Hartree Fock calculations with finite range interactions with tensor term

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We have studied the effects of the tensor terms of interactions D1ST and D1MT [1] constructed by considering global properties of the nuclei in Hartree Fock (HF) calculations for a set of nuclei in different region of the isotope chart. We have done calculations by using interactions with and without tensor terms in order to isolate the genuine tensor effects from the peculiarities of a specific choice of the force parameter. We always found great similarities between the results obtained with the two different type of parameterizations. Since the strength of the tensor force in D1MT is weaker than that of D1ST, we found smaller tensor effects in the results obtained with D1MT than in those obtained D1ST. We have done calculations for a set of spherical nuclei chosen such as all the s.p. levels below the Fermi surface are fully occupied. With this choice we avoided the effects of the deformation and we minimized those of the pairing.

Our HF calculations indicate that tensor forces do not produce sensitive effects on bulk observables such as binding energies, radii and density distributions. The situation changes when the s.p. energies are considered. A first quantity we have studied is the difference between the s.p. energies, ϵ of spin-orbit partners levels

$$s = \epsilon_{l-1/2} - \epsilon_{l+1/2} \,. \tag{1}$$

In particular, we have studied the difference between the values of s obtained by using forces with and without tensor terms

$$\Delta s = s_{\mathrm{D1}\alpha\mathrm{T}} - s_{\mathrm{D1}\alpha} \,. \tag{2}$$

In Figs. 1 and 2 we show the values of Δs calculated for the $1p$, $1d$ and $1f$ spin-orbit partners proton and neutron levels, respectively, for all the nuclei considered.

We can observe that the D1S and D1M results have identical behaviour: minima and maxima are in the same position for both type of calculations. A second observation is that, in general, Δs is negative: the tensor force reduces the energy difference between spin-orbit partner levels. A third observation is that the effects of the tensor force are minimal, almost zero, for those nuclei indicated with the arrows.

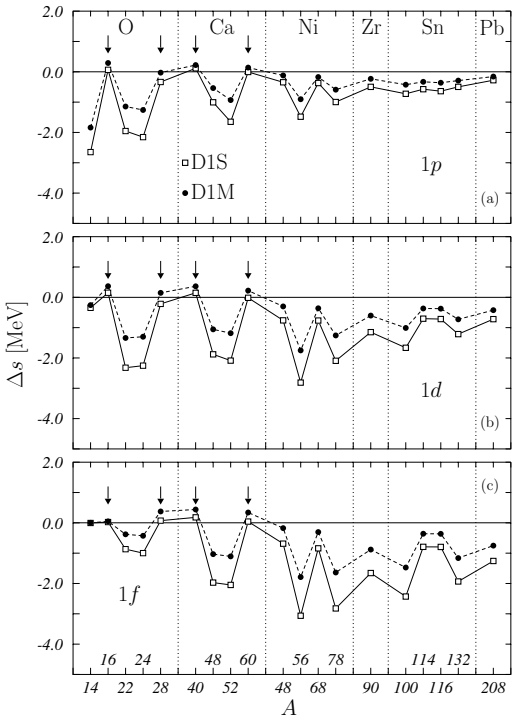

Figure 1. Differences between the s.p. energy differences of spin-orbit partners levels for proton levels.

The second and third observation are well understood within the scheme proposed by Otsuka *et al.* [3–5]. The effect of the tensor interaction between a proton and a neutron occupied s.p. level is attractive if one of the levels has an angular momentum $j_> \equiv l + 1/2$ and the other one $j_< \equiv l - 1/2$. If the angular momenta of the two s.p. levels are of the same type, i.e. both $j_>$ or both $j_<$, the effect of the tensor force has opposite sign.

In Fig.2 we see the same effect but acting between s.p. states with the same isospin.

Another quantity of interest related to the s.p. energies is the gap, g, between the energies of the levels just above and just below the Fermi surface.

These effects are emphasized in Fig. 3 where we show the difference

$$\Delta g = g_{\mathrm{D1}\alpha\mathrm{T}} - g_{\mathrm{D1}\alpha} \,, \tag{3}$$

between the gap values obtained by using interactions with and without the tensor force.

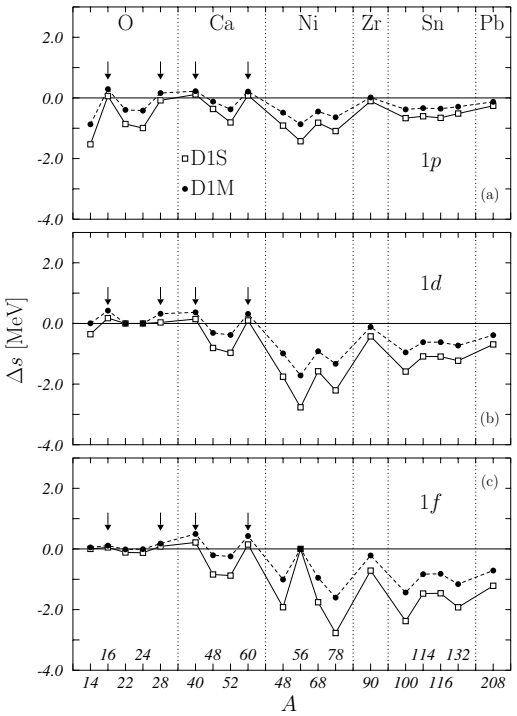

Figure 2. The same as Fig. 1 for neutron states.

Also these results can be well explained within the scheme proposed by Otsuka. Since oxygen and calcium isotopes are spin saturated in protons, the results presented in the panel (a) of Fig. 3 for these nuclei, are produced by the interaction of an unpaired neutron s.p. level of $j_>$ type with the neutron s.p. levels just below and above the Fermi surface. The comparison of the results of these nuclei shown in the two panels indicates that the effect of the tensor interaction between like nucleons is much smaller than that between neutrons and protons.

The effects of the tensor force on the s.p. levels, can modify their relative order, and this fact may have consequences on the spin of even-odd nuclei which is determined by the last unpaired nucleon. For each nucleus we have investigated the spin of all the neighboring nuclei having one nucleon more or less. We found some cases where the tensor force modifies the order of the levels near the Fermi surface, and therefore the spin of these nuclei. We present some of these results in Fig. 4, where we show the evolution of the states near the Fermi surface.

To summarize we may say that the tensor effects have remarkable consequences on those observables which we relate to s.p. properties of the nuclear system, such as s.p. energies and spin of the system.

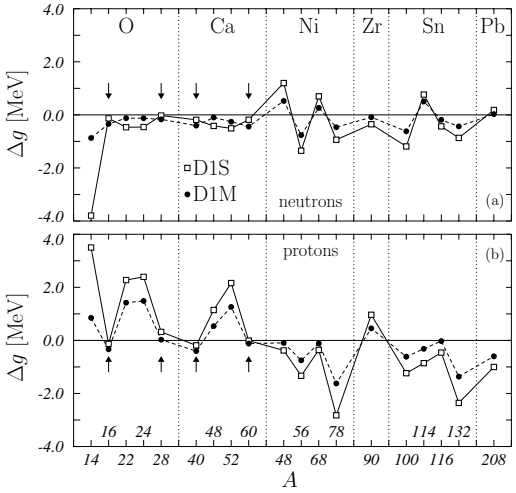

Figure 3. Differences between the energy gaps calculated with and without tensor force, for neutrons, panel (a), and protons, panel (b). The arrows indicate those isotopes where the tensor effect is expected to be zero.

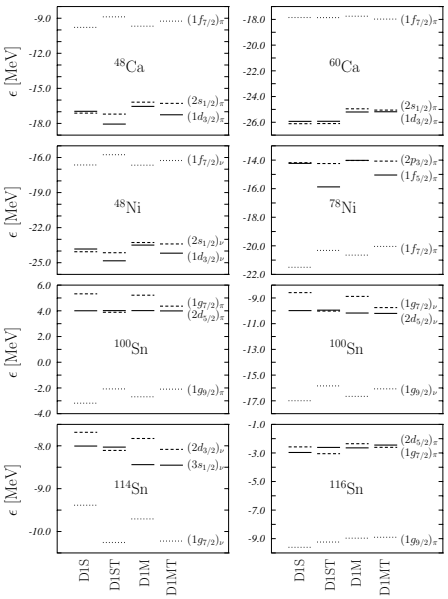

Figure 4. Single particle levels around the Fermi surface which change their order when the tensor force is used.

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