SPECTRUM OF THE INTERNAL CONVERSION ELECTRONS ACCOMPANYING THE ALPHA DECAY OF Pu^{238} *AND* Pu^{240}

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Submitted to JETP editor June 14, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 362-366 (February, 1959)

The spectrum of conversion electrons accompanying the alpha decay of Pu^{238} and Pu^{240} was studied by means of a high-transmission magnetic spectrometer with toroidal field shape, which measured α-e coincidences. Transitions from the 6+ excited levels were detected, and the multipolarity and more precise energy values were determined for transitions from the 4+ and 2+ levels.

THE decay of nonspherical even-even nuclei is of especially great interest for the theory of alpha decay because of its simplicity. Exact energy values for excited levels are essential for the theory of nonspherical nuclei. The decay of Pu^{238} and Pu^{240} are especially interesting because these nuclei lie in a region of almost constant eccentricity and reveal alpha decay to a well-developed system of rotational levels. The alpha decay of these nuclei (and of the levels of daughter nuclei resulting from alpha decay) was studied by means of alpha spectrometry, γ-γ coincidences, and internal conversion electrons accompanying alpha decay. The last method gives the most exact values of the energy levels and permits determination of radiation multipolarity but has thus far been applied only to the strongest transitions. In the present work we have investigated the conversion electron spectra of Pu^{238} and Pu^{240}.

EXPERIMENTAL TECHNIQUE

Measurements were performed by means of a beta spectrometer with a toroidal magnetic field utilizing α-e coincidences.[1] The only difference from the procedure described in references 1 and 2 was that in studying weak lines we obtained more rigorous amplitude discrimination of beta-counter pulses (using a scintillation counter with a stilbene crystal). This strongly reduced the background of scattered electrons resulting from the basic transitions. Electron energies were determined by comparison with the energies of conversion electrons associated with the transitions $2+ \rightarrow 0$ (43.5 kev) and $4+ \rightarrow 2+$ (99.8 kev) in U^{234} (daughter nucleus Pu^{238}). Accurate values of these energies have been given in reference 3.

CONVERSION SPECTRUM OF Pu^{238}

In studying the conversion spectrum of Pu^{238} we used a 40 μc source of 1 cm diameter. Our conversion spectrum (which is actually the spectrum of the daughter nucleus U^{234}) is shown in Fig. 1, where the lines are interpreted. Figure 2 shows the level scheme of U^{234} and Table I gives previously available as well as new numerical data. The intensities of peaks 4 and 5, which are associated with the conversion of 99.8-kev radiation in the L_{II} and L_{III} subshells, as well as the absence of conversion in the L_I subshell, provide reliable evidence of the electric quadrupole character of this transition. We also attempted to detect a direct transition from the 143.3-kev level to the ground state, the intensity of which is less than 2×10^{-4} of the intensity of the transition to the 2+ level. These data provide reliable evidence that the 143.3-kev level possesses spin 4 and positive parity. We also investigated the conversion electrons associated with the $6+ \rightarrow 4+$ transition, which had previously been known only through gamma emission and alpha spectrometry. The detected transition energy was 152.6 ± 0.3 kev, giving a level of 295.9 ± 0.4 kev. Although the L_{II} and L_{III} conversion lines of this transition were poorly resolved the statistics are adequate for the resolution of peak 8 into its components. This is undoubtedly an E2 transition. The intensity of conversion emission from the 6+ level is about 0.025 of that from the 4+ level to the 2+ level. Considering the energy dependence of the conversion coefficients and taking the value 0.13%[4] as the intensity of alpha decay to the 4+ level, we obtain $(4.3 \pm 0.4) \times 10^{-3}\%$ for the intensity of alpha decay to the 6+ level, which is in good agreement with references 3 and 4.

TABLE I. U^{234} energy levels and Pu^{238} alpha line intensities

Alpha line	Spin and parity of level	From alpha spectroscopy: Line intensity, % [4]	[5]	From alpha spectroscopy: Level energy, kev [4]	[5]	From gamma spectroscopy: Intensity, % [3]	From gamma spectroscopy: Energy, kev [3]	From conversion electrons: Energy, kev [3]	Energy, kev: Our data	Intensity, %: Our data
α_0	0+	71.1	72	0	0		0	0	0	
α_{44}	2+	28.7	28	43.7 ± 1	43		43.8	43.50	43.50 *	
α_{143}	4+	0.13	$9.5\cdot10^{-2}$	141.5 ± 1	145		143	143.31	143.31 *	
α_{296}	6+	$5\cdot10^{-3}$		288 ± 5		$4\cdot10^{-3}$	296.4		295.9 ± 0.4	$(4.3\pm0.4)\cdot10^{-3}$
α_{499}						$7\cdot10^{-6}$	499			

*These values were taken from reference 3 and were used to calibrate the spectrometer.

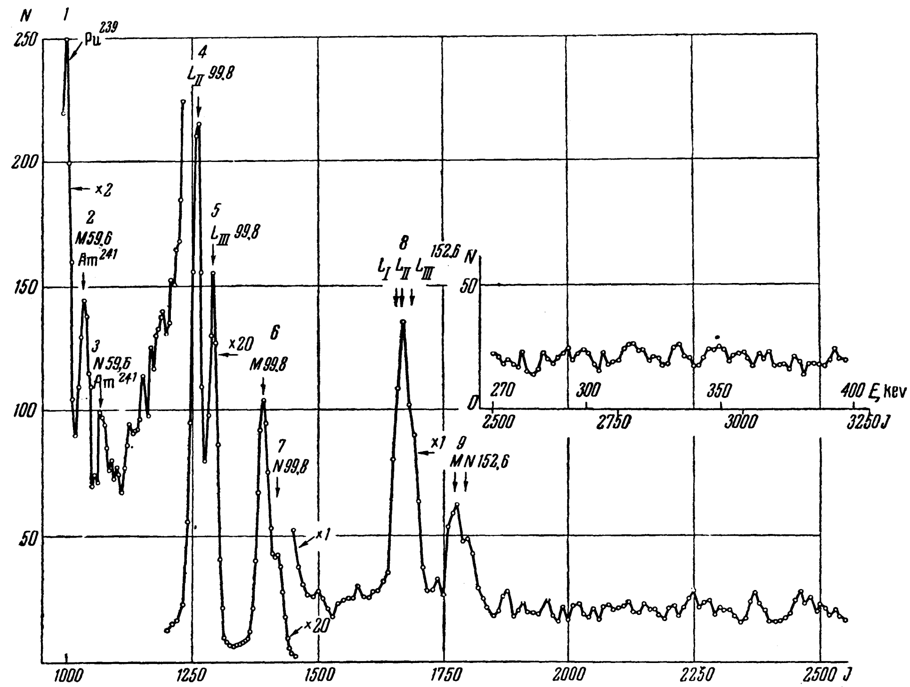

FIG. 1. Spectrum of conversion electrons accompanying the alpha decay of Pu^{238}. (Different portions of the spectrum were plotted on different scales.) Abscissas represent the current I through the spectrometer coil (in arbitrary units) and electron energy E_e. Ordinates represent the number of $e-\alpha$ coincidences. Line 1 represents the conversion of 51.7-kev radiation in the N shell.

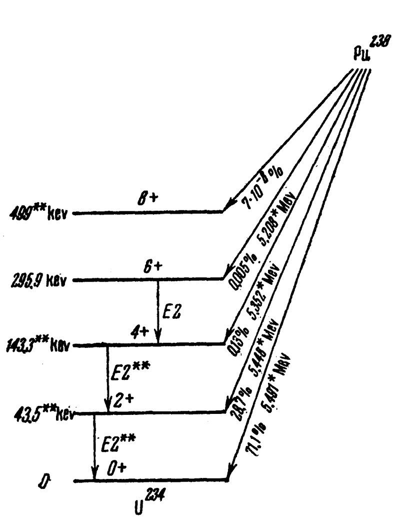

FIG. 2. Level scheme of U^{234}. * – according to reference 4 (alpha spectrum); ** – according to reference 3 ($\gamma-\gamma$ coincidences).

CONVERSION SPECTRUM OF Pu^{240}

We had at our disposal only a rather weak (5 μc) thick Pu^{240} source, so that recording of the spectrum required a relatively long time. Figure 3 shows the spectrum of conversion electrons in the 20 – 220 kev region accompanying alpha decay. Figure 4 shows the level scheme of the daughter nucleus U^{236}, and Table II gives the numerical data taken from the literature and that obtained in the present work.

Conversion intensities in the L_{II} and L_{III} subshells indicate that transitions from the first excited level to the ground level and from the second to the first excited level are of the E2 type. The transition energies are 45.3 ± 0.2 kev and 103.6 ± 0.3 kev, respectively.

The high transmission and the low background

TABLE II. U^{236} energy levels and Pu^{240} alpha line intensities

Alpha line	Spin and parity of level	From alpha-particle spectroscopy: Alpha-line intensity, % [3]	Alpha-line intensity, % [6]	Level energy, kev [3]	Level energy, kev [6]	From conversion electron studies: Level energy, kev [7]	Level energy, kev, Our data	Intensity, %, Our data
α_0	0+	75.5	75.5	0	0	0	0	
α_{45}	2+	24.5	24.4	45	45	45.6	45.3 ± 0.2	
α_{149}	4+	0.1	0.091	151	147 ± 2	149.6	148.9 ± 0.4	
α_{210}?	1—?		$2.7\cdot10^{-3}$		210 ± 8			
α_{239}?	3—?		$3.1\cdot10^{-3}$		239 ± 8			
α_{309}	6+		$3.2\cdot10^{-3}$		313 ± 5		309 ± 1.5	$(2+1)\cdot10^{-3}$

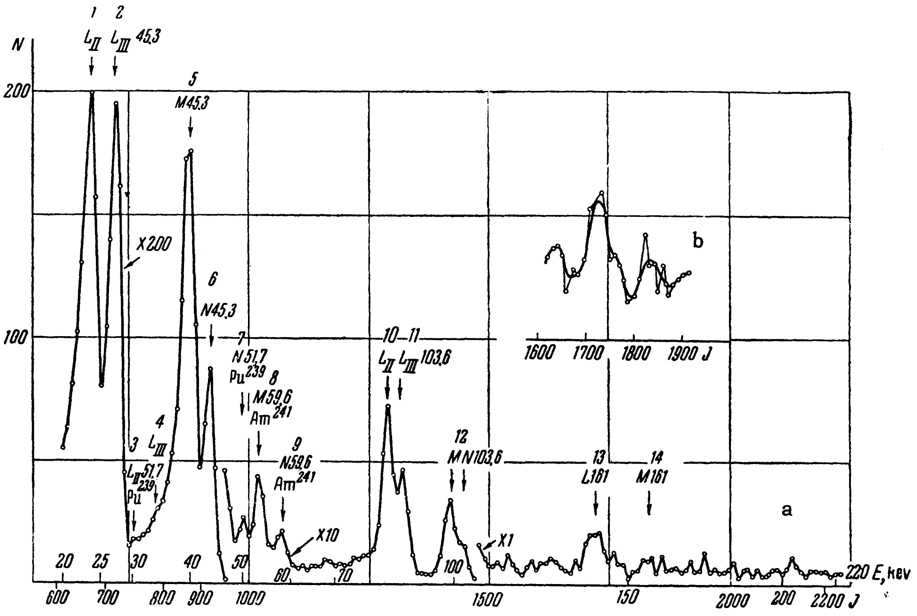

FIG. 3. Spectrum of conversion electrons accompanying the alpha decay of Pu^{240}. (Different portions of the spectrum were plotted on different scales.) The upper right-hand corner shows the spectrum around 140 kev summed over all exposures. The exposure times were 24 min in a and 60 min in b. Coordinates represent the same quantities as in Fig. 1.

level of our spectrometer permitted the detecting of a 6+ ⟶ 4+ transition. We were unable to determine the multipolarity of this transition, but the value 6+ for the spin is confirmed by the absence of transitions to lower excited levels. We measured the transition energy at 160 ± 1.5 kev, which gives 309 ± 1.5 kev for the energy of the excited 6+ level. The intensity of this transition is 1/60 of the intensity of the 4+ ⟶ 2+ transition. Taking the intensity of alpha decay to the 4+ level as $9.1 \times 10^{-2}\%$, we obtain $(2 \pm 1) \times 10^{-3}\%$ for the intensity of alpha decay to the 6+ level.

Two more alpha lines (α_{210} and α_{239}) were reported in reference 6, where it was suggested that they belonged to Pu^{240}. We were unable to detect any conversion electrons associated with radiation from such levels, but it must be noted that if these are actually 1− and 3− levels, as was suggested in reference 6, they would emit E1 radiation and we would have been unable to detect conversion

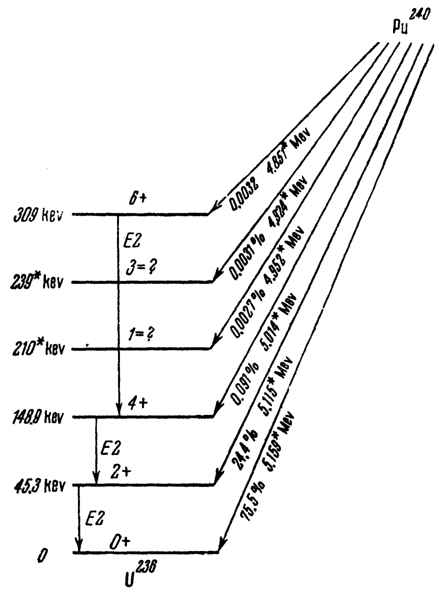

FIG. 4. Level scheme of U^{236}. * – according to reference 5.

electrons because of the small conversion coefficients for E1 transitions.

Comparison of Tables I and II indicates a "loss of individuality" of even-even nuclides that is characteristic of this portion of the periodic table. Energy levels are given by the familiar formula

$$E_{\mathrm{rot}} = aI\,(I+1) + b\,[I(I+1)]^2,$$

where the first term is the principal one and the second term serves as a correction. The best values of the constants a and b for U^{234} are: a = 7.29 kev and b = − 0.006 kev; for U^{236}: a = 7.60 kev and b = − 0.0075 kev.

The authors wish to thank G. I. Grishuk, V. F. Konyaev, and Yu. N. Chernov for assistance with the experiments.

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Translated by I. Emin
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