The Decay of Ho^{166}†

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The disintegration of Ho^{166} (27.3 hr) has been studied by scintillation counter coincidence techniques. Gamma rays of 1.53 Mev and 1.61 Mev are present in low intensity, in addition to the previously identified 80-kev and 1.36-Mev transitions. Both the 1.36-Mev and the 1.53-Mev gamma rays are in coincidence with the 80-kev transition. For the 80-kev $E2$ transition the K-conversion coefficient has been measured as 1.9 ± 0.2 and the total conversion coefficient as 7.6 ± 1.5. The β branching has been determined from $\beta-\gamma$ and $\gamma-\gamma$ coincidence measurements and by a comparison of the $\beta-\gamma$ coincidences with Tm^{170}. The results indicate a ground state branch of $\sim$25 percent, a branch of $\sim$74 percent to the 80-kev state, a branch of $\sim$1 percent to a state at 1.44 Mev and a branch of $\sim$0.3 percent to a state at 1.61 Mev in Er^{166}. The spin of Ho^{166} is probably $2-$.

AN investigation of the continuous β spectrum of Ho^{166} (27.3 hr) by several workers[1] has shown that the principal β^- component has an end point energy of $\sim$1.84 Mev. Two γ rays were known to be present in the disintegration scheme. The more intense 80.8-kev $E2$ transition[2,3] to the ground state of Er^{166} has a half-life[4] of 1.7×10^{-9} sec and a K-shell conversion coefficient[5] of 1.9. The number of L-conversion electrons of this transition per disintegration of Ho^{166} has been given[6,7] as about 0.3. Two intensity measurements of the 1.36-Mev γ ray are in disagreement. Grant and Hill[6] gave its intensity as $\sim$1.5 percent, whereas Siegbahn and Slätis[7] quote a value of $\sim$11 percent. It was not known whether the 1.36-Mev transition takes place to the 80-kev excited state or to the ground state of Er^{166}.[7]

TABLE I. Relative γ-ray intensities in the decay of Ho^{166}.

E_γ (Mev)	Relative intensity
0.080	8.5 ± 2
1.36	1
1.53	0.2 ± 0.05
1.61	$\sim$0.1

A study has been made of the decay of Ho^{166} by scintillation counter techniques. The γ-ray pulse-height distribution as observed from a 3-cm diameter and 2-cm thick crystal of NaI(Tl) on a Dumont type 6292 photomultiplier is shown in Fig. 1. The γ spectrum was measured through a Lucite absorber of $\sim$1100 mg/cm^2 to eliminate the hard β rays from the counter. A comparison of the unconverted 80-kev γ-ray intensity to the K x-ray intensity after corrections for K-shell fluorescent yield and for absorption in the Lucite absorber gives a value of 1.92 ± 0.20 for the K-shell conversion coefficient, in complete agreement with the measurement of McGowan.[5] The photopeaks in the high-energy portion of the γ-ray spectrum show the 1.36-Mev γ ray and a peak near 1.55 Mev. The latter peak is considerably too broad to be attributed to a single γ ray and may be decomposed into photopeaks at 1.53 and 1.61 Mev. The counting geometry used in the measurement insures that the broad photopeak is not due to addition of two pulses in the phosphor. After correcting for detection efficiency in our phosphor we obtain the γ-ray intensities listed in Table I.

$\gamma-\gamma$ coincidence measurements imposing pulse-height selection upon both γ counters have shown that both the 1.36-Mev and 1.53-Mev γ rays are in coincidence with the 80-kev γ ray or its associated K x-rays (see Fig. 2). The drop in the coincidence rate per recorded γ ray on the high-energy side of the 1.53-Mev photopeak suggests that the 1.61-Mev γ ray is not in coincidence with the 80-kev γ ray. We tentatively

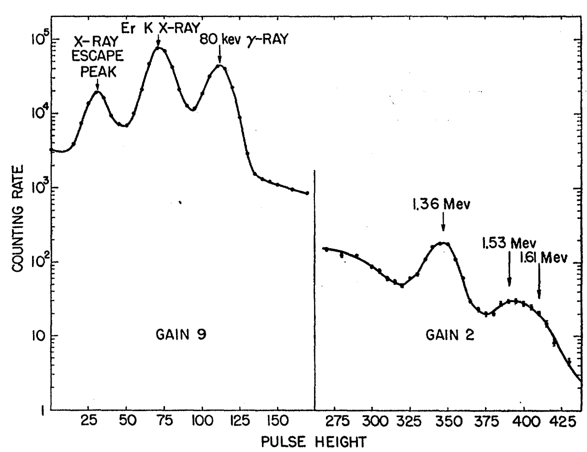

FIG. 1. Pulse-height distribution of γ-ray spectrum observed with NaI(Tl) scintillation counter. Note the change in pulse-height scale and amplifier gain for high-energy region.

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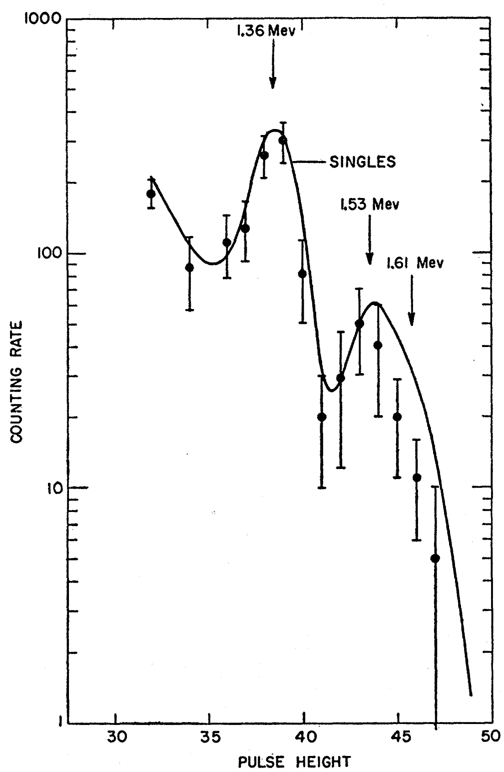

FIG. 2. Spectrum of γ radiation in coincidence with K x-rays and 80-kev γ ray. The solid curve is the singles spectrum in this region.

interpret this γ ray as a cross-over γ ray to the ground state of Er^{166}, as was suggested by its measured energy. A search has been made for a γ ray near 170 kev with negative results. If present, its photon intensity is less than 1 percent of the intensity of the 80-kev γ ray. There is also no evidence for a γ ray of 1.44 Mev. If present, its intensity is less than 20 percent of the 1.36-Mev γ-ray intensity.

A comparison has been made of the $\beta-\gamma$ coincidence rate per recorded β ray with the hard γ-ray—soft γ-ray coincidence rate per recorded hard γ ray under identical detection geometry for the soft γ rays in the two experiments. We find the ratio $(N_{\beta-\gamma}/N_\beta)\div(N_{\gamma-\gamma}/N_{\text{hard }\gamma})=0.74\pm0.03$. This number has been corrected for the fact that the 1.61-Mev γ ray does not contribute to $N_{\gamma-\gamma}/N_{\text{hard }\gamma}$. The error is estimated from the consistency of several measurements of this quantity under different geometrical conditions and using either pulse-height selection or absorbers for detecting only hard γ rays in the hard γ-ray counter. The above result indicates that about 25 percent of the β disintegrations of Ho^{166} take place to the ground state of Er^{166}.

To check the above determination, a direct comparison has been made of the $\beta-\gamma$ coincidence rate per recorded β ray for Ho^{166} with that for Tm^{170} in identical geometry. Tm^{170} was chosen as a standard for comparison for the following reasons:

(1) The β branching in Tm^{170} is known with good precision.[8]

(2) The γ ray of 84 kev and Yb K x-rays arising from its conversion are very similar to the 80-kev γ ray and Er K x-rays following the Ho^{166} decay.

(3) The conversion coefficients of the 84-kev γ ray following the Tm^{170} decay are known[8] for the K, L, and M shells.

(4) The total conversion coefficients for the 84-kev and 80-kev γ rays are expected to be very similar since both are $E2$ transitions[2,3] with nearly the same energy in elements of similar Z.

We find $(N_{\beta-\gamma}/N_\beta)_{\text{Ho}}/(N_{\beta-\gamma}/N_\beta)_{\text{Tm}}=2.9$. After making a small correction for the difference in absorption in Lucite ($\sim$1 percent) of the soft γ radiation from the two sources and taking 24 percent as the β branch to the 84-kev excited state in Yb^{170}, we obtain 71 percent for the β branch to the 80-kev state in Er^{166}. This assumes that the quantity $(1+F_K\alpha_K)/(1+\alpha_T)$ is the same for both transitions. F_K denotes the K-shell fluorescent yield, α_K the K-shell conversion coefficient, and α_T the total conversion coefficient. Since this quantity is not expected to differ much for these transitions, we conclude that the agreement between the two methods is satisfactory and adopt (74±3) percent as the value of the β branch to the 80-kev state in Er^{166}.

To obtain α_T for the 80-kev transition we have compared the Ho^{166} soft γ—hard γ coincidence rate per recorded hard γ ray with the Tm^{170} $\beta-\gamma$ coincidence rate per recorded β ray in identical geometry for detection of soft γ rays. We denote the soft γ counter geometry factor by Ω_γ, the Tm^{170} β branch by f_β, and the fraction of hard γ rays giving coincidences in the Ho^{166} source by f_γ. We assume unit intrinsic efficiency for detection of the low-energy γ and K radiation in our phosphor and for purposes of clarity neglect small differences ($\sim$1 percent) in absorption in Lucite for the Ho^{166} and Tm^{170} soft γ radiation. Then,

$$\left(\frac{N_{\beta-\gamma}}{N_\beta}\right)_{\text{Tm}}=f_\beta\Omega_\gamma\left(\frac{1+F_K\alpha_K}{1+\alpha_T}\right)_{\text{Tm}}$$

and

$$\left(\frac{N_{\gamma-\gamma}}{N_{\text{hard }\gamma}}\right)_{\text{Ho}}=f_\gamma\Omega_\gamma\left(\frac{1+F_K\alpha_K}{1+\alpha_T}\right)_{\text{Ho}}.$$

TABLE II. Conversion coefficients for the 80-kev γ ray in Er^{166} and the 84-kev γ ray in Yb^{170}.[a]

Isotope	E_γ (kev)	α_K	α_L	α_M	α_T
$_{68}Er^{166}$	80.8	1.9±0.2	$\alpha_{L+M}=5.7\pm1.5$		7.6±1.5
$_{70}Yb^{170}$	84.1	1.6±0.15	4.1±0.5	1.2±0.2	6.9±0.6

[a] The Yb^{170} measurements are taken from reference 8.

[8] Graham, Wolfson, and Bell, Can. J. Phys. 30, 459 (1952).

Finally,

$$(1+\alpha_T)_{\text{Ho}}=\frac{f_\gamma}{f_\beta}\left(\frac{N_{\beta-\gamma}}{N_\beta}\right)_{\text{Tm}}\left(\frac{N_{\text{hard }\gamma}}{N_{\gamma-\gamma}}\right)_{\text{Ho}}\times\frac{(1+F_K\alpha_K)_{\text{Ho}}}{(1+F_K\alpha_K)_{\text{Tm}}}(1+\alpha_T)_{\text{Tm}}.$$

We take $f_\beta=0.24$, $f_\gamma=0.92$, $F_K(Z=68)=0.922$, $F_K(Z=70)=0.93$, $(1+\alpha_T)_{\text{Tm}}=6.9$, $\alpha_K(\text{Ho}^{166})=1.9$, and $\alpha_K(\text{Tm}^{170})=1.6$. We find $\alpha_T=7.6\pm1.5$ for the 80-kev transition in Er^{166}. Thus $\alpha_K/\alpha_{L+M}=0.33\pm0.08$. The errors are estimated from consideration of the uncertainties in all factors entering into the determination. It may be noted here that if one takes an L/M ratio of ~3.5 as was found[8] for the Yb^{170} $E2$ transition, $\alpha_L\simeq4.5$. This agrees well with an estimate of $\sim(4.5-5)$ obtained by interpolation of the computations of Gellman, Griffith, and Stanley.[9] However, the inferred K/L ratio of 0.43 ± 0.12 is in disagreement with a previous determination.[10] Our conversion measurements for the 80-kev γ ray in Er^{166} and the measurements of Graham, Bell, and Wolfson[8] for the 84-kev γ ray in Yb^{170} are shown in Table II.

A decay scheme consistent with our data is shown in Fig. 3. The low-energy β branches are computed from the γ-ray intensity ratios, the total conversion coefficient of the 80-kev γ ray and the β branching to the ground state and first excited state of Er^{166}. The $\log ft$ of ~8.4 for the ground-state transition is in the right range for a $\Delta I=2$ (yes) transition. The quantity $ft(W_0^2-1)\simeq0.5\times10^{10}$, in accord with most $\Delta I=2$ (yes) transitions. A spin of two and odd parity in accordance with Nordheim's rule[11] seems likely for the Ho^{166} ground state. A measurement of the shape of the ground-state β transition could of course decide this question.

It is interesting to note that in the case of Tm^{170}, for which an assignment of $1-$ has been made to the ground state,[8] the β-branching ratio between the $2+$ state and the $0+$ ground state of Yb^{170} is just reversed from that in $\text{Ho}^{166}\rightarrow\text{Er}^{166}$. The ratio of ft values in the Tm^{170} decay are in accord[12] with computations based on the collective nuclear model of Bohr and Mottelson[13] assuming a spin $1-$ for Tm^{170}, Gamow-Teller selection rules, and pure tensor coupling. Under such conditions a value of 2 is expected[12] for the ft ratio $[(1-)\rightarrow(2+)]/[(1-)\rightarrow(0+)]$. For Ho^{166} this ft ratio is ~0.2. Since the spin of Ho^{166} may be $2-$, the same ft ratio is not necessarily expected to hold. In any event, the Ho^{166} spin can be determined unambiguously by a measurement of the shape of the ground-state transition or by a direct-spin measurement. The parity is almost certainly odd from the ft values of the β transitions.

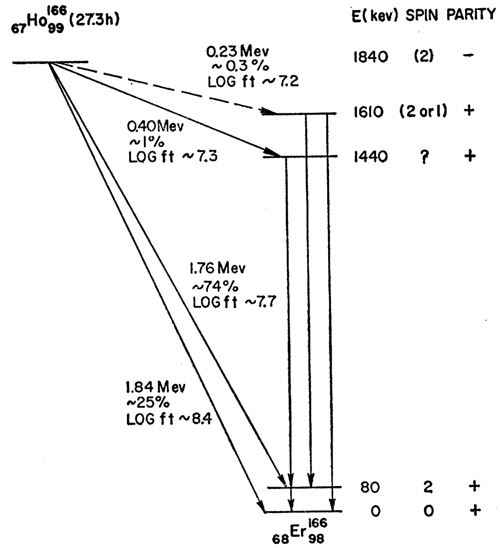

FIG. 3. Disintegration scheme for $\text{Ho}^{166}\xrightarrow{\beta-}\text{Er}^{166}$.

The spins of the excited states of Er^{166} at 1.44 Mev and 1.61 Mev cannot be stated with any degree of certainty. The parities of both states are probably even in view of the approximate ft values for the β transitions to these states. The fact that the 1.61-Mev state emits γ radiation to both the $0+$ ground state and $2+$ excited state of Er^{166} with comparable probability suggests that this spin may be $2+$ or $1+$. $\gamma-\gamma$ angular correlation measurements will be necessary to decide the spins of these more highly excited states of Er^{166}.

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