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High spin structure of ^{82}Sr using triaxial projected shell model

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Study of N≈Z nuclei in mass A~80 region, which is in the transitional region, is of interest due to the existence of abundant nuclear structure phenomena and this mass region is often characterized by shape co-existence. In present work, the multi-quasiparticle triaxial projected shell model (TPSM) approach is employed to study the high spin structures and to depict γ deformation in ^{82}Sr. TPSM results for the yrast band and γ band-energies are compared with known experimental energies. The possibility of a 2γ-band is also predicted. The change in staggering phases for the γ band as a result of configuration mixing is also discussed.

Keywords: Shape co-existence, Multi-quasiparticle, Triaxial projected shell model, Configuration mixing

1 Introduction

Several experimental and theoretical investigations show the existence of triaxiality for some nuclei in A~80 mass region[1-3]. In this mass region ^{76}Kr is known to have triaxiality[4,5]. Also, ^{76}Ge was reported to have rigid triaxial deformation and its staggering behaviour in the γ-band is consistent with that of the rigid-triaxial model of Davydov and Filippov (DF)[6]. Theoretical calculations have predicted triaxial deformations in ^{80}Srand ^{84}Zr[4,7]. Again, many neutron deficient nuclei in A~80 region have large quadrupole deformation in their ground state. Hence, the nuclei in this region are ideal candidates for the study of shape-mixing and triaxiality.

The isotope ^{82}Sr has been a subject of experimental and theoretical studies for its structure as the shape coexistence of prolate, oblate and triaxial deformations has been seen in this nucleus[8]. The purpose of present work is to carry out a study of the yrast-band and γ-band structure for ^{82}Sr nucleus using triaxial projected shell model (TPSM)[9-11].

2 Outline of Theory

The extended TPSM qp basis consists of angular momentum projected qp vacuum(0-qp) state, two-proton(2p), two-neutron(2n) and 4-quasiparticle(2-proton plus 2-neutron) state i.e.,

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$$\{\hat{P}^I_{MK}|\phi\rangle, \hat{P}^I_{MK}\hat{a}^\dagger_{p1}\hat{a}^\dagger_{p2}|\phi\rangle, \hat{P}^I_{MK}\hat{a}^\dagger_{n1}\hat{a}^\dagger_{n2}|\phi\rangle, \hat{P}^I_{MK}\hat{a}^\dagger_{p1}\hat{a}^\dagger_{p2}\hat{a}^\dagger_{n1}\hat{a}^\dagger_{n2}|\phi\rangle\} \quad \ldots (1)$$

An intrinsic triaxial state in this model is a rich superposition of different K-states. The triaxial deformed vacuum state is composed of K=0, 2, 4, ……… configurations. The projected bands from these K=0, 2 and 4 intrinsic states are the dominant components of the ground, γ- and 2γ- bands respectively. The three-dimensional angular-momentum operator is given by:

$$\hat{P}^I_{MK} = \frac{2I+1}{8\Pi^2}\int d\Omega\, D^I_{MK}(\Omega)\, \hat{R}(\Omega) \quad \ldots (2)$$

With the rotational operator

$$\hat{R}(\Omega) = e^{-i\alpha \hat{J}_z} e^{-i\beta \hat{J}_y} e^{-i\gamma \hat{J}_z} \quad \ldots (3)$$

and $|\phi\rangle$ represents the triaxial qp vacuum state. The triaxially deformed qp states are generated by the Nilsson Hamiltonian,

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

Here $\hat{H}_0$ is the spherical single-particle Hamiltonian. The parameters ε and ε' describe axial quadrupole and triaxial deformations respectively. The conventional triaxiality parameter γ is related to ε and ε' through the relation $\gamma = tan^{-1}(\varepsilon'/\varepsilon)$. The pairing plus quadrupole-quadrupole Hamiltonian is used,

$$\hat{H} = \hat{H}_0 - \frac{1}{2}\chi \sum_\mu \hat{Q}^\dagger_\mu \hat{Q}_\mu - G_M \hat{P}^\dagger \hat{P} - G_Q \sum_\mu \hat{P}^\dagger_\mu \hat{P}_\mu \quad \dots (5)$$

The monopole pairing strength G_M is of the standard form $G_M = [G_1 - G_2(N-Z)/A]A^{-1}$ for neutrons, $G_M = G_1/A$ for protons.

In the present calculation, we have taken G_1=20.75 and G_2=16.20. This choice of G_M is appropriate for the single particle space employed in the model, where three major shells are used for each type of nucleons (N=2, 3, 4 for both neutrons and protons) which are same as those used in literature[11,12] for the same mass region. The quadrupole pairing strength G_Q is proportional to G_M and the proportionality constant is fixed as 0.16.

3 Results and Discussion

TPSM calculations proceed in various steps. In the first step of TPSM calculations, the deformed basis space is constructed by solving the triaxially deformed Nilsson potential[13]. In the present work we have employed ε=0.300 and ε'=0.120 in the Nilsson potential to generate the deformed basis for ^{82}Sr. The value of ε and ε' has been chosen so that the behaviour of the yrast band and γ-band is properly described. In the second step, the good angular momentum states are obtained from the deformed basis by employing the three dimensional angular momentum projection techniques. The projected bands obtained from 0-, 2-, 4-qp states are displayed in Fig. 1. It is observed from Fig. 1 that the projected band from two quasi neutron state having K=1 cross the ground band at I=12 and becomes yrast until I=16. The 4-qp structure having K=2 cross the ground band at I=14and above I=15, becomes yrast up to I=20. Above I=20 the 4-qp structure having K=4 becomes yrast for all the spin values up to I=24.

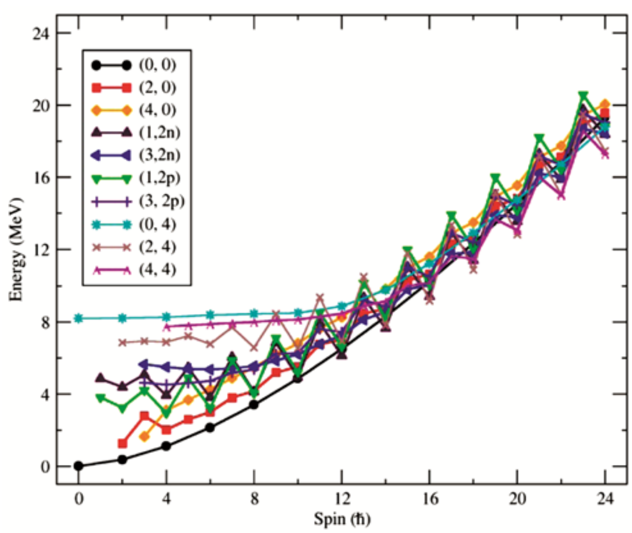

Fig.1 — Theoretical band diagram for ^{82}Sr. The labels (K, #) characterize the states, with K denoting the K quantum number of quasi particles and # the number of quasi particles. Here p and n denoting proton and neutron respectively.

In the final step, the projected basis is used to diagonalize the shell model Hamiltonian in Eq. (4). The lowest three bands obtained after diagonalization for each angular momentum are shown in Fig. 2 with the available experimental data. Theoretical results for the yrast band are in good agreement with experimental data up to known spin I=16 and this band is further theoretically extended up to spin I=24. Our calculations give slightly higher excitation energies from spin I=10 to 14.

For even-even nuclei usually γ band for even spin (α=0) is experimentally more favoured. But in this case γ band for only odd spin (α=1) is observed[14]. Theoretically we have predicted the γ- and 2γ band for even spin (α=0) and 2γ band for odd spin (α=1) with TPSM calculations. These bands may be populated in future experiments. The theoretical γ band for odd spin (α=1) is produced upto spin I=25. However experimental data are available up to spin I=9 and are well reproduced by TPSM calculations.

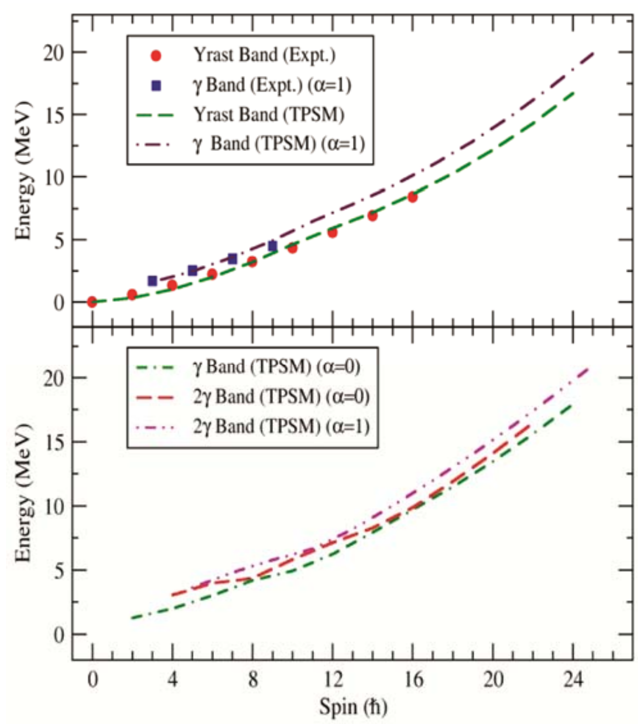

Fig. 2 — Comparison of the calculated band energies with available experimental data for ^{82}Sr. Experimental data taken from Ref.[14].

To know the alignment behaviour in ^{82}Sr, angular momentum is displayed as a function of transition energy ΔE in Fig. 3 for both calculated and experimental data. The alignment of yrast band is well reproduced by taking the mixing of multi-qp states. It is clear from the band diagram and mixing parameter obtained after diagonalization that until spin I=10 the yrast band is dominated by (0, 0) configuration. Two-quasi proton configuration with K=1 becomes the dominant configuration from spin I=10 to 16 with notable mixing of K=3 (2-quasiproton) state and K=0

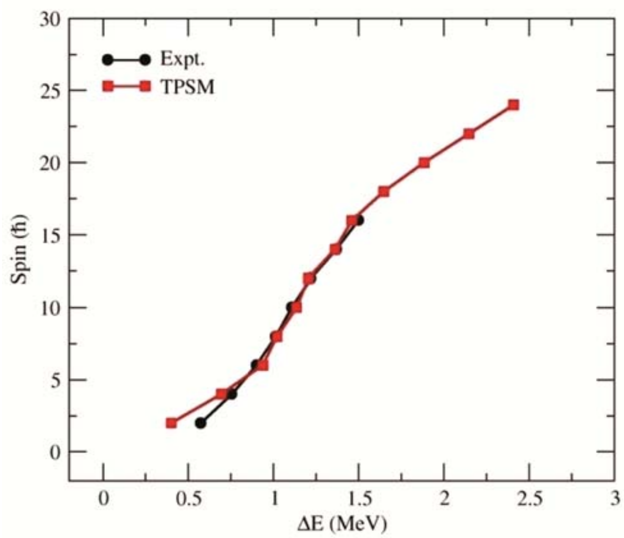

Fig. 3 — Comparison of the TPSM calculation with experimental data for the relation between spin I and transition energy ΔE.

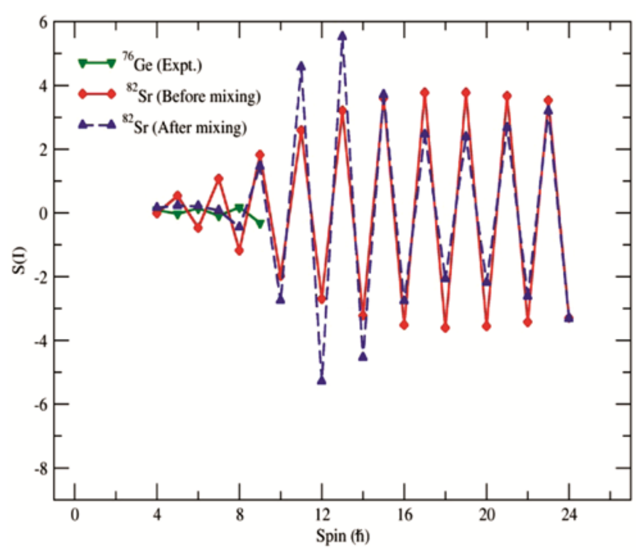

Fig. 4 — Comparison of calculated staggering parameter for the γ band of ^{82}Sr before and after configuration mixing with experimental staggering phases of ^{76}Ge. Experimental data taken from Ref.[14].

vacuum state. Above spin I=16 the yrast band is mostly dominated by 2-quasiproton and vacuum configurations with substantial mixing of quasi neutron and 4-qp configurations.

The staggering parameter defined as S(I)=[{E(I)-E(I-2)}-{E(I-1)-E(I-2)}]/E(2_1^+) is plotted for the theoretical γ band of ^{82}Sr before and after configuration mixing and compared with the staggering phases of experimental γ band of ^{76}Ge in Fig. 4. For low spins, the amplitude of oscillation is increasing with spin and shows a change in staggering phases after configuration mixing. However for high spin states after I=14 the staggering for ^{82}Sr follows the opposite phase as that of^{76}Ge and it predicts γ-softness in high spin region[6].

4 Conclusions

Theoretical calculations have been done for the yrast and γ vibrational bands of ^{82}Sr using multi-quasi particle TPSM approach. TPSM results for the yrast and γ band-energies are in good agreement with known experimental energies. Further, the 2γ band is predicted which may be identified in future experiments. In low spin region rigid triaxial shape is predicted from the change in staggering phases. It may be a scarce candidate with rigid triaxial shape in mass ~80 region, but current experimental data are not sufficient for confirmation and requires further investigation in both theory and experiment.

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