

PRECISION MEASUREMENTS OF THE HALF-LIVES OF THE POSITON EMITTERS ^{25}Al , $^{26}\text{Al}^{\text{m}}$, AND ^{33}Cl

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Synopsis

The half-lives of the positon emitters ^{25}Al , $^{26}\text{Al}^{\text{m}}$, and ^{33}Cl , produced by (p, γ) reactions at selected resonances, have been measured by means of two different methods:

- a) with a 70-channel pulse-analyser using time-to-pulse-height conversion;
- b) with an eleven-contact stepping switch and eleven sets of scales and mechanical registers.

The results are:

$$\begin{aligned} ^{25}\text{Al} & 7.24 \pm 0.03 \text{ sec;} \\ ^{26}\text{Al}^{\text{m}} & 6.28 \pm 0.04 \text{ sec;} \\ ^{33}\text{Cl} & 2.53 \pm 0.02 \text{ sec.} \end{aligned}$$

1. *Introduction.* The existing measurements of the half-life of ^{33}Cl scatter badly. Values of 2.8 sec ¹⁾, 2.4 ± 0.2 sec ²⁾, 2.8 sec ³⁾, and 1.8 ± 0.1 sec ⁴⁾ have been reported. In some of these measurements a mixture of ^{33}Cl and ^{34}Cl (1.4 sec) might have been studied.

In order to obtain the $^{33}\text{Cl}(\beta^+)^{33}\text{S}$ ft -value with good precision, it was decided to remeasure the ^{33}Cl half-life. The decay energy is known accurately at present ⁵⁾.

The half-lives of ^{25}Al and $^{26}\text{Al}^{\text{m}}$ were also measured, primarily as a check on the present method. These half-lives have been determined by other authors with relatively small errors (see Section 4).

From the $^{26}\text{Al}^{\text{m}}$ ft -value the Fermi interaction constant g_F can be obtained directly. The $^{25}\text{Al}(\beta^+)^{25}\text{Mg}$ and $^{33}\text{Cl}(\beta^+)^{33}\text{S}$ decay constants contain both Fermi and Gamow-Teller contributions. For these mirror transitions the Fermi contribution is known and thus the ft -values can be used to obtain the Gamow-Teller contribution. These theoretical implications of the present measurements, however, will be discussed elsewhere.

2. *Experimental procedure.* The radioactive nuclides to be investigated were produced by (p, γ) reactions, the protons being accelerated with the 800 kV Utrecht Cockcroft-Walton generator. As these reactions proceed through narrow resonances it is possible to obtain a quite high positon yield

from the nuclide under investigation compared to the yield from contaminants present on the target.

The ^{25}Al was produced at the $E_p = 220$ keV resonance in the $^{24}\text{Mg}(p, \gamma)^{25}\text{Al}$ reaction using a magnetically analysed $140 \mu\text{A}$ H_2^+ beam. The target consisted of a relatively thick natural MgO layer applied directly onto the inner wall of the target holder. As the lowest known $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$ resonance occurs at 317 keV ⁶⁾ the possibility that ^{26}Al is produced along with the ^{25}Al can be excluded. The $^{26}\text{Mg}(p, \gamma)^{27}\text{Al}$ reaction would only produce stable ^{27}Al . As a check some bombardments have also been performed on a highly enriched separated ^{24}Mg target ($65 \mu\text{g}/\text{cm}^2$ on a 0.5 mm copper backing). As a further check the gamma-ray spectrum was registered at the 220 keV resonance with a Hutchinson-Scarrott 70-channel pulse-analyser. No lines were observed other than those known ⁶⁾ to result from the $^{24}\text{Mg}(p, \gamma)^{25}\text{Al}$ reaction.

For the $^{26}\text{Al}^m$ measurements an enriched $100 \mu\text{g}/\text{cm}^2$ ^{25}Mg target on a 0.5 mm copper backing was used. The target was obtained from the Atomic Energy Research Establishment, Harwell, England. The first measurements were performed at the (unresolved) $E_p = 496$ and 513 keV resonances. Later the 683 keV resonance was chosen because of its higher positron yield ^{7,8)}. The 563 and 588 keV resonances which show a still higher yield could not be used because of the proximity of the 594 keV $^{32}\text{S}(p, \gamma)^{33}\text{Cl}$ resonance together with the fact that the target was slightly contaminated with sulphur. No $^{24}\text{Mg}(p, \gamma)$ resonances occur in the region of the $^{25}\text{Mg}(p, \gamma)$ resonances which were selected for the present measurements. The proton current amounted to about $45 \mu\text{A}$.

The ^{33}Cl was produced at the $E_p = 594$ keV resonance in the $^{32}\text{S}(p, \gamma)^{33}\text{Cl}$ reaction, making use both of a thick natural CuS target on 0.1 mm copper, and of an enriched $40 \mu\text{g}/\text{cm}^2$ Cd^{32}S target on 0.4 mm nickel. The only reaction which can interfere with the ^{33}Cl measurements is $^{33}\text{S}(p, \gamma)^{34}\text{Cl}$ producing 1.5 sec ^{34}Cl at the 449 and 513 keV resonances ⁹⁾. However, the abundance of ^{33}S in natural sulphur is so small (0.74%), and the resonances are so weak that the ^{34}Cl contribution to the initial positron counting rate can be estimated as at most 0.1%, and probably much less.

The bombardments activating the target and lasting about five half-lives were alternated with counting periods also lasting about five half-lives. During the latter periods the proton beam was suppressed by switching off the power supply and the magnetic field of the P.I.G. ion source. As a further precaution to make sure that no residual beam could reach the target through the 90° deflecting magnet a switch was mounted which was actuated at the end of the bombardment, and which reduced the generator high voltage by 10%. No residual beam on the target could be detected with a sensitive galvanometer (sensitivity 10^{-10} A/mm).

The positons originating from the decay of the radioactive nuclides under observation were detected with a thin (5 mm) anthracene crystal coated with MgO smoke and mounted on a Dumont 6292 photo-multiplier tube within a heavy lead shield. After amplification the pulses were fed through a differential discriminator to the apparatus for time analysis to be described below. To reach the crystal the positons had to penetrate the target backing and the wall of the target holder (0.5 mm brass). The maximum energy of the positons to be counted amounts to 3.24, 3.22, and 4.56 MeV for ^{25}Al , $^{26}\text{Al}^{\text{m}}$, and ^{33}Cl , respectively. On all targets carbon is present from which 10.1 min ^{13}N (positon endpoint 1.20 MeV) is formed at the strong and broad $E_p = 460 \text{ keV } ^{12}\text{C}(p, \gamma)^{13}\text{N}$ resonance. The discriminator bias was always chosen such that no ^{13}N positons could contribute to the registered counting rate. The energy response of the detector was calibrated with mono-energetic ^{137}Cs internal-conversion electrons.

3. *Time analysis.* Two methods have been used to analyse the time of arrival of the positon-induced scintillation pulses.

In the first method the pulses from the discriminator triggered a pulse generator from which pulses of constant amplitude were fed into the Hutchinson-Scarrott pulse-height analyser. The bias of the input amplifier of the analyser was swept through a suitable range of values by a sawtooth voltage from a Miller circuit, such that the pulses arriving at $t = 0$ were registered in channel 1 while those arriving at the end of the counting period were registered in channel 70. The time scale was calibrated by feeding into the pulse generator regularly spaced pulses from a quartz clock; if the system is exactly linear, an equal number of pulses should be registered in all channels. A deviation from linearity was observed of up to about 1%. A correction had to be applied for the rather large (600 μ sec) average dead-time of the pulse-analyser. For the first time channels this correction amounted to at most 5 percent. Because the read-out of the pulse analyser and the application of the corrections for alinearity and dead-time proved rather time consuming, this method was only used in the initial stage of the present measurements.

In the second method the output of the discriminator was switched in turn to eleven different sets of scales and mechanical registers by means of a stepping switch. The stepping switch was actuated by accurately spaced signals, at 1.024, 2.048, or 4.096 sec intervals, obtained by scaling down the 1000 Hz signal from a calibrated quartz clock. The switching time amounted to about 10^{-2} sec. The switching time itself does not enter into the calculation of the half-life. Only the variation in the switching time, for which an upper limit of 2×10^{-3} sec can be given, could cause a systematic error, which, however, is obviously completely negligible in the present case.

The half-life and the statistical error in the half-life were computed from the registered number of counts in the eleven time channels with a procedure indicated by Peierls¹⁰⁾. Of course, background had to be subtracted first. The background was measured frequently between runs. It was constant in time, within statistics, showing that no measurable build-up of long-lived activities occurred during the bombardments. On the average the background amounted to 0.25 counts/sec, while the average initial counting rates of the observed ²⁵Al, ²⁶Al^m, and ³³Cl activities amounted to about 75, 25, and 65 counts/sec, respectively. The ratio of the initial intensity to background determines the optimal duration of the counting period to obtain the best statistics in a given time. From the curve given in reference 8 one finds 52, 36, and 18 sec for the ²⁵Al, ²⁶Al^m, and ³³Cl measurements, respectively. The actual counting periods taken in the present measurements were 45 sec for most of the ²⁵Al and ²⁶Al^m runs (22.5 sec. for the remaining runs), and 11.3 sec for all ³³Cl runs.

The results of all runs were also plotted on logarithmic paper, which served as a check on the correct operation of the apparatus and on the possible presence of contaminant activities.

4. *Experimental results.* ²⁵Al. In Table I the results of the ²⁵Al half-life measurements at the 220 keV resonance are given. The errors indicated are of purely statistical character. The total number of bombardments amounts to 611 and the total number of positons counted to about 5×10^5 .

TABLE I

| Half-life measurements of ²⁵ Al. | | | | | |
|---|------------------------|-----------------|---------------|------------------------|-----------------|
| Number of run | Number of bombardments | Half-life (sec) | Number of run | Number of bombardments | Half-life (sec) |
| 1 *) | 30 | 7.14 ± 0.06 | 13 | 12 | 7.21 ± 0.06 |
| 2 *) | 120 | 7.43 ± 0.04 | 14 | 15 | 7.05 ± 0.06 |
| 3 *) | 20 | 7.47 ± 0.10 | 15 | 12 | 7.12 ± 0.05 |
| 4 *) | 30 | 7.21 ± 0.08 | 16 | 12 | 7.15 ± 0.06 |
| 5 †) | 14 | 7.24 ± 0.18 | 17 | 24 | 7.22 ± 0.05 |
| 6 †) | 24 | 7.42 ± 0.15 | 18 | 24 | 7.11 ± 0.05 |
| 7 †) | 24 | 7.23 ± 0.12 | 19 | 24 | 7.23 ± 0.05 |
| 8 †) | 22 | 7.68 ± 0.12 | 20 | 24 | 7.18 ± 0.05 |
| 9 ‡) | 20 | 7.02 ± 0.10 | 21 | 20 | 7.05 ± 0.06 |
| 10 ‡) | 20 | 7.16 ± 0.10 | 22 | 20 | 7.13 ± 0.06 |
| 11 ‡) | 20 | 7.31 ± 0.09 | 23 | 20 | 7.20 ± 0.06 |
| 12 ‡) | 20 | 7.20 ± 0.09 | 24 | 20 | 7.23 ± 0.06 |
| | | | 25 | 20 | 7.35 ± 0.06 |

*) Measurements with the pulse-analyser; all others with the stepping switch.

†) Measurements with a separated ²⁴Mg target; all others with a natural MgO target.

‡) Measurements with a 22.5 sec counting period; all others with a 45 sec counting period.

The ²⁵Al half-life average from all measurements is 7.24 ± 0.03 sec. This (standard) error was obtained by computing the internal error (0.012

sec) and the external error (0.025 sec) and rounding off the largest. Previous measurements yielded 7.3 sec ¹¹), and 7.62 ± 0.13 sec ⁸).

²⁶Al^m. The results of the ²⁶Al^m half-life measurements are presented in Table II. All these results were obtained with the stepping switch. Some measurements were also performed with the pulse-analyser at the 563–588 keV resonance. The latter results were rejected because of the sulphur contamination on the target (see Section 2). All measurements were performed with the enriched ²⁵Mg target. The runs given in Table II correspond to a total number of bombardments of 370 and to a total number of registered positons of 9×10^4 .

TABLE II

| Half-life measurements of ²⁶ Al ^m . | | | | | |
|---|------------------------|-----------------|---------------|------------------------|-----------------|
| Number of run | Number of bombardments | Half-life (sec) | Number of run | Number of bombardments | Half-life (sec) |
| 1 *) | 20 | 6.29 ± 0.22 | 9 †) | 40 | 6.07 ± 0.09 |
| 2 *) | 20 | 6.69 ± 0.21 | 10 | 20 | 6.32 ± 0.09 |
| 3 *) | 20 | 6.19 ± 0.20 | 11 | 20 | 6.28 ± 0.09 |
| 4 *) | 20 | 6.31 ± 0.18 | 12 | 20 | 6.55 ± 0.09 |
| 5 *) | 30 | 6.09 ± 0.15 | 13 | 20 | 6.31 ± 0.09 |
| 6 *) | 20 | 6.26 ± 0.19 | 14 | 20 | 6.31 ± 0.09 |
| 7 †) | 20 | 6.31 ± 0.13 | 15 | 20 | 6.21 ± 0.09 |
| 8 †) | 40 | 6.07 ± 0.09 | 16 | 20 | 6.41 ± 0.09 |

*) Measurements at the 496–513 keV resonance; all others at the 683 keV resonance.

†) Measurements with a 22.5 sec counting period; all others with a 45 sec counting period.

The average value of the ²⁶Al^m half-life is found as 6.28 ± 0.04 sec (internal error 0.03 sec, external error 0.04 sec). In previous investigations values were found of 6.47 and 6.40 sec ¹²), 6.49 ± 0.10 sec ¹³), 6.68 ± 0.11 sec ⁸), and 6.5 ± 0.1 sec ¹⁴).

³³Cl. The values obtained for the ³³Cl half-life are given in Table III. All measurements were performed at the 594 keV resonance. The total number of bombardments amounted to 540, and the total number of registered positons to 9×10^4 .

TABLE III

| Half-life measurements of ³³ Cl. | | | | | |
|---|------------------------|-----------------|---------------|------------------------|-----------------|
| Number of run | Number of bombardments | Half-life (sec) | Number of run | Number of bombardments | Half-life (sec) |
| 1 *) †) | 80 | 2.64 ± 0.04 | 6 | 50 | 2.50 ± 0.03 |
| 2 *) †) | 80 | 2.44 ± 0.04 | 7 | 50 | 2.52 ± 0.03 |
| 3 *) †) | 130 | 2.46 ± 0.04 | 8 | 50 | 2.52 ± 0.03 |
| 4 †) | 20 | 2.57 ± 0.05 | 9 | 50 | 2.54 ± 0.03 |
| 5 †) | 30 | 2.55 ± 0.07 | | | |

*) Measurements with the pulse-analyser; all others with the stepping switch.

†) Measurements with a separated ³²S target; all others with a natural CuS target.

The average value obtained for the ^{33}Cl half-life is 2.52 ± 0.02 sec (internal error 0.012 sec, external error 0.017 sec). Previous measurements yielded 2.8 sec ¹⁾, 2.4 ± 0.2 sec ²⁾, 2.8 sec ³⁾, and 1.8 ± 0.1 sec ⁴⁾.

5. *Discussion.* For all runs with the stepping switch the actual number of counts in each time channel was also added (after subtraction of background) and plotted on logarithmic paper. This plot is not given here because both the deviation of each point from a straight line, and the statistical error in each point would be almost invisible on the much reduced scale necessary for reproduction.

It has been remarked already that the errors assigned to the final results are purely statistical. A thorough search has revealed no systematic errors for which a correction should have been applied. Such a search was prompted by the two facts *a)* that the half-life values obtained for ^{25}Al and $^{26}\text{Al}^{\text{m}}$ are slightly smaller than those obtained in previous investigations, *b)* that for all three nuclides the external error comes out somewhat larger (by a factor of 1.3 to 2.0) than the internal error.

A proper correction for the dead-time of the pulse-analyser has been applied (see Section 3). The dead-time of the scales (5μ sec) is so small, that no correction is necessary.

From Tables I, II, and III it appears that no systematic difference can be found between the results obtained *a)* with different methods of time analysis (pulse-analyser or stepping switch), *b)* with different targets, *c)* with different counting periods.

No observable fatigue or overload effects have been found for the scintillation counter. The half-lives observed for large or for small proton currents during the bombardment were the same within statistics. Especially during the $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}^{\text{m}}$ bombardments the gamma-ray counting rate can be quite large, several times the initial positron counting rate. Fatigue effects due to this cause, if present, can be suppressed by raising the photo-cathode of the multiplier to a voltage positive in respect to that of the first dynode during the bombardment. This did not result, however, in any measurable difference on the observed half-lives. The actual time base used in the present experiments was the quartz clock. It has been very stable over many years never showing deviations of more than about one part per million. Rough checks (accuracy one part per thousand) of the timing signals have frequently been made between runs.

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