

RECENT ADVANCES IN THE SHELL MODEL CALCULATIONS OF THE SPECTROSCOPIC PROPERTIES OF $^{134,136,138}\text{Sn}^*$

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This manuscript reviews recent results of the shell model calculations based on a realistic interaction, where the properties of $^{134,136,138}\text{Sn}$ isotopes are investigated, including the model space above ^{110}Zr . Spectra, transitions strengths and masses are in overall good agreement with the experimental data.

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1. Introduction

In the heavy mass region around ^{132}Sn , many theoretical investigations within the mean field or the shell model [1–4] were devoted to study the properties of tin isotopes.

Recently, new experimental data has been obtained in RIKEN [5] by the observation of three delayed gamma rays each from ^{136}Sn and ^{138}Sn , originating from the 6^+ isomeric state, and are the first gamma ray transitions observed in these very neutron-rich tin nuclei. These results provide us with new information of great interest to study the nuclear structure of this mass region and for the development of empirical shell model interactions.

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2. Shell model framework

Our calculations were carried out within the shell model, including the valence space $0h_{11/2}, 1f_{7/2}, 0h_{9/2}, 1f_{5/2}, 2p_{3/2}, 2p_{1/2}, 0i_{13/2}$ orbitals for neutrons, and $0g_{9/2}, 0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2}$ orbitals for protons, taken above ^{110}Zr closed core. This model space allowed us to choose the closed core which will be used: ^{110}Zr by opening $0h_{11/2}$ for neutrons and $0g_{9/2}$ for protons, or ^{132}Sn by closing them. Opening the core constitutes a challenge in the diagonalisation of Hamiltonian matrix due to its extremely large size (of the order of 50 millions in the case of ^{138}Sn). We have used the shell model codes ANTOINE and NATHAN [6, 7], which nowadays can handle up to 10 billions Slater determinants equivalent matrices.

As a starting point, we have employed a realistic interaction, derived from CD-Bonn potential, renormalized following the so-called $V_{\text{low}-k}$ approach, and adopted to the model space by many body perturbation theory techniques, including all the diagrams up to the second order [8].

3. Applications and results

3.1. Transition rates of $^{134,136,138}\text{Sn}$

The first step of our calculations was to reproduce the experimental single particle energies and the masses of ^{133}Sn and ^{133}Sb nuclei [9], by doing monopole corrections to $V_{\text{low}-k}$, denoted hereafter by NNS110 interaction. As it is shown in figure 1, using this effective interaction, our calculations predict well the observed electromagnetic transitions $B(E2, 6^+ \rightarrow 4^+)$ of ^{134}Sn and ^{138}Sn , but they underestimate it for the mid-shell nucleus ^{136}Sn .

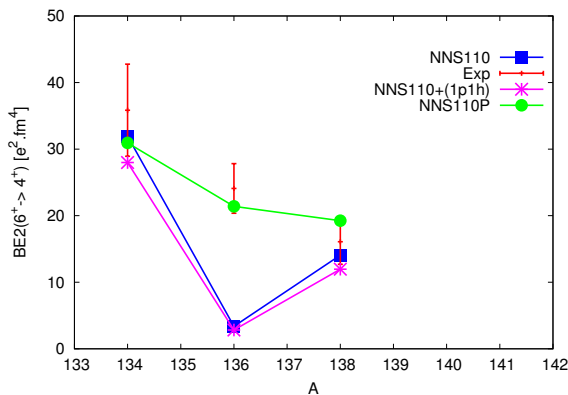


Fig. 1. Variation of the electromagnetic transitions as a function of the mass number.

Opening the ^{132}Sn core, and limiting to $1p1h$ excitations from $h_{11/2}$ neutrons, and $g_{9/2}$ protons to the above valence space, with effective charges $e_\nu = 0.5e$ and $e_\pi = 1.5e$ for neutrons and protons respectively, still fail to reproduce the experimental value of ^{136}Sn transition. Whereas, it seems that reducing the diagonal and off-diagonal $f_{7/2}$ pairing strength by about 130 keV (noted by NNS110P) reproduces correctly the observed values [5].

We can explain this result by the seniority model, where in the first two cases (NNS110 and opening ^{132}Sn core), the seniority $\nu = 2$ is the principal component of the wave functions of the first excited states in ^{136}Sn (82% in 4_1^+ , and 95% in 6^+ state), which leads to a vanishing transition strength between them. Another important point is that in this case, the 4_2^+ with dominantly $\nu = 4$ lies above the 6^+ state. Reducing the pairing force in the realistic interaction pushes down the 4_2^+ state below the 6^+ state, with a modification in the seniority structure of the two 4^+ states: their wave functions become slightly mixed 4_1^+ (52% of $\nu = 2$ and 48% of $\nu = 4$), and 4_2^+ (45% of $\nu = 2$ and 55% of $\nu = 4$), leading to a larger transitions from 6^+ to 4^+ in ^{136}Sn .

3.2. Energy levels of $^{134,136,138}\text{Sn}$

As it is displayed in figure 2, NNS110P interaction improves clearly the agreement with the data compared to NNS110 interaction, and the $(f_{7/2})^n$ (n is the valence neutron number varying from 2 to 6) is the principal component of the wave functions of the ground state and the first excited states for all tin isotopes, where its percentage decreases from 90% to about 50%, going from ^{134}Sn to ^{138}Sn . The fact of opening partially the core has a minor influence on the excited states energies of tins.

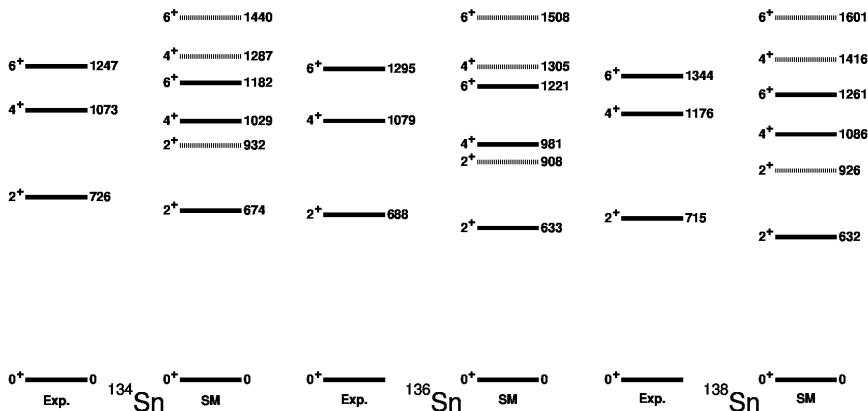


Fig. 2. Level schemes of tin isotopes, calculated using NNS110 (dotted line) and NNS110P (solid line) interactions.

3.3. Masses of $^{134,136,138}\text{Sn}$

Another challenge in the shell model is the calculation of the masses, which are reported in figure 3 relative to ^{132}Sn . As it is shown, our results using the modified interactions (NNS110 and NNS110P) are consistent with the data, compared to $V_{\text{low}-k}$ interaction, which is the initial realistic interaction derived without any empirical corrections. This result proves clearly that the monopole correction of the two-body interaction can imitate the effect of the three-body force not included in our interaction [10].

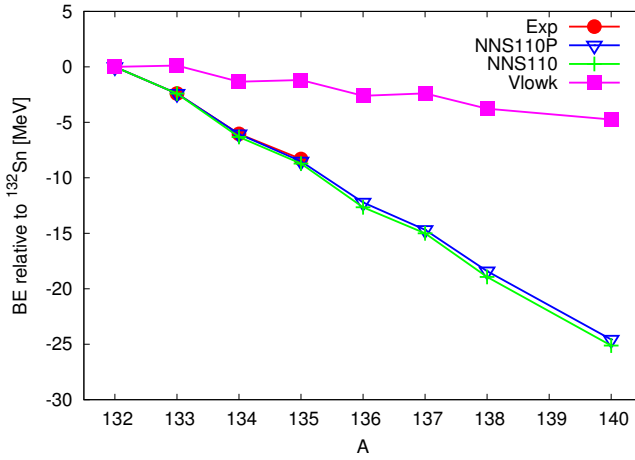


Fig. 3. Binding energies of tin isotopes relative to ^{132}Sn .

4. Conclusions

We have carried out SM calculations of excitation energies, transition rates and masses of $^{134,136,138}\text{Sn}$ isotopes, where our results using NNS110P interaction are in very good agreement with experiment.

Reducing the pairing force of the realistic interaction was necessary to reproduce the observed transition rates in ^{136}Sn , which leads to a seniority mixing effect.

The negligible impact of opening the core on the tins properties confirms the strong magicity of ^{132}Sn core.

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