# *ALPHA DECAY OF* $Pu^{239}$

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The $\alpha$ spectrum of $Pu^{239}$ was measured with a double focusing magnetic $\alpha$ spectrograph. Besides the well known $\alpha$ transitions, some new transitions to the excited levels of the $U^{235}$ nucleus (104, 198, 224 and 299 kev) have been detected. A possible interpretation of the $U^{235}$ levels is discussed. A $Pu^{239}$ decay scheme is presented.

WE undertook an investigation of the $\alpha$ spectrum of $Pu^{239}$ using a double focusing $\alpha$ spectrometer.[1] Plutonium sources prepared by sputtering in vacuum were used for the measurements. Several exposures were made under the conditions indicated in Table I. In experiments 1—4 the magnetic field was adjusted to make the focusing conditions optimal for different portions of the spectrum.

All the exposures were made at constant instrument aperture, which amounted to 0.21% of $4\pi$ for the central point of the source.

Figure 1 shows the $\alpha$ spectrum of $Pu^{239}$ obtained in exposures 1, 4, and 5; the measurement results are listed in Table II. In addition to the known $\alpha$ lines[2-4] we observed $\alpha$ transitions to the 104-, 198-, and 299-kev levels ($\alpha_4$, $\alpha_8$, and $\alpha_{11}$ in Table II). In [3,5] are given data on the existence of an $\alpha$ transition to the 234-kev levels; in this region of the spectrum we see the lines $\alpha_9$ and $\alpha_{10}$, corresponding to transitions to the 224-kev level and possibly to the 243-kev level. It must be noted that the analysis of the data obtained on low-intensity transitions is considerably hindered by the fact that the spectral lines have long "tails" on the low-energy side.

The transition $\alpha_5$ is probably connected with the $\alpha$ decay of $Pu^{240}$ (transition to the $4^+$ level of the daughter nucleus $U^{236}$), contained as an impurity in our source; the line $\alpha_{12}$ can be attributed to the presence of a $U^{233}$ impurity.

It is known[6,7] that the ground state of $U^{235}$ has spin and parity $7/2^-$ (the [743] level in the Nilsson scheme[8] for deformed nuclei). However, the excitation energy of the first single-particle state of $U^{235}$ is less than 1 kev. In the $\alpha$ decay of $Pu^{239}$ the transition to this level with characteristic $1/2^+$ [631] is facilitated. On the basis of the $\alpha$ decay of $Pu^{239}$ and the spectrum of the conversion electrons[2,3,5] it has been shown that the levels 13, 51, 84, and 150 kev are members of a rotation band with characteristic $K = 1/2^+$, and their spins and parities are respectively $3/2^+$, $5/2^+$, $7/2^+$, and $9/2^+$.

**Table I**

| No. of experiment | Source dimensions, mm² | E ($r_0$),* Mev | Line half-width, kev | Duration of exposure, hours |
|---|---|---|---|---|
| 1 | 0.5 × 10 | 5.150 | 8 | 1 |
| 2 | 0.5 × 10 | 5.138 | 10 | 98 |
| 3 | 0.5 × 10 | 5.040 | 10 | 120 |
| 4 | 0.5 × 10 | 4.980 | 10 | 150 |
| 5 | 2.0 × 15 | 4.850 | 20 | 85 |

*E ($r_0$) – energy of the $\alpha$ particles moving in the given field on a circular orbit with radius $r_0$ = 335 mm (the focusing conditions are optimal for particles with this energy).

Calculation based on the formula for the energy spectrum of the rotational band with $K = 1/2^+$ yields energies of 200 and 302 kev for the $11/2^+$ and $13/2^+$ levels. One must therefore assume that the lines $\alpha_8$ and $\alpha_{11}$ which we have observed are due to the decay of $Pu^{239}$ to the levels $11/2^+$ and $13/2^+$ of the rotational band of a state with spin and parity $1/2^+$ ($K = 1/2^+$).

Coulomb excitation of the $U^{235}$ nucleus[9] disclosed levels at 46 and 104 kev, which are members of the rotational band of the ground state of the nucleus ($K = 7/2^-$) with spins $9/2$ and $11/2$. The $\alpha$ spectrum shows clearly an $\alpha$ line corresponding to the transition to the 104-kev level. If we assume that this is indeed an $\alpha$ transition to the $11/2^-$ level of the band with $K = 7/2^-$, then there should exist two other transitions, to the ground state and to the 46-kev level. These, however, are practically impossible to observe, since the former coincides in energy with the transition to the $1/2^+$ level, and although the latter differs by 5 kev from the transition to the 51-kev level, its intensity is tens of times smaller, making its observation very difficult.

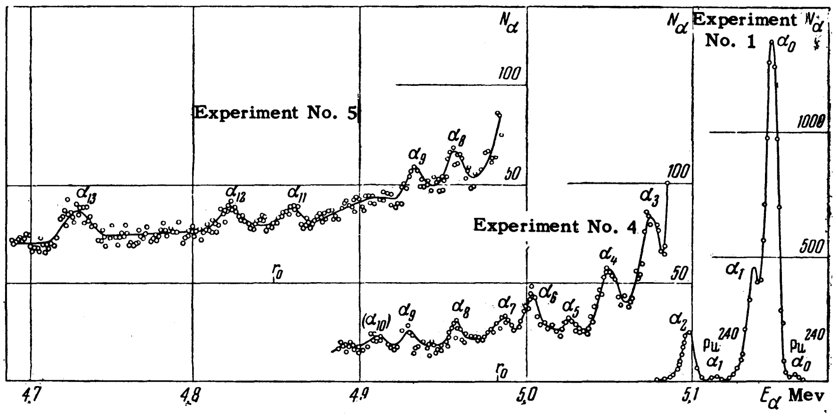


FIG. 1. The spectrum of $Pu^{239}$ obtained in exposures 1, 4, and 5.

**Table II**

| No. of line | Energy of level, kev | Transition intensity, % | Hindrance coefficient |
|---|---|---|---|
| $\alpha_0$ | 1 | 72 | 1.7 |
| $\alpha_1$ | 13 | 17 | 6.1 |
| $\alpha_2$ | 51 | 11 | 5.7 |
| $\alpha_3$ | 84 | 0.038 | 950 |
| $\alpha_4$ | 104 | 0.030 | 1030 |
| $\alpha_5$ | Transition of $Pu^{240}$ to the $4^+$ level of $U^{236}$. | | |
| $\alpha_6$ | 150 | 0.018 | 800 |
| $\alpha_7$ | 170 | 0.008 | 1290 |
| $\alpha_8$ | 198 | 0.008 | 860 |
| $\alpha_9$ | 224 | 0.008 | 580 |
| $\alpha_{10}$ | 243? | ~0.003 | ~1200 |
| $\alpha_{11}$ | 299 | 0.004 | 360 |
| $\alpha_{12}$ | $U^{233}$ impurity (ground-state transition) | | |
| $\alpha_{13}$ | 424 | 0.007 | 30 |

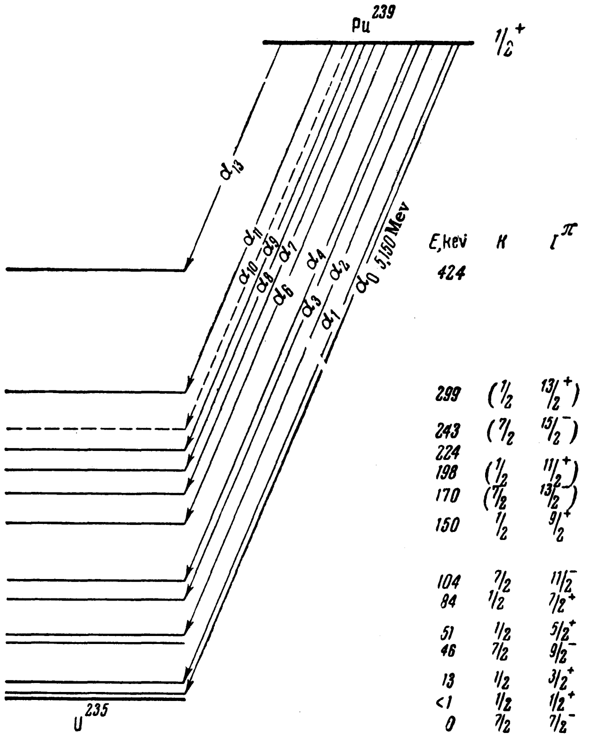


FIG. 2. Proposed decay scheme of $Pu^{239}$.

If our assumption concerning the nature of the 104-kev level is correct, the next members of this rotational band should be the 170- and 243-kev levels with spin and parity $^{13}/_2{}^-$ and $^{15}/_2{}^-$. The 170-kev level was observed earlier and the parity of this state was shown [5] to be negative. According to our data, the 243-kev level apparently also exists, although without complete reliability. The intensity ratios of the 104-, 170-, and 243-kev $\alpha$ transitions do not contradict the assumption that they belong to a single rotational band, but a serious objection to such an identification of the $\alpha_4$, $\alpha_7$, and $\alpha_{10}$ transitions is the excessive difference in the spins of the initial ($1/2^+$) and final ($^{15}/_2{}^-$) states of nuclei for the 243-kev level.

Naturally, a final solution of this problem can be obtained only if more complete and more accurate data are obtained on the $\alpha$ decay and on the spectrum of the conversion electrons, the latter being very complicated. The proposed decay scheme is shown in Fig. 2.

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