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Beta Decay of Thulium-171

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The radiations emitted in the decay of 1.9-year Tm^{171} have been studied with a 180°, 40-cm radius of curvature, shaped magnetic-field spectrometer, a scintillation spectrometer, and a 125-gauss permanent-field spectrograph. Beta-gamma coincidence measurements have also been made. Two beta groups with end-point energies of 96.5 ± 1 kev and ~30 kev were observed. A 66.7 ± 0.5 kev transition, probably an $M1$–$E2$ mixture, was also observed. Possible spin assignments are discussed.

Ketelle and Boyd[1] first identified Tm^{171} and reported that it decayed by the emission of 0.10-Mev electrons with a half-life of 680 days. Bisi, Terrani, and Zappa[2] reported an end point for the beta spectrum of 103 ± 2 kev. Using scintillation detectors, this group found no gamma rays. The spin of the daughter nucleus, Yb^{171}, was directly determined to be $\frac{1}{2}$ by Cooke and Park.[3] The spin of Tm^{169} was also found to be $\frac{1}{2}$, and it seems reasonable to assume that the spin of Tm^{171} is also $\frac{1}{2}$.

The energies of the first excited states of nearby odd neutron-number isotopes with spins $\neq\frac{1}{2}$, are ~80 kev above the ground states. It appeared to be of interest to look for an Yb^{171} excited state in this energy region or at an energy sufficiently low to be undetectable with scintillation methods. Bisi *et al.*[2] reported the presence of a large amount of Tm^{170} impurity (a 129-day electron emitter with an 84-kev transition in the daughter) in their source and this could obscure a weak transition in Tm^{171}.

The beta spectrum and conversion lines were measured in a high-resolution, 40-cm radius of curvature, 180°, shaped magnetic-field spectrometer. A specially designed end-window, loop-anode proportional counter was used for electron detection. Pure methane gas at a pressure of 10-cm of Hg was used in this counter and the plateau extended for ~300 volts. The conversion electrons were also studied in an ~125-gauss permanent magnetic-field spectrograph. The electromagnetic radiations were investigated by means of a $1\frac{3}{4}\times1$ inch and a $1\frac{1}{2}$ inch$\times$2 mm NaI crystal mounted on a Dumont 6292 photomultiplier tube.

A scintillation spectrometer was employed to detect both the singles beta spectrum and the coincident beta spectrum. For the singles measurement, the source was sandwiched between two cylindrical plastic phosphors, $1\frac{3}{16}\times1\frac{3}{16}$ inch. The beta pulses were recorded on a ten-channel pulse-height discriminator. The same arrangement with the addition of a $1\frac{3}{4}\times1$ inch NaI crystal for gamma detection placed at 90° to the two beta phosphors was used for the beta gamma coincidence measurements. The pulses from the NaI crystal were sent through a single-channel pulse-height analyzer. The coincidence analyzer had a 0.5-μsec resolving time.

The Tm^{171} was produced by slow-neutron capture by Er^{170} and subsequent beta decay of the 7.5 hr Er^{171} to Tm^{171}. High-purity Er_2O_3 was irradiated in the Materials Testing Reactor. Approximately 9 months after the end of the irradiation, a thulium fraction was separated using an ion-exchange procedure following specific rare-earth chemistry.

The beta source for the shaped magnetic-field spectrometer was prepared by the evaporation of a hydrochloric acid solution containing the activity on a laminated backing of ~25 μg/cm^2 of *LC* 600 and ~100 μg/cm^2 of Zapon. The former was the top laminate. The backing was aluminized on both sides to minimize source charging.

The beta-spectrum measurements were made using a counter window with a cutoff below 6 kev. These measurements gave an end-point energy of 96.5 ± 1 kev.

In addition to the continuous beta spectrum, *L*, *M*, and *N* conversion-electron lines of a 66.7 ± 0.5 kev transition were observed using a counter window with a cutoff at less than 1 kev. These lines were also observed in the permanent-magnet spectrogram. (The thulium was electrodeposited on a 0.01-inch platinum wire.[4]) The *K*-conversion line of this transition, with energy equal to 5.4 kev, was not resolved. The total intensity of the observed conversion lines was $\sim1\%$ of the total beta-spectrum intensity.

In the gamma scintillation study, only the Yb *K* x-rays and their escape peak and the *L* x-rays were observed. The scintillation spectrometer was calibrated by means of the Yb x-rays emitted in the decay of Tm^{170}, which was produced by slow-neutron capture by Tm^{169}. (The amount of Tm^{170} impurity present in the Tm^{171} sources was $\sim0.5\%$ of the Tm^{171}. The 84-kev gamma ray emitted in the decay of Tm^{170} was not observed in the gamma spectrum but the *L*, *M*, and *N* lines were observed in both magnetic spectrometers.) The energy of the Tm^{171} x-ray peak was not shifted by

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[1] B. H. Ketelle and G. E. Boyd, reported in Oak Ridge National Laboratory Report ORNL-65, July, 1948 [quoted in Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953)].

[2] Bisi, Terrani, and Zappa, Nuovo cimento **2**, 172 (1955).

[3] A. H. Cooke and J. G. Park, Proc. Phys. Soc. (London) **A69**, 282 (1956).

[4] W. G. Smith and J. M. Hollander, Phys. Rev. **101**, 746 (1956).

the presence of the 67-kev gamma ray which indicates that the K-conversion coefficient is quite large. This eliminates the possibility that this is an $E1$ transition. An estimate of 2 for the K/L x-ray intensities ratio was obtained after making fluorescent yield corrections.[5,6] This value is directly the ratio of the K/L conversion coefficients. A mixture of $M1$ and $E2$ multipoles could give 2 for the K/L ratio.

Although no attempt was made for great accuracy, the L-subshell intensities also appear to be consistent with an $M1$–$E2$ multipole mixture for this transition.

The combined effects of source and backing thicknesses probably broadened the K conversion line to the extent that it was unobservable in the presence of the continuous beta spectrum. However, there must be an appreciable number of K conversion electrons as evidenced by the presence of K x-rays.

The observed decay over a period of two months of the 96.5-kev β group and the 66.7-kev transition L conversion electrons is consistent with the reported 680-day half-life of Tm^{171}.

The source for the gamma scintillation, singles beta, and the beta-gamma coincidence measurements was prepared by evaporating the hydrochloric acid solution containing the activity on a Zapon backing which was $\sim 10\ \mu\mathrm{g/cm}^2$ thick.

The singles beta-spectrum measurements gave an end point of 98 ± 3 kev.

The beta particles in coincidence with the ytterbium K x-rays and the 67-kev gamma rays were observed. The electromagnetic radiations provided the gating pulses. A low-intensity beta group with end-point energy of ~ 30 kev was detected. This agrees very well with the energy difference between the 96-kev beta group and the 67-kev transition. This agreement may be somewhat fortuitous considering the many uncertainties involved, e.g., extrapolation of energy calibration, addition of pulse from the ~ 5-kev K conversion electron to the beta pulse when gating with x-rays, and corrections to the Fermi-Kurie plot because of finite resolution. However, it does appear certain that there is an approximately 30-kev beta group in coincidence with gamma radiation of ~ 60 kev. Also, because coincidences are observed with a resolving time of 0.5 μsec, octupole and higher multipole assignments for the 67-kev transition can be ruled out from lifetime arguments based on the single proton model.[7] This model suggests a mean life of 10^{-4} sec for such an $M2$ transition. This lifetime is considerably longer than what was experimentally observed. In addition, the relative L-subshell conversion intensities do not appear to be compatible with an $M2$ assignment.

From the conversion-electron and electromagnetic-radiation intensities and the coincidence measurements, the intensity of the 30-kev group is estimated to be $\sim 2\%$ of the 96-kev group. The transition depopulating the 67-kev level appears to be an $M1$–$E2$ mixture. The logft values for the 96- and 30-kev groups are 6.2 and ~ 6.3, respectively. These logft values suggest that both groups are once-forbidden beta decays with spin change 0 or 1 and a parity change.

Mottelson and Nilsson's[8] level calculations indicate that the ground state spin and parity of Tm^{169} is $\frac{1}{2}+$ or $\frac{7}{2}-$. The spin of Tm^{169} has been determined to be $\frac{1}{2}$, therefore the $\frac{1}{2}+$ assignments seems reasonable for Tm^{171}. The spin of Yb^{171} also is $\frac{1}{2}$. This work indicates that there are two once-forbidden, spin-change $=0$ or 1, beta groups in the decay of Tm^{171}. This requires that the spin and parity of the observed 66.7-kev level in Yb^{171} be $\frac{1}{2}-$ or $\frac{3}{2}-$. The former can be ruled out from the L-subshell intensities, which indicate that the transition is not a pure $M1$. The $\frac{3}{2}$ assignment is consistent with the interpretation that the 66.7-kev transition is an $M1$–$E2$ mixture. In addition, the unified model of Bohr and Mottelson[9] permits the prediction that the spin of the first excited state, with ground state spin $=\frac{1}{2}$, will be $\frac{3}{2}$ with the same parity as the ground state in this region of large nuclear deformation. It should be noted that the spins and parities suggested for Tm^{171} and Yb^{171} are not uniquely defined by the present work.

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