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Investigation of the high-spin yrast band structure of $^{236–246}$Pu isotopes

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The available data on some actinide nuclei point to certain significant features of the rotational yrast band and other excited bands. The rotational properties of plutonium isotopes ($^{236–346}$Pu) were studied via projected shell model (PSM). Calculations are based on the Hamiltonian of the PSM which includes the formed part of a single particle, the $Q-Q$ force, and the residual interaction of monopole and quadrupole pairings. The results of the calculated energy levels of the yrast band are then compared with available experimental data and a good agreement has been found. The crossing between two-quasiparticle (2qp) excited bands and the ground state band (g band) in the high-spin regions has been analyzed in terms of band diagrams. The upbendings observed in the kinematic moments of inertia ($j^{(1)}$ MOI) curves for $^{236–346}$Pu isotopes are due to the effect of two aligning nucleons that occupy excited bands and the $\nu(j_{15/2})$, $\pi(i_{13/2})$ high-j intruder orbits. The PSM successfully reproduces the observed upbending in $j^{(1)}$ as well as the upturning and downturning in $j^{(2)}$. For the ^{240}Pu isotope, the PSM predicts a simultaneous alignment of neutrons ν^2 $[1/2, -7/2]$ $K^\pi = 4^+$ and protons π^2 $[-3/2, 5/2]$ $K^\pi = 1^+$ bands cross the g band at spin $I = 22$. We expect it to be mainly responsible for the disagreement at $I = 22$. Furthermore, electric quadrupole transition probabilities $B(E2)$ and the gyromagnetic factor (g factor) for the yrast band energy levels are also studied.

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I. INTRODUCTION

The problem of heavy nuclei with a prohibitively complex system can be solved by simple realistic approaches that rely on pairing effects [1]. The Bardeen-Cooper-Schrieffer (BCS) theory can be seen as a microscopic model that deals with strong pairing correlations between the nucleons [2]. From another point of view, the pairing phenomenon describes accurately the collective properties of deformed valence shell(s) in an even-even nucleus. For an efficient quantitative description via the complete BCS approach, the issue of the strong interaction can be simplified by using a quasiparticle rather than particle system. However, extending the superconductivity theory requires taking into account the effect of correlated pairs and implementing Hartree-Fock-Bogoliubov (HFB) equations [3]. A general solution of the deformed HFB equations provides quasiparticle operators $a_i^\dagger, a_i^\dagger$ with its vacuum $\mid 0 >$ and the number of single-particle orbits, i. The study of the quasiparticle excitations may support our findings on several high-spin phenomena [4,5]. Many quasiparticle alignments with their angular momenta provide us with a basic understanding of the single-particle excitations of the nuclear system under extraordinary new conditions. It is a new symmetrical breaking within the deformed basis of a multiquasiparticle system [6].

The ground state band of deformed nuclei has many rotational properties. One of these properties is known as the moment of inertia (MOI). The variety in MOI at both high and low spins can be interpreted in relation to the changes in pairing correlations between the nucleons of $i_{13/2}$ and $h_{11/2}$ orbits in rare-earth nuclei. The Coriolis forces have very noticeable effects on pairing correlations between neutrons $j_{15/2}$ and protons $i_{13/2}$ at high angular momentum of the rotating actinide nuclei [7,8]. To investigate the high-spin states of actinide nuclei, the targets of enriched ^{240}Pu and ^{248}Cm are bombarded with beams of ^{208}Po [9]. The microscopic calculations predict that the proton alignment of the $i_{13/2}$ intruder orbit is responsible for the strong presence of backbending in the ^{244,246}Pu, but the irregularity is less pronounced in the neighboring ^{242}Pu [10].

The projected shell model (PSM) is an improved tool to describe the deformed nuclei [11–14]. The procedure of the PSM calculations is based on the Nilsson model which adjusts the observed rotational bands to fill the shell of the proper individual nucleus. A few quasiparticles that occupy the orbits close to the Fermi level are selected to construct the projected deformed basis. Pairing correlations between nucleons are incorporated into the deformed basis by using the BCS treatment. Sheikh *et al.* [15–19] have proposed an extension of PSM, introducing a three-dimensional angular momentum projection, made of a triaxial Nilsson plus a BCS deformed intrinsic wave function for the purpose of improving the description of rotational and transitional nuclei.

Extending the PSM to Heavy Shell Model (HSM) provides an opportunity to describe the collective excitations relevant to deformed actinide nuclei (^{240}Pu, ^{232,234}U, ^{230,232}Th). However, the D-pairs excitations ($D_0(\mathrm{K}^\pi = 2^+)$, $D_2(\mathrm{K}^\pi = 2^+)$) have been added to the intrinsic basis of the PSM [20]. The progressive increase of $J^{(1)}$ and $J^{(2)}$ in even and odd protons when $N = 114$ isotones is due to the processes of