Microscopic study of ^{159}Sm with deformed Hartree-Fock and Angular Momentum Projection model

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1. Introduction

Deep insights into the intricate nuclear processes can be acquired from the microscopic study of nuclear structure, especially at high-spin states. Neutron-rich rare-earth nuclei like Sm isotopes with $A \approx 150$ exhibit phenomena like rich shell structure, shape transition, octupole correlations, significant deformation, rotational bands, K isomers [1, 2]. In this mass region, deformation is highly sensitive to change in mass number of isotopes [3].

The rare-earth neutron-rich nuclei with $A \approx 160$, have their proton and neuron numbers between 50 to 82 and 82 to 126 respectively. In such midshell regions, the interactions among nucleons can lead to enhanced collective phenomena like nuclear deformation, vibrations, or rotations [4].

Occurence of high-Ω orbitals near proton and neutron Fermi surface [2] may lead to high-K rotational bands which makes these regions a proper platform to study behaviour of nuclear forces under extreme conditions of angular momentum and deformation.

Recent experiments on odd-N rare-earth isotopes have suggested the existence of a shell gap at $Z = 60$. This conclusion is based on the observations of systematic signature splitting [5].

Several theoretical models have been applied to study even-even nuclei, while the odd-A nucleus ^{159}Sm has been explored through few models like the projected shell model and the quasiparticle rotor model [2]. Although some properties have been explained, key aspects such as rotational bands, electromagnetic properties, and reduced transition probabilities still lack explanation and the spin values are yet to be confirmed. This work aims to explore the high-spin states of ^{159}Sm, offering new discoveries into its energy spectra, signature effects, electromagnetic transition rates, structural evolution, B(E2) and B(M1) values through the deformed Hartree-Fock model with Angular Momentum (J) Projection, along with a re-examination of previous findings for a comprehensive understanding.

2. Formalism

The nuclear Hamiltonian, implemented to derive the HF equation, consists of components for single particles and two-body interactions. This HF equation is solved to generate the deformed HF orbit [6]. The two body interaction between the active nucleons is considered to be the surface delta (SD) interaction with a strength of 0.36 MeV. These calculations have been performed with spherical core at $Z = 50$ and $N = 82$. The model space consists of 6 orbitals in both proton and neutron side. The list of orbitals alongwith their SPEs are listed in Table 1. Fig. 1 depicts prolate HF orbits for ^{159}Sm.

TABLE I: Single-particle energies (SPEs) of proton and neutron orbitals.

Proton	$g_{7/2}$	$d_{5/2}$	$s_{1/2}$	$d_{3/2}$	$h_{11/2}$	$h_{9/2}$
SPEs (MeV)	0	0.731	3.654	3.288	2.305	7.1
Neutron	$f_{7/2}$	$p_{3/2}$	$f_{5/2}$	$h_{9/2}$	$p_{1/2}$	$i_{13/2}$
SPEs (MeV)	0	2.794	3.432	0.686	4.462	1.487

An intrinsic state $|\phi_K\rangle$, is a superposition of several J states lacking a unique J (due to the axial deformation of the HF field, intrinsic states are states with good K but not of good J). We need good J states for calculation of spectra and other spectrosopic properties. The states with good J of a given in-

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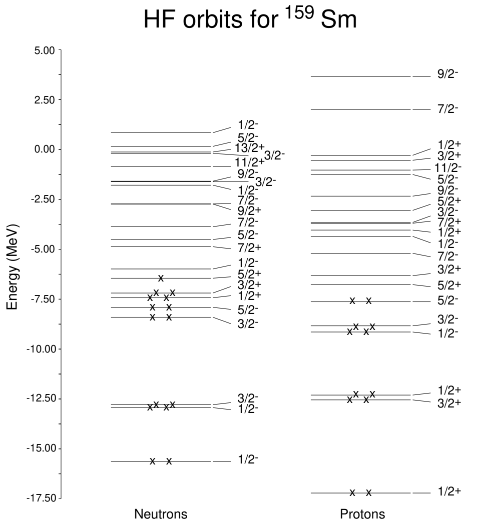

FIG. 1: HF Orbit for ^{159}Sm, particle occupied upto Fermi surface are shown by 'x'.

trinsic state are obtained through angular momentum projection. To calculate spectra and spectroscopic properties, states with good J are needed. These are obtained from a given intrinsic state through J projection. The J-projection operator is:

$$P_K^{JM} = \frac{2J+1}{8\pi^2} \int d\Omega \; D_{MK}^{J\;*}(\Omega) \; R(\Omega) \qquad (1)$$

More detail information about formalism is available at Ref.[6].

3. Results and discussions

Three negative parity bands with bandheads $K = 5/2^-$ (B1), $K = 13/2^-$ (B2), and $K = 11/2^-$ (B3) have been observed experimentally in ^{159}Sm isotope. Theoretical equivalent of these bands have been calculated by considering various combinations of one and three quasiparticles. For more qualitative results, we have mixed the Rotational aligned (RAL) configurations and compared the band-mixed data with bands that were observed experimentally. Fig.2(a,b) compares the theoretical and experimental bands. Results from our calculations appear to be in good agreement with the observed results. For every band, we have presented both favored and unfavoured signature partners. The highest observed experimental state is at spin $29/2^-$ while we observe it upto $63/2^-$. For the bands shown here, Q_0 lies around $4.7e^2b^2$ and $\beta \approx 0.23$. Magnetic moment of the bandhead are $0.348\mu_N$ and $0.997\mu_N$ for C1 and C2 respectively.

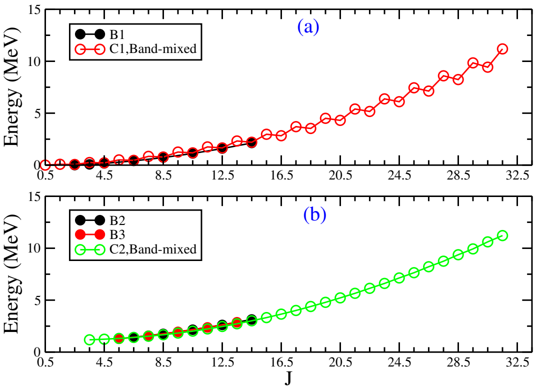

FIG. 2: Comparision of experimental (as given in [7]) and theoritical spectrum (band mixed).

4. conclusion

The experiment and our results match each other quite well. The data presented here reflects a portion of our results. In addition to the current spectrum, we have also computed spectra for a few additional configurations and values of Q_0, μ_N, β, B(E2) and B(M1) for future reference. More results will be presented at the symposium.

References

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