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Upper limits on the first-forbidden rank-one β decay of ^{20}F

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We used our (perviously described) system for high sensitivity measurements of β-delayed α-particle emission of light nuclei to measure upper limits of the branching ratios of the first-forbidden rank-one β decay of the 2^+ ground state of ^{20}F to the 3^-, 5.62 MeV, and 1^-, 5.79 MeV excited states of ^{20}Ne to be 1.5×10^{-6} and 7×10^{-7}, respectively. These limits are more than a factor of 300 smaller than previously measured. The obtained *ft* values are at least a factor of 10 smaller than that of the first-forbidden rank-zero β decay to the 2^- state at 4.97 MeV in ^{20}Ne, whose branching ratio was also measured to be $1.2(6) \times 10^{-4}$, in agreement with the precise value obtained by Alburger and Warburton of $0.90(4) \times 10^{-4}$.

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Weak interactions such as β decay are an important tool for investigating nuclear structure. Of particular importance are forbidden (i.e., parity changing) β decays as they probe pionic currents in nuclei. First-forbidden rank-one β decays ($\Delta\pi = -, \Delta J = 1$) are hindered and diffcult to measure, thus only a few are known despite their importance [1]. We measured upper limits for the branching ratios of the first-forbidden rank-one β decay of the 2^+ ground state of ^{20}F to the 3^- and 1^- excited states of ^{20}Ne at 5.62 and 5.79 MeV, respectively.

We used an experimental system originally designed for measuring the β-delayed α-particle spectrum of ^{16}N by Zhao *et al*. [2] and France *et al*. [3]. We produced ^{20}F using the reaction ^{9}Be(^{19}F,^{20}F)^{8}Be with 80 MeV ^{19}F beams extracted from the ESTU (Extended Stretched Trans-Uranium) tandem accelerator located at Yale University and a 25.4-μm -thick beryllium foil placed at 25° with respect to the beam, see Fig. 1. The recoil ^{20}F were collected on a thin (30 μg/cm^2) carbon foil which was tilted at 7° with respect to the beam to maximize capture efficiency. The capture foils were shielded with Tantulum collimators to prevent the implantation of reaction products into the frame of the catcher foil.

After a collection period of 16 sec the beam was chopped approximately 30 m from the target and the catcher foil was rotated to the detection area placed 1 m away, in three seconds–sufficient time to allow short-lived contaminants to decay. All detectors were inhibited from data collection during the rotation. The beam current was monitored measuring Rutherford backscattering of ^{19}F off a 30 μg/cm^2 gold on 30 μg/cm^2 carbon target with a monitor silicon surface barrier detector located at a backward angle of 140° and a distance of 7 cm.

In the detection area γ rays and α particles were detected in coincidence with the β decay of the ^{20}F implanted in the catcher foil. The allowed ($2^+ \to 2^+$) decay from the ground state of ^{20}F to the first excited state of ^{20}Ne at 1.63 MeV occurs with a branching ratio of 0.9999 [4]. To minimize systematic error the branching ratios of the forbidden β decays were measured relative to the 1.63-MeV γ line from the decay of this state.

The detector system is described in detail in Refs. [1,3]. The α particles were detected in an array of nine thin (50 μm), large area (450 mm^2) silicon surface barrier detectors (SSB) placed 69 mm from the catcher foil. The absolute efficiency of the α-array was measured using a calibrated ^{148}Gd α source. Twelve Bicron BC418 plastic scintillators (the β array) covered with a mylar foil to prevent detection of α particles were placed 3 mm from the catcher foil to detect the β particles. The absolute efficiency of the β detectors was measured at 1 MeV with a calibrated ^{207}Bi electron conversion source. A high-resolution HPGe detector placed 37 cm from the catcher foil was used to detect the isotropic 1.63-MeV

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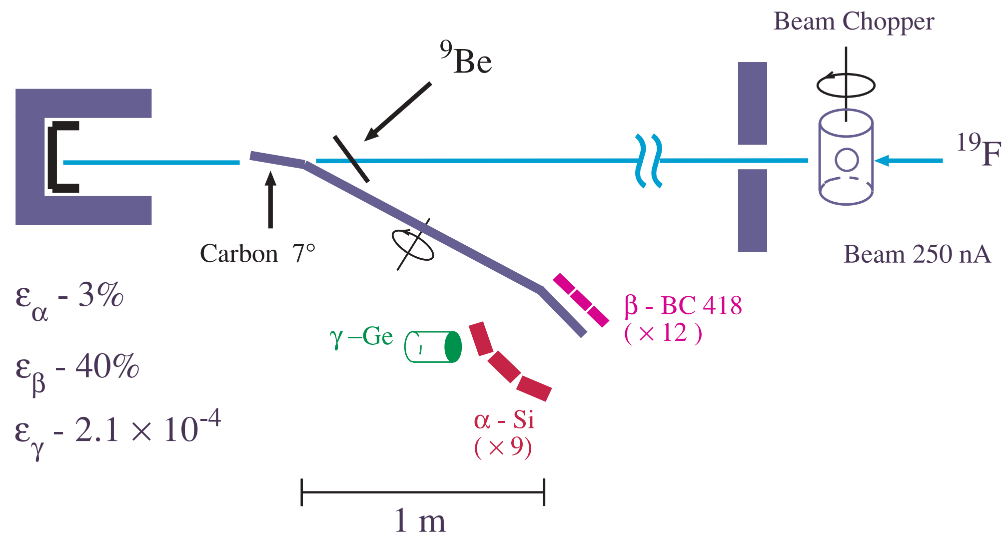

FIG. 1. (Color online) A schematic drawing of the experimental setup not drawn to scale.

γ line from the allowed decay and the 3.33-MeV γ line from the rank-zero forbidden decay. The γ-ray absolute detection efficiencies were measured using ^{57}Co, ^{60}Co, ^{137}Cs, and ^{152}Eu calibration sources. Absolute efficiency was calculated using a least-squares fit of these calibration data to the standard efficiency relationship. see Ref. [5]. The calculated efficiencies were found to be $2.1(3) \times 10^{-4}$ at 1.63 MeV and $1.6(3) \times 10^{-4}$ at 3.33 MeV. Because both the α detectors and the γ-detector measurements were made in coincidence with the β array, and the branching ratios of the forbidden β decays were measured relative to the 1.63-MeV γ line, it was not necessary to precisely measure the efficiency of the β array.

A signal from either the α array or the γ detector was used to to start a TDC with delayed timing signals from the β array providing the stop signal. Timing resolution for β-α coincidences was measured to be 4 ns and for γ-β coincidences to be 20 ns. β-γ coincidence timing was calibrated using an ^{227}Ac source as discussed by Zhao *et al*. [2].

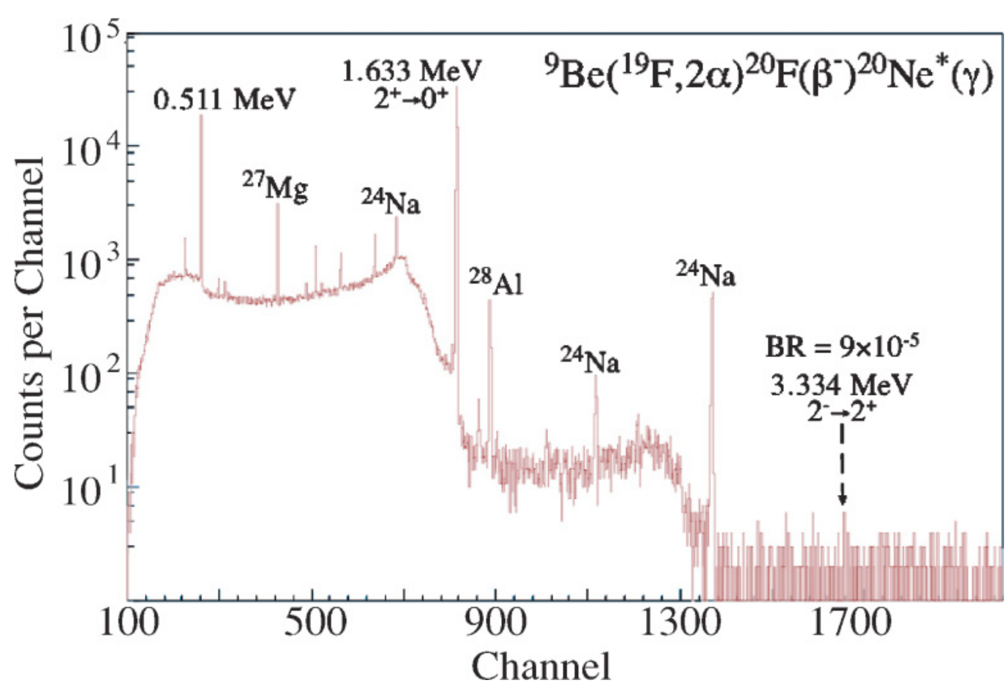

FIG. 2. (Color online) The measured gamma spectrum (of ^{20}Ne) in coincidence with β decay (of ^{20}F).

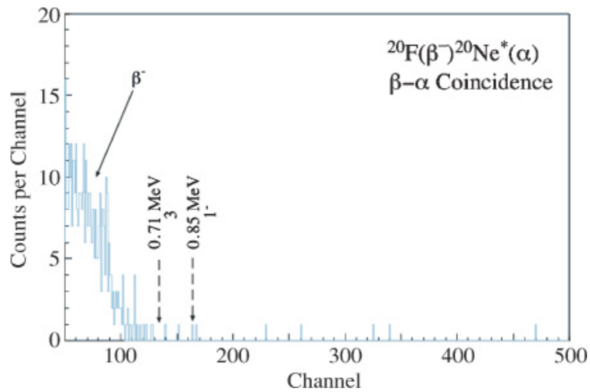

FIG. 3. (Color online) The measured α particle spectrum in fast ($\Delta t = 20$ ns) coincidence with β particles.

Background in the coincidence spectra was measured with the catcher foil removed to determine the rate at which ^{20}F was deposited on the catcher frame, as well as by the measuring random coincidences using a timing gate away from the prompt resolution function. After normalization to the ^{19}F beam current, we found a few counts in the expected regions of interest which are consistent with background as we discuss below.

In Fig. 2, we show the HPGe spectrum in coincidence with the β array. A total of 88,887(1600) counts above background were observed at 1.63 MeV. This γ-line, from the allowed ($2^+ \rightarrow 2^+$) decay from the ground state of ^{20}F to the first excited state of ^{20}Ne at 1.63 MeV, was used for normalization. During first-forbidden rank-zero β decay, ^{20}F decays to the 2^- state at 4.97 MeV in ^{20}Ne which subsequently decays to the 2^+ state at 1.63 MeV in ^{20}Ne via the emission of 3.33-MeV γ-ray with a branching ratio of 0.994 [6]. A total of 8(3) counts were observed in the HPGe detector at 3.33 MeV consistent with a branching ratio for first-forbidden rank-zero β decay of ^{20}F of $1.2(6) \times 10^{-4}$ and a log(ft) of 7.1(2). This is consistent with the previous measurement of Alburger and Warburton [6] of $9.0(4) \times 10^{-5}$ and a log(ft) of 7.16(2).

In Figure 3, we show the combined coincidence spectra of the α array. A total of 7 counts are observed in the region of interest (0.64 to 0.79 MeV) for the α-particle decay of the 3^- state at 5.62 MeV and 3 counts (0.77 to 0.93 MeV) for the 1^- state at 5.79 MeV in ^{20}Ne. The branching ratios for α decay from these states are 0.927 and 0.999, respectively [6]. The detected counts are consistent with background.

At a confidence level of 2σ, this measurement results in upper limits of 1.5×10^{-6} and 7×10^{-7} for the first-forbidden rank-one β decays of ^{20}F to the 3^- state at 5.62 MeV and the 1^- state at 5.79 MeV of ^{20}Ne, respectively. These upper limits are an improvement over previous measurements by factors of 320 and 1400, respectively [6]. The extracted upper limit on the log(ft) value for the first-forbidden rank-one decay of ^{20}F is at least a factor of 10 smaller than the measured first-forbidden rank-zero decay.

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