

Effects of a Skyrme-type tensor force on the spin-isospin excitations

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Abstract. The effects of the tensor force on the charge-exchange Gamow-Teller (GT) and spin-dipole (SD) states are studied by using the self-consistent Hartree-Fock plus Random Phase Approximation (HF+RPA) approach based on Skyrme zero-range forces. We have found, not surprisingly, that the tensor force has a large effect on the GT strength. In the case of the SD excitations, the tensor force produces a softening of the 1^- states, but a hardening of 0^- and 2^- states: these effects improve the agreement with the experimental findings. We have also studied how to constrain the magnitude of the tensor terms of the Skyrme interaction by using the empirical information on the collective GT and SD excited states in ^{90}Zr and ^{208}Pb .

1 Introduction

An effective zero-range tensor interaction has been proposed by Skyrme, at the same time as the well-known central and spin-orbit terms, in the 1950s [1]. There exist different strategies to fix the tensor part of the interaction. One possibility is to mimick a bare or a G-matrix tensor interaction [2, 3]. Since the tensor force affects the spin-orbit splittings of finite nuclei, another possibility is to add it to some existing Skyrme parameter set and to fit the tensor terms so to reproduce at best the evolution of single-particle states along isotopic or isotonic chains [4, 5]. Another plausible way to obtain an effective interaction with tensor terms is to implement a full variational procedure and fit the tensor and the central terms of the Skyrme interaction on equal footing [6]. In all these attempts, not much attention has been paid to check the effects of the tensor terms on the collective nuclear modes. We deem this subject is of interest, and in particular we have studied the spin-isospin modes by including the tensor terms in the self-consistent HF plus charge-exchange RPA approach [7, 8]. The reader who needs a general introduction to charge-exchange modes - and also to the RPA modelling of this kind of excitations - can consult review papers [9, 10] or the references quoted in [7, 8].

The present paper is organized as follows. The effects of the Skyrme tensor force on the GT and SD excitations will be discussed in Section 2, whereas the resulting constraints on the parameters

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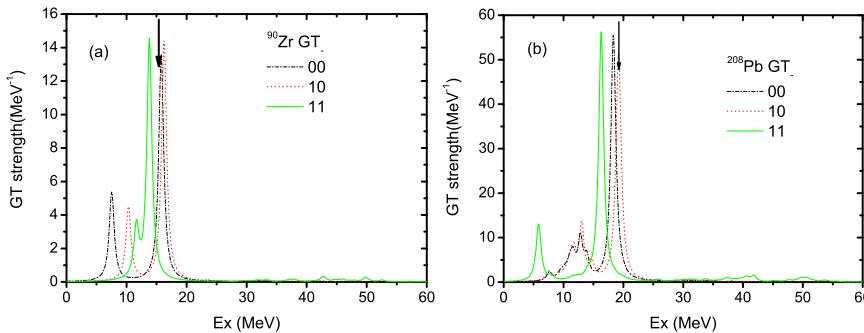


Figure 1. The GT₋ strength in ⁹⁰Zr and ²⁰⁸Pb is shown, respectively, in panels (a) and (b). The RPA results are smoothed by a Lorentzian functions with 1 MeV width. The result labelled by (00) corresponds to neglecting tensor terms both in HF and RPA; (10) corresponds to including the tensor terms in HF but neglecting them in RPA; finally, (11) corresponds to including the tensor terms both in HF and RPA. The arrows denote the experimental peak energies of the GT resonance.

associated with the tensor terms will be shown in Section 3. Finally, a brief summary is given in section 4.

2 Results for the spin-isospin excitations in ⁹⁰Zr and ²⁰⁸Pb

In this Section, we show the effects of the Skyrme tensor terms on the strength distributions associated with the GT and SD operators in the closed-shell nuclei ⁹⁰Zr and ²⁰⁸Pb [7, 8]. In Figure. 1, the results for GT₋ channel are obtained with a tensor force which was added perturbatively to set SIII so as to reproduce at best the evolution of single-particle states along isotopic or isotonic chains [5].

The most prominent effect induced by the tensor correlations is that the main GT₋ peaks are shifted downwards by about 2 MeV; as a result, their energies are somewhat lower than the experimental result (this can be improved by choosing different tensor parameters as will be discussed in Section 3) and this points to the necessity of refitting the Skyrme parameters after adding tensor terms. Another strong effect is associated with marked changes of the low-energy strength: this can have a strong impact on the β -decay half-lives of unstable-nuclei as shown in Ref. [11].

The effects of the tensor force on the charge-exchange SD₋ states having different J^π in ²⁰⁸Pb have been studied in Ref. [12]. The numerical results of the HF+RPA calculations performed with specific parameter sets (T43 [6] and SLy5+T_w) are shown in Fig. 2. The tensor terms produce a softening of the 1⁻ states, but a hardening of 0⁻ and 2⁻ states: this improves the overall agreement with experiment. A similar multipole-dependent effect has been found in the light nucleus ¹⁶O [14].

From the above discussion of this section, it is shown that the tensor force has strong effect on the main peak of GT and SD transitions, which indicate that the main peak energy of both GT and SD transition can be used to constrain the tensor parameters.

3 Quantitative Constraints to the Tensor Force

Based on the gained understanding, we can attempt to set quantitative constraints on the tensor force parameters, that is, we can see which values of the tensor-even and tensor-odd force parameters (T and U respectively) allow reproducing the observed properties of the GT₋ and SD₋ excitations in ⁹⁰Zr

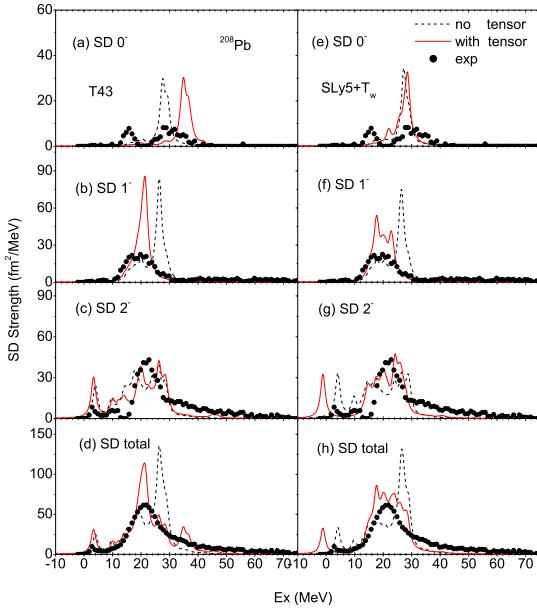


Figure 2. (Color online) Charge-exchange SD₋ strength distributions in ²⁰⁸Pb. The RPA results with the interaction T43 for the multipoles 0⁻, 1⁻, 2⁻ are displayed in the panels (a), (b) and (c), respectively. In panel (d) the total strength distribution is shown. Panels (e), (f), (g) and (h) are the same as panels (a)-(d) but with the parameter set SLy5+T_w. All discrete RPA results have been smoothed out by using Lorentzian functions with a width of 2 MeV. The excitation energies are referred to the ground state of ²⁰⁸Bi and the experimental data are taken from Ref. [13].

and ²⁰⁸Pb [15]. We have found that the 1⁻ SD₋ state plays a crucial role to constrain the triplet-even parameter T , while the range for the triplet-odd parameter U can be restricted by the GT₋ peak energy. It should be also noticed that the 0⁻ state is very sensitive to the U parameter [14].

In the study of Ref. [15], we have adopted the following criterion on acceptable interactions, i.e., for them, the discrepancy between calculated and experimental energies, $\delta E \equiv |E_{th} - E_{exp}|$, should be smaller than 2.5 MeV for the GT₋ resonance in ⁹⁰Zr and ²⁰⁸Pb and for the 1⁻ SD₋ resonance in ²⁰⁸Pb. Among the 36 T₁J parameter sets introduced in [6], only four (T21, T32, T43 and T54) fulfil this criterion. We were also interested in determining optimal values of the parameters T and U when the tensor terms are added in a perturbative fashion on top of existing Skyrme sets like SGII or SLy5. In general, we have found that the triplet-even T -term can be constrained in a rather narrow region, while the triplet-odd U -term is still not well constrained by the data. As an illustration, we show in Fig. 3 our result if the tensor force is added to SLy4. The value of U can range from -400 to -50 MeV·fm⁵ but for each value of U we see that T varies either between 200 and 300 MeV·fm⁵, or between 400 and 500 MeV·fm⁵ (cf. the shaded area in Fig. 3). We can require a stronger criterion ($\delta E \leq 2.0$ MeV), so that the ranges are smaller (doubly shaded area in Fig. 3).

4 Summary

In this contribution, we have summarised our understanding of the effects of the tensor forces on GT and SD excitations in ⁹⁰Zr and ²⁰⁸Pb, within the framework of self-consistent Skyrme HF+RPA calculations. Tensor correlations shift the main GT₋ peak downward, and change the low-energy tail of the strength while producing at the same time some spread of small amount of strength at (even very) high energies. In the case of SD₋ excitations, the tensor correlations have a pronounced multipole-dependent effect, that is, they give a softening of the 1⁻ states, and a hardening of 0⁻ and 2⁻ states: their effects improve the agreement with experimental data.

We have used these facts to set quantitative constraints on the parameters of the tensor force. The triplet-even part can be constrained in a narrow range of values, while the available experimental data are not enough to pin down the value of the triplet-odd part of the tensor interaction. This argument has

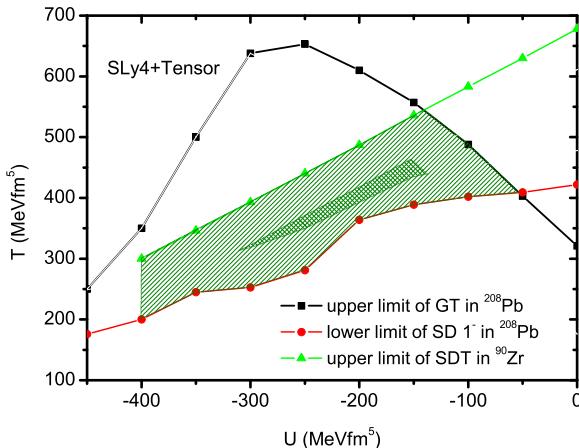


Figure 3. The range of values for the T and U parameters constrained by the data of the GT_- in ^{90}Zr and ^{208}Pb and of the $SD\ 1^-$ resonance in ^{208}Pb , through the conditions $\delta E \leq 2.5$ MeV ($\delta E \leq 2.0$ MeV), are shown with the shaded (double-shaded) area, respectively. The tensor terms are added on top of the central part of the SLy4 interaction.

been illustrated by adding the tensor force perturbatively on top of an existing central (and spin-orbit) set; since all these terms are not independent, when the tensor terms are added in the perturbative way the accepted range of their values may depend on the adopted central part of the interaction. A more consistent procedure amounts to fitting on equal footing every term of the interaction like in the case of the TIJ sets. However, both in this case and in the case of forces like SLy4 and SLy5, we have obtained that the triplet-even tensor strength coefficient must be positive and the triplet-odd tensor strength coefficient must be negative. In the case of SGII, the triplet-even tensor strength coefficient must be positive while the triplet-odd tensor can be either negative or positive. Further empirical data such as 0^- states are needed for a constraint of the triplet-odd term of the tensor interaction.

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