PHYSICAL REVIEW C VOLUME 15, NUMBER 5 MAY 1977

Deformed $9/2^+$ proton-hole states in odd-A I nuclei*

D. B. Fossan, M. Gai, A. K. Gaigalas,† D. M. Gordon,‡ and R. E. Shroy‡
Department of Physics, State University of New York, Stony Brook, New York 11794

K. Heyde, M. Waroquier,§ H. Vincx,‖ and P. Van Isacker¶
Institute for Nuclear Physics, Rijksuniversiteit Gent, Proeftuinstraat 86, B-9000 Gent, Belgium

(Received 15 February 1977)

$\Delta J = 1$ bands built on low-lying $9/2^+$ states (307 keV in ^{119}I) have been observed in odd-A $^{117-127}$I ($Z = 53$) nuclei via (^{6}Li,$3n\gamma$) reactions. Calculations of the total potential energy of these nuclear states in terms of a [404]$9/2^+$ Nilsson proton hole revealed minima at significant prolate deformations ($\epsilon = 0.22$ for ^{119}I). The resulting excitation energies and band spacing calculations are in good agreement with experiment. The properties of these deformed $9/2^+$ states, which involve a $1g_{9/2}$ proton excited through the $Z = 50$ major shell, are compared with those of the deformed $9/2^+$ states previously observed in odd-Sb ($Z = 51$) nuclei.

NUCLEAR REACTIONS $^{114-124}$Sn(^{6}Li, $3n$), $E_{\rm Li} = 25-35$ MeV, measured γ-γ coincidences, $\gamma(E, \theta, t)$; deduced level scheme in odd-A $^{117-127}$I, γ multipolarities, J^π. Enriched targets, Ge(Li) detectors.

NUCLEAR STRUCTURE Odd-A $^{117-127}$I, calculated $\frac{9}{2}^+$ proton-hole state energies, $\Delta J = 1$ rotational bands.

I. INTRODUCTION

The coexistence of spherical and deformed states in odd-A nuclei, which have either a proton or neutron number different from a closed-shell (magic) number by ±1, has recently been discussed for the $Z = 82$, $N = 82$, and $Z = 50$ closed-shell regions.[1] The spherical states include the expected single-particle (1p) or single-hole (1h) states, while the deformed states involve the excitation of a large-j particle through the major shell, namely 2p-1h or 1p-2h states. The total potential energy of such deformed states is a sum of the potential energy surface of the core and the energy for the odd particle (hole). The energy for odd-particle (-hole) orbitals of specific angular momentum projections decreases as the deformation increases. Thus, stable low-energy minima of the total potential can be achieved at sizable deformations provided the potential-energy surface of the core is sufficiently broad. Pairing contributions to the excitation energy for this type of deformed state are also very important. The experimental energies and deformation properties of these deformed states are thus of considerable theoretical interest in regard to the collective properties of nuclei.

For the $Z = 50$ closed-shell region, recent experiments have located a low-lying sequence of $\Delta J = 1$ rotational bands based on deformed $\frac{9}{2}^+$ proton-hole (2p-1h) states in four odd-Sb ($Z = 51$) nuclei.[2] Successful calculations in terms of a [404]$\frac{9}{2}^+$ Nilsson orbital and appropriate potential-energy surfaces for the Te cores have been made for these deformed states.[1] The calculated energies, which are expected to be greater than 2.5 MeV for a spherical core, drop to near 1 MeV, in general agreement with the experimental energies. Also, the calculated deformations determined by the potential-energy minima are consistent with the rotational band spacings and γ-ray properties. Additional (2p-1h) $\frac{9}{2}^+$ states have been identified[3] for heavier odd-Sb nuclei from pickup reactions on the even-Te core nuclei; the observed energies increase, consistent with the calculations,[1] as the neutron number approaches the closed shell at $N = 82$.

To further study the deformation properties of this proton-hole orbital, (^{6}Li, $3n\gamma$) measurements have been made on six stable even-Sn targets to investigate rotational bands in the odd-I ($Z = 53$) nuclei. Similar $\Delta J = 1$ bands based on the deformed $\frac{9}{2}^+$ proton-hole (4p-1h) states were observed. Theoretical calculations related to those in the odd-Sb nuclei have been carried out for the odd-I nuclei. The purpose of this paper is to present both the experimental and theoretical results regarding these $\frac{9}{2}^+$ deformed states in the odd-I nuclei. It is hoped that the mapping of this collective feature as a function of neutron number for the $Z > 50$ transitional nuclei will yield a better understanding of the collective properties of nuclei.

II. EXPERIMENTAL RESULTS

To study the collective excitations in the odd-A I isotopes, the $\Delta Z = 3$ (^{6}Li, $3n\gamma$) fusion-evaporation reactions were used for six isotopically enriched even-Sn targets, taking advantage of the stability

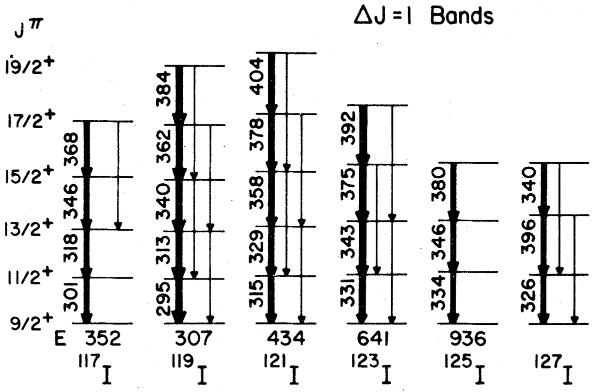

FIG. 1. $\Delta J=1$ bands observed in odd-A I nuclei via $(^6\text{Li}, 3n\gamma)$ reactions on even Sn targets. The $\frac{9}{2}^+$ bandheads, whose energies E are given, are lined up for the purpose of comparing the band spacings.

of the closed $Z=50$ proton shell. These reactions favor population with large alignment of high spin states whose dominant decay modes are via stretched γ-ray cascades. In order to determine the decay schemes and the level structure for the odd-A I isotopes, the following set of γ-ray measurements using Ge(Li) and intrinsic Ge detectors were performed: γ excitation, γ-γ coincidence, γ angular distribution, and pulsed beam-γ timing measurements. The details of the experimental techniques have been described earlier.[4] The excitation measurements taken over a ^{6}Li energy range from the Coulomb barrier to 35 MeV were compared with reaction calculations as a means of selecting the optimal beam energies and identifying the odd-I channels. Because of the complex nature of the γ-ray spectra from these reactions, γ-γ coincidence measurements with a Ge(Li)-Ge(Li) detector combination were required to determine the γ-ray cascades. The γ-γ coincidence results also established the identity of the residual nuclei via the connection of unknown γ-rays with those known from previous β-decay or light-ion reaction work. To obtain information on the spins of the levels and the γ-ray intensities I_γ, γ-ray angular distributions were measured in singles for four or five angles. The γ-ray photopeak areas were extracted and fitted to $W(\theta)=I_\gamma(1+A_2P_2+A_4P_4)$, where the P_k are the Legendre polynomials. Spin assignments were made on the basis of the $W(\theta)$, lifetime, and I_γ results. The pulsed beam-γ timing measurements yielded the lifetime information for the levels.

The γ-decay schemes deduced for the six odd-A I isotopes from the $(^6\text{Li}, 3n\gamma)$ measurements have considerable similarity. Although the analysis of the data and additional experiments are still in progress, the deformed $\frac{9}{2}^+$ states on which the present paper is focused are experimentally well defined. The complete experimental study will be presented later; several preliminary reports have been made.[5] These $\frac{9}{2}^+$ states are characterized by the existence of very similar $\Delta J=1$ rotational-like bands built on each of them in the six odd-A $^{117\text{-}127}$I isotopes. The decay schemes for these bands are collected in Fig. 1. The band members in each of these isotopes are connected by a γ-ray cascade whose angular distributions and timing information are consistent with $J \rightarrow J-1$ $M1$-$E2$ transitions, which are corroborated by the occurrence of $J \rightarrow J-2$ $E2$ crossover transitions. The $J^\pi = \frac{9}{2}^+$ assignments for the bandhead states are implied by the angular distributions of the decay γ-ray transitions to the $\frac{5}{2}^+$ ground states and to the $\frac{7}{2}^+$ first excited states, which are indicative of stretched $E2$ and $M1$-$E2$ multipolarities, respectively. The excitation-energy systematics for these $\frac{9}{2}^+$ states are shown in Fig. 2. These states are believed to be the deformed $\frac{9}{2}^+$ proton-hole (4p-1h) states that are related to the $1g_{9/2}$ orbital. The energy of these $\frac{9}{2}^+$ states drops from >1 MeV in ^{127}I to a low value of 307 MeV in ^{119}I. For comparison, the energies of the $2d_{5/2}$, $1g_{7/2}$, and $1h_{11/2}$ quasiproton states are also shown in Fig. 2; $\Delta J=2$ bands have been established as being built on most of these states.[5]

The observed properties of these $\frac{9}{2}^+$ bandhead states and their $\Delta J=1$ bands are consistent with the interpretation of a $[404]\frac{9}{2}^+$ proton hole strongly coupled to a prolate deformed rotor.[1,6] A deformation of the core is implied[1] by the rapid decrease in energy of these odd-I $\frac{9}{2}^+$ states as the neutron number decreases from $N=82$. In the theoretical Sec. III A, calculations of the energies of these states

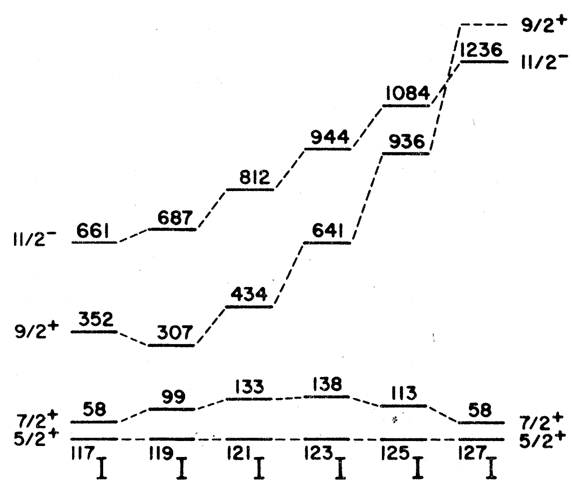

FIG. 2. Experimental excitation energies for the $\frac{9}{2}^+$ proton-hole states and the $\frac{5}{2}^+$, $\frac{7}{2}^+$, and $\frac{11}{2}^-$ quasiparticle states in odd-A I nuclei.

in terms of a hole in the $[404]\frac{9}{2}^+$ Nilsson orbital and the potential energy surface of the Xe cores are presented; the theoretical and experimental energies are in general agreement. The energies of these $\frac{9}{2}^+$ states for a spherical core as calculated are greater than 2.5 MeV.

In regard to the $\Delta J=1$ bands, the experimental energy spacings are approximately described by the rotor equation $(\hbar^2/2\mathscr{G})J(J+1)$ with $\hbar^2/2\mathscr{G}\simeq 30$ keV, where $\mathscr{G}$ is the moment of inertia. The $\hbar^2/2\mathscr{G}$ value is similar but slightly smaller than those of $\simeq 50$ keV observed[7] for the Xe core nuclei; Coriolis coupling effects and the influence of the proton hole are neglected in this approximate comparison. A more detailed calculation of the rotational band energies in terms of a symmetric rotor including Coriolis interactions is presented in Sec. III B; the agreement with the experimental energy spacings is good. A rotational interpretation is also implied by the γ-ray properties of the $\Delta J=1$ bands. The observed $J\to J-1$ γ-ray angular distributions are consistent with $E2/M1$ mixing ratios (δ) expected for rotational bands; a positive value of δ is obtained for these transitions which implies positive $(g_\Omega - g_p)Q_0$ and prolate deformations.[8] In addition, the intensity ratios of the $J\to J-2$ $E2$ crossover transitions to the $J\to J-1$ transitions observed within the bands yield values of $|(g_\Omega - g_p)/Q_0|$ which are approximately equal and which are consistent with rotor properties.

III. THEORETICAL RESULTS

Theoretical calculations of the energies of deformed $\frac{9}{2}^+$ states in the odd-A I nuclei and their $\Delta J=1$ rotational band spacings have been made in an effort to determine the validity of the proton hole plus deformed rotor interpretation for the present experimental results which are summarized in Figs. 1 and 2. These results are of particular theoretical interest because of their sensitivity to the deformation parameters and potential-energy surfaces for the states involving a high-j proton excited through the $Z=50$ major shell.

A. Deformed $\frac{9}{2}^+$ states

The $[404]\frac{9}{2}^+$ Nilsson proton orbital, which is related to the $1g_{9/2}$ orbital for a spherical nucleus, is expected[1] to be responsible for the low excitation energies of the odd-I $\frac{9}{2}^+$ states (as low as 307 keV in ^{119}I, see Fig. 2). The $[404]\frac{9}{2}^+$ Nilsson orbital has a steep positive slope in energy as a function of prolate deformation ϵ_2. Thus, a state involving the excitation of a proton out of this $[404]\frac{9}{2}^+$ orbital leaving a hole can achieve a low energy compared to the spherical particle-hole excitation energy[9] ($\Delta E\simeq 4.8$ MeV for the $Z=50$ major shell), provided the potential-energy surface of the core as a function of deformation is sufficiently broad. Pairing interaction contributions and shell corrections for different neutron number N are very important.

Explicit calculations for odd-A I isotopes have been performed by means of the macroscopic-microscopic renormalization procedure[10] in order to obtain the total potential energy (TPE) of these nuclei. The single-particle energies were calculated with a modified-harmonic oscillator potential[11] with only quadrupole degrees of freedom taken into account. The relevant parameters κ and μ as well as the pairing strength G for the I isotopes are discussed by Ragnarsson[12] and Heyde.[1] The total energy for the odd-mass nuclei is thus calculated to be

$$E_{N+1}^{(\Omega,i)}=\tfrac{1}{2}(E_{N+2}+E_N)+E_{1\text{qp}}^{(\Omega,i)}\,, \tag{1}$$

where E_N and E_{N+2} denote the TPE for the adjacent doubly even nuclei and $\frac{1}{2}(E_{N+2}+E_N)+\Delta$ corresponds, within the BCS approach, to a hypothetical "odd-even" system (dashed lines on Fig. 3). The last term, which is the one quasiparticle (1qp) energy in a particular orbit (Ω, i) has been calculated for

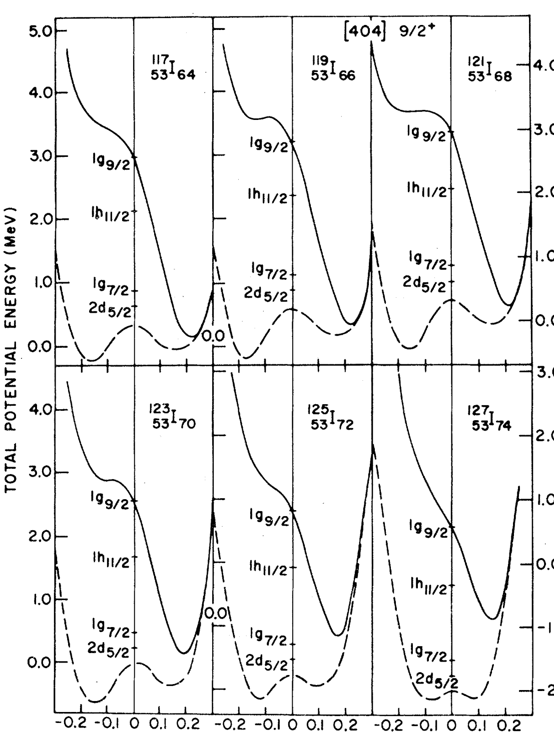

FIG. 3. The total potential-energy surfaces of the $[404]\frac{9}{2}^+$ Nilsson proton-hole orbital for the odd-A I nuclei. The odd-even background (see text) is shown in each case by the dashed lines.

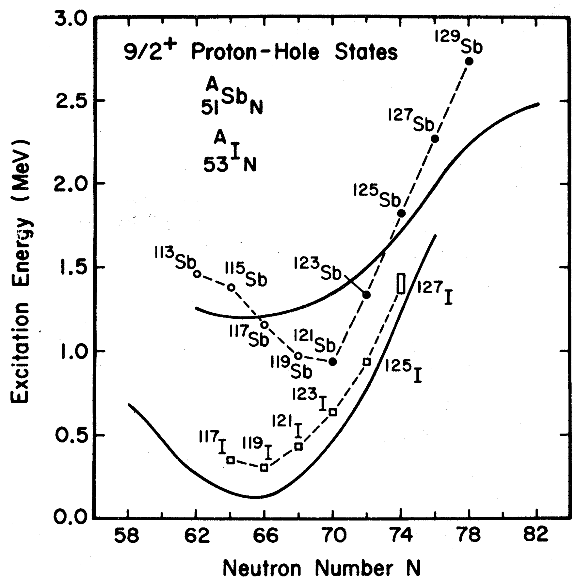

FIG. 4. Comparison of the experimental and theoretical excitation energies for the $\frac{9}{2}^+$ proton-hole states in odd-A I nuclei (open boxes give the experimental energies, lower curve represents the theoretical calculation). The related information for the odd-A Sb nuclei is also shown; experimental energies are given by open circles (Ref. 2) and filled circles (Ref. 3), while the theoretical calculation (Ref. 1) is given by the upper curve.

a system with an odd number of particles.

The results of the total potential-energy $E_{N+1}^{(\Omega,i)}$ calculations for the $[404]\frac{9}{2}^+$ state as a function of deformation ϵ_2 are shown in Fig. 3 by the solid lines for the six odd-A $^{117-127}$I nuclei. In all cases, the TPE exhibits a low-energy minimum at a significant prolate deformation. The excitation energy E_x of these $\frac{9}{2}^+$ states can be evaluated as the difference between the deformed minimum (solid line) and either the deepest or the prolate minimum of the "odd-even" system (dashed line). To summarize the theoretical calculations shown in Fig. 3, the following observations can be made: (i) the excitation energies for the $[404]\frac{9}{2}^+$ states drop from over 1 MeV in ^{127}I ($N=74$) to as low as a few hundred keV for ^{119}I ($N=66$), and (ii) the equilibrium deformations ϵ_2 defined by the minima gradually decrease ($\epsilon_2 \simeq 0.22$ for $N=66$, $\simeq 0.15$ for $N=74$) as the neutron number approaches the major shell at $N=82$ with a corresponding increase in E_x. For a spherical core ($\epsilon_2=0$), these $\frac{9}{2}^+$ states ($1g_{9/2}$) are typically at $E_x > 2.5$ MeV.

The unusually low E_x values for the $[404]\frac{9}{2}^+$ state in the ^{117,119,121}I nuclei are due to the strong shell-plus-pairing energy corrections for the neutrons in the midshell region ($N=64, 66, 68$) which have a strong deforming tendency. This is opposed by the weaker corrections for the protons which show a spherical tendency. For ^{123,125,127}I, the neutron shell-plus-pairing corrections are becoming smaller but still preferring small deformations. The steep rise in the liquid drop energy, however, produces an increase in E_x as N approaches 82.

The calculated excitation energies of these $[404]\frac{9}{2}^+$ states are presented by the solid curve in the lower part of Fig. 4 as a function of neutron number $N=58-76$ for comparison with the experimental values which are plotted as open boxes. The overall agreement between theory and experiment is generally good. This agreement lends support to the $[404]\frac{9}{2}^+$ proton hole plus prolate deformed core interpretation.

A similar theoretical comparison[1] for the deformed $\frac{9}{2}^+$ states of the odd-A Sb isotopes is presented in the upper part of Fig. 4. The open circles are the $\frac{9}{2}^+$ $\Delta J=1$ bandhead energies observed in the light Sb nuclei in previous γ-ray studies[2] and the solid circles are the $\frac{9}{2}^+$ states identified for the heavier Sb nuclei from (t,α) pickup reactions.[3] The theory and experiment for both the odd-I and odd-Sb show a minimum in the excitation energy; they occur at ^{119}I ($N=66$) and at ^{119,121}Sb ($N=68, 70$).

B. $\Delta J = 1$ rotational band

To further examine the validity of this theoretical interpretation, the $\Delta J=1$ rotational band structure, expected to be based on top of these deformed $[404]\frac{9}{2}^+$ states, has been calculated in order to compare with the experimentally observed band properties. In this calculation, all possible Nilsson orbitals from the $N=4$ oscillator shell are considered in a band-mixing calculation at the relevant equilibrium deformation ϵ_2. The band-mixing matrix elements are given by[13-15]:

$$\langle(\Omega',i')JM\,|H_{\text{core}}+H_{\text{sp}}|\,(\Omega,i)JM\rangle = 2\sum_{j,\,J_c=\text{even}} (-1)^{j-\Omega} C^{\Omega\ -\Omega\ 0}_{j\ \ J\ \ J_c} (-1)^{j-\Omega'} C^{\Omega'\ -\Omega'\ 0}_{j\ \ J\ \ J_c} E_{J_c} \times c_j^{\Omega,i} c_j^{\Omega',i'} (u_{\Omega,i}u_{\Omega',i'} + v_{\Omega,i}v_{\Omega',i'}) + E_{1\text{qp}}^{(\Omega,i)} . \quad (2)$$

In this equation, E_{J_c} denotes the energies of the Xe core nuclei, for which the experimental energies are used. The Nilsson wave functions, denoted by $C_j^{\Omega,i}$, the occupation probabilities $v_{\Omega,i}^2$, as well as the one-quasiparticle energies $E_{1\text{qp}}^{(\Omega,i)}$, have been calculated at the equilibrium deformation of the $[404]\frac{9}{2}^+$ Nilsson orbit in the odd-A $^{117-127}$I nuclei. The resulting wave functions

$$|\alpha JM\rangle = \sum_{\Omega, i} d_\alpha(\Omega i; J)\,|(\Omega, i)JM\rangle \qquad (3)$$

at the energy E_J^α are then obtained by diagonalizing the band-mixing matrix. The amplitudes $d_\alpha(\Omega i; J)$ obtained for ^{121}I are given in Table I. For this particular calculation, only the five Nilsson orbitals related to the $1g_{9/2}$ spherical orbit are taken into account; truncation effects have been studied and were found to be negligible. A gradual decrease in the $(\Omega, i) \equiv [404]\frac{9}{2}^+$ amplitude for all of the odd-A I isotopes is seen as the angular momentum J increases. Similar effects have also been obtained in other mass regions.[13,15]

The $\Delta J = 1$ band energies resulting from these band-mixing calculations are compared with the experimental energies for the odd-A $^{117-127}$I nuclei in Fig. 5; the experimental energies are displayed by horizontal lines and the theoretical energies by filled circles. The agreement between experiment and theory is very good, although the theoretical calculations slightly overestimate the experimental energies. Preliminary calculations following the triaxial rotor model of Meyer-ter-Vehn,[16] as opposed to the above symmetric rotor calculations, also have been made for the $\Delta J = 1$ bands based on these $\frac{9}{2}^+$ states; similar band energies were obtained with an asymmetry parameter γ near 0° (a symmetric prolate rotor). In the case of the $\Delta J = 1$ band in the odd-Sb nuclei, similar triaxial rotor calculations yielded the best fits with $\gamma = 20°$.[2] The above agreement between experiment and theory adds further support to the interpretation of a $\frac{9}{2}^+$ proton hole coupled to a prolate rotor.

IV. CONCLUSIONS

Low-lying $\frac{9}{2}^+$ states have been observed in six odd-A $^{117-127}$I nuclei with excitation energies which drop to a minimum of 307 keV at ^{119}I ($N = 66$). In addition, a $\Delta J = 1$ band was observed to be built on each of these $\frac{9}{2}^+$ states. Theoretical calculations of these properties have been carried out in terms of a $[404]\frac{9}{2}^+$ proton hole coupled to a prolate deformed core. Good agreement was found between experiment and theory which supports the validity of these interpretations. Similar experimental and theoretical systematics have been obtained previously for $\frac{9}{2}^+$ states in odd $^{113-129}$Sb nuclei with a minimum excitation energy of ~950 keV at ^{119,121}Sb ($N = 68, 70$). These excitation-energy minima are well below the values of >2.5 MeV expected for spherical cases.

The deformed $\frac{9}{2}^+$ states in the $Z = 53$ odd-A I nuclei are related to those in the $Z = 51$ odd-A Sb nuclei in that a $1g_{9/2}$ particle has been excited through the $Z = 50$ major shell. The coexistence of these deformed 2p-1h Sb states and 4p-1h I states with the more spherical states is an interesting nuclear structure feature of these transitional nuclei. A search[17] is presently underway to map this feature into possible 6p-1h $\frac{9}{2}^+$ states in $Z = 55$ Cs nuclei; theoretical calculations for these Cs states show the deformed $\frac{9}{2}^+$ states dropping from ~2.0 MeV in ^{133}C ($N = 78$) to below 400 keV in ^{123}Cs ($N = 68$).

The systematic behavior of deformed states near closed shells has led to the formulation of a two-component pairing residual force[18] which results from the inhomogeneity of prolate and oblate levels near the Fermi level. Continued studies of the systematic properties of these deformed states in both odd-A and even-A nuclei can help probe these new theoretical ideas.

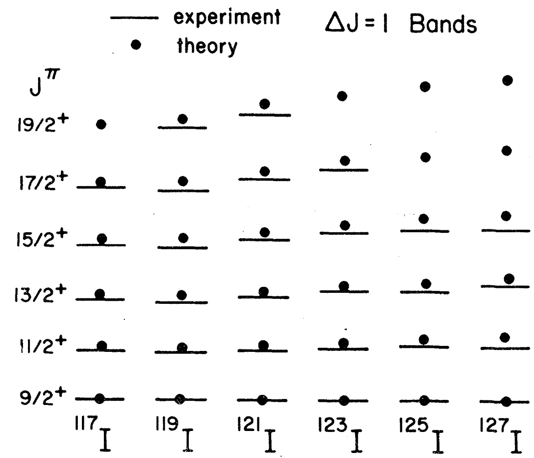

FIG. 5. Comparison of experimental and theoretical band energies (relative to the bandhead) for the $\Delta J = 1$ bands observed on the $\frac{9}{2}^+$ proton-hole states in odd-A I nuclei. The horizontal lines are the experimental energies and the filled circles represent the theoretical calculations.

TABLE I. The amplitudes $d_\alpha(\Omega_i, J)$ for ^{121}I [see Eq. (3) in text].

J^π	[404] $\frac{9}{2}^+$	[413] $\frac{7}{2}^+$	[422] $\frac{5}{2}^+$	[431] $\frac{3}{2}^+$	[440] $\frac{1}{2}^+$
$\frac{9}{2}^+$	0.98	0.21	0.05	0.02	0.01
$\frac{11}{2}^+$	0.96	0.27	0.07	0.02	0.00
$\frac{13}{2}^+$	0.94	0.31	0.09	0.03	0.01
$\frac{15}{2}^+$	0.93	0.35	0.01	0.03	0.01
$\frac{17}{2}^+$	0.92	0.38	0.12	0.04	0.01
$\frac{19}{2}^+$	0.90	0.40	0.14	0.04	0.01
$\frac{21}{2}^+$	0.89	0.42	0.15	0.05	0.02

The authors are indebted to Professor A. J. Deruytter for his interest during the course of this work.

*Supported in part by the National Science Foundation.
†Permanent address: SUNY at Binghamton, New York 13901.
‡Present address: Brookhaven National Laboratory, Upton, New York 11973
§Supported by the Nationaal Fonds voor Wetenschappelijk Onderzoek.
‖Supported by the Nationaal Fonds voor Wetenschappelijk Onderzoek.
¶Belgian Government Fellow.

[1]K. Heyde, M. Waroquier, H. Vincx, and P. Van Isacker, Phys. Lett. 64B, 135 (1976).
[2]A. K. Gaigalas, R. E. Shroy, G. Schatz, and D. B. Fossan, Phys. Rev. Lett. 35, 555 (1975); R. E. Shroy, A. K. Gaigalas, G. Schatz, and D. B. Fossan (unpublished).
[3]M. Conjeaud, S. Harar, M. Caballero, and N. Cindro, Nucl. Phys. A215, 383 (1973).
[4]B. A. Brown, P. M. S. Lesser, and D. B. Fossan, Phys. Rev. C 13, 1900 (1976).
[5]D. M. Gordon, M. Gai, R. E. Shroy, D. B. Fossan, and A. K. Gaigalas, Bull. Am. Phys. Soc. 20, 1187, 1188 (1975); 21, 96, 634 (1976).
[6]F. S. Stephens, Rev. Mod. Phys. 47, 43 (1975).
[7]M. Morinaga and N. L. Lark, Nucl. Phys. 67, 315 (1965); I. Bergstrom, C. J. Herrlander, A. Kerek, and A. Luukko, Nucl. Phys. A96, 318 (1969).
[8]K. Nakai, Phys. Lett. 34B, 269 (1971).
[9]A. H. Wapstra and N. B. Gove, Nucl. Data 9, 4 (1971).
[10]M. Brack, J. Damgaard, A. S. Jensen, H. C. Pauli, V. M. Strutinsky, and C. Y. Wong, Rev. Mod. Phys. 44, 320 (1972).
[11]S. G. Nilsson, C. F. Tsang, A. Sobiczewski, Z. Szymanski, S. Wyceck, C. Gustafson, I. L. Lamm, P. Moller, and B. Nilsson, Nucl. Phys. A131, 1 (1969).
[12]I. Ragnarsson, in Proceedings of the International Conference on Properties of Nuclei Far from the Regions of β-Stability, Leysin, 1970 [Report No. CERN 1970-30 (unpublished)], p. 847.
[13]N. DeTakacsy and S. Das Gupta, Phys. Rev. C 13, 399 (1976); Nucl. Phys. A263, 237 (1976).
[14]P. Vogel, Phys. Lett. 33B, 400 (1970).
[15]M. A. Deleplangue, C. Gerschel, N. Perrin, and P. Quentin, Phys. Lett. 46B, 317 (1973).
[16]J. Meyer-ter-Vehn, Nucl. Phys. A249, 111 (1975).
[17]U. Garg, T. P. Sjoreen, and D. B. Fossan, Bull. Am. Phys. Soc. 21, 635, 1003 (1976); 22, 595 (1977).
[18]John L. Wood and R. W. Fink, Bull. Am. Phys. Soc. 21, 1001 (1976); I. Ragnarsson and R. A. Broglia, Nucl. Phys. A263, 315 (1976).