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Nuclear structure of particle-hole odd-odd ^{130}In nucleus in tin-132 mass region

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Abstract. The spectra of odd-odd nuclides near drip lines, that are close to the path of astrophysical r-process flow, involving a single particle or a single hole in the vicinity of an inert core provide detailed and quantitative information on the N-N interaction. In this work, we have performed shell model calculation using recent experimental single particle and single hole energies, by means of Oxbash nuclear structure code, in order to reproduce the nuclear properties of odd-odd ^{130}In nucleus in the ^{132}Sn mass region. The two-body matrix elements (TBME) of the using effective interaction were deduced from those for ^{78}Ni mass region, using the single hole energies (SHE) of ^{132}Sn mass region.

1 Particle-hole configuration

The spectra of nuclei consisting a single particle or a single hole in addition to an inert core provide detailed and quantitative information on the nuclear independent-particle motion. A closed shell, which contains (2j+1) particles with an angular momentum j for each particle, must have total angular momentum J=0 and a positive parity, since each state of total angular momentum J possesses (2J+1) degenerate substates [1].

Thus, for a configuration of a single particle, in addition to closed shells, one expects a number of low-lying states having angular momentum and parity determined by the quantum numbers of the orbits available to the single particle. Configurations obtained by removing a particle from closed shells (single-hole configurations) are expected to have properties related in a simple manner to those of single-particle configurations.

The creation of a hole state with quantum numbers *nljm* is equivalent to the annihilation of a particle in the state with quantum numbers *nlj-m* (conjugate state). For the operator   creating a single hole [1]

$$b^{+}(jm) \equiv a(\overline{j}\overline{m}) = (-1)^{j+m}\, a(j\;-m) \tag{1}$$

Thus, the single particle state can be obtained using

$$\left|j^{-1}m\right\rangle = b^{+}(jm)\left|\hat{0}\right\rangle = a(\overline{j}\overline{m})\left|\hat{0}\right\rangle \tag{2}$$

The matrix elements for hole states and those for the single particle are related by

$$\begin{aligned}\left\langle j_2^{-1}m_2\right|F\left|j_1^{-1}m_1\right\rangle = \\ -\left\langle \bar{j}_1\overline{m}_1\right|F\left|\bar{j}_2\overline{m}_2\right\rangle + \left\langle\hat{0}\right|F\left|\hat{0}\right\rangle \delta\left(\left(n_1l_1\right)j_1m_1,\left(n_2l_2\right)j_2m_2\right)\end{aligned} \tag{3}$$

Here, F is an arbitrary single particle operator.

In this work, we carry out some modifications on the jj45apn interaction [2], basing on the consideration of mass factor effect with the use of the available experimental single hole energies taken from [3-5].

The calculations of some nuclear properties for ^{130}In are developed in the framework of the nuclear shell model by means of Oxbash nuclear structure code, and a new interaction named jj45pnh is introduced.

$$\left\langle j_1j_2\right|V\left|j_3j_4\right\rangle = \left\{\left\langle j_1j_2\right|V\left|j_3j_4\right\rangle_{jj45pna} * \textit{mass effect factor}\right\} \tag{4}$$

The space model is composed of $\{0f_{5/2}$, $1p_{3/2}$, $1p_{1/2}$ and $0g_{9/2}\}^{Z-28}$ orbitals for hole protons and $\{0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$, and $0h_{11/2}\}^{N-50}$ orbitals for hole neutrons.

2 Results and discussion

The structures of odd-odd nuclides provide best opportunities to examine and develop the properties of N-N interaction. The ^{130}In is one of these nuclei, with one proton hole and one neutron hole in addition to the tin-132 core. Their low-lying states, including the ground state which has $J^{\pi}= 1^{-}$ with a mean-life of 0.29 s and decays by β^{-}, are the result of β^{-} decay of the ground state which has a half-life 162 *ms* of the *r-process* waiting point nucleus ^{130}Cd [6].

The figures Fig.1 shows experimental spectrum of ^{130}In.

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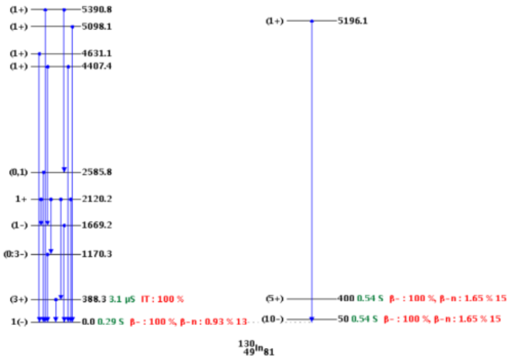

Fig. 1. Experimental spectrum of ^{130}In taken from nndc.bnl.gov [7].

The microscopic calculations for this nucleus are carried out by means of Oxbash code [3], in *jj45pn* space model. The Fig.2 shows the calculation results in comparison of the experimental data

For the ^{130}In nucleus, the energetic sequence is reproduced by the original interaction but the energy of the first excited state, which has an energy of 82 keV, is very far in comparison with the experimental one with an energy of 388.3 keV. Indeed, our new interaction gives 3^+ as the ground state, and the 1^- state has an energy of 669 keV. The other interaction (snhole) gives 5^+ as the ground state and the energy of the 1^- state is 233 keV. In these spectra, the energy of 1^+ state, dominated by $\pi\,(1g_{9/2})^{-1}$ $\nu\,(1h_{11/2})^{-1}$ as given by the three interactions, present an energetic maximum value.

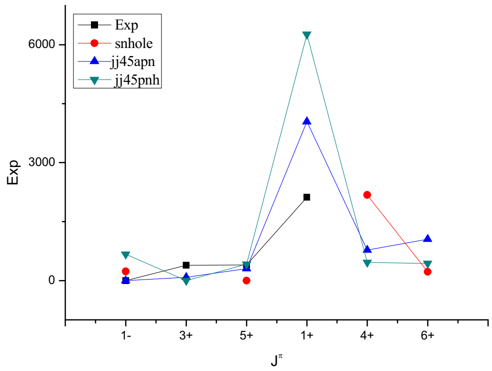

Fig. 2. Calculated spectrum of ^{130}In in comparison with experimental and *jj45apn* [2] ones.

Note that snhole interaction is obtained by using the *snet* interaction [2] and taking into account the mass effect.

The reduced electromagnetic transition probabilities can be calculated by the form:

$$B(M_{\sigma\lambda}: J_i \to J_f) = (2J_i+1)^{-1}\left|\left\langle J_f \left\| M_{\sigma\lambda} \right\| J_i \right\rangle\right|^2 \qquad (5)$$

The Tab.1 shows reduced electric transition probabilities calculated by means of *jj45pnh* and *jj45apn* interactions.

Table 1. Electromagnetic reduced transition probabilities of ^{130}In in ^{132}Sn mass region obtained using *jj45pn* and *jj45pnh* interactions.

$J_i \rightarrow J_f$		$2^+ \rightarrow 1^+$	$3^+ \rightarrow 1^+$	$3^+ \rightarrow 2^+$	$4^+ \rightarrow 2^+$	$4^+ \rightarrow 3^+$	$5^+ \rightarrow 3^+$	$5^+ \rightarrow 4^+$	$6^+ \rightarrow 4^+$
B(E2) e^2fm^4	*jj45pnh*	0.050	6.978	4.957	12.110	35.340	26.150	0.076	19.120
	jj45apn	1.148	5.931	2.232	15.030	14.880	39.120	3.865	24.600
B(M1) μ^2_N	*jj45pnh*	0.006	/	2.410	/	0.285	/	0.493	/
	jj45apn	0.040	/	1.262	/	0.045	/	1.104	/

The two interaction give different values of $B(E2)$ and $B(M1)$, using the two interactions. The difference is important for the mixed transitions. Indeed, these calculations give higher values for electric reduced transition probabilities in the case of pure transitions with ΔJ=2.

The lowest negative parity states of ^{130}In have the $\{\pi 1g_{9/2}, \nu 2h_{11/2}; J\}$ configuration with $j(p)=9/2$ and $j(n)=11/2$.

The value of the magnetic moment of a state with the spin $j=l\pm 1/2$, and $t_z=\pm 1/2$ for a proton or a neutron is [8]:

$$\mu_J = \mu_N \frac{J}{2}\left[\frac{\mu_j(p)}{j_p}+\frac{\mu_j(n)}{j_n}+\left(\frac{\mu_j(p)}{j_p}-\frac{\mu_j(n)}{j_n}\right)\frac{j_p(j_p+1)-j_n(j_n+1)}{J(J+1)}\right] \qquad (6)$$

Whereas, we calculate the quadrupole electric moment using $e_p=1.35e$ and $e_n=0.35e$ effective charges [8]:

$$Q_J = \begin{pmatrix} J & 2 & J \\ -J & 0 & J \end{pmatrix}(-1)^{j_p+j_n+J}(2J+1) \qquad (7)$$

$$*\left[\begin{Bmatrix} j_p & J & j_n \\ J & j_p & 2 \end{Bmatrix}\frac{Q_{j_p}}{\begin{pmatrix} j_p & 2 & j_p \\ -j_p & 0 & j_p \end{pmatrix}}+\begin{Bmatrix} j_n & J & j_p \\ J & j_n & 2 \end{Bmatrix}\frac{Q_{j_n}}{\begin{pmatrix} j_n & 2 & j_n \\ -j_n & 0 & j_n \end{pmatrix}}\right]$$

Here, $Q_{jp,\,jn}$ denote respectively single proton/neutron quadrupole moment

$$Q_j(p,n) = -\frac{(2j-1)}{(2j+2)}\left\langle r^2\right\rangle e^{p,n}_{\lambda=2}(eff.) \qquad (8)$$

The calculated electric quadrupole and dipole moments, by means of *jj45pnh* interaction, are illustrated in Fig.4.

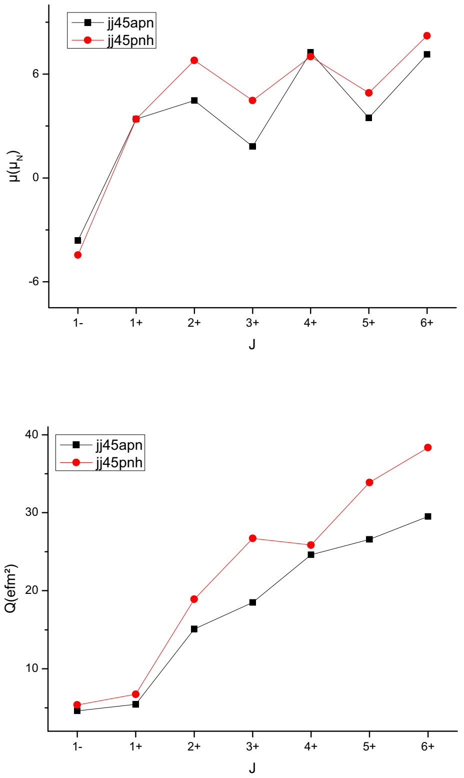

Figure 3. Electromagnetic multipole moment of ^{130}In in *^{132}Sn* mass region obtained using *jj45pnh* and *jj45apn* interactions.

For the electric quadrupole moment, *Q* the state 1^- gives the lowest value, then the minimum deformation for both interactions. This state, which represent the experimental ground state, has also the minimum value of the magnetic dipole moment μ.

Conclusion

This study is based on the nuclear properties calculations, for odd-odd ^{130}In nucleus, with hole-hole configuration of its valence space. The calculations are carried out in the framework of the shell model, by means of *OXBASH* nuclear structure code. Using the original interaction of the code, we carry out some modifications based on the mass effect to get *jj45pnh* interaction. Our new interaction cannot reproduce the experimental spectra of the studying nuclei. It is the same case for *the original interaction*. However, this later reproduce the energetic sequence of the low laying states. To ameliorate these results we have to consider other nuclear effects as the monopole interaction and shell evolution in tin-132 mass region.

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