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Half-lives of ^{6}He, ^{19}Ne, and ^{42}Sc^{m} †

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The half-lives of ^{6}He, ^{19}Ne, and ^{42}Sc^{m} have been measured as 808.1±2.0 msec, 17.36 ±0.06 sec, and 62.0±0.3 sec, respectively. The activities were formed in the ^{9}Be$(n,\alpha)^{6}$He, ^{19}F$(p,n)^{19}$Ne, and ^{42}Ca$(p,n)^{42}$Sc reactions. Half-lives of ^{6}He and ^{19}Ne were determined by multiscaling β rays detected in a plastic scintillator, whereas the ^{42}Sc^{m} half-life was obtained from the decay of the γ-ray spectrum in a Ge(Li) detector. The ft values deduced for ^{6}He, ^{19}Ne, and ^{42}Sc^{m} are, respectively, 815.7±4.2 sec, 1728.4±6.7 sec, and 14 758 ±91 sec. The values $|\langle\sigma\rangle|$ of the Gamow-Teller matrix elements are given by, respectively, $R_e\,|\langle\sigma\rangle|$=2.7472±0.0077, 1.6006±0.0042, and 0.6448±0.0021, where R_e is the magnitude of the ratio of the axial to vector coupling constants appropriate for the respective complex nuclei.

[RADIOACTIVITY ^{6}He, ^{19}Ne, ^{42}Sc^{m}: measured $T_{1/2}$; deduced ft values and GT matrix elements.]

I. INTRODUCTION

We report measurements of the lifetimes of the three β-decaying bodies ^{6}He, ^{19}Ne, and ^{42}Sc^{m}. The motivations for the three measurements were different; we describe them briefly here without extensive discussion:

^{6}He: This decay, to the ground state of ^{6}Li, is very fast ($\log ft \simeq 2.9$) and almost exhausts the Gamow-Teller sum rule as may be expected from the approximate validity of SU(4) symmetry in this light system. This, in turn, means that the decay is comparatively insensitive to forbidden terms and so is suitable for testing ideas about the mesonic or nucleonic renormalization of the axial coupling constant in nuclear matter.[1] The availability of detailed studies of the excitation, by electron inelastic scattering, of the analog, in ^{6}Li, of the ^{6}He ground state also permits an interesting comparison between the electromagnetic and weak transition radii that could throw light on the role of mesonic exchanges in the two types of process.[2] Finally, the great strength of the β-transition means that the uncertainty introduced into the theoretical value for the inverse reaction, ^{6}Li$(\mu^-,\nu_\mu)^{6}$He$_{\text{g.s.}}$, by the imperfectly known magnitudes of the induced terms is slight so that the confrontation between β decay and muon capture rates may be conducted without significant complication on that score.[3]

^{19}Ne: This decay is of importance as an example of a mirror transition in which the magnetic moments of both initial and final states are known so that: (i) the Gamow-Teller component of the transition may be linked to the isoscalar magnetic moment in the well-known way to give information about the renormalization of the axial coupling constant[1] and (ii) the contribution to correlations in the β decay arising from weak magnetism are presumably known so that such correlations may bring news of additional forbidden terms, in particular second-class currents.[4]

^{42}Sc^{m}: Simple transitions in the region of $A=40$ bear directly on configurational questions having to do with shell closure, or otherwise, at ^{40}Ca. It seems likely, from the substantial retardation of the β decays of ^{39}Ca and ^{41}Sc below their single-particle values,[5] that core excitation in ^{40}Ca must be significant, even after allowance for effective axial coupling constant renormalization.[1] The case of the decay of ^{42}Sc^{m} ($J^\pi=7^+$ at 0.618 MeV) to the $J^\pi=6^+$ state of ^{42}Ca at 3.190 MeV is also configurationally rather simple in the naive $(2p,1f)^2$ scheme; the magnetic moment of the ^{42}Ca state leads to a unique prediction for the β-decay rate. Taken together with the β-decay rates of ^{39}Ca and ^{41}Sc, the ^{42}Sc^{m} β-decay rate and the ^{42}Ca $J^\pi=6^+$ magnetic moment place constraints on the core-excitation of ^{40}Ca although the situation is somewhat complicated by mesonic and higher-order core-polarization effects.[6]

Of course, all three lifetimes have been measured before but the accord between the various previous measurements does not inspire one with great confidence. Thus the 14 values for the half-life of ^{6}He listed in the standard complication[7] display $\chi^2 = 3.4$ per degree of freedom $[Q(\chi^2, \nu) \simeq 3\times 10^{-5}]$ while the eight values listed[8] for ^{19}Ne display $\chi^2 = 22.3$ per degree of freedom $[Q(\chi^2, \nu) \simeq 10^{-30}]$. The situation for ^{42}Sc^m is also unsatisfactory since only two measurements appear in the literature: $t_{1/2} = 62.0 \pm 0.4$ sec,[9] $t_{1/2} = 60.6 \pm 0.4$ sec,[10] and agreement between them is obviously poor.

II. EXPERIMENTAL PROCEDURES AND RESULTS

^{6}He

^{6}He was produced in the ^{9}Be$(n, \alpha)^6$He reaction by irradiating Be with fast neutrons. The Be metal sample was in the form of a 1-cm^2 by 2-cm long "rabbit" that moved inside a square transfer tube from the irradiated position to a counting location in the accelerator control room. Neutrons were produced by bombarding a 0.025-cm thick Be foil target with a 0.25-μA beam of 3-MeV deuterons from the 3.5-MeV Van de Graaff. After a 1.5-sec neutron irradiation of the sample at a position immediately in front of the accelerator target, it was transferred and β rays emerging from the side of the rabbit that had received the highest neutron flux were detected in a 2.5-cm thick by 5-cm diam. NE102 scintillator. At the counting position the wall of the stainless steel transfer tubing, between the Be rabbit and the β-ray detector, had been reduced to a thickness of 0.4 mm in order to minimize the absorption of β rays.

The half-life of ^{6}He was measured by standard techniques[11] in which the β-ray counts were multiscaled at 0.06 sec per channel for 15 sec (19 half-lives), repeating this procedure until ~20 000 counts had been accumulated in the first channel. The long-term background toward the end of each counting cycle was always less than 0.03% of the initial counting rate. A total of nine runs was made at β-ray biases between 0.4 and 1.7 MeV. Good internal consistency of the computer fits to the data of the various runs was obtained over different portions of the decay curves. A value of 808.1 ± 2.0 msec is adopted for the half-life of ^{6}He based on all of the data.

^{19}Ne

The ^{19}Ne activity was formed in the ^{19}F$(p, n)^{19}$Ne reaction by bombarding a 2-mg/cm^2 thick BaF_2 target evaporated onto 0.012-cm thick Ta with 7-MeV protons from one of the MP tandem Van de Graaff accelerators. The target was mounted in a rabbit for irradiation and transfer to a remote counting station. A beam intensity of 20 nA for 5 sec made the desired source strength. For some of the runs the target was covered with a 0.00025-cm-thick gold foil, epoxyed around the edges, to insure that none of the radioactive ^{19}Ne could escape from the vicinity of the target even if it emerged from the target surface. Subsequent analyses showed no systematic variations of half-life values obtained with the covered and uncovered targets, indicating that a negligible amount of the ^{19}Ne escapes from the uncovered samples during the course of a measurement.

The procedure was to transfer the target after irradiation and to wait for 3 sec before starting the count in order to allow for the decay of any short-lived activities. β-ray counts from the NE102 detector were then multiscaled at 0.7 sec per channel for 512 channels (20 half-lives) and the cycle was repeated until at least 7000 counts had been accumulated in the first channel. 12 runs were made on the ^{19}Ne half-life at β biases between 0.5 and 1.3 MeV, of which eight made use of the Au covered targets. The adopted value for the ^{19}Ne half-life is 17.36 ± 0.06 sec, based on the various analyses of the 12 runs.

^{42}Sc^m

Of the various reactions that may be used to make ^{42}Sc^m we tried both ^{40}Ca$(t, n)^{42}$Sc at $E_t = 3$ MeV and ^{42}Ca$(p, n)^{42}$Sc at $E_p = 10$ MeV. In our initial work we multiscaled the β rays, as in the above examples. Unfortunately, there were contaminant β-ray activities present in both cases that could not be sorted out easily in the computer fits to the decay data. We therefore decided to measure the decay rate of the γ rays emitted by ^{42}Sc^m.

The procedure was to irradiate a calcium foil enriched to 94% in ^{42}Ca, with 10-MeV protons and to transfer the target to a counting station for measurement of the γ rays in a 70-cm^3 Ge(Li) detector. After a delay of 15 sec, to allow for the decay of the 0.684-sec ^{42}Sc ground-state β activity, the γ-ray spectrum was stored successively in six sections of the Σ-7 computer for one minute each. A beam current of 25–80 nA for 20 sec was sufficient to produce the desired amount of activity and the procedure was repeated 3–8 times to give suitable statistical accuracy. Pulses from a 60-cycle pulser were stored along with the γ-ray spectrum in order to correct for the dead time of the measuring system.

The analysis of the data consisted of determining the net area under each of the three strong ^{42}Sc^m γ-ray peaks at 438, 1220, and 1524 keV in each of the six time bins, together with the net area under the pulser peak. When there is an

TABLE I. Results and analysis of the lifetime measurements.

Body	E_β max (keV)	f [a]	$t_{1/2}$ (sec) [b]	ft (sec) [b]	$R_e\,\lvert\langle\sigma\rangle\rvert$
^{6}He	3509.8 ± 3.6 [c]	1009.4 ± 4.6	0.8081 ± 0.0020	815.7 ± 4.2	2.7472 ± 0.0077
^{19}Ne	2216.2 ± 0.9 [c]	99.56 ± 0.18	17.36 ± 0.06	1728.4 ± 6.7	1.6006 ± 0.0042
^{42}Sc^{m}	2836.5 ± 2.4 [c, d]	283.03 ± 0.90	62.0 ± 0.3	$14\,758 \pm 91$	0.6448 ± 0.0021

[a] From Ref. 19 via E_β max.
[b] Present results.
[c] A. H. Wapstra and N. B. Gove, Nucl. Data A9, 265 (1971).
[d] P. M. Endt and C. van der Leun, Nucl. Phys. A214, 1 (1973).

appreciable amount of decay during a time bin, as in the present case, a second-order correction may have to be applied to the pulser count in order to obtain the proper dead-time correction. For example, if the pulser count indicates an average dead time of 14.4% for a 60-sec count of a source composed entirely of a 60-sec half-life activity, then the actual fraction of unrecorded γ rays during that period is 15.0%, thus requiring a second order correction of 0.6%.

The sum of the net areas under the three γ-ray peaks, properly corrected for dead time, was used to determine the decay rate. Analyses of three such runs leads to an adopted value of 62.0 ± 0.3 sec for the half-life of ^{42}Sc^{m}.

III. ANALYSIS

It is not profitable to combine our half-life values with previously measured ones. In the case of ^{6}He our value of 808.1 ± 2.0 msec disagrees significantly with the two previous values of low stated error, namely 799 ± 3 msec[12] and 797 ± 3 msec,[13] although those values agree well with each other; it also disagrees with the adopted mean[7] of 802 ± 3 msec based on all 14 previous measurements. In the case of ^{19}Ne our value of 17.36 ± 0.06 sec agrees well with two earlier values of low stated error, namely 17.43 ± 0.06 sec[14] and 17.36 ± 0.06 sec,[15] but disagrees strongly with a third, namely 16.72 ± 0.05 sec.[16] In the case of ^{42}Sc^{m} our value agrees well with one of the two earlier reported values[9] but disagrees with the other.[10] In the subsequent analysis we therefore use just our own lifetime values. We also use a previously published expression[17] for extracting the magnitudes $R_e\,\lvert\langle\sigma\rangle\rvert$ of the Gamow-Teller matrix elements[18] and an accurate parametrization of the phase space factor that takes into account finite-size effects, screening, and radiative corrections.[19] The results are shown in Table I.

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[18]$\langle\sigma\rangle$ is the Gamow-Teller matrix element, R_e is the magnitude of the ratio of axial to vector coupling constants appropriate to the complex nuclei in question [which may differ significantly from its free-nucleon value of 1.251 ± 0.009 (see Ref. 1)].
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