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Nuclear structure of In isotopes in ^{100}Sn mass region

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Abstract. The monopole effect resulting from the interaction between the magic core and the valence particles has a particular interest in the study of nuclear structure. To understand the importance of this interaction, we have realized some spectroscopic calculations for odd-odd In isotopes containing one hole proton and few neutron particles in addition to ^{100}Sn doubly magic core in their valence spaces. The using interaction is derived from jj45apn one taking into account the monopole interaction in the studied mass region, and using recent single particle and hole energies. The calculations are performed in the framework of the nuclear shell model by means of Oxbash nuclear structure code.

1 Introduction

The region around the last magic N=Z nucleus ^{100}Sn, close to the path of rp-process, was the main of several theoretical and experimental works that aimed to give a global description of nuclear structure. With their one proton hole and few particle neutrons, Odd-Odd indium isotopes, near ^{100}Sn doubly magic core, are of great importance in nuclear structure studies. They give opportunity to develop our knowledge about proton-neutron interaction near astrophysical processes pathways.

^{102}In was identified for the first time by Béraud et al. [1,2]. They studied the A=102 isobars using an on-line mass isotopic separator operating on nuclear reactions induced by heavy ions. This isotope was produced by means of the reaction ^{92}Mo (^{14}N, 4n), and the half-life of 24(4) s is measured. Martín et al. [3] have investigated nuclei in end-point region of the rp-process near ^{100}Sn using direct mass measurements at SHIPTRAP by the Penning trap mass spectrometer at GSI Darmstadt, where they experimentally identified three nuclides for the first time. The mass excess of ^{102}In is determined to be -70694(12) keV, which is different by 16 keV from the given value Audi et al. [4]. In 2009, Elomaa et al. [5] have realised a mass filter of nuclei produced via proton and ^{3}H induced fusion-evaporation reactions in ^{100}Sn region. They have measured a new mass excess -70690.4(54) keV which is different by 4 keV from the previous one. This nucleus was the subject of a theoretical study in Ref. [6]. In which, Karny et al. have performed spectroscopic calculations of the β-decay of ^{102}Sn within the $\pi(2p_{1/2},1g_{9/2})$ $\nu(1g_{7/2}, 2d_{5/2}, 2d_{3/2}, 3s_{1/2}, 1h_{11/2})$ model space, and using SNC interaction [7]. In comparison with the experimental data, this interaction has reproduced the spin and parity of the ground state 6^+ and the three first excited states. However, the calculated energies for 2_1^+ and 3_2^+ states are far from the experimental ones.

In 1977, Varley et al. presented the discovery of ^{104}In [2,8]. They have realised measurement of half-lives, excitation functions, γ-x-ray and γ–γ coincidences in order to determine the energetic spectrum of ^{104}In. The measured half-life of the isomer was estimated to be 1.5(0.2) min. Szerypo et al. [9] studied the beta decay of ^{104}Sn at GSI, by means of ^{58}Ni+^{50}Cr reaction in order to evaluate the energetic spectrum of the ^{104}In descendent. Few years later, Karny et al. [6] have studied the beta decays of $^{102\text{-}104}$Sn and their $^{102\text{-}104}$In descendents using high-resolution germanium detectors as well as a Total Absorption Spectrometer (TAS). Elomaa et al. [5] have measured the mass excess of ^{104}In -76176.5(51) keV with a difference of 66 keV from the given one in [4]. The experimental spectra of these two isotopes are presented Fig.1.

2 Theoretical framework

The interactions the supposed inert core with the adding nucleons can lead to shell evolution and modification of the spectroscopic properties of nuclei near around this core [10-12].

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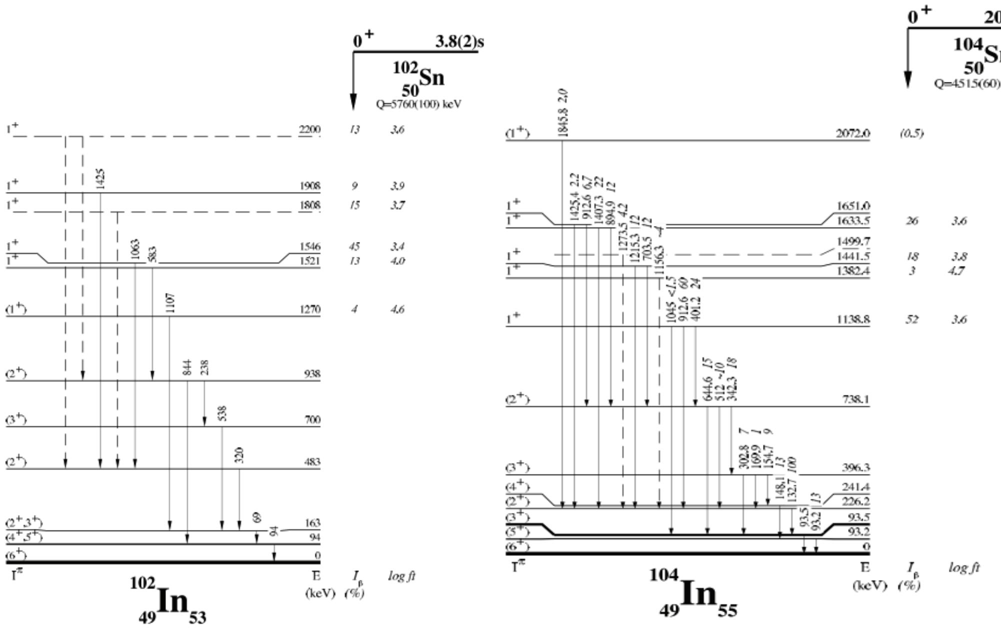

Fig.1. Experimental spectra of $^{102\text{-}104}$In [6, 9].

Poves and Zuker [13] have introduced the description of the monopole effect, in which the Hamiltonian of the system is defined in terms of the two-body interaction. Hence, the consideration of this effect can reproduce the missing nuclear properties of nuclei far from stability. They have proposed to express the monopole Hamiltonian of the system in terms°: [14-16],

$$H_m = \sum_s n_s \varepsilon_s + \sum_{s \le t} \left(a_{st} n_{st} + b_{st} T_{st} \right) \qquad (1)$$

s and/or *t* denote a proton and/or a neutron orbit. $n_{s,\,t}$ and $T_{s,\,t}$ refer, respectively, to the number and the isospin operator defined by Zuker [10,15] as a function of the monopole Hamiltonian diagonal part $V_{st}^{\tau\tau'}$ [12]. This amount can be defined as a function of the average two body matrix elements (*TBMEs*), of a given effective interaction V_J $(j_s j_t)$, over the configurations of *s* and *t* orbits [12,14],

$$V_{st}^{\tau\tau'} = \frac{\sum_J (2J+1) V_J \left(j_s j_t \right)}{\sum_J (2J+1)} \qquad (2)$$

Here, τ (τ') stands for proton or neutron.

In this work, we have used the recent single particle energies (*SPEs*), and considered the mass and the monopole effects to introduce some modifications on the two body matrix elements (*TBMEs*) of the original interaction *jj45apn* from ^{78}*Ni* mass region Jensen [17, 18]). These TBMEs are used in order to calculate the monopole term (Eq. 2): $V_{1g_{9/2}2d_{5/2}}^{pn} \approx -430\,keV$ to modify $\pi\upsilon \left(1g_{9/2} 2d_{5/2} \right)_{J=2,7}^{T=0}$ *TBMEs*. These *TBMEs* are chosen basing on the energetic sequence of the single particle space.

Using the resulting interaction *jj45m* and the original one, some calculations are carried out in order to reproduce the nuclear properties of $^{102\text{-}104}$*In* isotopes.

3 Results and discussion

In this work, we have performed shell model calculations, by means of the new interaction *jj45m* in $\pi\left(0f_{5/2}^{-1}, 1p_{3/2}^{-1}, 1p_{1/2}^{-1} \text{ and } 0g_{9/2}^{-1}\right)^{Z-28}$ and ν($0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$ and $1h_{11/2}$)$^{N-50}$ model space in ^{100}Sn magic core. The experimental single hole and single particle energies taken, respectively, from ^{99}In for protons and ^{101}Sn for neutrons are used as a starting point to calculate the effective single particle energies [19, 20].

The calculations for ^{102}*In* nucleus using *jj45m* interaction, shown in Fig. 2, allow to reproduce the parity of the low laying states. However, this interaction gives 7$^+$ as a ground state, which is different from 6+, the experimental one. The original interaction gives negative parity for the low laying states.

Neither the energetic excited states, nor the experimental sequence are reproduced using the two interactions for ^{104}*In* nucleus. However, the original interaction lead to reproduce the levels sequence except the 6$^+$ state, which is situated between 4$^+$ and 8$^+$ states.

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

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

Table 1 and 2 show the electromagnetic properties evaluated by means of *jj45apn* and *jj45m* interactions, for the studied nuclei.

The calculated values of reduced electric transition probabilities *B(E2)* are obtained using $e_p = 1.50e$ and $e_n = 0.50e$ for the effective charges. For the magnetic moments μ_J, we have used the free *g* factors. These results show that the two interactions give different values for the electromagnetic properties. However, the obtaining mean lives are close for ^{104}In.

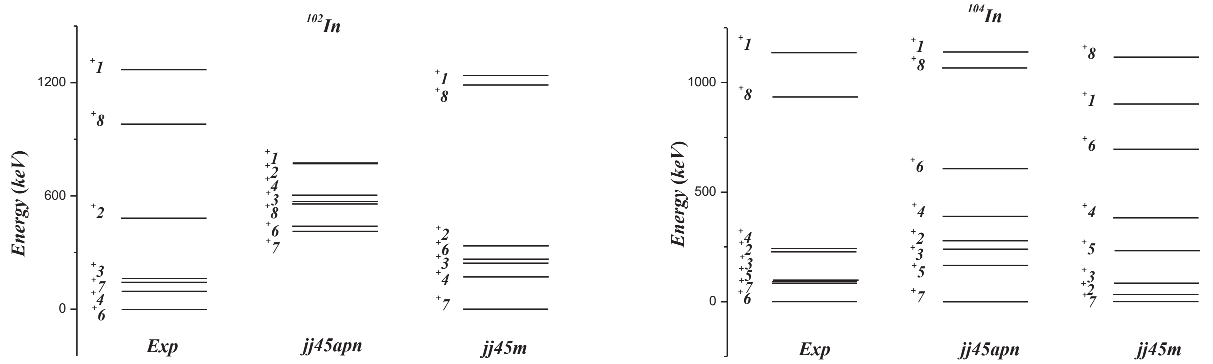

Fig. 1. Calculated energetic spectra for $^{102\text{-}104}$*In* isotope using *jj45apn* [17] and *jj45m* interactions in comparison with the experimental data [21].

Table 1. Electromagnetic properties and mean lives calculated using *jj45apn* and *jj45m* interactions, for ^{102}In.

J_i	J_f	$B(E2: e^2fm^4)$		$B(M1: \mu_N^2)$		$t_i(ps)$		$\mu(Ji: \mu_N)$		$Q(Ji:efm^2)$	
		jj45apn	**jj45m**	**jj45apn**	**jj45m**	**jj45apn**	**jj45m**	**jj45apn**	**jj45m**	**jj45apn**	**jj45m**
1^+	2^+	0.959	3.641	3.792	0.039	0.937 10^5	1.963	0.620	0.604	-8.990	-8.783
	3^+	25.100	1.836	/	/						
2^+	3^+	2.393	90.570	0.726	2.145	0.950	32.910	1.664	3.797	-8.998	8.844
	4^+	0.181	13.250	/	/						
4^+	3^+	35.480	104.144	0.184	1.579	62.690	3.048 10^3	5.124	5.026	6.980	6.441
	5^+	127.100	129.300	0.872	1.749						
	6^+	4.902	30.434	/	/						
5^+	6^+	35.570	30.916	0.242	0.834	984.200	5.016 10^5	5.913	5.723	12.080	8.253

Table 2. Electromagnetic properties and mean lives calculated using *jj45apn* and *jj45m* interactions, for ^{104}In.

J_i	J_f	$B(E2: e^2fm^4)$		$B(M1: \mu_N^2)$		$t_i(ps)$		$\mu(Ji: \mu_N)$		$Q(Ji:efm^2)$	
		jj45apn	**jj45m**	**jj45apn**	**jj45m**	**jj45apn**	**jj45m**	**jj45apn**	**jj45m**	**jj45apn**	**jj45m**
1^+	2^+	9.209	34.680	0.471	1.363	0.189	0.064	-0.099	3.079	-1.265	3.777
	3^+	1.485	1.234	/	/						
2^+	3^+	178.100	188.72	1.365	1.723	650.400		4.236	4.135	15.750	14.050
	4^+	44.046	61.812	/	/						
4^+	3^+	60.220	79.800	0.859	1.096	2.553	1.609	4.373	4.631	0.113	1.042
	5^+	78.150	82.870	1.716	1.809						
	6^+	37.570	52.173	/	/						
5^+	6^+	38.504	53.548	1.798	1.096	2.856 10^5	0.431 10^5	5.424	5.546	9.873	9.581

Conclusion

This study is based on the energetic spectra and electromagnetic properties calculations, for odd- odd Indium isotopes, with one hole proton and few neutrons 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 jj45apn original interaction of the code, we realized some modifications based on the mass effect and proton-neutron monopole interaction to get *jj45m* one. The new interaction lead to reproduce the parity of the first excited states for ^{102}In isotope. However, it can't reproduce neither the sequence nor the excited states for ^{104}In nucleus. The two interactions give different results for the electromagnetic properties and the mean lives are close for ^{104}In. These results are the consequence of the differences on the obtained energetic spectra for both nuclei.

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