Radioactivity of Scandium[44]*

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Because of the unusual beta-ray spectrum previously reported by Smith, a study of the Sc^{44} radioactivity has been made. Sc^{44} was prepared according to the reaction $K^{41}(\alpha, n)Sc^{44}$, and the activity was examined in two 180° focusing, shaped magnetic field spectrometers. A single positron group ($E_0=1.463\pm0.005$ Mev; $T_{\frac{1}{2}}=4.0\pm0.1$ hr.) was found; the Fermi plot of its momentum distribution has the allowed shape. The positron decay is fed by an isomeric transition ($E=271.3\pm0.7$ kev; $T_{\frac{1}{2}}=57\pm2$ hr.) and is followed by a gamma-ray ($E=1.16\pm0.01$ Mev) to the ground state of Ca^{44}. No positron transition directly to the ground state was observed. Evidence was found for a high proportion of K-capture to the excited state of Ca^{44}.

I. INTRODUCTION

THE radioactivity of Sc^{44} has been the subject of a number of investigations, notably those of Walke,[1] Smith,[2] and Hibdon, Pool, and Kurbatov.[3] The measurements, except those of Smith, were made using absorption techniques. Walke reported the presence of a 250-kev internally converted gamma-ray having a 52-hr. period, and positrons having 4.1-hr. and 52-hr. periods. Since the positron groups were found to have the same end-point energy, *viz.*, 1.50 Mev, Walke proposed a decay scheme (see Fig. 1 and Table I) according to which the gamma-ray emission represents an isomeric transition from a metastable state in Sc^{44} to the state from which the positron is emitted.

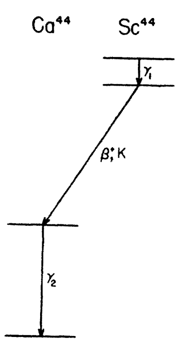

FIG. 1. Decay scheme for Sc^{44} (see Table I).

Hibdon, Pool, and Kurbatov obtained results in rough agreement with the above (see Table I), but found in addition a 1.33-Mev gamma-ray having the same composite period as that of the positrons, and evidence that the decay to Ca^{44} proceeded by means of K-capture about 50 to 75 percent of the time.

Smith, meanwhile, had made spectrometric measurements of the positron momentum distribution and of the internal conversion electrons from the long-lived gamma-ray, and arrived at approximately the same energy values (Table I). The most noteworthy of his results, however, was the unusual positron momentum spectrum obtained.[2] The shape of the Fermi plot of the momentum distribution shows a marked deviation from the straight line expected for an allowed transition. This suggests that either (1) the spectrum is complex, (2) the transition is forbidden, or (3) more than one isotope is present.

The first of these explanations is in disagreement with the findings of Walke and of Hibdon *et al.* The second seems very unlikely, because, even if the decay is 75 percent K-capture, the ft value for the positron transition is still less than 10^6. Smith considered the third possibility, but on the basis of several tests performed he concluded that not more than one isotope was present. Actually these tests, as described in

TABLE I. Summary of experimental results.[a]

Experimenter		Walke	Smith	Hibdon, Pool, and Kurbatov	Bruner and Langer
Method of production		$K^{41}(\alpha, n)Sc^{44}$	$Ca^{43}(d, n)Sc^{44}$	$K^{41}(\alpha, n)Sc^{44}$; $Sc^{45}(n, 2n)Sc^{44}$	$K^{41}(\alpha, n)Sc^{44}$
Method of measurement		Absorption	Spectrometer	Absorption	Spectrometer
γ_1	Period (hr.)	52±2	52±2	58.6±0.7	57±2
	Energy (kev)	250	269.3±1	280	271.3±0.7
β^+	Period (hr.)	4.1±0.1	4.1±0.1	3.92±0.03	4.0±0.1
	Energy (Mev)	1.50±0.05	1.47±0.2	1.33	1.463±0.005
γ_2	Energy (Mev)	—	—	1.33	1.16±0.01
Coincidence measurements (absorption)		—	—	—	$\beta-\gamma$'s—1 group

[a] See also the decay scheme of Fig. 1.

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[1] H. Walke, Phys. Rev. **57**, 163 (1940).
[2] G. P. Smith, Phys. Rev. **61**, 578 (1942).
[3] Hibdon, Pool, and Kurbatov, Phys. Rev. **67**, 289 (1945).

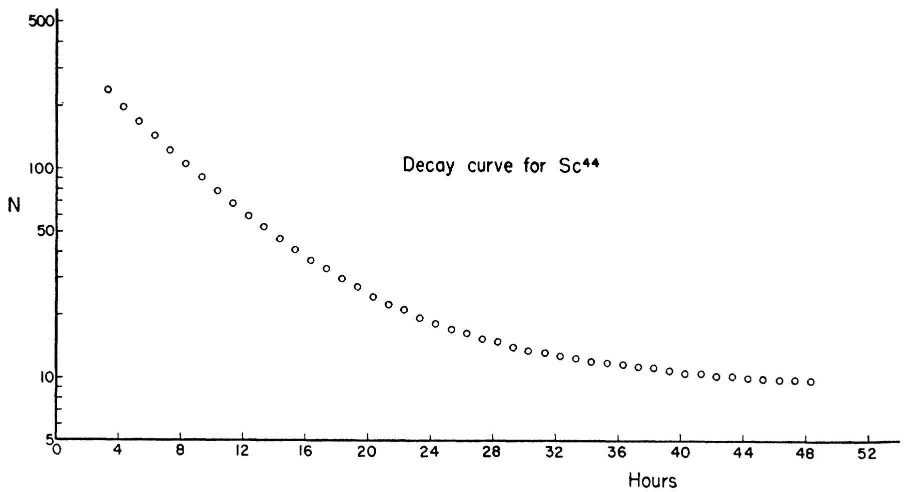

FIG. 2. Typical decay curve for Sc^{44}. To determine the periods of the activity, the decay was followed in this manner for five days.

detail,[4] appear to be inconclusive; this will be discussed later. In view of these facts it was considered worthwhile to reinvestigate the disintegration of Sc^{44}, with particular attention being paid to the positron spectrum.

II. EXPERIMENTAL APPARATUS AND METHODS

Sc^{44} was prepared according to the reaction $K^{41}(\alpha, n)Sc^{44}$. An enriched sample[4a] (92 percent K^{41}, 8 percent K^{39}) of K^{41} in the form of K_2SO_4 was bombarded with 17-Mev alpha-particles in the cyclotron, the bombardments ranging from 40 to 100 microampere hours. 0.5 mg carrier was added; the scandium was separated as $Sc(OH)_3$ and then redissolved in hot HCl.

Sources used for positron spectrum and conversion electron measurements were prepared by depositing the radioactive solution on a backing of 0.025 mg/cm^2 LC600 and drying it. The source thickness was about 0.4 mg/cm^2. Sources were electrically grounded at each end with 0.18 mg/cm^2 aluminum leaf.

The gamma-radiation was also studied by means of Compton and photo-electrons ejected from a 23-mg/cm^2 uranium radiator. The radiator was cemented to a small copper "box" inside of which the source solution was deposited and evaporated. The walls of the copper box were constructed $\frac{1}{32}$-in. thick in order to absorb all the positrons.

Two 180° focusing, shaped magnetic field spectrometers were employed in these studies, one[5] having a 15-cm radius of curvature, and the other[6] having a 40-cm radius of curvature (hereafter referred to as the "small" and "large" spectrometers, respectively). Sources for the small spectrometer measured 2 cm×0.3 cm, and those for the large spectrometer 2.7 cm×0.6 cm.

[4] G. P. Smith, Thesis, University of Michigan.

[4a] Supplied by the Y-12 Plant, Carbide and Carbon Chemicals Corporation, on allocation by the Isotopes Division of the United States AEC.

[5] J. A. Bruner and F. R. Scott, Rev. Sci. Inst. **21**, 545 (1950).

[6] L. M. Langer and C. S. Cook, Rev. Sci. Inst. **19**, 257 (1948).

Simultaneously with each spectrometer run, the decay of the source material was followed automatically by means of a scaler feeding into a tape recorder. In this way decay corrections could be applied directly to the data. A typical decay curve is shown in Fig. 2.

In addition to the spectrometric studies, beta-gamma-coincidences were measured as a function of positron energy by varying the thickness of aluminum absorber between the source and positron counter.

III. RESULTS

A. Positron Spectrum

The positron spectrum was first measured in the small spectrometer. About 160 mg K_2SO_4 were bombarded in the cyclotron for $2\frac{1}{2}$ hours with a total of 45 microampere-hours of alpha-particles. Spectrometric measurements were begun 3 hours after the end of bombardment. The resulting Fermi plot is shown in Fig. 3. A number of points over the entire spectrum were remeasured several hours later, and these points, when corrected for decay by means of a curve such as in

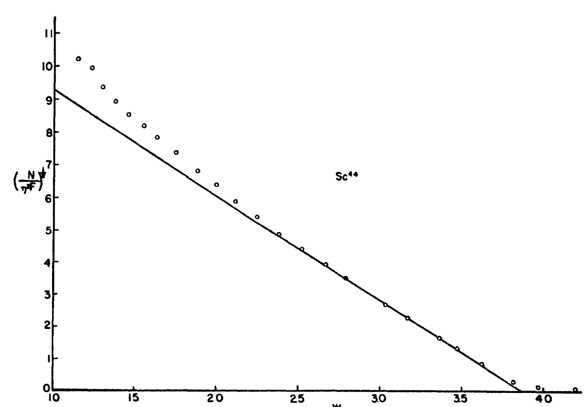

FIG. 3. Fermi plot of positron momentum distribution as measured soon after end of bombardment. The deviation from a straight line is caused by an impurity, probably Sc^{43}.

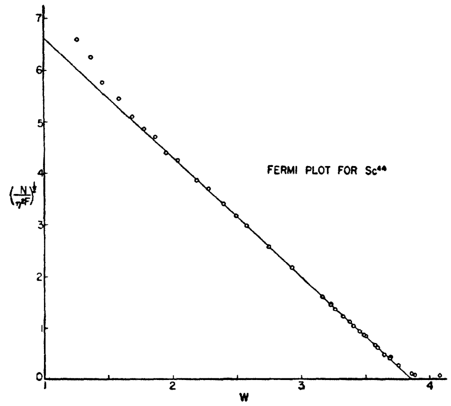

FIG. 4. Fermi plot of positron momentum distribution measured about 30 hours after the end of bombardment. The lower energy group does not appear, hence is not associated with Sc^{44}. The Sc^{44} positron spectrum end point energy is 1.463±0.005 Mev.

Fig. 2, appeared to be in good agreement with those taken earlier. This fact, together with the obvious curvature of the Fermi plot, was at first taken as evidence that two groups of positrons were present in the Sc^{44} activity[7] (the group of lower energy constituting only about 10 percent of the total).

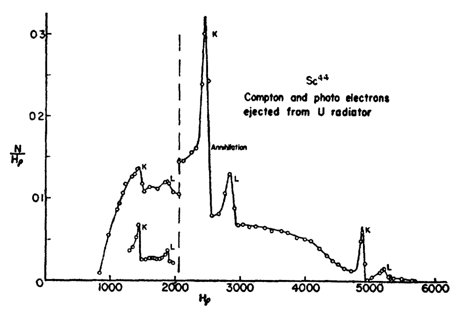

FIG. 5. Compton and photo-electrons from the 271.3-kev and 1.16-Mev gamma-rays. Points to the left of the dashed line have not been corrected for decay. The set of points at lower left was taken a day later than the rest.

The Fermi plot in Fig. 3 also shows a high energy "tail." To determine whether this tail was real or was the result of scattering, a more intense source was prepared, and the positron distribution above 1.3 Mev was examined in the large spectrometer. The tail was found to extend out to about 4 Mev, but the source was unfortunately too weak to determine accurately either the spectrum shape or the decay period.

Twenty-four hours later the main positron spectrum was measured with the same source in the large instrument. The result is shown in Fig. 4, and the contrast with Fig. 3 is quite apparent. Clearly only a single group is present; its end point is 1.463±0.005 Mev.

It then remained to determine whether the discrepancy was due to instrumental effects or to the different lapse of time after bombardment. The latter was found to be the case. A new bombardment was made, and two sources were prepared, differing in intensity by a factor of ten. The spectrum of the weaker source was measured immediately after bombardment, and that of the stronger source a day later, both in the large spectrometer. A comparison of the results showed that the low energy group, present soon after bombardment, disappeared after a day's decay. The indication is therefore that Sc^{44} has no positron group of energy less than 1.463 Mev.

B. Gamma-Ray Measurements

A search for gamma-rays was made in the small spectrometer, making use of the photo-electrons ejected from a uranium radiator. In addition to the intense annihilation radiation, two gamma-rays were found (see Fig. 5). Points to the left of the dashed line in Fig. 5 consist of photo-electrons from the 57-hour gamma-ray plus Compton electrons from all the gamma-radiation; hence in this region no attempt was made to correct the data for decay. Points to the right of the line have been corrected from a decay curve similar to that in Fig. 2. The lower set of points on the left was taken a day later.

Internal conversion electrons from these gamma-rays were sought and found in the large spectrometer. The results are shown in Fig. 6 and Table I. In Fig. 6 the 1.16-Mev line has been magnified 100 times.

C. Beta-Gamma-Coincidence Measurements

The beta-gamma-coincidence counting rate (see Fig. 7) was found to be constant up to 1.25 Mev, thus supporting the assertion that Sc^{44} has no positron group of less than that energy.

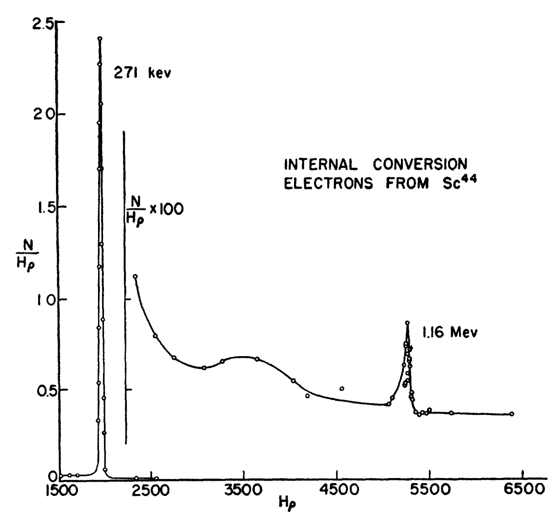

FIG. 6. Internal conversion electrons from the 271.3-kev and 1.16-Mev gamma-rays.

[7] J. A. Bruner and L. M. Langer, Phys. Rev. 79, 236 (1950).

D. Conclusions

The activity of Sc^{44} can be represented by a decay scheme as in Fig. 1. The metastable state has a half-life of 57 ± 2 hours and emits a gamma-ray of 271.3 ±0.7 kev. This is followed by a 1.463 ± 0.005-Mev positron group having a period of 4.0 ± 0.1 hr. A 1.16 ±0.01-Mev gamma-ray then completes the decay to the ground state of Ca^{44}. A comparison of the intensities of the annihilation radiation and the 1.16-Mev gamma-ray indicates that the 1.16-Mev gamma-ray is roughly twice as intense as is the positron disintegration. This argues in favor of a large proportion of K-capture, in agreement with Hibdon *et al.* Since, however, the amount of K-capture is not known accurately, the internal conversion coefficients cannot be calculated.

The positron transition directly to the ground state was not observed, possibly because its spectrum was masked by the high energy tail. On the basis of the nuclear shell model[8] one would expect the ground states of both Sc^{44} and Ca^{44} to have even parity; this indicates that the transition between these states is at least twice forbidden. If, as the ft value suggests, the positron transition to the excited state of Ca^{44} is allowed, then this excited state must also have even parity. Therefore the 1.16-Mev gamma-ray is probably either electric quadrupole or magnetic dipole radiation.[9]

It seems likely that the low energy positron group observed soon after bombardment is associated with the decay of Sc^{43}, which has a 1.1-Mev positron group[3] with a 3.92-hr. period. The Sc^{43} would be produced by the reaction $K^{41}(\alpha, 2n)Sc^{43}$. The high energy positron tail is most probably from either Sc^{42} [by $K^{39}(\alpha, n)Sc^{42}$] or Sc^{41} [by $K^{39}(\alpha, 2n)Sc^{41*}$], the long period in the latter case[10] resulting from a metastable state. An investigation of this question is planned for the near future.

[8] M. G. Mayer, Phys. Rev. **75**, 1969 (1949).
[9] S. M. Dancoff and P. Morrison, Phys. Rev. **55**, 128 (1939).
[10] L. D. P. King and D. R. Elliot, Phys. Rev. **60**, 489 (1941).

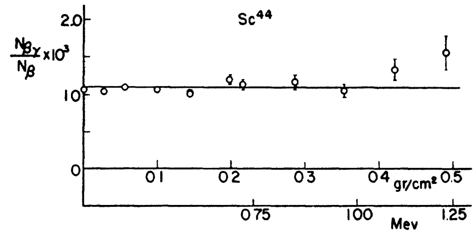

FIG. 7. Results of beta-gamma-coincidence measurements. The constant coincidence counting rate indicates a single group of positrons.

IV. DISCUSSION

The different results of Smith can now be explained in the following manner. In his experiment Sc^{44} was produced by $Ca^{43}(d, n)Sc^{44}$; but since Ca^{42} is almost 5 times as abundant naturally as Ca^{43}, it is to be expected that a large portion of Sc^{43} would be produced by the same type of reaction. The tests made by Smith to determine if more than one isotope were present were (1) comparison of spectral shapes, using bombarding deuterons of different energies, (2) observation of the decay at different values of $H\rho$, and (3) observation of the upper end point as a function of time. These tests would not serve to detect the presence of Sc^{43}, however, because *all of the test measurements*[4] *were made at or above 1.1 Mev;* i.e., near or beyond the Sc^{43} positron end point. Furthermore, Smith's curve can be resolved into two straight lines. On this basis, the end point of the lower group would be about 1.15 Mev. These facts indicate that a large fraction of Sc^{43} was present in his sources.

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