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Interplay between tensor force and deformation in even–even nuclei

Rémi N. Bernard *, Marta Anguiano

Departamento de Física Atómica, Molecular y Nuclear, Universidad de Granada, E-18071, Granada, Spain

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Abstract

In this work we study the effect of the nuclear tensor force on properties related with deformation. We focus on isotopes in the Mg, Si, S, Ar, Sr and Zr chains within the Hartree–Fock–Bogoliubov theory using the D1ST2a Gogny interaction. Contributions to the tensor energy in terms of saturated and unsaturated subshells are analyzed. Like–particle and proton–neutron parts of the tensor term are independently examinated. We found that the tensor term may considerably modify the potential energy landscapes and change the ground state shape. We analyze too how the pairing characteristics of the ground state change when the tensor force is included.

Keywords: Mean-field calculation; Tensor interaction; Axial deformation; Pairing; Slater approximation

1. Introduction

The tensor force get a major role in the nucleon–nucleon interaction. Indeed in a boson exchange picture the nuclear interaction is generated at long range by a pion exchange between two nucleons. The associated potential (One Pion Exchange Potential) is composed by a central and a tensor term. Besides the requirement to include a tensor term to the bare nucleon–nucleon

* Corresponding author at: Departamento de Física Atómica, Molecular y Nuclear, Facultad de Ciencias, Campus Fuentenueva S/N, Granada 18071, Spain.

E-mail address: rbernard@ugr.es (R.N. Bernard).

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interaction is supported by some well known experimental data such as the none zero quadrupole moment of the deuteron [1–3] or the differential cross section of the p–p scattering. Consequently all the most popular potentials used in the ab-initio approaches as the Paris [4], Bonn [5–7] or Argonne [8] potentials get a built-in tensor component. Its impact on the shell structure properties has been studied in a large extent: its contribution to the single particle energies depends on the filling of the shells; it induces correlations which strongly influence the n–p pairs structures in light nuclei [9]; the tensor force enables to get a convenient spectrum in the p-shell [10].

In contrast the tensor term was initially neglected in self-consistent mean field theories except for a few exceptions [11]. It should be emphasized here that in effective field theories some part of the bare tensor interaction is already taken into account in the central part of the effective interaction. As a consequence only the residual tensor interaction was neglected in the usual Skyrme [12,13] or Gogny [14,15] effective interactions.

However the tensor force got a renewed interest over the past few years in mean field theories. A lot of works recently aimed to determine the most reliable tensor term built-in effective interaction. It is now clear that the tensor term modifies the single particle energies [16] and the binding energies [17], the multipoles giant resonances [18,19] and even may affect the magic numbers and the spin–orbit splitting in some cases [20].

The inclusion of the tensor term in the effective interaction has been done in perturbation from pre-existing parametrizations [21–23] where all the other parameters remain unchanged. Alongside a full variational procedure is performed to get the new parametrizations for the Skyrme [24,25] and Gogny [20] interactions. In all cases it rises the problem of the way to fit the parameters. Otsuka et al. [20] make the overall fit of the interaction using the properties of the AV8 potential [17] to adjust the tensor strength. Lesinski et al. [24] built 36 parametrizations of the zero range Skyrme interaction including a tensor term. They are obtained by studying the structure properties such as the spin–orbit splitting or the single particle energies on the Ca, Ni and Sn chains. In the works of Zalewski et al. [26,27] and Grasso et al. [28] the spin–orbit strength is modified at the same time that the tensor parameters to reproduce some single particle properties, (spin–orbit splittings) in the doubly magic ^{40}Ca, ^{56}Ni and ^{48}Ca nuclei. The work of Grasso et al. enables to reduce the number of parametrizations suggested by Lesinski et al. excluding the ones whose parameter signs do not lead to satisfactory results. In addition, while the tensor term is adjusted in some local structure properties some efforts have been done to constraint the tensor strength from collectives excitations properties [30,29,31,18] in the Skyrme Hartree–Fock+Random Phase Approximation framework.

In the present study we aim to analyze the impact of the tensor term on the deformation of the even-e-ven nuclei in the Hartree–Fock–Bogoliubov approximation. We use the D1ST2a Gogny interaction proposed by Anguiano et al. and built on the finite range D1S Gogny interaction [15] with a finite range tensor term [23]. This tensor term incorporates both a pure tensor and a tensor–isospin contribution. Keeping the D1S parameters unchanged the two tensor parameters were adjusted to reproduce the neutron single particle energies $1f_{5/2}$ and $1f_{7/2}$ in ^{48}Ca. Refitting a nuclear effective interaction in a global procedure as it is done in [24] for the Skyrme plus tensor interaction or in [20] for the Gogny plus a tensor–isospin term interaction represents a considerable amount of work and is far beyond the scope of this study. In the present paper we are interested in the effect of tensor terms in the deformation of the ground state of various nuclei using the D1ST2a interaction. Keeping the D1S parameter set unchanged enables to isolate in a better way the specific tensor effects than in a consistent refit of the interaction. Thus this study aims to isolate the situations in which tensor contribution is important, in order to choose the most pertinent observables to consider for a consistent refit of the interaction.