SPECTROSCOPIC PROPERTIES OF THE VERY NEUTRON RICH NUCLEI BEYOND ^{132}Sn WITHIN THE SHELL MODEL

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FUSTIPEN 2014
“Recent Advances in the Nuclear Shell Model”

INTRODUCTION

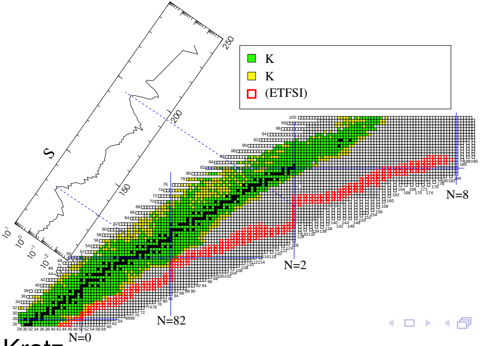
The advances in the nuclear shell model calculations in the study of the nuclei away from stability is due to

1. The extended valence spaces
2. The developments in the modern realistic effective interactions
3. The progress of the numerical codes(ANTOINE and NATHAN, NuShellX, OSLO...)

PURPOSE

☞ Study the spectroscopic properties of the even-even tin isotopes around the ^{132}Sn, which represents an interesting area for :

- Experimental : new results of the very neutron rich isotopes ^{136,138}Sn, obtained at Radioactive Isotope Beam Factor (RIBF) of the RIKEN Nishina center (EURICA Project).
- Astrophysics : responsible for their production by r-process, and their nuclear model properties predictions give the inputs for r-process simulations. (K.Sieja's talk)



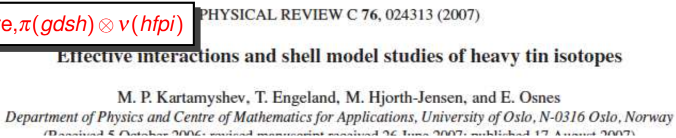
adapted from K.-L.Kratz

PLAN

1. To choose reasonable valence space/or core for this heavy mass region.
2. To develop an effective interaction valable for this region.
3. Calculations of the tin isotopes energies and $B(E2, J \rightarrow J+2)$.
4. To study core excitations effects.
5. Closure or NO of the sub-shell at N=90
6. Other Applications : Te isotopes and ^{140}Xe

SOME EXAMPLES TO SM INTEREST OF THE TIN REGION

G,^{132}Sn core,$\pi(gdsh)\otimes\nu(hfpi)$



PHYSICAL REVIEW C **76**, 024313 (2007)

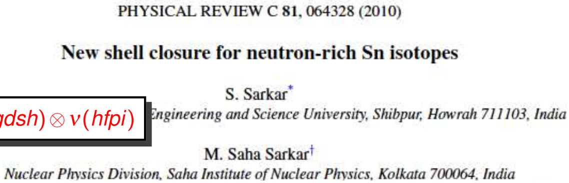
Effective interactions and shell model studies of heavy tin isotopes

M. P. Kartamyshev, T. Engeland, M. Hjorth-Jensen, and E. Osnes

Department of Physics and Centre of Mathematics for Applications, University of Oslo, N-0316 Oslo, Norway

(Received 5 October 2006; revised manuscript received 26 June 2007; published 17 August 2007)

SMPN,^{132}Sn core,$\pi(gdsh)\otimes\nu(hfpi)$



PHYSICAL REVIEW C **81**, 064328 (2010)

New shell closure for neutron-rich Sn isotopes

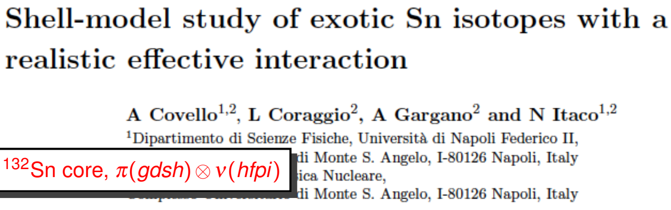
S. Sarkar*

Engineering and Science University, Shibpur, Howrah 711103, India

M. Saha Sarkar†

Nuclear Physics Division, Saha Institute of Nuclear Physics, Kolkata 700064, India

V_{low-k}, ^{132}Sn core, $\pi(gdsh)\otimes\nu(hfpi)$



Shell-model study of exotic Sn isotopes with a realistic effective interaction

A Covello[1,2], L Coraggio[2], A Gargano[2] and N Itaco[1,2]

[1]Dipartimento di Scienze Fisiche, Università di Napoli Federico II,

di Monte S. Angelo, I-80126 Napoli, Italy

ica Nucleare,

di Monte S. Angelo, I-80126 Napoli, Italy

OUR SM CALCULATIONS TOOLS

NUMERICAL CODE

The calculations are performed using shell model codes Antoine and NATHAN developed at IPHC Strasbourg.

- Antoine m-scheme
- Nathan coupled-scheme

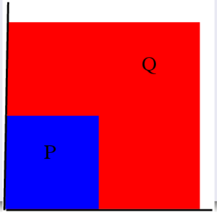
E.Caurier et al, Rev.Mod.Phys 77 (2007)427, and Antoine website

EFFECTIVE INTERACTION

The TBME are Derived from CD-Bonn Potentiel, renormalized by the V_{low-k} approach, and adopted to the model space by Many Body Perturbation Theory, using $\hat{P}$ and $\hat{Q}$ projection operators.

$$V_{eff} = V + V\frac{Q}{E-H_0}V + V\frac{Q}{E-H_0}V\frac{Q}{E-H_0}V$$

$$V \rightarrow V_{low-k}$$



M. Hjorth-Jensen et al. Physics reports 261 (1995)125-270

OUR SM CALCULATIONS TOOLS

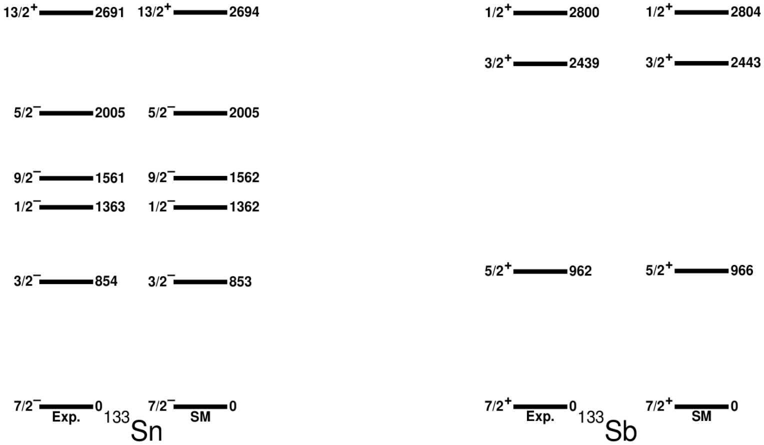
CORE AND VALENCE SPACE

OUR SM CALCULATIONS TOOLS

CORE AND VALENCE SPACE

- ☞ $1h_{11/2}$ and $1g_{9/2}$ closed $\equiv^{132}Sn$ core
- ☞ $1h_{11/2}$ and $1g_{9/2}$ opened $\equiv^{110}Zr$ core
- ✓ Opening the ^{132}Sn core constitutes a numerical chalenge in the diagonalisation of the matrix.

SINGLE PARTICLE ENERGIES



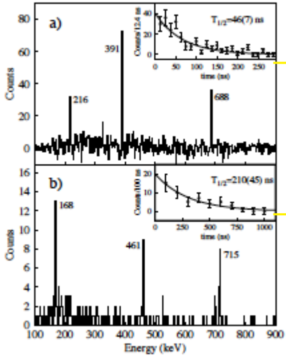
The re-adjustments of the monopole part of V_{low-k} interaction to obtain the experimental level scheme of the ^{133}Sn and ^{133}Sb.

TINS

Submitted to Phys.Rev.Lett

Yrast 6^+ Seniority Isomers of ^{136,138}Sn

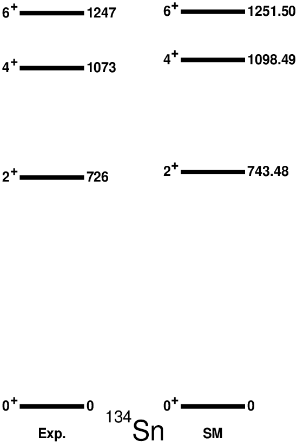
G.S. Simpson,[1,2,3] G. Gey,[3,4,5] A. Jungclaus,[6] J. Taprogge,[6,7,5] S. Nishimura,[5] K. Sieja,[8] P. Doornenbal,[5]
G. Lorusso,[5] P.-A. Söderström,[5] T. Sumikama,[9] Z. Xu,[10] H. Baba,[5] F. Browne,[11,5] N. Fukuda,[5]
N. Inabe,[5] T. Isobe,[5] H.S. Jung,[12,*] D. Kameda,[5] G.D. Kim,[13] Y.-K. Kim,[13,14] I. Kojouharov,[15]
T. Kubo,[5] N. Kurz,[15] Y.K. Kwon,[13] Z. Li,[16] H. Sakurai,[5,10] H. Schaffner,[15] H. Suzuki,[5] H. Takeda,
Z. Vajta,[17,5] H. Watanabe,[5] J. Wu,[16,5] A. Yagi,[18] K. Yoshinaga,[19] S. Bönig,[20] J.-M. Daugas,[21]
F. Drouet,[3] R. Gernhäuser,[22] S. Ilieva,[20] T. Kröll,[20] A. Montaner-Pizá,[23] K. Moschner,[24] D. Mücher,[22]
H. Naidja,[8,15,25] H. Nishibata,[18] F. Nowacki,[8] A. Odahara,[18] R. Orlandi,[26] K. Steiger,[22] and A. Wendt[24]



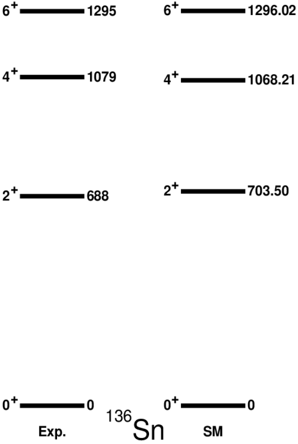
^{136}Sn

^{138}Sn

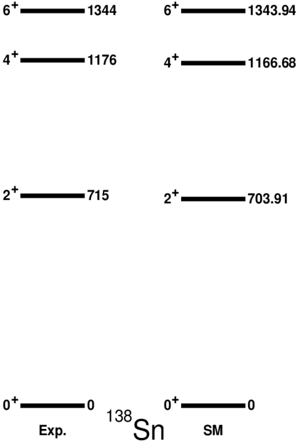
TINS



$(f_{7/2})^2 \approx 80\%\text{-}90\%$



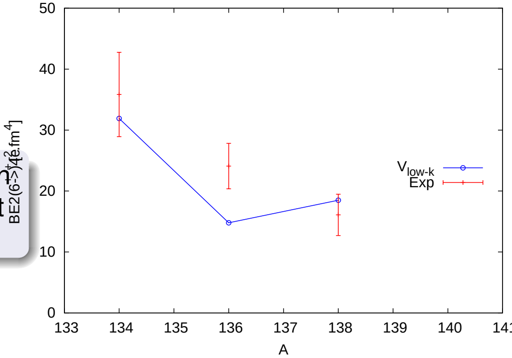
$(f_{7/2})^4 \approx 60\%\text{-}70\%$



$(f_{7/2})^6 \approx 50\%\text{-}60\%$

$B(E2, 6^+ \rightarrow 4^+)$

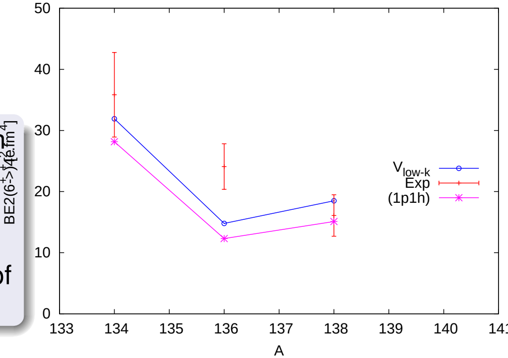
- V_{low-k} : predicts well the B(E2) in ^{134,138}Sn, but it underestimates it for ^{136}Sn.



$$e_{eff}(\nu) = 0.64e$$

$B(E2,6^+ \to 4^+)$

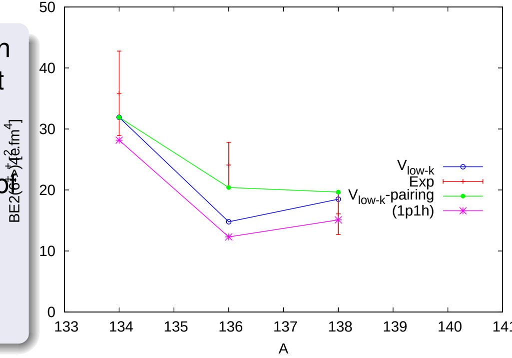
- V_{low-k} : predicts well the B(E2) in ^{134,138}Sn, but it underestimates it for ^{136}Sn.
- open core : still underestimated of ^{136}Sn.



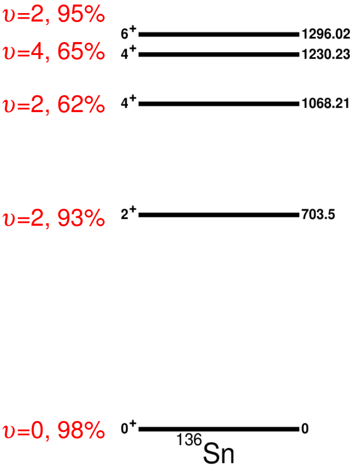
$$e_{eff}(\nu) = 0.5e$$
$$e_{eff}(\pi) = 1.5e$$

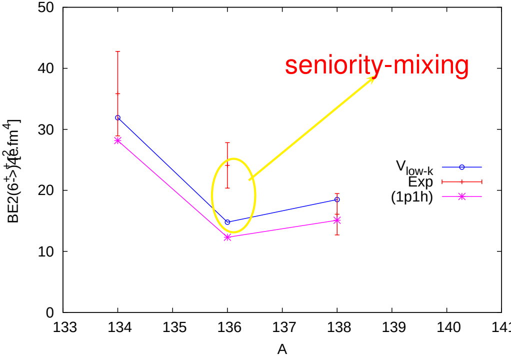
$B(E2,6^+ \rightarrow 4^+)$

- V_{low-k} : predicts well the B(E2) in ^{134,138}Sn, but it underestimates it for ^{136}Sn.
- open core : still underestimated of ^{136}Sn.
- reducing the pairing : gives a good agreement with the Exp.



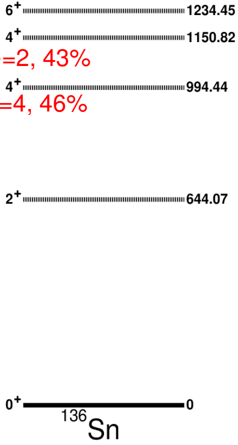
$B(E2, 6^+ \to 4^+)$





$$B(E2, \upsilon_f = \upsilon_i, J \to \upsilon_i, J-2) \propto \left(1 - \frac{2n}{2j+1}\right)^2$$

$B(E2, 6^+ \to 4^+)$



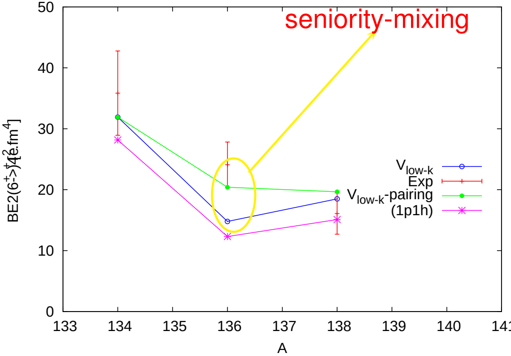
υ=2, 94%

υ=4, 57% υ=2, 43%

υ=2, 53% υ=4, 46%

υ=2, 98%

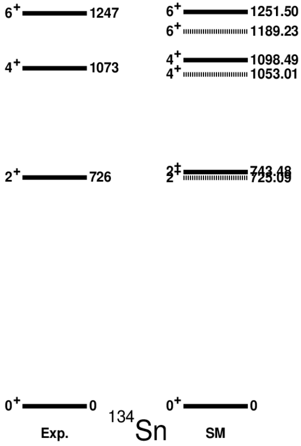
υ=0 ,98%

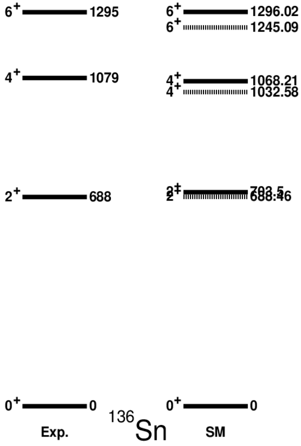


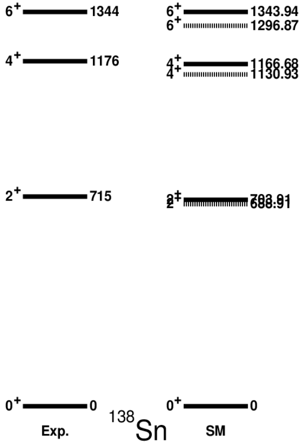
$$B(E2, \upsilon_f = \upsilon_i, J \to \upsilon_i, J-2) \propto \left(1 - \frac{2n}{2j+1}\right)^2$$

A.F. Lisetskiy et *al. PRC70, 044314 (2004)* : seniority mixing in the ^{72,74}Ni compared to ^{94}Ru and ^{96}Pd

TINS (^{110}Zr CORE)

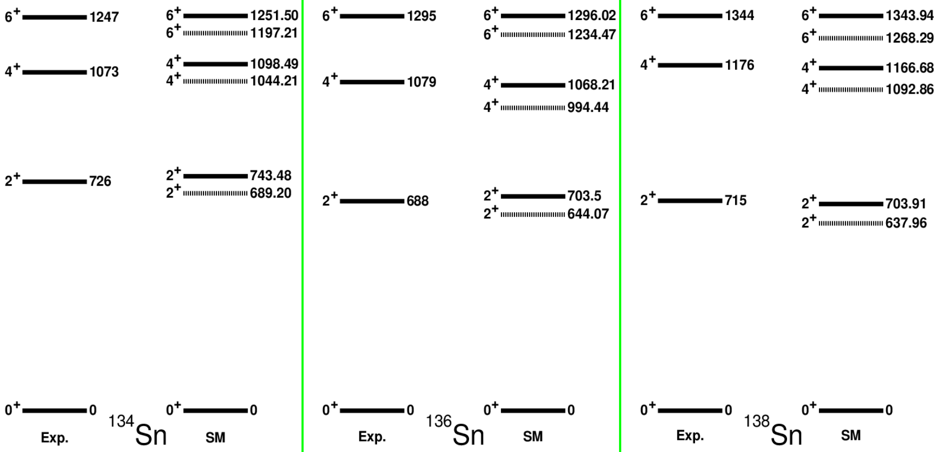






There is small effect to the level scheme of the tin isotopes, when considering the core excitations or reducing the pairing strength.

TINS (REDUCING THE PAIRING)



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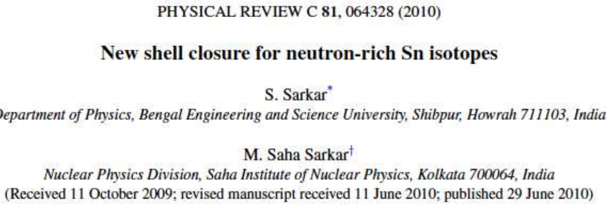
SHELL CLOSURE AT N=90 ?



PHYSICAL REVIEW C **81**, 064328 (2010)

New shell closure for neutron-rich Sn isotopes

S. Sarkar[*]
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Nuclear Physics Division, Saha Institute of Nuclear Physics, Kolkata 700064, India

(Received 11 October 2009; revised manuscript received 11 June 2010; published 29 June 2010)

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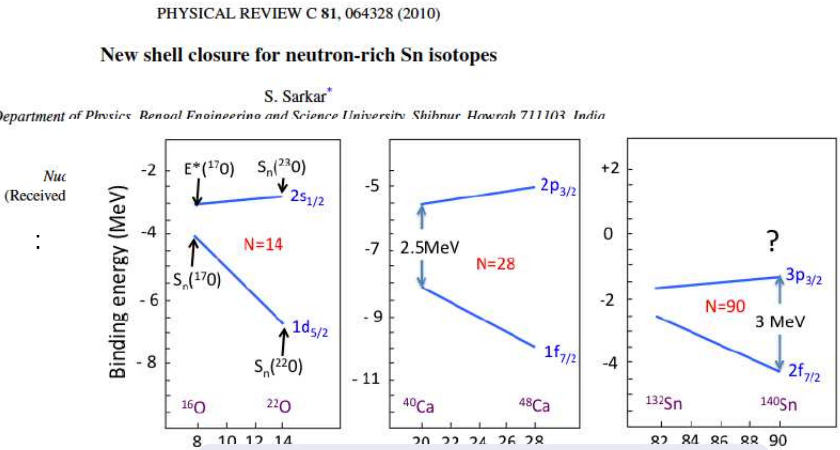

PHYSICAL REVIEW C 81, 064328 (2010)

New shell closure for neutron-rich Sn isotopes

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Department of Physics, Bengal Engineering and Science University, Shibpur, Howrah 711103, India

Nuc

(Received

:

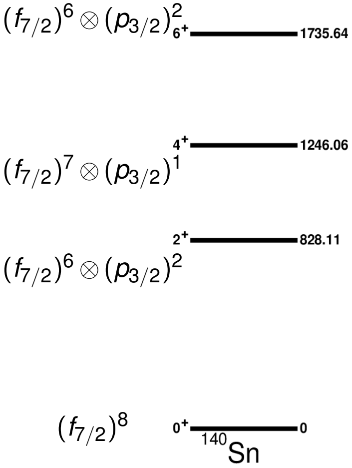
Taken from O.Sorlin notes

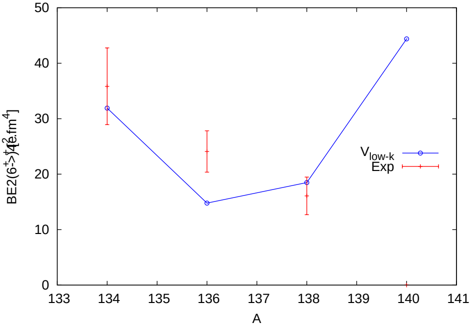
- Analogy between the ^{22}O, ^{48}Ca, and ^{140}Sn in the closure of the (sub-)shell at N=14,28, and 90 ?
- 3-body effect plays an important role for shell evolution in Sn isotopes, as also observed in *sd* and *fp* shells ?

A.P.Zuker, PRL 90, 042502 (2003)
T.Otsuka et al. PRL 105,032501 (2010)

SHELL CLOSURE AT N=90 ?

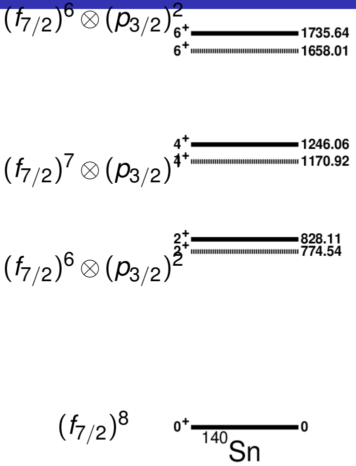
our predictions to the ^{140}Sn structure





- the excited states are characterized by a mixing configurations.

SHELL CLOSURE AT N=90 ?



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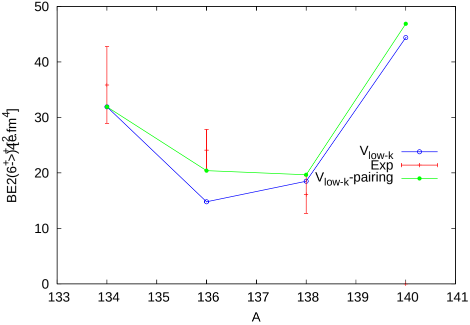
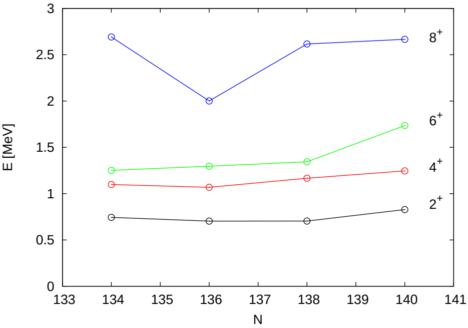
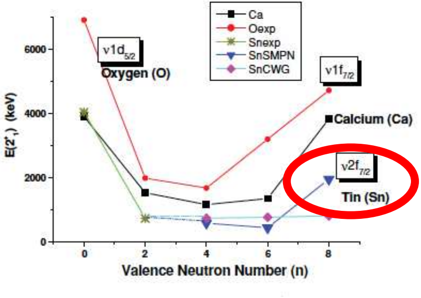


- the excited states are characterized by a mixing configurations.
- the same results when reducing the pairing strength, but with small increase of the percentage.

SHELL CLOSURE AT N=90 ?





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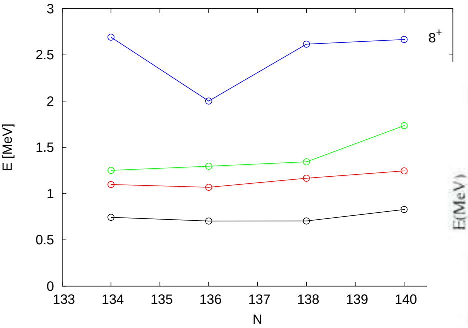
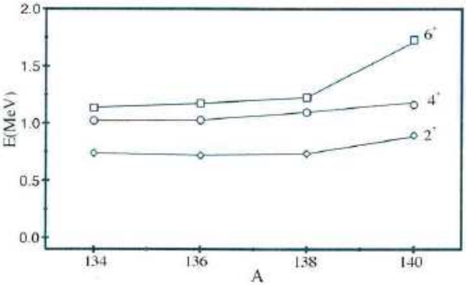
- the spacing $0^+ - 2^+$ remains nearly constant at around 700 keV, except for a small increase at ^{140}Sn owing to the filling of the $(f_{7/2})$.

- a sudden increase for N=90, indicating a closed-shell structure for ^{140}Sn.

2^+ energy in the ^{140}Sn in not higher than in the neighboring nuclei.

SHELL CLOSURE AT N=90 ?





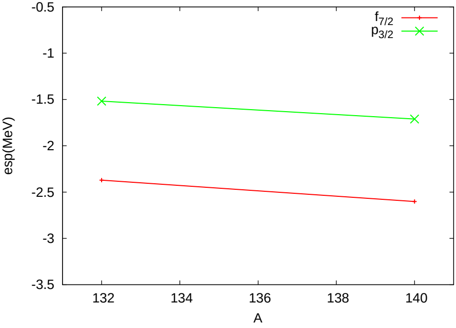
- the spacing $0^+ - 2^+$ remains nearly constant at around 700 keV, except for a small increase at ^{140}Sn owing to the filling of the $(f_{7/2})$.

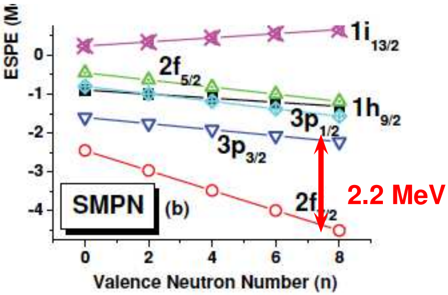
A.Covello et al. Journal Of Physics : Conf.Series 267 (2011) 012019.

A.Gargano's Talk

2^+ energy in the ^{140}Sn in not higher than in the neighboring nuclei.

EVOLUTION OF NEUTRON ESPE

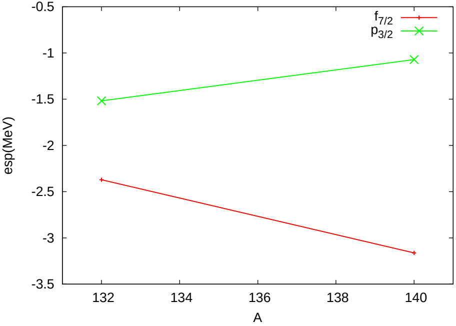


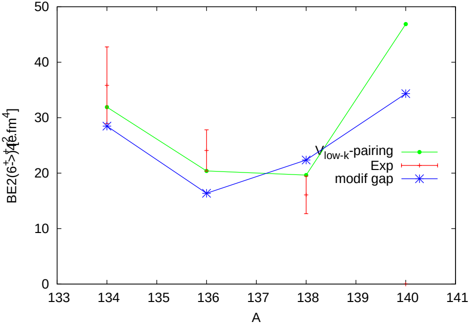


S.Sarkar and M.S.Sarkar Phys.Rev.C 81, 064328(2010)

- The difference energy between $\nu f_{7/2}$ and $\nu p_{3/2}$ remains constant ➪ No shell closure at N=90
- The gap $\nu f_{7/2}$ and $\nu p_{3/2}$ increases to 2.246 MeV ➪ it's sufficient to make the ^{140}Sn a doubly magic nucleus

EVOLUTION OF NEUTRON ESPE



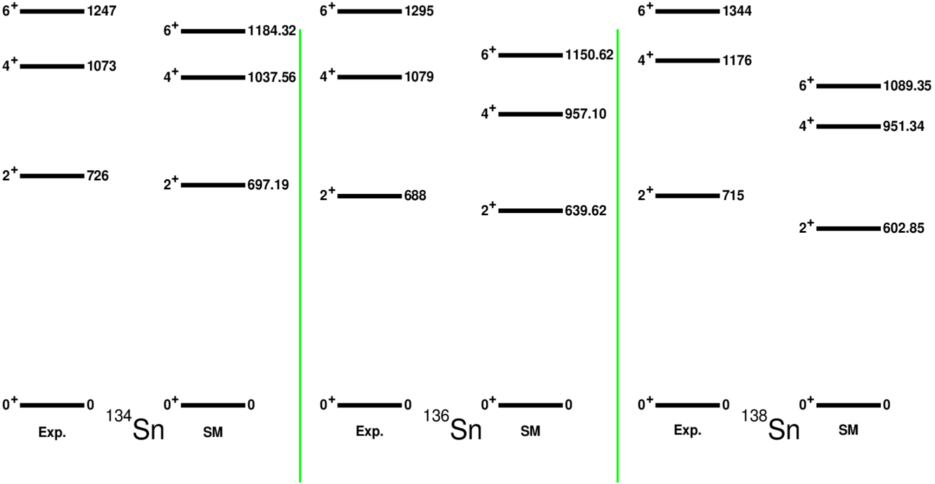


Increasing the gap by changing the monopole part

$\Downarrow$

Transitions are inconsistent with the experiment

TINS (INCREASING THE GAP)



increasing $f_{7/2} - p_{3/2}$ gap, has an apparent effect to the ^{138}Sn Structure.

$\Downarrow$

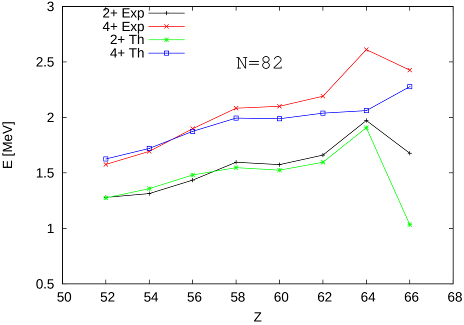
Losing the spectroscopic properties.

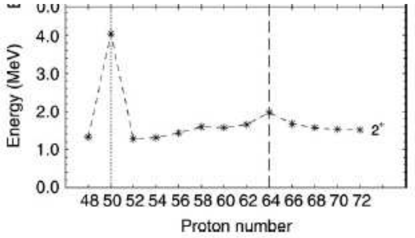
$\Downarrow$

NO closure of the sub-shell at N=90

ISOTONES N=82

- N=82, Z even





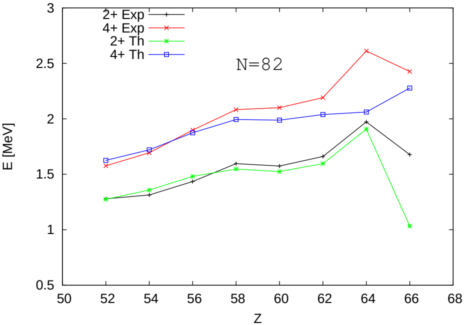
O.Sorlin, M,-G.Porquet, Prog.Part.Nucl.Phys.61(2008)602.

☞ The energies vary smoothly along the whole N=82 isotonic chain.

☞ A small increase is observed at Z=64, which is due to the subshell closure of the $\pi g_{7/2} d_{5/2}$.

ISOTONES N=82

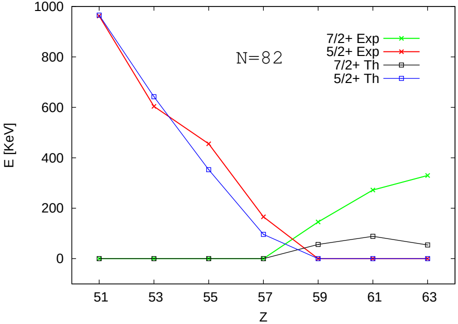
- N=82, Z even



☞ The energies vary smoothly along the whole N=82 isotonic chain.

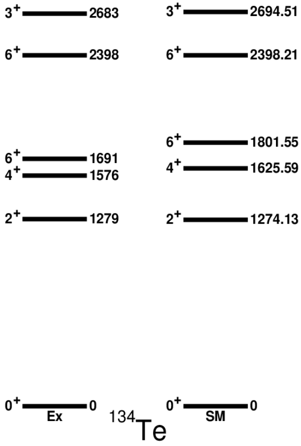
☞ A small increase is observed at Z=64, which is due to the subshell closure of the $\pi g_{7/2}d_{5/2}$.

- N=82, Z odd

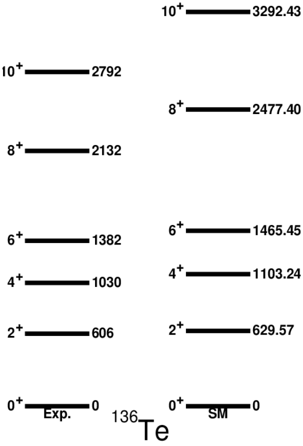


☞ The $\frac{5}{2}^+$ energy decreases as function of Z, until it becames the ground state at Z=59 (Pr).

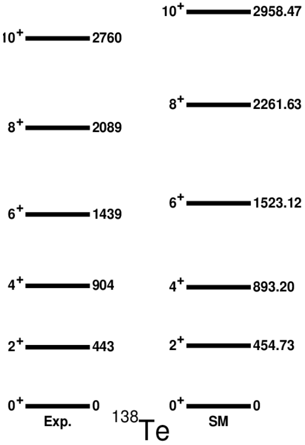
Te ISOTOPES $(2\pi\otimes n\nu)$



$B_{exp}(E2, 2^+ \to 0^+) = 208 \pm 8$
$B_{th}(E2, 2^+ \to 0^+) = 164$
$(e^2.fm^4)$



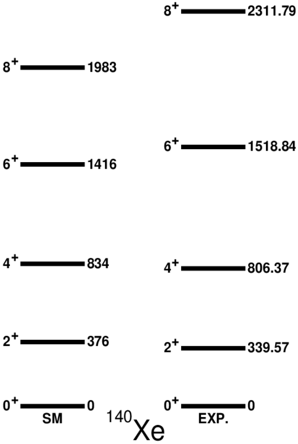
$B_{exp}(E2, 2^+ \to 0^+) = 244 \pm 36$
$B_{th}(E2, 2^+ \to 0^+) = 334$
$(e^2.fm^4)$



$B_{th}(E2, 2^+ \to 0^+) = 519$
$(e^2.fm^4)$

$$0^+ \equiv \nu(f_{7/2})^n \otimes \pi(g_{7/2})^2$$

$^{140}Xe\,(4\pi\otimes 4\nu)$



$0^+ \equiv \nu(f_{7/2})^4 \otimes \pi(g^2_{7/2} d^2_{5/2})$

$B_{exp}(E2;2^+ \rightarrow 0^+) = 1040 \pm 200(e^2.fm^4)$

$B_{Th}(E2;2^+ \rightarrow 0^+) = 1017(e^2.fm^4)$

$Q_i(e.fm^2)$ from $Q_s = 220$

$Q_i(e.fm^2)$ from $B(E2) = 226$
β_2=0.14

$\Downarrow$

prediction of rotational deformation

CONCLUSIONS

- ✓ Shell model calculations are an important tool for the theoretical and future experimental nuclear structure.
- ✓ the agreement between the experimental and calculated level energies is improved.
- ✓ the pairing force must be reduced to reproduce the experimental transitions rates,
- ✓ The core excitations and reducing the pairing force seem to have a weak effect to the tin isotopes energies.
- ✗ The ^{140}Sn doesn't exhibit the features of a doubly magic nucleus.(low energy of the 2^+).

PERSPECTIVES

the advancement of a realistic interaction in this heavy mass region allows us to study other nuclei from this region, in spite of "the lack of the experimental data."

THANKS TO

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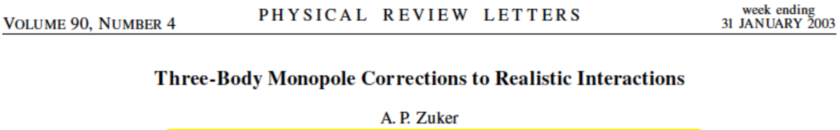
ANNEXES

^{140}Sn


6+ 2630.5
4+ 1910.8
2+ 1793.4
6+ 1735.64
6+ 1658.01
4+ 1246.06
4+ 1170.92
2+ 828.11
2+ 774.54
0+ 0
SM.
140Sn
0+ 0
increasing gap

3-BODY FORCE



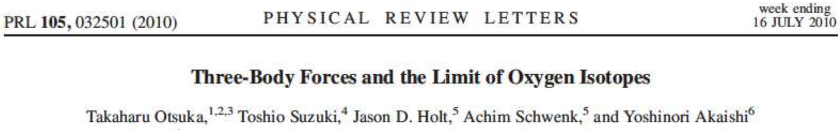
VOLUME 90, NUMBER 4 PHYSICAL REVIEW LETTERS week ending 31 JANUARY 2003

Three-Body Monopole Corrections to Realistic Interactions

A. P. Zuker

IReS, Bâtim *France*

3-body monopole corrections can solve pratically all the spectroscopic properties in the p, sd, fp

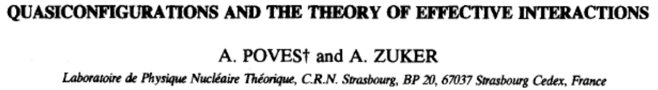


PRL **105,** 032501 (2010) PHYSICAL REVIEW LETTERS week ending 16 JULY 2010

Three-Body Forces and the Limit of Oxygen Isotopes

Takaharu Otsuka,[1,2,3] Toshio Suzuki,[4] Jason D. Holt,[5] Achim Schwenk,[5] and Yoshinori Akaishi[6]

3-body forces are necessary to explain the doubly magic ^{24}O



QUASICONFIGURATIONS AND THE THEORY OF EFFECTIVE INTERACTIONS

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taking p-h excitations from the core ➪ allow us to include the effect of the 3-body forces

INCLUSION OF THE 3-BODY FORCE EFFECT

The effect of the 3-body forces is taken into account in :

- ^{132}Sn core : The 3-body forces contribute to 1-body and 2-body terms

  3N→2N :
  $\sum_c a_{ijc} n_i n_j n_c = n_i n_j \sum_c a_{ijc} n_c \equiv n_i n_j a_{ij}$

  3N→1N
  $\sum_{cc'} a_{ic'c} n_i n_{c'} n_c = n_i \sum_{cc'} a_{ic'c} n_c n_{c'} \equiv n_i e_i$

  so the monopole corrections to the 2-body interaction can reduce the effect of the 3-body force not included directly.

- ^{110}Zr core :
  taking p-h excitations from the core $\nu h_{11/2}$ and $\pi g_{9/2}$ to the above shells ➪ We include the 3-body force effect.