MEASUREMENT OF THE LIFETIME OF THE LEVELS IN THE Eu^{152}, Ag^{110}, *AND* Cs^{134} *NUCLEI PRODUCED IN* $(n\gamma)$*-REACTIONS*

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Lifetimes are measured for the excited states of the odd-odd nuclei Eu^{152}, Ag^{110}, and Cs^{134} produced as a result of neutron capture. The limits of the lifetime for the 90-keV level in Eu^{152} are estimated at $3 \times 10^{-7} \leq T_{1/2} \leq 1 \times 10^{-6}$ sec. The value $T_{1/2} = (3.7 \pm 0.2) \times 10^{-8}$ sec is obtained for the 116-keV level in Ag^{110}. A set of lines with $T_{1/3} = (5.7 \pm 0.7) \times 10^{-8}$ sec has been detected in the Cs^{134} spectrum. Schemes of the lower excited states of Eu^{152} and Ag^{110} are proposed on the basis of the data obtained.

AN investigation of the radiation produced in the $(n\gamma)$ reaction enables us to obtain information on the excited states of a large number of nuclei, including odd-odd nuclei, which as a rule are not produced in β decay. The most accurate values of the transition energies in such nuclei can be obtained by investigating the γ-ray spectra with diffraction crystal spectrometers and the spectra of the conversion electrons with β spectrometers. However, owing to the complexity of the spectra obtained in such cases (the number of lines frequently exceeds 100), it is impossible to construct dependable schemes for the excited states of the nuclei without additional information on the transitions. Such information can be obtained by investigating the coincidences, angular correlations, and lifetimes of the excited states of the nuclei.

The present investigation is devoted to a study of the lifetimes of the levels of odd-odd nuclei Eu^{152}, Ag^{110}, and Cs^{134}, arising as a result of $(n\gamma)$ reactions. The half lives were measured by the method of delayed coincidences of the soft γ-quanta belonging to the transitions between the lower excited states of the nuclei with the hard γ quanta of energy more than 1 MeV, accompanying the neutron capture.

The work was done with the extracted horizontal beam of the VVR-M water-moderated, water-cooled reactor of the Physicotechnical Institute. The investigated isotope was bombarded with a collimated neutron beam 1 cm in diameter. In the plane perpendicular to the neutron beam were located two scintillation counters, at an angle of 90°, 5—10 cm away from the specimen. Both counters were placed in a lead and boron carbide shield. The entrance openings of the shield were covered with a B_4C plate 3 mm thick. To reduce the background due to the scattered radiation from the reactor, the neutron beam was filtered by 10 cm of bismuth.

The counter intended for the registration of the hard γ quanta consisted of an NaI(Tl) crystal 60 mm in diameter and 40 mm high, with an FÉU-33 photomultiplier. The efficiency for counting soft γ quanta by this counter was decreased by a 10 mm lead filter, located at the end window of the counter. The soft γ quanta were counted with an NaI(Tl) crystal 30 mm in diameter and 11 mm high and an FÉU-33 photomultiplier.

The delayed coincidences of the soft and hard γ quanta were measured with a fast-slow coincidence circuit with a time amplitude converter, using a circuit analogous to that of Green and Bell [1]. The circuit permits measurement of the pulses from the soft γ quanta with definite energy in intervals of 32, 64, or 200 nsec following the registration of a hard γ quantum, and also obtain amplitude spectra of the pulses from the prompt and delayed γ rays.

The measurement of the lifetimes of the excited states of Rh^{104}, Mn^{56}, and Cd^{156}, obtained in the $(n\gamma)$ reaction, yielded results that agreed with those previously published [2,3]. New data were obtained for the isotopes Eu^{152}, Ag^{110}, and Co^{134}.

$_{63}Eu^{152}_{89}$. An Eu_2O_3 specimen 100 mg/cm^2 thick was placed on an aluminum substrate. Figure 1a shows the γ-ray spectrum of Eu^{152}. The spectrum shows two lines, 90 and 40 keV (x rays from Eu). In the amplitude spectrum of the prompt coincidences (Fig. 1b) the 90-keV line disappears completely. On the delayed-coincidence line, no exponential fall-off is seen for 90 keV (Fig. 2) to the

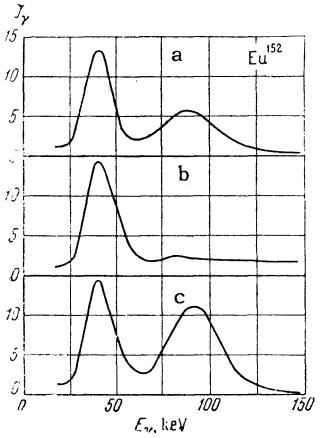

FIG. 1. γ-spectra from the $Eu^{151}(n\gamma)\,Eu^{152}$ reaction: a – single spectrum; b – prompt coincidence spectrum; c – delayed coincidence spectrum.

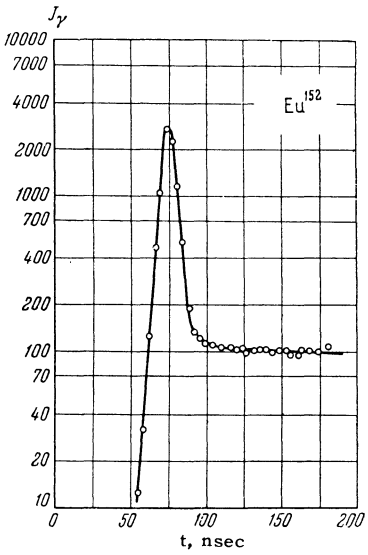

FIG. 2. Curve of delayed coincidences for the 90-keV transition in Eu^{152} ($3 \times 10^{-7} < T_{1/2} < 1 \times 10^{-6}$ sec).

right of the prompt-coincidence curve, but the count exceeds the random value. Control measurements were carried out with a Gd^{156} sample of the same dimensions as the Eu^{152}, with the same settings of the discriminators. The form of the delayed curve of Eu^{152} is due to the fact that the measured half life is larger than the range of the time analyzer. The half-life estimated from the slope of the curve is $T_{1/2} \sim 3 \times 10^{-7}$ sec. The same half life calculated from the excess above the background is estimated at $T_{1/2} \sim 1 \times 10^{-6}$ sec. The amplitude spectrum of the delayed coincidences, after subtracting the random coincidences, is shown in Fig. 1c. From the ratios of the areas under the 90-keV and the x-ray peak one can estimate the internal conversion coefficient at $\alpha_K = 1.25 \pm 0.25$. From a comparison of the obtained internal conversion coefficient with the theoretical value for different types of multipolarity (see the table) we can conclude that the most probable transition is of the E2 type.

Since the spectrum of the delayed coincidences contains no other lines of equal intensity except for the 90-keV line, the 90-keV transition can be regarded as going to the ground state of Eu^{152}. The 90-keV transition cannot go to an isomer level, since the isomer yield is 15% and the intensity of the 90-keV line amounts to 40 quanta per 100 neutron captures according to one source [4] and 20 according to another source [5]. If we take into account the total coefficient of internal conversion $\alpha_K = 3.3$ for the E2 transition, then these figures should be increased to 120 and 70, respectively. This indicates that probably the greater part of the transitions from the highly-excited states goes through the 90-keV level.

Taking into consideration the spin and parity of the ground state of $Eu^{152}(3^-)$, we can assign to the 90-keV level the following characteristics: 5^-, 4^-, 3^-, 2^-, 1^- (Fig. 3). However, a spin value of 1 is excluded, for this would call for the presence of a considerably intense transition between the 90-keV level and the isomer level with spin and parity 0^-.

$_{47}Ag^{110}_{63}$. The measurements were carried out with the separated isotope Ag^{109}. The specimen was a foil 0.6 mm thick. Control measurements were carried out on a specimen of separated Ag^{107} of identical dimensions. The scintillation spectrum of Ag^{110} contains γ lines with energies 80, 116, 195, and 235 keV, which agrees with the data of [6]. In the spectrum of the prompt γ quanta (that is, those coinciding with the hard γ rays with a resolution time of approximately 8 nsec), the relative intensities of the 80- and 116-keV lines decrease, meaning that some of these γ quanta did not coincide with the hard capture γ rays. The amplitude spectrum of the delayed coincidences shows clearly the 116-keV line and a weak 80-keV line. The intensity ratio of these lines is of the order of 10. These two transitions correspond to an exponent in the delayed-coincidence curves with a half life $T_{1/2} = (3.7 \pm 0.2) \times 10^{-8}$ sec.

An estimate of the internal conversion coefficient for the 116 keV transition gives $\alpha_K \lesssim 0.3$ as an upper limit for the possible values. On the basis of this estimate, we can assume that the

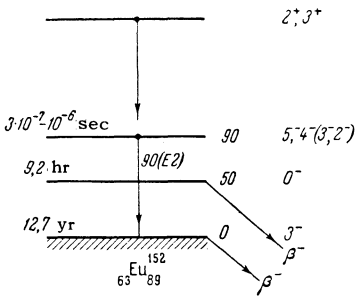

FIG. 3. Level scheme of excited states of Eu^{152} (the numbers at the arrows denote the transition energies in keV).

Nucleus and γ-quantum energy		Type of transition				Experimental value	Most probable type of transition
		E1	*E2*	*M1*	*M2*		
$_{63}Eu^{152}_{89}$, 90 keV	$T_{1/2}$, sec	$2.3\cdot10^{-13}$	$4.2\cdot10^{-7}$	$1\cdot10^{-11}$	$0.2\cdot10^{-5}$	$3\cdot10^{-7} \leqslant T_{1/2} \leqslant 1\cdot10^{-6}$	*E2*
	α_K	0.33	1.55	2.2	21	1.25 ± 0.25	
$_{47}Ag^{110}_{63}$, 116 keV	$T_{1/2}$, sec	$1{,}6\cdot10^{-13}$	$4{,}4\cdot10^{-7}$	$1\cdot10^{-11}$	$0.6\cdot10^{-5}$	$(3.7 \pm 0.2)\cdot10^{-8}$	*M1*
	α_K	0.09	0.67	0.22	1.85	$\leqslant 0.3$	
$_{47}Ag^{110}_{63}$, 80 keV	$T_{1/2}$, sec	$4.5\cdot10^{-13}$	$1.4\cdot10^{-6}$	$2.6\cdot10^{-11}$	$0.4\cdot10^{-5}$	$(3{,}7 \pm 0{,}2)\cdot10^{-8}$	
	α_K	0.3	2.6	0.8	9.3	—	
$_{55}Cs^{134}_{79}$, 63, 120, 184 keV	$T_{1/2}$, sec					$(5.7 \pm 0.7)\cdot10^{-8}$	

multipolarity of the transition is either E1 or M1. However, even a crude estimate of the lifetime for the 116-keV E1 transition in silver gives a value which is five orders of magnitude different from the experimentally measured value, and such a transition can be assumed to have low probability.

In view of the absence in the delayed-coincidence spectrum of other high-intensity lines, the 116-keV transition can be regarded as going to the ground state of Ag^{110}. The 116 keV transition cannot be located over the isomer level 6^+ (140 keV), since this transition has the highest intensity, and the isomer yield does not exceed 2.5%. If we assume that the multipolarity of the transition is M1, then we obtain for the spin and parity of the 116-keV level possible values 0^+, 1^+, and 2^+.

The structure of the lower levels of Ag^{110} is reminiscent of the structure of the Ra^{104} [7] and Ag^{108} [8] levels, in which two levels, 2^- and 2^+, lie between the ground and the isomer levels (Fig. 4). Such an analogy enables us to give preference to a value 2^+ from among all the possible spins and parities of the 116-keV level in Ag^{110}. The identical structure of the lower excited levels of these nuclei is possibly due to the fact that the initial nuclei Rh^{103}, Ag^{107}, and Ag^{109} have identical proton configurations ($p_{1/2}$).

The weak transition at 80 keV cannot be in cascade with the 116-keV transition, for in this case it would be necessary to ascribe to the 80-keV transition a conversion coefficient on the order of 10, in order to equalize the intensities of the two transitions, something possible only for the M2 transition (see the table), which has low probability in view of the 3.7×10^{-8} sec lifetime. It is most probable that the 80-keV transition proceeds in parallel with the 116-keV one.

$_{55}Cs^{134}_{79}$. The $CsNO_3$ specimen was in a packet of aluminum foil. The spectra of the Cs^{134} γ rays are shown in Fig. 5. The lines present in the single spectrum (Fig. 5a) are seen also in the amplitudes of the prompt and delayed coincidence spectra (Figs. 5b, c), but with somewhat different relative intensities. The curve of the delayed coincidences has an exponential fall-off for the 50—200 keV range, with $T_{1/2} = (5.5 \pm 0.7) \times 10^{-8}$ sec. The

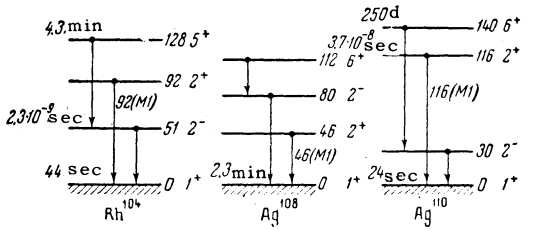

FIG. 4. Level schemes of lower excited states of Rh^{104}, Ag^{108}, and Ag^{110}.

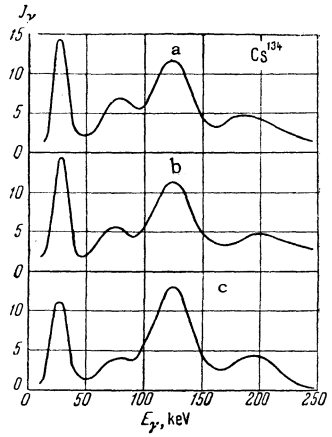

FIG. 5. γ spectra from the Cs^{133} (nγ) Cs^{134} reaction: a – single spectrum; b – prompt coincidence spectrum; c – delayed coincidence spectrum.

presence of the 63-, 120-, and 184-keV γ lines in both the spectrum of the prompt and in the spectrum of the delayed coincidences can be explained by assuming that the level with $T_{1/2} = 5.5 \times 10^{-8}$ sec is relatively high-lying. In this case the levels below the isomer level can be connected with both the prompt and the delayed coincidences. The data obtained are not sufficient for a unique determination of the level responsible for the delayed transition.

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