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Shell Model Calculation for Few Particle Even-Even Nuclei in ^{132}Sn Doubly Magic Mass Region

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The spectra of nuclides involving few valence particles or holes far from β^- stability are important tools to develop our knowledge about nuclear forces and N-N interaction. In order to understand the monopole interaction effect on the properties of nuclear structure of these nuclei, we have performed shell model calculations using recent experimental single particle energies, by means of Oxbash nuclear structure code. The two-body matrix elements of the effective interaction were deduced from those of kh5082 original interaction, taking into account the nuclear monopole effect in ^{132}Sn mass region. The obtained spectroscopic properties for ^{134}Te nucleus are in good agreement with the experiment.

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1. Introduction

The structures of few valence particle nuclides provide best opportunities to examine and develop the properties of N-N interaction [1, 2]. In this work, we have focused our calculation on the study of ^{134}Te nucleus in ^{132}Sn mass region. As mentioned in [3], this nucleus was first identified by Katcoff et al. (1948), as a fission fragment, following the irradiation of plutonium foil with neutrons. Sarkar and M. Sarkar in their paper from 2001 [4] have studied the structures of neutron rich $N = 82$ isotone in the framework of nuclear shell model, using available interactions for ^{132}Sn region. Their calculated spectroscopic properties for $N = 82$ isotone agree reasonably well with the experimental data. In [5], Radford et al. (2002) have measured the electric reduced transition probabilities $B(E2 : 0^+ \rightarrow 2^+)$ for ^{134}Te isotopes using Coulomb excitation of radioactive ion beams.

They have also performed shell model calculations for the studied isotopes, using a realistic effective interaction, derived from the CD-Bonn nucleon-nucleon interaction. They have reproduced the experimental spectra for the studied nuclei. Their calculated $B(E2 : 0^+ \rightarrow 2^+)$ values are in good agreement with the measured ones [5, 6].

2. Monopole interaction

The interactions between the core, previously assumed to be inert, and the valence nucleons can lead to modifications of the nuclear shell structure and, therefore, to modification of the spectroscopic properties of nuclei near drip lines [7–9]. A. Poves and A. Zuker [10] have tested, by perturbation method, the description of the monopole effect, in which the monopole Hamiltonian is defined in terms of the two-body interaction. Thus, the consideration of this effect is required to reproduce the missing nuclear properties. They have proposed to express the Hamiltonian of the system in terms of a monopole part H_m and a multipole one H_M [11–13],

$$H = H_m + H_M,$$

$$H_m = \sum_s n_s \varepsilon_s + \sum_{s \leq t} (a_{st} n_{st} + b_{st} T_{st}). \quad (1)$$

Here s and/or t denote a proton and/or a neutron orbit. n_{st} and T_{st} refer, respectively, to the number and the isospin operator [7, 12]. The operators a_{st} and b_{st} are defined in Ref. (12) as functions of the monopole Hamiltonian diagonal part $V_{st}^{\tau\tau'}$ [9]. This part can be defined as a function of the average energies over the configurations of s and t orbits with [9, 11],

$$V_{st}^{\tau\tau'} = \frac{\sum_J (2J+1)\, E_J\,(j_s j_t)}{\sum_J (2J+1)}. \quad (2)$$

Here, τ (τ') stands for proton or neutron. Sorlin and Porquet in Ref. (8) have proposed to evaluate $E_J\,(j_s j_t)$, the two body matrix elements (TBMEs), using the binding energies of neighbouring nuclei.

The monopole interaction, risen from addition of nucleon pairs to proton and/or neutron orbits, leads to the modification or evolution of single particle energies of these orbits [14].

In this work, we have used the recent single particle energies (SPEs), and have considered the monopole effect to introduce some modifications into the TBMEs of the original interaction *kh5082* (W.T. Chou and E.K. Warburton [15]). The binding energies of few valence particle nuclei in tin-132 mass region have been used [8] in order to calculate the monopole terms:

$$V^{pp}_{1g_{7/2}1g_{7/2}} \approx 200 \text{ keV}, \quad V^{nn}_{2f_{7/2}2f_{7/2}} \approx 290 \text{ keV}, \quad \text{and}$$

$$V^{pn}_{1g_{7/2}2f_{7/2}} \approx 400 \text{ keV},$$

to modify, respectively, TBMEs of the original interaction:

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$\pi\pi\left(1g_{7/2}1g_{7/2}\right)^{T=1}_{J=0-6}$, $\upsilon\upsilon\left(2f_{7/2}2f_{7/2}\right)^{T=1}_{J=0-6}$, and

$\pi\upsilon\left(1g_{7/2}2f_{7/2}\right)^{T=0}_{J=0,7}$.

These TBMEs are chosen based on the work of Corragio et al. (2013) [16].

Using the resulting interaction *mkh* and the original one, some calculations were carried out in order to reproduce the experimental spectra and electromagnetic properties of ^{134}Te nucleus.

3. Results and discussion

We have performed shell model calculations, with the new interaction *mkh* in *jj56pn* space model using ^{132}Sn as a magic core. The experimental single particle energies taken from the spectra of ^{133}Sb for protons and ^{133}Sn for neutrons were used [17, 18]. The calculations were performed by means of Oxbash nuclear structure code [19, 20].

The experimental ground state of ^{134}Te nucleus in ^{132}Sn mass region is dominated by $\pi(1g_{7/2})^2$.

Our spectroscopic calculations gave the same configuration for the ground state. Figure 1 shows that both the original *kh5082* and the new *mkh* reproduce the energetic sequence of the studied isotope. The new interaction gave 1237 keV for the first excited state 2^+_1, which is in agreement with the experimental value of 1279 keV. The obtained first excited state using *kh5082* interaction is $\sim$ 100 keV lower. However, the differences between the experimental values and values calculated using the new interaction for 2^+_2, 4^+_2 and 6^+_2 are around 200 keV.

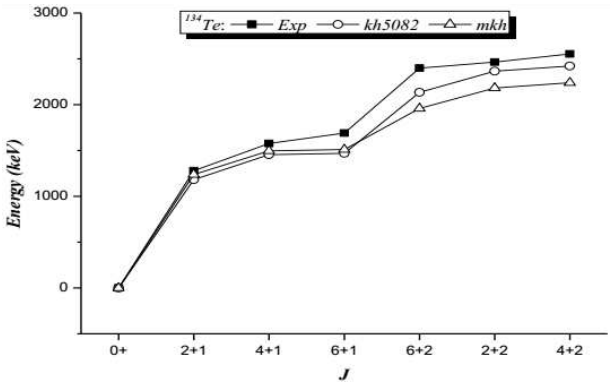

Fig. 1. Calculated energetic spectra for ^{134}Te isotope using *kh5082* and *mkh* interactions in comparison with the experimental one.

The reduced electromagnetic transition probabilities can be expressed in terms of the electromagnetic TBMEs $\langle J_f \left| M_{\sigma\lambda} \right| J_i \rangle$:

$$B(M_{\sigma\lambda} : J_i \to J_f) = \frac{1}{2J_i+1} \left| \langle J_f \left| M_{\sigma\lambda} \right| J_i \rangle \right|^2 . \qquad (3)$$

Table I shows the evaluated electromagnetic properties. The calculated values of reduced electric transition probabilities $B(E2)$ are obtained using $e_p = 1.47e$ and $e_n = 0.64e$ for the effective charges. In the calculation of the magnetic moments μ_J, we have used the free g factor.

TABLE I

Reduced electric transition probabilities and electromagnetic moments, calculated using *kh5082* and *mkh* interactions, in comparison with the experimental data [5, 4] for even-even ^{134}Te nucleus in ^{132}Sn mass region.

		$B(E2 : e^2fm^4)$			$\mu(J_i : \mu_N)$		$Q(J_i : efm^2)$	
J_i	J_f	Exp	kh5082	mkh	kh5082	mkh	kh5082	mkh
2^+_1	0^+	192.0	138.0	147.2	1.68	1.68	14.54	13.10
4^+_1	2^+_1	183.7	151.5	155.3	3.34	3.35	0.53	-0,25
6^+_1	4^+_1	83.5	96.00	70.90	5.01	5.02	-33,99	-34,78
2^+_2	0^+		19.28	19.27	1.75	1.78	7.23	6.74
	4^+_1		8.04	6.88				
	6^+_1		6.83	4.94				
4^+_2	6^+_2		85.93	94.15	3.34		-6,71	-7.00
	2^+_2		140.6	144.8				

With this choice, all results, obtained by accounting for two interactions, are close. For $B(E2)$, both the original and the new interaction reproduce the available experimental data. Our calculation result for the dipole magnetic moment $\mu(6^+) = 5.02\ \mu_N$ agrees reasonably with the experimental value of 5.08 μ_N reported in [4].

4. Conclusions

This study is based on the energetic spectra and electromagnetic calculations, for even-even ^{134}Te nucleus, with two protons in its valence space. The calculations are carried out in the framework of the shell model, by means of Oxbash nuclear structure code. Using *kh5082* the original interaction of the code, we carried out some modifications based on the proton-proton, neutron-neutron and proton-neutron monopole interactions, to get *mkh* interaction. Our new interaction gave a good agreement between the calculated and the experimental data. However, the differences between the experience and the calculations for 2^+_2, 4^+_2 and 6^+_2 are around 200 keV. For the electromagnetic properties, the two interactions gave close results. The new interaction gives close results to the available measured values of $B(E2)$. The calculated $\mu(6^+) = 5.02\ \mu_N$ is in agreement with the experimental value of 5.08 μ_N.

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