Isospin symmetry breaking in the β decay of ^{32}Cl

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The β^+ decay of ^{32}Cl has been investigated using the fast tape-transport system at the Cyclotron Institute to improve measurements of the γ branches. This work is motivated by the impact it can have on improving the theoretical isospin-symmetry breaking (ISB) corrections to the *ft* values of pure Fermi β decays: first, our shell-model prediction for the ISB correction of this decay's T=1 to T=1 isobaric analogue transition is δ_C=4.6(5)%, significantly larger than the cases used to test CVC, measure V_{ud} and test CKM unitarity. Secondly, a recent experiment measuring δ_C in the T=2 decay of ^{32}Ar requires precise knowledge of the γ branches from its decay; this can be improved with the present work because decays of ^{32}Ar are partially followed by decays of ^{32}Cl and thus provide an *in situ* efficiency calibration for γs.

The experiment was carried out at the Cyclotron Institute using a primary beam of ^{32}S which was produced by the ECR ion source and injected into the K500 superconducting cyclotron to accelerate it to 24.8 MeV/nucleon. The 400 nA ^{32}S beam exited the cyclotron and was directed towards the target chamber of the Momentum Achromatic Recoil Separator (MARS). A secondary beam of ^{32}Cl was produced via the inverse kinematic transfer reaction, ^{1}H(^{32}S,n)^{32}Cl on a LN_2 cooled, hydrogen gas target at approximately 1.4 atm. MARS was used to spatially separate the reaction products, resulting in a ^{32}Cl beam with an intensity of $\approx 2\times10^5$ ions/s. The activity was implanted mid-way in a 76 μm Aluminized-mylar tape which, as part of a fast tape-transport system, transferred the activity 180 cm away where β-γ coincidences were measured using a thin plastic scintillator and precisely-calibrated HPGe detector. Figure 1 shows the γ spectrum where almost every statistically significant peak is associated with the decay of ^{32}Cl; the only prominent contaminant is from ^{30}S, which is well separated from any of the ^{32}Cl γ energies.

Critical to the success of this experiment was the very precise efficiency calibration of the HPGe detector [1-3]. This previous work determined the efficiency to ±0.2% from 50-1400 keV, and from 1.4-3.5 MeV it is known to ±0.4%. We extended this efficiency out to 7.2 MeV, the energy range of the HPGe detector in this experiment, using Monte Carlo simulations. Since it is nevertheless an extrapolation, we assign a conservative 1% uncertainty from 3.5-5 MeV and even more conservative 5% uncertainty from 5-7 MeV. Similar simulations of the plastic scintillator's efficiency showed that it was independent of the β end-point energy. After fitting the areas of the γ peaks, we converted the observed yields into β branches to state i, β_i, and γ branches from state i to state j, $\gamma_{i,j}$, using an equation similar to:

$$N^{\gamma}_{i,j} = N_{tot}\left[\beta_i\eta_i + \sum_{k>i}\beta_k\eta_k\gamma_{k,i}\right]\gamma_{i,j}\epsilon_{i,j} \qquad (1)$$

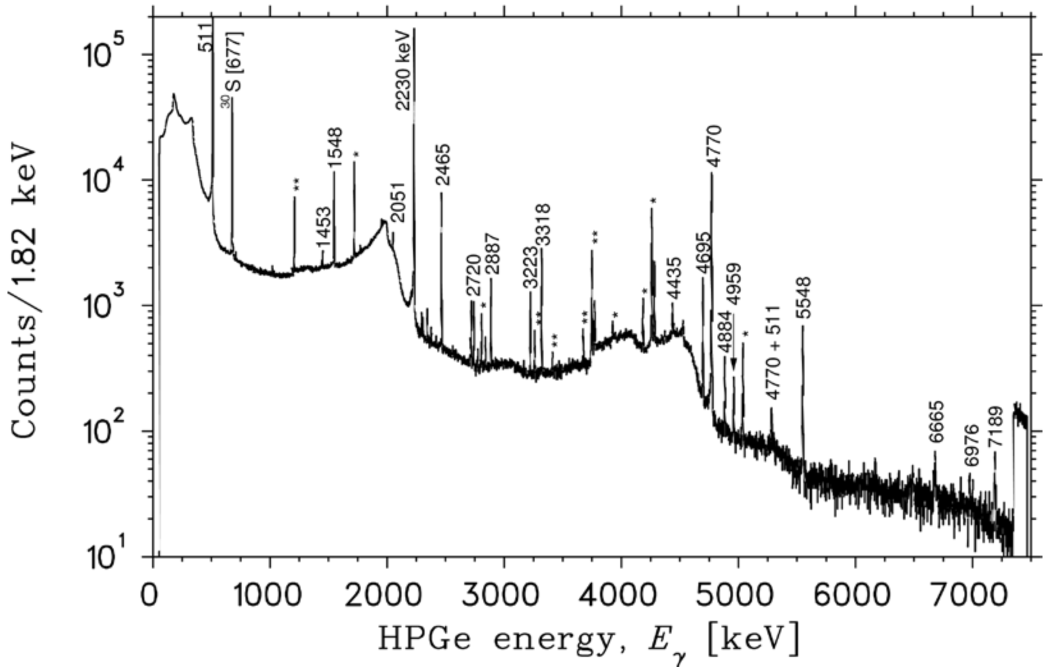

FIG. 1. The γ spectrum observed by the HPGe detector, with prominent peaks from the decay of ^{32}Cl labeled (a * indicates a single-escape peak and a ** indicates a double-escape). The only significant background peak is at 677 keV from the ^{30}S contamination.

where $N^{\gamma}_{i,j}$ is the observed number of counts at energy $E_{i,j}$ is the total number of decays, and the β and γ efficiencies are η and ε respectively. Small corrections to Eq. (1) that are included in the analysis but omitted here for clarity are required to account for (a) summing with cascade γs from above and below, and (b) summing with 511 annihilation radiation since this is a β^+ decay. From the 34 photopeaks we observed associated with the decay of ^{32}Cl, we improved the precision of known branches by about an order of magnitude, and found 22 new γ transitions, placing limits on 10 others. The result is shown graphically in decay scheme of Fig. 2. As indicated, the unseen ground state branch was taken from the work of Armini *et al.* [4] and the ENSDF Data Tables [5] were used to provide excitation energies and γ branches when necessary. Branches to higher levels that could not be observed in our experiment were estimated using shell-model calculations using the USD, USDA and USDB potentials, indicating 0.60(10)% of the β strength would also be missed. The range of energies spanned by the shell-model prediction includes β-delayed proton- and α-emitting states seen by Honkanen *et al.* [6].

Our integrated β strength over the range of end-point energies observed compares well with the prediction of the shell-model calculations, indicating that the quality of the USD wave functions is good. For the decay to the 7002-keV 1^+_2, *T*=1 isobaric analogue state, the shell model predicts a very weak Gamow-Teller strength; this gives us the opportunity to study this transition as if it were a pure Fermi decay, compare it the precisely measured pure Fermi transitions [7], and deduce the amount of isospin-symmetry breaking in this transition. A large ISB effect is anticipated because a 1+, T=0 state is only 188 keV away, leading to mixing between these states of differing isospin. With our isobaric analogue branch measured to better than 1%, we find an ISB effect of $(\delta_C - \delta_{NS})$ = 5.4(8)%, the largest yet determined and about 5´ larger than typical values found in superallowed pure Fermi transitions in the s,d-shell. This result agrees well with the shell-model prediction of 4.8(5)% and represents an important validation of the shell-model used to extract V_{ud} from precisely measured *ft* values.

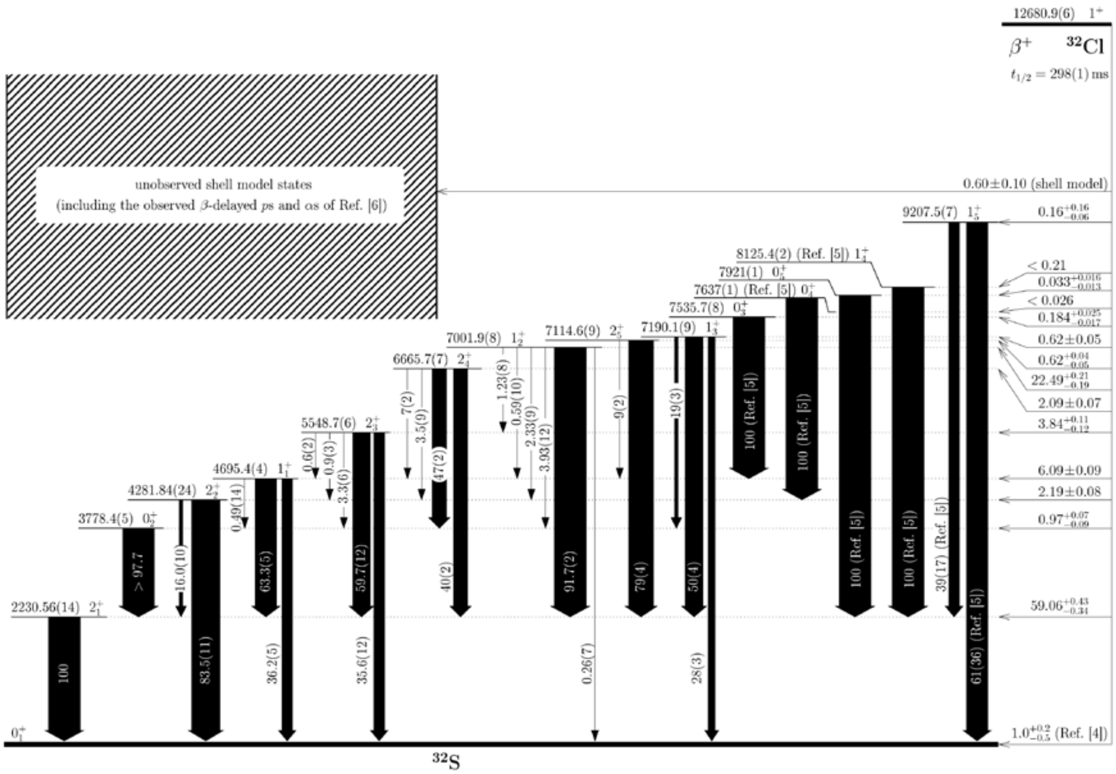

FIG. 2. Decay scheme for ^{32}Cl, summarizing the b and g branches deduced from this work (unless otherwise noted). All branches are expressed in percent.

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