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**RESEARCH ARTICLE**

# SHELL MODEL DESCRIPTION FOR SOME NUCLEI AROUND DOUBLE MAGIC NUCLEUS $^{132}$Sn

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**ABSTRACT**

The low lying Spectra and high spin states have been calculated for the isotopes ($^{134}$Te, $^{134}$Sb and $^{134}$Sn) in different model spaces. First set of calculations have been carried in ($0g_{7/2}$ - $0h_{11/2}$) valance space. The second set of calculations have been performed in ($1f_{7/2}$ - $0i_{13/2}$) valance space and the third set of calculations have been performed in ($0g_{7/2}$,$1f_{7/2}$) valance space. Nuclear shell model results showed that modified surface delta interaction is quite successful in introducing the spectrum energies of these nuclei and it able to produce the energy levels of the ground band clearly. In this work, the total angular momentum and parity for uncertainty and indeterminate experimentally energy levels were determinate and assured.



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## INTRODUCTION

Originally, the nuclear shell model was adopted when an attempt to describe the nuclear system with the atomic shell structure which proved to be successful. The model describes the filling of orbits and completing shells by nucleons with increasing energy within the nuclear potential. Shells are filling in a manner consistent with Pauli exclusion. Each nucleon is treating individually as an independent orbiting particle in a central potential despite of the existence of strong interactions between nucleons (Glassmaker, 1998). However, every nucleon retains an individual set of quantum numbers and wave function. The spherical shell model gives us an understanding of the observed magic numbers in atomic nuclei (Casten, 2000). The magic numbers in nuclei has clearly demonstrated the nuclear shell structure associated with the independent - particle model for nuclei (Vesselin, 2002). In this model each closed- shell configuration provides a convenient first approximation and one can assume that the system under consideration consists of a closed-shell core plus valence particles in a valence shell (Sheline *et al*., 1972).

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**Theory**

The concept of an effective two-body interaction has proved to be very successful in describing a vast amount of the observable nuclear structure properties. The effective two-body interaction can be determined by one of three basic approaches:

1. The model-independent method, based on fits of two-body matrix elements to nuclear properties.
2. The potential method which assumes an explicit mathematical form for the two-body interaction, with a small number of parameters determined experimentally.
3. The G-matrix interaction, which a more fundamental approach where the two body interaction is constructed from a measured nucleon-nucleon phase shifts (Mkhize, 2007).

The anti-symmetric matrix elements of the modified surface delta interaction used in this work, has the form (Lawson, 1980; Taqi, A.H, 2010).

$$\langle j_1 j_2 | V_{MSDI} | j_3 j_4 \rangle = C_0 \times f_J(j_1, j_2) \times f_J(j_3, j_4) \times \{ [1-(-1)^{J+T+\ell_3+\ell_4}] - K_J(j_1 j_2) K_J(j_3 j_4)[(1+(-1)^T]\} + \{[2T(2T+1)-3]B + C\}\delta_{12}\delta_{34}. \quad (1)$$

Where

$$f_J(j_1,j_2)=(-1)^{j_2+l_2}\sqrt{\frac{2(2j_1+1)\times(2j_2+1)}{2(2J+1)\times(1+\delta j_1 j_2)}}\times\left\langle j_1 j_2\,\frac{1}{2}(-\frac{1}{2})\right|J0\ \rangle$$

$$f_J(j_3,j_4)=(-1)^{l_4-j_4}\sqrt{\frac{2(2j_3+1)\times(2j_4+1)}{2(2J+1)\times(1+\delta j_3 j_4)}}\times\left\langle j_3 j_4\,\frac{1}{2}(-\frac{1}{2})\right|J0\ \rangle,$$

$$,C_0=(-1)^{n_1+n_2+n_3+n_4}A_T,A_T=\begin{cases}A_0.....for:T=0\\A_1.....for:T=1\end{cases},A_0\approx A_1\approx B\approx\frac{25}{A}Mev \qquad (2)$$

where $A_0$, $A_1$, B, and C are the strength parameters of the MSDI obtained from fitting to experimental spectra in various mass regions (Brussard and Glaudemans, 1977). The independent - particle Hamiltonian of a (Z- particle) system can be written in terms of two – particle interactions as:

$$H=\sum_{K=1}^{Z}T_K+\sum_{K=1}^{Z}\sum_{l=K+1}^{Z}W(\vec{r_K},\vec{r_l}) \qquad (3)$$

Where $W(\vec{r_K},\vec{r_l})$ is the two – body interaction between the kth and lth nucleons. Inserting an average potential ± U (rk), the Hamiltonian becomes:-

$$H=\sum_{K=1}^{Z}[T_K+U(r_K)\ ]\sum_{K=1}^{Z}\sum_{l=K+1}^{Z}W(\vec{r_K},\vec{r_l})-\sum_{K=1}^{Z}U(r_K) \qquad (4)$$

Where the first term is identical to the independent – particle Hamiltonian, and the second and third account for the deviation from independent particle motion, known as the residual interaction. Separating the summations into core and valence contributions, eq. (4) can be re – written as (Coraggio *et al*., 2009):

$$H=H_{Core}+H_1+H_2+V_{MSDI} \qquad (5)$$

Where $H_{Core}$ contains the interaction of nucleons making up the core, $H_1$ and $H_2$ are the single – particle contributions of particles (1) and (2), and $V_{MSDI}$ describe the residual interaction between particles (1) and (2), as well as any interaction with core nucleons, by inserting (eq (5)) into Schrödinger equation yields expression for the energy as:-

$$E=E_{Core}+E_1+E_2+\left\langle\Phi_{J,T}\left|V_{MSDI}\right|\Phi_{J,T}\right\rangle \qquad (6)$$

Here $E_{Core}$ is the binding energy of the nucleus core and $\left\langle\Phi_{J,T}\left|V_{MSDI}\right|\Phi_{J,T}\right\rangle$ is the residual interaction which needs to be defined by theory. It is important to note that the energy given by eq. (6) is for pure configurations only. In principle any close - lying state with the same total angular momentum (J) and total isospin (T) will mix. The mixed eigen states are giving by linear combinations of the unperturbed wave functions (Hasan and Hussain, 2013):

$$(\Psi_{J,T})_s=\sum_{K=1}^{n}a_{ks}(\phi_{JT})_s \qquad (7)$$

Where ( s) is the number of mixing configurations and takes values :(s=1,2,..,..n),The coefficients ($a_{ks}$ ) fulfill the condition (Caurier *et al*., 2005):

$$\sum_{K=1}^{n}\left|a_{ks}\right|^2=1 \qquad (8)$$

## RESULTS AND DISCUSSION

In this study, we have taken a doubly magic isotope $^{132}Sn$ as a closed core situated away from the line of stability , and let the last two protons in $^{134}Te$ nucleus occupy the five levels $0g_{7/2},1d_{5/2},1d_{3/2},2s_{1/2}$ *and* $0h_{11/2}$) and the last two neutrons in the $^{134}Sn$ nucleus occupy the six levels $(1f_{7/2},1f_{5/2},0h_{9/2},2p_{3/2},2p_{1/2}$ *and* $0i_{13/2})$ while in $^{134}Sb$ nucleus, which have one proton in orbital ($0g_{7/2}$) and one neutron in orbital($1f_{7/2}$).Asingle proton energies that have taken from the experimental spectrum of $^{133}$Sb isotope are $(0.962, 2.439, 2.791$ and $2.800)\,MeV$ for $(1d_{5/2},1d_{3/2},2s_{1/2}$ and $0h_{11/2})$ respectively. While, A single neutrons energies that have taken from the experimental spectrum of $^{133}Sn$ isotope are $(2.004, 1.561, 0.853, 1.363,$ *and* $2.694)\,MeV$ (Sonzogni, 2004).

### $^{134}Te$ Nucleus

In our calculations for this nucleus, the high spin levels scheme have been extended to $7.608\,MeV$ excitation energy and spin $6_6^+$ as shown in the table (1). Our found the levels {$0_1^+$, $2_1^+$ ,$4_1^+$ and $6_1^+$ }with energies{0, 1.119,1.269 and 1.406} MeV when comparison with experimental values{0,1.279, 1.576 and 1.691}MeV. We expect the levels {$1_1^+$ or 3} and $0_2^+$) at energies {2.196} and {2.655} MeV while experimental values are {2.397}and {2.682}MeV which were uncertain in spin and parity$(6)^+$and $(3^+)$ respectively. The {$2_3^+$} level at {3.048} MeV is correspond to experimental value {2.933} MeV. The energies {4.025,4.026,4.586,4.635,4.996 and 6.998) MeV which were so close to with experimental values {4.013, 4.269,4.556,4.563,5.079 and 7.050}MeV which were uncertainty in total angular momentum and parity. We found the {$2_6^+$,$2_8^+$ ,$6_5^+$and $6_6^+$} at {4.531,6.178,6.826 and 7.608} MeV were in a good agreement with experimental values{4.504,5.986, 6.709 and7.722} MeV respectively which were undetermined the total angular momentum and parity. There are several levels in the ranges:{{$4_2^+$ to $5_1^+$},{$4_3^+$ to $3_3^+$}, { $3_5^+$ to ($6_4^-$ or $8_2^-$)},{$0_3^+$,$7_3^-$ to $8_4^+$},{$0_4^+$ to$4_8^-$},$10_1^+$ and $0_5^+$}, in our calculations with energies {(2.057 to 2.168), (3.186 to 3.983), (4.636 to 4.987), (5.266, 6.227 to 6.817),(6.838 to 6.932),(6.999 and 7.123)} which were found without analoge experimental values and they were listed in Table (1).

**Table 1. Comparison between calculated excitation energy levels with experimental data for $^{134}Te$ nucleus**

| $J^\pi_{cal.}$ | $E_{.cal.}$ (MeV). | $J^\pi_{Exp.}$ | $E_{\cdot Exp\cdot}$(MeV) |
|---|---|---|---|
| $0_1^+$ | 0 | $0^+$ | 0 |
| $2_1^+$ | 1.119 | $2^+$ | 1.279 |
| $4_1^+$ | 1.269 | $4^+$ | 1.576 |
| $6_1^+$ | 1.406 | $6^+$ | 1.691 |
| $4_2^+$ | 2.057 | —— | —— |
| $2_2^+$ | 2.081 | —— | —— |
| $5_1^+$ | 2.168 | —— | —— |
| $1_1^+$,$3_1^+$ | 2.196 | $(6)^+$ | 2.397 |
| $0_2^+$ | 2.655 | $(3^+)$ | 2.682 |
| $2_3^+$ | 3.048 | $2^+$ | 2.933 |
| $4_3^+$ | 3.186 | —— | —— |
| $2_4^-$ | 3.357 | —— | —— |
| $7_1^-$ | 3.501 | —— | —— |
| $4_4^-$ | 3.534 | —— | |
| $8_1^-$ | 3.672 | —— | —— |
| $5_2^+$, $9_1^-$ | 3.673 | —— | —— |
| $3_2^+$ | 3.674 | —— | —— |
| $6_2^-$ | 3.667 | —— | —— |
| $4_5^+$ | 3.891 | —— | —— |
| $5_3^-$ | 3.936 | —— | —— |
| $4_6^+$ | 3.965 | —— | —— |
| $3_3^+$ | 3.983 | —— | —— |
| $6_3^-$,$2_5^+$ | 4.025 | $(9^-)$ | 4.013 |
| ${}_4^-3$ | 4.026 | $(7^-)$ | 4.269 |
| $2_6^+$ | 4.531 | —— | 4.504 |
| $4_7^+$ | 4.586 | $(8^+)$ | 4.556 |
| $1_2^+$ | 4.635 | $(8^-)$ | 4.563 |
| $3_5^+$ | 4.636 | —— | —— |
| $2_7^+$ | 4.824 | —— | —— |
| $7_2^-$ | 4.981 | —— | —— |
| $6_4^-$,$8_2^-$ | 4.987 | —— | —— |
| $3_6^+$ | 4.996 | $(9^+)$ | 5.079 |
| $0_3^+$ | 5.266 | —— | —— |
| $2_8^+$ | 6.178 | —— | 5.986 |
| $7_3^-$ | 6.227 | —— | —— |
| $2_9^+$ | 6.386 | —— | —— |
| $1_3^+$ | 6.474 | —— | —— |
| $5_4^-$ | 6.603 | —— | —— |
| $8_3^-$ | 6.646 | —— | —— |
| $8_4^+$ | 6.817 | —— | —— |
| $6_5^+$ | 6.826 | —— | 6.709 |
| $0_4^+$ | 6.838 | —— | —— |
| $4_8^-$ | 6.932 | —— | —— |
| $2_{10}^+$ | 6.998 | $(14^+)$ | 7.050 |
| $10_1^+$ | 6.999 | —— | —— |
| $0_5^+$ | 7.123 | —— | —— |
| $6_6^+$ | 7.608 | —— | 7.722 |

**Table 2. Comparison between calculated excitation energy levels with experimental data for $^{134}Sn$ nucleus**

| $J^{\pi}_{cal.}$ | $E_{.cal.}$ (MeV). | $J^{\pi}_{Exp.}$ | $E_{\cdot Exp\cdot}$ (MeV) | $J^{\pi}_{cal.}$ | $E_{.cal.}$ (MeV). | $J^{\pi}_{Exp.}$ | $E_{\cdot Exp\cdot}$ (MeV) |
|---|---|---|---|---|---|---|---|
| $0_1^{+}$ | 0 | $0^{+}$ | 0 | $2_7^{+}$ | 4.392 | — | — |
| $2_1^{+}$ | 1.011 | $2^{+}$ | 0.725 | $4_8^{+}$ | 4.446 | — | — |
| $4_1^{+}$ | 1.406 | $^{+}4$ | 1.073 | $4_9^{+}$ | 4.515 | — | — |
| $6_1^{+}$ | 1.565 | $6^{+}$ | 1.247 | $2_8^{+}$ | 4.654 | — | — |
| $2_2^{+}$ | 1.923 | — | — | $4_{10}^{+}$ | 4.689 | — | — |
| $4_2^{+}$ | 2.164 | — | — | $6_6^{+}$ | 4.694 | — | — |
| $1_1^{+}$ | 2.269 | — | — | $2_9^{+}$ | 4.715 | — | — |
| $5_1^{+},3_1^{+}$ | 2.322 | — | — | $8_3^{-}$ | 4.786 | — | — |
| $3_2^{+}$ | 2.575 | $(8^{+})$ | 2.508 | $2_{10}^{-}$ | 4.819 | — | — |
| $0_2^{+}$ | 2.649 | — | — | $3_8^{+}$ | 4.836 | — | — |
| $4_3^{+}$ | 2.685 | — | — | $6_7^{+}$ | 4.984 | — | — |
| $5_2^{-}$ | 2.746 | — | — | $3_9^{-}$ | 5.012 | — | — |
| $6_2^{-}$ | .7572 | — | — | $6_8^{-},8_4^{+}$ | 5.016 | — | — |
| $3_3^{+}$ | 2.832 | — | — | $7_3^{+}$ | 5.021 | — | — |
| $7_1^{+}$ | 2.913 | — | — | $2_{11}^{+},4_{11}^{+}1_6^{+}$ | 5.033 | — | — |
| $4_4^{+},2_3^{+},8_1^{+}$ | 3.029 | — | — | $4_{12}^{-}$ | 5.384 | — | — |
| $2_4^{+}$ | 3.098 | — | — | $7_4$- | 5.439 | — | — |
| $6_3^{+}$ | 3.248 | — | — | $0_4^{+}$ | 5.461 | — | — |
| $3_4^{+}$ | 3.331 | — | — | $2_{12}^{+}$ | 5.509 | — | — |
| $2_5^{+}$ | 3.431 | — | — | $0_5^{-}$ | 5.526 | — | — |
| $5_3^{+}$ | 3.472 | — | — | $8_5^{-}$ | 5.607 | — | — |
| $_2^{+}3_5^{-},1$ | 3.473 | — | — | $4_{13}^{+}$ | 5.651 | — | — |
| $_3^{+}1$ | 3.554 | — | — | $10_2^{+}$ | 5.658 | — | — |
| $1_4^{+}$ | 3.685 | — | — | $3_{10}^{-},5_7^{-},6_9^{-}, 7_5^{-}$ | 5.723 | — | — |
| $6_4^{+}$ | 3.763 | — | — | $9_2^{-}$ | 5.900 | — | — |
| $5_4^{+}$ | 3.787 | — | — | $2_{13}^{+}$ | 6.038 | — | — |
| $4_5^{+}$ | 3.831 | — | — | $7_6^{-}$ | 6.095 | — | — |
| $7_2^{-}$ | 3.882 | — | — | $5_8^{-}$ | 6.137 | — | — |
| $3_6^{+}$ | 3.955 | — | — | $4_{14}^{-}$ | 6.166 | — | — |
| $4_6^{-}$ | 3.992 | — | — | $6_{10}^{-},8_6^{-},4_{15}^{+}$ | 6.167 | — | — |
| $2_6^{+}$ | 4.026 | — | — | $0_6^{+}$ | 6.714 | — | — |
| $9_1^{-}$ | 4.033 | — | — | $12_1^{+}$ | 6.769 | — | — |
| $5_5^{-}$ | 4.094 | — | — | $8_7^{+}$ | 6.870 | — | — |
| $4_7^{+},6_5^{-},8_2^{-}, 10_1^{-}$ | 4.163 | — | — | $6_{11}^{+}$ | 6.977 | — | — |
| $5_6^{-}$ | 4.291 | — | — | $10_3^{-}$ | 6.982 | — | — |
| $3_7^{+}1_5^{+}$ | 4.326 | — | — | $11_1^{-}$ | 7.071 | — | — |
| $0_3^{+}$ | 4.379 | — | — | | | | |

**Table 3. Comparison between calculated excitation energy levels with experimental data for $^{134}Sb$ nucleus**

| $J^{\pi}_{cal.}$ | $E_{.cal.}$ (MeV). | $J^{\pi}_{Exp.}$ | $E_{\cdot Exp\cdot}$(MeV) |
|---|---|---|---|
| 1 | 0 | $(0^{-})$ | 0 |
| 8 | 0.404 | $(5^{-})$ | 0.441 |
| 2 | 0.519 | $(4^{-})$ | 0.555 |
| 6 | 0.594 | $(6^{-})$ | 0.617 |
| 4 | 0.606 | — | — |
| 3 | 0.622 | — | — |
| 5 | 0.725 | — | — |
| 7 | 0.778 | — | — |

### $^{134}$Sn Nucleus

The comparison between the calculated values and experimental data (Sonzogni, 2004) has shown in Table (2). Recently, the levels of $^{134}Sn$ nucleus are extended to 2.508 MeV in the experimental data. The first, three calculated levels are found to be $\{0_1^+, 2_1^+, 4_1^+ \; and \; 6_1^+\}$ with energies {0,1.011,1.406 and 1.565} MeV which were rather close to with experimental values as {0,0.725, 1.073 and 1.247} MeV . We expect the level $\{3_2^+\}$ at {2.575} MeV while experimental value is {2.508} MeV uncertain in spin and parity ($8^+$). Another energy levels in the range$\{0_2^+$ to $11_1^-\}$in our calculations which were undetermined the spins and energies in the experimental data, because the highest experimental level for this nucleus is {2.508}MeV (Sonzogni, 2004), with spin and parity ($11^-$) while in this work the energies reached the values {7.071} MeV which increased (64) extra level on experimental values. We found in the framework of shell model calculations (64) new energy levels were determined for ($^{134}$Sn) isotope. This investigation increases the theoretical Knowledge of all isotopes with respect to energy levels

### $^{134}$Sb Nucleus

Experimental levels are available to 5.324 MeV excitation energy and spin ($14^-$) for this nucleus. Comparison of the calculated levels with experimental data (Saleem *et al*., 2004) presented in table (3). The levels $\{1^-, 8^-$ and $2^-\}$ are predicted by nuclear shell model with energies{0, 0.404 and 0.519}MeV, while experimental values are {0, 0.414 and 0.555}MeV uncertainty at $\{(0^-)$ , $5^-$ and $4^-\}$ spins and parity. We expect certain the level ($6^-$) to energy 0.617 MeV uncertainty experimentally. Our choosing for this nucleus in this shell, we found that the number of levels limited compared with experimental values.

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