Tensor effects in shell evolution at Z, N=8, 20 and 28

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The tensor component is a noncentral contribution of the nucleon-nucleon interaction, which has been extensively discussed in the past years. Ab initio calculations based on realistic nucleon-nucleon interactions have demonstrated the important role played by the bare tensor force in the description of the binding energy of nuclei [1], [2]. It is reasonable to expect that some nuclear observables are strongly sensitive to the tensor force owing to the rich spin-isospin structure of finite nuclei. For instance, the shell evolution and the magicity modification far from stability line are often interpretated in terms of tensor effects [3]. In the framework of the shell model, the tensor contribution in shell evolution has been explored and its effects have been underlined by Otsuka and collaborators [4]. In spite of these indications, the tensor term of the interaction has been usually neglected so far in effective theories at the mean-field level.

In this work we have discussed how the tensor component contributes to the shell evolution in some regions of the nuclear chart at the mean-field level, using non relativistic Skyrme and Gogny Hartree-Fock (HF) models, as well relativistic HF (RHF) models. In particlar we have analized the behaviour of the proton (neutron) gaps at magic numbers Z(N)=8 [5], 20, and 28 [6]. In the evolution of the magic gaps we were mainly interested in the effects induced by neutron-proton interaction related to the tensor contribution, that is, the effects on proton (neutron) levels due to the filling of neutron (proton) orbits.

The theoretical gaps obtained with and without the tensor contribution have been compared with the experimental ones, when available, to evidentiate the cases where the tensor effects are unambiguosly important (or not) in determining the shell evolution. The teoretical gaps have been calculated as differences of HF single-particle energies. In the case of the Gogny force we have used the GT2 parameterization of the interaction where the stregth of the tensor channel is given by the F_T parameter [4], in the case of Skyrme we used the $SLy5_{wT}$ [7] where the strength of the tensor channel is given by the parameters α_T and β_T.

We show here only the case of Z=8. The values of the gaps obtained for ^{16}O and ^{22}O are shown in the three panels of Fig.1 for the Gogny (a), Skyrme (b) and relativistic (c) cases, respectively. Results obtained with the tensor contribution (solid lines) are compared with the corresponding results obtained without tensor (dotted lines) and with the experimental values (dashed lines) [8].

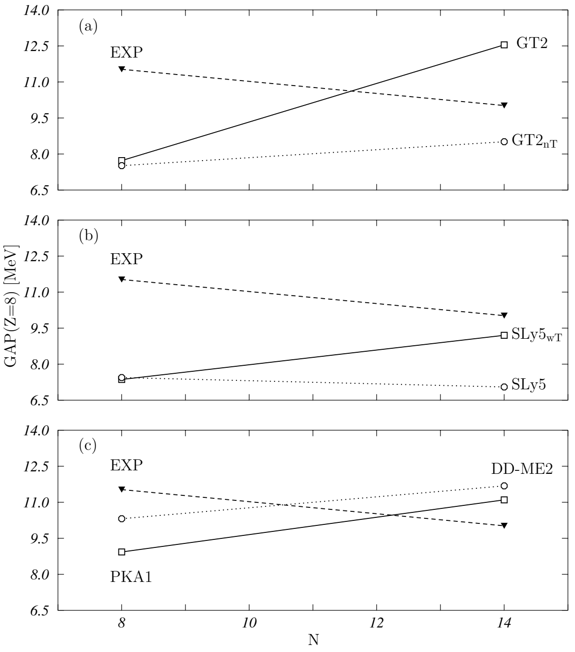

Figure 1. Proton gap Z=8 with Gogny (a), Skyrme (b), and relativistic calculations (c) with (full lines) and without (dotted lines) tensor compared with experimental data (dashed lines).

The effect of the tensor force is very clear in all the calculations: the slope is always increased by tensor going from ^{16}O to ^{22}O and the gap Z=8 is more strongly enhanced with respect to the results without tensor. This is coherent with what is expected according to the mechanism described in Ref. [4]. However, the experimental gap decreases when going from ^{16}O to ^{22}O. In the case of Skyrme the predicted trend depends on the sign of the parameter β_T which is positve in the present calculations. A value of $\beta_T < 0$ would trivially lead to a decreasing of the gap from ^{16}O to ^{22}O. This is what we observe in Fig.(2) panel (b)where the parameter has been changed and the correct trend obtained. For Gogny case the tensor parameter (and its sign) is fixed on a realistic case. However, if F_T is trated as a free parameter one can obtain similar results as in the Skyrme case by changing its sign (panel (a) of Fig.(2)). In the relativistic case the scenario is more complicated and the tensor contribution cannot be easily isolated.

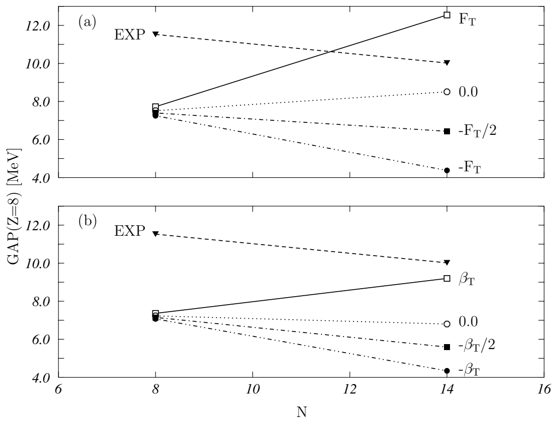

Figure 2. Proton gap $Z = 8$ for different choices of parameters of the interactions for Gogny (a) and Skyrme (b) case. The current choices are indicated by F_T and β_T in panel (a) and (b) respectively. The otehr choices have been expressed in terms of them.

The same study has been done for N=8 and Z and N equal to 20 and 28 and we have obtained similar results.

In conclusion we have observed that, in the non relativistic cases, it is possible to modify the trends of the theoretical results by changing the signs of parameter β_T in the Skyrme case and F_T in the Gogny case. This means that, in principle, a fitting procedure including the experimental gap evolutions at the magic number 8 and 20 could generate some sets of parameters able to reproduce these experimental trends owing to the tensor contribution. To conclude, since the evolution of the gaps is an important feature characterizing exotic nuclei we strongly suggest that the observables related to this feature should be included in the fit procedures when the tensor terms have to be constrained. It is also important to properly choose the regions where to perform these fits and we recommend $Z, N = 8$ and 20 as suitable regions where the role played by the tensor force can be less ambiguously identified in the mean-field framework.

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