SHELL MODEL STUDY OF EVEN–EVEN $^{132-136}$Te NEUTRON-RICH NUCLEI

F.A. Majeed

Dept. of Physics, College of Science, Al-Nahrain University, Baghdad, Iraq
and
The Abdul Salam International Centre for Theoretical Physics, Trieste, Italy

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Large-scale shell model calculations were performed for neutron-rich even–even $^{132-136}$Te using a realistic effective interaction derived from CD-Bonn nucleon–nucleon potential for the positive and negative parity states. The calculated results are compared with the recently available experimental data and with the recent theoretical work. The transition rates $B(E2;\, 0^+ \to 2^+)$ are also calculated by taking into consideration core polarization effect by choosing best effective charges for proton and neutron. The result of our theoretical calculations are compared with experimental data and with the previous theoretical work. A very good agreement were obtained for all nuclei.

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1. Introduction

In recent years, there has been significant progress in the experimental knowledge of neutron-rich nuclei with few particles or holes outside doubly magic ^{132}Sn [1]. The region of neutron-rich Sn and Te nuclei with the number of protons at, or just above, the $Z = 50$ closed shell becomes recently important for both experimental and theoretical study [2]. Previous shell-model calculations (see Ref. [3] for details) provided reasonable agreement with energy spectra and $B(E2)$ in $N = 80$ and $N = 82$ Sn and Te isotones but failed to explain the $B(E2)$ value in ^{136}Te. Magnetic moments were calculated for ^{134}Te, ^{136,137}Xe and ^{137}Cs by Sarkar and Sarkar [4] with the KH5082 and CW5082 interactions fitted in the ^{208}Pb and scaled to the ^{132}Sn region, and with empirical effective single-particle g-factors. Shell-model calculations for the 2^+, 4^+ and 6^+ states in $^{130-134}$Te and $^{132-136}$Xe were reported in Ref. [5], where the surface delta interaction (SDI) was used with two different sets of parameters. The single particle states were chosen to reproduce single proton states in $^{133}_{51}$Sb and single neutron states in $^{131}_{50}$Sn. The single-particle spin and orbital effective g-factors were based on the experimental g-factors of the low-lying $(7/2)^+$ and $(5/2)^+$ states in the odd-Z, $N = 82$ isotones. Shell model calculations with modified empirical Hamiltonian that was obtained by some modifications of a Hamiltonian (CW5082) originally derived from the ^{208}Pb region and scaled to the ^{132}Sn region were performed by Sarkar and Sarkar [6]. The g-factor of the first 2^+ state in ^{132}Te and energy levels of nuclei near ^{132}Sn has been studied by Brown *et al.* [2] using microscopic interaction based on CD-Bonn nucleon–nucleon interaction [7].

The aim of the present work is to study the level energies including the high J^π-values, which are not studied before to test the ability of the "new developed effective interaction obtained starting with a G matrix derived from CD-Bonn nucleon–nucleon interaction by Brown *et al.* [2] and this interaction codenamed lately as SN100PN in the new released version of OXBASH for Windows [8]" in reproducing the J^π-values. The main difference of the present work and Brown *et al.* work is that we consider the core to be ^{100}Sn instead of ^{132}Sn. It means that with our choice of core as ^{100}Sn, the valence neutrons are particles, not as in the case of Ref. [2], were the valence neutrons are holes for the case of $N \leq 82$. We try to investigate if this change of choosing different core would improve the calculations of level spectra for ^{132}Te and ^{134}Te. On the other hand, since the electromagnetic transition rates provide one of the most sensitive probes of nuclear structure, therefore it is studied in this work for the first 2^+, to give clear picture of the present large-scale shell model calculations in reproducing the experiment.

2. Outline of calculations

In our calculations ^{100}Sn is considered as the core with 32 and 34 particles outside the core for ^{132}Te and ^{134}Te, respectively. The model space SN100PN were used with SN100PN Hamiltonian [2] based on CD-Bonn renormalized G matrix using the code OXBASH [8]. The single particle energies used in the present work are quoted from Ref. [2] for $N \leq 82$ as follows: the proton single-particle energies are $-9.68, -8.72, -7.24, -7.34$ and -6.88 MeV for the proton model space $0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2}$ and $0h_{11/2}$, respectively. The neutron single-particle energies are $-9.74, -8.97, -7.31, -7.62$ and -7.38 MeV for the neutron model space $0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2}$ and $0h_{11/2}$, respectively.

For ^{136}Te, where $N \geq 82$, ^{132}Sn is taken as the core with 4 particles outside the core. The effective interactions KH5082 [9] which are originally fitted for ^{208}Pb and scaled to the ^{132}Sn region were employed in the calculations of ^{136}Te by replacing the single-particle energies (SP) used with KH5082 effective interaction by those quoted from Ref. [2] as follows: the proton single particle energies were taken for the same model space for protons as above, while the neutron orbits should be changed for those quoted from Ref. [2] as follows: −0.894, −2.455, −0.450, −1.601, −0.799 and 0.25 MeV for the neutron model space $0h_{7/2}$, $1f_{7/2}$, $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$, $0i_{13/2}$, respectively.

3. Results and comparison with experiment

3.1. Excitation energies

The calculated excitation energies for ^{132}Te are presented in Fig. 1. Good agreement was obtained comparing our theoretical calculations with the experiment for both, positive and negative parity states. Our calculations are very close and sometimes exactly the same as the results obtained in Ref. [2] and if we focus our attention to the prediction of the first 2^+, our work predicts this level at 954 keV and the experiment is 974 keV. The absolute difference between the two values is 20 keV and if we compare this result with the previous theoretical work of Terasaki *et al.* [10,11], where they use quasi random phase approximation (QRPA) and their theoretical work predicts 2^+ at 1211 keV and the absolute difference between experiment is 237 keV, we find our result to be in significantly better agreement with experiment.

Fig. 2 presents the comparison of results obtained in this work with the experimental data and with previous theoretical work obtained in Ref. [2] for ^{134}Te. From the figure we can notice that this model is in good agreement with experiment up to $J \leq 8$, but if there is large discrepancy in predicting 9^+ and 10^+ in comparison with experiment this reflects the inadequacy of the model space. If we compare the prediction of the first 2^+, we find our work predicts this level at 1211 keV and the absolute difference with experimental value is 68 keV in comparison with the previous theoretical work in Ref. [12], which predicts this level at 1375 keV with absolute difference 96 keV from experimental value.

In Fig. 3, all the experimental and calculated levels up to 7782 keV in comparison with the previous theoretical work taken from Ref. [6] are reported for ^{136}Te. Good agreement was obtained comparing our theoretical calculations with the experimental values up to $J^\pi = 10^+$, but for the higher spin $J > 12$ the calculations start to deviate from the experimental values and this reflects the inadequacy of the model space. The first 2^+ is predicted at 866 keV which is very close to the value predicted by Sarkar and Sarkar [4]. Their work [6] using empirical Hamiltonian named SMPN5082 obtained from some modifications of a Hamiltonian CW5082 predicts the energy levels for positive and negative parity states much better than this work.

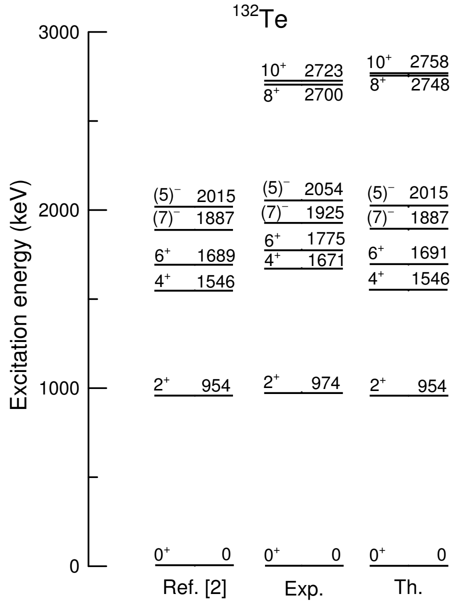

Fig. 1. Calculated energy levels for positive and negative parity states of ^{132}Te in comparison with experiment taken from Ref. [10] and the previous theoretical work taken from Ref. [2].

3.2. Transition probabilities

The electromagnetic transition probability $B(E2;\, 0^+ \to 2^+)$ values calculated for both model spaces and interactions are compared with those obtained from the measured lifetimes of states in different nuclei. The radial integral involved in calculation of $E2$ matrix elements is calculated with the harmonic oscillator radial wave function, with $\hbar\omega = 45A^{-1/3}$–$25A^{-2/3}$ [15].

Fig. 4 shows the comparison of the calculated results from this work with the experimental values and with the recent calculations of Sarkar and Sarkar [6]. The effective charges for proton, $e_p^{\rm eff} = 1.47$, and for neutron, $e_n^{\rm eff} = 0.72$, are taken also from Ref. [6]. From this figure we can see that our work is in better agreement with the experiment than those calculated by Sakar and Sakar at neutron number $N=80$ and $N=82$, but their result for $N=84$ are better than those in our work. It seems that their modifications improve the prediction of level spectra for ^{136}Te as well as the transition rates.

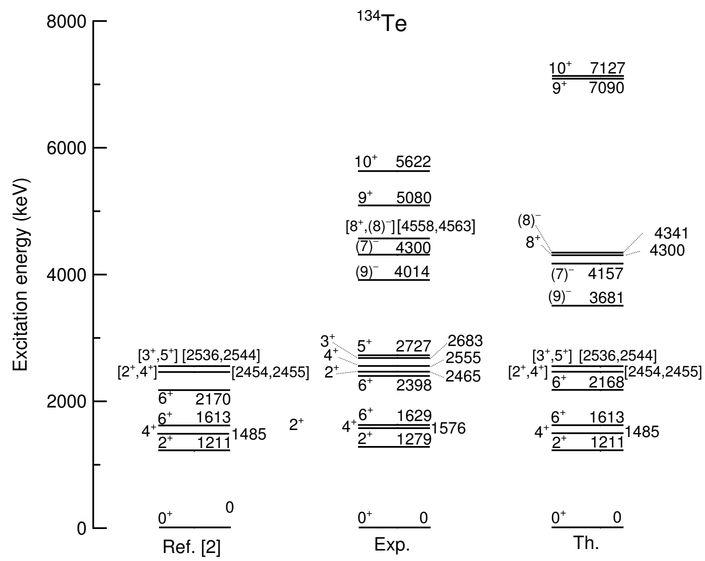

Fig. 2. Calculated energy levels for positive and negative parity states of ^{134}Te in comparison with experiment taken from Ref. [13] and the previous theoretical work taken from Ref. [2].

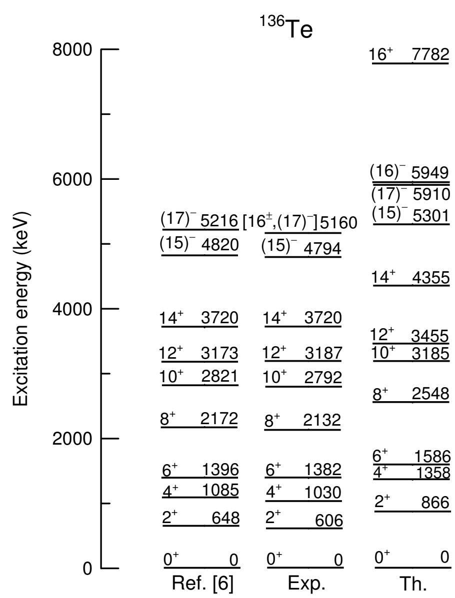

Fig. 3. Calculated energy levels for positive and negative parity states of ^{136}Te in comparison with experiment taken from Ref. [14].

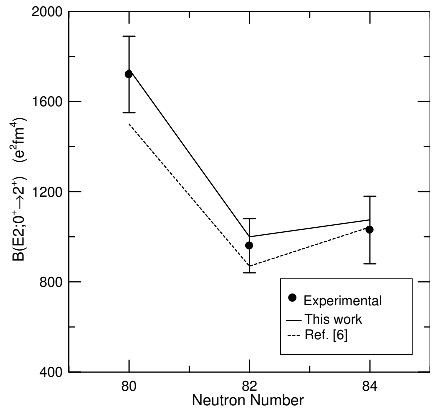

Fig. 4. Comparison of the calculated $B(E2; 0^+ \rightarrow 2^+)$ from this work (solid line) with the experimental values (closed circles) and with the theoretical work from Ref. [6] (dashed line) for ^{132,134,136}Te. Experimental data are taken from Refs. [3, 11].

4. Summary

Unrestricted large-scale shell model calculations were performed using the model space SN100PN with Hamiltonian SN100PN for ^{132,134}Te by choosing ^{100}Sn as the core rather than ^{132}Sn which is taken as core by most authors from previous theoretical work. Conclusions were drawn that the choice of ^{100}Sn as the core does not effect the calculations and this is due to the fact that the same proton model spaces for both cores were employed for the calculations. The core ^{132}Sn were chosen with the effective interaction KH5082 by choosing suitable single-particle energies (SP) quoted from Ref. [2] for the nucleus ^{136}Te. The results of this work are compared with the recently available experimental data and with the best results achieved from the previous theoretical work. Overall good agreement was obtained for all nuclei up to $J \leq 10$, but for high spin states $J > 10$ the model fails to reproduce the experiment. The transition rates are in excellent agreement with the experimental $B(E2; 0^+ \rightarrow 2^+)$ values and are consistent with the previous theoretical work.

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