# Radioactive Decay of $Yb^{167}$

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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 $1\frac{3}{4}$- ×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 |

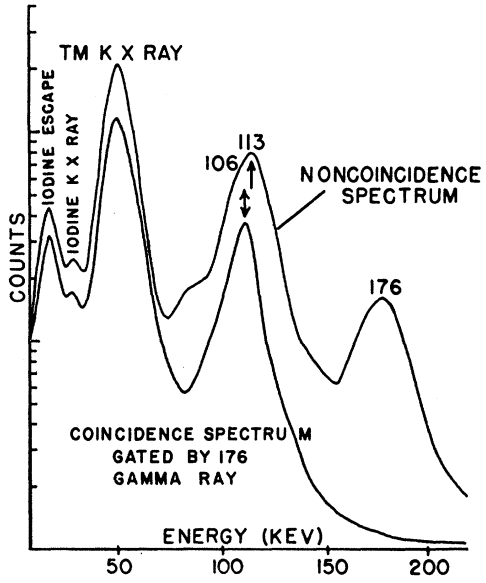


FIG. 1. Gamma-ray spectrum of $Yb^{167}$ measured with a $1\frac{3}{4}$×2 inch NaI(Tl) and a 100-channel analyzer.

[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, $N_\gamma$, $K$-converted transitions, $N_k$, and multipole orders, M. O., for the gamma-ray energies of $Yb^{167}$, $E_\gamma$, expressed in kev. The data are obtained from the results of this investigation and Harmatz *et al.*[a] and Rose.[b]

| $E_\gamma$ | M. O. | $N_t$ | $N_\gamma$ | $N_k$ |
|---|---|---|---|---|
| $K$ 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 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.

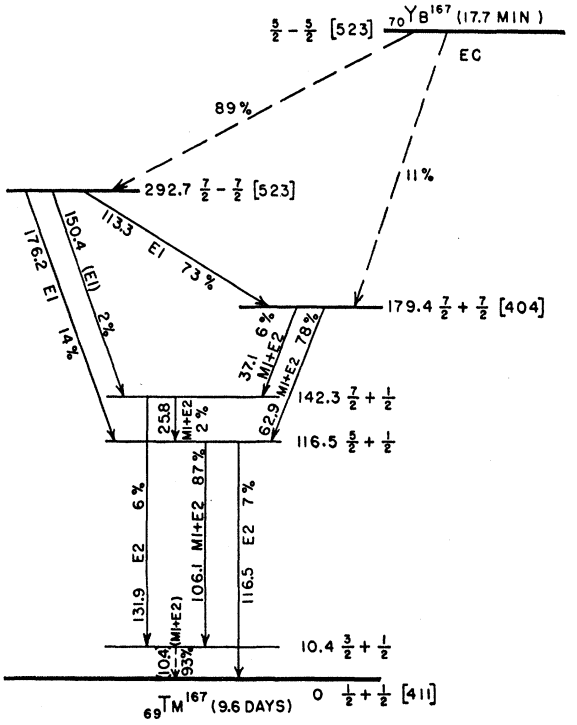


FIG. 2. Proposed energy level scheme for the decay of $Yb^{167}$.

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