# Triaxial projected shell model study of yrast and near-yrast bands in $^{98\text{-}106}$Ru isotopes

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## Introduction

Atomic nuclei are well known to manifest changes in their energy spectra as well as in the electromagnetic properties among them when the number nucleons are varied, resulting in the shape transition from one kind of behaviour to another [1-3]. The fundamental modes of excitations in nucleus are vibration, rotational and multi-quasiparticle and there exists numerous regions in nuclear chart where these three modes coexist and are supposed to change the nuclear structure through the admixture of various interactions.

Departures from the expected behavior of structure of nucleus has provided us with subtle hints that our understanding of the complete behavior of nuclei is not complete and must be explored more closely. In particular, for A~100 region of Segre chart, with the advancement of various experimental techniques there has been an immense accumulation of data for neutron deficient/rich nuclei on both sides of $\beta$-stability valley [4]. A lot of factors such as overlapping neutron and proton Nilsson single particle orbitals, deformed and spherical shell gaps, sharp shape transition with varying proton and neutron number enrich the structure of nuclei falling in this mass region and therefore, various interesting phenomena have been observed.

With atomic number Z=44, the Ruthenium nuclei with six proton holes are positioned in an interesting region around proton shell closure at Z=50 where they are expected to show interesting asymmetric features. To gain insights into the high spin band structures as well as the extent of triaxiality present in various nuclei of different mass regions, the microscopic approach of TPSM [5] has been developed and provided successful description of phenomenon of triaxiality in these nuclei. The present work incorporates a systematic theoretical study of $^{98\text{-}106}$Ru isotopes using the microscopic framework of TPSM. The purpose of the present work is to stress the importance of $\gamma$ degree of freedom so as to describe the deformation present in A~100 region and the discussion will be concentrated on the question of $\gamma$ softness and band structures at high spins in these isotopes.

### The Theory of the Applied Model

In order to carry out the nuclear structure calculations for $^{98\text{-}106}$Ru nuclei, Triaxial Projected Shell Model is employed. In TPSM, apart from 0-qp, the higher qp like 2- and 4-qp configurations are explicitly included in the basis space. Hence, it is possible for the model to study high-spin band structures, which incorporates the interplay between collective and single-particle excitations. To describe the asymmetric nucleus triaxially-deformed Nilsson states are employed in TPSM. Three-dimensional angular-momentum projection is then performed for configurations built by using deformed Nilsson states. A triaxial qp configuration is an admixture of numerous K (projection along the symmetry axis) states, and for even-even system the vacuum configuration is composed of K=0,2,4,...states. It has been shown that the angular-momentum projection from the K = 0, 2, and 4 states correspond to the ground, γ- and 2γ-bands, respectively.

The TPSM calculations proceed in different stages. In the very first stage, the deformed basis space is constructed by solving the triaxially deformed Nilsson potential. The triaxially deformed single-particle basis is obtained from the Nilsson model [6]. In the second step, the good angular-momentum states are obtained from the deformed basis by using the three dimensional angular-momentum projection technique. In the third and the last stage, the projected bases are used to diagonalize the shell model Hamiltonian. The set of deformation parameters, axial ($\varepsilon$) and triaxial ($\varepsilon_4$) are set as 0.250 and 0.175, 0.257 and 0.160, 0.268 and 0.155, 0.280 and 0.179 and 0.29 and 0.175 for $^{98\text{-}106}$Ru nuclei, respectively.

## Results and Discussions

The angular-momentum projected energies from 0 qp, 2-qp (proton and neutron), and 4-qp configurations, calculated with axial and non-axial deformation parameters given above, are depicted in Fig. 1 for $^{98}$Ru isotopes. This is known as the band diagrams. In a similar way, the band diagrams have been made for rest of the isotopes. To extract structural information from the applied theoretical framework, it is useful to discuss the energies in terms of band diagram. The projected energies of only the few lowest 0- 2- and 4-qp configurations are plotted for clarity as only these are significant to extract the physics of interest.

For $^{98}$Ru, it is observed that the band head of $\gamma$-band and $2\gamma$-band are at excitation energies 1.52 MeV and 3.787 MeV with respect to ground band, respectively. It can be seen from fig. that from the spin $10^+$ onwards, the ground band and $\gamma$-band become almost degenerate *i.e.,* the energies of these two bands become almost same for these spin values and after the spin value $14^+$, the energy of $\gamma$-band band becomes slightly lower than that of ground band which indicates the presence of triaxiality at high spin values. For this isotope, the yrast band is composed of ground band (0,0) up to the spin $8^+$. After this spin value, the 2-quasineutron band with $K$=1 *i.e.,* (1,*2n*) crosses the ground band and becomes lower in energy, thereby contributing towards the formation of yrast. At spin value $14^+$, the 2-quasineutron band with $K$=3 *i.e.,* (3,*2n*) also lowers its energy and crosses the ground band. The 2-quasiproton bands with $K$=1 and $K$=3 *i.e.,* (1,*2p*) and (3,*2p*) are at higher energies and do not cross the ground band up to spin $26^+$. The drop in the energy has been observed for 4-quasiparticle configurations with $K$=2 and $K$=4 which results in crossing the (0,0) configuration at $22^+$ and $24^+$, respectively. In a similar way, the intrinsic structure of all the isotopes is extracted from their band diagrams.

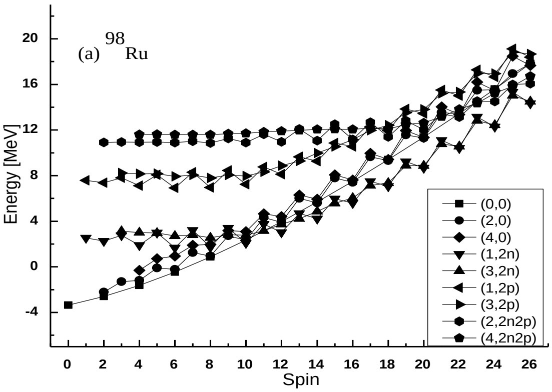

**Fig. 1** Band diagram of $^{98}$Ru.

The band energies for yrast and near-yrast bands obtained after the process of diagonalization, are shown in Fig. 2 with the available experimental data. It is evident from the figure that TPSM results are in very good agreement with the known experimental energies.

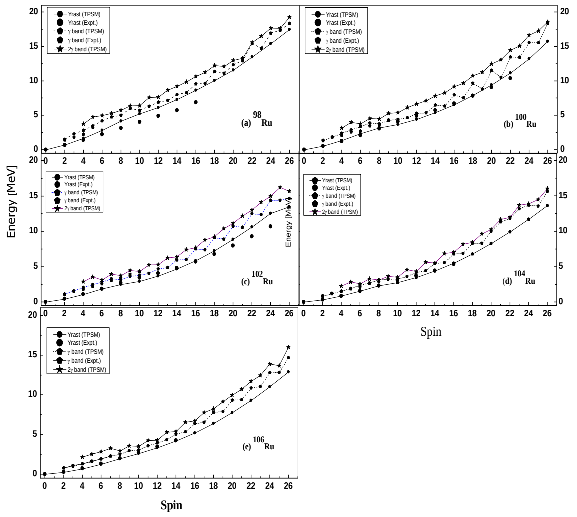

**Fig. 2** Comparison of the Experimental and TPSM yrast spectra and near-yrast bands for $^{98-106}$Ru.

## Summary

The $^{98-106}$Ru nuclei have been studied within a theoretical framework of Triaxial Projected Shell Model. The band structures of yrast and near-yrast bands for these nuclei have been interpreted in terms of multi quasi-particle configurations and are well reproduced by the TPSM. The obtained results are discussed with their available experimental counterparts and an excellent agreement has been obtained between them.

## References

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