Reproduction of backbending phenomena in ^{48}Cr: A shell model approach

Yashraj[1*] and R. P. Singh[1]
[1]*Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA*

Introduction

In N = Z nuclei, neutrons and protons occupy the same orbitals and study of such nuclei is expected to give the important information about neutron-proton (n-p) interaction. The spectroscopy of $1f_{7/2}$ nuclei provides a good test for shell model calculations and associated effective interactions in A∼40-50 region. The nucleus ^{48}Cr, with four protons and four neutrons outside the doubly closed shell nucleus ^{40}Ca, has the maximum number of particles to develop deformation in the $1f_{7/2}$ orbital and displays a rotational-like ground state band [1].

The backbending phenomena, as well as shape changes can be understood in terms of the dynamical evolution of the interactions among nucleons in various orbitals with increasing excitation energy and angular momentum. In $1f_{7/2}$ shell nuclei, the neutron-proton correlations play a crucial role as the valence nucleons are filling the same shell. For N=Z nuclei in a single-j shell, cranked deformed shell model calculations which include T=0 and T=1 pairing correlations, predict the simultaneous alignment of proton and neutron pairs in case of ^{48}Cr [2].

The rotational properties of the $1f_{7/2}$ nuclei are also affected by the underlying microscopic structure since the valence nucleons can align fully along the rotational axis creating band-terminating states. A fingerprint of the band-termination process in this mass region could be the smooth decrease of the moment of inertia as the nucleus approaches the upper limit of spin available in the single-j shell and has been observed in this mass region [2].

*Electronic address: yashraj1324@gmail.com

I($\hbar$)	Exp	GXPF1	GXPF1A	KB3	KB3G
2	752	884	788	806	774
4	1106	979	929	1017	967
6	1586	1578	1512	1575	1512
8	1743	1576	1524	1730	1655
10	1875	1702	1676	1850	1793
12	1348	1251	1293	1481	1451
14	1869	2024	1979	2135	2063
16	3029	3232	3105	3291	3222

TABLE I: Comparison of experimentally obtained γ-ray energies of ground state band (in keV) and SM calculations using GXPF1, GXPF1A, KB3 & KB3G as effective Hamiltonian.

Understanding the backbending phenomena in ^{48}Cr using Large Scale Shell Model (LSSM) calculations was the prime motivation of this work.

Methodology

The shell model (SM) calculations were performed for ^{48}Cr using M-scheme based KSHELL code [3, 4]. Four effective Hamiltonians *viz.* KB3, KB3G, GXPF1 & GXPF1A with^{40}Ca as core and $1f_{7/2}$, $2p_{3/2}$, $1f_{5/2}$ and $2p_{1/2}$ orbitals as (fp) model space for both protons and neutrons were used to calculate the energy levels upto $I = 16\hbar$ for even spins only.

The calculations were performed using the FUJITSU workstation at IUAC having Intel Xeon processor with clock speed 2.40 GHz and 64GB RAM. This machine has 20 cores (10x2) and a 1TB storage.

Results & Discussion

The experimental γ-ray energy of ground state band compares very well with KB3 eigen values upto $I = 10\hbar$ and for higher spin

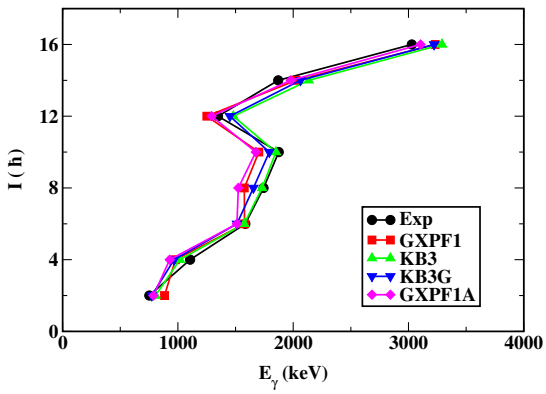

FIG. 1: Plot of experimental and SM calculated γ-ray energy of ground state band *vs.* spin using GXPF1, GXPF1A, KB3 & KB3G interactions.

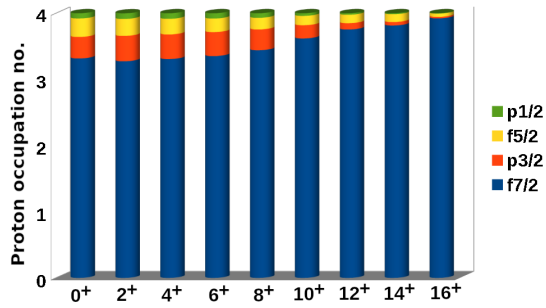

FIG. 2: Occupation probability plot for even spin ground band states for protons using KB3 interaction (same results obtained for neutrons).

states with GXPF1A interaction. Although the SM results with all the effective hamiltonians nicely reproduce the experiment data including the backbending at $I = 10\hbar$ can be observed from the plot of γ-ray energy of ground state band*vs.* spin in Fig. 1. The occupation probability plot with KB3 interaction (Fig. 2) shows maximum contribution from $1f_{7/2}$ orbital that plays a major part in the two yrast regimes: below backbend ($I = 10\hbar$) as well as above it.

Conclusions

The experimental and SM calculations are in good agreement for all the effective hamiltonians conforms the large scale SM calculations as a potent and reliable tool in the full fp space. Moreover the interesting case of bend-bending in ground state band at $I = 10\hbar$ has been conformed in ^{48}Cr using these calculations.

Acknowledgments

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