ON THE LEVEL SCHEME OF Eu^{153}

L. I. RUSINOV*, R. L. APTEKAR', V. S. GVOZDEV, S. L. SAKHAROV, and Yu. L. KHAZOV

Leningrad Physico-Technical Institute

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The decay scheme of Sm^{153} ($T_{1/2}$ = 47 hours) obtained in the (n, γ) reaction was investigated. The γ transition types were determined for transitions with energies of 69.7 kev (96.4 percent M1 + 3.6 percent E2); 84.4 kev (60 percent M1 + 40 percent E2); 103.2 kev (98.5 percent M1 + 1.5 percent E2) and 98 kev (M1). The 98-kev transition has been observed for the first time. The experimental results are compared with theory. Some new details of the level scheme of Eu^{153} are presented.

INTRODUCTION

THE nucleus Eu^{153} is formed both in β decay of Sm^{153} with a half-life $T_{1/2}$ = 47 hours and also from Gd^{153} in the capture of orbital electrons with a half-life $T_{1/2}$ = 230 days. The scheme of the excited levels of Eu^{153} was investigated in great detail in a large number of researches, and the spins and parities of the excited levels were established up to energies of 200 kev. However, there are a number of peculiarities which require further determination.

1. The excited level with energy of 97.5 kev is observed only in the formation of Eu^{153} from Gd^{153}.

2. The intensity of transitions with energies 89.5 and 172.9 kev is small in comparison with the intensity of transition with energy of 69.7 kev.

3. The transition with energy 83.4 kev between the rotational levels with K = $5/2$ has a larger admixture of the E2 type than the transition with energy 69.7 kev between the rotational levels with K = $3/2$. In connection with the foregoing, an investigation of the level scheme of the Eu^{153} nucleus, formed in β decay of Sm^{153} was again undertaken in the present research.

EXPERIMENTAL RESULTS

The spectrum of internal conversion electrons was measured on a β spectrometer with focusing of the electrons at an angle of $\pi\sqrt{2}$ with a resolving power $\Delta H\rho/H\rho$ = 0.25 per cent and with an aperture of 0.25 percent of 4π. As a source, we used samarium oxide enriched by the isotope Sm^{152} to 98.5 percent, which was coated on aluminum foil of 4μ thickness in the form of a layer of thickness 0.03 — 0.05 mg/cm^2. The prepared source was exposed for 4 — 5 days in the flux of thermal neutrons of the reactor. The K, L, M and N lines of the γ transitions were observed in the spectrum of internal conversion electrons, with energies of 69.7, 83.4 and 103.2 kev, as well as the L and M lines of the γ transition with energy of 89.5 kev and the K line of the γ transition with energy of 172.9 kev. The transition with energy 89.5 kev was observed for the first time in the decay of Sm^{153}.

The types of transitions with energies of 69.7, 83.4 and 103.2 kev were determined from a comparison of the experimental and theoretical[1] relations of the coefficients of internal conversion on the L sub-shells (Table I). The results obtained for γ transitions of 83.4 and 103.2 kev are identical with the data of Graham et al.[2] For the transition with energy of 69.7 kev, there is an important difference: in reference 2, the admixture of the transition of type E2 is shown to be equal to 1.5 percent.

It should be noted that the values of the ratio α_L/α_M obtained by us differ sharply from the theoretical.[3]

In addition to the conversion lines mentioned, an electron line was discovered in the spectrum with an energy of 49.5 kev (Fig. 1). It was interpreted by us as a K line of the γ transition with energy of 98 kev in Eu^{153}. The ratio of the intensities of the K internal conversion electrons of the γ transition of 98 kev and the L electrons of the γ transition of 69.7 kev was shown to be equal to 0.06 per cent.

For clarifying the location of the γ transition of 98 kev in the level scheme of Eu^{153}, investigations were carried out on the $\gamma\gamma$ coincidences

*Deceased.

Table I

E_γ, kev	$\alpha_{L_I} : \alpha_{L_{II}} : \alpha_{L_{III}}$ Theoretical values M1	$\alpha_{L_I} : \alpha_{L_{II}} : \alpha_{L_{III}}$ Theoretical values E2	$\alpha_{L_I} : \alpha_{L_{II}} : \alpha_{L_{III}}$ Experimental values	Type of transition	α_L / α_M Theoretical values M1	α_L / α_M Theoretical values E2	α_L / α_M Experimental values	Intensity of the transition
69.7	65,8:5,57:1	0.09:0,89:1	9,47:1,53:1	96,4±0,5% M1 +3,6∓0,5% E2	0,44	0,47	0.20±0,01	100
83,4	66.8:5.57:1	0.15:0,93:1	0,74:1,02:1	60±2% M1+40∓2% E2	0,44	0,47	0.18	3
103,2	68.1:5,55:1	0,26:0,995:1	24:2,75:1	98,5±0,1% M1 +1,5∓0,1% E2	0,44	0,47	0.181±0.005	220,5
89.5				>85% M1+<15% E2*				1,49
172.9				60% M1+40% E2*				0,24

E_γ, kev	α_K Theoretical values E1	E2	M1	M2	α_K Experimental values	Type of transition	Intensity of the transition
98	0,24	1.18	1,62	14	1,5±0.5	M1 (+E2)	1.3

*Taken from reference 2.

(Fig. 2). The measurements were made on a coincidence circuit with a resolving time of $\tau = 2 \times 10^{-8}$ sec. In one of the channels of the coincidence circuit, there was a differential amplitude analyzer which made it possible to select any portion of the gamma spectrum. The coincidence spectrum was recorded by a 100 channel amplitude analyzer.

In tuning of the amplitude analyzer to the line of 103.2 kev in the spectrum for a single channel (the portion a in the upper curve of Fig. 2), a γ line with energy 98 ± 5 kev was observed in the coincidence spectrum (lower curves). The spectrum of $\gamma\gamma$ coincidences is shown in the figure; here random coincidences have been deducted.

In order to eliminate the effect of coincidences of γ rays with energies of 103.2 and 69.7 kev, the analogous spectrum of coincidences with the portion b (upper curve) was also studied. The relation of the intensities of the γ lines with energies of 98 and 69.7 kev remained the same in both series of measurements (coincidence with the portion a and coincidence with the portion b) and was equal to 0.03 ± 0.01.

For the γ transition with energy of 69.7 kev, the internal conversion coefficient on the L shell was calculated for the value of the mixture 96.4 percent M1 + 3.6 per cent E2. From the relation of the intensities of the conversion electrons for the γ transition of 98 kev on the L shell and for

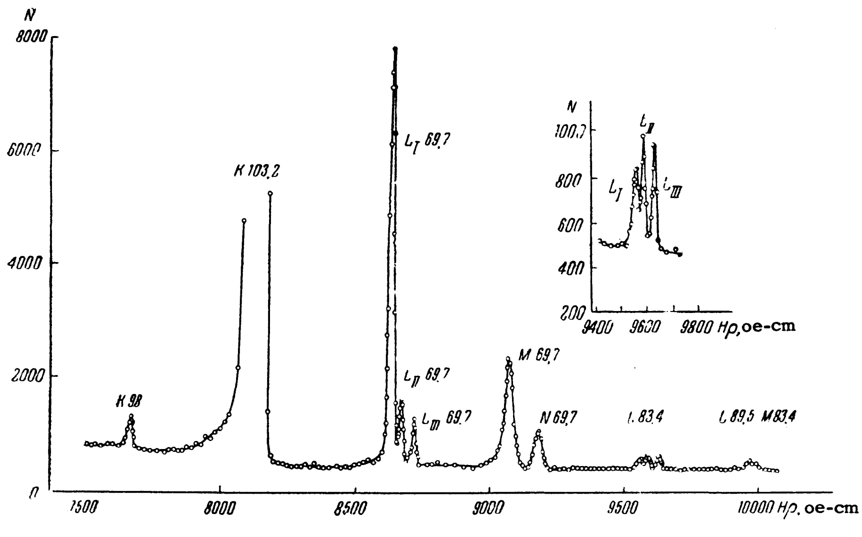

FIG. 1. A portion of the spectrum of internal conversion electrons of Eu^{153}.

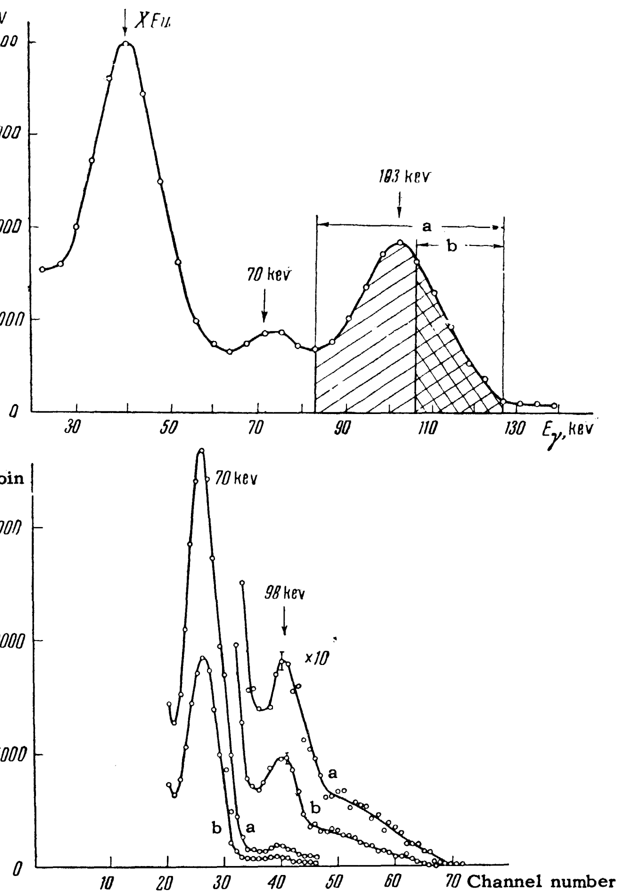

FIG. 2. Spectrum for a single channel (upper curve) and the spectrum of $\gamma\gamma$ coincidences. The curves a and b have been partially expanded in scale by a factor of 10, XEu is the characteristic x-radiation of europium.

the γ transition of 69.7 kev on the L shell, and also from the relation of the intensities of γ rays for the same transitions, we can compute the coefficient of internal conversion on the K shell for the transition of 98 kev. It turned out to be equal to 1.5 ± 0.5, which corresponds to an M1 transition or to a mixture of M1 and E2.

DISCUSSION OF RESULTS

The value of the internal conversion coefficient for the γ transition of 98 kev, and the presence of coincidences of γ quanta of this transition with γ quanta of 103.2 kev indicate that the observed transition does not take place from the level of 97.5 kev.

There are two rotational structures in the level scheme of Eu^{153}. One of these is connected with the ground state of the nucleus. The first excited level of this structure (E = 83.4 kev and I = $^7\!/_2$) is formed both in the decay of Sm^{153}, and also in the decay of Gd^{153}. The second excited level (E = 190 kev and I = $^9\!/_2$) is not discovered in the

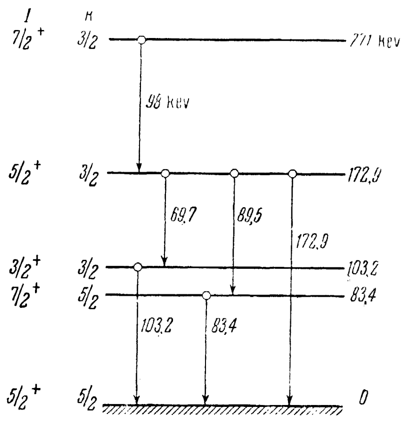

FIG. 3. Level scheme of Eu^{153}.

decay of Sm^{153} and Gd^{153} because of the large value of the spin, and is observed only in the experiments on Coulomb excitation.

The second rotational structure has its ground state level with excitation energy 103.2 kev (I = $^3\!/_2$). The transition from the first excited level of this structure (E = 172.9 kev) to its ground state takes place with energy of 69.7 kev. The excitation energy of the next level is computed by a well-known formula (see reference 10) and is equal to 271 kev (relative to the ground state of Eu^{153}). The transition from the second excited level to the first should take place with energy of 97.6 kev. This value is identical with the value of the energy of the observed transition.

Thus one can draw the conclusion that the γ transition with energy of 98 kev is a transition of type M1 with a possible admixture of E2. This transition refers to the second rotational structure and takes place between the levels with excitation energies of 271 and 172.9 kev (Fig. 3).

In the decay of Gd^{153}, the level of 271 kev in Eu^{153} is not generated because of the small total energy of decay.[4]

In strongly deformed nuclei, the relations of the probabilities of transitions from any state to the rotational state belonging to one rotational band are computed according to the well-known rule of Alaga.[5] It was noted by Gnedich et al.[6] that there are certain cases of violation of this rule. The deviation consists in the fact that the transitions to the excited states of the rotational band are more intense (in comparison with the transition to the ground state of the same band) than follows from Alaga's rule. In this case a higher probability of transition is observed to the second excited state than to the first excited state.

It is of interest in the case of Eu^{153} to compare the probabilities obtained for the transitions B(λ) with energies of 89.5 and 172.9 kev (transitions to

Table II

Type of transition	$B(\lambda)_{89.5}/B(\lambda)_{172.9}$		Favoring of 89.5-kev transition
	By Alaga's rule	Experiment	
$M1$	2.5 : 1	24.8 : 1	9.9
$E2$	0.037 : 1	17.9 : 1	483

the first excited state and to the ground state of the rotational band). Both transitions are mixed and it is necessary to make the comparison independently for each type of transition, M1 or E2. The relation of the intensities of γ rays for these transitions was computed from the intensities of the internal conversion electrons. The value of the mixture M1 and E2 is taken from the work of Grant et al.[2] The comparison of the theoretical and experimental relations for the probabilities obtained for different transitions $B(\lambda)$ is written down in Table II. As is seen from the table, the transition of 89.5 kev is facilitated in a considerable degree in comparison with the theoretical predictions.

The reason for the departure from Alaga's rule is not known at the present time. In the case of Eu^{153}, it is impossible to explain this deviation by a mixture of the wave functions of the states (both states have spin and parity of $5/2^-$), because such a mixture can bring about only the opposite effect — the facilitating of the transition of 172.9 kev in comparison with the γ transition of 89.5 kev.

As is seen from Table I, the intensities of transitions with energies of 89.5 and 172.9 kev are very small in comparison with the transition intensity for the energy of 69.7 kev. The reasons for this circumstance consist of the following. The initial state of the internal excitation with energies of 89.5 and 172.9 kev is a state characterized by the asymptotic quantum numbers N, n_z, λ, Σ, equal to [4, 1, 1, −], the final state is characterized by the numbers [4, 1, 3, −].[7] The transition of the type M1 between these states, in accord with the rules of the review of reference 8, is seen to be forbidden according to the asymptotic quantum number λ, while the transition of the type E2 remains allowed. This prohibition leads to a certain "retardation" of transitions with energies of 89.5 and 172.9 kev. This circumstance also clearly explains the fact of the larger admixture of E2 in transitions with energy of 89.5 and 172.9 kev in comparison with transitions of 69.7, for which there are no prohibitions.

A striking fact is the higher value of the admixture of E2 for the transition of 83.4 kev than for the transition of 69.7 kev, in spite of their rotational character. One can attempt to explain this fact in the following fashion.

The probability of the electromagnetic transition of multipolarity λ is connected with the reduced transition probability $B(\lambda)$ by a well-known relation (see reference 10). For strongly deformed nuclei and for transitions within the limits of a single rotational band, $B(\lambda)$ is expressed in terms of the statistical moment of the ground state of the K band, μ, Q_0, the general magnetic ratios g_K and g_R, and the Clebsch-Gordan coefficients.[9] From these relations, and with a knowledge of the partial lifetime,[10] the value of the mixture of E2 and M1 for the corresponding transition, and the value of the magnetic moment for the ground state of the rotational band, one can determine the values of Q_0, g_K, and g_R for this state.

The lifetime of the 172.9-kev level of the Eu^{153} nucleus is known. The partial lifetime for the 69.7-kev transition can be determined from the relations of the intensities of the 69.7-, 89.5-, and 172.9-kev transitions. As the value of the magnetic moment of the Eu^{153} nucleus in a state with excitation energy 103.2 kev, we can take a quantity equal to the magnetic moment μ of the Tb^{159} nucleus in the ground state ($\mu = 1.52$). Under these conditions, the values of Q_0, g_K, and g_R for Eu^{153} in the 103.2-kev state were found to be equal respectively to 5.1×10^{-24} cm^2, 1.4 and 0.44.

The quadrupole moment of the Eu^{153} nucleus in the ground state is known from experiments on Coulomb excitations[11] and is equal to 7.7×10^{-24} cm^2. Thus the experimental data testifies to the fact that the different deformation corresponds to different internal states.

The value of the mixture of M1 and E2 for any transition is determined by the ratio of probabilities $B(M1)/B(E2)$ for this transition. From the known values of Q_0, g_K and g_R for the Eu^{153} nucleus in the ground and excited states, we can determine the ratio $[B(M1)/B(E2)]_{83.4}$: $[B(M1)/B(E2)]_{69.7}$, which is shown to be equal to 0.03. In the same way, it is explained why the transition with 83.4 kev energy has a much larger admixture of E2 than the transition with energy of 69.7 kev.

In conclusion, the authors express their deep gratitude to D. A. Varshalovich for discussion of the results.

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