Measurement of the Half-Lives of ^{34}Cl and ^{34}Ar

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As part of our program [1] to test the unitarity of the CKM matrix through superallowed nuclear decay, we have measured the half-lives of ^{34}Cl and ^{34}Ar with a precision of 0.03% and 0.4% respectively. Although ^{34}Cl is a $T_z = 1$ superallowed emitter whose half-life is already relatively well-known [2], it is also the daughter of ^{34}Ar and, as discussed in last year's Progress Report [3], any measurement sensitive only to particles will not only record those from the decay of ^{34}Ar will necessarily include the particles from the decay of ^{34}Cl. Since our ability to determine the ^{34}Ar half-life is limited by the precision with which the ^{34}Cl half-life is known, we have been motivated to re-measure the latter with improved precision. The results of these two separate experiments will be described in this report.

We performed these measurements at the end of the MARS recoil spectrometer, using our fast tape-transport system [4]. For the ^{34}Cl experiment, we used a cooled hydrogen gas target and a 25 *A*MeV ^{35}Cl beam from the cyclotron to initiate the ^{1}H (^{35}Cl,pn) ^{34}Cl reaction. A high-purity beam of fully stripped ^{34}Cl ions at 20 *A*MeV was separated from the other recoil products by the MARS spectrometer. Those ions exited MARS through a 50- m-thick Kapton window, passed through a 0.3-mm-thick BC–404 scintillator and a stack of aluminum degraders optimized in thickness so that the ^{34}Cl ions eventually stopped in the 76- m-thick aluminized mylar tape of our tape-transport system. The beam consisted of two components: the 0^+ ground-state of ^{34}Cl ($t_{1/2}$ = 1.53 s) and the 3^+ isomeric state in ^{34}Cl ($t_{1/2}$ = 32.2 min.). In principle, it might also have included a very small amount of ^{30}P ($t_{1/2}$ = 150 s) but, since the range of ^{30}P was different from ^{34}Cl, very little of it should have been deposited in the tape. We checked for this possibility, however, by making measurements with two different sets of aluminum degraders chosen to increase the amount of ^{30}P stopped in the tape if, indeed, any were present.

In our experiment, the ^{34}Cl activity was collected on the tape for 3 s; then the beam was turned off and the sample moved within 180 ms to the center of a 4 proportional gas counter [5], located in a low-background region. The counter signals were then multiscaled for a period of 35 s and a 250 channel decay spectrum was recorded in a similar manner to that used for ^{22}Mg [6]. This collect/move/detect cycle was clock-controlled and was repeated continuously. Within the counting period a pulse synthesizer accurate to 5 ppm provided the channel advance. Special care was taken to avoid any systematic errors that could be generated by the acquisition system. The counter signals were amplified and sent to a fast discriminator, whose signals then went to a gate generator. The time duration of the gate signal was chosen to be much longer than any dead-time introduced by the up-stream modules. This produced a well-defined,

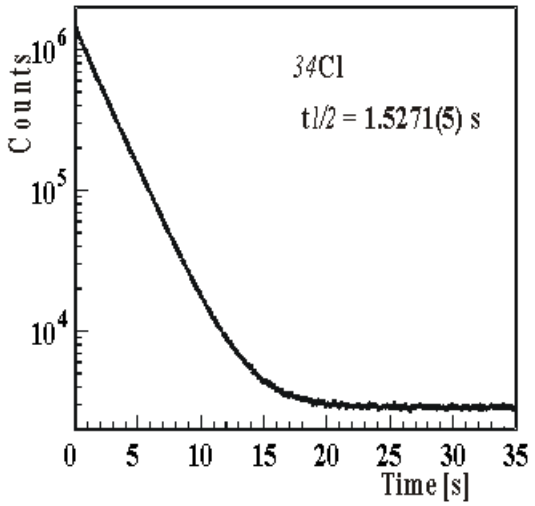
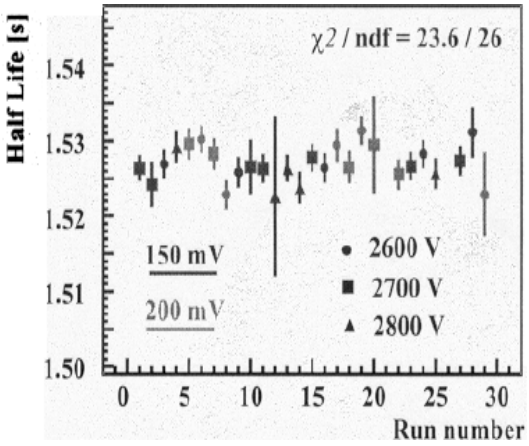


Figure 1: Total time spectrum obtained for the β-decay of ^{34}Cl.

dominant and non-extendable dead time. A total of about 24 million ^{34}Cl decays were recorded in 27 separate runs. We pre-sorted the data by testing each cycle and rejecting any that had significantly too many or too few counts relative to the number of ^{34}Cl ions recorded in the plastic scintillator. Very few cycles were rejected in this way. The decay curve for the sum of all accepted cycles is shown in Figure 1. We then individually analyzed the data from each run with a maximum-likelihood fit to a spectrum obtained by summing the dead-time-corrected spectra from all accepted cycles. As a systematic check on the fitting procedure, a parallel fit was also performed on Monte-Carlo-generated spectra with the same statistics and composition as the experimental set. The agreement of the fitted parameters with the values used to generate the artificial data validated the fitting procedure.

To check for the existence of systematic errors introduced by the electronics, the individual runs were made with different settings for the discriminator threshold, the detector bias, and the dominant dead-time. No indication of a systematic bias was evident when these measurements were compared (see Figure 2). In addition, we checked for the presence of short-lived impurities or other possible counting-rate dependence by progressively removing the data from time bins at the beginning of the counting cycle and repeating the analysis procedure. As can be verified in Figure 3, the derived half-life is stable as channels are removed.

For the ^{34}Ar experiment, a high-purity radioactive beam of ^{34}Ar was produced via the ^{1}H (^{35}Cl, 2n) ^{34}Ar reaction. As in the ^{34}Cl experiment, the ^{34}Ar atoms were stopped in the tape by passing them first through a a plastic scintillator and a stack of aluminum degraders. The ^{34}Ar activity was collected for either 0.7 s or 1 s, and then moved rapidly via the tape-transport system to the 4 proportional gas counter located in a low-background region The counter signals were then multiscaled for a period of 12 s, and a 500 channel decay spectrum was recorded. We had previously checked that argon does not diffuse out of the tape by implanting 1.77-



s ^{35}Ar in the tape and measuring its half-life

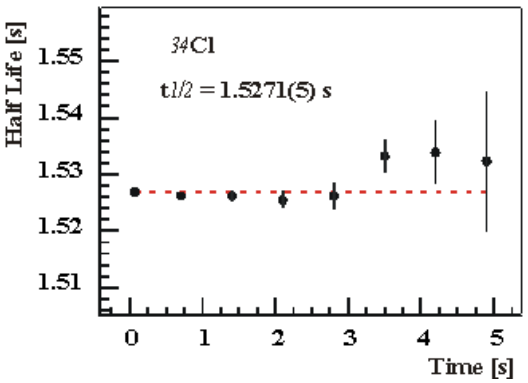


Figure 3: Test for possible systematic errors in the measurement of the decay of ^{34}Cl caused by undetected short-lived impurities or by rate-dependent counting losses. The abscissa represents the time period at the beginning of the counting cycle for which the data are omitted from the fit.

Figure 2: Search for possible systematic bias in the ^{34}Cl measurement due to the acquisition set-up: discriminator threshold or detector bias.

by the same technique: our results agreed with the well-known half-life of ^{35}Ar, thus ruling out diffusion from the tape on this time scale.

A total of about 140 million decay events, from both ^{34}Ar and its ^{34}Cl daughter, were recorded in 40 separate runs. The data were pre-sorted as before, with high-noise and low-count cycles removed. Once again, very few cycles were rejected. We then analyzed the data run-by-run by summing the dead-time-corrected spectra from all cycles in each run and then least-squares fitting the sum spectrum for that run using the maximum-likelihood technique. Unfortunately, because the decay spectra contain both parent and daughter decays (see Figure 4), both of which have very similar half-lives, the fits are relatively insensitive to the half-life of ^{34}Ar. Thus, even though we acquired over 10^8 events in all, the uncertainty ultimately achievable on the ^{34}Ar half-life is over an order of magnitude worse than that quoted for ^{34}Cl. Again, tests of the data for possible systematic errors yielded no observable effect.

From these results, our preliminary values for the half-lives of ^{34}Cl and ^{34}Ar are 1527.1(5) ms and 0847.0(37) ms, respectively. Our result for ^{34}Cl is consistent with the value obtained [2] from current world data, 1525.8(9) ms, but represents more than a factor of two improvement in precision over any previous single measurement. In the case of ^{34}Ar, our result also agrees with the only comparable previous measurement [7], which yielded 844.5(34) ms, but with a similar uncertainty. Actually, in this case, the previous measurement used a different technique – analyzing the decay of β-delayed

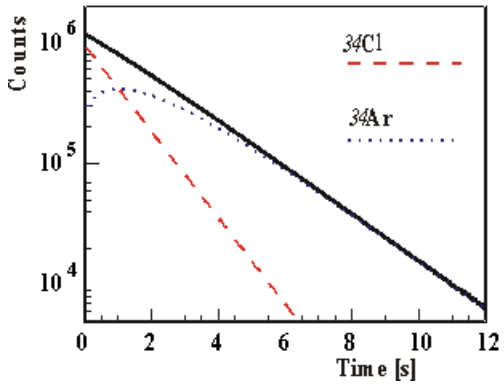


Figure 4: Total time spectrum for the β-decay of ^{34}Ar and its daughter ^{34}Cl. The calculated contributions of the two components are also shown.

γ-rays in ^{34}Cl – so consistency between the two results is an important conclusion in itself. It is interesting to note that, in our present experiment, approximately half the uncertainty quoted for the ^{34}Ar half-life is still due to the very small uncertainty remaining in the ^{34}Cl value.

We are considering making one more measurement of the ^{34}Ar half-life with the gas counter in order to improve its uncertainty somewhat.

References

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