NEGATIVE PARITY INTRUDER STATES IN SD SHELL NUCLEI: A COMPLETE $1\hbar\omega$ SHELL MODEL DESCRIPTION*

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A new interaction called PSDPFB has been derived in the full p–sd–pf model space allowing one jump with a ^{4}He core to describe the $1\hbar\omega$ intruder states in sd shell nuclei. This new interaction was tested by calculating the evolution of the negative parity states throughout the shell. A low-lying 0^- state in ^{40}Ca is predicted. The interaction was applied to obtain the $N = 18$ and 20 isotones spectra. Results for the isotones ^{32}Si, ^{34}S and ^{36}Ar and those for ^{34}Si, ^{36}S and ^{38}Ar are presented and compared to experiment.

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1. Introduction

The structure of sd shell nuclei has been the subject of many experimental and theoretical investigations. The shell model using the USD Hamiltonian [1] has been used with considerable success to describe the energy levels and spectroscopic properties of these nuclei in the full sd model space. In this case where an inert ^{16}O core is assumed, only the positive parity states are concerned. Recently, much more and improved data appeared in the literature on neutron-rich nuclei. Using the recent growing of computational power, the theorists have refined the derivation of the USD Hamiltonian with an updated and complete set of energy data [2]. The new Hamiltonians are called USDA and USDB. Negative parity states are known experimentally throughout the sd shell, they can of course not be described by the USD interaction with an inert ^{16}O core. These levels named intruder states result from the excitation of one nucleon ($1\hbar\omega$ excitation) from the p to the sd shell

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for nuclei near ^{16}O, or from the sd to fp shell for nuclei close to ^{40}Ca. In the middle of the sd shell, there is a competition for the intruders between the two types of excitation. To describe these states, we must enlarge the model space from the sd space (^{16}O core) to the full p–sd–pf space (^{4}He core). It is the aim of our work to construct a new interaction compatible with this extended shell model space. For our calculations, the code Antoine [3] was used. In this paper, we will first present the derivation procedure of our PSDPFB interaction. We will then give various results predicted by our model and compare them with known experimental data.

2. Derivation of the PSDPFB interaction

Our proposed PSDPFB interaction contains four main parts: CK [4], USDB [2] and PSDT [5] for the p, sd and p–sd shells, respectively, IOKIN [6] for the pf and sd–pf shells. The main aim of the present work is to get for the first time a consistent description of the negative parity states throughout the sd shell. To reach this goal we had to modify the cross p–sd and sd–pf contributions without changing the $0\hbar\omega$ states in ^{17}O and ^{41}Ca nuclei. For the major shells, the previously determined interactions [2,4,5] have been adopted. The single particle energies of the p shell are taken form CK and those of the sd and pf shells have been adjusted in order to obtain the $0\hbar\omega$ energy levels of ^{17}O and ^{41}Ca nuclei. To eliminate the spurious states, a centre of mass Hamiltonian for the full p–sd–pf space was added to this interaction. To test our interaction, we applied it to calculate the energy evolution of the negative parity states of different spins throughout the complete sd shell. As an example, we present in Fig. 1 the evolution of the first excited 0^- state in $N = Z$ nuclei and the first excited $1/2^-$ state in $N = Z + 1$ nuclei, indicated by circles, compared to the experimental results [7] given by squares. In both cases, we reproduce quite well the experimental excitation energies variation and values.

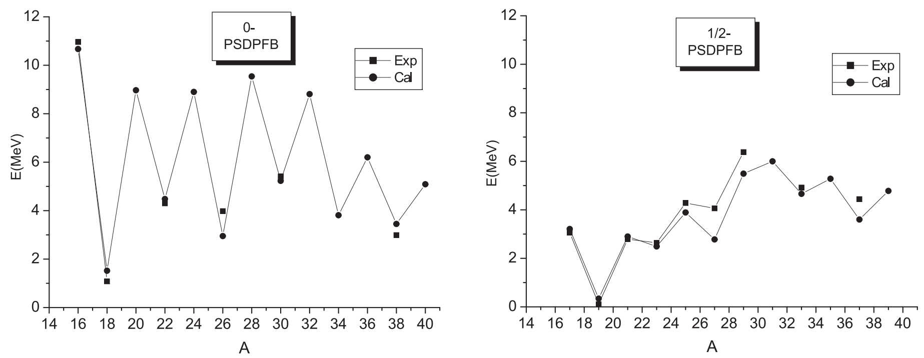

Fig. 1. Evolution of the 0^- state in $N = Z$ and $1/2^-$ state in $N = Z + 1$ nuclei.

3. Results and discussion

3.1. A predicted 0^- *state in* ^{40}*Ca*

The first 0^- states are well known in odd–odd nuclei and are located at relatively low excitation energy. This location is well reproduced with our interaction (see Fig. 1). For the even–even *sd* shell nuclei, this level is only known in ^{16}O. It is predicted at high excitation energy for ^{20}Ne, ^{24}Mg, ^{28}Si and ^{32}S. Towards the end of the shell, the energy of this 0^- state is decreasing and is predicted to be at 5.09 MeV for ^{40}Ca. We calculated the full spectrum up to 6 MeV of this nucleus; the comparison with experiment [7] is shown in Fig. 2. The spin and parity of ^{40}Ca levels are well established and there is a one to one correspondence except for the predicted 0^- state which has a pure $d^{-1}_{3/2}p^{1}_{3/2}$ configuration. Experimentally, there is an unknown spin and parity level at 5.35 MeV which is a good candidate to be a 0^-. If this latter has 0^-, it can only γ decay to the 2^+ state at 3.90 MeV by an M2 transition. In this case, we have estimated the mean lifetime of this state to be ≈ 8.6 ns (an isomer!). It would be nice to confirm experimentally our prediction.

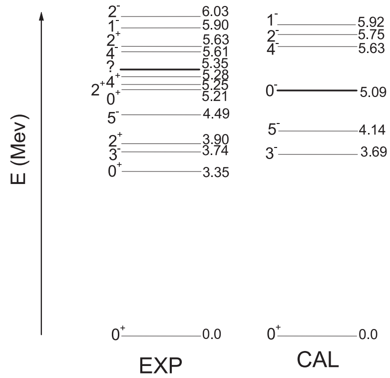

Fig. 2. Experimental level scheme of ^{40}Ca positive and negative parity states compared to the calculated negative parity intruder states.

3.2. Results for $N = 18$ *and 20 isotones*

With our new interaction, we have calculated the negative parity states of the *sd* neutron-rich nuclei $N = 18$ and 20 isotones with $Z = 14$, 16 and 18. The results are presented in Fig. 3, in which we can see the good agreement between our predictions and experiment. In general, all the observed levels are nicely reproduced; especially, those of spins 2 to 5 which are members of the $\nu(d^{-1}_{3/2}f^{1}_{7/2})$ multiplet. According to our results, we can confirm some spins not well established experimentally, for example, the 5^- level in ^{32}Si and the 2^- state in ^{38}Ar. A low energy 0^- state is also predicted for all the studied nuclei, which up to now has not been observed experimentally. Most of the data are taken from the compilation work of Ref. [7]. In the case of ^{34}Si, the states reported have been obtained in a recent deep inelastic (^{36}S + ^{208}Pb) experiment performed at Legnaro using the fragment spectrometer Prisma in coincidence with the γ array Clara (see Ref. [8] for more information).

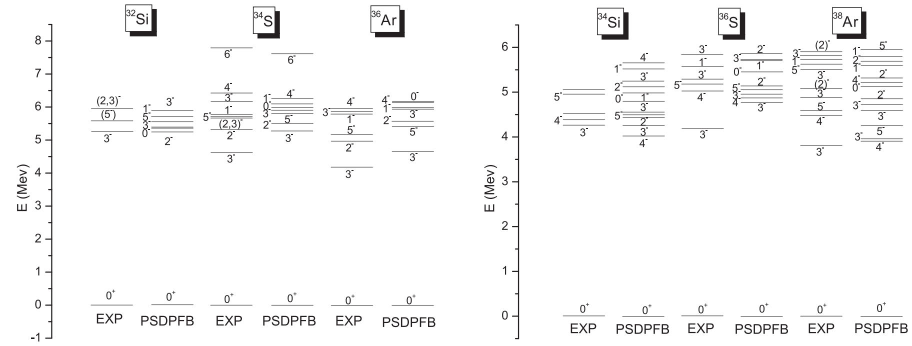

Fig. 3. Comparison of our calculations using the PSDPFB interaction and experimental data of $N = 18$ isotones (left) and $N = 20$ isotones (right).

4. Summary and conclusions

We have determined for the first time a *psdpf* interaction named PSDPFB, with the aim to study in a consistent way the negative parity states of *sd* shell nuclei. This interaction was used to calculate neutron-rich nuclei spectra, our results are generally in good agreement with the experimental data, but of course the agreement is not perfect. For this reason we will try to improve our interaction using a fitting procedure. We will also calculate the electromagnetic transitions probabilities of the intruders which are a stringent test of the wave functions of these states.

REFERENCES

[1] B.H. Wildenthal, *Prog. Part. Nucl. Phys.* **11**, 5 (1984).
[2] B.A. Brown, W.A. Richter, *Phys. Rev.* **C74**, 034315 (2006).
[3] E. Caurier, Code ANTOINE, Strasbourg 1989.
[4] S. Cohen, D. Kurath, *Nucl. Phys.* **73**, 1 (1965); **A101**, 1 (1967).
[5] E.K. Warburton, B.A. Brown, *Phys. Rev.* **C46**, 923 (1992).
[6] S. Nummela *et al.*, *Phys. Rev.* **C63**, 044316 (2001).
[7] `http://www.nndc.bnl.gov`
[8] X. Liang *et al.*, *Phys. Rev.* **C74**, 014311 (2006).