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Shell model analysis of intruder states and high-K isomers in the fp shell

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Abstract. We perform a systematic shell-model study of collective intruder structures and fully aligned high-spin states in nuclei from the lower-fp shell in the $sdfp$ configuration space. We analyze the intruder structures associated with the 1p-1h cross-shell excitations from the sd shell that have been observed in several nuclei from this region, including ^{44}Ti and ^{44}Sc. We compare the shell-model calculations to the recent mean-field work (H. Zduńczuk, W. Satuła, R.A. Wyss, nucl-th/0408018) and experimental data (M. Lach, J. Styczeń, private communication). The high-spin behavior may be understood in terms of the competing cross-shell proton and neutron excitations. The interplay between proton and neutron intruder states is reflected in the angular-momentum dependence of electromagnetic rates.

PACS. 21.60.Cs Shell model – 21.10.Ky Electromagnetic moments – 21.10.Pc Single-particle levels and strength functions – 27.40.+z $39 \leq A \leq 58$

1 Introduction

The nuclei of the $f_{7/2}$ shell are of special interest due to the presence of intruder states which can give rise to shape coexistence phenomena. These nuclei lie close to the doubly magic ^{40}Ca and ^{56}Ni, and therefore their structure can often be interpreted in terms of the competition between collective or single-particle excitations. One objective of this work is to analyze high-spin states of the lower-fp shell nuclei based on large-scale shell-model (SM) calculations using the code ANTOINE [1]. In particular, we are interested in the intruder structures associated with cross-shell excitations across the $N = Z = 20$ gap.

2 Shell model analysis

In this work, we study high-spin excitations in $A \sim 44$, $20 \leq Z \leq N \leq 24$ nuclei. An excellent agreement is observed between experiment and SM for the energies at the maximally aligned states of $f^n_{7/2}$ (fig. 1, top) and $d^{-1}_{3/2} f^{n+1}_{7/2}$ (fig. 1, bottom) structures. The black bars represent our SM calculations in which 1p-1h cross-shell excitations were allowed. They are compared to experimental data given by grey bars. We used the interaction of ref. [2] where the mass scaling of the SM matrix elements was done consistently, thus reducing the sd interaction channel by $\sim 4\%$ as compared to the previous work [2].

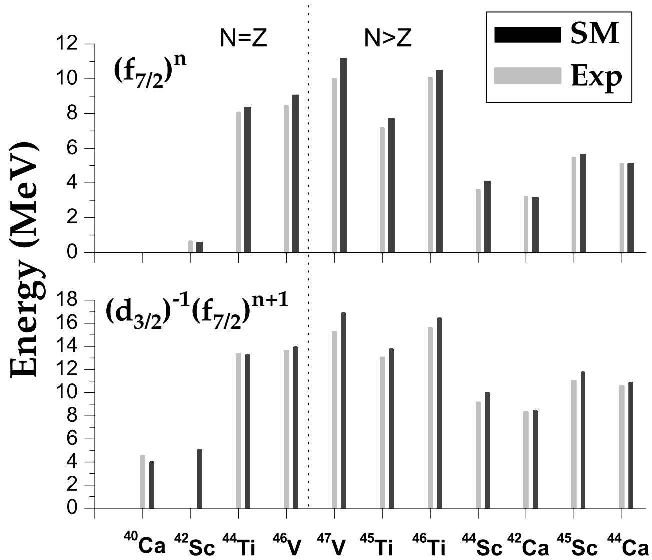

Fig. 1. Comparison between SM and experiment for the maximum spin states in $f^n_{7/2}$ (top) and $d^{-1}_{3/2} f^{n+1}_{7/2}$ (bottom) configurations in several $N = Z$ (left) and $N > Z$ (right) nuclei in the fp shell.

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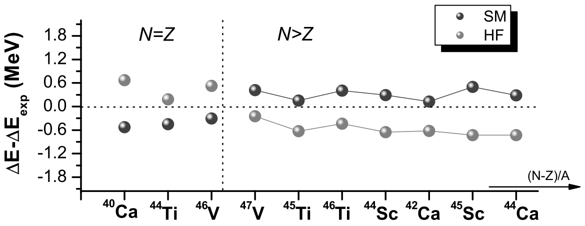

Fig. 2. Energy differences, $\Delta E - \Delta E_{\mathrm{exp}}$, for SM and HF [3] calculations.

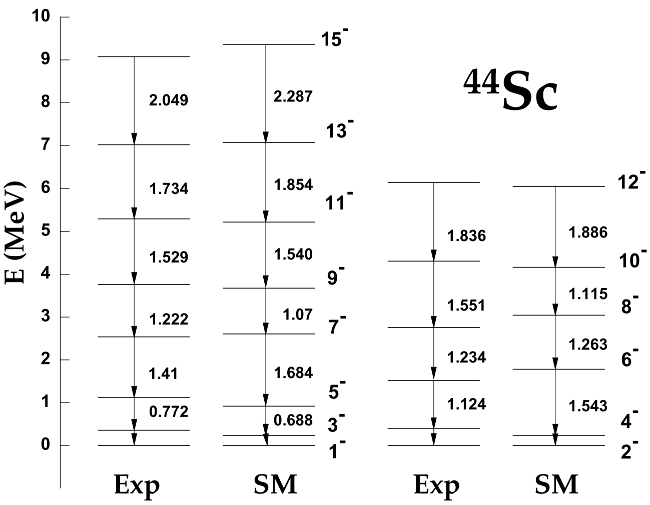

Fig. 3. Calculated negative-parity yrast structures in ^{44}Sc compared to experimental data [4].

Figure 2 shows the SM and Skyrme Hartree-Fock (HF) [3] energy differences, $\Delta E \equiv E(d_{3/2}^{-1} f_{7/2}^{n+1}) - E(f_{7/2}^{n})$, of the maximally aligned states, relative to experimental values. While for the $N \neq Z$ nuclei, the SM calculations overestimate the data by $\sim 10\%$, HF underestimates them by $\sim 10\%$. However, it is interesting to see that the resulting energy difference patterns in the SM and HF are indeed very similar. In general, excellent agreement between the SM and experiment was obtained.

High-spin states of the odd-odd ^{44}Sc nucleus have been studied in a recent experiment [4]. In the SM description, the positive-parity yrast structure of ^{44}Sc has one proton and three neutrons in the $f_{7/2}$ shell, and the maximum aligned state has $I^{\pi} = 11^{+}$. The negative-parity states up to $I^{\pi} = 15^{-}$ can be associated with the holes in the *sd* shell.

A comparison between the experimental and calculated negative-parity band is given in fig. 3, while fig. 4 (bottom) shows the predicted $B(E2)$ transition rates. The effective proton and neutron charges that are used in the calculations, $e_p = 1.33e$ and $e_n = 0.64e$, have been determined from $E2$ transitions in lower-fp shell nuclei [5]. The transition rates and the shell occupations in the wave function (fig. 4, top) nicely show the interplay between proton and neutron intruder configurations for a given angular

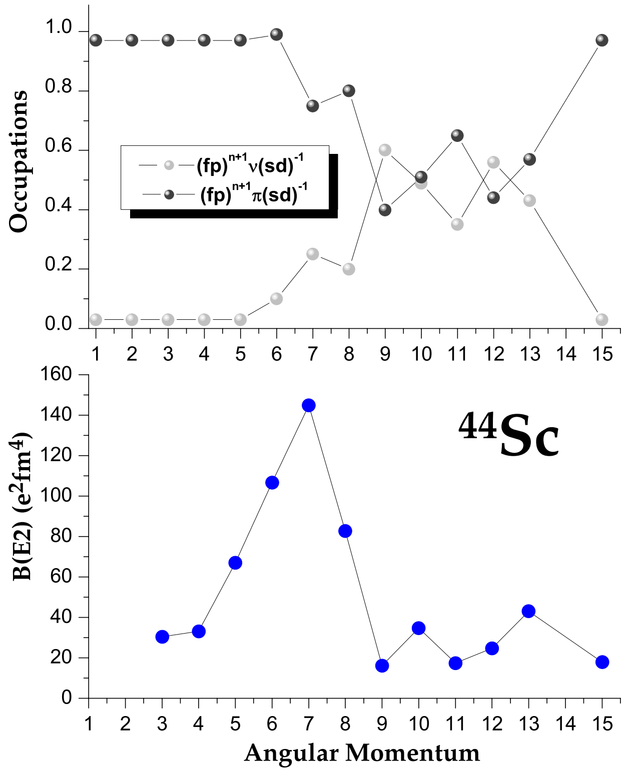

Fig. 4. Top: proton and neutron SM occupations in the $\pi = -$ intruder structure of ^{44}Sc. Bottom: calculated $B(E2)$ rates within the intruder structure.

momentum I^{π}. It is predicted that the lower spin states as well as the highest $I^{\pi} = 15^{-}$ spin state, are dominated by proton excitations. The intermediate angular-momentum spin states between $I^{\pi} = 8^{-}$ up to $I^{\pi} = 13^{-}$ are fairly equal mixtures of proton and neutron excitations.

As our present calculations are limited to 1p-1h cross-shell excitations only, some correlations are missing in our SM description. In particular, the structure $N = Z$ nuclei can be affected by an explicit absence of the 2p-2h cross-shell $T = 0$ excitations. This is shown in fig. 2, which clearly demonstrates a different behavior of ΔE for $N \neq Z$ and $N = Z$ nuclei. Detailed studies of this effect are in progress [6].

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