Intensity of a weak 519-keV γ ray following β decay of the superallowed emitter ^{34}Ar determined via the ^{33}S(p,γ)^{34}Cl reaction

H.I. Park,[1] J.C. Hardy,[1] M. Bencomo,[1] K.T. Macon,[2] W. Tan,[2] M. Brodeur,[2] A. Boeltzig,[2] B. Frentz,[2] S.L. Henderson,[2] J. Long,[2] S. McGuinness,[2] O. Olivas-Gomez,[2] P. O'Malley,[2] G. Seymour,[2] B. Vande Kolk,[2] and A. Kayani[3]

[1]*Cyclotron Institute, Texas A&M University, College Station, Texas 77843*

[2]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556*

[3]*Department of Physics, Western Michigan University, Kalamazoo, Michigan 49008*

In the late summer of 2018 we have conducted the ^{33}S(p,γ)^{34}Cl experiment proposed at the University of Notre Dame to investigate the effect that weak γ-ray transitions potentially have on the superallowed β decay of ^{34}Ar, the parent nucleus of ^{34}Cl. Our focus was on determining the gamma-branching of the 666-keV level populated in ^{34}Cl. A possible weak 519-keV γ-ray from this level can affect the ^{34}Ar superallowed branching-ratio result for which we seek 0.1 % precision to yield a ft value contributing meaningfully to the determination of V_{ud}, the up-down quark-mixing element of the Cabibbo-Kobayashi-Maskawa matrix.

For our experiment the ^{33}S(p,γ)^{34}Cl reaction was initiated by protons from the 5U 5-MV single-ended vertical Pelletron at the Nuclear Science Laboratory of the University of Notre Dame. The proton beam, with an energy spread of less than 1 keV, passed through a 90° dipole magnet on its way to the water-cooled ^{33}S target, which was installed at the center of the compact germanium-detector array GEORGINA [1]. After exploring several candidate resonances, we chose the proton beam energy to be 1072 keV, which corresponds to a resonance in ^{34}Cl at an excitation energy of 6181 keV. This resonance was previously known [2] to preferentially decay to the state at 666 keV, whose decay we wished to study. Throughout our two-week measurement the beam current was limited to a maximum of 10.0 μA to prevent damage to the ^{33}S target.

The GEORGINA array consists of 5 Canberra n-type germanium detectors, each with a relative γ-ray of 100%. In our measurement, the beam was stopped in the tantalum containing the target material, so one of the detectors could be placed directly downstream from the target; the other four were arranged symmetrically in close geometry around the target and slightly upstream of it. The preamplified signals from each detector were directly read by a Mesytec MDPP-16 [3] fast high-resolution time and amplitude digitizer. We began the measurement with all five detectors in operation, but unfortunately were limited to four for most of the data taking.

Immediately following the end of data collection, we made calibration measurements with ^{6}Be, ^{60}Co, ^{137}Cs, ^{133}Ba, and ^{152}Eu. These sources provided us with the twenty well-known γ peaks covering energy range from 120 keV to 1410 keV, and therefore our energy calibration for all five Ge detectors was well established in the region of our interest between 500 keV and 700 keV. The efficiency calibration was done for each individual Ge detector using ^{60}Co, ^{137}Cs, and ^{152}Eu sources. The ^{60}Co and ^{137}Cs sources have a simple decay scheme to permit clean determination of detector's efficiency. A very complicated decay of the ^{152}Eu (to ^{152}Sm by electron capture and to ^{152}Gd via positron emission) source, on the other hand, made us consider only the 244-keV, 344-keV, 444-keV, 779-keV, 867-keV, 964-keV, 1086-keV, 1090-keV, 1112-keV, 1299-keV, and 1408-keV γ -rays. This provided detection efficiency in each detector for the most important 519-and 666-keV peaks of interest.

Data collected from the $^{33}S(p,\gamma)^{34}Cl$ measurement were processed to extract prompt γ-γ coincidence events, which were then stored in a database that could be accessed by analysis software developed at Texas A&M University. Each entry in the database consisted of the energies and time-stamps of two coincident γ-rays, the time difference between their arrivals, and an identifier of the two germanium detectors from which the signals originated. As the firrst step in analysis, all detector spectra were adjusted so as to place them on a common energy scale. Next, six two-dimensional γ-γ coincidence spectra were created, each with $2^{15}\times2^{15}$ channels and having 0.25 keV per channel. These spectra corresponded to the six possible pairs of our four operating germanium detectors.

The 6181-keV state we had populated in ^{34}Cl decays predominantly to the state at 666 keV via a 5515-keV transition, so by gating on the observed 5515-keV γ ray in one detector of a pair we could observe in the other detector the γ rays emitted in the subsequent decay of the 666-keV state. Peaks at 519 and 666 keV were clearly visible in each projected spectrum, and the relative intensity of the former to the latter was evaluated and found to be statistically consistent from one pair to another, thus indicating that any possible effects of angular correlations between the coincident γ rays can be neglected. As a result, we could safely add together all the projections for a given detector and determine the relative γ-ray intensities using the appropriate efficiency curve for that detector. Indeed, the relative efficiency curves of the four detectors were similar enough that we could also sum all of the detector projections into a single spectrum and use an averaged calibration curve for an analysis with the highest statistical precision.

We determined the areas of the 519- and 666-keV γ-ray peaks using GF3, the least-squares peak fitting program in the RADWARE [4] package. A Gaussian peak with a constant background in the peak region was sufficient to properly describe the data in the spectrum. The ratio of peak areas was determined to be $N\gamma_{519}/N\gamma_{666}$ = 0.0155(20), where the uncertainty includes provision for both counting statistics and systematic uncertainties associated with the spectral background and our specific choice of gates in the region of the 5515-keV peak. Taking this result together with the corresponding detector efficiency ratios, we found that the intensity of the 519-keV transition to the 146-keV isomeric state is 1.46(19) % relative to the dominant 666-keV transition to the ground state. Our result has made important contributions to new precise measurements of the superallowed decay of ^{34}Ar [5, 6].

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