Shell-model calculations of $f_{7/2}$ shell nuclei in the full pf configuration space

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Introduction

Nuclei with A∼50 are referred to as $f_{7/2}$ shell nuclei, whose proton and neutron numbers lie between the magic numbers 20 and 28. Although the number of active valence particles is low enough in these nuclei to allow for a full shell-model description, these nuclei form an interesting island in the nuclide chart. Among the $f_{7/2}$ shell nuclei, ^{48}Cr plays a central role because it has the maximum number of valence protons and neutrons in the $1f_{7/2}$ orbit, thereby exhibiting the maximum quadrupole collectivity.

The level structures of the nuclei from ^{40}Ca to ^{56}Ni are well described within the framework of the shell model, and are dominated by the $(f_{7/2})^n$, and $(f_{7/2})^{n-r}$ $(f_{5/2}p_{3/2}p_{1/2})^r$ configurations, where r = 1,2,... . Yrast levels of the majority of $f_{7/2}$-shell nuclei follow the shell model pattern, exhibiting somewhat irregular level spacings, often with a marked discontinuity at the termination of the $f_{7/2}$ band of states at $J_{max} = J_{p\ max} + J_{n\ max} = \frac{1}{2}$ [Z(8-Z)+N(8-N)]. This is particularly apparent in the nuclei near N or Z = 20, 28 where J_{max} is not large.

Shell-model calculations in the full pf shell have been attempted many a times earlier, and reasonable descriptions of experimental observables were obtained [1, 2]. However, due to limitations of computing power, valence space truncation or restrictions on occupation of orbitals for valence particles were imposed in several instances [1].

In the present work, Large Scale Shell Model (LSSM) calculations for several $f_{7/2}$ shell nuclei have been performed in the full pf shell with no restriction in the available valence space. The calculations have been carried out to look for exotic behavior, such as, shape change and the evolution of collectivity as a function of spin along the yrast sequence. A high performance computing system in the Nuclear Physics Division, BARC, Mumbai, has been used for the aforesaid calculations. The present work will demostrate the effect of valence space truncation, as well as the effectiveness of several effective interactions that are being regularly employed to describe experimental observables in this region.

1. Shell model calculations

The model space that has been used has ^{40}Ca as the core, and the $f_{7/2}p_{3/2}f_{5/2}p_{1/2}$ orbitals constitute the valence space. As previously mentioned, all the valence particles above the ^{40}Ca core were allowed to excite from the $f_{7/2}$ orbit to the rest of the pf-shell. The code NuShell@MSU [3] was used in conjunction with the various commonly used effective interactions for the pf-shell including $GXPF1$ [4–6]. The effective interactions can, in principle, be derived from the free nucleon-nucleon interactions. The monopole-modified interaction $KB3$ [7], and also the shell-gap readjusted version $KB3G$ [8], appear to be quite successful in the lower pf-shell (A≤52). On the other hand, the $FPD6$ [9] interaction assumes an analytic two-body potential, with parameters determined from fits to the experimental data in the A = 41∼49 nuclei. The $GXPF1$ [4–6] interaction has been derived from a microscopic interaction where

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a subset of the 195 Two Body Matrix Elements ($TBME$) and 4 Single Particle Energies (SPE) were determined by fitting to experimental energy data for 699 energy levels from 87 nuclei (47≤A≤66).

In the calculations, apart from the configurations of the states, the transition probabilities have also been computed from the associated wavefunctions, and compared with the experimental values. It is to be noted that the proton (e_p) and neutron (e_n) effective charges were taken as 1.5 and 0.5, respectively, in the calculations.

Calculationsign of static (spectroscopic) quadrupole moment provides an indication of the shape of a nucleus. Zamick *et al.* [10, 11] had reported a possible change in shape in ^{50}Cr by observing multiple sign changes in the static quadrupole moment in going up the even-spin states along the yrast line. The same prescription of Zamick *et al.* [10, 11] has been followed in the present calculations for other $f_{7/2}$ shell nuclei.

Calculations for the positive parity levels of a few $f_{7/2}$ shell nuclei have also been performed including the *sd* shell using the SDPF interaction, allowing excitations of valence particles from the $d_{3/2}$ orbit to the pf shell. All these aforesaid calculations and results in detail will be presented during the symposium.

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