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ABSTRACT

The structure of low–lying states in heavy odd–mass $N = 82$ isotones $(147 \leq A \leq 153)$ is investigated in terms of a number–projected one– and three–quasiparticle Tamm–Dancoff approximation (PBCS). A surface delta interaction (SDI) is taken as the residual nucleon–nucleon interaction. Excitation energies, spin and parity are calculated and compared with the experimental data. Some predictions about dipole and quadrupole moments are presented.

NUCLEAR STRUCTURE: ^{147}Tb, ^{149}Ho, ^{151}Tm and ^{153}Lu; calculated levels J, π, μ and Q. Number–projected one– and three–quasiparticles. Surface δ interaction.

I. INTRODUCTION

The structure of the light $Z > 50$, $N = 82$ odd–isotones $(55 \leq Z \leq 65)$ is generally well explained in terms of quasi–particle degrees of freedom assuming that the properties of low–lying states of these nuclei can be described by pure proton one– and three–quasiparticle excitations[1–4].

In a recent paper[4] we presented a interpretation of the structure of these nuclei by means of a number–projected one– and three–quasiparticle Tamm–Dancoff approximation (PBCS), in which the projection is performed after the minimization of the ground state energy. It would be interesting to examine, along the same lines, the structure of heavy $N = 82$ odd–nuclei $(65 \leq Z \leq 71)$ for which experimental data have recently became available[5–12].

In earlier calculations, the low–energy part of the spectrum of the heavy odd–isotones $(65 \leq Z \leq 69)$ is studied considering only seniority one degrees of freedom[13–15]. In spite of the small amount of experimental data, the good results obtained within the one– and three–quasiparticle space for light isotones justify the inclusion of the seniority three degrees of freedom in the description of heavy isotones.

So, the purpose of the present work is to investigate the influence of three–quasiparticle states in these mass region using the PBCS approximation. The full details of the formalism and some applications of it may be found in Ref. 16.

In this paper an examination of the properties of positive– and negative–parity low–lying states of ^{147}Tb, ^{149}Ho, ^{151}Tm and ^{153}Lu isotones is performed. In Sec. II the set of input parameters is presented. In Sec. III the results are compared with the experimental data. Finally, in Sec. IV some conclusions are drawn.

II. PARAMETERS

We describe the states of $N = 82$ isotones, with $65 \leq Z \leq 71$, assuming ${}^{132}_{50}Sn_{82}$ as a inert core. The low–lying levels are assumed to come from 15–21 protons distributed over the single particle orbitals $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$ and $1h_{11/2}$. A surface–delta interaction (SDI) is used as the residual nucleon–nucleon force

$$V_{SDI} = -4\pi G\, \delta(r_i - R)\, \delta(r_j - R)\, \delta(\Omega_{ij}) \ .$$

Our starting point for the choice of parameters was based on the values used for $Z = 63$ in Ref. 4. The final values were determined requiring a good overall fit of the energies of one–quasiparticle (1qp) states. Parameters used in the present calculations are summarized in Table I. It should be noted that the variation of single–particle energies with the mass is similar to those observed experimentally[17]. Our values for the parameter G agrees with that employed in parametrization (B) of Ref. 5 and that obtained by Chasman[13].

The electromagnetic properties were evaluated with the usual values[1,3,4] for the effective electric charge and the effective gyromagnetic ratios, namely $e_p^{eff} = 2e$ for electric transitions, and $g_l = 1$, $g_s^{eff} = 2.91$, and 4.464 for the magnetic ones.

III. RESULTS AND DISCUSSION

The experimental data and calculated schemes of the energy spectra for ^{147}Tb, ^{149}Ho, ^{151}Tm and ^{153}Lu are compared in Fig. 1. Our calculations include the first low–lying positive–parity states with $1/2^+ \leq J \leq 23/2^+$ and negative–parity states with $9/2^- \leq J \leq 19/2^-$, and the states $7/2_2^+$, $23/2_2^+$ and $29/2_2^-$. Exclusively for ^{149}Ho the state $23/2_3^+$ is considered. We connected by dotted line a tentative identification between theoretical and experimental levels.

In Table II, wave functions calculated for a few low–lying states are listed. These states are characteristic 1qp states $(1/2_1^+,\ 3/2_1^+,\ 5/2_1^+,\ 7/2_1^+$ and $11/2_1^-)$ or 3qp states, except the $7/2_1^+$ state in ^{153}Lu which has a mixed (1qp + 3qp) character.

There is good agreement, in general, between experimental and theoretical energy spectra for 1qp states. For ^{147}Tb, ^{149}Ho, and ^{151}Tm the theory reproduces the experimental sequence for the first five levels, and the differences in energy is ≤ 60 keV. The other experimentally known or predicted levels in ^{149}Ho, and ^{153}Lu isotones up to 2.5 MeV can be assigned as being 3qp states which differs less than 250 keV in energy, except for the measured $(13/2^+)$ level at 1.38 MeV in ^{149}Ho. Based on the theoretical spectra and earlier calculations for light isotones[4], we can forsee that these nuclei may have a high density of levels above 1.5 MeV excitation energy. Thus, the lack of experimental data on electromagnetic properties makes it impossible to compare the predictions on spin and parity assignments with experiments.

In Ref. 4 we have obtained an excellent agreement between experimental and theoretical electromagnetic moments of low–lying states in light isotones $(55 \leq Z \leq 63)$. Accordingly, in Table III, theoretical predictions on magnetic dipole and electric quadrupole moments calculated for 1qp states in ^{147}Tb and ^{153}Lu are displayed. The results for ^{149}Ho and ^{151}Tm fall in between the corresponding results for ^{147}Tb and ^{153}Lu nuclei.

IV. SUMMARY AND CONCLUSION

The properties of the odd $N = 82$ isotones, in the mass region $147 \leq A \leq 153$, were performed within the framework of the projected 1qp + 3qp calculations (PBCS) using an SDI force as the residual interaction. The different input parameters, proton single particle energies and interaction strength, were obtained via an overall fit to 1qp state excitation energies. The available data on the energy spectra were examined. Good agreement between the existent data and theoretical results were obtained.

In this mass region, the experimental data are scarce. New measurements are necessary for a detailed examination of the properties of low–lying states in ^{147}Tb, ^{151}Tm and ^{153}Lu isotones. Therefore, considering the excellent results obtained for light isotones in earlier calculations[4] using the same formalism (number projected one– and three–quasiparticles), the present work furnishes important foresights to guide future measurements.

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REFERENCES

1. M. Waroquier and K. Heyde, *Nucl. Phys.* **A144**, 481 (1970).
2. N. Freed and W. Miles, *Phys. Lett.* **32B**, 313 (1970).
3. K. Heyde and M. Waroquier, *Nucl. Phys.* **A167**, 545 (1971).
4. L. Losano and H. Dias, *Phys. Rev.* **C** (in press).
5. C.F. Liang, P. Paris, P. Kleinheinz, B. Rubio, M. Piiparinen, D. Schardt, A. Plochocki and R. Barden, *Phys. Lett.* **191B**, 245 (1987).
6. J.A. Szücs, M.W. Johns, B. Singh, *Nucl. Data Sheets* **46**, 1 (1985).
7. R.B. Firestone, J.M. Nitschke, P.A. Wilmarth, K. Vierien, J. Gilat, K.S. Toth and V.A. Akovali, *Phys. Rev.* **C39**, 219 (1989).
8. P. Kleinheinz, B. Rubio, M. Ogawa, M. Piiparinen, A. Plochocki, D. Schardt, R. Barden, O. Klepper, R. Kirchner and E. Roeckl, *Z. Phys.* **A323**, 705 (1985).
9. B. Singh, J.A. Szücs and M.W. Johns, *Nucl. Data Sheets* **55**, 185 (1988).
10. G.D. Alkhazov, K.A. Mezilev and Yu.N. Novikov, N. Ganbaatar, K.Ya. Gromov, V.G. Kalinnikov, A. Potempa, E. Sieniawski and F. Tarkanyi, *Z. Phys.* **A310**, 247 (1983).
11. M.O. Kortelahti, K.S. Toth, K.S. Vierinen, J.M. Nitschke, P.A. Wilmarth, R.B. Firestone, R.M. Chasteler and A.A. Shilab–Eldim, *Phys. Rev.* **C39**, 636 (1989).
12. J.H. McNeill, J. Blomquist, A.A. Chishti, P.J. Daly, W. Gelletly, M.A.C. Hotchkis, M. Piiparinen, B.J. Varley and P.J. Woods, *Phys. Rev. Lett.* **63**, 860 (1989).
13. R.R. Chasman, *Phys. Rev.* **C21**, 456 (1980).
14. G. Wenes, K. Heyde, M. Waroquier and P. Van Isacker, *Phys. Rev.* **C26**, 1692 (1982).
15. F. Andreozzi, A. Covello, A. Gargano and A. Porrino, *Phys. Rev.* **C41**, 250 (1989).

16. L. Losano, H. Dias, F. Krmpotic and B.H. Wildenthal, *Phys. Rev.* C38, 2902 (1988).

17. Y.A. Akovali, K.S. Toth, A.L. Goodman, J.M. Nitschke, P.A. Wilmarth, D.M. Moltz, M.N. Rao and D.C. Sousa, *Phys. Rev.* C41, 1126 (1990).

TABLE CAPTIONS

Table I Parameters used in the present calculations.

Table II Calculated wavefunctions of some low–lying (J_i^π) states in N=82 isotones. For each nucleus, the 1qp and 3qp basis states are denoted by $|j>$ and $|(j_a\, j_b)J_{ab}\, ,\, j_c>$ respectively. Only amplitudes larger than 4% are listed.

Table III Calculated electric quadrupole and magnetic dipole moments, in units of eb and μ_N, respectively. Q refers to $e_p^{eff} = 2e$, μ_1, μ_2 refer to $g_s^{eff} = 2.91$ and $g_s^{eff} = 4.464$, respectively.

FIGURE CAPTION

Figure 1. Calculated and experimental[5,12] spectra of N=82 isotones. The spins are in 2J form.

TABLE I

	^{147}Tb	^{149}Ho	^{151}Tm	^{153}Lu
$\varepsilon_{g_{7/2}}$ (MeV)	0.0	0.0	0.0	0.0
$\varepsilon_{d_{5/2}}$ (MeV)	0.35	0.45	0.55	0.65
$\varepsilon_{d_{3/2}}$ (MeV)	2.20	2.20	2.05	2.05
$\varepsilon_{s_{1/2}}$ (MeV)	1.85	1.95	1.95	1.95
$\varepsilon_{h_{11/2}}$ (MeV)	1.85	1.85	1.85	1.85
G(MeV)	0.13	0.13	0.13	0.13

TABLE II

J_i^π	j_a	j_b	J_{ab}	j_c	^{147}Tb	^{149}Ho	^{151}Tm	^{153}Lu
$1/2_1^+$				1/2	0.976	0.986	0.991	0.994
$3/2_1^+$				3/2	0.972	0.983	0.991	0.995
$5/2_1^+$				5/2	0.988	0.990	0.989	0.985
$7/2_1^+$				7/2	0.985	0.984	0.971	0.936
	11/2	11/2	2	3/2	——	——	——	−0.254
$11/2_1^-$				11/2	0.990	0.989	0.991	0.992
$9/2_1^-$	5/2	1/2	2	11/2	0.829			
	5/2	1/2	3	11/2	−0.403			
	7/2	3/2	2	11/2	0.263			
	11/2	11/2	4	11/2	——	0.990	0.996	0.997
$13/2_1^-$	5/2	1/2	2	11/2	0.876			
	5/2	1/2	3	11/2	−0.294			
	7/2	3/2	2	11/2	0.261			
	11/2	11/2	4	11/2	——	0.988	0.996	0.989
$15/2_1^-$	5/2	1/2	2	11/2	0.885			
	7/2	3/2	2	11/2	0.319			
	11/2	11/2	4	11/2	——	0.993	0.997	0.998
$13/2_1^+$	11/2	11/2	4	5/2	−0.598	0.203		
	11/2	11/2	6	5/2	0.405	——		
	11/2	11/2	8	5/2	0.677	0.220		
	11/2	11/2	6	1/2	——	−0.912	0.380	
	11/2	11/2	6	3/2	——	0.217	−0.891	0.930
	11/2	11/2	8	3/2	——	——	0.230	−0.361
$15/2_1^+$	11/2	11/2	8	5/2	0.350			
	11/2	11/2	10	5/2	0.896			
	11/2	11/2	8	1/2	——	0.971	0.957	0.823
	11/2	11/2	6	3/2	——	——	0.248	0.562

TABLE III

	^{147}Tb			^{153}Lu		
J^{π}	Q	μ_1	μ_2	Q	μ_1	μ_2
$1/2^+_1$	—	1.58	2.46	—	1.54	2.38
$3/2^+_1$	−0.12	0.92	0.44	−0.05	0.90	0.42
$5/2^+_1$	0.23	3.65	4.59	0.20	3.52	4.35
$7/2^+_1$	0.23	2.74	2.12	0.23	2.83	2.28
$11/2^-_1$	−0.23	6.54	7.38	−0.05	6.49	7.30

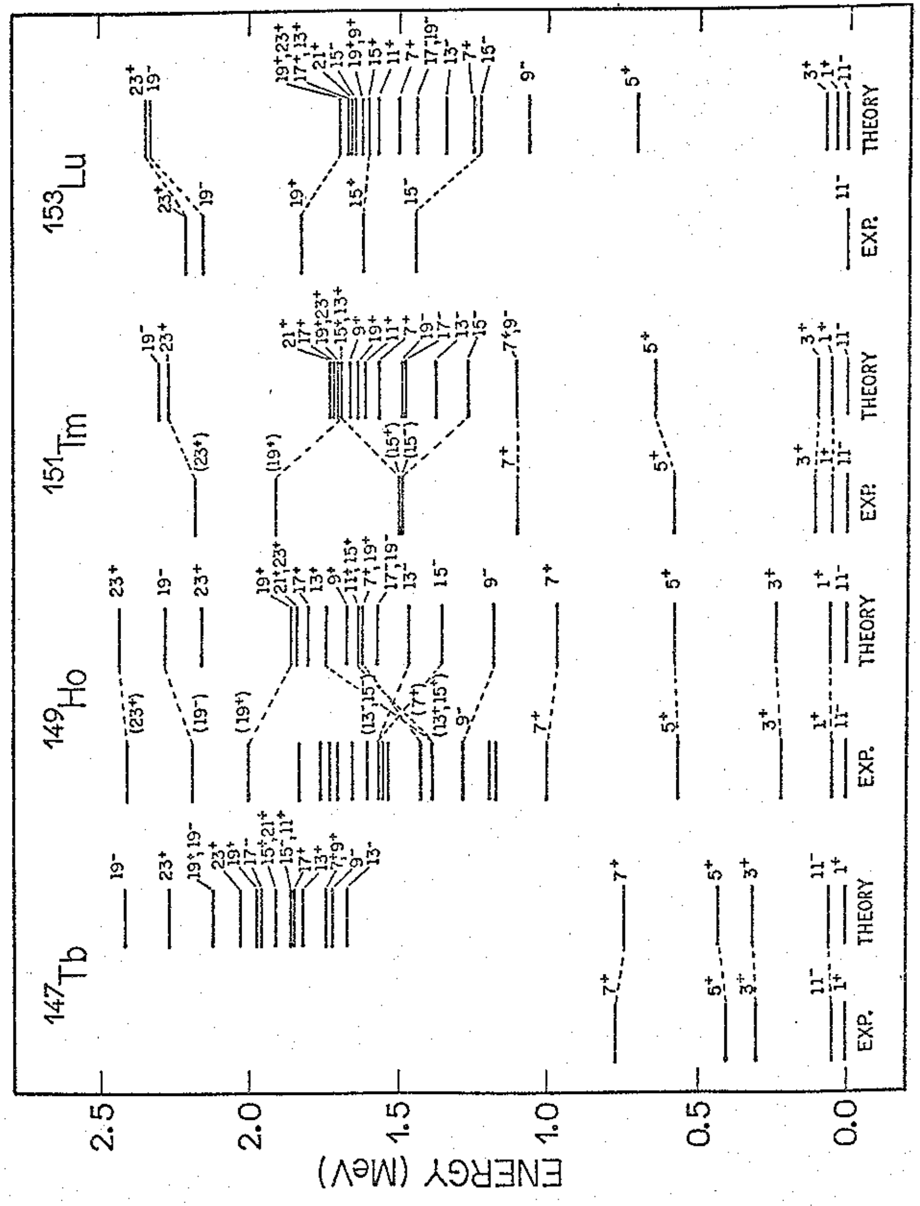

Fig. 1