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Half-Lives of Be^{11}, C^{15}, N^{16}, O^{19}, and Al^{28}†

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The half-lives of several radioactivities induced by Van de Graaff bombardment have been measured using plastic and NaI(Tl) scintillation detectors, together with a time-channel analyzer controlled by a quartz-crystal clock. The half-lives obtained are as follows: Be^{11}, 13.81 ± 0.08 sec; C^{15}, 2.46 ± 0.01 sec; N^{16}, 7.13 ± 0.04 sec; O^{19}, 27.1 ± 0.1 sec; and Al^{28}, 2.252 ± 0.006 min.

INTRODUCTION

Several recent studies[1,2] have been made at this laboratory of mirror symmetry in β decay. The experimental part of that work was undertaken partly because of substantial discrepancies in the values reported for the half-lives of the activities under study. Thus, the measured half-life values which had been reported previously for 11-sec F^{20} differed by as much as 10% even though the accuracies of the individual results were quoted to better than 1%.

A search of the literature has shown that similar discrepancies exsist in the reported half-lives of several other short-lived radioisotopes whose other properties have been studied in the past at this laboratory. Since the statistical accuracy was usually high, and there was an excellent exponential fit to the data, it may be concluded that in some of the measurements there must have been undetected systematic errors considerably larger than the quoted uncertainties.

Our program of half-life measurements, five of which are reported in this paper, was carried out in order to obtain accurate and hopefully more reliable values for these half-lives. There has recently been an increasing emphasis on the importance of obtaining precise and reliable ft values for comparison with theoretical calculations.

EXPERIMENTAL PROCEDURES

The radioactivities were produced by bombarding various targets with beams from a 3.5-MeV Van de Graaff accelerator. In most cases a β-ray detector was located close to a thin-walled glass target chamber. After irradiating for several half-lives the beam was shut off by turning down the voltage on the accelerator terminal, so as to minimize the background in the target room, and the measurement was started. Measurements on the Al^{28} β and γ rays were made by removing the sample from the target chamber and carrying it to detectors located in the control room. The output of the detector system was fed to a discriminator which in turn supplied pulses to a time-channel analyzer. The latter was a Northern Scientific Company 4096-channel pulse-height analyzer equipped with a multiscaler driven by a quartz-crystal clock. For the conditions used in the present experiments the channel advance rate of the analyzer was checked against an electric stop-clock and was found to be accurate to better than 0.1% in all cases.

β rays were detected in a 5-cm-diam × 2.5-cm-thick NE-102 scintillator mounted on an RCA 6342 photomultiplier tube. Because of the small integrated light output of β-ray pulses from this type scintillator, together with the excellent gain stability of the 6342 photo tube, this detector system is particularly suitable for measuring the decay rate of β emitters without appreciable systematic gain-shift effects. All pulses were counted above a bias level that was adjusted as desired.

The decay of Al^{28} was also measured by detecting the γ rays in a 12.7-cm × 12.7-cm NaI(Tl) scintillator. This system was tested for counting-rate effects and was found to have a negligible gain shift for the total rates of <3000/sec used in this work. Optimum conditions were obtained by multiscaling only those pulses occurring within a window encompassing the full-energy-loss peak of the 1.78-MeV γ rays from the Al^{28} decay. A substantial amount of lead shielding was placed around the NaI(Tl) detector so as to reduce the room background.

In all cases a given run was counted for 15 to 20 half-lives which was sufficient for the counting rate to reach the room background level during the final portion of the run. Since the initial counting rate was carefully controlled so as to minimize systematic effects, including losses due to the 4-μsec length of the discriminator pulses, the buildup of statistical accuracy was achieved by repeating many such runs. The channel advance rate was generally set so there would be at least 10 points per half-life, and the data were taken un-

til the first channel contained at least 20 000 counts. In all of the β-ray runs the background level was <0.1% of the initial counting rate, while in the γ-ray measurements it was 0.3%.

Each decay curve was analyzed by computer methods[3] on the initial assumption that it consisted of a single exponential plus a flat background. The quality of the fit indicated that this assumption was justified in all cases except for O^{19} where it was evident that a small amount of F^{20} contamination was present. The error in the value of the half-life from the computer fit was usually smaller than the differences between the results under various conditions of β-ray bias, etc., thereby suggesting that the accuracy was not being limited by statistics but by small systematic effects of undetermined origin. The error assigned to each resulting half-life was estimated from the degree of consistency of various runs.

RESULTS AND DISCUSSION

Be^{11}

A Be foil 1 mil thick was bombarded with a beam of 3-MeV tritons to form the Be^{11} activity via the $Be^9(t,p)Be^{11}$ reaction. In the initial runs the count was started within 5 sec after removal of the beam from the target. Since the first few channels indicated a strong Li^8 activity ($T_{1/2}=0.85$ sec) produced by the $Be^9(t,\alpha)Li^8$ reaction, a period of 12 sec was allowed in the final runs before starting the multiscaler. The β detector was used at several bias levels from 1.2 to 4.5 MeV. A half-life value of 13.81 ± 0.08 sec was derived based on the analysis of the final runs.

Only two previous measurements of the Be^{11} half-life have been reported. A value of 14.1 ± 0.3 sec was obtained by Nurmia and Fink[4] in their paper reporting the discovery of this radioisotope. The following year Wilkinson and Alburger[5] studied the decay scheme of Be^{11} and found a half-life value of 13.57 ± 0.15 sec. The present result is consistent with both previous measurements, but is more accurate. A new study of the Be^{11} decay scheme has recently been completed.[6]

C^{15}

The C^{15} activity was produced via the $C^{14}(d,p)C^{15}$ reaction using 3.0-MeV deuterons on a 0.7-mg/cm^2-thick target enriched to 80% in C^{14}. Runs were made with β-ray biases from 1.2 to 4 MeV, and the final result is 2.46 ± 0.01 sec for the C^{15} half-life.

The two previously reported C^{15} half-lives, i.e., 2.25 ± 0.05 sec obtained by Douglas, Gasten, and Mukerji[7] and 2.49 ± 0.07 sec obtained by Nelson, Hudspeth, and Bernstein[8] (NHB) differ by twice the sum of the errors. The present result is consistent only with the work of NHB and is very much more accurate. Since previous analyses[9] of the C^{15} decay scheme used the value 2.25 sec for the half-life, it would be necessary to increase the experimentally derived logft values of the various β branches by about 0.1 on the basis of the present work.

N^{16}

A target of TiN^{15} enriched to 96% in N^{15} was bombarded with a 3.0-MeV deuteron beam to produce N^{16} via the $N^{15}(d,p)N^{16}$ reaction. β-ray detector biases from 1.2 to 4 MeV were used and the final adopted value for the half-life is 7.13 ± 0.04 sec.

Since 1964 there have been three accurate and consistent values reported for the N^{16} half-life, i.e., 7.14 ± 0.02 sec by Bienlein and Kalsch,[10] 7.16 ± 0.04 sec by Gray and Zander,[11] and 7.10 ± 0.03 sec by Scott and Notea.[12] Prior to those measurements a number of earlier results were reported that were higher in value, including 7.35 ± 0.05 sec by Bleuler *et al.*,[13] 7.38 ± 0.05 sec by Martin,[14] 7.31 ± 0.04 sec by Malmskog and Konijn,[15] and 7.352 ± 0.009 sec by Elliott and Young[16]. Our result agrees very well with the average of the three more recent reports. It should be pointed out that in most of the previous measurements the N^{16} activity was reactor produced.

O^{19}

A target of O^{18}, made by anodizing tantalum with H_2O enriched to 22% in O^{18}, was bombarded with 3.0-MeV deuterons to form the O^{19} activity via the $O^{18}(d,p)O^{19}$ reaction. As mentioned previously, the decay curve of β rays exhibited a complex structure from which it was evident that a weak short-lived component of ~11-sec half-life was present in addition to the O^{19} activity. That the shorter-lived activity was very probably F^{20} due to the $F^{19}(d,p)F^{20}$ reaction on a target contaminant, was confirmed by the observation that its intensity relative to the O^{19} activity increased somewhat when the β bias was raised. The end point energy of F^{20} is 5.4 MeV, whereas O^{19} decays with two β branches, the weaker ground-state branch having an end-point of 4.6 MeV.

The computer analysis of the complete decay curve was made by assigning a half-life value[1] of 11.03 sec to the F^{20} component and allowing the O^{19} half-life to be a variable. About 10% of the initial counting rate was due to the F^{20} activity. Based on the analysis of runs at β biases of 1.2

to 2 MeV the final result is 27.1 ± 0.1 sec for the O^{19} half-life.

There have been three previously reported measurements of the O^{19} half-life. A value of 29.1 ± 0.3 sec was obtained by Malmskog and Konijn,[15] 26.27 ± 0.59 sec by Vaughn *et al.*,[17] and 26.76 ± 0.08 sec by Yule.[18] While the latter two values agree with each other, the measurement by Malmskog and Konijn is about 10% higher. Our result does not agree within the errors with any of the previous three numbers, although it lies in their range of values.

Al^{28}

The Al^{28} activity was made in the $Al^{27}(d,p)Al^{28}$ reaction by bombarding a 10-mil-thick pure aluminum foil with 3.0-MeV deuterons. Runs were made on the β rays at a bias of about 1 MeV and on the γ-ray photopeak. The separate averages of the half-lives from the β-ray and the γ-ray runs agreed to 0.1%. A final value of 2.252 ± 0.006 min is adopted for the half-life of Al^{28}.

Previous values reported for the half-life of Al^{28} seem to fall into two groups, one around 2.30 min and the other around 2.26 min. In the first group are the values of 2.30 ± 0.03 min by Elkund and Hole,[19] 2.305 ± 0.006 min by Elliott and Young,[16] and 2.31 ± 0.01 min by Malmskog and Konijn[15]; while in the second group are the values 2.27 ± 0.02 min by Bartholomew *et al.*,[20] 2.26 ± 0.01 min by Newman,[21] and 2.238 ± 0.006 min by Weiss.[22] Our result agrees with the latter group of measurements and disagrees with the former.

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