Fission of oriented U^{235} nuclei

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We present the results of the measurements of the angular anisotropy of the fragments in the fission of oriented U^{235} nuclei by thermal neutrons and by neutrons of energy $E_n = 10$, 50, 80, 100, and 150 keV. At the neutron energies 50, 80, and 150 keV we measured also the anisotropy on nonoriented nuclei. The experimental results are compared with data by others. The observed anisotropies are interpreted within the framework of the existing model representations of nuclear fission.

An interesting method of studying the internal structure of the fission barrier is to use oriented target nuclei. The first experiments of this type were performed by Dabbs, Roberts, *et al.*,[1] and consisted of investigating the reaction (n, f) with thermal neutrons on the nuclei U^{235} and U^{233}, aligned in single-crystal uranyl-rubidium nitrate (URN) through the electric quadrupole interaction of the hyperfine structure.[2] The experiments were subsequently carrier out with neutrons of resonance energies and with analysis of the data obtained from many resonances.[3] Experiments of this kind were also performed, under improved conditions, by Pattenden and Postma.[4]

All the listed cases pertain to fission by s-neutrons in the energy interval from 0 to 2 keV. It is of interest to investigate the fission of the oriented U^{235} nuclei by neutrons of higher energy, when the comparable contribution to the cross section for the production of the compound nucleus is made also by p neutrons. A small negative anisotropy in the fragment spurting was observed in this region in the fission of nonoriented nuclei.[5,6] The changes introduced into the kinematics of the reaction by the orientation of the target nucleus should yield additional information on the properties of the transition states of U^{236}.

We report here the measured anisotropy of the spreading fragments of U^{235} nuclei oriented in a URN crystal and fissioned by neutrons of energy 10–150 keV, at a crystal temperature 0.2 °K. The sample was cooled by the adiabatic demagnetization method. The sample was a plate ~1.5–2 mm thick, cut from a single crystal based on natural uranium on which a single-crystal of ~1 mg/cm² layer of URN with enriched uranium (90% U^{235}) was grown. The sample was glued to a copper

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Kinematic coefficients $F_2^{J\pi k}(T)$ in the absence and presence of alignment of target nuclei for states with positive parity produced when p neutrons are captured by U^{235} nuclei ($I_0^\pi = 7/2^-$).

		Nonaligned target nuclei	Aligned target nuclei (T = 0.2K)
2^+	0	+ 0.09	+ 0.166
	1	- 0.09	+ 0.166
	2	- 0.18	- 0.332
3^+	0	Parity forbidden	
	1	- 0.44	+ 0.031
	2	0	0
	3	+ 0.733	- 0.052
4^+	0	- 0.161	+ 0.233
	1	- 0.273	+ 0.395
	2	- 0.129	+ 0.186
	3	+ 0.113	- 0.163
	4	- 0.45	- 0.651
5^+	0	Parity forbidden	
	1	+ 0.824	- 1.189
	2	+ 0.55	+ 0.794
	3	- 0.09	+ 0.132
	4	- 0.55	- 0.794
	5	- 1.374	- 1.983

cold finger making thermal contact with the paramagnetic-salt block. A superconducting solenoid was used for the magnetization. The crystal substrate temperature was measured with a carbon resistance thermometer. The cryostat, the method of growing the single crystals, and the preparation of the samples are described in greater detail in[7]. The neutron source was the reaction Li(p, n) on the KG-2.5 accelerator of the Physics and Power Institute. The neutron energy and their energy scatter were calculated from the measured excess above threshold, with allowance for the target thickness and the finite dimensions of the sample and of the target, using the kinematic relations.[8]

The C axis of the crystal, relative to which the alignment of the U^{235} nuclei was observed, was oriented along the neutron beam. The fission fragments were registered by a pair of glasses placed at angles 0° and 90° to the C axis. After the irradiation, the glasses were etched in an HF solution and the fragment tracks were examined under a microscope. In the reduction of the results, geometrical corrections were introduced for the finite dimensions of the sample and of the detectors; these corrections were calculated in an approximation in which it is assumed that the neutron flux is uniformly distributed over the sample and the angular distribution of the fragments is given by $W(\theta) = 1 + A_2 P_2(\cos\theta)$.

The experimental results are shown in the figure. The measurements were performed in parallel for aligned and nonaligned nuclei, and in addition the thermal point was plotted, under fixed conditions of the experiment, for a number of energy values. This complete experiment makes it possible to obtain both the "alignment effect," i.e., the contribution due to the alignment of the target nuclei, and the absolute values of the fragment anisotropy with aligned target nuclei and with nonaligned ones. It is these three types of data which are shown in the figure.

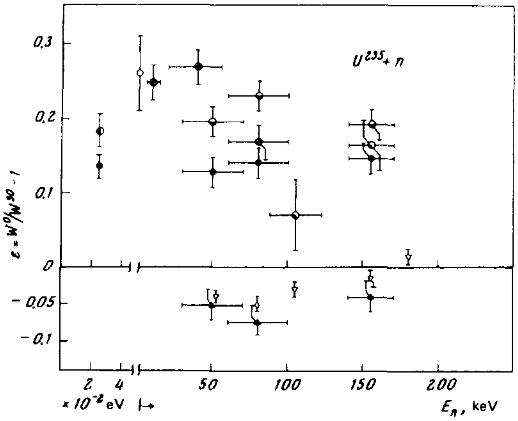
The expression for the angular distribution of the fragments can be represented in the form

$$\frac{d\sigma_f}{d\Omega}(E_n, T, \theta) = \frac{\pi^2}{4} \sum_{l, N=0,2,4,\ldots, J,\pi} T_l^{J\pi}(E_n) \sum_k F_N^{J\pi k}(T) \gamma^{J\pi k}(E_n) P_n(\cos\theta)$$

$T_l^{J\pi}(E_n)$ are the neutron-penetrability coefficients, $\gamma^{J\pi k}$ is the fissility of a compound nucleus whose quantum numbers are the angular momentum J of the compound nucleus and its projection k on the fission direction, π is the parity, and $P_N(\cos\theta)$ is a Legendre polynomial. The contribution of each partial state $J\pi k$ is determined by the value of the corresponding kinematic coefficient $F_N^{J\pi k}(T)$. These coefficients, calculated for positive-parity states produced when the U^{235} nucleus ($I_0 = 7^-/2$) captures a p neutron, are listed in the table and serve as a convenient basis for the discussion of the measurement results.

The data obtained for the nonaligned nuclei agree with the results of[5,6], and confirm the presence of a small negative anisotropy; for the aligned nuclei, on the other hand, the anisotropy is positive and approximately constant. The tabulated data show that both facts can be explained in most natural fashion by assuming that the fission of states of positive parity, at the energies in question, takes place principally via collective transition states $k^\pi = 0^+$. Since the states with angular momenta $J^\pi = 3^+$ and 5^+ are parity-forbidden for this band, the anisotropy is determined by the competition between the contributions of the states $J^\pi = 2^+$ and 4^+. If the target nuclei are aligned, both states have positive anisotropy, as seen from the table, while in the absence of alignment the state $J^\pi = 4^+$ has negative anisotropy, which is noticeably larger in absolute magnitude than the contribution of the state $J^\pi = 2^+$.

The estimates shows, in addition, that the anisotropy in the fission of oriented nuclei is more sensitive to the change in the ratio of the contributions of the s and p waves than the anisotropy of nonoriented nuclei. Its



value can therefore serve as a criterion for refining this ratio in the considered neutron-energy region.

In conclusion, it is our pleasant duty to thank G. N. Smirenkin for useful discussions.

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