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sd–pf SHELL MODEL STUDIES OF M1 STRENGTH IN Ar ISOTOPES*

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The M1 strength distributions in the ^{36,38}Ar isotopes calculated in configurational space of two major $N=2$ and $N=3$ harmonic oscillator shells are discussed. It is shown that considerable breaking of ^{40}Ca core is required to reproduce total M1 sum rule and fragmentation of the M1 strength for ^{38} Ar.

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1. Introduction

Recent experimental findings show that shell closures might get eroded in very neutron-rich nuclei and that the inter-shell correlations among nucleons play a decisive role for the structure of these nuclei. A famous example is the nucleus ^{32}Mg which is strongly deformed in the ground state, despite its neutron number $N=20$, *e.g.* [1]. Thus, shell closures are not "rigid" and there have been for a long time indications for cross-shell correlations even in nuclei close to classical double-magic nuclei like ^{40}Ca. For this nucleus, these include the observation of a strong M1 transition [2] and of a non-vanishing Gamow–Teller (GT) strength built on the ^{40}Ca ground state [3–5]. On the theory side, recent studies [6,8] show that there are very large admixtures of *sd* configurations in low-energy states of Ca isotopes with $A \geq 40$, although these nuclei are usually considered as "good" pf-shell nuclei.

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In this contribution we demonstrate that the large admixtures of pf-shell configurations for both ground and excited states in ^{36,38}Ar isotopes are required to reproduce their M1 properties.

2. Large-scale shell-model calculations in the truncated *sdpf* model space

Extending the truncation scheme approach used in [6] ($s_{1/2}$, $d_{3/2}$, $f_{7/2}$ and $p_{3/2}$ orbitals are taken into account) we have performed diagonalization calculations in the $sdpf_1$ model space which includes the spin-orbit partners (missing in the [6]) approximately by allowing $1p1h$ excitations from the $d_{5/2}$ orbital to the rest of the sd shell, and from the $f_{7/2}p_{3/2}$ space to the $f_{5/2}p_{1/2}$ sub-space, respectively. In other words we put $1p1h$ predominantly spin-flip excitations on top of the complex $npnh$ $(s_{1/2}d_{3/2})^{A-28-n}(f_{7/2}p_{3/2})^n$ cross-shell configurations. This extension increases the dimension of the model space from 2.3 million to nearly 75 million for ^{38}Ar.

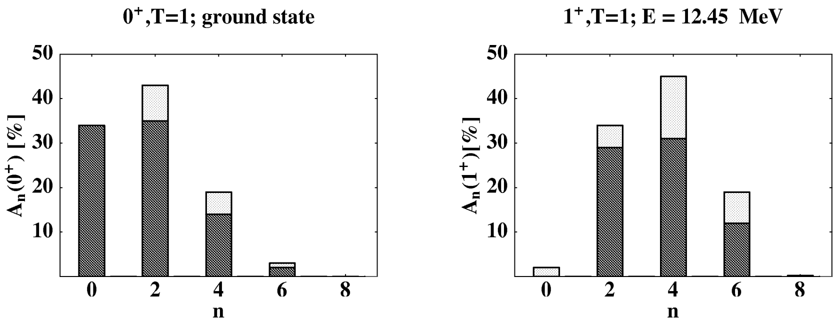

Fig. 1. The structure of the $J^\pi = 0^+$, $T = 1$ ground state (left) and $J^\pi = 1^+$, $T = 1$ state at $E = 12.45$ MeV (right) with large B(M1) value calculated for ^{38}Ar in $sdpf_1$ space. The coefficient $A_n(J^\pi)$ gives the contribution of the component with n particles promoted across the sd–pf shell gap. The upper light part of the bar shows the fraction of the n-configuration containing $1p1h$ spin-flip excitations.

For the calculations we have used the shell model code ANTOINE [9] and the same effective interaction as in [6]. Following Ref. [7] we have added the 1.5 fold of the center-of-mass Hamiltonian to the original Hamiltonian which practically eliminates spurious center-of-mass contaminations. The $sdpf_1$ model space allows up to 8 or 10 particles to be promoted from the sd-shell to the pf-shell for ^{36}Ar and ^{38}Ar, respectively. It turns out these cross-shell excitations are sufficient to achieve a good agreement between our calculations and the experimental ^{38}Ar spectrum [11]. The role of $npnh$ cross-shell and $1p1h$ spin-flip excitations in the $sdpf_1$ space for the ^{38}Ar ground and excited states is illustrated in Fig. 1.

In the $sdpf_1$ model space, only 34% of the ^{38}Ar ground state corresponds to pure sd-shell configurations. Cross-shell $2p2h$ components contribute about 43% to the ^{38}Ar ground state, where the couplings to the spin-orbit partners (main source of the spin part of the M1 strength) are sizable (8%). Higher-order cross-shell components with $n = 4$ and $n = 6$ are less important for the ground state, however they are largely represented in wave functions of the 1^+ states between 10 and 18 MeV. Worthwhile to note that there is a strong mixing of several configurations with different n-values for all the analyzed states at low and high energies. This strongly limits an application of fixed-n configuration approach to describe deformed structures at $A \approx 40$ commonly used in this mass region.

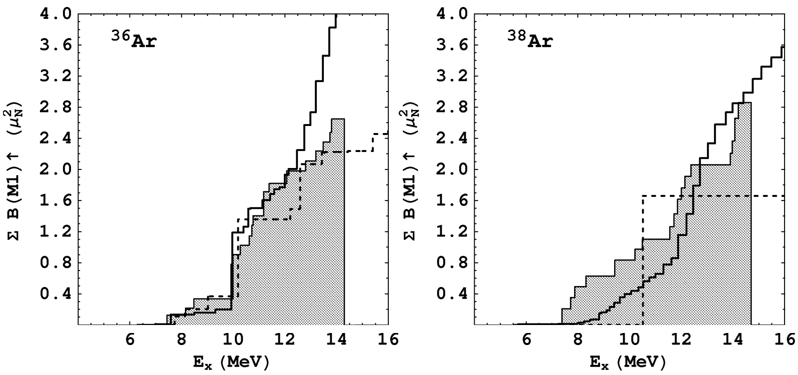

Fig. 2. Running sums of B(M1) values for ^{36}Ar (left) and ^{38}Ar (right) *versus* excitation energy. Gray shaded histograms correspond to the experiment [10]. The solid line and dashed line are the shell model results for the $sdpf_1$ and sd spaces, respectively.

We have calculated the M1 strength distributions for ^{36}Ar and ^{38}Ar in the framework described above. The spin part of the M1 operator has been scaled by a constant factor of $q = 0.75$, as it is customary in shell model calculations. The calculated M1 distributions are in good agreement with the experimental ones. To illustrate the changes for the M1 properties of Ar isotopes when we switch from the sd to $sdpf$ space we have plotted the running sums of B(M1) *versus* excitation energy in Fig. 2. There is a considerable improvement for the ^{38}Ar in comparison to the pure sd-shell results. The M1 strength below 12 MeV is slightly underestimated however the total strength is well reproduced. There are no drastic changes for M1 strength distribution in ^{36}Ar below 12 MeV but the $sdpf$ shell model overestimates the total strength above 12 MeV. In both cases (^{36}Ar and ^{38}Ar) a lot of M1 strength is predicted above 15 MeV, the region that has not been explored yet experimentally. Many other interesting details of the $sdpf$ shell model studies are discussed in [11].

3. Conclusions

We have performed large-scale shell model calculations for ^{36}Ar and ^{38}Ar within the complete $s_{1/2}d_{3/2}f_{7/2}p_{3/2}$ model space and additionally allowing $1p1h$ excitations from $d_{5/2}$ to the $s_{1/2}$, $d_{3/2}$ orbitals or from $f_{7/2}$ and $p_{3/2}$ to the rest of the pf-shell. We reproduce the energy spectra for both isotopes, including the negative parity states. Importantly our calculations identify sizable contributions of cross-shell components in the ^{36}Ar and ^{38}Ar ground states, implying the onset of erosion of the $N = 20$ shell closure. However, this erosion is a slow process involving many $npnh$ excitations until, for example, convergence of the energies of the lowest excited states is achieved. These studies reveal the onset of fragmentation in the M1 strength distributions. However, only a marginal agreement with the data has been obtained, which might be improved if higher-order cross-shell excitations are considered.

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