{12}	$3.0\pm0.4\%$	[e]
	Branch to 10.1-MeV state of C^{12}	Unknown, assumed zero	
For the ground-state decays:		$ft(N^{12})=(1.33\pm0.027)\times10^4$ $ft(B^{12})=(1.17\pm0.012)\times10^4$ $ft(N^{12})/ft(B^{12})=1.14\pm0.025$	

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[2] *Tables for the Analysis of Beta Spectra*, Applied Mathematics Series, No. 13 (National Bureau of Standards, Washington, D. C., 1952).