Alpha Decay of Pu^{240}

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In this work results are given of investigations on the α-spectrum of Pu^{240} carried out with the help of an α-spectrometer. The α-spectra obtained are presented along with a level scheme for the U^{236} nucleus. The parameters of the 4^+ level are given with precision; the first α-line corresponding to the transition to a 6^+ level is observed and the parameters of this level measured; two weak lines are found which can be assigned to the α-decay of Pu^{240}. A comparison of the experimental data with the theoretical formula of Landau is made for the intensities of the 0^+, 2^+, 4^+ and 6^+ levels.

As is now well known, the low-lying levels of heavy nuclei have a rotational character if the number of neutrons and protons in these nuclei are sufficiently distant from the magic numbers. The low-lying levels of nuclei are particularly clearly exhibited in α-decay; for this reason the investigation of the fine structure of α-spectra appears to be an important method for studying rotational levels. Particularly interesting is the investigation of the α-decay of even-even nuclei for which the theoretical formulas have a simple form and the comparisons with experiment take place in the most direct way.

For rotational levels of even nuclei the excitation energies are described by the known formula[1]

$$E_I = (\hbar^2/2J)\, I\,(I+1), \tag{1}$$

where J is the effective moment of inertia of the nucleus, and I is the angular momentum of the nucleus in the excited state having an energy E_I.

For the calculation of the intensities of the α-decay to levels belonging to the same rotational band, there is an approximate formula by Landau[2]

$$\lambda = (2I+1)\, e^{-\alpha I\,(I+1)}, \tag{2}$$

where λ is the probability of the α-decay to a level with momentum I and α is a constant which can be determined experimentally. Formula (2) is in good agreement with the intensities of the decay to the 2^+ and 4^+ levels of even nuclei. Until now it was not possible to check this formula for 6^+ levels because of the lack of experimental data.

We carried out investigations of the α-spectra in the energy region 4.800 to 5.050 mev for two plutonium sources. The isotopic composition of these two sources is shown in Table I.

The measurements were carried out with the α-spectrometer of the Academy of Sciences of the USSR[3]. The results of two exposures, each of which lasted two weeks, are shown in Fig. 1.

TABLE I

Source	Isotopic Composition			
	Pu^{239} in %	Pu^{240} in %	Pu^{241} in %	Pu^{242} in %
A	12	88	<0.2	<0.2
B	80	17	3	0.5

Line A_1, clearly displayed in Fig. 1A, is known from the literature[4,5] as the line due to the α-decay of Pu^{240} to the 4^+ level of the daughter nucleus. This level was measured by us in this work with substantially better resolution than in a previous experiment[5] and therefore we were able to determine more precisely the parameters obtained earlier for this level (see Table III).

In the spectrum of source A, besides line A_1, several other lines are also observed: A_2, A_3, A_4 and A_5. In the spectrum of source B, besides line B_1 which corresponds to A_1, lines B_4 and B_5 are observed. These last two lines are explained by the admixture of Pu^{241} and Pu^{242} in source B. The energy of line B_4 is in good agreement with the energies of the main levels in the α-spectra of Pu^{241} and Pu^{242}, while line B_5 is due to their unresolved first satellites.

As illustration the energies and relative intensities of α-particles from Pu^{241} and Pu^{242}, taken from Ref. 4, and lines B_4 and B_5 are displayed in Table II.

Line A_5 is known not to belong to either Pu^{241} or Pu^{242}, since its intensity is larger, rather than

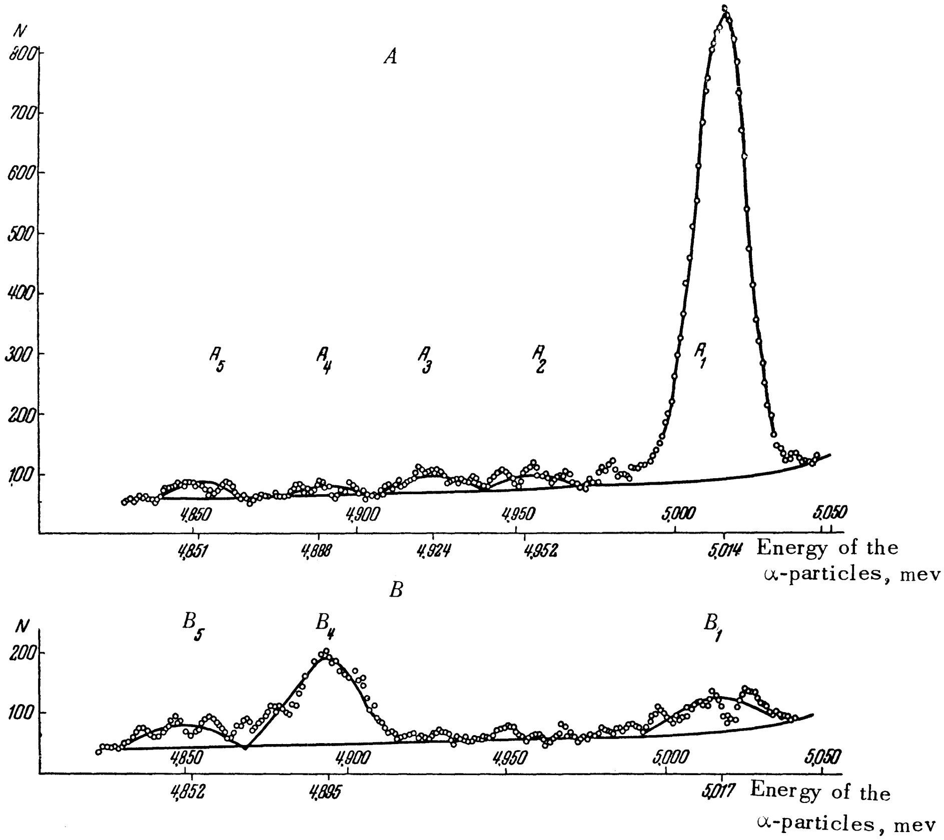

FIG. 1. The α-spectrum of two samples of Pu with different isotopic compositions. (N is the average number of particles in a 0.2 mm strip.)

TABLE II. The energies and intensities of the α-lines from Pu^{241} and Pu^{242} and lines B_4 and B_5.

	Energy of the α-particles	Intensity in %
Pu^{241}	4.893	75
	4.848	25
Pu^{242}	4.898	80
	4.854	20
Line B_4	4.895	80
Line B_5	4.852	20

3 times smaller, than the intensity of line A_4. By comparison with the intensities of the main Pu^{239} α-lines of sources A and B (not shown in Fig. 1) it is not difficult to calculate that any line belonging to Pu^{239} must be 3.5 times more intense on Fig. 1B than on Fig. 1A. Therefore, one can state that none of the lines on Fig. 1, including also line A_5, belong to Pu^{239}.

There remains the assumption that line A_5 belongs to Pu^{240}. This assumption is particularly natural because the excitation corresponds to a level at 313 kev, which is the energy calculated from Eq. (1) for a 6^+ state. According to Ref. 6, the excitation energy of the first level of Pu^{240} is 44.9 kev. The excitation energy of the 4^+ level calculated from the spectrum presented in Fig. 1*A* is 147 kev. The ratios of the energies of the 2^+, 4^+ and 6^+ levels go as 1:3.28:7.0, while Eq. (1) predicts 1:3.33:7.0 in excellent agreement with experiment.

At this time it is difficult to say anything about the weak lines A_2 and A_3. They cannot belong to Pu^{239}, or Pu^{241} or Pu^{242}. Evidently they are also connected with the α-decay of Pu^{240}. In such a case, it is natural to assume that they belong to an odd rotational structure and that they have angular moments and parities of 1^- and 3^-. The experimental results of the work are presented in Table III. The energies of the α-lines in Table III were computed relative to the main Pu^{240} line, the energy of which was taken to be 5158.9 kev[6].

The α-decay scheme of Pu^{240} and the levels of the daughter nucleus U^{236} are shown in Fig. 2.

TABLE III. New lines in the α-spectrum of Pu^{240}.

Line	Energy of the α-particles, in mev	Energy of the level, in kev	Intensity	Spin and parity
α_{147}	5.014 ± 0.002	147 ± 2	$(9.1 \pm 0.6) \cdot 10^{-4}$	4+
α_{210}?	4.952 ± 0.008	210 ± 8	$(2.7 \pm 2) \cdot 10^{-5}$	1—?
α_{239}?	4.924 ± 0.008	239 ± 8	$(3.1 \pm 1) \cdot 10^{-5}$	3—?
α_{313}	4.851 ± 0.005	313 ± 5	$(3.2 \pm 1) \cdot 10^{-5}$	6+

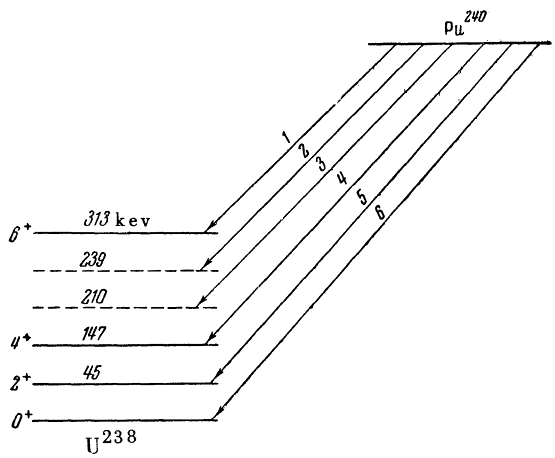

FIG. 2. The α-decay of Pu^{240} and the level scheme of U^{236}. Transitions: *1* – 4.851 mev (3.2×10^{-3} percent); *2* – 4.924 mev (3.1×10^{-3} percent); *3* – 4.952 mev (2.7×10^{-3} percent); *4* – 5.014 mev (0.091 percent); *5* – 5.115 mev (24.4 percent); *6* – 5.159 mev (75.5 percent).

Let us compare the intensity of the α-lines of Pu^{240} with Eq. (2). Choosing constant $\alpha = 0.46$, so that the formula describes correctly the intensities of the first levels, we will find the theoretical ratios $1:0.32:1.2 \times 10^{-3}: 5 \times 10^{-8}$ for the intensities of the transitions to the 2^+, 4^+ and 6^+ levels. The observed intensity of the transition to the 6^+ level then turns out to be 800 times larger than the calculated value. Let us note that the fact that the experimental intensities are greater than the calculated ones was already noted in the work of Gol'din, Novikov and Tret'iakov[5] for U^{233}.

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