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Pairing and high-spin states in proton-rich $N=82$ nuclei

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This paper is an extension of a previous study of the pairing effects in the $N=82$ isotones. It is concerned with high-spin states in the nuclei from ^{146}Gd through the recently explored ^{153}Lu and ^{154}Hf. The results obtained confirm the importance of proton pairing correlations in the $N=50$–82 shell.

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In a recent paper [1] (hereafter referred to as I) we carried out an extensive study of the pairing effects in the $N=82$ nuclei. Shortly after submission of this paper, level schemes of the previously unknown proton-rich $N=82$ nuclei ^{153}Lu and ^{154}Hf were established [2,3], thus providing a new opportunity for investigating the proton shell structure above $Z=64$. Particularly interesting in this respect are the high-spin states with a single dominant configuration for which the high-j unique-parity $\pi h_{11/2}$ orbital plays an especially important role.

In I we studied the $N=82$ isotones with A ranging from 135 to 151, focusing attention on the seniority-zero and seniority-one states. Concerning the seniority-two states we only reported (and compared with the experiment): (i) the energies of the $\pi h_{11/2}g_{7/2}\, I^{\pi}=9^-$ states in ^{146}Gd and in the four lighter nuclei ^{144}Sm, ^{142}Nd, ^{140}Ce, and ^{138}Ba; (ii) the energies of the $\pi h_{11/2}^2\ 10^+$ states in ^{146}Gd and the two adjacent nuclei ^{144}Sm and ^{148}Dy. The new experimental results mentioned above stimulated the present work in which our interest is centered on high-spin states in the $N=82$ isotones with $Z=64$ through $Z=72$.

As in I, we start by assuming that $N=82$ and $Z=50$ are closed inert cores and letting the valence protons occupy the single-particle states $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$, and $1h_{11/2}$. As for the pairing strength G, we choose a value of 0.22 MeV which is about 5% larger than that used in I (0.21 MeV). The reasons for this change may be summarized as follows.

In I the calculations were carried out by making use of a very simple number-conserving approach which we ourselves developed in prior work [4–7]. This approach has proved to be a much better approximation scheme than the usual BCS theory. In fact, even at the lowest order of approximation, which we call first-order theory (see Sec. II of I), it provides a very accurate treatment of the seniority-zero ground state for even nuclei and of the seniority-one states for odd nuclei. Inherent in the first-order treatment [see Eq. (9) of I], however, is some loss in the accuracy of the approximation for states of higher seniority. More precisely, the energy of these states turns out to be higher in general than that corresponding to an exact calculation. In I we fixed the pairing constant G by reproducing the energy of the 10^+ state in ^{148}Dy which was assumed to be a pure seniority-two $h_{11/2}^2$ state. An exact calculation brings this state down in energy by about 0.130 MeV. For states of seniority three and four this discrepancy may become as large as 0.5 MeV. In this situation, it seemed to us appropriate for the present study to perform an exact pairing calculation (this was done within the framework of the method described in Ref. [5]) and to redetermine accordingly the value of G. We found that a good overall agreement with experiment requires the choice $G=0.22$ MeV. It may be worth mentioning that this increase in the value of G would also imply, in principle, a redetermination of the single-particle energies. This is not necessary in practice, however, since the ϵ_j are fairly insensitive to small changes in the pairing strength (see Sec. III of I).

In Table I we show the calculated excitation energies for the high-spin states with seniority $v=2$, 3, and 4 arising from the configurations $h_{11/2}^2$, $h_{11/2}g_{7/2}$, $h_{11/2}^3$, $h_{11/2}^2g_{7/2}$, and $h_{11/2}^3g_{7/2}$. Where possible we compare our results with the experimental energies [2,8–14] of the states of highest spin that can be formed from the relevant configuration. The behavior of the energy of the 10^+ and $\frac{27}{2}^-$ states as a function of A is plotted in Figs. 1 and 2.

The remarkable agreement shown by the above comparison confirms the prominent role of proton pairing correlations in this region [1]. This can be further illustrated by the following remarks.

Let us first consider the $v=2$ states. Of particular interest are the $h_{11/2}^2\ 8^+$ states. Arising from the $h_{11/2}^2$ configuration, these states are obviously predicted by the pairing model to be degenerate with the 10^+ states reported in Table I. Actually, the experimentally observed 8^+ states [2,8–11] in the five nuclei considered lie below the 10^+ states by less than 100 keV.

Concerning the $v=3$ states, let us focus attention on the $\frac{23}{2}^-$ states. In principle, these states could be an admixture of the three configurations $h_{11/2}^3$, $h_{11/2}g_{7/2}^2$, and $h_{11/2}d_{5/2}g_{7/2}$. However, starting from ^{149}Ho the $h_{11/2}^3$ configuration is expected to be the dominant one in the lowest $\frac{23}{2}^-$ state. Actually, the experimentally observed

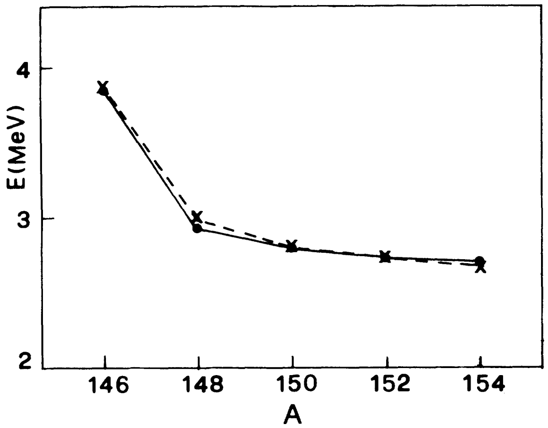

FIG. 1. Energy of the 10^+ excited state in even $N=82$ isotones with A ranging from 146 to 154. The theoretical results are represented by $\times$'s and the experimental data by solid circles.

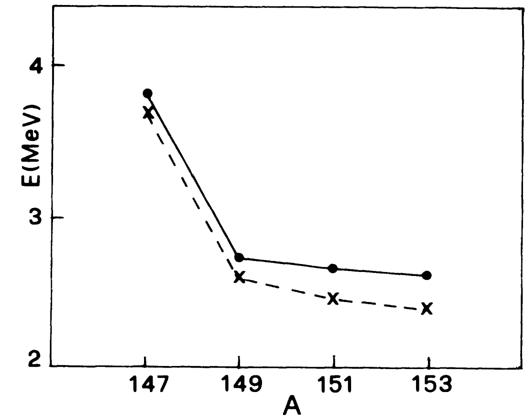

FIG. 2. Energy of the $\frac{27}{2}^-$ excited state in odd $N=82$ isotones with A ranging from 147 to 153. The conventions of the presentation are the same as those used in Fig. 1.

$\frac{23}{2}^-$ states [2,13,14] in ^{149}Ho, ^{151}Tm, and ^{153}Lu (2.59, 2.52, and 2.50 MeV excitation energy, respectively) compare well with the theoretical values for the $h_{11/2}^3$ configuration reported in Table I.

A similar situation occurs for the $v=4$ 16^+ states. In this case the relevant configurations are $h_{11/2}^4$, $h_{11/2}^2 g_{7/2}^2$, and $h_{11/2}^2 g_{7/2} d_{5/2}$. The first one is clearly favored when one reaches ^{150}Er. As a matter of fact, the 16^+ state observed in ^{150}Er lies at an energy of 5.22 MeV [10] to be compared with our calculated value of 5.02 MeV. For ^{152}Yb and ^{154}Hf no experimental data are available. Our

TABLE I. Comparison of experimental and calculated energies (in MeV) of the high-spin states in the $N=82$ isotones with $Z \geq 64$ (see text for comments). The experimental data are taken for $A=146$, 148, 150, 152, and 154 from Refs. [8, 9, 10, 11, and 2], respectively. For $A=147$, 149, 151, and 153 the data are from Refs. [12, 13, 14, and 2], respectively.

Configuration	J^π_{max}	Nucleus	Expt.	Calc.
$h_{11/2}^2$	10^+	^{146}Gd	3.86	3.87
		^{148}Dy	2.92	3.01
		^{150}Er	2.80	2.82
		^{152}Yb	2.73–2.74	2.73
		^{154}Hf	2.68–2.74	2.69
$h_{11/2} g_{7/2}$	9^-	^{146}Gd	3.43	3.51
		^{148}Dy		3.74
		^{150}Er		3.97
		^{152}Yb		4.19
		^{154}Hf		4.39
$h_{11/2}^3$	$\frac{27}{2}^-$	^{147}Tb	3.84	3.71
		^{149}Ho	2.74	2.61
		^{151}Tm	2.66	2.47
		^{153}Lu	2.63	2.41
$h_{11/2}^2 g_{7/2}$	$\frac{27}{2}^+$	^{147}Tb	3.42	3.32
		^{149}Ho		3.60
		^{151}Tm		3.85
		^{153}Lu		4.08
$h_{11/2}^3 g_{7/2}$	17^-	^{146}Gd		7.24
		^{148}Dy	6.26	6.18
		^{150}Er		6.30
		^{152}Yb		6.48
		^{154}Hf		6.69

predicted values are 4.85 and 4.79 MeV, respectively.

In summary, the present work completes our previous study of the pairing effects in the $N=82$ isotones. The results obtained here lend further support to the conclusions reached in I. The success achieved by both of our calculations, while being a clear manifestation of the inherent simplicity of the $N=82$ nuclei in terms of shell model, puts on a fully quantitative basis the role of proton pairing correlations in this region.

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[1] F. Andreozzi, A. Covello, A. Gargano, and A. Porrino, Phys. Rev. C **41**, 250 (1990).

[2] J. H. McNeill, J. Blomqvist, 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).

[3] P. J. Daly, in *Proceedings of the Third International Spring Seminar on Nuclear Physics, Ischia, 1990,* edited by A. Covello (World Scientific, Singapore, 1991), p. 53.

[4] F. Andreozzi, A. Covello, and A. Porrino, Phys. Rev. C **21**, 1094 (1980).

[5] F. Andreozzi, A. Covello, A. Gargano, Liu Jian Ye, and A. Porrino, Phys. Rev. C **32**, 293 (1985).

[6] F. Andreozzi, A. Covello, A. Gargano, and A. Porrino, Phys. Rev. C **37**, 2228 (1988).

[7] F. Andreozzi, A. Covello, A. Gargano, and A. Porrino, Phys. Scr. **T32**, 7 (1990).

[8] S. W. Yates, R. Julin, P. Kleinheinz, B. Rubio, L. G. Mann, E. A. Henry, W. Stöffl, D. J. Decman, and J. Blomqvist, Z. Phys. A **324**, 417 (1986).

[9] L. K. Peker, Nucl. Data Sheets **42**, 111 (1984).

[10] Y. H. Chung, P. J. Daly, H. Helppi, R. Broda, Z. W. Grabowski, M. Kortelahti, J. McNeill, A. Pakkanen, P. Chowdhuri, R. V. F. Janssens, T. L. Khoo, and J. Blomqvist, Phys. Rev. C **29**, 2153 (1984).

[11] E. Nolte, G. Korschinek, and Ch. Setzensack, Z. Phys. A **309**, 33 (1982).

[12] J. Styczen, M. Piiparinen, Y. Nagai, P. Kleinheinz, D. Bazzacco, J. Eberth, and J. Blomqvist, Z. Phys. A **312**, 149 (1983).

[13] J. Wilson, S. R. Faber, P. J. Daly, I. Ahmad, J. Borggreen, P. Chowdhuri, T. L. Khoo, R. D. Lawson, R. K. Smither, and J. Blomqvist, Z. Phys. A **296**, 185 (1980).

[14] H. Helppi, Y. H. Chung, P. J. Daly, S. R. Faber, A. Pakkanen, I. Ahmad, P. Chowdhuri, Z. W. Grabowski, T. L. Khoo, R. D. Lawson, and J. Blomqvist, Phys. Lett. **115B**, 11 (1982).