Microscopic study of γ-deformation in atomic nuclei

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Introduction

Spontaneous breaking of rotational symmetry that leads to the deformation of a quantum system in the intrinsic frame, has played a pivitol role in unraveling the underlying shapes and structures of atomic nuclei [1]. The properties of deformed nuclei are elucidated by considering the ellipsoidal shape, which is conveniently parameterized in terms of axial and non-axial deformation parameters of β and γ. The majority of the deformed nuclei are axially-symmetric ($\gamma = 0$) with angular-momentum projection along the symmetry axis, K, a conserved quantum number and the electromagnetic transition probabilities obeying the selection rules based on this quantum number [2]. There are also regions in the nuclear periodic table, referred to as transitional, where the axial symmetry is broken and the non-axial degree of freedom plays an essential role in determining the properties of these nuclei. Atomic nuclei may have either a localized minimum or a flat potential energy surface along the γ degree of freedom and correspond to γ-rigid and γ-soft nuclei, respectively. How to distinguish between the two shapes from the observable properties has been an outstanding issue in nuclear physics for more than sixty years. It is known that Davydov-Filippov and Wilets-Jean potentials belonging to γ-rigid and γ-soft limits, respectively, give rise to similar excitation spectra for the ground-state band [3, 4]. It is, therefore, impossible to dileneate the two shapes from the ground-state properties for which rich data is available for most of the nuclei. Never the less, it has been demonstrated that energy staggering in the γ-band may shed light on the nature of the γ-motion. For γ-soft nuclei described by Wilets-Jean potential, the energies of the $\gamma-$band are bunched as $(2^+), (3^+, 4^+), (5^+, 6^+)$........ and in the Davydov-Filippov model corresponding to the γ-rigid limit, the energy levels of the γ-band are arranged as $(2^+, 3^+), (4^+, 5^+), (6^+, 7^+)$......... The sequence of the energy levels of the γ-band leads to opposite phase of the staggering parameter in the two cases.

The purpose of the present work is to investigate the γ-band staggering in even-even ^{108,112}Ru isotopes using the microscopic triaxial projected shell model (TPSM) approach [5]. The study is performed for Ru isotopes for which γ-bands are observed up to high angular momentum for both even- and odd-spin members. It is demonstrated that angular-momentum projection from the intrinsic triaxial vacuum or 0-quasiparticle state in the TPSM approach gives rise to γ-band staggering corresponding to Davydov-Filippov model or rigid-γ motion. However, it is demonstrated that inclusion of quasipartile excitations transforms the γ-band staggering from Davydov-Filippov kind to what is expected from Wilets-Jean or γ-soft motion for ^{108}Ru nucleus while in ^{112}Ru is reverse.

Outline of TPSM

For the even-even system, the TPSM basis are composed of 0-qp vacuum, two-proton, two-neutron and the four-quasiparticle con-

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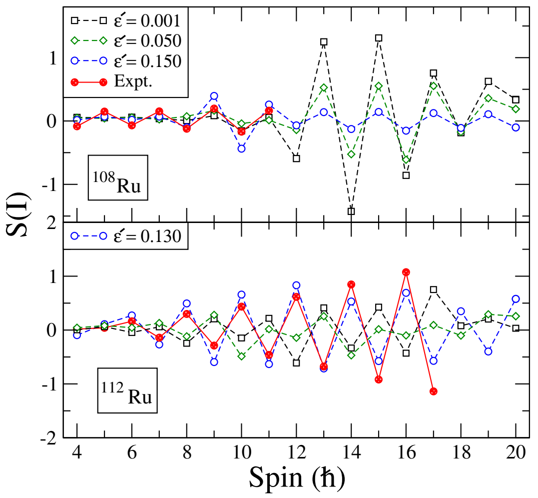

FIG. 1: (Color online) Comparison of experimental and the calculated band energies for ^{108,112}Ru.

figurations. As in the PSM calculations, we use the pairing plus quadrupole-quadrupole Hamiltonian.

$$\hat{H} = \hat{H}_0 - \frac{1}{2}\chi \sum_{\mu} \hat{Q}^{\dagger}_{\mu}\hat{Q}_{\mu} - G_M \hat{P}^{\dagger}\hat{P} - G_Q \sum_{\mu} \hat{P}^{\dagger}_{\mu}\hat{P}_{\mu}. \quad (1)$$

where $\hat{H}_0$ is the spherical single-particle shell model Hamiltonian, which contains the spin-orbit force. The second, third and fourth terms in Eq. (1) represent quadrupole-quadrupole, monopole-pairing, and quadrupole-pairing interactions, respectively.

Results and Discussions

To probe the dependence of the γ-band staggering on the triaxial deformation parameter, in Fig. 1 $S(I)$ is displayed for ^{108}Ru and ^{112}Ru with different values of ϵ'. It is noted from Fig. 1 that the phase of $S(I)$ remains unchanged for ^{108}Ru as the motion is γ-soft and any value of ϵ' can be chosen to reproduce the phase of the staggering. On the other hand, it is observed that in order to reproduce the observed phase for the γ-band in ^{112}Ru, the triaxial deformation value of $\epsilon' = 0.13$ ($\gamma = 24^0$) is needed. What emerges from the above discussion is that ^{112}Ru is a unique nucleus for which phase of the staggering for all spin states remains that of Davydov-Filipov kind even after considering quasiparticle excitations. For other ^{108}Ru nucleus, the phase of the staggering changes, atleast, for some spin states with the inclusion of the quasiparticle states. Thus, from the present analysis, ^{112}Ru can be considered as a truely γ-rigid nucleus. The question that naturally arises is what is the magnitude of the quasiparticle configurations in ^{112}Ru as comapred to a γ-soft nucleus. In order to address this question, the wavefunction amplitudes indicate that in ^{108}Ru, both yrast and γ bands are dominated by the vacuum configuration up to I=8 and above this spin value the two-quasiparticle configurations dominate. This is due to the well established crossing of the two-quasiparticle aligned band with the ground-state band. For ^{112}Ru, the only difference as compared to ^{108}Ru is that crossover occurs at I=10 rather than at I=8. In particular, the magnitude of the two-quasiparticle amplitude is very similar in two nuclei. In conclusion, It would have been normally expected that due to smaller contribution from quasiparticle excitations, ^{112}Ru maintains the γ-rigid motion of the vacuum state. Therefore, the reason for the γ-rigid motion in ^{112}Ru appears to be more deeper and is rooted in the basic shell structure of nucleus.

References

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