Exploring the interplay between single-particle and collective modes in $f_{7/2}$ shell: A case study of ^{50}Cr

Yashraj[1,2],[*] U. S. Ghosh[1], R. P. Singh[1], and B. R. Behera[2]
[1]*Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA and*
[2]*Department of Physics, Panjab University, Chandigarh - 160014, INDIA*

Introduction

The study of the collective behavior of deformed nuclei is a classical problem in nuclear physics. The detailed investigation of nuclear structure, driven by the significant occupancy of the $f_{7/2}$ shell, offers an excellent opportunity to explore the interplay between single-particle and collective degrees of freedom as functions of both angular momentum and the number of valence particles [1]. This exploration has only become feasible due to the development of highly efficient detector arrays and advancements in theoretical methods, which allow for detailed studies of these relatively light nuclei at high spins.

The nuclei in the $f_{7/2}$ shell are particularly interesting as they are heavy enough to exhibit complex rotational behavior, including backbending and band termination, while still being accessible for extensive shell model (SM) calculations. These nuclei also allow for alternative descriptions through mean-field methods, providing a complementary perspective [2]. A detailed microscopic understanding of the various phenomena observed in these nuclei is essential for testing the nuclear residual interaction in both collective and shell model frameworks.

Of particular interest is the nucleus ^{50}Cr, which demonstrates quadrupole collectivity at low and intermediate spins. As the rotational frequency increases, several effects emerge from the interplay between single-particle and collective properties. The first backbending, observed at I=10$\hbar$ is interpreted as a consequence of a change of shape from collective prolate to noncollective oblate. However, at I=16$\hbar$, a second backbending occurs, indicating a further configuration change, which eventually leads to a triaxial shape [3, 4].

Recent advances in large-scale shell model calculations have enabled computations for these nuclei involving the full pf shell model space. In this study, the SM calculations for the ^{50}Cr, located near the middle of the $f_{7/2}$ shell are presented. These calculations offer new insights into the microscopic origins of the interplay between single-particle and collective modes, thereby enhancing our understanding of nuclear structure in this region.

Methodology

In the SM calculations, ^{50}Cr is described in $0\hbar\omega$ space *i.e.* ten particles are allowed to occupy all the states available in the pf shell, including the $1f_{7/2}$, $2p_{3/2}$, $1f_{5/2}$ and $2p_{1/2}$ orbitals. The total m-scheme dimension for diagonlisation was $\sim 10^7$. A minimally modified version of the Kuo-Brown G matrix: `KB3` [5], along with `gxpf1` [6], is used as the effective Hamiltonian. The effect of core polarization on quadrupole properties is taken into account by the use of effective charges q_π=1.5, q_ν=0.5. The secular problem is solved using the code `KSHELL` [7], a very fast and efficient implementation of the thick-restart block Lanczos method.

Results & Discussion

The computed energy levels using SM calculations matches very well with the

---

[*] Electronic address: `yashraj1324@gmail.com`

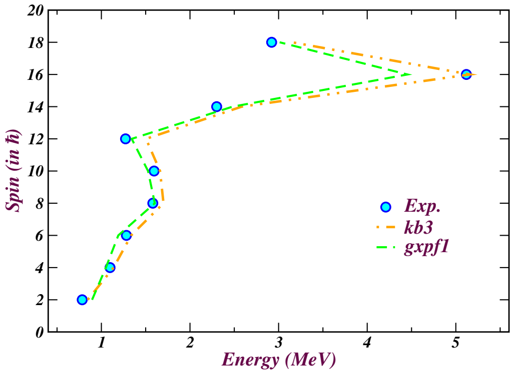

FIG. 1: Experimental and shell model computed stretched quadrupole yrast transitions of ^{50}Cr.

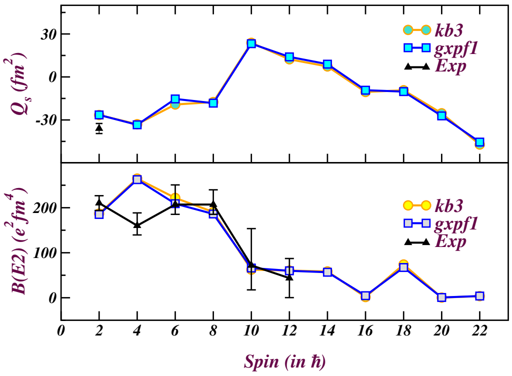

FIG. 2: Spectroscopic quadrupole moment Q_s (upper panel) and B(E2, I→I-2) (lower panel) computed in the SM approach using `kb3` and `gxpf1` interactions. The experimental values are also shown as triangles.

experimental data [8]. Both the interactions, `kb3` and `gxpf1`, successfully reproduce the observed two backbendings, as depicted in Fig. 1. The computed spectroscopic quadrupole moment (upper panel) and B(E2) values (lower panel) are illustrated in Fig. 2 along with experimental data. It is evident that the calculations demonstrate a rotor-like behavior up to I=8$\hbar$, with a large negative Q_s, consistent with a constant positive Q_0. Following this, a backbending occurs at I=10$\hbar$, with an abrupt change to positive Q_s that persists from I=12$\hbar$ to 14$\hbar$, while the B(E2) values are simultaneously reduced.
At I=16$\hbar$, Q_s changes sign abruptly again and second backbending occurs. These results are in complete agreement with the HFB picture, which predicts ^{50}Cr as an axially symmetric prolate at low spin, becomes weakly deformed and oblate due to backbending (I=10$\hbar$) and eventually becomes triaxial after the second backbending (I=16$\hbar$) [4].

Further comprehensive details of transition probability, g-factors, and occupation probabilities of distinct orbitals, along with an elaborate discussion regarding different modes of excitations in terms of these observables, will be presented during the symposium.

Acknowledgments

The authors would like to thank the National Supercomputing Mission (NSM) for providing computing resources of 'PARAM RUDRA' at IUAC, New Delhi, implemented by C-DAC and supported by the Ministry of Electronics and Information Technology (MeitY) and Department of Science and Technology (DST), Government of India.

References

[1] E. Caurier *et al.*, Phys. Rev. Lett., **75**, 2466 (1995).
[2] S. M. Lenzi, Physica Scripta, **T88**, 100 (2000).
[3] S. M. Lenzi *et al.*, Phys. Rev. C **56**, 1313 (1997).
[4] G. Martínez-Pinedo *et al.*, Phys. Rev. C **54**, R2150 (1996).
[5] A. Poves *et al.*, Phys. Rep. **70**, 235 (1981).
[6] M. Honma *et al.*, Phys. Rev. C **65**, 061301(R) (2002).
[7] N. Shimizu *et al.*, Comp. Phys. Comm. **244**, 372 (2019).
[8] https://www.nndc.bnl.gov/