NUCLEAR MONOPOLE EFFECT ON ODD–ODD PARTICLE-HOLE NUCLEI IN ^{132}Sn MASS REGION*

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Study of nuclear monopole interaction effects around closed shell cores provides important information on the shell evolution and the effective single-particle energies. In the aim of studying and understanding the role of these effects, and in order to resolve spectroscopic problems originated from the ignored three-body interactions, shell-model calculations have been realized for interpreting and developing the two-body matrix elements of N–N interaction. In this context, and in order to reproduce the nuclear spectra of odd–odd $N = 81$ isotones, we have performed some calculations using recent experimental single particle and single hole energies, by means of the Oxbash nuclear structure code. The two-body matrix elements (TBMEs) of the used effective interaction were deduced from the sn100pn realistic interaction for ^{100}Sn mass region, and the single particle or single hole energies were taken from ^{132}Sn mass region. The getting results for the one particle–one hole nucleus are in agreement with the experimental data. However, the new interaction cannot reproduce the experimental spectra of three particles–one hole and five particles–one hole isotones.

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1. Introduction

Understanding the nuclear structure of odd–odd nuclei far from stability is a key point in determination of the proton–neutron interaction properties, in order to well understand and to develop the existing theoretical nuclear models. The $N = 81$ isotones, with few valence particle protons and one hole neutron in ^{132}Sn mass region are of special interest in deriving proton–neutron interaction properties. ^{132}Sb was produced for the first time via a fission of uranium with thermal neutrons, as mentioned in [1].

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Mach *et al.* [2] determined the low-lying states in ^{132}Sb populated in the β^- decay of ^{132}Sn. This nucleus was a subject of various theoretical studies. Covello *et al.* [3] have performed shell-model calculations using an interaction derived from Bonn-A nucleon–nucleon potential, for nuclei in ^{100}Sn mass region. These calculations for ^{132}Sb have led to reproducing well the positive parity states. They have found that the first negative state 8^-, which is dominated by $(\pi 1g_{7/2})^1(\nu 1h_{11/2})^{-1}$ configuration, lies at 126 keV. Then in 2003 [4], they studied this isotope using $V_{\rm low}$ approach to reproduce its spectroscopic properties. Using this approach, the low-lying positive states risen from $(\pi 1g_{7/2})^1(\nu 2d_{3/2})^{-1}$ were in agreement with the experimental data. Nevertheless, those risen from $(\pi 2d_{5/2})^1(\nu 2d_{3/2})^{-1}$ and $(\pi 1g_{7/2})^1(\nu 1h_{11/2})^{-1}$ came about 300 keV above and 200 keV below their experimental counterparts, respectively. According to Kathawa *et al.* [1], the ^{134}I isotope was identified in 1948 by Katcoff *et al.* [5], following the neutron irradiation of a plutonium foil in Los Alamos homogeneous pile. Liu *et al.* [6] have identified spin states in ^{134}I from the spontaneous fission of ^{252}Cf. They have observed five levels and five de-exciting transitions, and they have built its level scheme. Corragio *et al.* [7] have interpreted the observed high-excited states on the framework of a realistic shell-model calculation basing on $V_{\rm low}$ approximation with $\Lambda = 2.2$ fm^{-1}. They made spin-parity assignments accordingly. The obtained results were in agreement with the experimental data. Experimental information on ^{136}Cs was provided in Refs. [8, 9]. In Ref. [8], Puppe *et al.* measured the Gamow–Teller (GT) strength distribution in this nucleus, by means of a $(^3\mathrm{He}, t)$ charge–exchange reaction experiment on the double-beta decaying ^{136}Xe nucleus at an incident energy of 420 MeV. Wimmer *et al.* [9] proposed a level scheme. They have realized shell-model calculations for ^{136}Cs using CD-Bonn interaction [10], and reproduced the experimental spectrum. However, the obtained first excited energy 4^+ is different from the experimental one.

In this work, we are interested in the study of odd–odd particle-hole nuclei in ^{132}Sn mass region and the effect of proton–neutron monopole interaction on the nuclear structure of $N = 81$ isotones with $Z = 51, 53$ and 55.

2. Theoretical framework

The focus on the evolution of shell structure in neutron-rich nuclei is increased, in order to understand the appearance of new magic numbers [11, 12]. The effect of the addition of proton or neutron pairs on the single particle energies SPEs is governed by the monopole part of the system Hamiltonian [13]

$$H = H_{\rm m} + H_{\rm M}\,, \tag{1}$$

where H_{M} denotes the multipole part of the Hamiltonian, and H_{m} is the monopole one. The latter is expressed in term of the average energies over the configurations of s and t orbits with $T = 1$ for proton–proton and neutron–neutron, and $T = 0, 1$ for proton–neutron parts, see [14–16] for more details,

$$V_{st}^{T} = \frac{\sum_J (2J+1) \langle j_s j_t |V_{st}| j_s j_t \rangle_J^T \left[1 - (-1)^{J+T} \delta_{st}\right]}{\sum_J (2J+1) \left[1 - (-1)^{J+T} \delta_{st}\right]} \,. \tag{2}$$

The two-body matrix elements $\langle j_s j_t | V_{st} | j_s j_t \rangle_J^T$ arisen from the interaction between the particles in the orbits s and t can be extracted from the proton and/or the neutron separating energies of neighbouring nuclei. For a doubly closed shell core (A, Z), the monopole component of the proton–neutron interaction can be written in terms of proton separation energies (S_p) [17]

$$V_{j_\pi j_\upsilon}^{pn} = \tfrac{1}{2} \left[S_p\,(A+3, Z+1) - S_p\,(A+1, Z+1)\right] . \tag{3}$$

In this context, and basing on the monopole interaction between $\pi g_{7/2}$ and $\nu d_{3/2}$ orbits, we carried out spectroscopic calculations aimed to estimate some nuclear properties of $N = 81$ isotones near ^{132}Sn mass region in the framework of the nuclear shell model by means of Oxbash nuclear structure code [18]. We have used this method in the ^{132}Sn mass region to reduce the computational complexity of large-scale shell calculations. By correcting SPEs, proton–neutron monopole effect consideration introduces some modifications on two-body matrix elements (TBMEs) of the original interaction sn100pn, see Brown *et al.* [10]. Using Eq. (3), the monopole $V_{1g_{7/2}2d_{3/2}}^{pn}$ was estimated to be $\simeq$ 150 keV. This value is used to modify $(1g_{7/2}2d_{3/2})_{J=2-5}^{T=0}$ TBMEs and a new interaction named cdbm is introduced (modified CD-Bonn interaction using the monopole effect). Some calculations are released by means of this new interaction.

3. Spectroscopic calculations and discussion

We have performed shell-model calculations using the new interaction cdbm in $\pi(0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2},$ and $0h_{11/2})^{Z-50}$ and $\pi(0g_{7/2}{}^{-1}, 1d_{5/2}{}^{-1},$ $1d_{3/2}{}^{-1}, 2s_{1/2}{}^{-1},$ and $0h_{11/2}{}^{-1})^{N-50}$ model space using ^{132}Sn as a magic core. The experimental single particle (SPEs) and single hole (SHEs) energies taken from ^{133}Sb for protons and ^{131}Sn for neutrons are used [19, 20].

The calculations using cdbm and the original interactions for ^{132}Sb nucleus give a reasonable agreement with the experimental data, especially for the ground and the first excited states. However, the differences between the calculations with the new interaction and the experimental data for the 2^+ and 5^+ states are around 100 keV (Fig. 1 (a)). For these latter, the original interaction gives values higher than the experimental data by about 100 keV. The snh interaction, obtained by the modification of sn100pn original interaction using the pairing hole effect [21], gives different results from the experimental spectrum. It reproduces only the ground state.

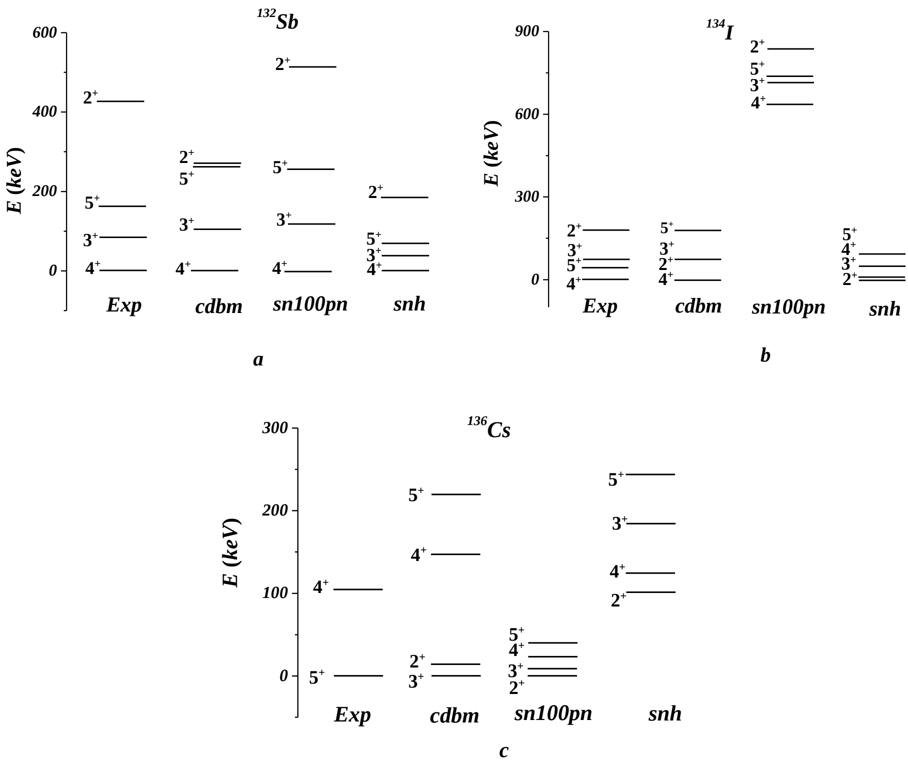

Fig. 1. Calculated energetic spectra using cdbm, sn100pn and snh interactions in comparison with the experimental ones for ^{132}Sb, ^{134}I and ^{136}Cs nuclei.

Figure 1 (b) shows that the calculations for ^{134}I nucleus using cdbm interaction allow reproducing the ground state. However, this interaction gives an inversion between the 2^+ and 5^+ states in comparison with the experimental energetic sequence.

As one can see in Fig. 1 (c), the new interaction cdbm cannot reproduce the experimental J^π of the ground state for ^{136}Cs. However, it reproduces the excited experimental energy for 4^+ state. The sn100pn and snh intearctions give different energies from the experimental ones.

4. Conclusion

This study is based on the energetic spectra calculations, for odd–odd $N = 81$ isotones with few valence protons and one hole neutron in their valence spaces. The calculations are carried out in the framework of the nuclear shell model, by means of Oxbash nuclear structure code. Using the sn100pn original interaction of the code, we carried out some modifications based on the proton–neutron monopole interaction to get cdbm interaction. The getting results for the one particle–one hole nucleus are in agreement with the experimental data in comparison with those of original and our previous calculations [21]. However, the new interaction cannot reproduce the experimental spectra of three or five particles–one hole isotones. The consideration of the monopole effects in odd–odd nuclei can ameliorate the calculation results of nuclear properties in these nuclei.

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