Precise β branching ratios in ^{34}Ar from β-γ coincidences

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As part of our program to test the Standard Model *via* the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1] we have measured the β-branching ratios in the decay of ^{34}Ar with the aim of extracting a precise *ft* value (0.1% or better) for the superallowed $0^+ \rightarrow 0^+$ β branch. The *ft* value is determined from three experimental quantities: the half-life, branching ratio and Q_{EC} value. For the experimental results to contribute significantly to the CKM unitarity test, the required precision for each quantity must be better than 0.1%, making the experiment very demanding.

In the case of ^{34}Ar, precise measurements now exist for the Q_{EC} value [2] and half-life [3], which lead to contributions to the *ft*-value uncertainty of 0.04% and 0.05% respectively. However, the branching ratio for the superallowed transition is only known to 0.26% based on a measurement published more than 30 years ago [4]. Thus, a more precise measurement of the branching ratio would add this nucleus to the list of superallowed β emitters whose corrected $\mathcal{F}t$ values contribute to tests of CVC and CKM unitarity [5]. More important still is that the calculated correction for isospin symmetry breaking [6] in the ^{34}Ar decay is larger than the comparable correction for any other well known transition with A<40, where the nuclear models used in the calculation are expected to be the most reliable. Conformity of the corrected $\mathcal{F}t$ value for ^{34}Ar with the average result from the other cases [5] would provide strong confirmation of the validity of the correction calculations.

The ^{34}Ar radioactive beam was produced from the ^{35}Cl(p,2n) reaction with the primary beam at 30*A* MeV impinging on a liquid-nitrogen-cooled gas target at 1.6 atm. An ^{34}Ar beam at 26*A* MeV was separated by the Momentum Achromat Recoil Spectrometer (MARS) [7]. The beam exited the vacuum chamber through a thin Kapton window and then passed through a 0.3-mm-thick plastic scintillator and a series of Al degraders, which were adjusted to ensure the implantation of the ^{34}Ar nuclei at the center of a 76-μm-thick aluminized Mylar tape, part of our fast tape transport system. With an ^{34}Ar beam intensity of about 3×10^4 particles/s, we collected a radioactive sample (> 99.7% pure) for 2 s, then turned off the beam and transported the activity in 180 ms to a well-shielded counting location 90 cm away from the beam line. At the counting location the collected sample stopped between a 70% HPGe detector for γ rays and a 1-mm-thick plastic scintillator for β's, the former being 151 mm away on one side of the source and the latter 5 mm away on the opposite side. We then recorded β singles and β-γ coincidences for a 2-s period before repeating the collect-move-count cycle. These cycles were repeated until the desired statistics were achieved.

The total γ-ray spectrum we obtained for the decay of ^{34}Ar is presented in Figure 1. Even though only about 5% of the ^{34}Ar decays populate excited states in ^{34}Cl, the relatively weak γ-rays from the de-excitation of these states appear as prominent peaks in this spectrum. The only notable peak not related to the ^{34}Ar decay is the 1779 keV peak, which was generated by neutron activation of the Al structural materials surrounding the detectors.

From our data, we could obtain the β-branching ratio BR_i for a particular transition populating state i, which decays by emitting γ ray, γ_i. If the total number of β singles is N_β and the total number of β-γ coincidences measured in the γ_i peak is $N_{\beta\gamma i}$, then the branching ratio BR_i is given by

$$BR_i = \frac{N_{\beta\gamma i}}{N_\beta \varepsilon_{\gamma i}} k \,, \qquad (1)$$

where $\varepsilon_{\gamma i}$ is the detector efficiency for γ ray, γ_i, and *k* is a small correction factor (*i.e.* k = ~1) that, among other things, takes into account the differences in the β-detector efficiency for the different transitions participating in ^{34}Ar decay. 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 [8]. 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 [9] and checked by comparison with conversion-electron sources and with ^{22}Mg β-decay data [10].

The components of the correction factor *k* have been described in detail in Ref. [11]. In the present measurement, they are:

- differences in the total β-detection efficiency induced by the low-energy threshold set in the plastic-scintillator electronics; since the threshold is fixed, a different (small) fraction of the β's will be lost for transitions with different β end-point energies. This contributes 0.2% to *k*;
- dead time corrections in the β singles and β-γ coincidence channels, which give a combined effect of 0.5%;
- real coincidence summing of the positron-annihilation radiation with the observed γ rays, which accounts for 0.1%; and
- random coincidence summing, a 0.3% effect.

Including all these small corrections we determine the sum of all branching ratios for transitions populating excited states in ^{34}Cl to be:

$$\sum BR^* = 5.64(8)\% \qquad (2)$$

These branches are all Gamow-Teller in character, and it is the ground-state transition that is the superallowed one. Subtracting the sum of excited-state transitions from 100%, we obtain the superallowed branching ratio to be:

$$BR_{GS} = 94.36(8)\% \qquad (3)$$

Although the uncertainty quoted in Eq. (2) on the measured sum of branching ratios is ±1.4%, because of the subtraction from 100%, the superallowed branch uncertainty in Eq. (3) is ±0.08%. The former was principally determined by counting statistics on these relatively weak transitions. In detail, the error budget comprises:

- the peak-areas counting statistics (±1.3%);

- the uncertainty in ε_γ (±0.7%), which is dominated here by the uncertainty in the position of the tape along the detector axis (±0.5mm); and
- the uncertainty in the relative efficiency of the beta detector (±0.3%).

Using the branching ratio in Eq. (3) for the superallowed branch together with the known half life [3] and Q_{EC} value [2], we find a corrected $\mathcal{F}t$ value of 3072.3(32) s. This is in good agreement with the current world average, $\mathcal{F}t$ = 3073.9(8) s [5]. However, our result should still be considered as preliminary, since we want to confirm the techniques employed here with a similar measurement of the β-decay of ^{10}C, where the population of the 718-keV exited state in ^{10}B must yield a branching ratio of exactly 100%. Currently we are processing the data from a ^{10}C measurement and, if the results agree with expectations and confirm our approach, we will publish the ^{34}Ar branching ratio very shortly.

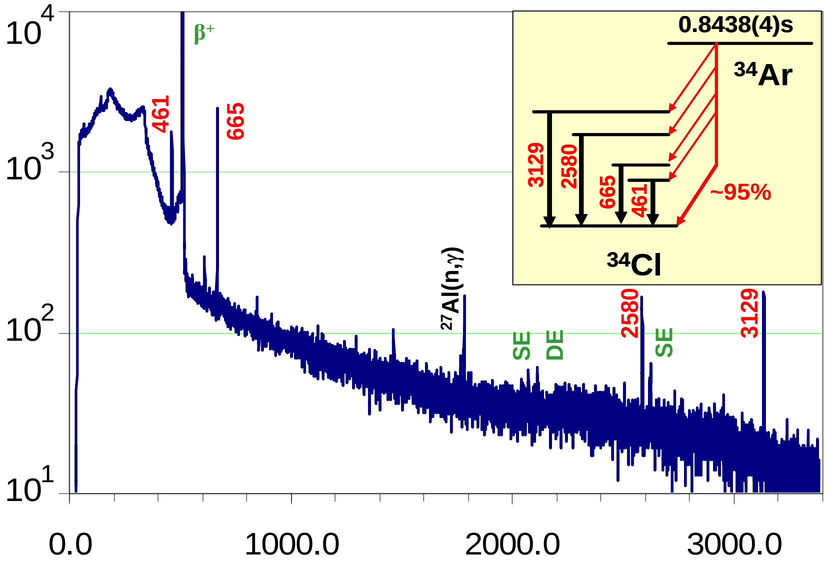

Figure 1. Spectrum of β-delayed γ-rays observed in coincidence with positrons following the decay of ^{34}Ar. The decay scheme is shown in the inset.

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