# Anomalous influence of the angular momentum on the fission of light nuclei by protons and $\alpha$ particles

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We present the results of measurements of the fission probability of the nuclei $Po^{210}$, $Bi^{209}$, $Bi^{207}$, $Hg^{198}$, $Ir^{189}$, and $Os^{186}$ in the reactions $(p, f)$ and $(\alpha, f)$. All six pairs of reactions reveal at low excitations a decrease of the fission probability on going from protons to $\alpha$ particles, in spite of the traditional notion that the fissility increases with increasing angular momentum. A theoretical interpretation of the observed anomalous effect is presented.

According to the available experimental data and theoretical concepts,[1] the probability of the fission process is an increasing function of the angular momentum transferred to the nucleus by the bombarding particles. In[2], an investigation of the excitation functions of the reactions $Pb^{206}(\alpha,f)$ and $Bi^{209}(p,f)$, which lead to the fission of the $Po^{210}$ nucleus, it was established that at low excitations, in spite of this point of view, the probability of fission by protons, the angular-momentum contribution of which is smaller by a factor 2.5, is several times larger. This result was not satisfactorily interpreted and was attributed to methodological errors.[2,3]

A study of a large group pf pre-actinidenuclei by $\alpha$ particles[4] and protons has convinced us that the phenomenon noted in[2] is observed systematically. Figure 1 shows the results of measurements of the fission probability $\sigma_f/\sigma_c$ for the six compound nuclei $Po^{210}$, $Bi^{209}$, $Bi^{207}$, $Hg^{198}$, $Ir^{189}$, and $Os^{186}$, obtained in reactions with protons and $\alpha$ particles ($\sigma_f$ is fission cross section and $\sigma_c$ is the compound-nucleus-formation cross section). It can be seen that the traditional idea that the fissility increases with increasing angular momentum is valid only at sufficiently high excitation energies, whereas the opposite holds true at energies close to the fission barrier. The experiment was performed with the Alma-Ata isochronous cyclotron using targets of separated isotopes; the measurement procedure is described in[5].

Analysis of the obtained data has convinced us that the anomalous dependence of the fission probability on the angular momentum reflects singularities in the behavior of the parameter $K_0^2$, which determines the angular distribution of the fission fragments.[6] Within the framework of the statistical description of the fission

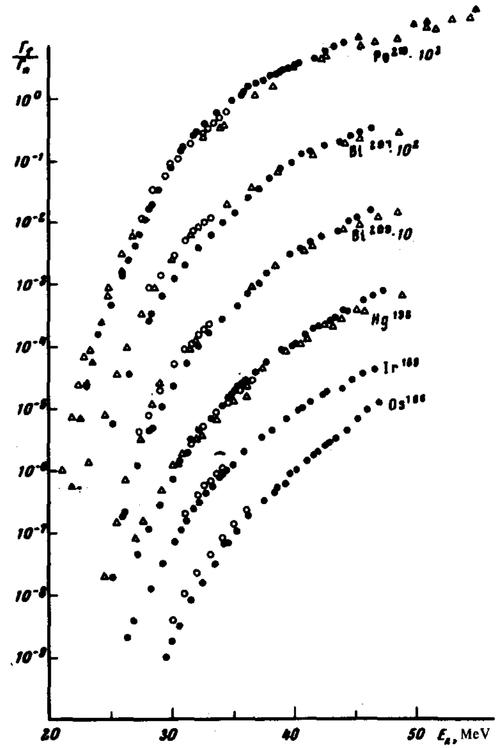


FIG. 1. Dependence of the fission probability $\sigma_f/\sigma_c$ in the reactions $(\alpha,f)$ (dark symbols) and $(p,f)$ (light symbols) on the compound-nucleus excitation energy $E$ (▲, △—[1]; ●, ○—present paper).

width $\Gamma_f$ and the neutron width $\Gamma_n$, one can represent the dependence of the ratio of these widths on the angular momentum in the form

$$\frac{\Gamma_f^J}{\Gamma_n^J} = \frac{\Gamma_f^\circ}{\Gamma_n^\circ}(2J+1)^{-1}\sum_{K=-J}^{J}\exp\left|\beta J^2 - \frac{K^2}{2K_0^2}\right|, \qquad (1)$$

where the parameters $\beta$ and $K_0^2$ characterize the distribution of the angular momentum $J$ and its projection $K$ on the fission axis: $\beta = 1/2(1/F_n t_n = 1/F_\perp t_f)$; $K_0^2 = t_f F_\parallel F_\perp (F_\perp - F_\parallel)^{-1}$; $t_n$ and $F_n$ are the temperature and the moment of inertia of the residual nucleus produced in the neutron channel; $t_f$ is the temperature of the fissioning nucleus in the transition state, while $F_\perp$ and $F_\parallel$ are the perpendicular and parallel moments of inertia corresponding to this state. For the nuclei investigated by us, with low fissility ($\Gamma_n \gg \Gamma_f$), the fission probability can be expressed in the form

$$\frac{\sigma_f}{\sigma_c} = J_{max}^{-2}\int_0^{J_{max}} 2J\frac{\Gamma_f^J}{\Gamma_n^J}\,dJ = \frac{\Gamma_f^\circ}{\Gamma_n^\circ}\frac{\sqrt{\pi}}{2p}\int_0^p \frac{e^{qx}}{\sqrt{2x}}\,erf(\sqrt{2x})\,dx, \qquad (2)$$

where $J_{max}^2 = 2\overline{J(J+1)}$, $p = J_{max}^2/4K_0^2$, $q = 4\beta K_0^2$, and the summation with respect to $J$ and $K$ is replaced by integration.

The dependence of the ratio $\sigma_f/\sigma_c$ on $p$ and $q$, calculated from formula (2), is shown in units of $\Gamma_f^0/\Gamma_n^0$ in Fig. 2. The insert of the figure shows the dependence of the parameters $p_{He}$ and $p_H$ and $q$ on the excitation energy of the fissioning $Po^{210}$ nucleus; these plots were obtained by using the results of[4,5]. The dashed curves join the values of the parameters realized for the protons and $\alpha$ particles. The points of intersection of these curves with the curves $q = \text{const}$ enable us to assess the values of $(\sigma_f/\sigma_c)_H$ and $(\sigma_f/\sigma_c)_{He}$ at various excitation energies. The traditionally investigated region of excitation energies[1] corresponds to values $q \gtrsim 2/3$, and in this region the ratio $\sigma_f/\sigma_c$ increases with increasing angular momentum. However, on going to lower excitation energies, the dependence of $\sigma_f/\sigma_c$ on the angular momentum turns out to be more complicated, and at small $q$ arrive at the region of an anomalous influence of the angular momentum on the fission probability.

Thus, a correct allowance for the dependence of the fission width on the angular momentum $J$ and on its projection $K$ on the fission axis makes it possible to explain all the main features of the experimentally observed relations (Fig. 1). The behavior of $\sigma_f/\sigma_c$ in Fig. 1 is approximately the same for all the considered nuclei, and this fact agrees with the weak dependence of the parameters $p$ and $q$ on the nucleon composition.

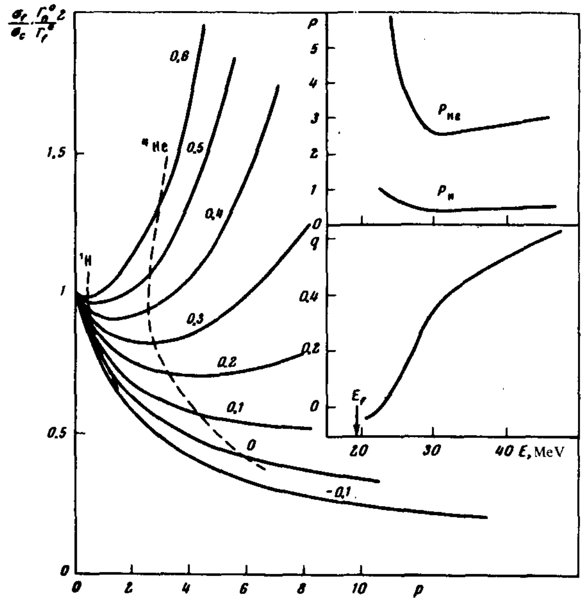


FIG. 2. Dependence of the fission probability $\sigma_f/\sigma_c$ (in units of $\Gamma_f^0/\Gamma_n^0$) on the parameters $p$ and $q$. The values of the parameter $q$ are shown in the curves. The dashed curves show the values of the parameters realized for protons and $\alpha$ particles in the $Po^{210}$ nucleus. Their dependence on the excitation energy is shown in the insert ($E_f$ is the height of the fission barrier).


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