Radioactive Decay of Yb^{167}

R. G. WILSON AND M. L. POOL

Department of Physics and Astronomy, Ohio State University, Columbus, Ohio

(Received May 27, 1960)

Erbium oxide enriched to 35.1% in the mass number 164 was irradiated with 17- and 24-Mev alpha particles. An activity decaying by electron capture with a half-life of (17.7 ± 0.2) minutes was produced and its assignment to Yb^{167} confirmed by the identification of the thulium K x-ray and the well-known daughter activity of Tm^{167}. Gamma rays with energies of 106, 113, and 176 kev were observed in the spectrum of Yb^{167}. Gamma-gamma coincidence measurements were performed on the observed radiations. Transition probabilities, multipole order admixtures, and electron capture branching ratios have been calculated. Approximately 89% of the electron capture transitions occur to the 292.7-kev ($\frac{7}{2}-$) level of Tm^{167}.

INTRODUCTION

AN activity decaying by electron capture with a half-life of 18.5 minutes has been assigned to Yb^{167} by Handley and Olson.[1] The conversion electron spectrum of this activity has been examined and a decay scheme proposed on the bases of transition energies and multipole orders by Harmatz, Handley, and Mihelich.[2] In the present investigation, the gamma-ray spectrum of Yb^{167} has been examined with a 100-channel scintillation spectrometer and gamma-gamma coincidence measurements performed.

EXPERIMENTAL RESULTS

Samples of erbium oxide enriched to 35.1% in the mass number 164 were irradiated with 17- and 24-Mev alpha particles. The composition of the remaining portion in percentages is 0.2 Er^{162}, 47.4 Er^{166}, 9.8 Er^{167}, 6.2 Er^{168}, and 1.5 Er^{170}. The atomic number of the resulting activity was determined by the identification of the thulium K x ray which was compared with the known K x rays of terbium, thulium, ytterbium, lutetium, and tantalum, emitted from radioactive Dy^{159}, Yb^{169}, Tm^{170}, Hf^{175}, and W^{181}, respectively.

The daughter of the 18.5-minute activity was the well-established Tm^{167}, and its assignment to Yb^{167} is therefore confirmed. However, the half-life of Yb^{167} as determined by following the decay of the two gamma peaks and the K x ray for five half-lives with a 100-channel scintillation spectrometer is (17.7 ± 0.2) minutes.

The gamma-ray spectrum of Yb^{167} is shown in the top curve of Fig. 1 as observed with a $1\frac{3}{4}$- $\times$ 2-inch NaI(Tl)

crystal and a 100-channel analyzer. The thulium K x ray and gamma rays with energies of 106, 113, and 176 kev are seen. The 106-kev gamma ray is weaker than the 113 but its existence is clearly shown by coincidence measurements. No gamma rays with energies greater than 200 kev were observed nor was any annihilation radiation. This substantiates the conclusion that no positron emission occurs in the decay of Yb^{167}.[1] The relative numbers of counts in the spectral distributions of the observed radiations are $100:38:8=K$ x ray: 106 and $113\gamma:176\gamma$. The relative number of K x rays can be corrected for fluorescence by division by 0.935.[3]

Table I is a summary of the gamma-gamma coincidence information obtained for the activity of Yb^{167} with a coincidence circuit of resolving time $2\tau=1.5$ μsec. The lower curve in Fig. 1 shows the gamma-ray spectrum in coincidence with the 176-kev gamma ray. This spectrum shows the 106-kev gamma ray which is largely
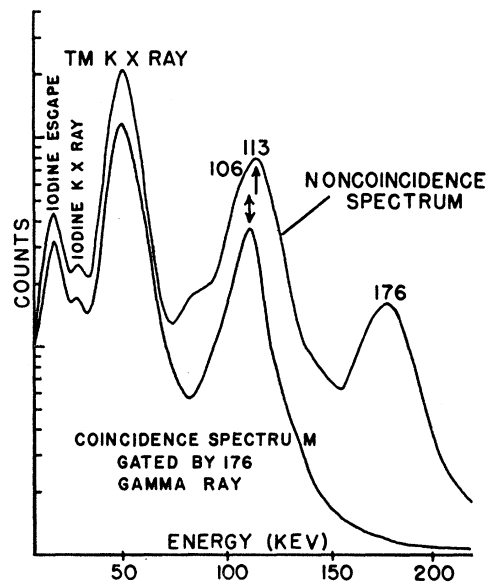
TABLE I. Gamma-gamma coincidence information for the activity of Yb^{167}.

	K x-ray	106	113	176
K x-ray	yes	yes	yes	yes
106, 113	yes	yes	yes	yes
176	yes	yes	no	no

FIG. 1. Gamma-ray spectrum of Yb^{167} measured with a $1\frac{3}{4}\times2$ inch NaI(Tl) and a 100-channel analyzer.

[1] T. H. Handley and E. L. Olson, Phys. Rev. 94, 968 (1954).
[2] B. Harmatz, T. H. Handley, and J. W. Mihelich, Phys. Rev. 114, 1082 (1959).
[3] A. H. Wapstra, G. J. Nijgh, and R. Van Lieshout, *Nuclear Spectroscopy Tables* (North-Holland Publishing Company, Amsterdam, 1959).

obscured by the 113-kev gamma in the noncoincidence spectrum. The existence of the 106-kev radiation is also shown by the self-coincidence of the 106-113 kev peak.

Nine transitions have been observed in the conversion electron spectrum and some multipole orders assigned.[2] A tentative assignment of $E1$ was made to the 113-kev transition. The gamma-ray spectrum substantiates this assignment and also leads to the conclusion that the 176-kev transition is also $E1$. It is estimated from the gamma-ray and coincidence spectra that the 106-kev gamma is about one-third as strong as the 113-kev gamma ray while the respective numbers of conversion electrons observed in reference 2 are in about the inverse ratio. The ratio of the number of 113- to 176-kev gamma rays observed in this investigation is the same as that calculated from the data of reference 2 and the internal conversion coefficients calculated by Rose,[4] when both transitions are assumed to be $E1$.

TABLE II. Relative number of transitions, N_t, gamma rays, N_γ, K-converted transitions, N_k, and multipole orders, M. O., for the gamma-ray energies of Yb^{167}, E_γ, expressed in kev. The data are obtained from the results of this investigation and Harmatz et al.[a] and Rose.[b]

E_γ	M. O.	N_t	N_γ	N_k
K x-ray		7920	7920[c,d]	
(10.4)	$(M1+E2)$	3180		0
25.8	$(M1+E2)$	165	2	0
37.1	$M1(15\%)+E2(85\%)$	105	2	0
62.9	$M1(99+\%)+E2(<1\%)$	2670	175	2100
106.1	$M1(97\%)+E2(3\%)$	2970	750[d]	1830
113.3	$E1$	2490	1980[d]	420
116.5	$E2$	250	85	60
131.9	$E2$	200	90	50
150.4	$(E1)$	55	50	5
176.2	$E1$	485	455[d]	30

[a] See reference 2.
[b] See reference 4.
[c] Corrected for fluorescence.
[d] Observed in the gamma-ray spectrum of this investigation; all others are calculated.

DISCUSSION

The multiple order assignments for the 37.1-, 106.1-, 113.3-, 116.5-, and 131.9-kev transitions are made in reference 2, that of the 176.2 is based on the above arguments, and that of the 150.4 follows from the level scheme. The 10.4-kev transition has not been observed but its existence follows from the level scheme. The admixture percentages shown in Table II have been calculated from the data of references 2 and 4 as have the relative numbers of transitions, gamma rays, and K-converted transitions.

The proposed energy level scheme for the decay of Yb^{167} is shown in Fig. 2 with the calculated transition

[4] M. E. Rose, Internal Conversion Coefficients (North-Holland Publishing Company, Amsterdam, 1958).
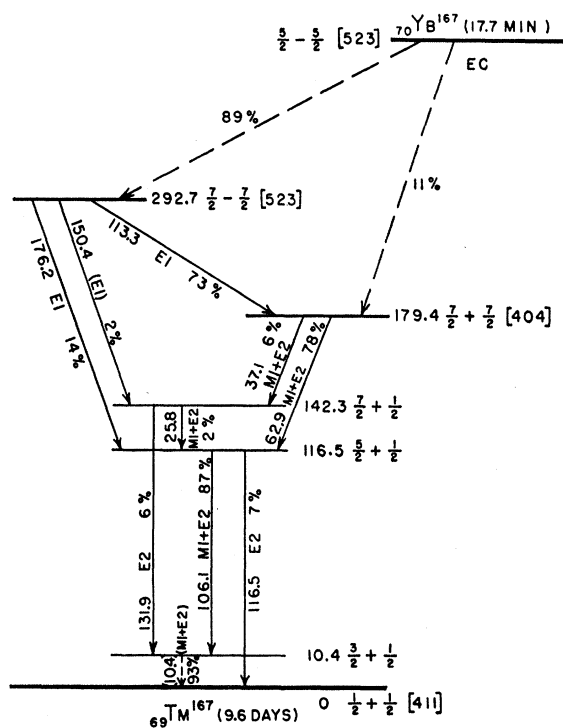

FIG. 2. Proposed energy level scheme for the decay of Yb^{167}.

probabilities and branching ratios for electron capture. The branching ratios were determined by supplying enough electron capture transitions to each level to balance the difference between the numbers of transitions from and to the level. The relative number of K x rays observed in this investigation is just the number necessary to account for all of the electron capture transitions to the levels of Tm^{167} and all of the K x rays resulting from K conversion of the transitions in Tm^{167} as obtained by summing the numbers in the last column of Table II. This implies that essentially all of the disintegrations of Yb^{167} are by K capture. Figure 2 shows the intrinsic and rotational level assignments in the structure of Tm^{167} and for the ground state of Yb^{167}. The high percentage of electron capture from the ground state of Yb^{167} to the 293-kev level of Tm^{167} is consistent with the assignment of the same asymptotic quantum numbers to these two levels. The decay of the 5/2− ground state of Yb^{167} by K capture to the 7/2+ and 7/2− intrinsic levels of Tm^{167} is consistent with the fact that there are no other observed levels to which this decay can occur. L capture to the 5/2+ rotational level is not expected to occur because of the difference between the asymptotic quantum numbers as well as the strong K capture competition to the two intrinsic levels.