Quadrupole photofission of ^{232}Th and role of symmetry of the nucleus in the fission process

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An increase in the quadrupole component of the angular distribution of the fragments was observed deep below the photofission barrier of ^{232}Th. We discuss the influence of the symmetry of the saddle configurations in the double-hump-barrier model on the spectrum of the fission channels of even-even nuclei and the resonant structure of the cross section.

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In accordance with A. Bohr's hypothesis[1] it is customarily assumed that in the photofission of even-even nuclei near the threshold an important role is played only by the contribution of channels with quantum characteristics $K^{\pi}=0^{+}(J=2)$ and $K^{\pi}=0^{-}(J=1)$, which are excited in quadrupole electric and dipole electric absorption. The corresponding photoabsorption cross sections $\sigma_{\gamma}^{J\pi}$ differ considerably, $\sigma_{\gamma}^{2+}/\sigma_{\gamma}^{1-}\approx 1/15$ to $1/30$,[2] as a result of which the dipole fission predominates in the energy region above the barrier. An increase in the role of the quadrupole fission is expected, on the contrary, in the subbarrier region of energies, where the difference $\Delta E_{f}=E_{f}^{0-}-E_{f}^{0+}$ between the heights of the barriers for 0^{+} and 0^{-} channels causes the ratio of their penetrabilities to increase and to offset the smallness of the ratio of the partial photoabsorption cross sections. Experiment[2] has confirmed this prediction of the channel model, and revealed simultaneously a strong Z-dependence of the relative contribution of the quadrupole photofission Y_c/Y in the Th–Pu region, as shown in the lower part of Fig. 1. The probability components of the fission by photons with different multipolarity are identified from the form of the angular distribution of the fragments $W(\theta)$, which depends strongly on the spin J of the fission channel and on its projection K on the axis of the nucleus.

Ideas concerning the nature of the observed regularity were advanced in[6]. They are based on the double-hump fission-barrier assumption and on the theoretically predicted[7] asymmetry of the nucleus ($\alpha_3\neq 0$) in the vicinity of the second saddle point—on the hump B. For nuclei with pear-shaped deformation, the energy gap between the lowest levels $K=0$ of the positive and negative parity decreases stronger the smaller the penetrability of the barrier to the inversion transition, i.e., it can be assumed in the limit that $\Delta E_{fB}=0$. In this case $\Delta E_{fA}\neq 0$. Therefore nuclei having a higher hump B, which apparently include ^{232}Th, the contribution of the quadrupole component is determined mainly by the low ratio $\sigma_{\gamma}^{2+}/\sigma_{\gamma}^{1-}$. For the Pu isotope with higher symmetrical saddle point ($\alpha_3=0$)—hump A— the difference ΔE_{fA} of the heights of the barriers to the channels 0^{+} and 0^{-} act to enhance the quadrupole fission.

If the foregoing interpretation is correct, then the relative contribution of the quadrupole component should increase for ^{232}Th when the photon energy decreases below the barrier E_{fA}^{0-}. The available data[2,3] on the fraction of the quadrupole component in the total yield Y_c/Y of the photofission of ^{232}Th (lower part of Fig. 1, light points) exhibits a tendency opposite to that expected. Whereas at $E_{\max}\approx 6$ MeV, i.e., near the top of the barrier B, the ratio Y_c/Y is of the order of ≈ 5–6%, corresponding to $\sigma_{\gamma}^{2+}/\sigma_{\gamma}^{1-}$, at lower energies it not only fails to increase, but decreases

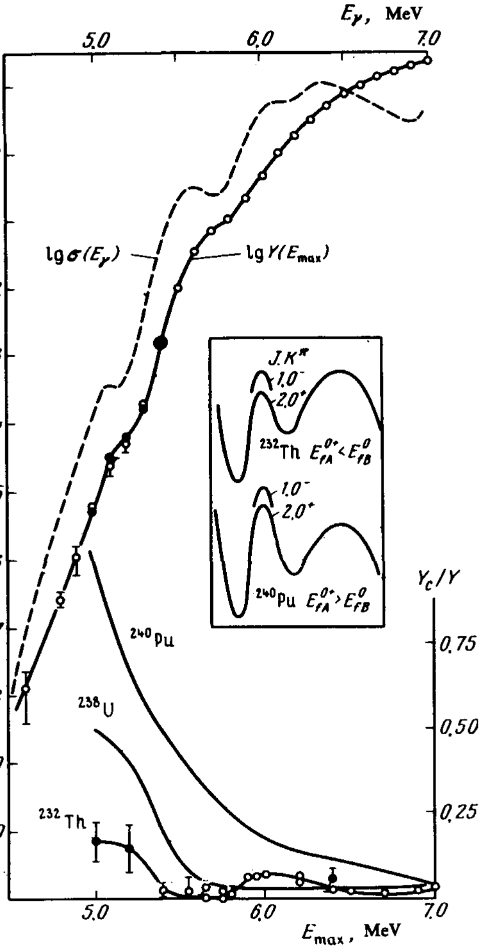

FIG. 1. Bottom: dependence of the relative contribution Y_c/Y of the quadrupole component to the total yield; for ^{232}Th: (•)—data of present paper, (∘)—data of[2,3]; for ^{238}U and ^{240}Pu—dependence in accordance with the data of[2,3]. Top: dependence of the yield of the reaction ^{232}Th$(\psi_0 f)$ on the end-point energy of the bremmstrahlung spectrum: (∘)—data of[4], (•)—data of present paper; the dashed curve shows the dependence of the photofission cross section $\sigma_f(E_\gamma)$ obtained by te method of[5]. Insert: schematic representation of the structure of the ^{232}Th and ^{240}Pu fission barriers.

rapidly, remaining $\lesssim 2\%$, within the limits of the measurement errors, to the very end of the investigated range $E_{max} = 5.4$ MeV. On the upper part of Fig. 1 (light points) is shown the yield Y of the photofission of ^{232}Th by bremmstralung γ quanta.[4] A comparison of the data on the total yield and its quadrupole components suggests the conclusion that because of the suppression of Y_c/Y in the 5.4–5.8 MeV region is resonance of the dipole component of the cross section (dashed curve in Fig. 1), which manifests itself clearly also directly in the total yield Y. But then, at an energy much lower than this resonance, we should observe a noticable growth of Y_c/Y provided, of course, we do not have $\Delta E_f \approx 0$ on both humps. This question is of fundamental significance for the ideas concerning the spectra of the fission channels in the double-hump-barrier model, and we have therefore undertaken a new search for the quadrupole component of $W(\theta)$ in the reaction ^{232}Th(γ, f) at lower energies.

The angular distributions of the ^{232}Th fragments were measured with the bremmstrahlung beam of the microtron of our Institute, using a procedure previously employed by us to investigate deep subbarrier photofission of ^{238}U.[8] The procedure made possible registration, with mica detectors, in practically the entire space around the fissioning target made of metallic thorium foil. We were able to perform new measurements of $W(\theta)$ for ^{232}Th in the photon end-point energy regio $E_{max}=5.2$–5.0 MeV. Simultaneously, to check on the procedure, we performed measurements als at $E_{max}=6.4$ MeV, an energy investigated in[2] with a simpler fragment detector. Furthermore, i the 5.0–5.4 MeV range, additional measurements were made of the total ^{232}Th photofission yielc which differed from that of[4] in having a much higher statistical accuracy. This made it possible t establish reliably the presence of the resonance at $E_{max}\approx 5.1$ MeV, which could only be guessed ε on the basis of the previous data.

The reuslts of the new measurements of the yield Y and of the angular distributions of Y_c/Y c the fragments are shown in Fig. 1 by dark circles. They reveal, as expected, an increase in th contribution of the quadrupole components, but its level Y_c/Y reaches for ^{232}Th a value much lowe than in the two other even-even nuclei in the figure. A not insignificant role in the cause of thi difference is played by the resonances of the dipole component of ^{232}Th, which predominates in th total yield: the resonance at $E_{max}\approx 5.6$ MeV, as already noted, produces in Y_c/Y a dip on th section $E_{max}=5.4$–5.8 MeV, and the resonance at 5.1 MeV suppresses the quadrupole componen at the lowest energies investigated in the present study.

The barriers of ^{232}Th and ^{240}Pu, which are shown schematically on the insert in Fig. 1 constitute two characteristic cases in which the sign of the difference $E_{fA}-E_{fB}$ of the heights of th humps is different in the ground state 0^+. Since $E_{fA}^{0^-}>E_{fA}^{0^+}$ and $E_{fB}^{0^-}\approx E_{fB}^{0^+}$, the heights of the hump for the dipole-fission channel of ^{232}Th become equalized, while those of ^{240}Pu become even mor different than in the ground state. Since the region of the existence of sufficiently narrow an strong fission resonances is bounded by the condition $E<\min(E_{fA},E_{fB})$, dipole resonances can b observed in the former case, if $E_{fA}^{0^-}\approx E_{fB}^{0^-}$, at the very threshold, while in the latter case, when th difference between the 0^- hump heights is appreciable, there will be no resonances near th threshold, or more accurately, in the interval $E_{fB}^{0^-}<E<E_{fA}^{0^-}$.

The main conclusion of the study is the importance of the influence of effects of the double hump structure of the barrier and the change of the symmetry of the nucleus when the barrier i penetrated on the realized spectrum of the fission channels and on the resonance structure of th cross section.

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