SHELL MODEL STUDY OF NEUTRON-RICH TIN ISOTOPES A=135-136

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Résumé

La région ^{132}Sn doublement magique est très intéressante pour plusieurs raisons. Elle fournit des informations importantes sur le modèle de calculs des processus astrophysiques, donne l'opportunité d'extraire les interactions empiriques N-N et de tester des descriptions théoriques du modèle en couches de la structure nucléaire des noyaux dans cette région. L'interaction CW5082 du code OXBASH a été dérivée à l'origine de la région ^{208}Pb en utilisant les informations expérimentales récentes de la région ^{132}Sn. Cette interaction a alors subit des modifications par différents auteurs tel que ceux de S. Saha (interactions SMN et SMPN). Nous avons procédé par de nouvelles modifications de l'interaction CW5082, aux calculs des énergies d'excitation et des probabilités réduites B(E2) des isotopes de l'étain de A=135-136, dans le cadre de modèle en couches. Les résultats obtenus montrent une amélioration remarquable dans le pouvoir prédictif lorsqu'on les compare avec les résultats expérimentaux disponibles. Ils sont aussi en bon accord avec les résultats calculés par les deux interactions SMN et SMPN.

Mots clés: Isotopes de Sn, Modèle en couches, Code OXBASH, Interactions effectives, Énergies d'excitation, Probabilité réduite B(E2).

Abstract

The doubly magic ^{132}Sn region is interesting for many reasons. It offers the important information for the astrophysical processes model calculation, can gives the opportunity to take out the empirical N-N interactions as well as to test theoretical shell model description of nuclear structure in this region. The CW5082 interaction of the shell model code OXBASH has originally derived from the ^{208}Pb region by using recent experimental information of the ^{132}Sn region. Then, this interaction has undergone the other modifications by different authors such as them S. Saha (SMN and SMPN interactions). We have developed by the new modifications of CW5082 interaction, at the calculations of the excited energies and the reduced probabilities B(E2) with A=135-136 Sn isotopes, in the shell model. The gotten results show a remarkable improvement in the predictive power when we compared them with the available experimental results, and contrast well with the calculated results with the SMN and SMPN interactions.

Keywords: Sn isotopes, Shell Model, OXBASH code, Effective interactions, Excited energies, Reduced probability B(E2).

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ملخص

المنطقة المضاعفة السحرية ^{132}Sn مهمة لعدة أسباب. لكونها توفر معلومات مهمة لنمط الحسابات للسير الفلكي. و هي تمنح أيضا الفرصة لاستنباط التفاعلات الملاحظة N-N كما تختبر خاصيات النموذج الطبقي للبنية النووية لهذه المنطقة. التفاعل CW5082 للبرنامج OXBASH مشتق أصلا من المنطقة ^{208}Pb و ذلك باستعمال المعلومات التجريبية للمنطقة ^{132}Sn. خضع هذا التفاعل إلى تغيرات من مختلف المؤلفين مثل تغيرات S. Saha (التفاعلات SMN و SMPN). قمنا بواسطة تغيرات جديدة للتفاعل CW5082 بحسابات لطاقات الإثارة و للاحتمالات المختصرة B(E2) لنظائر القصدير A=135-136 في إطار النموذج الطبقي, أدت النتائج المحصل عليها إلى تحسن ملحوظ بالمقارنة مع النتائج التجريبية المتوفرة و كذلك بالمقارنة مع نتائج التفاعلين SMN و SMPN.

الكلمات المفتاحيــة: نظائر Sn، النموذج الطبقي، البرنامج OXBASH، التفاعلات الفعالة، طاقات الإثارة، الاحتمال المختصر B(E2).

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Introduction

The region around ^{132}Sn, with its closed shells of both protons and neutrons, is a region of the many isotopes which constitute an area of significant mass allowing to extort the precise information on the fundamental nuclear properties, such as to explain the most interesting phenomena as the doubly magic of shell, the isomeric states, the high spins of the rotational bands corresponding to the nuclei which have a very high number of protons exceeding the magic number 50.

In few last years, there were important appreciations in the experimental knowledge of the neutron-rich nuclei with few particles outside the doubly magic ^{132}Sn nucleus. These nuclei are of special interest since they provide direct information about the effective charges, nucleon-nucleon effective interaction, and particle energies [1]. Moreover, the study of very neutron-rich nuclei both experimentally as theoretically is important not only for the nuclear structure, but also for the applications in the astrophysical rapid neutron capture r-process model calculations. The astrophysical modeling of the synthesis processes of elements and their abundance in nature relies heavily on nuclear structure data and predictions from nuclear models. In r-process about half of the nuclei heavier than iron are produced in sequences of neutron capture and β decays [2].

In this paper, we have studied the neutron-rich tin isotopes by using CW5082 modified interactions. Our modifications on CW5082 interaction is based on the Saha's ones [3]. However, we have used the binding energies in all of our modification steps. Then, we have compared the obtained results with that of S. Saha et al., and with the experimental results. These new interactions give an available agreement of the excited energies and reduced probabilities B(E2) for $^{135-136}$Sn, $^{135-136}$Sb, $^{135-136}$Te and ^{135}I isotopes as well as S. Saha's interactions (SMN and SMPN).

2. OXBASH calculations and Modified interactions

Shell model calculations for the $^{135-136}$Sn, $^{135-136}$Sb, $^{135-136}$Te and ^{135}I nuclei have been performed using the code OXBASH [4], the calculations induced a model space consisting of the ^{132}Sn inert core and all orbitals between ^{132}Sn and ^{208}Pb as following: $1g_{9/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$ and $1h_{11/2}$ for proton with the energies in MeV: -9.6629, -8.7005, -7.2233,-6.9657 and -6.8714 [5] respectively and $1h_{9/2}$, $2f_{7/2}$, $2f_{5/2}$, $3p_{3/2}$, $3p_{1/2}$ and $1i_{13/2}$ for neutron with the energies in Mev: -0.8944, -2.4553, -0.4507, -1.6016, -0.7996 and +0.2397 [5] respectively. The neutron and proton single particle energies are acquired from the experimental values [6], except $3s1_{/2}$ spe is obtained from the local systematic [7] and 1i13/2 spe which is taken from the reference [8].

The CW5082 interaction was obtained by replacing the five proton-neutron 0^- and 1^- levels that were nearly degenerated, as is known for ^{210}Bi [9] of KH5082 interaction, where this later was obtained from the Kuo-Herling “bare + one particle-one hole” or “bare G matrix + core polarization” matrix elements of the ^{208}Pb region by multiplying them by the mass-scaled factor $(132/208)^{-1/2}$ [9].

We have changed the neutron-neutron tbme and proton-neutron tbme were keeping the same ones as those in CW5082. The six neutron-neutron diagonal TBME with $J^\pi=0^+$ being too attractive were multiplied by the factor of 0.48 [3]. This factor is obtained by reproducing the experimental binding energy -6.365 MeV of ^{134}Sn.
Then, we have used the experimental binding energies -5.6394, -5.2916, -5.1176 and -3.8561 MeV of the first four excited states $J^\pi=2^+$, 4^+, 6^+ and 8^+ respectively of ^{134}Sn nucleus. By the same steps of modifications, we have also used the experimental binding energies: -12.9520, -12.9390, -12.6213, -12.5685, -12.3972, -12.6690, -11.8790, -105180, -10.8260, 8.8580, -8.5270 and -8.4350 MeV of the levels: $J^\pi=0^-$, 1^- ,2^- , 3^- , 4^- , 7^- , 8^- , 9^+, 10^+, 10^- , 11^- , and 12^- respectively of the ^{134}Sb nucleus for modifying its matrix elements.

Thereafter, we have modified four proton-proton TBME by using the binding energies of the ^{134}Te nucleus of $J^\pi=0^+$, 2^+, 4^+, and 6^+ with $(\pi g_{7/2})^2$ which are: -20.560, -19.281, -18.984 and -18.868 MeV respectively.

Finally, we have obtained two new interactions. The first interaction is called SLN, by the modification of 22 matrix elements of CW5082 interaction; and the second one is named SLPN by changing 26 matrix elements of the CW5082 interaction.

3. Results, comparison and discussion

In this work we have calculated the level spectra and B(E2) values for Sn, Sb and Te isotopes of A=135-136 masses and also of ^{135}I nucleus by the new interactions SLN and SLPN, where we have attempted to find the different between these interactions and the ones of S. Saha et al.,.

The figure (1) shows the comparison between the interactions SLN and SMN with very recent experimental spectra for the ^{135}Sn, ^{135}Sb, ^{135}Te and ^{135}I isotopes. Then, in the figure (2), we compare also the calculated spectra that have obtained by using the new interactions, with the ones that calculated by SMN and SMPN interactions and with the experimental spectra for ^{136}Sn, ^{136}Sb and ^{136}Te isotopes.

According to the figures (1.a) and (1.d); one can observe that for the ^{135}Sn and ^{135}I isotopes which have three neutrons and three protons of valence respectively (identical valence nucleons), the different between SLN and SMN isn't notable where the great value of $|\Delta E|$ is 12 keV for the first excited level $5/2^-$ of ^{135}Sn, and both of these interactions have given a good agreement with the experimental value for ^{135}I spectrum except the $19/2^-$,$23/2^-$ and $21/2^-$ levels. However, the figure (1.b) shows a great different between SLN and SMN for the ^{135}Sb nucleus that has one proton and two neutrons (non-identical valence nucleons), the great value of $|\Delta E|$ is 250 keV for the level $23/2^+$. Whereas, the figure (1.c) illustrates that the difference between the SLN and SMN [10] interactions isn't important for the low spin, although, it is very big for high spin where the big value of $|\Delta E|$ is 426 keV for the level $21/2^-$.

Similarly, SLN and SMN interactions have given the analogous results for ^{136}Sn and ^{136}Sb approximately (figures (2.a) and (2.b)). On the other hand, they haven't given good results for ^{136}Te; there is a remarkable difference between the SLN and SMN interactions, and between the SLPN and SMPN interactions, too.

Furthermore, it is seen that even with the minor change, the result for the binding energies with the SLPN interaction is regularly better than that of SLN.

Therefore, we can acquire from these comparisons, that the modification of neutron-neutron and proton-proton TBME have given a similar results as of S. Saha et al, especially for the tin isotopes that have the identical valence nucleons like $^{135\text{-}136}Sn$ and ^{135}I, for the ^{135}I nucleus is of special interest for a test of the basic ingredients of a shell model calculation like ^{134}Te because they represent a direct source of knowledge of the effective interaction proton-proton interaction [11]. At the same time as, the modification of proton-neutron TBME has given the different results that of S. Saha et al., if we would apply them on the isotopes which include the non identical valence nucleons with the same number like ^{135}Sb (1proton-2neutron) and ^{136}Te (2protons-2neutrons), however, they have given the same results as of SMN and SLMP if the number of valence proton is bigger than valence neutron and vice versa. Hence, our modifications are dependent on the valence nucleons interaction.

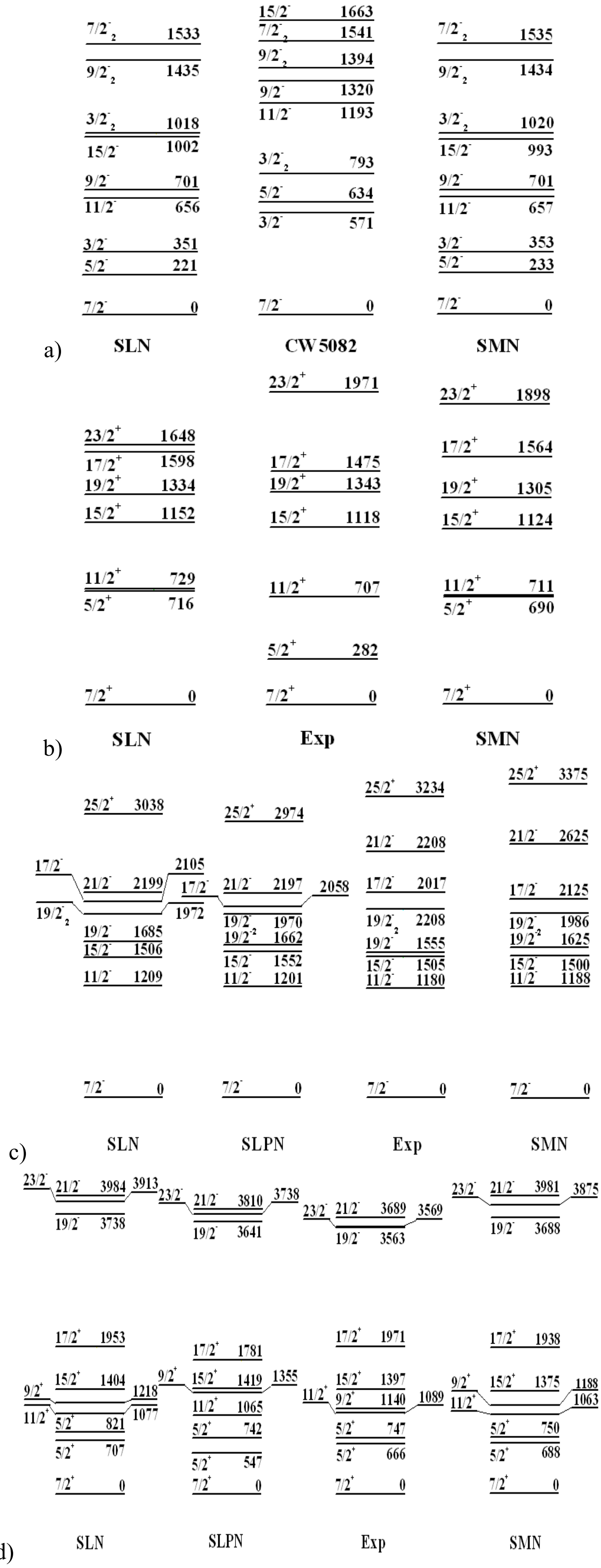

Figure (1): Comparison of calculated (SLN, SLPN, SMN and SMPN) and experimental excitation energies for A=135 mass a) ^{135}Sn, b) ^{135}Sb, c) ^{135}Te and d) ^{135}I.

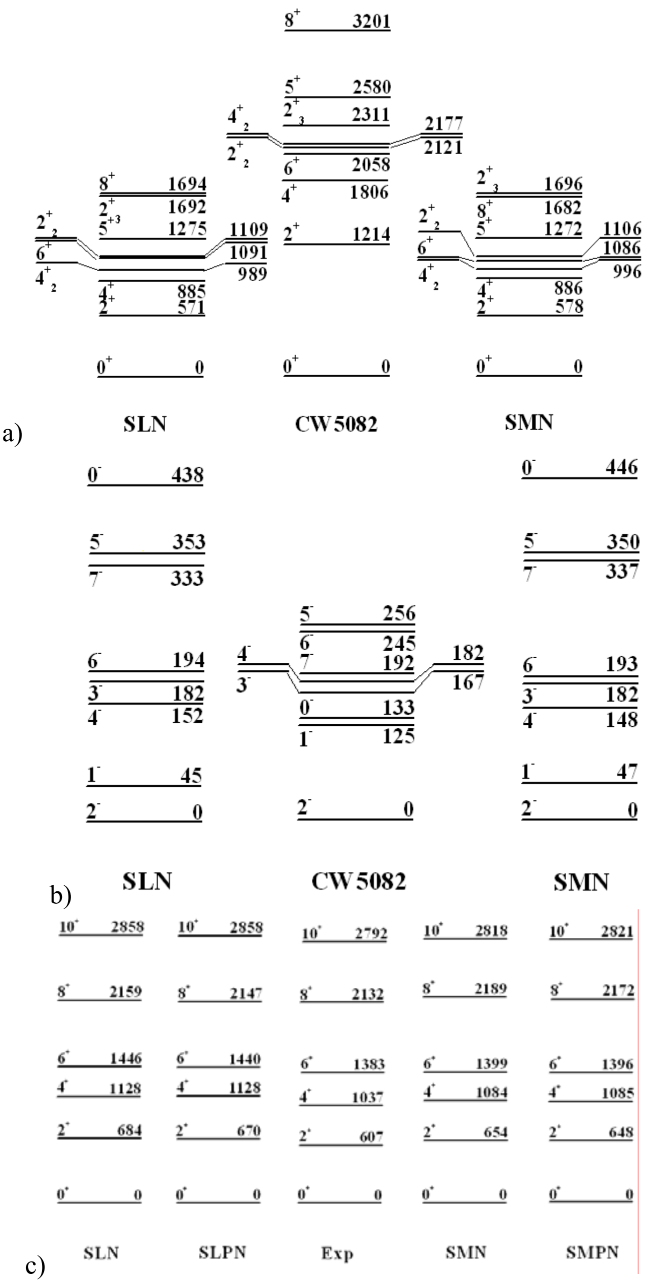

Figure (1): Comparison of calculated (SLN, SLPN, SMN and SMPN) and experimental excitation energies for A=136mass a) ^{136}Sn, b) ^{136}Sb and c) ^{136}Te.

According to the results of the exited energies of Sn, Sb, and Te that calculated with SLN, we have calculated its reduced probability B(E2) for the effective charge 1.47e and 0.72e of proton and neutron respectively (table (1)) and have compared with SMN and with the experimental B(E2) results.

We have obtained a good results of B(E2) with SLN as well as SMN ^{134}Sn and ^{134}Te isotopes. For ^{135}Sb, the calculated B(E2) value of $19/2^+ \rightarrow 15/2^+$ transition with both of SLN and SMN are too far from the experiment, but we see that SLN and SMN give the nearly value, it is the contrary the exited energies results.

Isotopes	$I_i^\pi \rightarrow I_f^\pi$	Exp	SLN	SMN
^{134}Sn	$0^+ \rightarrow 2^+$ $6^+ \rightarrow 4^+$	36 -	36.65 365.4	37 366
^{134}Te	$0^+ \rightarrow 2^+$ $6^+ \rightarrow 4^+$	83.5 960	100.3 872.1	100.2 869.8
^{135}Sb	$\rightarrow 19/2^+$ $15/2^+$	≈ 45	85.94	84
^{136}Te	$0^+ \rightarrow 2^+$	1030	1781	2165

Table (1): Comparison of calculated (SLN with SMN) and experimental B(E2) (in e^2fm^4) values for N=84 isotones using 1.47e and 0.72e proton and neutron effective charge respectively.

CONCLUSION

On conclusion, the two modified interactions SLN and SLPN of CW5082 interaction following the S. Saha's modification steps [3] supply the very interesting results for a ^{132}Sn region. We find that these interactions have the same behavior that of SMN and SMPN, hence, one be able to demonstrate that a binding energy of the ground state doesn't have a great influence on the nucleon-nucleon interaction and especially for the nuclei of identical valence nucleons as example, the $^{135\text{-}136}$Sn and ^{135}I nuclei. We must make other modifications on the proton-neutron matrix elements of the non-identical valence particles nuclei in order to improve the spectra results of these nuclei. The calculated values of reduce probability B(E2) for 1.47e and 0.72e proton and neutron effective charges respectively, are in a good agreement with the experiment.

REFERENCES

[1] A. Gargano,Eur. Phys. J. A20, 103 (2004).
[2] A. Korgul et al., Phys. Rev. C64, 021302(R) (2001).
[3] S. Saha and M. S. Sarkar, Eur. Phys. J. A 21, 61-66 (2004)
[4] B. A. Brown, A, A. Etchegoyen, W. D. H. Rae code OXBASH (1984).
[5] B. Fogelberg et al., Phys. Rev. Lett 82, 1823 (1999).
[6] Data extracted using the NNDC on line Data Service from ENSDF and XUNDL
data bases, file revised as of 22 November 2002.
[7] W. T Chou and E. K. Warburton, Phys. Rev. C45, 1720 (1992).
[8] W. Urban et al., Eur. Phys. J. A5, 239 (1999).
[9] E. K. Warburton and B. A. Brown, Phys. Rev. C43, 602 (1991).
[10] S. Sarkar and M. S. Sarkar, arXiv: nucl-th/0503067 (2005).
[11] F. Anderozzi et al., Phys.Rev. C56 (1997)