Competition in rotation-alignment between high-j neutrons and protons in transfermium nuclei

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The study of rotation-alignment of quasiparticles probes sensitively the properties of high-j intruder orbits. The distribution of very-high-j orbits, which are consequences of the fundamental spin-orbit interaction, links with the important question of single-particle levels in superheavy nuclei. With the deformed single-particle states generated by the standard Nilsson potential, we perform Projected Shell Model calculations for transfermium nuclei where detailed spectroscopy experiments are currently possible. Specifically, we study the systematical behavior of rotation-alignment and associated band-crossing phenomenon in Cf, Fm, and No isotopes. Neutrons and protons from the high-j orbits are found to compete strongly in rotation-alignment, which gives rise to testable effects. Observation of these effects will provide direct information on the single-particle states in the heaviest nuclear mass region.

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I. INTRODUCTION

The occurrence of superheavy elements (SHE) is attributed to the nuclear shell effect because the macroscopic liquid-drop model would predict that such heavy elements cannot exist due to large Coulomb repulsive force. The distribution of single-particle (SP) states as a consequence of the shell effect has thus become the discussion focus in the SHE problem. One important question has been where are the next magic numbers in the superheavy mass region beyond the known magic number 126 for neutrons and 82 for protons. The precise location of the new magic numbers depends sensitively on the SP structure. Theoretically, stability is predicted for the nuclei close to the spherical shells with $N = 184$ and $Z = 114$ (also $Z = 120$ or 126, depending on theoretical models employed), which suggests the existence of "island of stability" [1] next to the well-known doubly magic nucleus ^{208}Pb.

Exploring the island is the current goal in nuclear science. In the past few years, researchers have made significant progress in synthesis of new elements (for review, see Refs. [2–5]). Presently, little is known about their structure. The heaviest nuclei for which detailed spectroscopy measurement can be performed lie in the transfermium mass region, such as for instance, the californium, fermium, and nobelium isotopes [6–9]. These nuclei, typically with $Z \approx 100$ and $N \approx 150$–160, are not really SHE. However, they are at the gateway to the SHE region, and furthermore, they are well deformed. One can clearly see from the deformed SP spectra [10] that, with deformation, the Fermi surfaces of these nuclei are surrounded by some orbitals originating from the subshells near the anticipated new magic numbers. Thus, the study of these deformed transfermium nuclei may provide an indirect way to access the SP states of the closed spherical shells, which are of direct relevance to the location of the predicted island.

In-beam measurements for the transfermium region have been performed for yrast γ-ray spectroscopy of even-even nuclei (for example, ^{250}Fm [11], ^{252}No [12], ^{254}No [13]). The data reveal that these nuclei are well deformed. At low spins near the ground state, they all exhibit very similar collective behavior with regular rotational level sequence. This tells us that near the ground state these nuclei behave like a heavy, rigid rotor. They show a strong collectivity, diluting any individual role of single particles. Therefore, not much information can be extracted from these low-spin rotor states.

More useful information may be obtained through the study of high-spin states with quasiparticle excitations. In fact, some nonyrast and isomeric states have been observed (see, for example, Refs. [14–21], and for the most recent review, see Ref. [9]). The yielded data contain useful information on excited levels and configurations of multi-quasiparticle states in this mass region, and moreover, they test strictly current nuclear models that have been used for prediction. There are several types of quasiparticle excitation. One possibility is the study of K isomers through isomer spectroscopy measurement [22]. Isomer study has become an important branch of nuclear structure research [23]. The suggestion of Xu *et al.* [24] has made the study of isomeric states in SHE more interesting. These authors suggested that the occurrence of isomeric states in SHE can enhance the stability because the multi-quasiparticle excitations decrease the probability for both nuclear fission and α decay. In the present article, we concentrate on another possibility of quasiparticle excitations; namely, we discuss rotation-alignment at high spins along the yrast line.

On the theoretical side, the early study by Munitian, Patyk, and Sobiczewski [25] on rotational structure in very heavy nuclei employed cranking approximation based on a macroscopic-microscopic approach. The first microscopic

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