Angular anisotropy of the fission of Th^{232} by neutrons deep below the threshold

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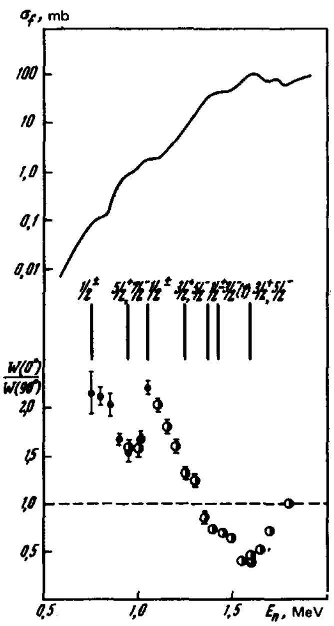
We measured, for the first time, the angular distributions of the fragments of the fission $Th^{232}(n, f)$ in the deep subbarrier neutron energy range 0.75–1.05 MeV. The spectrum and quantum characteristics of the observed quasistationary states in the second well of the fissioning Th^{232} nucleus, and the prospects for its further investigation, are discussed in light of the obtained data.

In the present study we have continued the investigation of the fission of Th^{232} by neutrons deep below the threshold, which was initiated in[1–3]. We report here for the first time the measured angular anisotropy of the fission $Th^{232}(n,f)$ for neutron energies $E_n = 0.75$–1.05 MeV, where the fission probability σ_f/σ_c is 10^{-5}–10^{-4}. Just as in[3], the angular fragment distributions $W(\theta)$ were measured with cylindrical glasses and a fissioning target of "infinite" thickness in the form of a metallic foil. Monoenergetic neutrons with resolution $\pm(40$–$50)$ keV were obtained from the reaction $T(p, n)$ produced with the aid of a cascade generator.

The angular anisotropy $W(0°)/W(90°)$ of the fission obtained in our experiment, together with the analogous data of[3], are compared in the figure with the fission cross section curve.[1] The energy dependences of the two characteristics reveal irregularities that exhibit a clear cut correlation. The positions of many of the irregularities correlate also with the thresholds of the (n, n') reaction—the levels of the Th^{232} nucleus.[1,2] It is impossible, however, to attribute the irregular structure of σ_f, and all the more of $W(0°)/W(90°)$, to competition by the elastic scattering of the neutrons.[2,3] The modern theory (the double-hump barrier model) relates the cause of the irregular structure with the presence of quasistationary states in the second well and with the ensuing resonance effects in the penetrability of the barrier.[4]

To exclude the influence of the competing processes it is customary to resort to the so-called channel analysis. It makes it possible to determine from the observable quantities the penetrability $P_{K^\pi}(E)$ of the barrier for individual bands of the fission channels with quantum characteristics K^π $(J = K, K+1)$ where K is the projection of the angular momentum of the fissioning nucleus on the symmetry axis and π is the parity, such an analysis of the reaction $Th^{232}(n,f)$ at $E_n = 0.95$–1.65 MeV was performed in[3]. The vertical lines in the figure show the resonances P_{K^π}.[3] Many of them are seen directly in the plots of σ_f and of $W(0°)/W(90°)$. Nor is there any need to resort to a detailed analysis in order to identify the quantum characteristic $K = 1/2$ for the states $E_n = 0.75$ and 1.1 MeV. It follows from the magnitude and sign of $W(0°)/W(90°) - 1$ at the given energies. However, the two characteristics K and π cannot be established for these states or for most others even with the aid of a quantitative analysis. The figure shows therefore, as a rule, two difficultly-distinguishable combinations of K^π.

Difficulty in the identification of the quantum characteristic is an inherent feature of the channel analysis of the fission process, and in this sense the reaction $Th^{232}(n,f)$ is no exception. Nonetheless, it should be regarded as one of the most convenient objects for the investigations of the spectrum of quasistationary states in the second well. Of all the readily fissionable nuclei, Th^{232} has the largest difference (~1.5 MeV) between the height of the barrier (apparently the hump B) and the binding energy $B_n = 5.1$ MeV. In addition, judging from the data obtained for the neighboring nuclei Th^{233} and Th^{234} from an analysis of the excitation functions of the (t, pf) reactions,[4] this nucleus has a rather shallow well, the ground state in which (~4.5 MeV) is close to B_n. In other words, the greater part of the spectrum of the excited states in the second well lends itself to an investigation in the reaction $Th^{232}(n,f)$. Of particular interest is the study of the excitation region near the binding energy of the neutron, where a resonance $P_{1/2^+}$ is predicted.[4] To penetrate still deeper below the barrier, all the way to $E_n \sim 0$, where the fissility is 10^{-7}–



Characteristics of neutron fission of Th^{232}: Top—fission cross section σ_f. Bottom—angular anisotropy $W(0°)/W(90°)$ of the fission; ○—[3], ●—present work. Middle—spectrum and quantum characteristics of the quasistationary states in the second well (see the text).

10^{-6}, we need more intense neutron sources and a more sensitive procedure for registering the fission fragments.

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