Branching ratios for the beta decay of ^{21}Na

V. E. Iacob, J. C. Hardy, C. A. Gagliardi, J. Goodwin, N. Nica, H. I. Park, G. Tabacaru,
L. Trache, R. E. Tribble, Y. Zhai and I. S. Towner

A recent publication by Scielzo *et al.*[1] reported a measurement of the β-ν angular correlation coefficient, $\alpha_{\beta\nu}$, for the β-decay transition between ^{21}Na and the ground state of its mirror, ^{21}Ne. The authors compare their result with the standard-model prediction for $\alpha_{\beta\nu}$, with a view to testing for scalar or tensor currents, the presence of which would signal the need for an extension of the standard model. Although they found a significant discrepancy – the measured value, $\alpha_{\beta\nu} = 0.524(9)$ disagrees with the standard-model prediction of 0.558 – they stop short of claiming a fundamental disagreement with the standard model.

Scielzo *et al.* [1] offer two alternative explanations that would have to be eliminated before their result could begin to raise questions about the need for an extension to the standard model. One is that some ^{21}Na$_2$ dimers formed by cold photoassociation could also have been present in their trap, thus distorting the result; they themselves propose to do further measurements to test that possibility. The other is that the branching-ratio value they used for β decay to the first excited state of ^{21}Ne might not be correct. Because Scielzo's measurement could not distinguish between positrons from the two predominant β-decay branches from ^{21}Na (see Fig. 1), the adopted branching ratio for the β transition to the first excited state not only affects their data analysis but also helps determine the theoretical prediction for $\alpha_{\beta\nu}$ itself, since the axial-vector component of the ground-state branch can only be determined from its *ft* value, which also depends on the branching ratio. This branching ratio is a key component of their standard-model test, yet the five published values [2-6] are between 25 and 45 years old, are quite inconsistent with one another and range from 2.2(3) to 5.1(2)%. To remedy this problem, we measured the excited-state branching ratio, for which we quote ±0.8% relative precision, five times better than the best precision claimed in any previous measurement. This experiment has been published [7].

We produced 22.5-s ^{21}Na using a 28*A*-MeV ^{22}Ne to initiate the ^{1}H(^{22}Ne, 2*n*)^{21}Na reaction on a LN$_2$-cooled hydrogen gas target. The ejectiles from the reaction were fully stripped and, after passing through the MARS spectrometer, produced a ^{21}Na secondary beam of >99% purity at the extraction slits in the MARS focal plane. This beam, containing $\sim 3\times10^5$ atoms/s at 24.4*A* MeV, then exited the vacuum system through a 50-μm-thick Kapton window, passed successively through a 0.3-mm-thick BC-404 scintillator and a stack of aluminum degraders, finally stopping in the 76-μm-thick aluminized Mylar tape of a tape transport system. Since the few impurities remaining in the beam had ranges different from that of ^{21}Na, most were not collected on the tape; residual collected impurities were concluded to be less than 0.1% of the ^{21}Na content.

In a typical measurement, we collected ^{21}Na on the tape for a few seconds, then interrupted the beam and triggered the tape-transport system to move the sample in 180 ms to a shielded counting station located 90 cm away, where the sample was positioned between a 1-mm-thick BC404 scintillator to detect β^+ particles, and a 70% HPGe detector for γ rays. We then recorded β singles and β-γ coincidences for a pre-determined counting period. Two timing modes were used: in one, the collection and detection periods were 3 and 30 s, respectively; in the other, they were 6 and 60 s. In both cases, after the detection period was complete, the cycle was repeated and, in all, some 3,200 cycles were completed over a span of 32 hours.

From our data, we could obtain the β-branching ratio BR_1 for the transition populating the first excired state in ^{21}Na, which decays by emitting a 351-keV γ ray. If the total number of β singles is N_β and the total number of β-γ coincidences measured in the γ peak is $N_{\beta\gamma}$, then the branching ratio BR_1 is given by

$$BR_1 = \frac{N_{\beta\gamma}}{N_\beta \varepsilon_\gamma} k , \tag{1}$$

where ε_γ is the detector efficiency at 351 keV and k is a small correction factor (*i.e.* $k = \sim 1$) that, among other things, takes into account the differences in the β-detector efficiency for the transitions to the ground and first excited states of ^{21}Ne. This relation highlights the importance of a precise absolute efficiency calibration for the γ-ray detector and a reasonable knowledge of relative efficiencies in the beta detector. Our HPGe absolute efficiency is accurately known (to ±0.2% for 50-1400 keV and ±0.4% up to 3500keV) from source measurements and Monte Carlo calculations [10]. The relative efficiency as a function of β energy in the plastic scintillator was determined by Monte Carlo calculations using the DOSRZNRC code from the EGS package [11] and checked by comparison with conversion-electron sources and with ^{22}Mg β-decay data [12].

Our measured branching-ratio value is compared with previous measurements in Table I. All previous experiments determined the branching ratio from a comparison of the area of the 351-keV peak to that of the annihilation radiation. This method has the advantage that only relative detector efficiencies are required, but it has three serious disadvantages: i) contaminant activities may well make an unknown contribution to the annihilation radiation; ii) most positrons do not annihilate at the source position, where the γ rays originate, so the relative detection efficiencies cannot be simply determined from calibration sources; and iii) the significant effect (~5%) of positron annihilation in flight is a first-order correction that must be calculated and corrected for. All previous measurements except possibly reference [4] were susceptible to potential contaminants; only the last three references [4, 5, 6] mention accounting for a spatially distributed source of 511-keV radiation; and only the last two [5, 6] appear to have taken account of annihilation in flight.

Table I. Measurements of the branching ratio R_1

Date	Reference	Result(%)
1960	Talbert & Stewart [2]	2.2(3)
1963	Arnell & Wernbom [3]	2.3(2)
1974	Alburger [4]	5.1(2)
1977	Azuelos, Kitching & Ramavataram [5]	4.2(2)
1980	Wilson, Kavanagh & Mann [6]	4.97(16)
2006	This measurement	4.74(4)

Given the age of the previous measurements and the potential hazards associated with their experimental method – not to mention their mutual inconsistency – we choose not to average our result with them but instead to use our present result alone in extracting the properties of the ^{21}Na β-decay scheme.

Since there are only two significant β-decay branches from ^{21}Na – to the ground and first excited states of the daughter – with BR_1 determined, the branching ratio to the ground state, R_0, follows directly from it: *viz.* R_0 = 0.9526(4). This result is actually determined to a precision of 0.04%. From this value for R_0 we obtain the *ft* value for this transition, the relative contributions of axial-vector and vector components, and ultimately the standard-model expectation for its β-γ angular correlation coefficient (see Ref. [7]). Our final computed result is $\alpha_{\beta\nu}$ = 0.553(2). This value can now stand as the "standard-model prediction" for $\alpha_{\beta\nu}$, against which the measured angular-correlation coefficient can be compared. It is 0.9% lower than the one originally used by Scielzo *et al.* [1] and still leaves that experimental result in disagreement with the prediction. However, the authors themselves expressed concern about the possible presence of ^{21}Na$_2$ dimers in their trapped samples; this would have caused a dependence of their result on the trapped-atom population and could easily reconcile their result with the standard model. With a precise branching ratio now determined, an investigation of the actual make-up of the trapped-atom samples in the Scielzo *et al.* experiment is essential if the ^{21}Na result is to become a real test of the standard model.

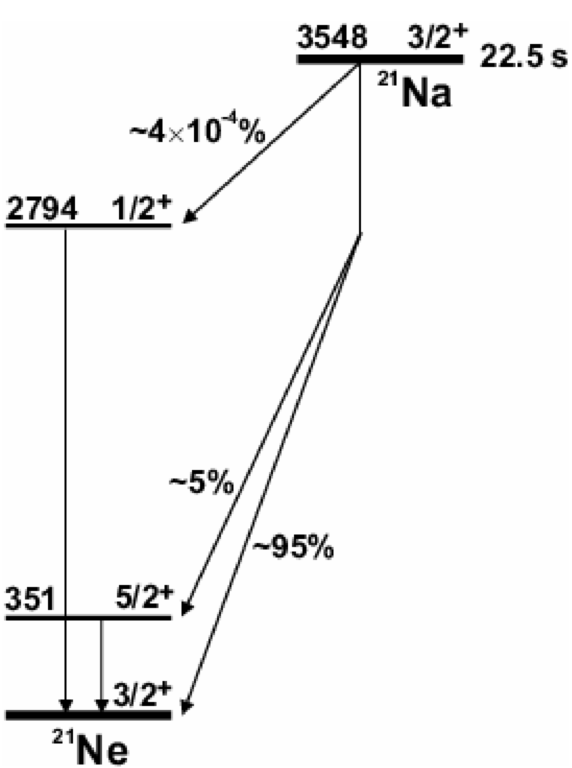

Figure 1. β-decay scheme for ^{21}Na

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