Role of Dynamical Effects in the Formation of T-Odd Asymmetries for Products of Polarized-Neutron-Induced Ternary Fission of Nuclei

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Received January 19, 2015

Abstract—Basic dynamical effects that accompany the cold-polarized-neutron-induced binary and ternary fission of actinide nuclei and which determine the properties of T-odd asymmetries in angular distributions of various precission and evaporated light third particles emitted in true and delayed ternary fission are analyzed on the basis of quantum-mechanical fission theory. It is emphasized that effects associated with the conservation of axial symmetry of the fissioning system under study at all stages of its evolution from the formation of neutron resonance states of the fissile compound nucleus to the separation of its fission fragments, including the appearance of zero wriggling vibrations of the cold compound nucleus in the vicinity of its scission point, are of particular importance, the influence of quantum collective rotation of the polarized fissile system on the asymmetry of the angular distribution of both fission fragments and third particles being taken into account. It is shown that the difference in the behavior of the coefficients characterizing the T-odd asymmetries under analysis for the target nuclei being studied can be explained, upon taking into account the interference between the fission amplitudes for the neutron resonance states of fissile compound nuclei, by the difference in the contributions of even and odd components of the amplitudes of angular distributions of third particles to the coefficients in question.

DOI: 10.1134/S1063778815050105

1. INTRODUCTION

The experiments reported in [1–5] were devoted to studying T-odd asymmetries in the differential cross sections $d\sigma_{n,f}/d\omega_3$ for the reactions in which the true ternary fission of $^{233}$U, $^{235}$U, and $^{239}$Pu target nuclei was induced by cold polarized neutrons. Here, $\Omega_3$ is the solid angle that determines the direction of the asymptotic momentum $p_3$ for a third particle, which was an alpha particle in those experiments [1–5]. The differential cross sections $d\sigma_{n,f}/d\omega_3$ were analyzed in the laboratory frame where the $z$ and $y$ axes were aligned with, respectively, the asymptotic momentum of the light fission fragment, $p_{LF}$, and the polarization vector of the incident neutron, $s_n$. A coefficient that was intended for characterizing the T-odd asymmetries under analysis, $D(\Omega_3)$, was chosen in the form

$$ D(\Omega_3) = \frac{d\sigma_{n,f}^{(+)} - d\sigma_{n,f}^{(-)}}{d\omega_3} \left( \frac{d\sigma_{n,f}^{(+)} + d\sigma_{n,f}^{(-)}}{d\omega_3} \right), $$

where the signs $(\pm)$ corresponded to two opposite directions of the neutron polarization vector $s_n$.

Figures 1–3 show that the experimental T-odd-asymmetry coefficients $D^{\text{exp}}(\Omega_3)$ from [1–5] differ substantially in shape for the three target nuclei studied there.

For the $^{233}$U target nucleus, the coefficient $D^{\text{exp}}(\Omega_3)$ is approximately a constant over a rather broad range of the angle $\theta_3$ between the vectors $p_{LF}$ and $p_3$. In [1], this coefficient was associated with TRI-type T-odd asymmetry, since its was assumed that this asymmetry was due to $T$-invariance violation in the ternary fission of nuclei that was induced by cold polarized neutrons. However, it became clear before long [6] that the appearance of a T-odd asymmetry that belonged to that type stemmed from the effect of rotation of a polarized fissile compound nucleus formed in the reaction under study, provided that one employs, for the fissile system in question, a total Hamiltonian that respects $T$ invariance.

However, the coefficients $D^{\text{exp}}(\Omega_3)$ for $^{235}$U [4] and $^{239}$Pu [5] target nuclei show a different type of behavior: they change sign in the angular region around $\theta_3 = 82^\circ$, where the angular distributions of alpha particles emitted in the reactions where the ternary fission of these actinide nuclei is induced by
cold unpolarized neutrons develop a maximum [7]. In [4, 5], this behavior of the coefficients $D^\text{exp} (\Omega_3)$ was associated with an ROT-type $T$-odd asymmetry, since the structure of this asymmetry can be explained on the basis of the classical trajectory-calculation method upon taking into account [6] the effect of rotation of a polarized fissile compound nucleus on the angular distribution of a charged polarized third particle.

Quite recently, $T$-odd asymmetries were observed by Danilyan and his coauthors [8, 9] in the differential cross sections $d\sigma_{n,f}/d\Omega_3$ for the delayed ternary fission of $^{235}$U target nuclei that was induced by cold polarized neutrons and which was accompanied by the emission of evaporated photons and neutrons as third particles, and their coefficients were also associated with ROT-type $T$-odd asymmetries.

Searches for mechanisms that lead to the appearance of observed $T$-odd asymmetries are being vigorously performed at the present time. Specifically, it is necessary to answer the question why the $^{233}$U, $^{235}$U, and $^{239}$Pu nuclei, which are close in charge and mass and which has similar mass, charge, angular, and energy distributions for the products of their binary and ternary fission induced by cold neutrons, may have $T$-odd-asymmetry coefficients so different in shape in the reactions of their ternary fission induced by cold polarized neutrons.

The objective of our study was to assess the present-day level of understanding of the nature of the $T$-odd asymmetries in question and to analyze their properties on the basis of quantum-mechanical fission theory [6, 10–21] with allowance for dynamical effects that determine basic properties of low-energy binary and ternary fission of nuclei.