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Half-lives of ^{62}Ga, ^{66}As, and ^{70}Br

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The Fermi superallowed β^+ activities ^{62}Ga, ^{66}As, and ^{70}Br were produced in the reactions ^{58}Ni(^{6}Li,2n) ^{62}Ga at $E_{^6\mathrm{Li}} = 25$ MeV ^{58}Ni(^{10}B,2n)^{66}As at $E_{^{10}\mathrm{B}} = 30$ MeV, and ^{58}Ni(^{14}N,2n) ^{70}Br at $E_{^{14}\mathrm{N}} = 44$ MeV. Half-lives were determined by multi-scaling pulses from a plastic β ray detector. The measured half-lives are as follows: ^{62}Ga—115.95 $\pm$ 0.30 ms, ^{66}As—95.78 $\pm$ 0.39 ms, and ^{70}Br—80.2 $\pm$ 0.8 ms. An attempt to observe the decay of ^{74}Rb, produced in the ^{58}Ni(^{19}F,3n)^{74}Rb reaction at $E_{^{19}\mathrm{F}} = 60$–68 MeV, was unsuccessful.

[RADIOACTIVITY ^{62}Ga, ^{66}As, ^{70}Br; measured $T_{1/2}$.]

I. INTRODUCTION

The vector coupling constant effective for nuclear β decay is best determined from the systematics of the ft values for pure Fermi superallowed β^+ transitions of $J^\pi = 0^+ \rightarrow 0^+$. During the past few years measurements have been made at several laboratories on eight cases from ^{14}O to ^{54}Co and their ft values have been determined to an accuracy of ~±0.1%. In the most recent review[1] of this series a plot of $f^R t$ versus Z (where f^R includes outer radiative corrections) shows an apparently smooth systematic behavior, with $f^R t$ increasing by about 0.6% between ^{14}O and ^{54}Co. However, the analysis hinges to a large extent on the ft value for ^{14}O in the derivation of which there are still unresolved discrepancies[1] in the measured decay energy. Thus, on the basis of the experimental evidence, Towner and Hardy[2] find no clear preference for a particular theoretical treatment of the results.

Whatever the eventual outcome of the studies of the systematics of these eight cases, it would be very useful to extend the series to higher Z with ft values of comparable accuracy. The sequence of possible Fermi superallowed β^+ emitters above ^{54}Co consists of ^{58}Cu, ^{62}Ga, ^{66}As, ^{70}Br, and ^{74}Rb. In the case of ^{58}Cu, King *et al.*[3] showed from their data and previous work that the 0^+, $T = 1$ state is above the ground state and no superallowed β transition is expected. ^{62}Ga has been reported by several groups. Using the ^{46}Ti(^{19}F,3n)^{62}Ga and ^{50}Cr(^{16}O,p3n)^{62}Ga reactions, Jackson *et al.*[4] obtained a rough value of 115 ± 10 ms for the half-life. More recently, Chiba *et al.*[5] made this activity in the ^{64}Zn(p,3n)^{62}Ga reaction at $E_p = 44$ MeV and reported values of 116.4 ± 1.5 ms for $T_{1/2}$ and 8.3 ± 0.3 MeV for $E_{\beta^+\,\mathrm{max}}$. During the course of the present work a preliminary value for the half-life of ^{62}Ga was reported by Davids *et al.*[6] using the ^{58}Ni(^{6}Li,2n)^{62}Ga reaction at $E_{^6\mathrm{Li}} = 24$ MeV. Their result has now been superseded[7] by a final value of 116.34 ± 0.35 ms obtained from new measurements made with a plastic scintillator for detecting the positrons.

^{66}As has been reported[4] as having a half-life of 93 ± 5 ms. The reactions ^{40}Ca(^{32}S,αpn)^{66}As and ^{50}Cr(^{19}F,3n)^{66}As were used to make the activity.

^{70}Br appears to be as yet unreported but is expected to have a half-life of ~80 ms. However, the next one in the series, ^{74}Rb, has been found[8] to have a half-life of 64.9 ± 0.5 ms. It was produced in spallation reactions induced by 600-MeV protons, followed by collection in the Isolde-2 mass separator.

In the present work the activities ^{62}Ga, ^{66}As, and ^{70}Br were produced in heavy-ion reactions and their half-lives were measured. An attempt was also made to produce ^{74}Rb.

II. EXPERIMENTAL METHODS AND RESULTS

In all of the half-life measurements the target material consisted of Ni foil 0.01 mm in thickness enriched to 99.93% in ^{58}Ni. A 2.5-cm diameter glass tube was used as a target chamber and into this was inserted a target ladder for holding four samples clamped in Ta-backed holders. Any one of the samples could be adjusted so as to be in line with the beam collimator. A plastic scintillator was placed next to the glass tube to detect the emerging β rays. Thin lead was wrapped around the tube in such a way as to reduce the yield of β rays from all but the sample in line with the beam. By occasionally changing to a different target, the effect of the build up of long-lived activities was reduced.

The β-ray detector consisted of an NE102 scintillator 4.7 cm long by 5.0 cm in diameter attached to an RCA 6342 photomultiplier tube. As described previously,[1] a fast amplifier and discriminator system (50 ns time constants) was used and the output was multi-scaled in a Northern Scientific Co. pulse-height analyzer. The general procedure was to irradiate the target for 0.2 s with a beam from an MP Tandem Van de Graaff, cut the beam off using a mechanical chopper, and then start the multi-scaler after a delay of 0.05 s. All operations were controlled automatically by a timer-programmer which continuously repeated the sequence.

Analysis of the resulting decay curves was made by a nonlinear least-squares minimization computer program to fit the data to an exponential plus constant background. Fits were made starting in the first usable channel and after one or two half-lives. Details of experiments on the individual activities are as follows.

^{62}Ga

The reaction ^{58}Ni(^{6}Li,$2n$)^{62}Ga at $E_{^6\mathrm{Li}} = 25$ MeV was used to produce ^{62}Ga. A ^{6}Li^{3+} beam of ~100 nA (charge) irradiated the target for 0.2 sec and the detector output was multi-scaled at 8 ms per channel for 256 channels (17.7 half-lives). Runs were from 1 to 3 hours in duration with accumulations of 6600 to 11000 counts in the first channel. Because of the relatively intense low-energy β-ray background, the detector bias had to be set at ≥ 3 MeV. For the 3-MeV setting the long-lived background was 2% of the initial ^{62}Ga counting rate but at higher biases of up to 4 MeV the background was as low as 0.14% of the initial rate.

Seven runs were made altogether at biases between 3 and 4 MeV. Typical errors for fits to individual runs starting in the first channel were ±0.33 ms. Fits starting after one half-life had larger errors but the values were expected to be less subject to rate dependency and other nonstatistical effects. The procedure adopted for deriving the final value in the analyses of all experiments, including those described below for ^{66}As and ^{70}Br, was to find the weighted average value from all runs for fits starting in the first channel and to average that value and its error equally with the corresponding value for fits starting after one half-life. The average error was then inflated by a factor of 2 and adopted to allow for possible systematic effects. This follows the analysis procedures used in previous half-life experiments.[9] In this way the half-life of ^{62}Ga was found to be 115.95 ± 0.30 ms.

^{66}As

In making ^{66}As using the ^{58}Ni(^{10}B,$2n$)^{66}As reaction, it was necessary to avoid the simultaneous production of ^{62}Ga from the ^{58}Ni(^{10}B,$\alpha 2n$)^{62}Ga reaction. Calculations of the expected cross sections for these competing reactions, using the code ALICE, were carried out by C. N. Davids who very kindly provided this information. Thus, at $E_{^{10}\mathrm{B}} = 30$ MeV one can expect to produce ^{66}As with a negligible amount of ^{62}Ga present. Above 30 MeV the (α,$2n$) cross section rises rapidly so that erroneous results might be anticipated from the mixing of ^{62}Ga with the ^{66}As.

^{10}B^{4+} beams of up to 300 nA (charge) were accelerated to 30 MeV. The general procedures were the same as for ^{62}Ga except that the multiscaling rate was 7 ms per channel for 256 channels corresponding to 18.7 half-lives. Yields of ^{66}As were considerably lower than in the case of ^{62}Ga, and the long-lived background problem was more severe. Thus it required runs of $2\frac{1}{2}$ to 9 hours to accumulate 1500–6500 counts in the first channel and the relative long-lived background for the various runs was from 0.5 to 5% of the initial ^{66}As rate, depending on the bias setting.

Seven runs were made on the ^{66}As half-life at β biases from 3.5–4.5 MeV. By following the same analysis procedures as described above for ^{62}Ga, the half-life obtained for ^{66}As was 95.78 ± 0.39 ms.

^{70}Br

^{70}Br was made in the ^{58}Ni(^{14}N,$2n$)^{70}Br reaction using a 44-MeV ^{14}N^{5+} beam of 350–400 nA (charge). Cross section calculations, again kindly provided by C. N. Davids, indicated that at this energy a negligible amount of ^{66}As would be produced in the competing ^{58}Ni(^{14}N,$\alpha 2n$)^{66}As reaction. The experiment on ^{70}Br was characterized by very low yield and a high long-lived background. Thus in one of the runs of 12 hours duration, multiscaling at 5 ms per channel for 256 channels (16 half-lives), and at a β-ray bias of 4.5 MeV, only ~2000 counts were accumulated in the first channel and the relative long-lived background at that bias was 10% of the ^{70}Br rate in the first channel. In the most favorable case the background was still 5% of the initial rate.

Six runs were made on ^{70}Br totaling about 50 hours of data taking. By analysis of the results in the same way as for ^{62}Ga and ^{66}As, the value adopted for the half-life of ^{70}Br is 80.2 ± 0.8 ms. Although firm proof is lacking that the observed activity is in fact ^{70}Br, the assignment is highly probable because of the agreement of both the measured yield and the half-life with calculated estimates.

^{74}Rb

An experiment was carried out in order to find out if a usable amount of ^{74}Rb could be produced in the ^{58}Ni(^{19}F,$3n$)^{74}Rb reaction. The setup was exactly the same as for the ^{70}Br experiments except that the beam was changed to ^{19}F^{6+} with ~300 namp (charge) on target. Beam energies of 60 and 68 MeV (the highest available at the time) were tried. In runs of 10–15 minutes at each energy, and at a β-ray bias of 4.0 MeV, background counts were observed but there was no indication whatsoever of any short-lived activity.

III. DISCUSSION

The present result for the half-life of ^{62}Ga, 115.95 ± 0.30 ms, is in good agreement with previous work including the accurate value of 116.34 ± 0.35 ms due to Davids *et al.*[7] The weighted mean value of all results to date, including the present work, is 116.12 ± 0.26 ms. In order to derive an *ft* value for comparison with the other Fermi superallowed β^+ emitters, an accurate decay energy is also needed. Work is in progress by Davids *et al.*[6,7] to determine the β^+ end-point energy of ^{62}Ga decay, but because of the 8-MeV positron end-point energy the best accuracy anticipated in this type of measurement is ~30 keV. Because of the fifth power dependence of f on the β^+ end-point energy, an order-of-magnitude more accurate decay energy will be needed if the error on f is to be comparable with the 0.22% error on $T_{1/2}$ as given above, and if the overall error on the *ft* value is to be of significance in extending the study of the systematics. Thus, the usefulness of ^{62}Ga and its possible impact on the systematics will have to await a future determination of the mass of this isotope to an accuracy of a few keV or better.

There are no other values of comparable accuracy for the half-life of ^{66}As with which to compare the present result of 95.78 ± 0.39 ms. It will obviously be necessary to obtain an accurate mass value for ^{66}As as well as to improve on the accuracy of the half-life before a significant *ft* value can be derived.

Similar comments apply to the decay of ^{70}Br, and here it is even more evident that much improved methods will be needed to produce this activity in sufficient intensity and with less background for more accurate half-life determinations.

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