Beta Decay of $^{12}$B and $^{12}$N to the First Excited State of $^{12}$C (4.44 MeV)*

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The branching ratios of the beta-decay of $^{12}$B and $^{12}$N to the 4.44 MeV state in $^{12}$C were determined by ($\beta\gamma$)-coincidences to be $(1.182 \pm 0.019)\%$ and $(1.898 \pm 0.032)\%$ of the total rate, resp. This gives $f_{t^-} = (1.407 \pm 0.023) \cdot 10^5 \text{s}$ and $f_{t^+} = (1.406 \pm 0.024) \cdot 10^5 \text{s}$. For the $f_t$-asymmetry $\delta = (f_{t^+}/f_{t^-}) - 1$ the value $\delta = - (1 \pm 14) \cdot 10^{-3}$ was obtained. This is in contrast to other GT mirror transitions which show positive $\delta$ of a few percent.

1. Introduction

We report here on a new measurement of the branching ratios and of the $f_t$-asymmetry for the mirror Beta-decays of $^{12}$B and $^{12}$N to the first excited state of $^{12}$C at 4.44 MeV excitation energy. Previously published values of these quantities [1, 2, 3] are shown in Table 1. The motive for a new experiment came from the need to have more precise branching ratios for the analysis of the $^{12}$B and $^{12}$N Beta-spectra. The determination of the weak magnetism term from the slopes of these beta-spectra, as originally proposed by Gell-Mann [4], is one of the key tests of vector current conservation in the weak interaction. For the evaluation of the slopes, the measured spectra must be corrected for the weak branches to the excited states of $^{12}$C. In particular the ones to the first excited state at 4.44 MeV give – over the useful part of the $\beta$-spectrum – an effect similar to the weak magnetism term. In a recent experiment [5] the slope difference of the $^{12}$B and $^{12}$N Beta-spectra was found to be in good agreement with the prediction for the weak magnetism, thereby giving support to CVC, while the slope of each spectrum separately differed from the predicted value by about $+(2 \pm 1) \times 10^{-3}$ MeV$^{-1}$. Using too high values for the branching ratios could be responsible for part of this discrepancy.

Another aim was to clear up the situation of the $f_t$-asymmetry $\delta = f_{t^+}/f_{t^-} - 1$. For the decay to the ground state, $\delta = 0.11 \pm 0.01$ [2, 6].

For the decay to the first excited state, the experimental situation is not clear as the three most precise values of $\delta_{4.44}$ from earlier experiments (Table 1) are in poor agreement. In spite of the decline of second class currents [16, 17], a comparison of $\delta_{4.44}$ with $\delta_{8.8}$ and with the analysis of Wilkinson [7] is still interesting, bearing on the mirror decay problem, and a precise measurement of $\delta_{4.44}$ is therefore required.

2. Experimental Method

The $^{12}$B and $^{12}$N sources are produced in the usual way through the reactions $^{11}$B($d, p$)$^{12}$B and $^{12}$N($^3$He, $p$)$^{12}$B with deuterons of 1.5 MeV and $^3$He-ions of 5 MeV. The decay to the first excited state of $^{12}$C is identified by coincidences between $\beta$-particles and 4.44 MeV $\gamma$-rays, the activity is monitored through the rate of $\beta$-particles. The set-up selects large ($e, \gamma$) - angles in order to suppress ($e\gamma$) - coincidences due to internal bremsstrahlung from the decay to the $^{12}$C ground state, which at small
Table 1. Branching ratios for the β-decay to the first excited state in 12C

<table>
<thead>
<tr>
<th></th>
<th>12B</th>
<th>12N</th>
<th>ratio of the branching ratios 12N/12B</th>
<th>ft-asymmetry δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alburger [1]</td>
<td>1.27 ±0.06</td>
<td>1.93 ±0.12</td>
<td>1.52 ±0.06</td>
<td>0.06 ±0.04</td>
</tr>
<tr>
<td>McDonald et al. [2]</td>
<td>1.44 ±0.06</td>
<td>1.80 ±0.10</td>
<td>1.74 ±0.08</td>
<td>-0.08 ±0.04</td>
</tr>
<tr>
<td>Spoden [3]</td>
<td>1.29 ±0.05</td>
<td>2.10 ±0.16</td>
<td>1.58 ±0.03</td>
<td>0.01 ±0.02</td>
</tr>
<tr>
<td>Ajzenberg-Selove [10]</td>
<td>1.14 ±0.06</td>
<td>1.80 ±0.10</td>
<td>1.63 ±0.14</td>
<td>-0.01 ±0.09</td>
</tr>
<tr>
<td>present paper</td>
<td>1.18 ±0.019</td>
<td>1.898 ±0.032</td>
<td>1.607 ±0.021</td>
<td>-0.004 ±0.014</td>
</tr>
</tbody>
</table>

angles yields coincidence rates of the same order as the decay to be studied.

The branching ratio \( R = \Gamma_{\alpha,4}/\Gamma \), where \( \Gamma \) and \( \Gamma_{\alpha,4} \) are the total decay rate and the decay rate to the first excited state of 12C, respectively, of 12B(12N), is expressed in the quantities to be determined in the experiment as

\[
R = \frac{n_{\beta} \cdot e_{\beta}}{n_{\beta} \cdot e_{\beta}(4.4) \cdot e_{\gamma} \Omega} \cdot \left[ 1 + k(\Theta_{e\gamma}) \right].
\]

Here, \( n_{\beta} \) and \( n_{\beta\gamma} \) are the numbers of β-particles and (βγ)-coincidences registered in a given time; \( e_{\beta} \) and \( e_{\beta}(4.4) \) the detection efficiencies for β-particles from the total Beta-spectrum and from the one of the decay to the 4.44 MeV state, respectively; \( e_{\gamma}(4.4) \) and \( e_{\gamma} \) the detection efficiency for 4.44 MeV γ-rays and \( \Omega \) the solid angle of the γ-detector. The solid angle of the β-detector drops out of course. The \( k(\Theta_{e\gamma}) \) is a small correction which takes into account the anisotropy of the (eγ) angular correlation due to the weak magnetism term.

In the experiments \( n_{\beta} \) and \( n_{\beta\gamma} \) are measured. The efficiencies \( e_{\beta} \) and \( e_{\beta}(4.4) \) are determined experimentally by means of a momentum selected e⁻/e⁺-beam. The product \( e_{\gamma} \cdot \Omega \), is obtained from a \((\gamma\gamma)\)-coincidence measurement of the 12.14 MeV-4.44 MeV cascade from the decay of the 16.58 MeV state in 12C.

3. Apparatus

The experimental set-up is shown in Fig. 1. The Boron targets are placed in a vacuum chamber made from stainless steel, which has two large windows opposite each other for the β- and γ-rays.

The Beta-detector consists of two plastic scintillators \( S_1 \) and \( S_2 \), 1 and 10 mm thick, respectively. A 3 mm plexiglass absorber between them reduces background from low energy electrons, a lead collimator and hollow anticoincidence counter \( S_3 \) suppress the detection of electrons scattered off the walls of the chamber, and the plexiglass window in front of the γ-detector keeps backscattering of electrons into the Beta-detector low. The electron signal is a coincidence \((S_1S_2S_3)\) with a threshold of 0.8 MeV in counter \( S_2 \). Together with the plexiglass absorber this threshold prevents detection of positrons from 11C and 13N decays, the dominant spurious activities which are produced through the reactions \(^{10}\text{B}(d, n)^{11}\text{C}\) and \(^{10}\text{B}(^{3}\text{He}, d)^{11}\text{C}\) and \(^{11}\text{B}(^{3}\text{He}, n)^{13}\text{N}\) on the Boron targets. The Beta-detector subtends a solid angle, determined by \( S_1 \), of \( \frac{\Omega}{4\pi} = 0.5\% \) when seen from the target.

The γ-detector is a cylindrical NaI-crystal of 114 mm diameter, 127 mm depth with a plastic scintillator \( S_4 \) in front to veto charged particles.

Targets of about 1 mg cm⁻² of Boron with the isotopic composition 85% \(^{10}\text{B}\), 15% \(^{11}\text{B}\), evaporated onto 2 μm Nickel foils, were used. This isotopic composition had the advantage that \(^{12}\text{B}\) and \(^{12}\text{N}\) could be created on the same target, the disadvantage, however, compared to isotopically pure targets, to give rise to part of the above mentioned \(^{11}\text{C}\) and \(^{13}\text{N}\) background.

The targets were mounted on very light frames in order to suppress scattering of electrons into the β-detector. The normal of the target foil points paral-