

## Improved the half-life of the $\beta^+$ emitter $^{31}\text{Cl}$

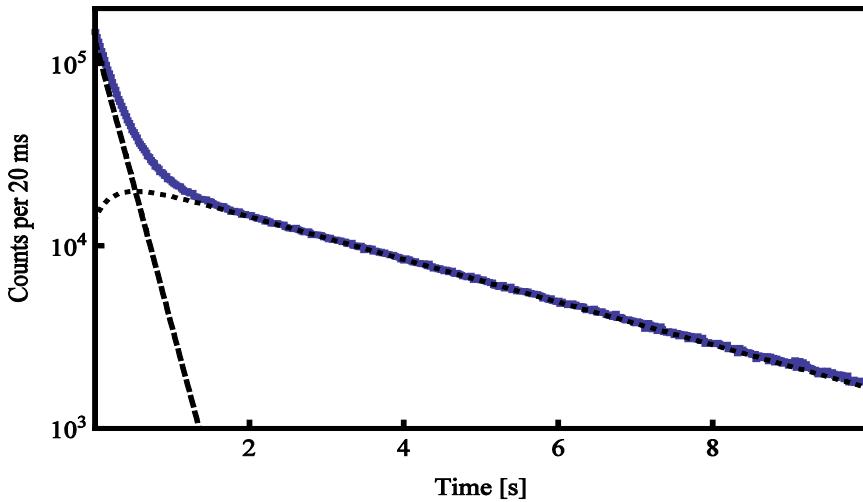
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We report here a significant improvement in the accuracy of the measured half-life of the proton-rich nucleus  $^{31}\text{Cl}$ , which is important for understanding explosive H-burning in novae. Previous measurements of this half-life [1] were based on the He-jet method and reported the result  $t_{1/2} = 150 \pm 25$  ms. Our new value is  $t_{1/2} = 189.7 \pm 1.8$  ms.

We produced a  $^{31}\text{Cl}$  radioactive beam via the  $p(^{32}\text{S}, 2n)^{31}\text{Cl}$  reaction in inverse kinematics: We used a 40-A MeV  $^{32}\text{S}$  beam and a cryogenic  $\text{H}_2$  target kept at liquid nitrogen temperature and at 2 atm pressure. A >90%-pure  $^{31}\text{Cl}$  beam at 34.4-A MeV and with an intensity of up to 3000 pps was separated in the Momentum Achromat Recoil Separator (MARS) [2]. The radioactive beam was extracted in air, and then passed through a thin plastic scintillator, a series of Al degraders, and eventually implanted in the 76- $\mu\text{m}$ -thick mylar tape of our fast tape-transport system (see Ref. [3]). The thickness of the Al degraders was experimentally tuned to optimize the implantation of the  $^{31}\text{Cl}$  beam. The measurement was performed in cycles. We collected a sample of  $^{31}\text{Cl}$  nuclei for 0.3 s; then the beam was turned off and the collected activity was moved in 60 ms to the center of a  $4\pi$  proportional gas counter, where the decays were subsequently multiscaled for 10 s. Such collect-move-detect cycles were repeated until the desired



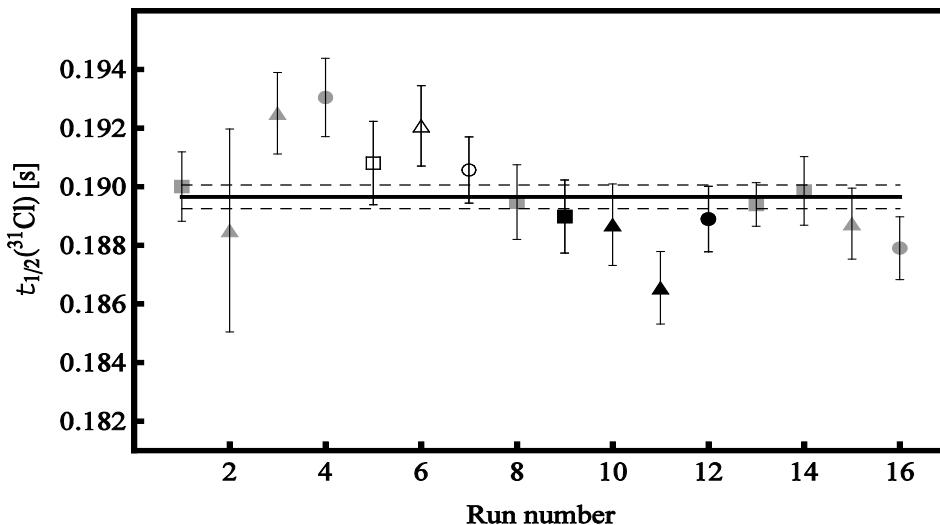
**FIG. 1.** Measured time-decay spectrum (solid line) for the total of all data obtained from the  $\beta^+$  decay of  $^{31}\text{Cl}$  and its daughter  $^{31}\text{S}$ . The dotted/dashed lines represent the derived  $^{31}\text{Cl}/^{31}\text{S}$  contributions.

statistics had been achieved. We collected a total of  $6 \times 10^6 \beta^+$  events from the combined decays of  $^{31}\text{Cl}$  and  $^{31}\text{S}$ . The total decay spectrum is presented in Fig. 1.

While the experimental setup was similar to the one used in Ref. [4], three differences should be noted:

- (1) The short half-life of  $^{31}\text{Cl}$  required us to reduce the time taken for the tape to move a sample into the detector. Using a close geometry, we were able to reduce our standard move-time of  $\sim 180$  ms [4] to  $\sim 60$  ms.
- (2) The relatively short cycle time prompted us to use a loop arrangement for the mylar tape rather than the pair of reservoir/take-up tape units that unwind/wind-up the tape in our standard measurements [4]. The loop length was  $\sim 40$  times longer than the distance moved in a single cycle, thus ensuring that an implanted sample could not possibly reenter the detector in less than  $\sim 7$  min, ample time for it to have decayed to background level.
- (3) The parent nucleus  $^{31}\text{Cl}$  decays either by  $\beta^+$  or  $\beta^+ p$ , creating respectively  $^{31}\text{S}$  or  $^{30}\text{P}$ . Since their half lives are 2.6 s and 2.5 min, respectively, the  $^{30}\text{P}$  contribution was indistinguishable from the background.

The electronic scheme used to process the data was identical to the one used in the  $^{34}\text{Ar}$  experiment [4]. To allow us to test for possible systematic effects, the experiment was split into 16 separate runs, differing from one another in settings of various electronic parameters: detector bias,



**FIG. 2.** Test for possible systematic bias in the  $^{31}\text{Cl}$  half-life measurement resulting from different settings of the discriminator threshold or detector voltage. Open/grey/black symbols represent the three discriminator settings, 150 mV/200 mV/250 mV; the three detector biases, 2550 V, 2650 V, and 2750 V are represented by the symbol shapes  $\Delta$ ,  $\square$ , and  $O$ , respectively. The average value for the half-life is  $189.65 \pm 0.40$  ms (statistical uncertainty only) with  $\chi^2/ndf = 26.2/15$ . The average value appears as the solid line, with dashed lines as uncertainty limits.

discriminator threshold and dominant dead-time. As seen in Fig. 2, the half-life results show no systematic dependence on detector bias or discriminator threshold. Although not illustrated, the results were also found to be independent of the imposed circuit dead time.

In contrast with our  $^{26}\text{Si}$  measurement [3], for  $^{31}\text{Cl}$  decay the contributions of the two decaying nuclei to the total decay spectrum are easily disentangled. This allowed for an unlinked fit of the decay, which is described as the sum of two exponentials plus background:

$$\Lambda_{tot} = C_1 e^{-\lambda_1 t} + C_2 e^{-\lambda_2 t} + B,$$

where four parameters were determined in the least-squares fit:  $C_{1,2}$ ,  $\lambda_1$  and  $B$ . The daughter's decay constant  $\lambda_2$  was held at the known value of its half life,  $2.572 \pm 0.013$  s [5]. The result of our fit for the  $^{31}\text{Cl}$  half-life is  $t_{1/2} = 189.65 \pm 0.40$  ms, with statistical uncertainty only. If we now include systematic uncertainties our final result is  $t_{1/2} = 189.7 \pm 1.8$  ms. The complete error budget is detailed in Table I.

**TABLE I.** Error budget for the  $^{31}\text{Cl}$  half life.

Contribution	Value [ms]
Statistics	0.40
$t_{1/2}(^{31}\text{S})$	0.71
Impurity $^{30}\text{S}$	0.16
Impurity $^{28}\text{P}$	1.61
<i>Total</i>	1.81

While the unlinked fit just described was the best option in this case since it did not limit the precision of the result, the linked parent-daughter procedure described in [2,3] can also be applied although it is essential to take account of the  $^{31}\text{Cl}$  decay branches that go by  $\beta$ -delayed proton emission, thus bypassing the  $^{31}\text{S}$  daughter. In effect, this means that the linked fit can be used to extract the magnitude of the total proton branching ratio, for which we obtain  $8 \pm 1\%$ .

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