The absolute γ and β branches following the β^+ decay of ^{32}Cl

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

The β and γ branches of the β^+ decay of 1^+, $T = 1$ ^{32}Cl have been measured to provide a discriminating test of the isospin-mixing corrections, δ_C, applied to the 0^+ to 0^+ superallowed transitions used to determine V_{ud}. Up until now, there have been no nuclei studied where δ_C is larger than ~2%. We focused on improving the branching ratio of the transition to the analogue 1^+, $T = 1$ state in ^{32}S whose position in the spectrum at 7002-keV excitation is very close to a known 1^+, $T = 0$ state at 7190 keV; this greatly enhances the size of the isospin-symmetry-breaking (ISB) correction. Our calculation of the ISB effect for this nucleus is $\delta_C = 4.6(5)\%$ [1], a value significantly larger than those found in any of the nuclei used to extract V_{ud}. In this way, ^{32}Cl provides a unique opportunity to test ISB calculations where the effect is relatively quite large. Furthermore, a precise knowledge of the absolute β and γ branches following the β decay of ^{32}Cl may be used as an *in situ* efficiency calibration for the β-delayed proton decay of ^{32}Ar which itself may be used to test isospin-mixing corrections (see Ref. [2]).

The ^{32}Cl was produced via the inverse-kinematic transfer reaction ^{1}H(^{32}S, *n*)^{32}Cl using a LN_2-cooled, H_2 gas target with a 400 nA ^{32}S primary beam at 24.8 MeV/nucleon. The reaction products were spatially separated by MARS, resulting in a 91% pure, 20 MeV/nucleon ^{32}Cl beam with an intensity of ~2 $\times 10^5$ ions/s. The beam was implanted and collected in an aluminized-Mylar tape for 0.8 s before a fast tape-transport system moved the activity to a shielded counting station 90 cm away. Data for β-γ coincident events, shown in Fig. 1, were acquired using a 1.5 inch-diameter, 1 mm-thick scintillator and a

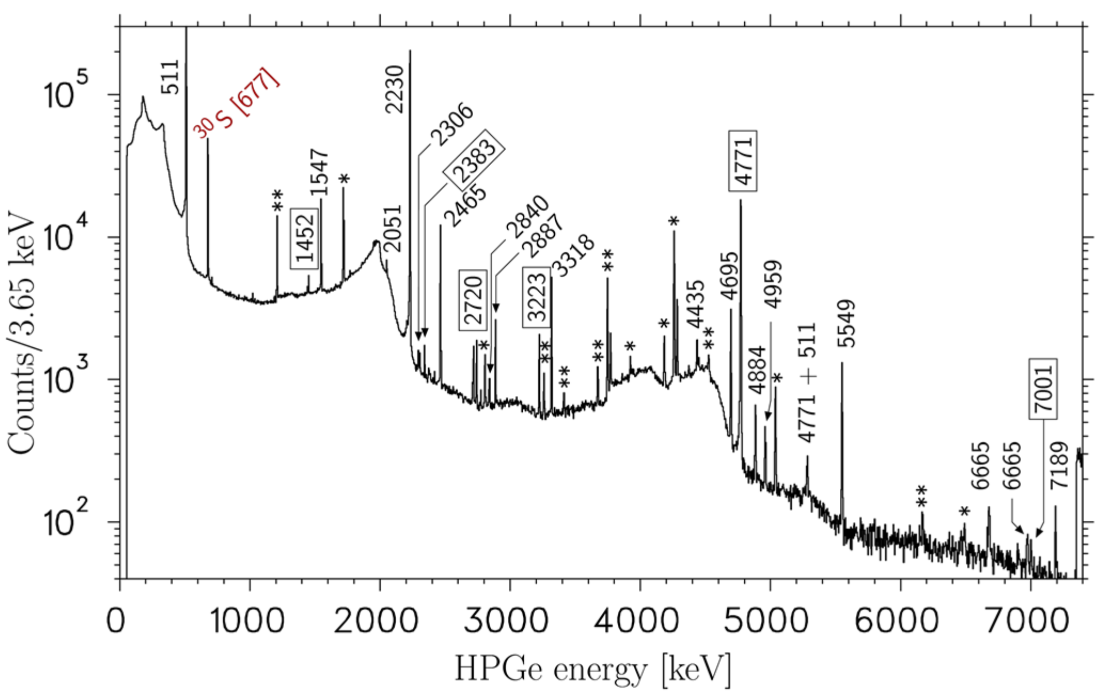

FIG. 1. γ spectrum observed by the HPGe in coincidence with a β. Full-energy peaks are labeled with their energy, and ones associated with the 7001-keV isobaric analogue state are highlighted with boxed values. The symbol * and the symbol ** refer to single- and double-escape peaks, respectively.

70% HPGe detector. Count times were for 1, 2, and 4 sec (83%, 11%, and 6% of the data, respectively). The scintillator was placed 0.5 cm from the activity, detecting >40 keV positrons with ~32% efficiency. On the opposite side of the tape the HPGe was placed a large distance away (15.1 cm) to reduce the effects of coincidence summing of the γ rays. The cycle of collecting, transporting and measuring the ^{32}Cl activity was repeated continuously throughout the experiment.

Once the peak areas were obtained, we used the precisely known efficiency of the HPGe detector to convert them into relative yields of γ rays. We then fit the β and γ branches to reproduce these yields. Our measurement has found 3 new β branches, 22 new γ lines, placed limits on 10 potential γ transitions, and improved the precision of the branches and yields reported previously [3, 4] by about an order of magnitude and is summarized in Fig. 2.

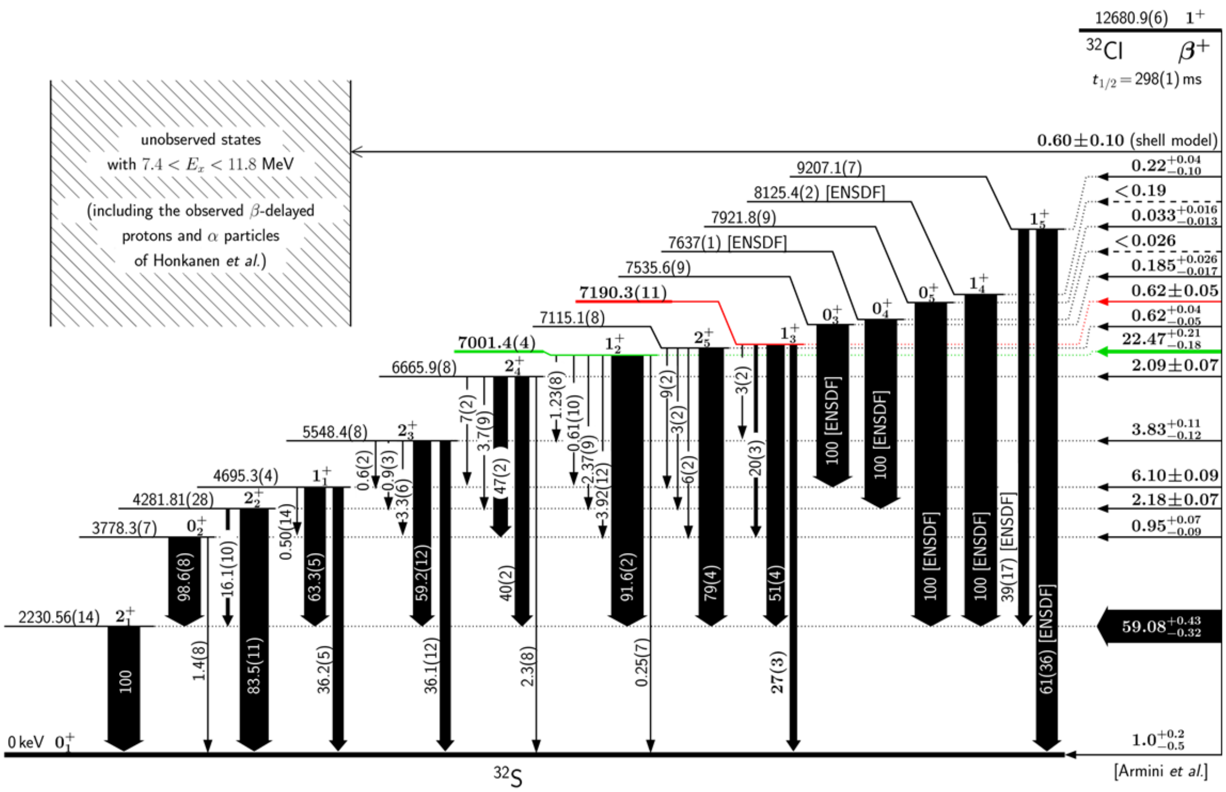

FIG. 2. Decay scheme for ^{32}Cl based on this work (with results taken from Armini et al. and ENSDF labeled). The 1^+, T = 1 analogue state at 7001 keV mixes with the nearby 1^+, T = 0 state, giving rise to the (relatively) large observed isospin-mixing correction.

With regard to ISB effects, we found the β branch to the isobaric-analogue state (IAS) at 7002 keV is R = $(22.47\pm0.13^{+0.16}_{-0.12})$%. The first uncertainty is statistical and the second is dominated by two sources of systematic uncertainty: $^{+0.11}_{-0.12}$ % is from the $(1.0^{+0.2}_{-0.5})$% ground state branch reported by Armini *et al.* [5], and ±0.10% from the photopeak efficiency of the HPGe detector. The partial half-life of the superallowed branch is given by $t = \frac{t_{1/2}}{R}(1 + P_{EC})$, where the ^{32}Cl half-life is $t_{1/2}$ = 298(1) ms, R is the superallowed branching ratio quoted above, and the small electron-capture fraction is calculated to be P_{EC} = 0.071%. The statistical rate function is calculated to be f = 2411.6±2.3±0.3, where the first uncertainty is from the Q_{EC} value and the second is from the shell-model calculation of the shape-correction factor. Combined, we find the experimental *ft* value for decay to the IAS is ft = 3200(30) s, where the precision is dominated by the ±0.9% uncertainty in the branch to the IAS. This result can be interpreted in terms of an ISB effect via

$$\delta_C^{\text{exp}} = 1 + \delta_{\text{NS}} - \frac{2\langle \mathcal{F}t^{0^+\to 0^+}\rangle}{ft(1+\delta_R')[B(\text{F})+B(\text{GT})]},$$

where δ_{NS} is a nuclear-structure-dependent radiative correction calculated to be -0.15(2)%, $\langle \mathcal{F}t^{0^+\to 0^+}\rangle$ = 3071.81(83)s is the average corrected *ft* value of the 13 most precisely measured pure Fermi superallowed transitions [6], δ'_R = 1.421(32)% is another radiative correction, and *B*(GT) is calculated to be $(1.8^{+2.3}_{-1.7})$ $\times 10^{-3}$ which is negligibly small compared to the dominant Fermi strength of *B*(F) = 2. Thus we arrive at an ISB effect of δ_C^{exp} = 5.3(9)%, the largest ever determined in a superallowed Fermi transition.

This result has been recently published in Refs. [7, 8].

[1] J.C. Hardy, V.E. Iacob, D. Melconian, N. Nica, H.I. Park, G. Tabacaru, I.S. Towner, L. Trache, R.E. Tribble, and Y. Zhai, *Progress in Research*, Cyclotron Institute, Ttexas A&M University (2011-2012), p.I-13.

[2] M. Bhattacharya, D. Melconian, A. Komives, S. Triambak, A. Garcia, E. Adelberger, B. Brown, M. Cooper, T. Glasmacher, V. Guimaraes and P. Mantica, Phys. Rev. C **77**, 065503 (2008).

[3] C. Détraz, C. Zaidins, D. Frantsvog, R. Wilson and A. Kunselman, Nucl. Phys. **A203**, 414 (1973).

[4] W. Anderson, L. Dillman and J. Kraushaar, Nucl. Phys. **77**, 401 (1966).

[5] A. Armini, J. Sunier and J. Richardson, Phys. Rev. **165**, 1194 (1968).

[6] J.C. Hardy and I.S. Towner, Phys. Rev. C **79**, 055502 (2009).

[7] D. Melconian, S. Triambak, C. Bordeanu, A. Garcia, J. Hardy, V. Iacob, N. Nica, H. Park, G. Tabacaru, I. Towner, L. Trache, R. Tribble and Y. Zhai, Phys. Rev. Letts. **107**, 182301 (2011).

[8] D. Melconian, S. Triambak, C. Bordeanu, A. Garcia, J. Hardy, V. Iacob, N. Nica, H. Park, G. Tabacaru, I. Towner, L. Trache, R. Tribble and Y. Zhai, Phy. Rev. C **85**, 025501 (2012).