Role of central, spin-orbit and tensor part of SDPF-MU interaction in Mg isotopes

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The importance of different components of the nucleon-nucleon (NN) interaction was reported earlier in Ref. [1]. Recent study in Ref. [2] suggested that the central spin-isospin-exchange part of the NN interaction plays a major role in the shell formation. Ref. [3] suggest that the tensor force plays dominant role in the NN interaction for the heavier nuclei. Motivated from the literature, we have splitted SDPF-MU[4] realistic interaction into central, spin-orbit and tensor part to see the importance of these terms in the shell formation. In the present work we have reported shell model study of Mg isotopes in the $sd-pf$ model space. We have compared our theoretical results corresponding to $2p-2h$ and $4p-4h$ for $E_{2_1^+}$ with experimental data in the Fig. 1. Further we have interpreted our results by splitting effective interaction into central, spin-orbit and tensor parts. To see the importance of different parts of effective interaction, the variation of effective proton single-particle energies (ESPEs) for Mg isotopes are also reported in Fig. 2.

It is possible to separate the central, vector and tensor parts of the effective interaction by spin-tensor decomposition of the two-body interaction, which involves tensors of rank 0, 1 and 2 in spin and configuration space. In general the two-body interaction can be written as:

$$V(1,2) = \sum_{k=0,1,2} V^{(k)} = \sum_{k=0,1,2} (S^{(k)}.Q^{(k)})$$

The LS-coupled matrix elements of $V^{(k)}$

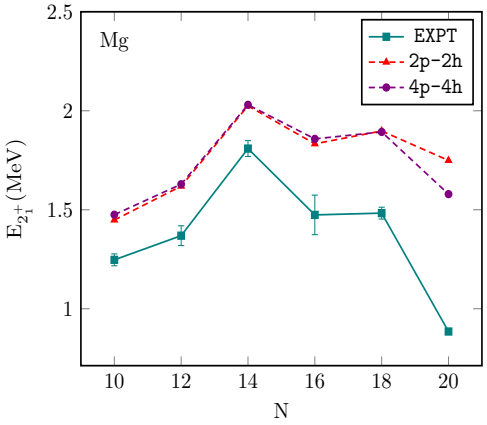

FIG. 1: The variation of $E_{2_1^+}$ energy levels for Mg isotopes in $sd-pf$ model space corresponding to $2p-2h$ and $4p-4h$ excitations.

can be calculated from the LS coupled matrix elements of V as [5]

$$\langle (AB) : LS, JMTM_T | V^{(k)} | (CD) : L'S', JMTM_T \rangle$$

$$= (2k+1)(-1)^J \left\{ \begin{array}{ccc} L & S & J \\ S' & L' & k \end{array} \right\} \times$$

$$\sum_{J'} (-1)^{J'} (2J'+1) \left\{ \begin{array}{ccc} L & S & J' \\ S' & L' & k \end{array} \right\} \times$$

$$\langle (AB) : LS, J'MTM_T | V | (CD) : L'S', J'MTM_T \rangle,$$

where k = 0, 1, and 2 matrix elements are corresponding to central, spin-obit and tensor part, respectively. In order to split realistic interaction into three parts first we convert matrix elements from JJ to LS coupling.

The monopole corrected single particle proton energy is given by

$$\tilde{\epsilon}_{j_\pi} = \epsilon_{j_\pi} + \sum_{j\nu} \bar{E}(j_\pi j_\nu) \hat{n}_{j_\nu}$$

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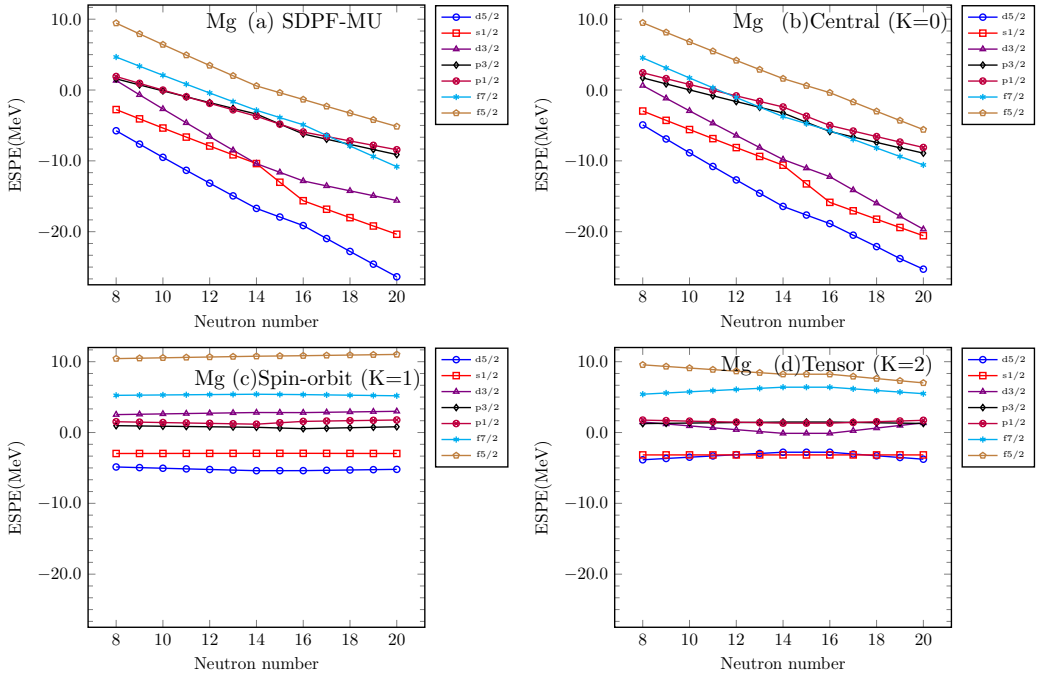

FIG. 2: Variation of proton effective single-particle energies of Mg isotopes using the realistic SDPF-MU interaction (Fig. a) and its central (Fig. b), spin-orbit (Fig. c) and tensor (Fig. d) components.

The operator $\hat{n}_{j_\nu}$ is replaced by its expectation value $\langle\hat{n}_{j_\nu}\rangle = \hat{n}_{j_\nu}$, i.e. the number of neutrons occupying in the orbital j_ν.

The term $\bar{E}(j_\pi j_\nu)$ is angular momentum averaged interaction energy

$$\bar{E}(j_\pi j_\nu) = \frac{\sum_J (2J+1)\langle j_\nu j_\pi; J \mid V \mid j_\nu j_\pi; J\rangle}{\sum_J (2J+1)}$$

The modified single particle energies $\tilde{\epsilon}_{j_\pi}$ are also called the effective single particle energies (ESPE).

From the Fig. 2, it is clear that the central part is playing major role in comparison to other parts of the NN interaction. It is possible to reproduce correctly the $E_{2_1^+}$ energy levels by reducing the single-particle energies of pf orbital to allow more mixing between sd and pf shell.

As neutrons fill in the $0f_{7/2}$ orbital the gap between the $d_{5/2}$ and $d_{3/2}$ orbitals is increasing this is mainly due to the tensor force. The decomposition of the different parts of the monopole matrix element $V^{T=1}_{f_{7/2}d_{3/2}}$= -0.278 are $V^{T=1}_{f_{7/2}d_{3/2}}$= -0.105 (central), $V^{T=1}_{f_{7/2}d_{3/2}}$= -0.069 (spin-orbit) and $V^{T=1}_{f_{7/2}d_{3/2}}$= -0.104 (tensor). Thus it is possible to optimize the tensor part of the interaction to get results more close to the experimental data.

References

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