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ANISOTROPY AND ENERGY DISTRIBUTION OF Th^{232} *FISSION FRAGMENTS*

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The kinetic energy and anisotropy of Th^{232} fission fragments are measured as functions of the fragment mass ratio. A kinetic energy peak is found at mass ratio R = 1.25. The anisotropy is independent of the mass ratio within experimental error limits.

INVESTIGATIONS of nuclear fission[1-4] have shown that the fragment mass ratio $R = M_h/M_l = 1$ does not correspond to symmetric fission in the full sense, and that the kinetic energy is not a monotonic function of fission asymmetry as predicted by the liquid drop model. There is great interest in the possible dependence of fragment anisotropy on the mass ratio. According to A. Bohr,[5] the angular distribution of fragments is determined by the nuclear parameters at the saddle point. If the fragment mass distribution also depended on the nuclear parameters at the saddle point, we would expect to find a direct relation between asymmetry and the anisotropy of fragments. The present paper is an investigation of these questions.

EXPERIMENTAL METHOD

The kinetic energies of the two fission fragments were measured simultaneously using a double ionization chamber in conjunction with a collimator for determining the directions of fragment motion with respect to the neutron beam.

A layer of fissile material (15 μg/cm²) was deposited on collodion film 20 μg/cm² thick. The fast reactor BR-5[6] was used as the neutron source.

The electronic equipment consisted of two linear amplifiers, a coincidence circuit, a pulse shaper and a double-beam oscilloscope. The pulse shaper transformed pulses to a rectangular shape (T = 15 μsec) without changing their amplitude. The coincidence circuit controlled oscilloscope-beam brightness and triggered the pulse shaper. Pulses from both chambers were photographed on film. This apparatus was equivalent to a system of analyzers with a capacity of 50 × 50 channels.

EXPERIMENTAL RESULTS

Several corrections were introduced into the measurements. Computations showed that the motion of the fragment center of mass, neutron emission by fragments, fragment energy loss in passage through the collodion film, and the influence of the fissile material and of the collimator increased the half-width of the energy distribution by 2–3 MeV.

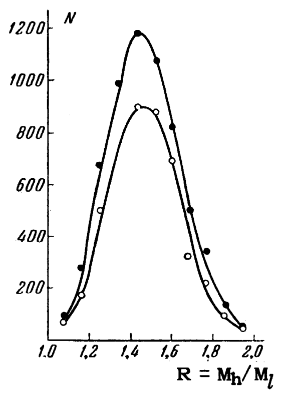

FIG. 1. Number of observed fragments as a function of the mass ratio. ●, ○ – fragments moving at 0° and 90°, respectively, with respect to the neutron beam. Yields are normalized to the same total number of fission events.

The ionization defect was taken at the same percentages for heavy and light fragments as in the case of U^{235}. Figure 1 shows the fragment yields as functions of the mass ratio. Because of the insufficient resolving power of the ionization method and the small amount of data, the properties of fragments were not considered at R ~ 1 and R > 2.

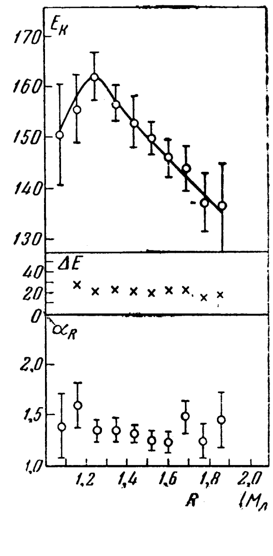

FIG. 2. Kinetic energy (E_k), half-width of energy distribution (ΔE), and anisotropy (α_R) as functions of the mass ratio. Energies are given in MeV.

The mean kinetic energy of fragments and the character of the dependence of the total kinetic energy on the mass ratio were identical for fragments moving at 0° and 90° with respect to the neutron beam. The half-width of the fragment energy distribution was 16%, which does not differ from experimental results for other fissile nuclei.

It is characteristic of fissile nuclei heavier than Th that the most probable fragment mass is close to 140. This results from the influence of the shell structure of fragments. For this entire class of nuclei very similar limitations therefore are imposed on the possible deformations and fragment charge distributions at the instant when the scission neck of the fissioning nucleus is severed. This leads to approximately identical half-widths of the fission-fragment energy distribution.

Figure 2 shows the kinetic energy E_k and the anisotropy of fragments $\alpha = \sigma_f(0°)/\sigma_f(90°)$ (where σ_f is the fission cross section) as functions of the mass ratio. The most probable total kinetic energy (upper curve) exhibits a peak at $R = 1.25$ and decreases as symmetric fission is approached. Our measurements of E_k as a function of R revealed no other region of nonmonotonic change (see [7], for example). The half-width of the fragment energy distribution (middle curve) diminishes on the average as R increases. The anisotropy, shown in the lower part of the figure, is evidently independent of the mass ratio within error limits. It can apparently be concluded that fragment masses are determined later than the passage over the saddle point.

The idea that the anisotropy increases with the mass ratio [5,8] is also refuted by other work. According to this theory the predominantly symmetric fission of bismuth should be accompanied by very small anisotropy. However, Halpern and Coffin [9] have shown that the anisotropy is large when bismuth fission is induced by α particles. The strong dependence of anisotropy on the mass ratio that was observed in several investigations [9-11] is accounted for by the superposition of different fission modes: (n, f), (n, nf), and (n, 2nf). This means that the fission events occurred at different excitation energies. The angular distributions and yields of fragments with different masses depend on the excitation energy and spin of the fissioning nucleus. These circumstances were reflected in the corresponding measurements. [8,10,11]

In the present work fission was induced by nonmonoenergetic neutrons. In this case the measured anisotropy is given by

$$\bar{\alpha}_R = \int_0^\infty f(E)\, \sigma_f(E)\, \varepsilon_R(E)\, \alpha_R(E)\, dE,$$

where f(E) is the neutron spectrum of the beam, $\epsilon_R(E)$ is the yield of fragments with mass ratio R, $\alpha_R(E)$ is the anisotropy of fragments with mass ratio R, and E is the energy of fission-inducing neutrons. Calculations showed that $\sim 90\%$ of the fission events were induced by neutrons with $E_n < 6$ MeV. In this energy region the yield ϵ_R depends strongly on energy only for $R \sim 1$ and $R > 1.9$. In the range $1.2 \le R \le 1.9$, ϵ_R changes by only 10% to 15% as E increases from the threshold to 6 MeV, [12] and the influence of $\epsilon_R(E)$ can be neglected in Eq. (1). Since α_R is independent of R within error limits, we would hardly expect $\alpha_R(E)$ to show any essential dependence on R.

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16