Interplay between pairing and tensor effects: a study of $N = 82$ even-even isotones

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The study of the structure of nuclei in the region $N = 82$ is very interesting to understand some characteristics of astrophysics processes, like the r-process nucleosynthesis [1]. Recently experimental data about nuclei far from stability [2] indicate important changes in shell structure, and motivate a more detailed analysis of nuclei with neutron excess in the region of Sn isotopes and $N = 82$ isotones, that are accesible for the experimentalists.

In our work [3] we have first tested the fully self-consistent Hartree–Fock plus Bardeen–Cooper–Schrieffer (HF+BCS) approach with a finite-range interaction developed in [4] in the study of the isotonic chain $N = 82$. Then we have investigated the role of the tensor force on these calculations. We used two forces of Gogny type, the D1S [5] and the D1M [6]. For calculations with the tensor terms we used the D1ST2a parameterization [7] and a new one fitted in the same way but for the D1M interaction called D1MT2a.

We made comparisons between HF+BCS and HF-Bogoliubov (HFB) calculations, using the same finite range interaction: first of all, we have calculated some ground state properties, as binding energies, radii and densities with both models, obtaining a good agreement. After that, we have studied the particle number fluctuation index $\langle(\Delta N)^2\rangle$. This quantity is directly related to the relevance of the pairing effects and is defined as:

$$\langle(\Delta N)^2\rangle = 4\sum_k (2j_k + 1)\, u_k\, v_k \,, \tag{1}$$

where $|v_k|^2$ is the probability that the state $|k\rangle$, with total angular momentum j_k, is occupied, and is related to u_k by the condition

$$|u_k|^2 + |v_k|^2 = 1\,. \tag{2}$$

Also in this case, we found an overall agreement and we remark that, in general, pairing correlations are larger in the HFB model than in the HF+BCS one.

On the other hand, our main interest was to study the effect of the tensor interaction on the pairing contribution.

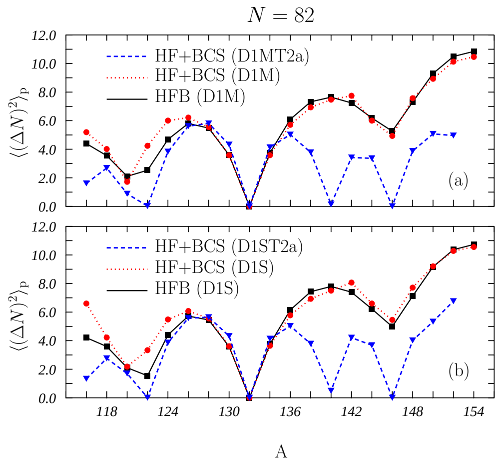

Figure 1. Values of the proton particle fluctuation index, $\langle(\Delta N)^2\rangle_{\rm p}$ obtained in HF+BCS (solid red circles) and HFB (solid black squares) calculations carried out with the D1M (panel (a)) and D1S (panel (b)) interaction, for $N = 82$. The solid blue triangles correspond to the results with the interaction with tensor D1MT2a (panel (a)) and D1ST2a (panel (b)).

In Fig. 1 we plot the value of $\langle(\Delta N)^2\rangle_{\rm p}$using the D1M and D1MT2a interactions (panel (a)) and the D1S and D1ST2a ones (panel (b)). Red solid circles (black squares) correspond to the HF+BCS (HFB) calculations. We observe that the behaviour is very similar, having only some undervalued results with HF+BCS for ^{116}Se, ^{122}Zr. Differences between both interactions are not very significative. In panel (a) we also show the results obtained using the D1MT2a interaction in the HF+BCS model (blue triangles). The tensor terms are introduced only at the HF level, then the contribution of this interaction to the BCS step is coming from the single particle states generated in the HF procedure. In general, we find that the tensor force acts in the direction of reducing the pairing correlations. The same happens when the D1ST2a interaction is used, as it can be seen in panel (b) of Fig. 1. This effect can be understood better by looking at Fig. 2 where we present the evolution of the proton single particle state occupation numbers (panel (a)) and the corresponding values for the single particle energies, calculated with the D1M (dashed lines) and D1MT2a (solid lines) interactions.

It seems clear that the states are being occu-

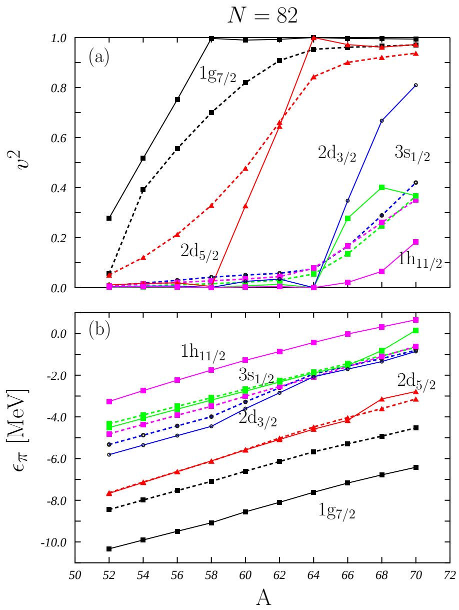

Figure 2. The occupation number for proton single particle states, calculated with the D1M interaction (dashed lines) and with the D1MT2 one (solid lines) (panel (a)). In panel (b) we present the single particle energy for each level.

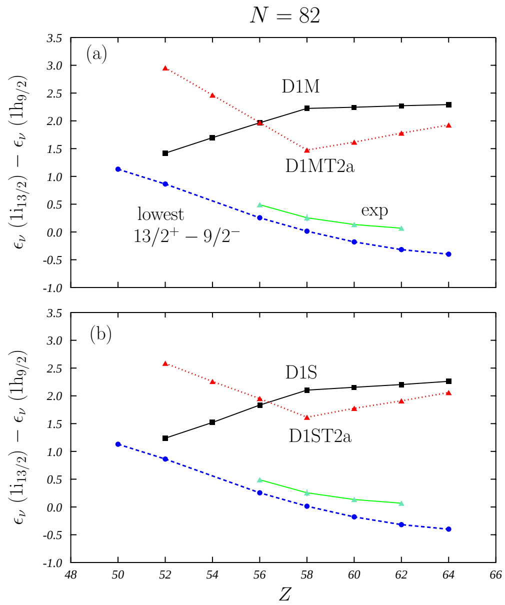

Figure 3. The difference in experimental centroid energies of the neutron states $1i_{13/2}$ and $1h_{9/2}$, from [9], compared with the energy differences between the lowest $13/2^+$ and $9/2^-$ states (dashed line) and our results using the D1M (solid line) and the D1M2T including tensor (dotted line).

pated in a more abrupt manner when tensor is included, being the proton pairing correlations less important. The reason for this reduction of the pairing effects when adding the tensor force is the increase of the proton s.p. energy difference $\epsilon_\pi(1\text{h}_{11/2}) - \epsilon_\pi\ (1\text{g}_{7/2})$ of approximately 3 MeV, as a consequence of the interaction with the neutron single particle state $1h_{11/2}$. This interaction is attractive for the proton state $1\text{g}_{7/2}$, but repulsive for the other proton state, $1h_{11/2}$ [8]. This increases the energy splitting and produces a decrease of the pairing correlations. This point indicates that the tensor–isospin contribution, which is responsible of the particle–unlike tensor contribution must play the main role.

We have also analyzed how the behaviour of the $1i_{13/2}$ and $1h_{9/2}$ single neutron strength along the $N = 82$ isotones is modified. This has been measured very recently, and its trend has been related to the tensor interaction [9,10]. In Fig. 3 we plot this energy difference, calculated with the interactions D1S and D1ST2 (panel (a)), D1M and D1MT2 (panel (b)).

For both cases, we observe a decreasing of this quantity only for the interactions with tensor, in agreement with the previous results of Otsuka [8,11] and improving the comparison with the experimental data. Taking into account Fig. 2, it is clear that the main effect in the neutron splitting $1i_{13/2} - 1h_{9/2}$ is due to the filling of the $1\pi g_{7/2}$: as the number of protons increases, the occupation of the level is greater, and so the tensor effect on the neutrons levels. This tensor effect is repulsive for the neutron level $1h_{9/2}$ and attractive for the level $1_{13/2}$, doing that the splitting between those levels decreases with the number of protons.

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