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Abstract

Full Text

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New Isomeric States of Spherical Europium Nuclei with Odd Mass Number

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The level schemes of the nuclei Eu^{147}, Eu^{149}, and Eu^{151}, investigated in the works of B. S. Dzhelepov and A. A. Bashilov ([1]) from the spectra of internal-conversion electrons and photoelectrons, have certain common features. In particular, in all three nuclei the presence is assumed of an $h_{11/2}$ level, which gives rise to transitions of type $M2$, and in the nuclei Eu^{147} and Eu^{149}, to transitions of type $E3$. We have investigated the most essential parts of the level schemes of these nuclei by means of the coincidence method. In addition, we measured the lifetimes of isomeric levels with energies 624, 496, and 197 keV, respectively, in the nuclei Eu^{147}, Eu^{149}, and Eu^{151}.

The nucleus Eu^{147}**.** First of all, the position of the 370 keV transition in the level scheme of the Eu^{147} nucleus was determined. Two scintillation spectrometers with sodium iodide crystals and photomultipliers of the FEU-14 type were connected in a coincidence circuit, whose resolving time 2τ could be varied within the limits from 0.2 to 18 μsec. An adjustable time delay (up to 250 μsec) could be introduced into either branch of the coincidence circuit. In addition, a 100-channel amplitude analyzer was used for the investigation; it was connected into one branch of the circuit: the analyzer "gate" was opened by a synchronizing pulse obtained from the second branch, to which the window of a single-channel amplitude analyzer was set on a selected portion of the amplitude spectrum. The investigations were carried out with the aid of a source obtained from the gadolinium fraction, extracted by a chromatographic method from the rare-earth group of elements that arise in a tantalum target under the action of a 660 MeV proton beam from the synchrocyclotron of the Joint Institute for Nuclear Research. For several days after irradiation (with a duration of 3–4 hours), the activity of the source was due mainly to 35-hour Gd^{147}. With the aid of such investigations it was unambiguously shown that there are "prompt" (with a resolution of 0.2 μsec) and delayed coincidences between the 370 and 396 keV quanta. Between the 396 and 229 keV quanta only "prompt" coincidences were observed, whereas delayed coincidences were absent. This agrees with the upper limit of the lifetime of the 229 keV level established by us with the aid of a double magnetic spectrometer: $T_{1/2} \leqslant 5 \cdot 10^{-10}$ sec.

Fig. 1. Decay curve of the 625-keV state of the Eu147 nucleus. t—time delay, N—number of coincidences

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In measuring the lifetime of the 625 keV level ($h_{11/2}$), the windows of the single-channel analyzers in both branches of the circuit were set to the region of unresolved (because of their proximity in energy) photopeaks from the 370 and 396 keV quanta. Figure 1 shows (on a semilogarithmic scale) the decay curve of the state under investigation, which, with the aid of introduced delays, could be followed over approximately 7 half-life periods. The value obtained for the half-life proved to be $T_{1/2} = (7.1 \pm 0.4) \cdot 10^{-7}$ sec. This result was confirmed by control measurements of coincidences of x-rays and 396 keV γ-rays.

From the ratios of the total intensities of the two transitions from this level, which, according to the estimate made in (1), are $I_{396} : I_{625} = 10 : 1$, we obtain the experimental half-lives for the 396- and 625-keV transitions, respectively:

$$T_{1/2\,396} = 7.8 \cdot 10^{-7} \text{ s}, \qquad T_{1/2\,625} = 7.8 \cdot 10^{-6} \text{ s}.$$

Nucleus Eu^{149}. This nucleus was studied using a source obtained from the gadolinium fraction after the decay of 35-hour Gd^{147}, when the principal activity was determined by 10-day Gd^{149}.

In the level scheme of the Eu^{149} nucleus, the placement of an $M1$-type transition with energy 298 keV is ambiguous: the existence of a level with energy 298 keV is admitted, from which a direct transition to the ground state occurs. In direct experiments the presence was established of both "prompt" and delayed coincidences between quanta with energies 298 and 346 keV; this fixed the position of the 298-keV transition above the 496-keV level ($h_{11/2}$). In addition, the presence of "prompt" coincidences between the 346- and 150-keV quanta and the absence of delayed coincidences between them were established. As in the case of the Eu^{147} nucleus, this agrees with the upper limit on the lifetime of the first excited level of the Eu^{149} nucleus with energy 150 keV obtained using a double magnetic spectrometer:

$$T_{1/2} \leqslant 5 \cdot 10^{-10} \text{ s}.$$

Fig. 1. Decay curve of the 625-keV state of the Eu^{147} nucleus.
t—time delay, N—number of coincidences.

Figure 2 gives the results of measurements of the half-life of the 496-keV state of the Eu^{149} nucleus, obtained by studying coincidences between 298- and 346-keV quanta as a function of delay time. From the curve it was found that

$$T_{1/2} = (2.48 \pm 0.05) \cdot 10^{-6} \text{ s.}$$

According to (1), the ratio of the total intensities of the two transitions from the 497-keV level is

$$I_{346} : I_{496} = 0.4 : (0.02),$$

where the parentheses indicate that the intensity of the direct transition is determined less accurately.

This leads to the following values of the experimental half-lives for the 346- and 497-keV transitions, respectively:

$$T_{1/2\,346} = 2.62 \cdot 10^{-6} \text{ s}, \qquad T_{1/2\,497} = 5.24 \cdot 10^{-5} \text{ s.}$$

Nucleus Eu^{151}. For the study a Gd^{151} source was used ($T_{1/2} = 150$ days), one year old, obtained by irradiating a tantalum target that had been exposed to a scattered proton beam for about half a year. All short-lived isotopes, including 60-day Gd^{146}, as well as 5-day Eu^{146} and 24-day Eu^{147}, had completely decayed in this source. The main difficulty of the measurement lay in the presence of very intense γ-radiation accompanying the decay of Gd^{153} ($T_{1/2} = 230$ days), with energies 98 and 103 keV.

To measure the lifetime of the 197-keV level it proved convenient to study coincidences between γ-quanta with energy 155 keV and internal-conversion electrons of the 175-keV transition (the internal-conversion coefficient on the K-shell for this transition is 2.4), which were detected with the aid of a thin stilbene crystal plate. The conversion electrons ···

versions of the intense 103-keV transition in the nucleus Eu^{153} were for the most part absorbed by an aluminum filter of the appropriate thickness.

The measurement results (Fig. 3) give for the half-life of the 197-keV state of the nucleus Eu^{151}: $T_{1/2} = (5.8 \pm 0.3) \cdot 10^{-5}$ sec, which agrees well with the result obtained in the work of Shirley [(2)]: $T_{1/2} = (5.8 \pm 1.0) \cdot 10^{-5}$ sec. The $E3$-type transition from the 197-keV level to the ground state was not observed experimentally in this case (the intensity of such a transition must be too small in comparison with the $M2$-type transition with an energy of 175 keV).

Table 1

Fig. 2. Decay curve of the 496-keV state of the nucleus Eu^{149}.

Figure 2: Fig. 2. Decay curve of the 496-keV state of the nucleus Eu^{149}.

Nucleus	Transition type	E_γ, keV	T_γ exp., sec	$F = \frac{\lambda_\gamma \text{ exp.}}{\lambda_{\text{Weissk}}}$	Logarithm of comparative lifetimes
${}_{63}Eu^{147}_{84}$	$M2$	396	$9.04 \cdot 10^{-7}$	0.022	7.55
${}_{63}Eu^{149}_{86}$	$M2$	346	$3.21 \cdot 10^{-6}$	0.012	7.81
${}_{63}Eu^{151}_{88}$	$M2$	175	$2.4 \cdot 10^{-4}$	0.005	6.21
${}_{63}Eu^{147}_{84}$	$E3$	625	$7.9 \cdot 10^{-6}$	2.1	2
${}_{63}Eu^{149}_{86}$	$E3$	497	$5.45 \cdot 10^{-5}$	1.4	2.14

Each of the half-life values given above was obtained as a weighted mean from several series of measurements. In the graphs, in all cases, the results of only one of the series are shown. Each series was processed by the method of least squares. The indicated error values considerably exceed the statistical ones and take into account errors associated with the calibration of delay lines and with instability of the apparatus.

Table 1 summarizes the results obtained in the present work for three $M2$-type transitions and for two $E3$-type transitions. In calculating the radiative half-lives of the latter, we used the theoretical values of the conversion coefficients from the tables (3), in view of the fact that the multipolarities of the transitions are determined fairly reliably and the experimental values of the ratios α_K/α_L and α_K are close to the theoretical ones (1). The coefficient on the remaining shells was taken equal to $0.3\alpha_L$.

Fig. 2. Decay curve of the 496-keV state of the nucleus Eu^{149}.

The acceleration factors F represent the ratios of the radiative probabilities obtained from experiment to the single-particle probabilities calculated by the Weisskopf formula (4). The table also gives the logarithms of the comparative lifetimes: $\lg(\tau_\gamma A^{4/3} E_\gamma^5)$ for $M2$-type transitions and $\lg(\tau_\gamma A^2 E_\gamma^7)$ for $E3$-type transitions.

All $M2$-type transitions proved to be hindered on average by 2 orders of magnitude in comparison with the single-particle estimates. At the same time, the effect of shell structure is clearly expressed: the magnitude of the hindrance increases monotonically as the number of neutrons increases from 84 in Eu^{147} to 88 in Eu^{151}. The increase in the degree of hindrance with increasing distance from the $N = 82$ shell apparently reflects a deterioration in the degree of "purity" of the single-particle wave functions as the number of neutrons beyond the filled shell increases.

Fig. 3. Decay curve of the 197-keV state of the nucleus Eu-151.

Figure 3: Fig. 3. Decay curve of the 197-keV state of the nucleus Eu-151.

The results obtained provide an example of a change in the properties, considered in the work of V. S. Shpinel [5], of "corresponding" states, i.e.

states with a given odd number of nucleons of one type (protons) and different even numbers of nucleons of the other type (neutrons). The properties of such states and, in particular, the reduced transition probabilities from these states vary smoothly.

The probabilities of transitions of type $E3$ proved to be very close to single-particle estimates, in contrast to most known transitions of this type, which, as a rule, are strongly hindered. An exception similar to that observed by us in the region of the shell $N = 82$ is also known in the region of doubly "magic" numbers: $N = 126$, $Z = 82$ ([6]). The two observed cases are insufficient to make a statement about the behavior of the probability with increasing neutron number. In any case, if the slight decrease in the reduced transition probability that appears when the neutron number changes from 84 to 86 is real, it is very small.

Fig. 3. Decay curve of the 197-keV state of the nucleus Eu^{151}.

The analogy in the level schemes of the nuclei Eu^{147}, Eu^{149}, and Eu^{151}, as well as the monotonic change in the level energies and in the reduced transition probabilities, do not agree with assigning negative parity to the ground state of Eu^{151}, as was done in the works of Nilsson ([7]) and Gottfried ([8]).

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Note: Figure translations are in progress. See original paper for figures.