The Radioactive Decay of Calcium 47*

J. M. CORK, J. M. LEBLANC, M. K. BRICE, AND W. H. NESTER
Department of Physics, University of Michigan, Ann Arbor, Michigan
(Received June 8, 1953)

Spectrometric studies have been made of the beta and gamma radiations from calcium 47 (5.35 day) and its radioactive daughter scandium 47 (3.4 day). Using conversion and photoelectrons and the scintillation spectrometer, gamma rays of energy 149.5, 234, 495, 800, and 1303 kev are found in scandium following beta emission from the calcium. The beta spectrum is complex with energies of 0.46 and 1.4 Mev.

Scandium 47 decays with a single allowed beta transition with upper energy limit of 0.64±0.03 Mev and a single gamma ray of 159.5 kev. A satisfactory level scheme is proposed for the decay and checked in some of its details by coincidence observations.

THE irradiation of normal calcium by neutrons and by deuterons was found[1] to yield a beta-emitting activity of half-life 5.8 days. This was attributed to the isotope of mass 47 although calcium 46 from which it would be derived exists with a natural abundance of only 0.0033 percent. Subsequent studies have substantiated the assignment and have shown that a previously observed[2] activity, scandium 47, which decays by beta emission to titanium 47, with a half-life of 3.4 days, exists[3] as a daughter product in the decay.

From its absorption in aluminum the beta energy of the calcium 47 has been reported[3] as 1.1 or 1.2 Mev and that from scandium 47 as 0.61 Mev. A single gamma ray, whose energy appeared by absorption in lead to be 1.3 Mev, has been reported to exist in scandium 47 following the first beta emission.

In the present investigation samples of calcium enriched 3000-fold in mass 46, up to 9.45 percent, were irradiated for two weeks in the Argonne heavy water pile. The scandium daughter product was chemically separated from the irradiated specimens and spectrometric studies made of each activity. The gamma energies have been evaluated both by a scintillation crystal spectrometer and more accurately by observing both conversion and photoelectrons in photographic magnetic spectrometers. The beta radiations have been observed in a double-focusing magnetic spectrometer. The half-life of the calcium 47 activity is found to be 5.35±0.10 days and that of the separated scandium 47 is 3.40±0.05 days.

The composite beta spectrum resolves into four components as shown in Fig. 1. These beta transitions have upper energy limits of 0.46±0.02, 0.64±0.03, and 1.4 ±0.10 Mev. The low-energy component at 260±20 kev is probably due to long-lived calcium 45. The 0.64-Mev beta ray is associated with the decay of the 3.4-day daughter product, scandium 47. The branching ratio for the 0.46- and 1.4-Mev transitions is about 60 to 40 percent, and their $\log ft$ values are 5.7 and 7.7, respectively. The $\log ft$ for the 0.64-Mev radiation is 5.6, thereby indicating an allowed transition.

The strongest electron conversion lines are observed for a gamma ray of energy 159.5 kev. Both the K and L lines are observed in the photographic spectrometer with work functions characteristic of titanium. The K/L ratio is large (visual estimate $\sim$10) which at this low Z^2/W (2.7) does not discriminate as to its multipolarity. Single K electron conversion lines are observed for the gamma rays of energy 149.5, 234, and 495 kev. By using a lead radiator, photoelectrons are observed for the gamma rays of energy 160, 495, and 1303 kev. The scintillation spectrometer revealed the existence of

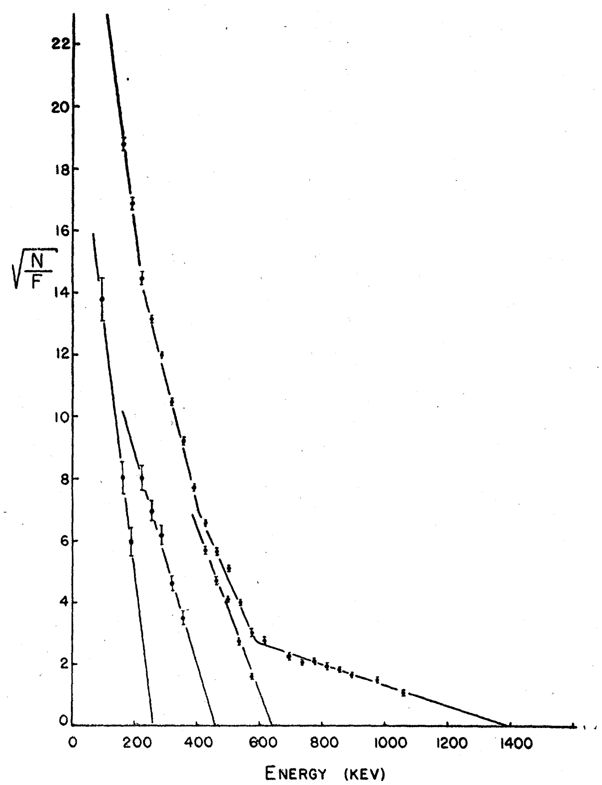

FIG. 1. Resolution of the beta spectra of Ca^{47} and Sc^{47}.

* This project received the joint support of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] D. Matthews and M. Pool, Phys. Rev. **72**, 163 (1947).

[2] C. Hibdon and M. Pool, Phys. Rev. **67**, 313 (1945); N. Krisberg and M. Pool, Phys. Rev. **75**, 1693 (1949); R. Hein and A. Voigt, Phys. Rev. **74**, 1265 (1948).

[3] Batzel, Miller, and Seaborg, Phys. Rev. **84**, 671 (1951); Rudstam, Stevenson, and Folger, Phys. Rev. **87**, 358 (1952).

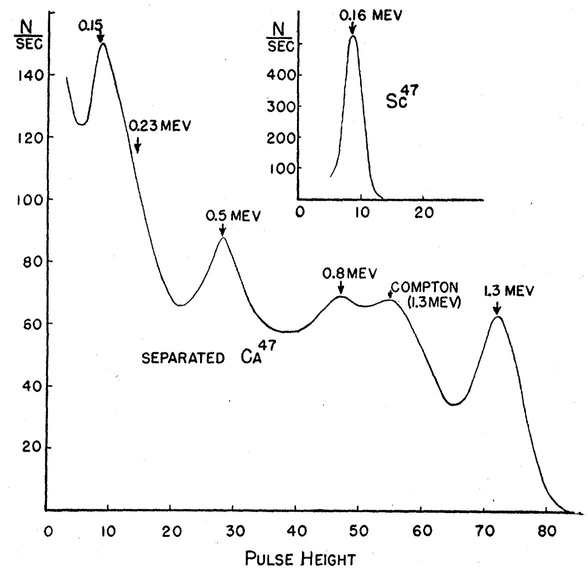

FIG. 2. Gamma distribution by scintillation spectrometer.

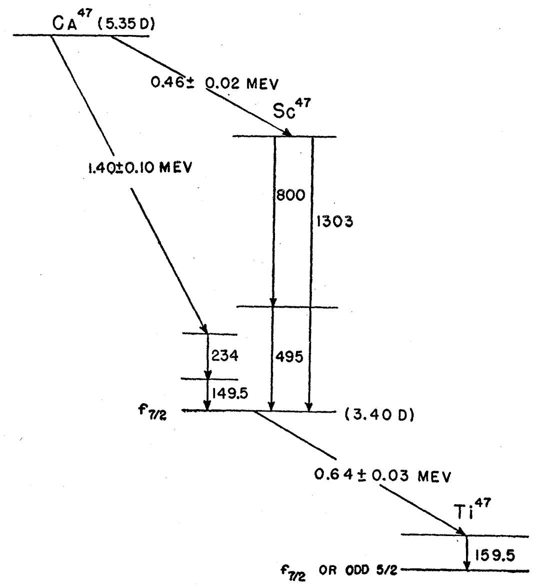

FIG. 4. Proposed nuclear level scheme for Ca^{47}-Sc^{47}-Ti^{47}.

several gamma rays, some of which showed little internal conversion. Figure 2 shows the gamma-energy distribution for the chemically separated isotopes as revealed by the scintillation spectrometer. The separated calcium probably contained some scandium. The uncertainty in the energy of the lines at 495, 800, and 1300 kev may be as great as plus or minus 3 percent. The low-energy peak near 0.15 Mev is probably largely due to the 159.6-kev gamma radiation in the incompletely separated scandium. The gamma ray at 234 kev lies on the edge of this peak and is so weak that it cannot be resolved. The fact that both the 149.5- and the 234-kev gamma rays appear by internal conversion and not by photoelectrons indicates that although weak, their conversion coefficients are large.

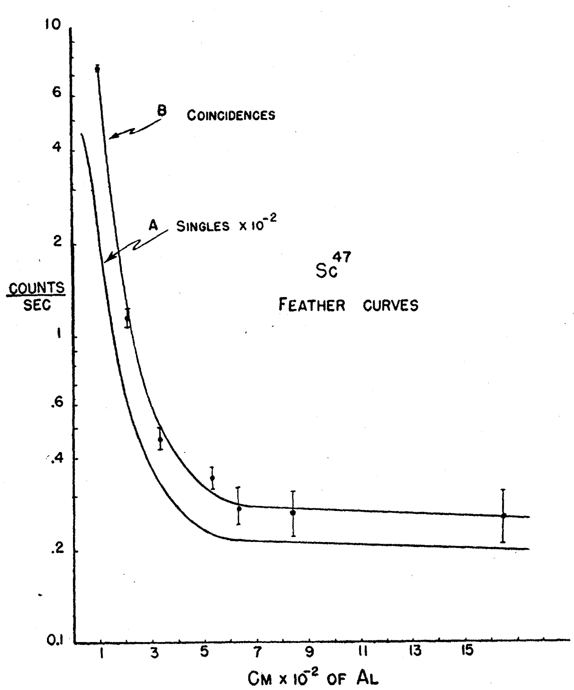

FIG. 3. Feather curve for the beta radiation from Sc^{47}.

A summary of the observed gamma energies and the methods of detection is presented in Table I.

Using an anthracene crystal to detect beta radiations and a NaI crystal for gamma energies, certain important coincidence data are obtained. In the separated scandium isotope a "Feather" absorption curve for the beta spectrum is shown singly in Curve *A*, Fig. 3. A similar trace in which only coincident counts between the beta radiation and the gamma radiation of energy 160 kev is shown in Curve *B*. It is apparent that the end point is the same in both curves, thus showing that the 0.64-Mev beta transition does not terminate in the ground state of Ti^{47}. The background count is probably due to coincidence between backscattered Compton gamma rays and their associated electrons. In the separated calcium the anthracene was shielded by about 0.25 g per cm^2 of aluminum so as to respond to energies greater than 600 kev. In this arrangement definite coincidence counts occurred with gamma

TABLE I. Gamma energies in Ca^{47} and Sc^{47}.

Gamma energy kev	Observed by—*A*. Conversion electrons. *B*. Photoelectrons. *G*. Scintillation
149.5	*A*
159.5 (Sc)	*A*, *B*, *C*
234.0	*A*
495	*A*, *B*, *C*
800	*C*
1303	*B*, *C*

energies around 200 kev. When unshielded so as to respond to low-energy betas, coincidence counts were observed with gamma energies greater than 250 kev.

It is thus possible to arrange the observed transitions in a rather simple decay scheme which essentially satisfies every observation, as shown in Fig. 4.

The final titanium 47 nucleus with 22 protons and 25 neutrons, from shell theory, would have five particles in the $f_{7/2}$ level and an $f_{7/2}$ ground state. It is, however, possible that the five $f_{7/2}$ particles couple to form a 5/2 odd ground state, similar to the coupling observed in Mn^{55}. In this event the first excited level is $f_{7/2}$ and the beta transition goes to the excited state with no change in spin or parity, since the scandium 47 is likely to have an $f_{7/2}$ ground state as does the similar Sc^{45}. Selection rules do not forbid a decay to the 5/2 odd ground state. Such a transition, however, would not be a simple one-particle process, thus it would probably have a much longer lifetime than the simple $f_{7/2}$ to $f_{7/2}$ transition. The 159.5-kev radiation is then an $M1$ transition. The Ca^{47} nucleus is given an assignment of $f_{7/2}$ from the shell theory. It then seems difficult to explain the lack of a beta transition to the ground state of Sc^{47}.

PHYSICAL REVIEW VOLUME 92, NUMBER 2 OCTOBER 15, 1953

A Long-Lived Activity in Neutron-Irradiated Niobium

DAVID L. DOUGLAS, ANITA C. MEWHERTER, AND ROBERT P. SCHUMAN
Knolls Atomic Power Laboratory, Schenectady, New York*
(Received July 8, 1953)

An activity has been found in samples of niobium metal irradiated for long periods in the Chalk River reactor. Extensive chemical tests showed that the activity is niobium. The activity is most likely the long-lived ground state of Nb^{94}. If so, its half-life is estimated as $(2.2\pm0.5)\times10^4$ years from its yield. It has a 0.50 ± 0.05-Mev beta and three gammas, 0.70 ± 0.01 Mev (92 percent), 0.87 ± 0.01 Mev (92 percent), and 1.57 ± 0.02 Mev (8 percent). The capture cross section of Nb^{94} is 15 ± 4 barns.

I. INTRODUCTION

A NUMBER of investigators have reported the presence of a 6.6-min activity in neutron-irradiated niobium.[1,2] The same activity has also been produced by a (d,p) reaction on niobium.[3] This activity has been assigned as class A (element and mass number certain) to Nb^{94}.[4] The activity has been found to decay almost entirely by isomeric transition to a long-lived ground state.[5,6] The energy of the transition is 41.5 kev as determined from the energies of the K, L, and M conversion electrons.[7] In addition, about 0.1 percent of the activity has been found to decay by emitting a 1.3-Mev β[8] and a 0.9-Mev γ.[9]

Goldhaber and Muehlhause[6] set a lower limit of $\gg$100 years for the half-life of the ground state. Hein, Fowler, and McFarland,[10] who studied niobium metal that had been irradiated four months in the Argonne reactor, set a minimum half-life of 5×10^4 years.

This laboratory has had some samples of niobium irradiated for a long period in the Chalk River reactor in order to look for a long-lived activity which might be the ground state of Nb^{94}. An activity has been found which the authors feel is the ground state of Nb^{94}.

II. CHEMICAL SEPARATIONS

Two samples of niobium metal were irradiated in the Chalk River reactor at an average flux of $4-5\times10^{13}$ n/cm^2 sec, one sample for a total $nvt=1.33\times10^{21}$ n/cm^2, the other for a total $nvt=2.5\times10^{21}$ n/cm^2. The total nvt received was checked by cobalt flux monitors. The niobium metal was spectrographically standardized niobium powder. A spectrographic analysis, made by the supplier, showed very faint lines of Mg, Cu, Fe, Si, and Ca, and no lines of Al, Ag, B, Co, Cr, Mn, Mo, Ni, Pb, Sn, Ta, Th, Ti, V, Zr, or Zn.

The samples were returned to the laboratory about two months after the end of irradiation. Decay curves and aluminum absorption curves on the irradiated metal showed that the major beta activity was Ta^{182}. Scintillation spectrometer scans on the metal showed the 0.76-Mev gamma of Nb^{95} in addition to the characteristic spectrum of Ta^{182}. Aluminum absorption curves made with a low-absorption counter also showed the presence of the weak beta of Nb^{95}.

An initial chemical purification of the niobium by

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.
[1] Pool, Cork, and Thornton, Phys. Rev. **52**, 239 (1937).
[2] Sagane, Kojima, Miyamoto, and Ikawa, Phys. Rev. **54**, 970 (1938).
[3] D. N. Kundu and M. L. Pool, Phys. Rev. **70**, 111 (1946).
[4] Hollander, Perlman, and Seaborg, University of California Radiation Laboratory Report UCRL 1928, 1952 (unpublished).
[5] M. Goldhaber and W. J. Sturm, Phys. Rev. **70**, 111 (1946).
[6] M. Goldhaber and C. O. Muehlhause, Phys. Rev. **74**, 1248 (1948).
[7] R. L. Caldwell, Phys. Rev. **78**, 407 (1950).
[8] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).
[9] E. der Mateosian, Phys. Rev. **83**, 233 (1951).
[10] Hein, Fowler, and McFarland, Phys. Rev. **85**, 138 (1952).