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ANGULAR ANISOTROPY OF THE FISSION OF Pb^{204} AND Pb^{208} BY ALPHA PARTICLES NEAR THE THRESHOLD

K. G. Kuvatov, V. N. Okolovich, and G. N. Smirenkin
Nuclear Physics Institute, Kazakh Academy of Sciences
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Recently published results of the measurement of the angular anisotropy of the fission of Pb^{206} by alpha particles [1] have established that the energy gap in the spectrum of the internal excitations of the nucleus Po^{210} in the transition state is anomalously large, $2\Delta_f = 4$ MeV. This is moure than double the value $2\Delta_g = 1.5$ for the equilibrium ground state, in which the Po^{210} nucleus is close to spherical. The contradictory character of the information [1-4] on the dependence of the parameter Δ, which determines the role of the effect of paired nucleon correlation, on the nuclear deformation has stimulated us to perform similar measurements for the other even-even isotopes of lead, Pb^{204} and Pb^{208}.

The experiments were performed with the cyclotron of our institute, using a track procedure for registering the fission fragments. The experiments were so organized that simultaneous measurements could be made of the fission cross section σ_f and the angular distribution of the fragments $W(\theta)$. The alpha-particle energies were decreased to 29 - 38 MeV with the aid of aluminum foils. The accuracy with which the alpha-particle energy was measured was not worse than ±0.2 MeV. The targets were prepared by an electrolytic method from separated Pb^{204} and Pb^{208}. The upper limit of the extraneous strongly-fissioning impurities was less than 10^{-6} %, as estimated in reactor experiments, and guaranteed background-free measurements in the entire investigated energy range.

The results of the measurements of the angular anisotropy $W(o^\circ)/W(90^\circ)$ of the fission of Po^{208}, Po^{212}, and Po^{210} are shown in the figure as functions of the excitation energy in the transition state $E^* = E_x - E_f$, where E_x is the initial excitation energy of the compound nuclei and E_f is the height of the fission barrier. The values of E_f for Po^{208}, Po^{210}, and Po^{212} were assumed equal to 19.8, 20.5, and 18.8 MeV, respectively (the last two according to [5], and for Po^{208} from the measured course of $\sigma_f(E_x)$).

A comparison of the data shown in the figure reveals a striking difference in the energy dependence of $W(0^\circ)/W(90^\circ)$ near threshold namely a sharp growth in the case of Po^{210}, and constancy in the case of Po^{208} and Po^{212}, similar to that observed for Tl^{201} and At^{213} in the (α, f) reaction on gold in bismuth [6]. This discrepancy between the results of [1] and the aggregate of the experimental data for other nuclei may possibly the consequence of an individual perculiarity of the Po^{210} nucleus and deserves a special study. All that matters to us here is that these difference in the course of the angular anisotropy should influence our ideas concerning the value of Δ_f.

An estimate of the energy gap $2\Delta_f$ in [1] was based on the following considerations. In the vicinity of $E^* = 2\Delta_f$, the mean-squared projection of the angular momentum ℓ on the symmetry axis of the nucleus, $K_0^2 = \overline{K^2}$, experiences a jumplike increase in the two-quasiparticle value $K_0^2 = 2\overline{K^2} \approx 10 - 14$ in accordance with [7],

$$W(0^\circ)/W(90^\circ) = \frac{2}{3} p^{3/2} \Big/ \int_0^p x^{1/2} e^{-x} I_0(x)\,dx \approx 1 + \frac{3}{5}p + \ldots\ldots;$$

$$p = \frac{\overline{\ell^2}}{2K_0^2}.$$

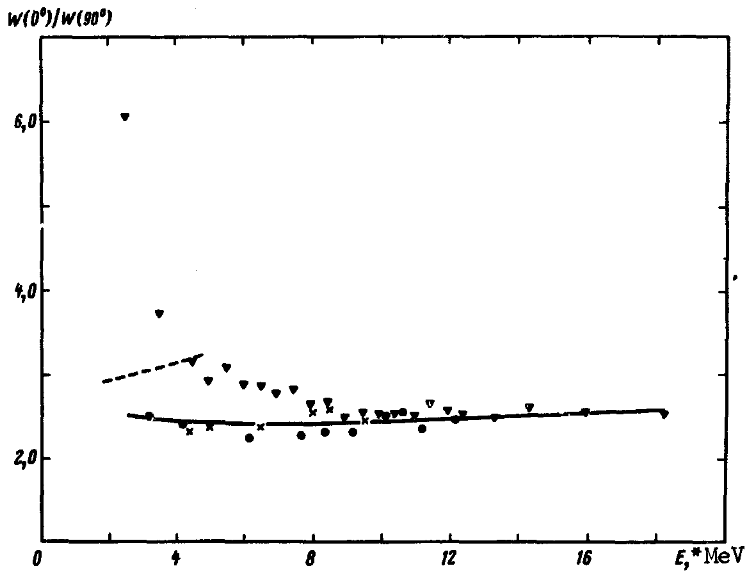
This leads to an appreciable increase of the angular anisotropy inside the energy gap. The value of $W(0^\circ)/W(90^\circ)$ corresponding to $K_0^2 = 2\overline{K^2_{cr}} = 12$ in the reaction $Pb^{206}(\alpha, f)$ is shown dashed in the figure. The point of intersection of the dashed curve with the experimental one at $E_{cr} \approx 4$ MeV was indeed used in [1] for the estimate of $2\Delta_f$. All the values of $W(0)/W(90^\circ)$ for the reaction $Pb^{204}(\alpha, f)$, investigated in practically the same range of E^*, lie below the dashed curve.

This discrepancy stimulates a search for other ways of estimating Δ_f. A method with greater freedom from uncertainties and individual peculiarities of the variation of K_0^2 in regions of $E_x = E_f$ that are narrow and difficult to investigate was realized in [3, 4, 8]. It consists of estimating the energy of the phase transition from the superfluid state into the Fermi-gas state, $E_{cr} = 0.48 a_f \Delta_f^2$, which serves as a measure of the deviations of $K_0^2 = J_{effT}/\hbar^2$ from the Fermi-gas model. When $E^* < E_{cr}$ we have $K_0^2 = C\sqrt{E^*}$. The solid plot of $W(0^\circ)/W(90^\circ)$ in the figure corresponds to this dependence of K_0^2 on E^* with a coefficient $C = J_{eff}/\hbar^2 a_f^{1/2} = 10.5$ MeV$^{-1/2}$, calculated under the assumption that the level-density parameter of the transition states is $a_f = A/8$, and the effective moment of inertia of the nucleus for J_{eff} is equal to its rigid-body value in the liquid-drop model with $(Z^2/A)_{crit} = 46$ [9].

The entire set of values of $W(0^\circ)/W(90^\circ)$, including those for Po^{210} [1], agree well, at least up to 10 MeV, with the Fermi-gas relation, and by the same token with the published [4, 8, 10] estimates $E_{cr} = 10 - 16$ MeV. When $a_f = A/8$, these values of E_{cr} correspond to $\Delta_f = 0.8$ to 1.1 MeV, which are close to Δ_g for the ground state.

If we substitute $\Delta_f = 2$ MeV in the expression for E_{cr} and make the same choice of a_f, which is confirmed by many data, then we obtain the unreasonably high value $E_{cr} = 50$ MeV.

Thus, the results of our experiment and of our analysis confirm



Fission angular anisotropy vs. excitation energy in the transition state of Po^{208}(●), Po^{210}(▼), and Po^{212}(×). The curves are explained in the text.

the opinion that Δ_f has a weak dependence on the deformation of the nucleus in the fission process [2, 4].

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CAUSALITY AND SCATTERING OF WAVE PACKETS

L. A. Khalfin
Leningrad Division of the Steklov Mathematics Institute
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1. An attractive possibility of solving the fundamental difficulties with the divergences within the framework of the theory with pseudo-Hermitian Hamiltonian was proposed in recent papers [1,2]. If this pseudo-Hermitian operator satisfies certain additional conditions, then the S matrix for physical particles (states with positive metric) turns out to be unitary [1]. The question of causality within the framework of this theory, however, remains moot.

2. Let us consider the space-time picture of the scattering of wave packets [3]. For simplicity we confine ourselves to elastic scattering in the s-state in the relativistic region, so that $E = k$.[1)] At sufficiently large $r > R$, we represent the vector of the wave-packet scattering in the form

$$\psi(r,t) = r^{-1}\{ \phi_{in}(r,t) + \phi_{out}(r,t) \}, \tag{1}$$

$$\phi_{in}(r,t) = \int_0^\infty C(k)\exp[-ik(r+t)]\,dk, \tag{1a}$$

$$\phi_{out}(r,t) = \int_0^\infty C(k)\exp[2i\delta(k) + ik(r-t)]\,dk, \tag{1b}$$

where $C(k)$ is the distribution of the wave packets with respect to the energy (momentum), and $\delta(k)$ is the scattering phase shift. The classical concept of stability stipulates that when

1)The notation is that of [1].