ANGULAR ANISOTROPY OF FISSION OF U^{238} BY NEUTRONS NEAR THRESHOLD

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Until recently it was customary to employ in the physics of the fission process the parabolic-barrier concepts that follow from the liquid-drop model. Calculations by Strutinskii [1] with allowance for the nucleon shell effect have shown that for heavy nuclei the deformation potential energy has the form of a curve with two minima (I and II) and two maxima (A and B), as shown schematically in Fig. 1. New experimental data on the grouping of the anomalously strong resonances of the cross sections of fission of "threshold" nuclei (Pu^{240} [2] etc.) by slow neutrons, offer strong evidence in favor of the "two-hump" barrier. A review of the barrier concepts may lead to very important consequences concerning the course of the fission process near threshold, channel effects, subbarrier fission, etc. An analysis of the experimental data characterizing these phenomena in light of the new ideas concerning the form of the fission barrier was performed by Strutinskii and Bjornholm [3].

We shall dwell on the effects concerning the energy dependence of the fission anisotropy. We assume, following [3], that the transition state II is similar in many respects to the ordinary compound state of the nucleus of equilibrium form I, and has a lifetime larger than the period of migration of the K-projection of the angular momentum I on the symmetry axis. Under this assumption, the nucleus "forgets" the states it possessed while passing through the barrier A, and the picture of the fission is determined by the spectrum of the states on the barrier B. An analysis of the aformentioned experimental data [2] allows us to estimate the depth of the minimum II and the difference between the barriers A and B, but leaves open the question of which of the barriers is higher [3].

It is obvious that if B > A the traditional situation will obtain, namely a variety of angular distributions of the fragments $W(\vartheta)$ and sizeable changes in the angular-anisotropy coefficient $\alpha = W(0^\circ)/W(90^\circ) - 1$ near the observed fission threshold, as a consequence of the discrete structure of the channels on the barrier B. In the opposite case A > B, a new situation may arise in principle, not compatible with the earlier concepts. It results from

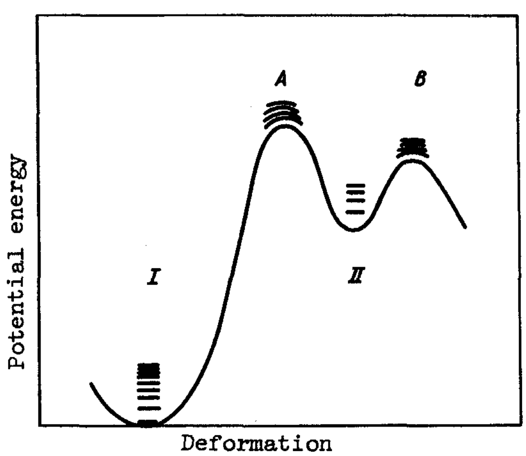

Fig. 1. Schematic representation of the deformation potential energy of the fissioning nucleus.

the fact that the observed fission threshold is determined by the height of the larger of the barriers, i.e., the barrier A, and the realized spectrum of the channels is determined by the excitation energy at the critical point B. When the barrier difference is sufficiently large, the density of the channels at the barrier B may turn out to be appreciable. In other words, in this case the channel effects in the usual meaning of this term will not arise. The very scanty available experimental data [4] actually show that the heaviest of the investigated nuclei, such as Pu^{240} and Am^{241}, have a small angular anisotropy that varies slightly with the energy, and the anisotropic part of $W(\vartheta)$ depends from the very threshold on the $\cos\vartheta$. In this connection, a thorough study of the fission of nuclei with weakly pronounced channel effects is of great importance.

We report here the results of detailed measurements of the angular distributions of the fragments of U^{238} fission by 0.8 - 3.4 MeV neutrons.

The neutron source was the reaction T(p, n), which was effected with an electrostatic generator. We used solid tritium targets 0.4 - 0.8 mg/cm^2 thick. The fragments were registered by a track procedure, using glass detectors of flat and cylindrical form. This simple and reliable method of measuring $W(\vartheta)$ was investigated in detail in [5], and we shall not dwell on it here. We only indicate that we used fissioning targets of natural uranium and of uranium with 250-fold depletion of the isotope U^{235}, fission of which in the essentially subbarrier region could greatly distort the results.

In the investigated energy range, we measured 18 angular distributions, more than half of which were on the section where the fission cross section σ_f drops steeply. The most significant experimental data are shown compactly in Fig. 2, which demonstrates the good agreement between the experimental results and the formula of the statistical theory [6]

$$W(\vartheta) \sim \sin^{-3}\vartheta \int_0^{p\sin^2\vartheta} x^{1/2} e^{-x} I_0(x)\,dx = \sin^{-3}\vartheta\,\phi(p\sin^2\vartheta), \qquad (1)$$

where $p = I^2/2K_0{}^2$, and $K_0{}^2$ characterizes the width of the distribution of K

$$F(K) \sim \exp(-K^2/2K_0^2). \qquad (2)$$

The representation of the experimental data in Fig.2 makes use of the fact that the ratio

$$\frac{W(0^\circ)}{W(\vartheta)} = \frac{2(p\sin^2\vartheta)^{3/2}}{3\phi(p\sin^2\vartheta)} \qquad (3)$$

depends on the sole parameter $x = p\sin^2\vartheta$. As shown in Fig. 2, the right side of (3) is linearly dependent, with great accuracy, on x when $p < 1$.

The main result of this experiment, which agrees qualitatively with the hitherto known data, is that the observed form of $W(\vartheta, E)$ is highly stable and agrees with the statistical distribution F(K) (2) not only near the threshold, but also in the essentially-subbarrier

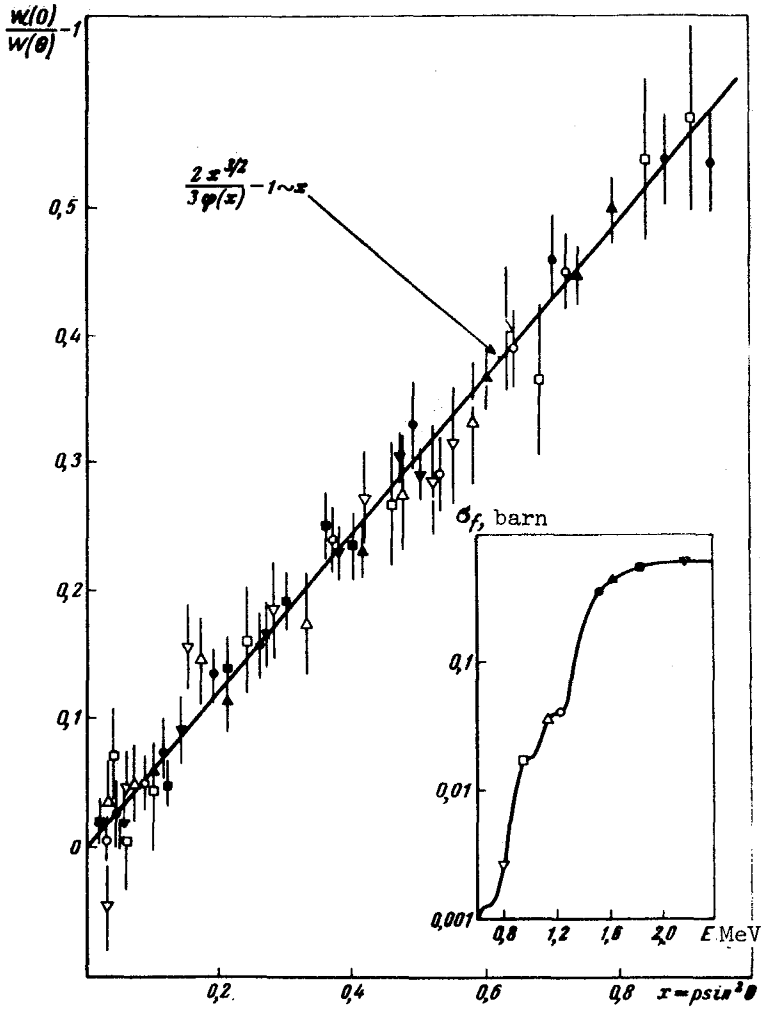

Fig. 2. Comparison of the experimental data on $W(\vartheta)$ with expression (1) of the statistical theory of the angular distribution of fission fragments (see the text). Insert - energy dependence of the cross section $\sigma_f(E)$ for the fission of U^{238} by neutrons [7]. Symbols: ▽ - 0.8 MeV, □ - 0.95 MeV, Δ - 1.15 MeV, O - 1.25 MeV, ● - 1.55 MeV, ▲ - 1.65 MeV, ■ - 1.85 MeV, ▼ - 2.2 MeV.

region of energy. When E = 0.8 MeV, σ_f is approximately 1/200-th of the value at the plateau. The fission of U^{238} at 0.5 - 0.7 MeV below the threshold occurs as if a large number of channels were to take part in it. This effect, which is surprising from the point of view of the customary notions, finds a natural interpretation within the new concept of the two-humped barrier [1, 3].

The fission of lighter nuclei (Th^{230}, Th^{232}, etc.) with clearly pronounced channel effects near the threshold can correspond to the case B > A or B < A, but at a small difference between the barriers. It is further assumed in [3] that the "well" in the transition state becomes shallower with decreasing number of nucleons in the nucleus.

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