Theoretical study of band structure of even–even ^{54,56}Cr isotopes

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Introduction

The nucleus is a quantum mechanical many-body system consisting of many nucleons and the fundamental theory to govern the nuclear structure is Quantum Mechanics, therefore the basic equation to describe it must be the Schrodinger equation. It is however very difficult and almost impossible to precisely solve the many-body Schrodinger equation for such a complicated system comprising of nuclei and therefore we assume a simple model which is very easy to treat and understand. The recent development in the experimental gamma-ray spectroscopy techniques allowed for a systematic study of the nuclei filling the $f_{7/2}$-shell [1]. The structure of these nuclei is characterized by a large variety of phenomena of collective and single-particle nature. These nuclei form a unique island in the nuclide chart as they have a low number of active valence particles to allow for a full shell model description but already large enough to develop a collective behavior with all its consequences. Therefore, they constitute the ideal ground for comparing very different nuclear models, such as the shell model and mean field calculations in the intrinsic reference system (e.g., Cranked Hartree-Fock-Bogolyubov), within the same nucleus[1]. The middle of the shell is characterized by large deformations near the ground state, but moving away toward the ends of the shell the collective behavior is replaced by single-particle effects. As the excitation energy increases, the single-particle degrees of freedom and the collective ones compete to produce band termination, shape changes and backbending effects[1]. The single-particle structure that exists for spherical nuclei near closed shells gives way to more collective rotational structure for deformed nuclei that have a large number of valence nucleons outside closed shells. The neutron-rich Cr isotopes are located at a key point on the pathway from the N = 40 subshell closure via a deformed region to spherical nuclei at N = 28 and these neutron-rich *fp*-shell nuclei, bounded by $20 \leq Z \leq 28$ and $28 \leq N \leq 40$, represent one region of the nuclear chart where significant developments have occurred recently. [2].Hence, with this aim in mind, the present work has been mainly focused on studying the correlation between the proton and neutron orbitals in evaluating the structure of even-mass ^{54,56}Cr nuclei.

In order to explain the structure of ^{54,56}Cr nuclei , an effort has been made in the present work to elucidate the structure of even-mass ^{54,56} Cr (Z = 24) nuclei in the PSM and the present PSM calculations have been found to explain most of the experimental observation quite successfully in these nuclei.

The Theory of the Applied Model

To carry out the nuclear structure calculations for, ^{54,56}Cr nuclei, Projected Shell Model [3,4] is employed, which is the modified form of the shell model approach. However, unlike the conventional shell model, the PSM begins with the deformed (Nilsson-type) single particle basis. Such a shell model basis violates the rotational symmetry, but it can be restored by the standard angular-momentum projection technique. In this section, we are giving a brief introduction of the PSM. The total Hamiltonian is of the form

$$\hat{H} = \hat{H}_o - \frac{\chi}{2}\sum_{\mu}\hat{Q}^{\dagger}_{\mu}\hat{Q}_{\mu} - G_M \hat{P}^{\dagger}\hat{P} - G_Q\sum_{\mu}\hat{P}^{\dagger}_{\mu}\hat{P}_{\mu}$$

Where H_o represents the spherical single particle Shell Model Hamiltonian, 2nd, 3rd and 4th terms in the Hamiltonian denote the two-body interactions: quadrupole-quadrupole, monopole-pairing and quadrupole-pairing forces, respectively. χ denotes the Q.Q force strength and its value is adjusted via self-consistent conditions with a given quadrupole deformation ε_2. The choice of the strengths G_1 and G_2 depends on the size of the single particle gaps in the calculations. The quadrupole pairing strength, G_Q, is supposed to be proportional to G_M and is adjusted to be 0.24. For the present calculations, pairing strengths G_1 and G_2 are adjusted as 22.50 and 13.00 respectively. The other set of deformation parameters, quadrupole (ε_2) and hexadecapole (ε_4) are set as 0.295 and 0.050 and 0.285 and 0.140 for ^{54,56}Cr nuclei, respectively.

Results and Discussions

To extract structural information from the PSM calculations, it is useful to discuss the energies in terms of band diagram. Also, band diagram plays a crucial role for the interpretation of the yrast states, which is the lowest band and is obtained after configuration mixing of various multi quasi-particle configurations. In the present study, the yrast levels and their composition i.e., band structures from multi-quasi-particle configurations for ^{54,56}Cr nuclei have been investigated.

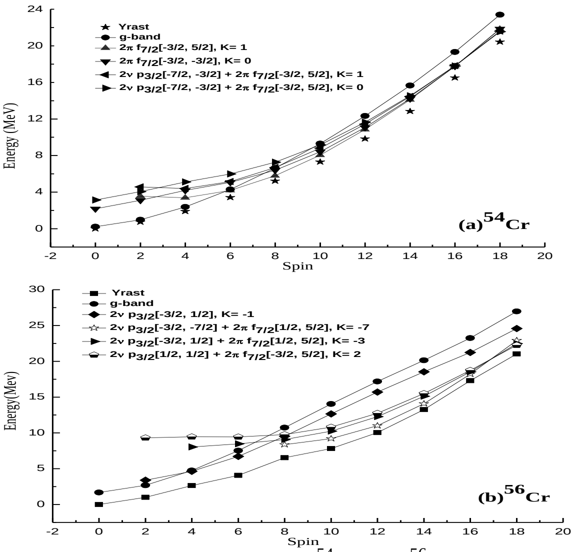

Fig. 1 Band diagrams of (a) ^{54}Cr, (b) ^{56}Cr

For ^{54}Cr isotope (fig. 1(a)), the yrast spectra upto spin 4^+ coincides with the g-band arising from 0-qp intrinsic state. At spins 6^+ and 8^+, the g-band is crossed by two 2-qp proton bands having configurations $2\pi f_{7/2}$[-3/2,5/2], K = 1 and $2\pi f_{7/2}$ [-3/2,-3/2], K= 0, respectively which contributes to the formation of yrast spectra upto 18^+. But, for reaching at spin 18^+, two 4-qp bands having configurations $2\nu p_{3/2}$[-7/2, -3/2] + $2\pi\ f_{7/2}$[-3/2, 5/2], K= 1 , $2\nu p_{3/2}$[-7/2, -3/2] + $2\pi\ f_{7/2}$[-3/2, 5/2], K= 0, cross the g-band at 10^+ and get lower in energy, thereby contributing in the yrast formation upto the last calculated along with the afore mentioned two 2-qp bands. In case of ^{56}Cr (fig. 1(b)), the yrast states upto spin 4^+ arise from g-band. At spin 6^+, a 2-qp neutron band having configuration $2\nu p_{3/2}$[-3/2, 1/2], K= -1 crosses the g-band and contributes to the yrast upto spin 10^+. From spin 10^+ upto last calculated spin value i.e., 18^+ , the yrast state is contributed by the superposition of three 4-qp bands having configuration $2\nu p_{3/2}$[-3/2, -7/2] + $2\pi\ f_{7/2}$[1/2, 5/2], K= -7, $2\nu p_{3/2}$[-3/2, 1/2] + $2\pi f_{7/2}$[1/2, 5/2], K= -3 and $2\nu p_{3/2}$[1/2, 1/2] + $2\pi\ f_{7/2}$[-3/2, 5/2], K= 2. Furthermore, Figs. 2(a) & 2(b) present the yrast spectra of ^{54,56}Cr. The experimental data (taken from Refs. [5,6]) has been reproduced with an overall good agreement by the calculated values of energy for ^{54,56}Cr.

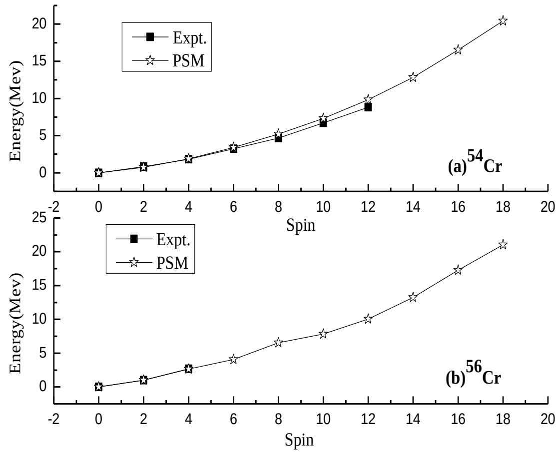

Fig. 2 Comparison of the Experimental and PSM yrast spectra for (a) ^{54}Cr, (b) ^{56}Cr

Summary

The ^{54,56}Cr isotopes have been studied within a theoretical microscopic technique-Projected Shell Model. The compositions of the yrast levels from various multi-quasi-particle configurations for ^{54,56}Cr isotopes have been well described. Further, the comparison of the yrast levels with the available experimental data has also been made and a good level of agreement has been obtained.

References

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