Non-central forces of effective interactions

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Shell model (SM) is one of the most successful approaches to study the nuclear A-body problems. Since its inception [1], it has been widely used to determine the properties of nuclei, for instance, spectra, multipole moments, and transition rates in lower, medium and heavy mass region. The effective interactions are the strongest pillar of shell model which are derived by following the microscopic and empirical approaches [2]. Since, in effective interactions, internal structure (central, spin-orbit and tensor force) of realsitic nucleon-nucleon interaction is enfolded into summed effective values, therefore, it cannot be determined straightforward that which component(s) of non-central force along with central force plays important role to reproduce the properties of nuclei, in particular, spectra. With the motivation to study this crucial property of the component(s) of non-central force, we performed calculations with CK(8-16), USDB, GXPF1A and JUN45 effective interactions of *p, sd, pf,* and *fpg* valence space, respectively [3]. In this article, we report about our primarily calculations. The central and non-central forces of all four effective interactions are obtained by determining the interaction between two-nucleons as the scalar product of irreducible configuration (**C**) and spin (**S**) space operators of rank r; $V(1,2) = \sum_{r=0}^{2} V^r = \sum_{r=0}^{2} \mathbf{C}^r.\mathbf{S}^r$ [4]. Here, rank $r = 0$ refers to central force whereas rank $r = 1$ and 2 refer to spin-orbit and tensor force component of non-central force, respectively. Since, the effective interaction does not necessarily conserve parity, we also have anti-symmetric (ALS) spin-orbit force for r = 1.

In order to understand that which component(s) of non-central force along with central force is close to the total force, we have calculated the root mean square (*rms*) deviation for four types of forces. The first force includes only central force, whereas the successive force include symmetric spin-orbit (LS), anti-symmetric spin-orbit (ALS) and tensor (T) force along with central force.

Firstly, calculations have been performed for isospin T = 1 force matrix elements of all four effective interactions, and the results are shown in Fig. 1. The *rms* deviation for central force for CK(8-16), USDB, GXPF1A and JUN45 interactions are 0.68 MeV, 0.25 MeV, 0.21 MeV and 0.36 MeV, respectively. These *rms* deviations are quite large and reduced by tensor force in CK(8-16) and GXPF1A interactions, and by ALS force in USDB and JUN45 interactions. The smaller *rms* deviations for central plus ALS force of USDB interaction and central plus tensor force of GXPF1A interaction support the pivotal role of these combined forces to reproduce ground state binding energies and excitation energies of first 2^+ states of oxygen and calcium isotopes, respectively [5]. Likewise, central plus tensor force of CK(8-16) interaction and central plus ALS force of JUN45 interaction can be contemplated to reproduce ground state binding energies and excitation energies of 2^+ states of helium and nickel isotopes, respectively. It should also be noted that the *rms* deviation of central plus LS force and central plus ALS force in USDB interaction and the *rms* deviation of central plus ALS force and central plus tensor force in GXPF1A interaction are very close to each other. Therefore, central plus LS force of USDB interaction and central plus ALS force of GXPF1A interaction may effectively contribute to the evolution of high energy states in oxygen and calcium isotopes, respectively.

In the second step of our calculations, we have calculated *rms* deviation for afore-discussed four forces using T = 1 and T = 0 force matrix elements of employed four effective interactions. The results are shown in Fig. 1. In this case, central force has *rms* deviation

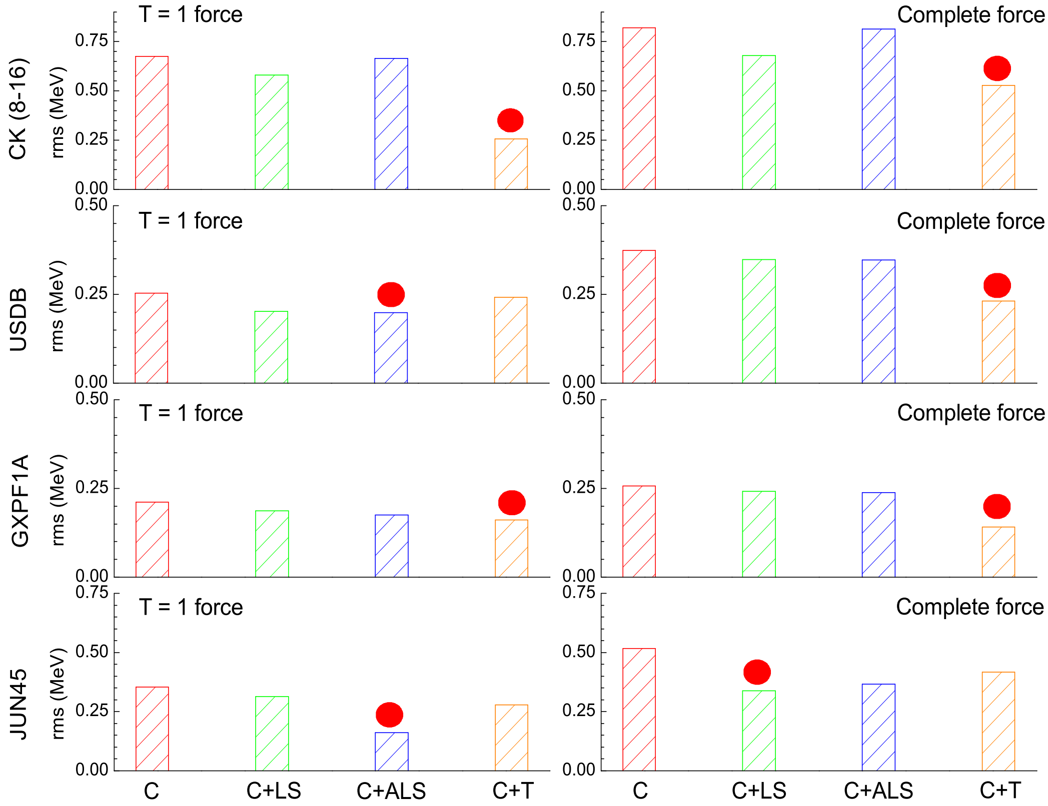

FIG. 1: Root mean square (*rms*) deviation of Central (C), Central+LS (C+LS), Central+ALS (C+ALS) and Central+Tensor (C+T) force matrix elements with respect to total matrix elements for CK(8-16), USDB,, GXPF1A, and JUN45 interactions. The force which has minimum rms deviation is highlighted by solid red circle. The complete force includes T = 1 and T = 0 force matrix elements.

0.82 MeV, 0.37 MeV, 0.26 MeV and 0.52 MeV for CK(8-16), USDB, GXPF1A and JUN45 interactions, respectively which are reduced by tensor force in CK(8-16), USDB and GXPF1A interactions and by LS force in JUN45 interaction. The central force plus tensor force in *p, sd, pf* shell and central plus LS force in *fpg* shell, thus, can be considered to play a crucial role in the evolution of low and high energy states of nuclei consisting of both neutrons and protons. In fpg-space, central plus ALS force of JUN45 interaction is also expected to contribute competitively with central plus LS force in the evolution of spectra since its *rms* deviation is close to *rms* deviation of central plus LS force.

In order to determine the comprehensive role of the components of non-central force in the evolution of low and high energy states of nuclei, the apposite calculations are under way for series of isotopes, isotones and N = Z nuclei. Detailed results will be presented during the symposium.

The financial support from DST-SERB, India vide grant no. SB/S2/HEP-007/2013 for the present work is acknowledged. Pawan Kumar thanks S. K. Ghorui for his interest and useful scientific discussions.

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