Beta-ray branching and half-lives of ^{12}B and ^{12}N†

D. E. Alburger and A. M. Nathan*
Brookhaven National Laboratory, Upton, New York 11973
(Received 17 August 1977)

The ratio of ^{12}B and ^{12}N β-ray branches to the 4.44-MeV excited state of ^{12}C was measured by detecting β rays in a 4π plastic scintillator and γ rays in two Ge(Li) detectors. Activities were made in the $^{11}B(d,p)^{12}B$ and $^{10}B(^{3}He,n)^{12}N$ reactions using a chopped Van de Graaff beam. Data were stored in two successive computer time bins of two half-lives each in order to establish by subtraction the shape of the short-lived β-ray spectrum and its net number of counts. The ratio of these branches was found to be $^{12}N/^{12}B = 1.56 \pm 0.05$. A measurement of the ^{12}B absolute β-ray branch to the 4.44-MeV state via β-γ coincidences using an NaI(Tl) detector for the γ rays gave a value of $1.276 \pm 0.050\%$. Half-lives, obtained by multiscaling β-ray counts, were found to be 20.20 ± 0.02 msec for ^{12}B and 11.000 ± 0.016 msec for ^{12}N. The mirror asymmetries derived from these results are $\delta = +0.044 \pm 0.034$ for the decay to the 4.44-MeV state of ^{12}C and $\delta = +0.129 \pm 0.008$ for the branch to the ground state.

[RADIOACTIVITY ^{12}B, ^{12}N: Measured I_β, I_γ, β-γ coin, $T_{1/2}$; deduced β-ray branches, mirror asymmetries.]

I. INTRODUCTION

The β-ray branches of ^{12}B and ^{12}N to the 4.44-MeV first-excited state of ^{12}C have been involved in several crucial tests of β-decay theory. One test has to do with the conserved vector current (CVC) theory which predicts certain deviations of the ground-state β-ray branches of ^{12}B and ^{12}N from the so-called allowed shape. In an experimental determination[1] of the ground-state β-ray shape factors it is important to correct for the presence of inner β-ray branches and thus an accurate knowledge of the branching intensities to the 4.44-MeV state is important. These branches are also significant[2] in the study of mirror symmetry and the search for possible second-class currents in the β-ray interaction. While a large asymmetry has been known for a long time in the $A = 12$ ground-state β-ray branches, and indeed was largely responsible for starting a long series of experiments on other mirror decays, the corresponding information on the $A = 12$ branch to the 4.44-MeV state has been very elusive because of the small values for these branches and the general difficulties of the measurements. Although fairly accurate and concordant results have been obtained for the absolute β-ray branching of ^{12}B to the 4.44-MeV state, leading to an adopted mean[3] of $1.29 \pm 0.05\%$, the various measurements of the ratio of $^{12}N/^{12}B$ branches to this state have been in poor agreement. Two early results for this ratio were 1.84 ± 0.1 obtained by Peterson and Glass[4] and 1.72 ± 0.15 found by Wilkinson *et al.*[5] In the two most recent measurements the ratio $^{12}N/^{12}B = 1.52 \pm 0.06$ at this laboratory[6] gave an asymmetry $\delta = +0.06 \pm 0.04$ while the results of McDonald *et al.*[3] for $^{12}N/^{12}B$ was 1.74 ± 0.08. By itself the latter would have given a large negative value for δ but because of uncertainties in both experiments McDonald *et al.* combined their result with that of Ref. 6 and used the mean ratio $^{12}N/^{12}B = 1.63 \pm 0.11$ to derive an asymmetry of $\delta = -0.013 \pm 0.066$.

There were several major sources of error in these two recent measurements of the $^{12}N/^{12}B$ β-ray branching ratio. Common to both experiments was a 4π plastic well-type detector for β rays and a large NaI(Tl) detector for the γ rays. In principle the measurement was simply a matter of activating a target with a chopped beam and then finding the number of 4.44-MeV γ rays per short-lived β ray in the delayed emissions, doing this for each activity without changing the geometry of the detecting system. A characteristic of the γ-ray spectra, whether in singles or in coincidence, is the presence of a continuum lying under the 4.44-MeV peaks and decreasing roughly exponentially with energy. This is due to bremsstrahlung in the case of ^{12}B and a mixture of bremsstrahlung and annihilation-in-flight radiation in the ^{12}N case. The background is especially severe in the ^{12}N spectrum making it difficult with NaI(Tl) detectors to extract the net area under the 4.44-MeV full-energy-loss peak to better than about 4% accuracy even when the statistical precision of the spectrum points is very high.

Another difficulty was in establishing the total number of short-lived β rays. In both experiments this problem was compounded by the fact that the β-ray detector was of insufficient size to absorb all of the β-ray energy thereby resulting in gross distortions of the spectrum shape. At low energies long-lived components were present in both β spectra but again ^{12}N presented a much more severe background problem because of β rays due to ^{14}O and ^{11}C. In order to correct for these long-lived backgrounds the approach used by McDonald *et al.*[3] was to multiscale the detector outputs so that the net number of short-lived β rays could be found down to very low energies. This was done at a considerable cost in the statistical accuracy of the γ-ray spectrum. The method[6] at this laboratory, on the other hand, used a short irradiate-count cycle with inherently high statistical accuracy but depended on an uncertain spectrum extrapolation to derive the net number of short-lived β rays. It has been evident that improved methods were needed to measure these branches.

The half-lives of ^{12}B and ^{12}N are, of course, fundamental in studying the mirror symmetry of the $A = 12$ ft values. For ^{12}B the presently accepted value of the half-live is 20.41±0.06 msec[7] representing the weighted mean of 10 measurements. In the case of ^{12}N there have been five measurements leading to a weighted mean of 10.97±0.04 msec[7] for the half-life. The most recent half-life determinations were those of Fisher[8] who obtained 20.3±0.1 msec for ^{12}B and 10.95±0.05 msec for ^{12}N. Curiously enough, in spite of the prime importance of the $A = 12$ system in mirror symmetry studies there have been no measurements of these half-lives to better than 0.5% accuracy and none reported more recently than 1963. In Fisher's work single runs of 1-h duration each were made on ^{12}B and ^{12}N and the decay curves were not multiscaled long enough to reach the long-lived background. Furthermore the ^{12}N data had to be corrected for the presence of a small ^{12}B contaminant. With the more modern techniques now available it was felt that both of these half-lives should be remeasured. The means also exist at our laboratory for making ^{12}N completely free of ^{12}B contamination.

II. EXPERIMENTAL PROCEDURES FOR BRANCHING RATIO MEASUREMENTS

The present experiment was designed to overcome some of the difficulties of the two most recent measurements[3,6] of the β-ray branches. It was felt that a well-type β-ray detector should be used that is large enough to absorb the energies of all β rays emitted from the target so as to yield an undistorted spectrum. In order to properly account for the long-lived background in the β-ray spectrum without a severe loss of statistical accuracy the scheme adopted was to store all of the data in two successive time bins of approximately two half-lives each. If N_0 is the number of short-lived radioactive nuclei present in the target at the beginning of counting then the number of short-lived counts in the first time bin is proportional to $\frac{3}{4}N_0$ (if the bin is exactly two half-lives in duration) and to $\frac{3}{16}N_0$ in the second bin. Thus, if the accumulated spectrum in the second bin is subtracted from that of the first bin, after correcting each bin for dead time, all of the long-lived background should subtract out, as well as some of the short-lived spectrum, leaving a number proportional to $\frac{9}{16}N_0$ in the net spectrum. It should then be possible with this presumably undistorted net spectrum to extrapolate below the low-energy bias to zero energy thus correcting for counts below the bias. The total short-lived β-ray spectrum thus obtained may then be multiplied by $\frac{4}{3}$ to compare with γ rays recorded during the first time bin. This method should remove the long-lived background without the excessive time consumption of multiscaling, as in the Lockheed experiments,[3] although the data accumulation is slower than in the earlier Brookhaven measurements.[6]

The other major difficulty of extracting the intensity of 4.44-MeV γ rays against the background continuum as experienced with NaI(Tl) detectors can be solved by the use of Ge(Li) detectors. The high resolution of a Ge(Li) detector greatly enhances the peak amplitudes against background effects, thus reducing the errors in background subtraction but, of course, the efficiency of even the largest such detectors is substantially smaller than that of an NaI(Tl) cyrstal. To some extent this can be made up for by using two Ge(Li) detectors and longer counting periods. Finally, it was realized that since every 4.44-MeV γ ray is necessarily accompanied by a β ray, which is detected in the 4π scintillator, a coincidence setup is not necessary and accordingly we only counted γ-ray and β-ray singles events.

The setup for the experiments included a cylindrical NE102 plastic β-ray detector 15.2 cm diam by 15.2 cm deep with an axial hole 0.71 cm diam drilled halfway through. The reasons for using 4π geometry have been discussed previously.[3,6] This size crystal is sufficient to stop all of the β rays from either ^{12}B or ^{12}N when the source is produced in the center (except for $\lesssim 0.1\%$ escaping from the entrance hole). A 13.3-cm diam phototube (type RCA-4522) was attached to the other end of the crystal with a Lucite adaptor and optical grease. A thin-walled Be target tube was inserted in the well and the beam was collimated to a diameter of 2 mm such that it struck the target attached to a Be foil at the end of the tube. The mounting was made so that the β-ray detector could be slid back away from the target tube for convenience in changing the target. Apiezon putty was used around the well to exclude light. On either side of the NE102 crystal were located two Ge(Li) γ-ray detectors of 15% and 19% efficiency, respectively. They were placed as close as possible to the NE102 crystal so as to remain fixed in position and not interfere with the changing of targets.

Activation of the target was accomplished by chopping the beam with a slotted wheel driven by a motor of adjustable speed. There are four slots 1 cm wide in the radial direction at 90° intervals and of tangential length 2.5 cm at 10.5 cm from the center of the wheel. A light source and diode on the other side of the wheel provide a timing pulse. For the branching ratio measurements all four slots were used and in this case the beam is on 15.2% of the time.

Outputs of the three detectors were amplified and sent to a Σ-7 computer where their spectra could be routed into two successive time bins as determined by a timer-programmer.[9] Resetting of the timer-programmer cycle was done with the chopper synchronization pulse. Six scalers were used to record the number of counts in the two time bins for each of the three detectors, and thus by comparison with the total number of counts stored in the corresponding spectrum, the individual computer dead times could be determined.

The procedures for the ^{12}B and ^{12}N experiments were very similar. In the case of ^{12}B the target was a thin powder deposit of boron enriched to 97% in ^{11}B and this was bombarded with a beam of 1.5-MeV deuterons to form ^{12}B in the ^{11}B$(d,p)^{12}$B reaction. The chopper was set for a cycle time of about 140 msec allowing two successive counting intervals of 40 msec each following a bombardment of 21-msec duration and a wait of 10 msec before the start of counting. For ^{12}N the reaction was ^{10}B(^{3}He$,n)^{12}$N using a 97% enriched ^{10}B target and a 3.3-MeV ^{3}He beam. In order to avoid the production of any contaminant ^{12}B from the interaction of an HD$^+$ beam component on the 3% of ^{11}B in the target, the accelerated ^{3}He$^+$ beam was passed through a gas stripper and the resulting ^{3}He^{++} beam was analyzed. The timing sequence for the ^{12}N measurements consisted of a total cycle time of 65 msec including 10 msec of bombardment, a wait of 5 msec, and two counting intervals of 20 msec each.

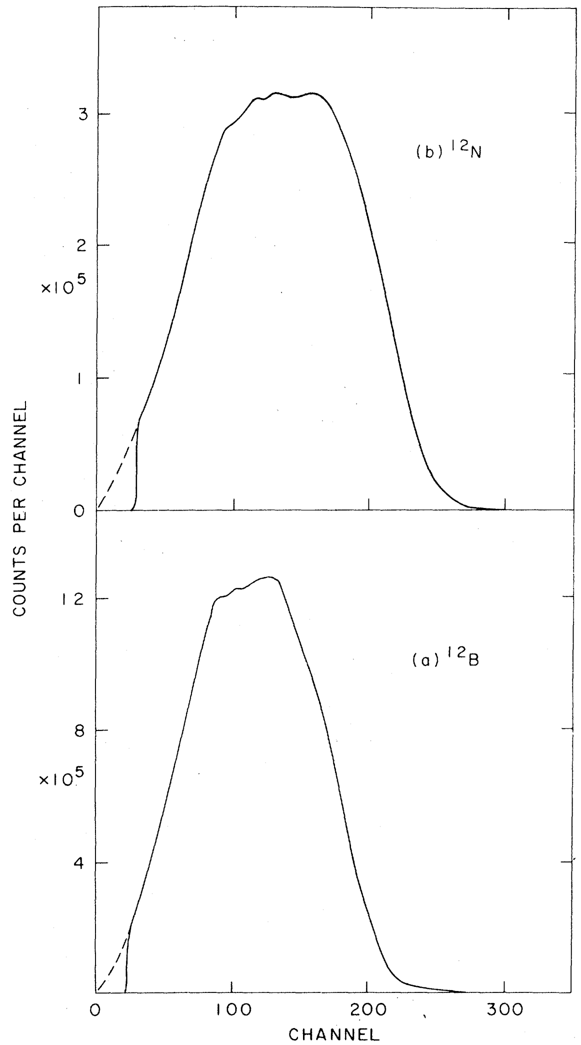

FIG. 1. (a) Net β-ray spectrum of ^{12}B observed in a 4π well-type NE102 scintillator 15.2 cm diam by 15.2 cm high. (b) Corresponding β-ray spectrum of ^{12}N. Data points have been omitted. Both spectra were obtained by computer subtraction of successive time bins of equal length (approximately two half-lives each) after dead-time corrections.

III. RESULTS OF BRANCHING RATIO MEASUREMENTS

A. Ratio of branching ratios

Four runs were made on ^{12}B using average chopped beam currents of 2, 0.5, 0.26, and 0.15 nA and total counting times of 1, 2, 4, and 8 h, respectively. After correction for dead time the net β-ray spectrum (first time bin minus the second) in one of the runs is shown in Fig. 1(a). The dashed line gives the extrapolation to zero energy according to which the fraction of counts below the bias is 1.0% of the total spectrum. The corrected total was then multiplied by the proper factor to normalize it to the first time bin duration. The multiplying factors for both ^{12}B and ^{12}N were derived by using the new half-life values reported below.

The 4.44-MeV γ-ray spectrum from each of the Ge(Li) detectors was analyzed by extracting the net areas under the full-energy, one-escape, and two-escape peaks and correcting for dead time.

For detectors of the sizes used the 4.44-MeV γ-ray one-escape and two-escape peaks are more than half as intense as the full-energy peak and thus the statistical accuracy can be improved by summing all three peaks. Thus, in the ^{12}B 8-h run at 0.15-nA beam current the sum of the net areas of the six γ-ray peaks from both detectors in the first time bin was 3621±66 counts (±1.8%). Figure 2(a) shows the peak regions from one of the detectors in the first time bin of this run.

Because of the relatively high counting rates in the ^{12}B experiments a further correction had to be made for the dead time of the β-ray scalers. This was done by plotting the ratio of the sum of γ-ray peaks to net β rays versus the beam current as shown in Fig. 3. Extrapolation to zero beam current gives a value that may be compared with the corresponding result from ^{12}N.

In the ^{12}N measurements the average $^{3}He^{++}$ beam intensity was 22 nA for four comparable runs of approximately 8 h duration each. When the subtraction of the β-ray spectrum in the second time bin from the first was made, after correcting for dead time, it was noted that not quite all of the long-lived low-energy β rays were removed. Dead times obtained by comparison of the stored β spectrum with the scalers were about 18% for the first bin and about 10% for the second bin. It was then realized that in a given time bin, because of the large amount of decay of the short-lived component, the effective dead times of the long-lived and short-lived components are somewhat different. In particular, the application of the average dead-time factor to the data of the first bin, for example, results in too little of the short-lived component and too much of the long-lived component in the corrected spectrum. A proper correction for this effect was carried out by a numerical integration method which showed that an additional correction of 1% must be made in order to subtract out all of the long-lived component. The resulting net β-ray spectrum from one of the ^{12}N runs is given in Fig. 1(b). Extrapolation of this spectrum to zero energy, as given by the dashed line, shows that 1.88% of the total spectrum was below the bias. The above dead-time effect in ^{12}N was not important for ^{12}B because of the almost negligible amount of long-lived background in the latter case. On the other hand the scaler dead-time effect described in the ^{12}B analysis was negligible for ^{12}N because of the much lower β-ray counting rate of the ^{12}N.

One may note from Fig. 1 that the shapes of the ^{12}B and ^{12}N β-ray spectra are quite similar and that the end points are approximately proportional to the known maximum energies of 13.37 MeV for ^{12}B and 16.32 MeV for ^{12}N. β-γ summing in the crystal of one or both 0.51-MeV annihilation γ rays modified the ^{12}N spectrum to some extent. The small wiggles at the tops of the two β-ray spectra may be due to variations in light-collection efficiency from different regions of the crystal, but their origin is not understood.

The γ-ray peaks from ^{12}N were well defined but the background was higher than in ^{12}B as seen in Fig. 2(b) which shows the peak regions for one of the detectors in the first time bin of one of the runs. In this run the sum of the six peak areas (for both detectors) in the first time bin was 1835 ±62 counts (±3.4%). An estimate of the summing in the Ge(Li) detector of the 0.51-MeV annihilation

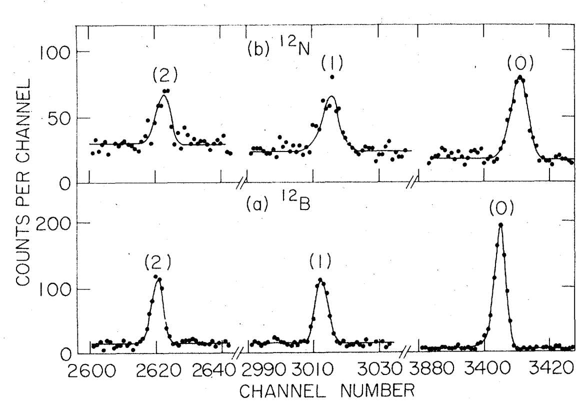

FIG. 2. Regions of the full-energy (0), one-escape (1), and two-escape (2) peaks of the 4.44-MeV γ-ray spectrum. (a) First time bin of one of the ^{12}B runs for one of the detectors. (b) First time bin of one of the ^{12}N runs for the same detector as in (a). The ^{12}N peaks were presumably broadened by a gain drift. These data represent about 15% of the total used for the analysis of the branching ratios.

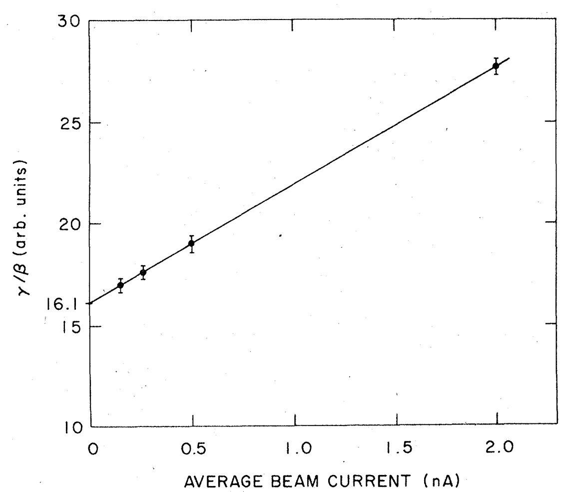

FIG. 3. Ratio of γ/β versus beam current from the four runs on ^{12}B showing the effect of scaler dead time. The extrapolation to zero beam current was used for comparison with ^{12}N.

radiation from the ^{12}N positrons with the 4.44-MeV peaks was made for the geometry of the experiment using the known efficiencies of the Ge(Li) detectors. This effect was shown to be completely negligible.

After correction of the γ/β ratios of the ^{12}B runs for scaler dead time as discussed above the final result is as follows:

$$\frac{(\gamma/\beta)_{^{12}N}}{(\gamma/\beta)_{^{12}B}} = 1.56 \pm 0.05 .$$

Contributions to the overall error include $\pm 3.0\%$ for the uncorrected ratio of (γ/β) ratios, $\pm 1\%$ for uncertainties in the extrapolation of the β-ray spectra below their biases, and $\pm 2.0\%$ for the uncertainty in the scaler dead-time correction of the ^{12}B β-ray spectrum.

B. Absolute ^{12}B β-ray branch to the 4.44-MeV state

As a check on the absolute β-ray branching of ^{12}B to the ^{12}C 4.44-MeV state, a 12.7-cm×12.7-cm NaI(Tl) detector was placed next to the NE102 β-ray detector and the β- and γ-ray spectra were recorded using coincidence techniques essentially identical to those described previously.[6] From the source-to-crystal distance and the known efficiency function[10] for this size detector, the absolute photopeak efficiency for 4.44-MeV γ rays was obtained. A calculated correction of 20% was made for the absorption of the 4.44-MeV γ rays in passing through the NE102 scintillator. After correcting for dead times and for the fraction of β rays below the low-energy bias, the ^{12}B ratio γ/β was found to be $(1.276 \pm 0.050)\times 10^{-2}$. This is in good agreement with the mean value 1.29×10^{-2} previously adopted.[3]

IV. HALF-LIVES: METHODS AND RESULTS

For the half-life measurements on ^{12}B and ^{12}N one pair of opposing slots on the chopper wheel was covered such that the beam was on 7.6% of the time. Targets were placed in a 2.5-cm diam thin-walled glass target tube, and β rays were detected in a 7.5-cm diam by 5-cm deep NE102 scintillator on an RCA 6342A photomultiplier placed next to the target tube. A special circuit was constructed that could turn off the phototube during the irradiation of the target. This was done by raising the voltage on the cathode to a value slightly more positive than that of the first dynode with a switching circuit controlled by the timer-programmer. Tests with a constant intensity source showed that the gain of the phototube was reestablished to its proper value within $\lesssim 0.2\%$ in less than 1 msec after turning the tube back on. Subsequent analysis of runs taken on both ^{12}B and ^{12}N with and without the switching circuit indicated no essential differences and all data were incorporated into the final results. The anode output of the phototube was fed directly to a fast amplifier and fast discriminator (~50-nsec pulse widths), to a gate-and-delay generator (0.4-μsec pulse width), and thence to a multiscaler.

The ^{12}B activity was produced in the $^{11}B(d,p)^{12}B$ reaction at $E_d = 1.5$ MeV. Average beam currents were from 0.06–0.2 nA in the various runs and counts were multiscaled at 2.0 msec per channel for 256 channels corresponding to a counting interval of 25 half-lives. The chopper speed was set for an overall period of about 575 msec to accomodate this sequence. β-ray biases were from 1.5 to 6.0 MeV in the various runs and spectra were accumulated until there were at least 20 000 counts in the first channel. As in the branching ratio measurements ^{12}N was made in the $^{10}B(^3He,n)^{12}N$ reaction using the $^3He^+$ accelerated beam stripped to $^3He^{++}$ to avoid any ^{12}B contamination. In this case the counts were multiscaled at 0.8 msec per channel for 256 channels, corresponding to 19 half-lives, and to accommodate this sequence the chopper was set for a cycle time of about 240 msec. Average beam currents were from 15 to 40 nA and biases ranged from 2.5 to 7.5 MeV. Data were accumulated in each run until there were at least 20 000 counts in the first channel.

The decay curves were analyzed using a nonlinear least-squares minimization program to fit the data points to an exponential plus constant. This long-lived background was typically 0.03–0.05% for ^{12}B and 0.2–0.3% for ^{12}N of the counts in the first channel. In Fig. 4 we plot the half-lives deduced from this analysis. The final result was 20.20 ± 0.02 msec for the half-life of ^{12}B (based on the weighted average of 20 runs) and 11.000 ± 0.016 msec for the half-life of ^{12}N (based on the weighted average of 14 runs). The final uncertainty is about 3 times the statistical error and represents the scatter of the individual runs as a function of both the detector bias and the region of the decay curve over which the fit was performed.

V. ANALYSIS

Our result for the ^{12}B absolute β-ray branch of $1.276 \pm 0.05\%$ to the 4.44-MeV state may be combined with the previously adopted value[3] of 1.29 $\pm 0.05\%$ to obtain a mean of $1.283 \pm 0.040\%$. We make no attempt to combine our new result for the ratio of γ/β ratios with previous measurements but use our own value of 1.56 ± 0.05 in this analysis and obtain a ^{12}N branch of $2.00 \pm 0.10\%$ to the 4.44-MeV state. These new values together with previously measured β-ray branches of both ^{12}B and ^{12}N to other excited states[7] lead to the following ground-

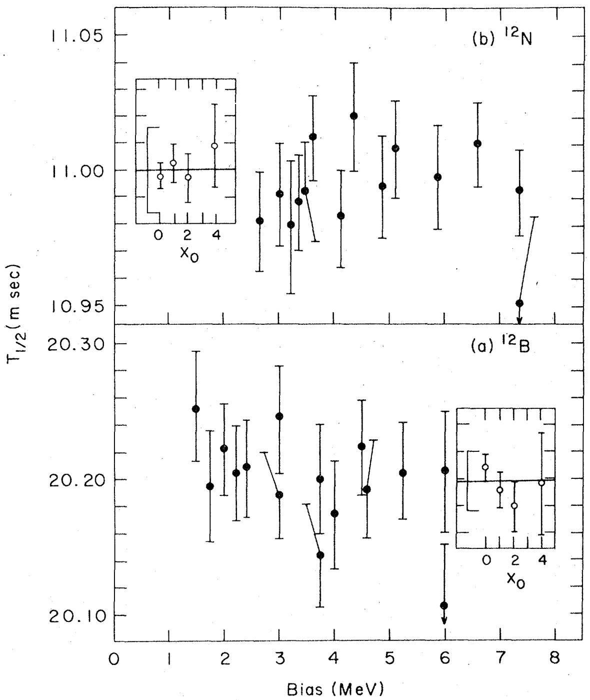

FIG. 4. Values of $T_{1/2}$ deduced from the decay curves for (a) ^{12}B and (b) ^{12}N, plotted as a function of detector bias. The errors are purely statistical. The insets show the weighted averages of fits performed by excluding the first N half-lives from the fit ($N = 0, 1, 2, 4$). The grand average of all results, 20.20±0.02 msec for ^{12}B and 11.000± 0.016 msec for ^{12}N, is indicated by the horizontal line. The final uncertainty, indicated in the inset by the vertical line, represents both the statistical uncertainty and the scatter of the individual points as a function of both the detector bias and N.

state branches—^{12}B, 97.14±0.30%; ^{12}N, 94.55 ±0.60%.

By using the f values calculated by McDonald *et al.*[3] and our own results for the half-lives and the ratio of β-ray branches we summarize the calculations of ft values for the branches of ^{12}B and ^{12}N to both the ground and 4.44-MeV states in Table I. From the last column of Table I we derive our final results for the mirror asymmetries of the $A = 12$ nuclei for decay to the 4.44-MeV and ground states of ^{12}C as follows:

$$\text{4.44-MeV state} \quad \delta = +0.044 \pm 0.034\,,$$

$$\text{ground state} \quad \delta = +0.129 \pm 0.008\,.$$

Note that the experimental error in the ratio of branches to the 4.44-MeV state leads to a smaller error for δ than would obtain from the errors of the individual absolute ft values given in the last column of Table I.

VI. DISCUSSION

In this section we consider our results in light of both the second-class-current problem and the shape factor for the $A = 12$ β-ray spectra.

Before one can examine the ft-value mirror asymmetries in terms of second-class weak currents, one must first remove the "trivial" asymmetry due to electromagnetic effects. These effects are trivial in the sense that they are physically uninteresting in the present context but quite nontrivial in that they are not easily calculable. Since these effects are generally as large as the entire effect that is observed (~10%), the study of mirror ft-value asymmetries has not been a fruitful way to look for effects of second-class currents in nuclei. Nevertheless, for the sake of further discussion, we use the calculated values, which were quoted in Ref. 3 based upon four different sets of nuclear wave functions, namely, 0.135±0.037 and 0.091±0.043 for the Coulomb part of δ for the ground-state and first-excited state decay, respectively. We are thus left with second-class contributions

$$\delta_0^{\text{scc}} = -0.006(38)\,,$$

$$\delta_1^{\text{scc}} = -0.047(37)\,,$$

which are both essentially consistent with zero.

TABLE I. ft values for ^{12}B and ^{12}N β-ray branches to the ^{12}C 4.44-MeV and ground states using present half-life values of 20.20± 0.02 msec for ^{12}B and 11.000± 0.016 msec for ^{12}N.

Final state of ^{12}C	Body	f [a]	Branch (%)	$T_{1/2}$ (msec) (Partial)	ft (sec)
4.44	^{12}B	$(8.1739 \pm 0.0056) \times 10^4$	1.283±0.040 [b]	1574 ±50	$(1.287 \pm 0.040) \times 10^5$
4.44	^{12}N	$(2.4452 \pm 0.0050) \times 10^4$	2.00 ±0.10 [c]	550 ±28	$(1.344 \pm 0.070) \times 10^5$
Ground	^{12}B	$(5.6113 \pm 0.0026) \times 10^5$	97.14 ±0.30	20.79 ± 0.07	$(1.1669 \pm 0.0037) \times 10^4$
Ground	^{12}N	$(1.1327 \pm 0.0017) \times 10^6$	94.55 ±0.60	11.634 ± 0.070	$(1.3178 \pm 0.0084) \times 10^4$

[a] Taken from Ref. 3.

[b] Weighted mean of present and previous measurements.

[c] Present measurement only. The weighted mean of this and the values in Refs. 3 and 6 results in a branch of 2.02±0.09%.

Thus although the numbers have changed slightly from the results of McDonald *et al.*,[3] the basic conclusion remains the same; i.e., there is no compelling evidence for second-class-current effects in the mirror decay rates of the mass 12 system. If we analyze our results in terms of the two-parameter theory of Kubodera, Delorme, and Rho,[11,12] using the two-body matrix elements quoted in Ref. 12, we find

$$\xi = (-0.4 \pm 1.6) \times 10^{-3}/\mathrm{MeV},$$

$$\lambda = (2.5 \pm 2.1) \times 10^{-3},$$

where ξ is related to the second-class induced tensor coupling constant for the neutron β decay and λ is a more complicated object involving second-class-current meson-exchange effects. Our present values for ξ and λ are reasonably consistent with the values $(-3.3\pm0.9)\times10^{-3}$/MeV and $(5.4 \pm 2.0)\times10^{-3}$, respectively, determined by Kubodera *et al.*[12] from analysis of the $A = 8$ ft-value symmetry and angular correlation experiments in the $A = 12$ and $A = 19$ systems.

As mentioned in the Introduction, a precise interpretation of the experimental shape factors of Lee *et al.*[1] for the ground-state β decay of ^{12}B and ^{12}N requires making the appropriate corrections for decay branches to excited states of ^{12}C. For ^{12}N the situation is particularly uncertain because of the discrepancies in the published values of the β-decay branch to the 4.44-MeV level. Thus, for example, Wu, Lee, and Mo[13] calculate that changing this branching ratio from the value accepted in 1963, 2.4%, to the weighted average prior to the present work,[3-6] 2.1%, results in a change in the slope of the ^{12}N shape factor of −0.07%/MeV. We note that this latter value is consistent with the number from the present work, 2.0±0.1%. However, because of the continuing controversy concerning the analysis of these shape factors,[13-15] we offer no further conclusions at this point *vis-a-vis* weak magnetism and CVC except to suggest that future experimental measurements of the $A = 12$ shape factors utilize the updated weighted average for the ^{12}N and ^{12}B branching ratios to the 4.44-MeV level of 2.02±0.09% and 1.283±0.040%, respectively.

---

†Work supported by the U. S. Energy Research and Development Administration.

*Present address: Physics Department, University of Illinois, Urbana, Illinois 61801.

[1]Y. K. Lee, L. M. Mo, and C. S. Wu, Phys. Rev. Lett. 10, 253 (1963); C. S. Wu, Rev. Mod. Phys. 36, 618 (1964).
[2]D. H. Wilkinson, Phys. Rev. Lett. 27, 1018 (1971).
[3]R. E. McDonald, J. A. Becker, R. A. Chalmers, and D. H. Wilkinson, Phys. Rev. C 10, 333 (1974).
[4]R. W. Peterson and N. W. Glass, Phys. Rev. 130, 292 (1963).
[5]D. H. Wilkinson, D. E. Alburger, A. Gallmann, and P. F. Donovan, Phys. Rev. 130, 1953 (1963).
[6]D. E. Alburger, Phys. Rev. C 6, 1167 (1972).
[7]F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. A114, 1 (1968); F. Ajzenberg-Selove, Nucl. Phys. A248, 1 (1975).
[8]T. R. Fisher, Phys. Rev. 130, 2388 (1963).
[9]G. E. Schwender, D. R. Goosman, and K. W. Jones, Rev. Sci. Instrum. 43, 832 (1972).
[10]J. W. Olness (private communication).
[11]K. Kubodera, J. Delorme, and M. Rho, Nucl. Phys. B66, 253 (1973).
[12]K. Kubodera, J. Delorme, and M. Rho, Phys. Rev. Lett. 38, 321 (1977).
[13]C. S. Wu, Y. K. Lee, and L. W. Mo, Phys. Rev. Lett. 39, 72 (1977).
[14]F. P. Calaprice and B. R. Holstein, Nucl. Phys. A273, 301 (1976).
[15]J. P. Deutsch, P. C. Macq, and L. van Elmbt, Phys. Rev. C 15, 1587 (1977).