Decay properties of ^{153}Yb and ^{153}Tm; Excitation energies of the $s_{1/2}$ and $h_{11/2}$ proton states in ^{153}Tm

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The decay properties of ^{153}Yb and ^{153}Tm, produced in ^{64}Zn bombardments of ^{92}Mo, were investigated following on-line mass separation. A decay scheme, incorporating 34 transitions and 25 levels in ^{153}Tm, was constructed for ^{153}Yb. It establishes the $s_{1/2}$ proton level in ^{153}Tm to be isomeric at an excitation energy of 43.2 keV. The α-decay branch of the $h_{11/2}$ ^{153}Tm ground state was determined to be 91±3%. In addition, a partial decay scheme was put together for the 9% β^+ branch. About 66% of this β^+ decay proceeds to the $h_{9/2}$ neutron state located at 299.3 keV in ^{153}Er. Only one transition, 266.5 keV, could be assigned to the β^+ decay of the ^{153}Tm $s_{1/2}$ isomer; it is suggested that the γ ray deexcites the $p_{3/2}$ neutron level to the $f_{7/2}$ ^{153}Er ground state. Based on the intensity of this 266.5-keV γ ray, the isomer's α branch was estimated to be ~93%.

I. INTRODUCTION

The isotope ^{153}Yb was first identified[1] in a study of α-particle decay from ytterbium nuclides. Although ^{153}Yb is not an α emitter, its existence was inferred[1] from the α activity of its daughter, ^{153}Tm, growing in with a 4-*s* half-life; no additional information on the decay properties of ^{153}Yb has subsequently been reported.[2] We recently undertook an investigation of $A=153$ isobars at the OASIS mass separation facility[3] on-line at the Lawrence Berkeley Laboratory's Super Heavy Ion Linear Accelerator (SuperHILAC). The observation of the ^{153}Yb β-delayed proton branch was reported[4] in a short note. Here, the β^+ decay of ^{153}Yb and ^{153}Tm to levels in ^{153}Tm and ^{153}Er, respectively, are discussed. We should add that, up to the present, only the α-decay branch of ^{153}Tm has been investigated.[2]

A 1.85-mg/cm^2 foil of ^{92}Mo (enriched to 97.37%) was bombarded with 285-MeV ^{64}Zn ions from the SuperHILAC. At the center of the target the ^{64}Zn energy was calculated to be 267 MeV. The $A=153$ products were selected by an analyzing slit in the focal plane of the separator, transported ionoptically to a fast-cycling tape system, and positioned between an array of detectors. These consisted of a Si particle ΔE-E telescope and a hyperpure Ge detector facing the radioactive layer, with a 1-mm thick plastic scintillator and an *n*-type Ge detector (relative efficiency of 52%) located on the other side of the tape. In addition, a 24% *n*-type Ge detector, oriented at 90° with respect to the other two Ge detectors, was placed ~4.5 cm from the radioactive source. (A schematic drawing of this arrangement, with the 24% and 52% detectors interchanged in position can be seen in Refs. 5 and 6.) Coincidences between particles, γ rays, x rays, and positrons were recorded in an event-by-event mode with all events tagged with a time signal for half-life information. Collection and counting cycles of 1.28, 4.0, and 12.8 s were used. Singles data were acquired with the 52% *n*-type and the hyperpure Ge detectors in a multispectrum mode wherein cycle times were divided into eight time bins. Additionally, a singles spectrum was also accumulated with the 24% detector to provide data in which geometrical summing effects were minimized.

II. RESULTS

A. General

The incident energy of 267 MeV was selected to optimize the production of ^{153}Yb and ^{153}Tm in ^{92}Mo (^{64}Zn, $n2p$) and ^{92}Mo (^{64}Zn, $3p$) reactions, respectively. Because the ^{64}Zn + ^{92}Mo compound system is $^{156}_{72}$Hf, $A=153$ nuclides with $Z<69$ could be produced directly only in reactions involving molybdenum isotopes with $A\geq 94$ (less than 2.7% of the target material). Thus, ^{153}Er and ^{153}Ho seen in our experiment resulted mainly from ^{153}Tm β decay. Since ^{153}Tm is primarily an α emitter,[2] we also observed γ rays from the β decays of the $A=149$ nuclei ^{149}Ho (α-decay daughter of ^{153}Tm), ^{149}Dy, and ^{149}Tb.

Figure 1 shows the singles γ-ray spectrum accumulated during the 12.8-s counting intervals with the 24% *n*-type Ge detector. For clarity, only the intense γ-ray peaks of ^{153}Yb and ^{153}Tm are labeled by energy and element. Nuclidic assignments for observed γ rays were

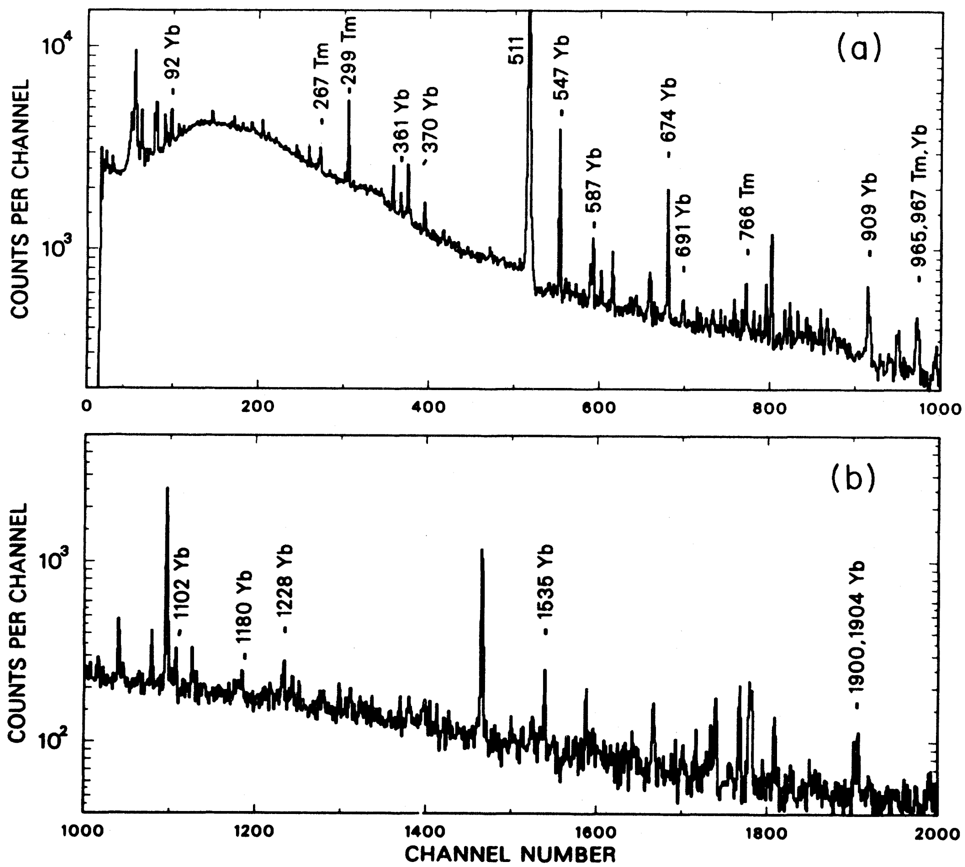

FIG. 1. Singles γ-ray spectrum measured with the 24% Ge n-type detector during 12.8-s counting intervals. Only intense transitions assigned to ^{153}Yb and ^{153}Tm β decay are identified by energy and elemental symbol.

based on coincidences with characteristic K x rays and other γ-ray transitions and on half-life measurements.

B. Decay of $^{153}_{70}$Yb to levels in $^{153}_{69}$Tm

On the basis of decay curves measured for several intense ^{153}Yb γ rays, we determined the half-life of ^{153}Yb to be 3.9$\pm$0.1 s. This half-life agrees with previously reported values.[2]

In Table I we list the energies and photon intensities of γ rays assigned to ^{153}Yb, while in Figs. 2 and 3 we show some of the γ-γ coincidence information gathered in this experiment. Figure 2(a) displays the γ-ray spectrum coincident with Tm $K\alpha_1$ x rays; Figs. 2(b), 3(a), and 3(b) display spectra observed in coincidence with the three strongest transitions, i.e., 91.8, 547.4, and 674.1 keV, respectively. These and other coincidence data, together with the singles information in Table I, allowed us to construct the ^{153}Yb β-decay scheme shown in Fig. 4. The Q_{EC} value, 6.97$\pm$0.45 MeV, for ^{153}Yb is taken from Ref. 7.

We suggest the ^{153}Yb ground-state spin and parity to be $\frac{7}{2}^-$ since the $f_{7/2}$ single-neutron orbital is the first one available after the 82-neutron shell closure. All known even-Z, $N=83$ nuclei have $J^\pi=\frac{7}{2}^-$. Also, the final-state feedings[4] to the 0^+ ground state, and the first 2^+ and 4^+ levels in ^{152}Er by ^{153}Yb β-delayed-proton decay are consistent with a $\frac{7}{2}^-$ assignment for ^{153}Yb. This $\frac{7}{2}^-$ level is expected to β decay *via* Gamow-Teller allowed transitions to $\frac{5}{2}^-$, $\frac{7}{2}^-$, and $\frac{9}{2}^-$ states in ^{153}Tm which should then deexcite to the $s_{1/2}$ and $h_{11/2}$ (single proton) quasidegenerate ground-state isomers of ^{153}Tm. The existence of these two isomers has recently been established by Schardt *et al.*[8] In their study of ^{153}Tm α decay they demonstrated that, in addition to the previously known 5.103-MeV α particles emitted by the $h_{11/2}$ level, there is a less intense 5.096-MeV α group associated with the α decay of the $s_{1/2}$ level. However, the question as to which of the two levels is the ^{153}Tm ground state remained open.

In Fig. 4, we indicate the $\frac{11}{2}^-$ level as the ^{153}Tm ground state and the $\frac{1}{2}^+$ level as an isomer at an excitation energy of 43.2 keV. This level placement was arrived at in the following way. Detailed β-decay schemes for the ^{149}Er $h_{11/2}$ $s_{1/2}$ isomers have recently been constructed.[9] They show for the first time that the ground state in ^{149}Ho is the $h_{11/2}$ proton level, while the $s_{1/2}$ state is isomeric and is located at 49.0 keV. From the Q_α values reported by Schardt *et al.*[8] for the two ^{153}Tm α groups that connect the respective $h_{11/2}$ and $s_{1/2}$ states in the parent and daughter nuclei, one can then deduce that in

TABLE I. Energies and photon intensities for γ rays assigned to the decay of ^{153}Yb.

$E\gamma$ (keV)	$I\gamma$ (relative)[a]
91.8(1)	19(2)[b]
126.7(2)	2.2(4)
264.8(3)	5.5(6)
361.3(1)	9.4(9)
369.6(1)	32(3)
427.6(2)	2.1(4)
515.7(2)	4.8(7)
547.4(1)	100
554.3(2)	3.5(5)
586.6(1)	20(2)
597.3(2)	8.5(9)
669.8(2)	3.7(6)
674.1(1)	61(5)
690.7(3)	4.8(7)
708.4(2)	3.9(8)
752.3(1)	8.0(8)
757.3(2)	4.2(8)
781.6(2)	4.9(7)
817.2(1)	10(1)
826.6(1)	8.0(8)
908.8(2)	25(2)
942.8(3)	5.2(7)
966.7(2)	8.8(9)
1017.2(3)	3.2(7)
1101.5(2)	10(1)
1179.7(2)	4(1)
1192.4(4)	~2
1228.2(2)	10(1)
1306.6(2)	5.1(7)
1364.6(2)	5.2(7)
1534.8(2)	15(2)
1853.7(4)	2.5(5)
1900.1(3)	6.5(8)
1904.4(2)	8.5(9)

[a]Normalized to a value of 100 for the 547.4-keV transition; to obtain intensities per 100 ^{153}Yb β decays these relative values should be multiplied by 0.37. This normalization factor was arrived at by requiring that the intensity sum for the 91.8-, 547.4-, 674.1-, 1364.6-, and 1853.7-keV transitions be equal to 100% of all ^{153}Yb β decays; the internal conversion intensity of the 91.8-keV transition is included in this intensity sum.

[b]A total intensity of 103(10) has been assumed for this transition; if the transition is $M1$, the total intensity is 100; if $E2$, it is 105.

^{153}Tm, as well, the $s_{1/2}$ level is isomeric and that it lies at 43±7 keV above ground. With this information to guide us, we used our data to put together the ^{153}Yb decay scheme (Fig. 4) which then establishes the excitation energy of the $s_{1/2}$ isomer to be 43.2±0.2 keV. In particular, the 1101.7-keV level that has γ rays deexciting to the 674.1-, 547.4-, 504.6-, and 135.0-keV states serves as a linchpin which locks together the population by ^{153}Yb β^+ decay of both the high- and low-spin levels in ^{153}Tm.

The $s_{1/2}$ and $h_{11/2}$ proton orbitals represent the lowest-lying levels in odd-Z, even-N nuclei near $N=82$ after the $g_{7/2}$ and $d_{5/2}$ orbitals have been filled at $Z=64$. Table II summarizes their excitation energies in ^{147,149,151}Tb (Refs. 10–12), ^{149,151,153}Ho (Refs. 9, 10, and 13), and ^{153}Tm. We include energies for ^{147}Tm (deduced from direct proton decay results[14]) and for ^{155}Tm where the value is based on the assumption that the single α group reported[15] for its α decay is in fact a doublet as is the case for ^{153}Tm. This energy systematics is illustrated in Fig. 5 where one notes that in terbium ($Z=65$) the $s_{1/2}$ orbital is the ground state, while in holmium ($Z=67$) and thulium ($Z=69$) the $h_{11/2}$ orbital is the ground state and the $s_{1/2}$ level has become a hole state. The reversal of level sequences between ^{147}Tb and ^{149}Ho has been predicted by Hartree-Fock-Bogoliubov calculations.[16] Based on the information in Table II, the $s_{1/2}$ orbital most probably is the first-excited level in ^{151}Tm (it and the $d_{3/2}$, $d_{5/2}$, and $g_{7/2}$ states have been observed[17] *via* ^{151}Yb β decay). As one proceeds to higher atomic numbers this orbital's energy should increase, and for some element above thulium the low-lying $d_{3/2}$ state should become the first-excited level.

We suggest that the 135.0-, and 504.6-keV levels, deexcited by the intense 91.8- and 369.6-keV transitions, represent the $d_{3/2}$ and $d_{5/2}$ proton states in ^{153}Tm. Our proposal is based not only on information available for levels in ^{149}Tb (Ref. 18) and ^{151}Ho (Ref. 19), but on systematics[17,20] of single-proton states in odd-Z, $N=82$ nuclei as well. A candidate for the $g_{7/2}$ proton state is the 1020.3-keV level which is deexcited by a 515.7-keV γ ray to the 504.6-keV level. Because of the strong 547.4- and 674.1-keV transitions to the $\frac{11}{2}^-$ ground state, the levels at 547.4 and 674.1 keV have possible spins that range from $\frac{7}{2}$ to $\frac{15}{2}$. The parent spin of $\frac{7}{2}^-$ and γ-ray intensity imbalances ($\log ft$ limits of ≥ 5.1 and ≥ 5.5 are calculated for the 674.1- and 547.4-keV levels) at both states suggest $\frac{7}{2}^-$ or $\frac{9}{2}^-$ as the probable spin assignments. In considering these assignments one should bear in mind that, most probably, there are γ rays from ^{153}Yb decay that we have not observed. However, the intensities of the γ-ray transitions [see footnote (a), Table I] that proceed to the $s_{1/2}$ and $h_{11/2}$ ^{153}Tm isomers add up to ~90% of the β-decay strength calculated by using the Tm $K\alpha_1$ x-ray intensity and the 6.97-MeV Q_{EC} of ^{153}Yb; the indication, then, is that the total intensity of γ rays missing from our scheme in Fig. 4 might be ~10% of the ^{153}Yb decay strength.

C. Decay properties of $^{153}_{69}$Tm

As we mentioned earlier, up to this time only the α-decay branch of ^{153}Tm had been observed.[2] During the course of our x- and γ-ray spectral measurements we identified the isotope's β-decay branch as well. Some of the ^{153}Tm γ rays can be seen in Fig. 1 and in Figs. 6(a) and 6(b) where we show spectra in coincidence with Er $K\alpha_1$ x rays and with the intense 299.3-keV transition (assigned to the decay of the $\frac{11}{2}^-$ ground state). Note in Fig. 6(a) the presence of ^{149}Tb γ rays; they are in coincidence with Gd $K\beta_1$ x rays whose energy, 48.7 keV, is close to that of the Er, 49.1-keV, $K\alpha_1$ x-ray peak.

We assign all but one (i.e., 266.5±0.1 keV) of the observed ^{153}Tm γ rays to the decay of the $h_{11/2}$ ground

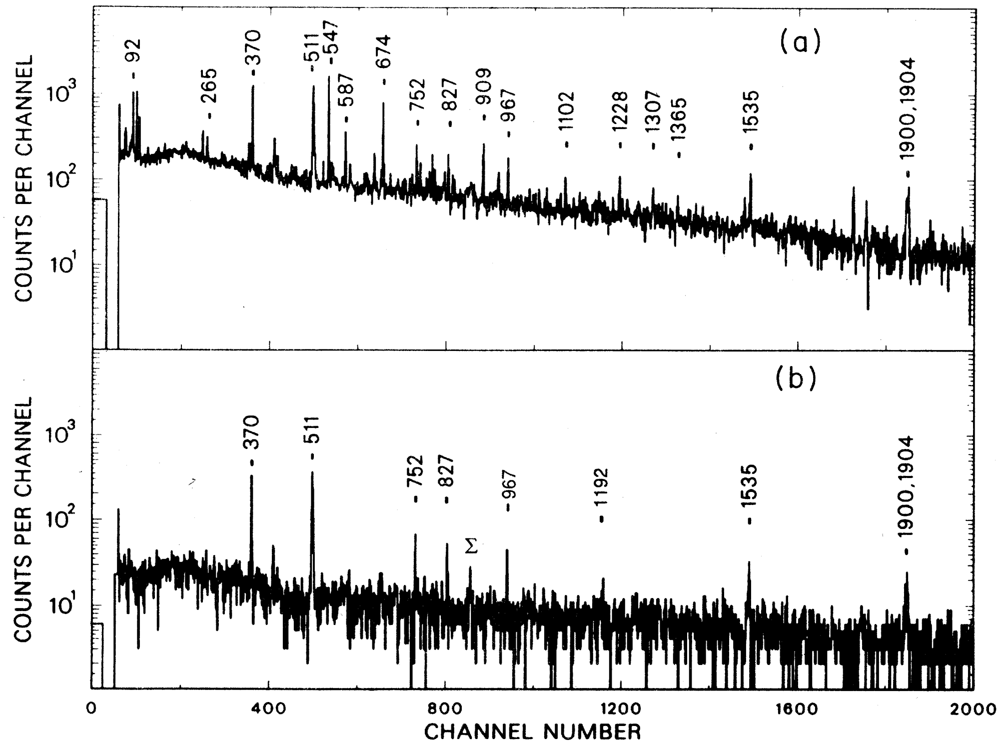

FIG. 2. Parts (a) and (b) show spectra accumulated in the 52% n-type Ge detector in coincidence with Tm $K\alpha_1$ x rays and the 92-keV ^{153}Yb γ ray, respectively; gates were set with data recorded by the hyperpure Ge x-ray detector. Background gated spectra were subtracted.

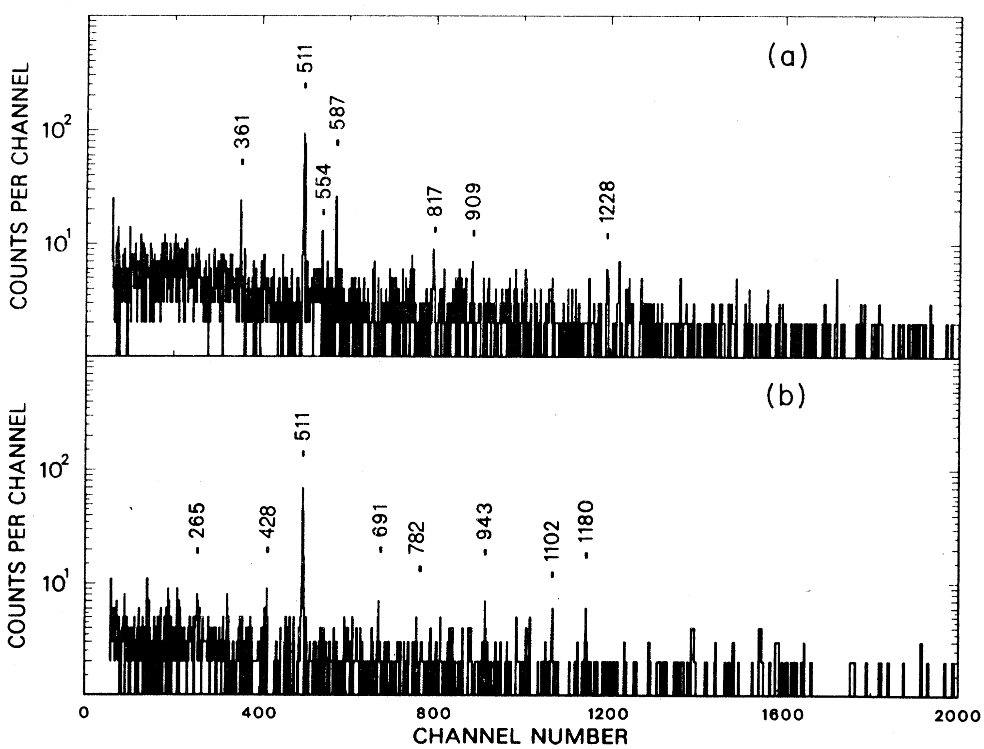

FIG. 3. Parts (a) and (b) show spectra accumulated in the 52% n-type Ge detector in coincidence with the 547- and 674-keV ^{153}Yb γ rays, respectively; gates were set with data recorded by the 24% n-type Ge γ-ray detector. Background gated spectra were subtracted.

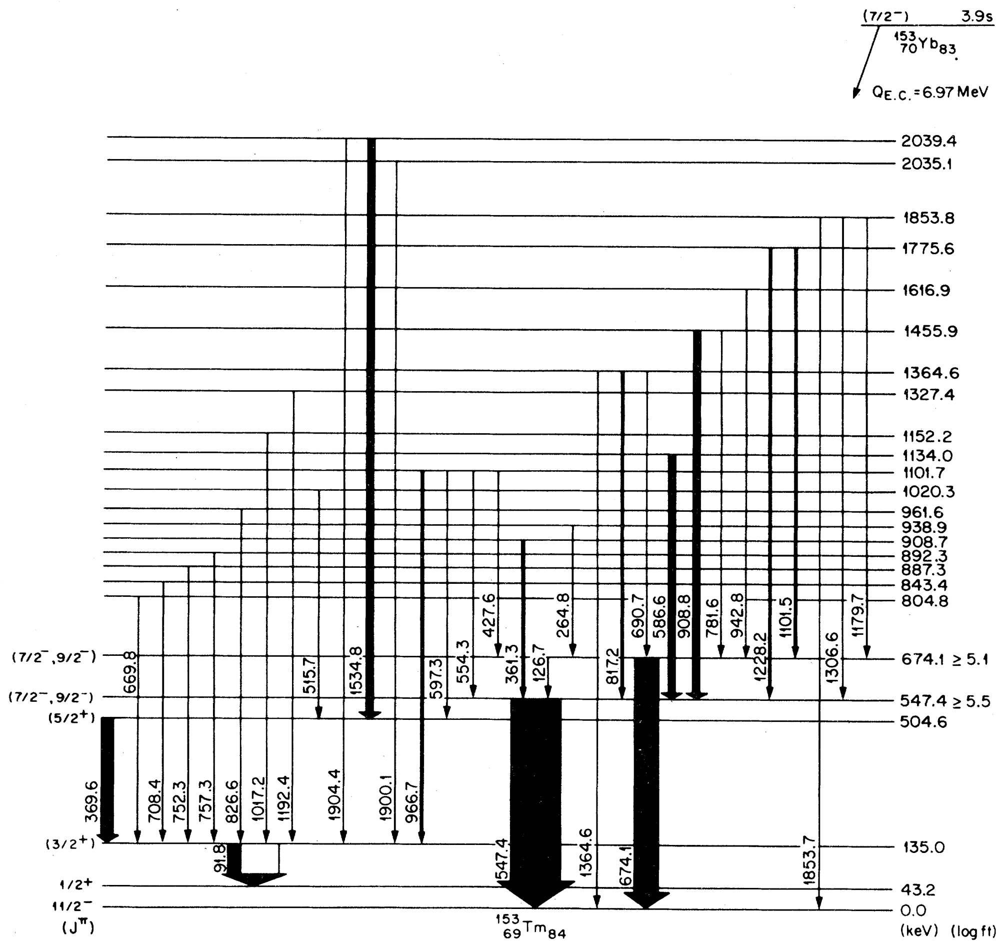

FIG. 4. Proposed β-decay scheme for ^{153}Yb.

state. Their energies and photon intensities are summarized in Table III. Based on our coincidence results and on the ^{153}Er level scheme deduced from in-beam γ-ray measurements,[21] we propose the decay scheme shown in Fig. 7. Indicated spins and parities are from Ref. 21. The logft value of 4.8 for the β transition to the 299.3-keV level is a strong confirmation that the state has indeed a spin assignment of $\frac{9}{2}^-$. The Q_{EC} value of

TABLE II. Excitation energies of $h_{11/2}$ and $s_{1/2}$ proton states.

Nucleus	[Z,N]	Energy (keV) $s_{1/2}$	$h_{11/2}$	References
^{147}Tb	[65,82]	0.0	50.6	10
^{149}Tb	[65,84]	0.0	36.0	11
^{151}Tb	[65,86]	0.0	99.5	12
^{149}Ho	[67,82]	49.0	0.0	9
^{151}Ho	[67,84]	41.4	0.0	10
^{153}Ho	[67,86]	68[a]	0.0[a]	11,13
^{147}Tm	[69,78]	67	0.0	14
^{153}Tm	[69,84]	43.2	0.0	This work
^{155}Tm	[69,86]	$\sim$41[b]	0.0[b]	15

[a]The excitation energy for the low-spin isomer in ^{153}Ho was originally reported[13] to be $\sim$60 keV. Our value of 68 keV is calculated by using α decay energies reported in Ref. 13 and the 36.0-keV excitation energy recently determined[11] for the $\frac{11}{2}^-$ isomer in ^{149}Tb.

[b]Based on the assumption that the α group reported[15] for the α decay of ^{155}Tm is, in fact, a doublet where the two α transitions originate from the $s_{1/2}$ and $h_{11/2}$ isomers in ^{155}Tm and feed the corresponding proton states in ^{151}Ho.

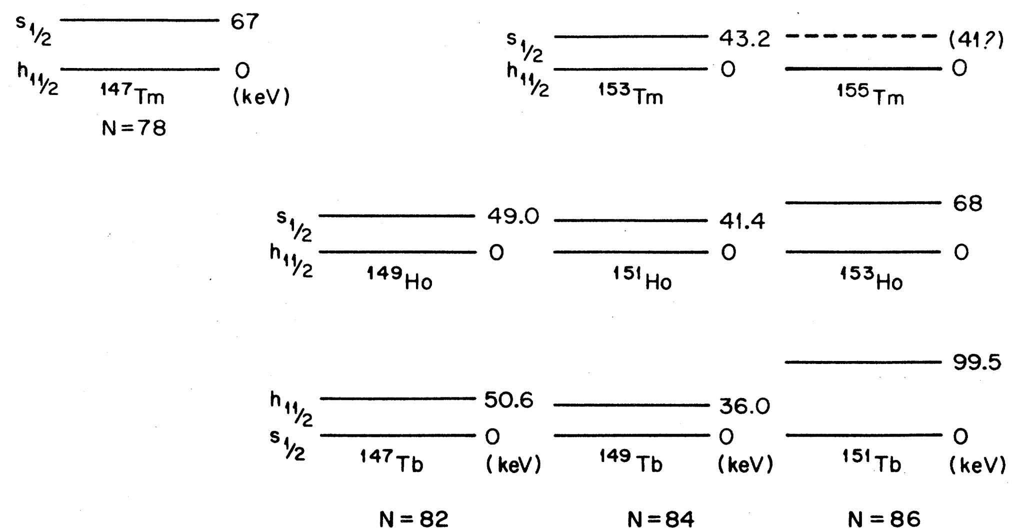

FIG. 5. Excitation energies of $h_{11/2}$ and $s_{1/2}$ proton states in ^{147,149,151}Tb ($Z=65$), ^{149,151,153}Ho ($Z=67$), and ^{147,153,155}Tm ($Z=69$).

6.43 ± 0.21 MeV is taken from Ref. 7.

The 299.3-keV level presumably is the $h_{9/2}$ neutron state in $^{153}_{68}$Er$_{85}$. Supporting evidence for this assignment is summarized in Fig. 8 where we have plotted excitation energies of the lowest $\frac{9}{2}^-$ and $\frac{13}{2}^+$ levels in gadolinium, dysprosium, and erbium nuclei with $N=83$, 85, and 87. Data for the $N=83$ isotones are taken from Ref. 22 wherein systematics of single-neutron orbitals in even-Z nuclei, $^{137}_{54}$Xe$_{83}$ to $^{151}_{68}$Er$_{83}$, are discussed, while information for the $N=85$ and $N=87$ isotones (with the exception of

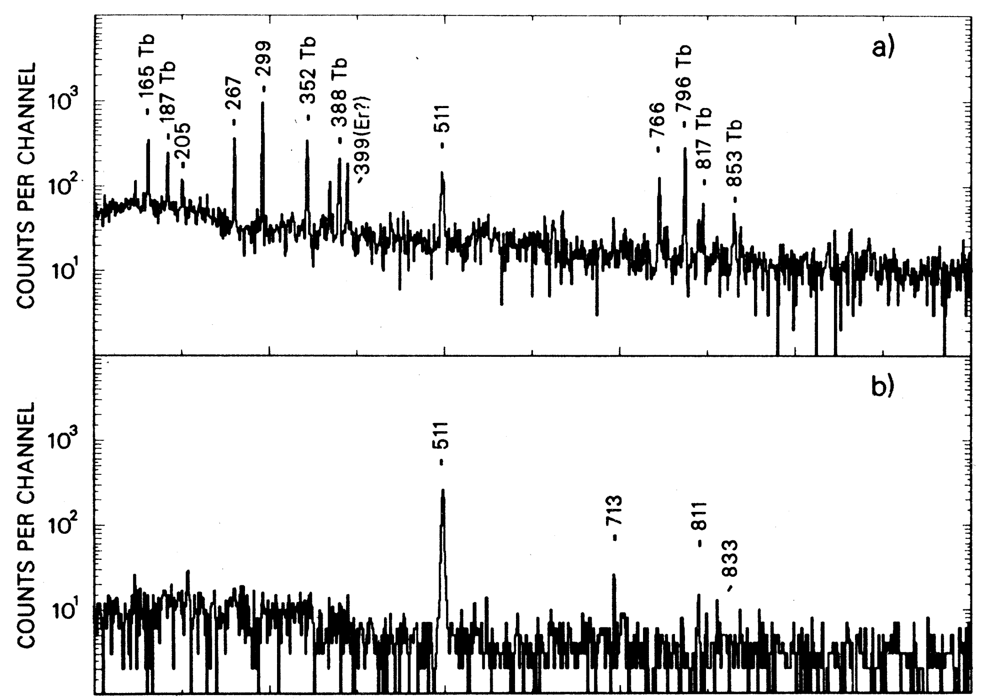

FIG. 6. Parts (a) and (b) show spectra accumulated with the 52% n-type Ge detector in coincidence with Er $K\alpha_1$ (and Gd $K\beta_1$) x rays and the 299-keV ^{153}Tm γ ray, respectively; gates were set with data recorded by the hyperpure Ge x-ray detector. Background gated spectra were subtracted. The intense 267-keV transition assigned to ^{153}Tm follows the β decay of the $s_{1/2}$ isomer; it is, therefore, not included with the $h_{11/2}$ transitions in Table III and is not part of the β-decay scheme shown in Fig. 7 for the $h_{11/2}$ ground state.

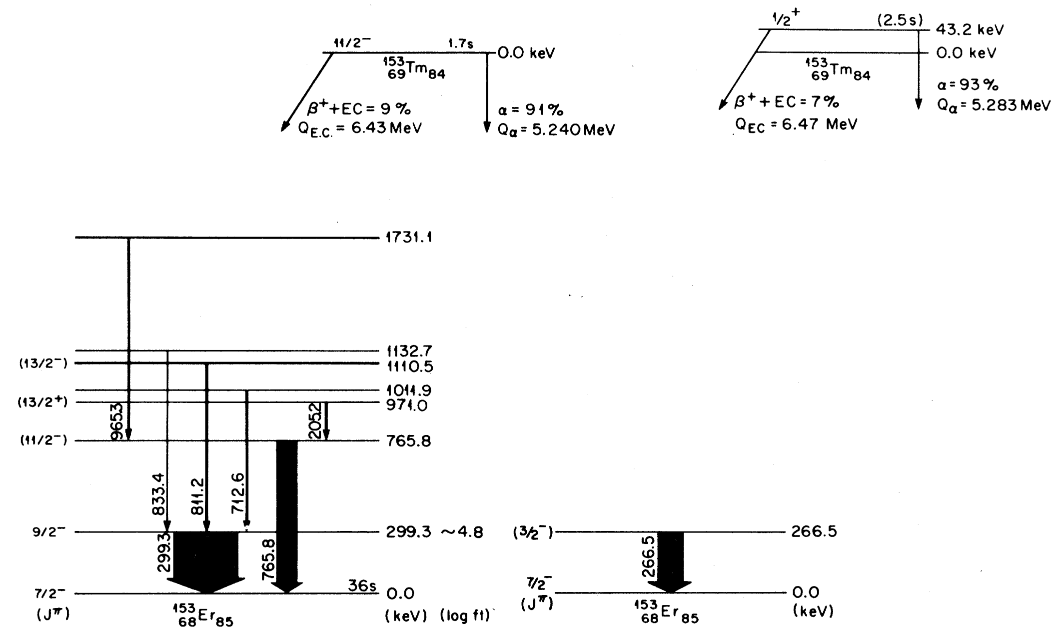

FIG. 7. Proposed β-decay schemes for the $h_{11/2}$ ground (left-hand portion of figure) and the $s_{1/2}$ isomeric (right-hand portion) states of ^{153}Tm.

^{153}Er) are from appropriate *Nuclear Data Sheets.*[2,18,23,24] The 299.3-keV level fits well into the trends of the $\frac{9}{2}^-$ states as a function of both neutron and proton number. In Ref. 22 it is noted that the $h_{9/2}$, $p_{1/2}$, $p_{3/2}$, and $f_{5/2}$ neutron states all increase in excitation with respect to the $f_{7/2}$ ground state as Z increases from 54 to 64 and then decrease as Z increases further. There is also a regular compression of the $\frac{9}{2}^-$ level energies (Fig. 8) as the valence neutron number becomes larger. The $i_{13/2}$ orbital behaves[22] differently, i.e., its excitation energy decreases with increasing Z, reaches a minimum of gadolinium, and then increases (Fig. 8). Its behavior with N also differs from that of the $h_{9/2}$ orbital. The accumulated evidence indicates that the $\frac{13}{2}^+$ levels may not be pure single-particle states; they may be admixed[22] with 3^- octupole collectivity.

Only the 266.5-keV γ ray [see Figs. 1 and 6(a)] could be assigned to the β^+ decay of the ^{153}Tm low-spin isomer. The assignment is based on the following evidence: (1) the γ ray was not observed in coincidence with any transition including those listed in Table III, and (2), its decay curve, for each counting cycle, indicated a half-life longer than that of the 299.3- and 765.8-keV γ rays. For both ^{153}Tm isomers the decay data are distorted by feeding from ^{153}Yb. This is particularly true for the low-spin species since its direct production is much less than that of the high-spin state while it is fed by about 40% of ^{153}Yb decay. Thus, in the 12.8-s cycle times, we determined a 1.7±0.2 s half-life for the high-spin isomer in agreement with published values.[2,8] For the 266.5-keV γ ray, however, a multicomponent decay analysis could only provide us with the following half-life limits: 0.5 s

TABLE III. Energies and photon intensities for γ rays assigned to the β decay of the $\frac{11}{2}^-$ ^{153}Tm ground state.

$E\gamma$ (keV)	$I\gamma$ (relative)[a]
205.2(2)	9.6(9)
299.3(1)	100
712.6(3)	6.5(8)
765.8(2)	30(3)
811.2(3)	8.9(10)
833.4(4)	~3
965.3(3)	12.9(15)

[a]Normalized to a value of 100 for the 299.3-keV transition; to obtain intensities per 100 decays of the ^{153}Tm ground state these relative values should be multiplied by 0.063. In calculating this normalization factor the 299.3-keV transition was assumed to be $M1$ and to have an internal conversion coefficient of 0.137.

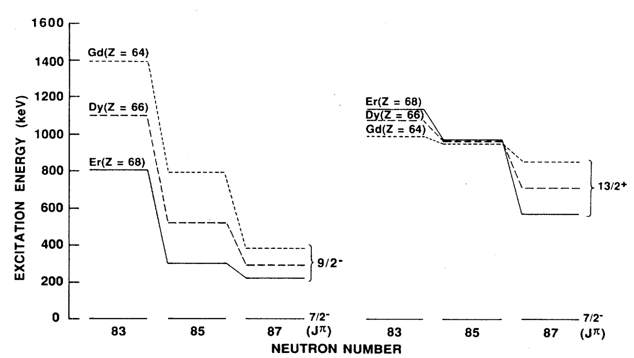

FIG. 8. Energy systematics of the $h_{9/2}$ and $i_{13/2}$ neutron states in Gd, Dy, and Er nuclei whose neutron numbers are 83, 85, and 87.

$<T_{1/2}<2.5$ s; in Fig. 7, we therefore show (enclosed in parentheses) the 2.5-s half-life reported[8] for the ^{153}Tm low-spin isomer.

As indicated in the right-hand part of Fig. 7, we suggest that the 266.5-keV transition proceeds directly from the $p_{3/2}$ neutron level in ^{153}Er to the $f_{7/2}$ ground state. In the $N=83$ nuclei ^{147}Gd, ^{149}Dy, and ^{151}Er, the energies[22] of the $p_{3/2}$ levels are 1153, 1035, and 984 keV, respectively, i.e., close to the energies of the $h_{9/2}$ levels (see Fig. 8) in the same three nuclei. Since the $h_{9/2}$ level, which is at 802 keV in ^{151}Er, decreases in energy to 299 keV in ^{153}Er, our proposed 266.5-keV excitation energy for the $p_{3/2}$ orbital in ^{153}Er is just about what one would expect from systematics. By comparing spectra in coincidence with the 266.5- and 299.3-keV γ rays we found the (K x ray)/(annihilation radiation) intensity ratio for the first γ ray to be twice that of the second one. This indicates that, in contrast to the 299.3-keV level, the 266.5-keV state receives much less direct β-decay feeding. Instead, it must be fed from high-lying levels by γ rays that we do not observe because of the small β-decay branches (see below) of the ^{153}Tm $h_{11/2}$ and $s_{1/2}$ states.

Because of the 60-keV full-width-at-half-maximum resolution of the telescope for α particles, we could not resolve the ^{153}Tm α group into the 5103-keV (high-spin) and 5096-keV (low-spin) components.[8] However, we did see γ rays that follow the β decays of both the $s_{1/2}$ and $h_{11/2}$ ^{149}Ho isomers. Since ^{153}Yb does not α decay, all of the observed ^{149}Ho radioactivity must originate from ^{153}Tm. Then, by assuming that the 1091.1-keV transition[25,26] represents 85% of the ^{149}Ho $h_{11/2}$ β-decay strength and by comparing its intensity with the sum of the 299.3- and 765.8-keV ^{153}Tm transition intensities we deduce an α-decay branching ratio of 91±3% for the ^{153}Tm $h_{11/2}$ ground state. Similarly, by assuming that the ^{149}Ho 1035.0-keV transition[27] (it deexcites[22] the $p_{3/2}$ level to the $f_{7/2}$ ^{149}Dy ground state) and the 266.5-keV γ ray represent 100% of the β-decay strengths of the $s_{1/2}$ isomers in ^{149}Ho and ^{153}Tm, respectively, we estimate the α branching ratio of the ^{153}Tm $s_{1/2}$ state to be ~93%. If one compares the total number of ^{153}Tm α particles observed with the sum of the 266.5-, 299.3-, and 765.8-keV transition intensities, then a ^{153}Tm α branch of 92±3% is arrived at. It agrees with the two values listed in Ref. 2, i.e., 90^{+10}_{-20}% (Ref. 1) and 95^{+5}_{-8}% (Ref. 28), but not with the lower ratio of 80±10% reported by Berlovich *et al.*[29] With our branches and the α-decay data of Schardt *et al.*,[8] we calculate reduced widths (the formalism developed by Rasmussen[30] was used) for $l=0$ α waves of 0.091 and 0.065 MeV for the ^{153}Tm high- and low-spin isomers, respectively. Because these widths are comparable[31] to those of neighboring even-even nuclei the α decays must be unhindered. This decay-rate information supports the picture proposed in Ref. 8 and used in our discussion, i.e., the two α transitions proceed between the respective $h_{11/2}$ and $s_{1/2}$ states in ^{153}Tm and ^{149}Ho.

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