Multi-phonon gamma vibrational bands in odd-proton ^{107}Tc nucleus

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In the study of nuclear structure, the multi-phonon γ-vibrational bands are very important subjects. The multi-phonon excitations in deformed nuclei can provide valuable information of the nuclear vibrational collectivity. However, to experimentally observe the multi-phonon bands is difficult. So far, considerable efforts have been made to search for the multi-phonon bands in even-even nuclei. Several low lying $K^{\pi} = 4^{+}$ two-phonon $\gamma(\gamma\gamma)$ bands have been identified, such as in ^{166,168}Er [1–3] ^{164}Dy [4] and ^{232}Th [5]. In A=110 neutron-rich nuclear region, the one-phonon 1γ and $\gamma\gamma$-bands have been observed in even-even ^{104,106,108}Mo [6] and ^{108,110,112}Ru [7]. For the odd-A nuclei, the study of the $\gamma\gamma$-bands is scarce. Piepenbring and Durand [8] made some predications using the extended multi-phonon method (MPM). They indicate that in the odd-A nuclei, if the K is a band-head quantum number of a quasiparticle band, there exist two γ states with $K+2$ and$K-2$. For the $\gamma\gamma$ states, there may exist three states with $K-4$, K and $K+4$. It is also expected that the K+2 γ state and the K+4 $\gamma\gamma$ state may be easy to be observed, and others may be difficult. Recently, in A 110 neutron-rich region, a first $\gamma\gamma$-band in an odd-N nucleus has been observed in ^{105}Mo, and ^{103}Nb is the first nucleus where $\gamma\gamma$-band has been observed in odd-Z nuclei. Not much is known about the odd-Z neutron-rich nuclei in this region. Because of the deformations driven by N $\geq$60 neutrons, various proton subshells are near the Fermi levels and may play a role in the odd-Z nuclei. Rotational bands built on $\pi g_{9/2}$ and $\pi p_{1/2}$ and $\pi(g_{7/2}/d_{5/2})$ ^{103,105,107,109}Tc with Z=45. It is quit evident that in this mass region the proton orbitals originating from the $\pi g_{9/2}$ subshell closest to the Fermi level are affected in special ways by triaxial nuclear shapes. Neutron states from the $\nu h_{11/2}$ subshell strongly drive nuclei in this region to prolate deformation, since the neutron Fermi level is below or near the bottom of the $\nu h_{11/2}$ subshell. In contrast to the sharp shape transitions and coexistence observed in nuclei of Z$\leq$40, the appearance of triaxiality and soft shape transitions were found in nuclei of Z$\geq$40 in A $\sim$ 110 region.

The neutron-rich ^{107}Tc nucleus with Z = 43 and N = 64 is located within the A $\sim$ 100 deformed region. Recently, remarkable progress on the study of the nuclear structures has been made in this region, such as the sudden onset of large quadrupole deformation, triaxial deformation, $\gamma\gamma$-vibrational bands, chiral doublet bands. For the neutron-rich Tc isotopes, some high spin state results have been published for odd-Z ^{103,105,107,109}Tc and odd-odd ^{106,108,110}Tc. Many collective bands were discovered. However, compared with the other isotopes, some results in the odd-A isotope of ^{107}Tc still need to be reexamined, as the inconsistent results in ^{107}Tc were reported in the different articles. In order to clarify these inconsistencies, here we reinvestigate the high spin band structures in ^{107}Tc In the present work, we have further generalized the TPSM approach to study the γ-vibration in odd-mass nuclei. A preliminary application of this new development for the odd-proton system, ^{103}Nb, has already been reported [10]

The present study generalizes the triaxial projected shell model (TPSM) to odd-mass nuclei with the inclusion of quasiparticle (qp) configurations in the model basis. For the study of odd-proton system, our model space is spanned by (angular-momentum-projected) one- and three-qp basis

$$\{\hat{P}^{I}_{MK}\, a^{\dagger}_{p}|\Phi>,\, \hat{P}^{I}_{MK}\, a^{\dagger}_{p}a^{\dagger}_{n1}a^{\dagger}_{n2}|\Phi>\}, \tag{1}$$

where the projector

$$\hat{P}^{I}_{MK} = \frac{2I+1}{8\pi^2}\int d\Omega\, D^{I}_{MK}(\Omega)\,\hat{R}(\Omega), \tag{2}$$

and $|\Phi>$ represents the triaxially-deformed qp vacuum state. The qp basis chosen in (1) includes the configurations of two-neutron aligned states built on the one-quasiproton states. It should be noted that in the present case of triaxial deformation, any qp-state is a superposition of all possible K-values. The rotational bands with the triaxial basis states (1) are obtained by specifying different values for the K-quantum number in the projection operator, Eq. (2).

As in the earlier PSM calculations, we use the quadrupole-quadrupole plus pairing Hamiltonian [11]

$$\hat{H} = \hat{H}_0 - \frac{1}{2}\chi\sum_{\mu}\hat{Q}^{\dagger}_{\mu}\hat{Q}_{\mu} - G_M\hat{P}^{\dagger}\hat{P} - G_Q\sum_{\mu}\hat{P}^{\dagger}_{\mu}\hat{P}_{\mu}. \tag{3}$$

The corresponding triaxial Nilsson mean-field Hamiltonian is given by

$$\hat{H}_N = \hat{H}_0 - \frac{2}{3}\hbar\omega\left\{\varepsilon\hat{Q}_0 + \varepsilon'\frac{\hat{Q}_{+2}+\hat{Q}_{-2}}{\sqrt{2}}\right\}, \tag{4}$$

where ε and ε' specify the axial and triaxial deformations, respectively. In the above equations, $\hat{H}_0$ is the spherical single-particle Hamiltonian, which contains a proper spin-orbit force. The interaction strengths are taken as follows: The QQ-force strength χ in Eq. (3) is adjusted such that the physical quadrupole deformation ε is obtained as a result of the self-consistent mean-field calculation [11].

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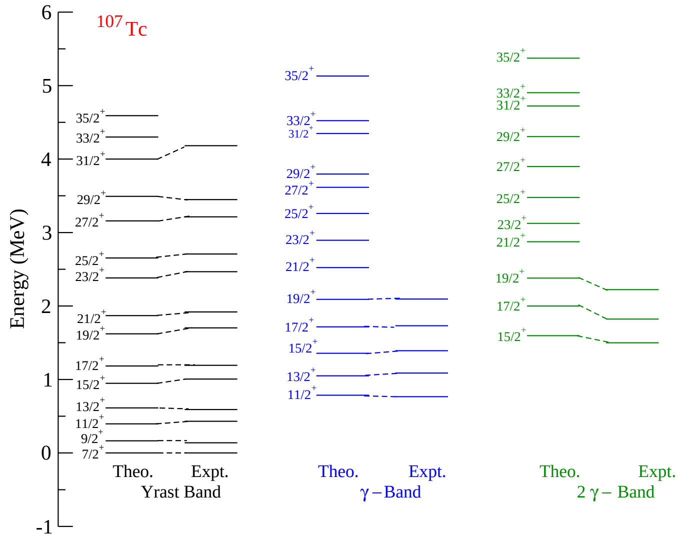

FIG. 1. Detailed comparison of Yrast, γ- and $\gamma\gamma$ - bands for ^{107}Tc.

Calculations have been performed for ^{103}Nb with the quadrupole deformation parameter $\varepsilon = 0.320$ and the triaxial one $\varepsilon' = 0.15$. The value of ε has been chosen from the total-routhian-surface (TRS) calculations based on the cranked shell model approach with Woods-Saxon potential and Strutinisky shell correction formalism. Nuclei in this mass region are known to exhibit triaxiality. The value of ε' in our calculation has been chosen such that the bandhead energy of the experimental γ-band is reproduced, or simply for triaxially deformed nuclei, ε' was fixed from the minimization of the ground state energy as a function of this parameter. The TPSM analysis is performed in two stages: In the first stage, a set of quasiparticle states are chosen for which the angular-momentum-projection is to be performed. In the second stage, the shell model Hamiltonian is diagonalized in the projected states.

The projected states obtained from a total of forty-four intrinsic states are used as basis for diagonalizing the shell model Hamiltonian (4). The final energy levels after diagonalization are displayed in Fig. 1 for the yrast-, γ- and $\gamma\gamma$-bands. This figure also depicts the corresponding experimental band structures obtained in Ref. [12]. It is quite evident from Fig. 1 that TPSM describes the yrast- and γ- bands remarkably well. For the $\gamma\gamma$-band, the TPSM predicted band lies higher by about 200 keV as compared to the experimental $\gamma\gamma$- band.We have proposed that this discrepancy could possibly be resolved by performing GCM calculations with triaxial deformation ε' as the generator coordinate.

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