Excited states in 110I and core polarization effects of the h11/2 proton and neutron orbitals

著者	Starosta K., LaFosse D. R., Chiara C. J., Fossan D. B., Koike T., Lane G. J., Sears J. M., Smith J. F., Boston A. J., Nolan P. J., Paul E. S., Semple A. T., Devlin M., Sarantites D. G., Lee I. Y., Macchiavelli A. O.
journal or publication title	Physical Review. C
volume	62
number	4
page range	044309
year	2000
URL	http://hdl.handle.net/10097/52624

doi: 10.1103/PhysRevC.62.044309

PHYSICAL REVIEW C, VOLUME 62, 044309

Excited states in ^{110}I and core polarization effects of the $h_{11/2}$ proton and neutron orbitals

K. Starosta,* D. R. LaFosse, C. J. Chiara, D. B. Fossan, T. Koike, G. J. Lane,† J. M. Sears, and J. F. Smith‡
Department of Physics and Astronomy, State University of New York at Stony Brook, Stony Brook, New York 11794-3800

A. J. Boston, P. J. Nolan, E. S. Paul, and A. T. Semple
Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom

M. Devlin§ and D. G. Sarantites
Department of Chemistry, Washington University, St. Louis, Missouri 63130

I. Y. Lee and A. O. Macchiavelli
Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720
(Received 2 February 2000; published 8 September 2000)

Excited states in ^{110}I have been identified for the first time using the αpn evaporation channel from the ^{58}Ni+^{58}Ni reaction at a beam energy of 250 MeV. The experiment was carried out using GAMMASPHERE coupled to the MICROBALL charged-particle detector array and an array of 15 neutron detectors. Two collective structures were observed with the yrast band built on the $\pi h_{11/2}\otimes\nu h_{11/2}$ configuration. Comparisons of the yrast-band energies with the excitation energies of the yrast states in even $_{52}$Te and in odd $_{52}$Te and $_{53}$I isotopes for $A\sim110$ were analyzed, revealing different responses of the underlying cores to the valence $\pi h_{11/2}$ and $\nu h_{11/2}$ orbitals. It is concluded that the neutron $h_{11/2}$ valence orbital has a larger influence than that of the proton $h_{11/2}$ valence orbital.

PACS number(s): 21.10.Re, 23.20.Lv, 27.60.+j

Excited states resulting from the coupling of unique-parity neutron and proton valence orbitals in odd-odd nuclei are of special interest for nuclear structure studies due to the relatively simple configuration space. These states in the neutron-deficient $A\sim110$ region involve $\pi h_{11/2}$ and $\nu h_{11/2}$ orbitals which become yrast at moderate spins and excitation energies. In the current paper, excited states in ^{110}I are presented for the first time with the yrast band identified as built on the $\pi h_{11/2}\otimes\nu h_{11/2}$ configuration. The ^{110}I nucleus is the most neutron deficient iodine isotope that is stable with respect to proton emission. The ground state was previously shown to have a 0.65 s half-life, decaying predominantly by electron capture and β^+ decay with a competing 17% α decay branch [1]. The ground state of the neighboring ^{109}I nucleus was reported to proton decay in Ref. [2]; the proton decay was recently employed in recoil delayed tagging (RDT) studies of excited states in ^{109}I (see Refs. [3,4]).

Nuclear structure in the $A\sim110$ region is determined by the few valence nucleons outside the doubly magic ^{100}Sn core. The number of valence particles is large enough to develop collective behavior, but single-particle aspects still play an important role. In the current paper, this issue is addressed through a comparative systematic study of yrast states in even $_{52}$Te isotopes, odd $_{52}$Te and $_{53}$I isotopes, and odd-odd $_{53}$I isotopes, employing recent results for ^{109}Te (Ref. [5]), ^{111}Te (Ref. [6]), ^{109}I (Ref. [4]), ^{111}I (Ref. [7]), and ^{112}I (Ref. [8]).

Excited states in ^{110}I were populated following the ^{58}Ni(^{58}Ni,αpn) reaction at a beam energy of 250 MeV. The experimental setup consisted of the GAMMASPHERE array of 83 HPGe detectors [9] coupled with the MICROBALL array of 95 CsI(Tl) charged-particle detectors [10], and an array of 15 scintillators for neutron detection, which replaced the 15 front Ge detectors. Charged-particle and neutron gating turned out to be essential in the analysis of the weak channels populated in the experiment, for example, as for the odd $_{52}$Te isotopes (see Refs. [5,6]). More information concerning the optimum utilization of the neutron-detector array is presented in Ref. [5].

Two self-supporting $\sim$500 μg/cm^2 stacked targets were used in the current experiment. Measured γ-ray energies were corrected off line for Doppler shifts; the Doppler correction procedure involved event-by-event reconstruction of the momentum vector of the residual nucleus based on reaction kinematics and measured charged-particle momentum vectors [10]. The average velocity of the recoiling nuclei was measured to be $\beta\sim4.4\%$ in agreement with the value calculated based on reaction kinematics. In the αpn channel, an overall γ-ray energy resolution of 4.3 keV full width at half maximum (FWHM) at 0.5 MeV was achieved.

The 527-, 569-, 622-, 664-, 716-, and 742-keV transitions assigned to ^{110}I were identified in the αpn-gated γ-ray spectrum shown in the upper panel of Fig. 1. These transitions are not observed in the $2\alpha pn$-gated or in the $\alpha 2pn$-gated spectrum shown in the lower panels of Fig. 1. This suggests that these transitions originate from a nucleus having atomic

*On leave from: Institute of Experimental Physics, Warsaw University, Hoża 69, 00-681 Warsaw, Poland.

†Present address: Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720.

‡Present address: Schuster Laboratory, The University of Manchester, Manchester M13 9PL, United Kingdom.

§Present address: LANSCE-3, Los Alamos National Laboratory, Los Alamos, NM 87545.

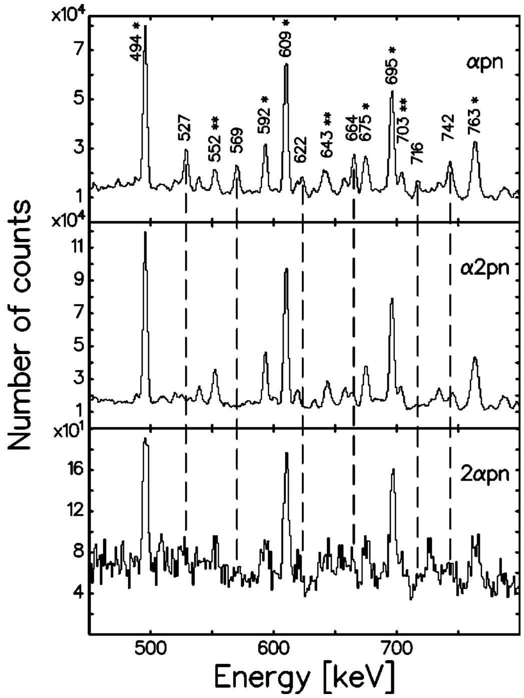

FIG. 1. Charged-particle and neutron gated γ-ray spectra from the current experiment for αpn (top), $\alpha 2pn$ (middle), and $2\alpha pn$ (bottom) gates. The 527-, 569-, 622-, 664-, 716-, and 742-keV transitions are assigned to ^{110}I. Transitions identified as contaminants belonging to ^{109}Te or ^{112}I are labeled with asterisks or double asterisks, respectively.

number $Z=53$ and $A \leqslant 110$. The only alternative assignment for these transitions is to αpxn channels with $x \geqslant 2$. This hypothesis can be ruled out, however, with quantitative analysis of the $\alpha p2n$-gated spectrum. The above transitions are observed in the $\alpha p2n$ spectrum; however, their reduced intensities are consistent with those expected from instrumental effects. Such effects include scattering of a single neutron between two neutron detectors and imperfect

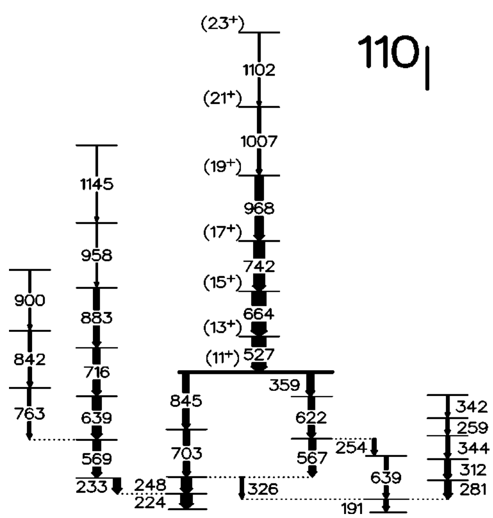

FIG. 2. Level scheme proposed for ^{110}I. The widths of the arrows represent the relative intensity of the γ-ray transitions.

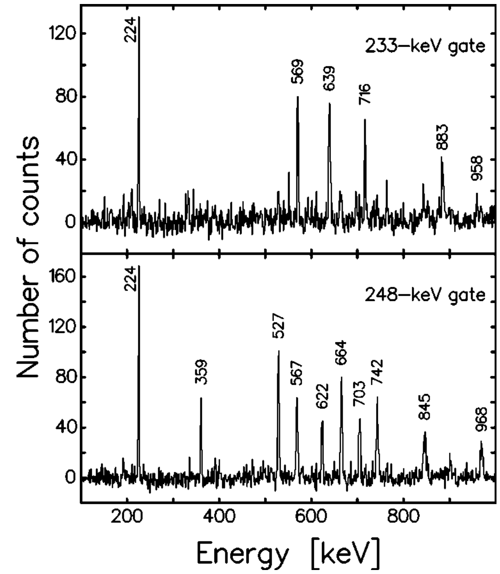

FIG. 3. Coincidence spectra gated on the 233-keV (top) and 248-keV (bottom) γ-ray transitions, taken from the αpn-gated matrix.

γ-neutron separation. In addition, the assignment of these transitions to the $\alpha p2n$ channel would be in disagreement with the recent RDT study on ^{109}I (Ref. [4]). Transitions identified in ^{109}I in Refs. [3,4] were not observed in the current data. This suggests that the reaction used in the current study does not populate the αpxn channels with $x \geqslant 2$ with cross sections above the experimental sensitivity, and further confirms the proposed assignment of the 527-, 569-, 622-, 664-, 716-, and 742-keV transitions to ^{110}I.

The main contaminants observed in the spectra shown in Fig. 1 are from ^{109}Te and ^{112}I populated in the $\alpha 2pn$ and $3pn$ channels, respectively. Transitions of ^{109}Te are observed in the αpn-gated spectrum because of the $\sim$80% MICROBALL efficiency for proton detection that resulted in a $\sim$20% probability for missing one proton. Transitions of ^{112}I are observed in the α-gated spectra due to the small probability of proton-α misidentification. The same is true for the ^{109}Te transitions observed in the $2\alpha pn$-gated spectrum.

For subsequent analysis, coincident γ-ray events were sorted into an αpn-gated two-dimensional (2D) matrix and αp-gated 3D cube. In the αp-gated data, the αpn evaporation channel had an intensity of $\sim$1% compared to the intensity of the most intense $\alpha 2p$ evaporation channel that leads to ^{110}Te; therefore most of the analysis was performed using the αpn-gated matrix. The number of events in the matrix was 2.2 million. The most intense channel in the matrix was the $\alpha 2pn$ channel that populates ^{109}Te. The intensity of ^{110}I in the matrix was $\sim$15% compared to the intensity of ^{109}Te. The γ-ray spectroscopy software package RADWARE [11] was used for the data analysis.

The level scheme deduced for ^{110}I is shown in Fig. 2. Two characteristic γ-ray sequences are observed, the first at low excitation energy with 569-, 639-, 716-, and 883-keV transitions (see upper panel of Fig. 3) and the second at higher excitation energy with 527-, 664-, 742-, and 968-keV

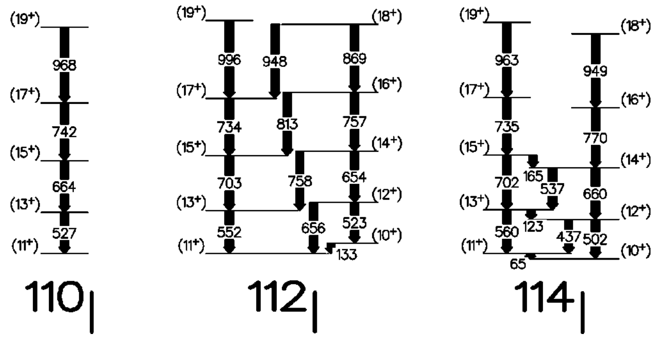

FIG. 4. Systematics of the yrast bands in neutron-deficient odd-odd $_{53}$I isotopes. Data for ^{112}I and ^{114}I are taken from Refs. [8] and [12], respectively.

transitions (see lower panel of Fig. 3). The first sequence can be interpreted as a collective rotational band built on the $\pi(g_{7/2}d_{5/2})\otimes\nu h_{11/2}$ configuration, which is expected to be favored at moderate spin due to the position of the proton and neutron Fermi levels. The second sequence, populated with significantly more intensity, is interpreted as a collective band built on the $\pi h_{11/2}\otimes\nu h_{11/2}$ configuration, which is expected to be yrast at higher spin as in other odd-odd nuclei in the $A\sim110$ region.

The current data lack sufficient statistics to confirm the proposed configuration/spin assignments with an angular correlation analysis. Additionally, it is not certain that the links to the ground state have been established in the current study, and the ground state spin and parity for ^{110}I are not known. Some conclusions about spins and parities of the observed excited states can be drawn, however, from the energy systematics of the yrast bands in the odd-odd $_{53}$I isotopes shown in Fig. 4. With the ^{110}I assignment proposed in Fig. 4, the energies of the odd-spin members of the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands relative to the (11^{+}) bandhead energies smoothly decrease with decreasing neutron number. The energies of the even-spin members (unfavored signature) are increasing relative to the odd-spin members as the neutron number decreases, which explains why the even-spin members are not observed in ^{110}I.

The influence of the unique parity $h_{11/2}$ neutron and proton orbitals on the collectivity of the transitional nuclei above the $Z=50$ closed proton shell is of special interest. The transition from quadrupole vibrations to deformed rotors should be affected by these shape driving high-spin valence orbitals. Information on such possible effects as a function of the Fermi level might be obtained from comparisons of the level sequence (band) energies of the even core nuclei with those of the odd nuclei having an added neutron or proton to a valence orbital, and with those of the nuclei having both valence orbitals occupied. These comparisons over the neutron-deficient region $N=56-62$ are presented in Fig. 5. The energy systematics of the yrast states in $\pi h_{11/2}\otimes\nu h_{11/2}$ bands in odd-odd $_{53}$I isotopes are compared to the yrast states in even $_{52}$Te isotopes, $\nu h_{11/2}$ bands in odd $_{52}$Te isotopes, and $\pi h_{11/2}$ bands in odd $_{53}$I isotopes. All energies are plotted relative to the bandheads of the corresponding bands. The comparisons show several interesting features.

The energies of the yrast states in even $_{52}$Te isotopes decrease as the neutron number decreases.

The energies of the states in the $\nu h_{11/2}$ bands in odd $_{52}$Te isotopes are substantially reduced with respect to the core energies, and decrease as the neutron number decreases showing the same trend as the even $_{52}$Te cores.

The energies of the states in the $\pi h_{11/2}$ bands in odd $_{53}$I isotopes are generally smaller than the corresponding energies of the even $_{52}$Te cores, but increase with decreasing neutron number. The response of an even-even core to the $h_{11/2}$ proton coupling is different therefore from the response to the $h_{11/2}$ neutron coupling, despite the fact that the position of the Fermi level favors the same low-K orbital for both protons and neutrons.

The decreasing trend established for the energies in the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands in odd-odd $_{53}$I isotopes follows more

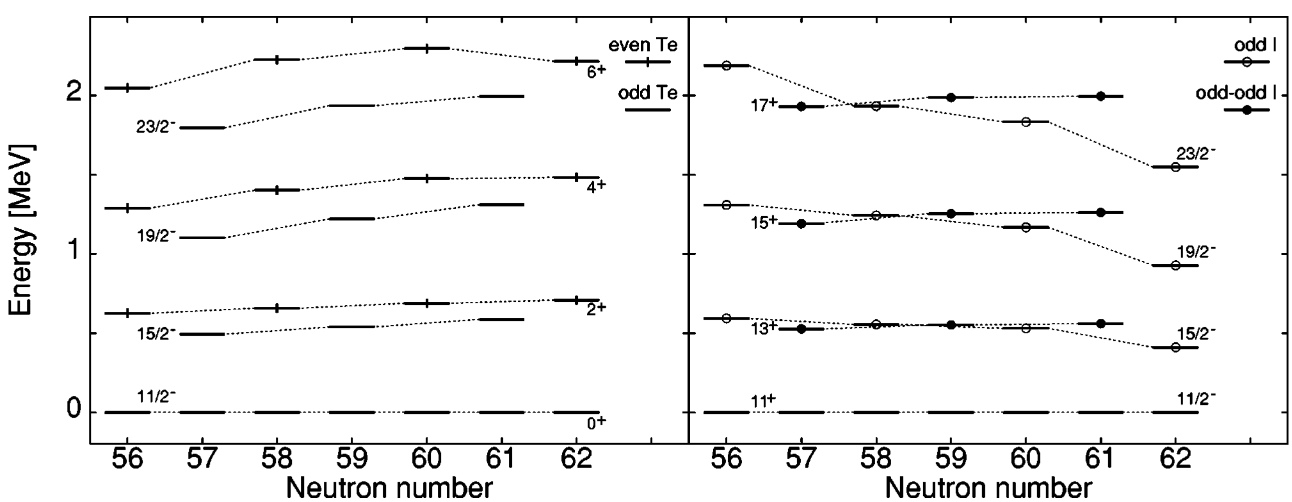

FIG. 5. Systematics of the yrast $\pi h_{11/2}\otimes\nu h_{11/2}$ bands in neutron-deficient odd-odd $_{53}$I isotopes compared to the systematics of the yrast bands in even-A $_{52}$Te isotopes, the yrast $\nu h_{11/2}$ bands in neighboring odd-A $_{52}$Te isotopes, and the yrast $\pi h_{11/2}$ bands in neighboring odd-A $_{53}$I isotopes. For each band, the bandhead is plotted at zero energy. Energy systematics for even-A $_{52}$Te isotopes were taken from Ref. [3]. Energy systematics for odd-A nuclei were taken from Ref. [6] for $_{52}$Te isotopes and from Ref. [7] for $_{53}$I isotopes.

closely the trend for the $\nu h_{11/2}$ bands in the odd $_{52}$Te isotopes rather than that for the $\pi h_{11/2}$ bands in the odd $_{53}$I isotopes.

These unusual energy trends would suggest that any theoretical interpretation would not be simple. As the neutron number decreases and the neutron Fermi level approaches the closed core at $N=50$, collective vibrators should become stiffer and collective rotors should become less deformed, both of which would have increasing energy trends. Although the different effects of the combinations of high-spin valence orbitals are indicated by these systematics, the lack of simple explanations will hopefully motivate a thorough theoretical investigation.

In conclusion, excited states were identified for the first time in neutron-deficient odd-odd ^{110}I, taking advantage of the resolving power of the GAMMASPHERE array in conjunction with the MICROBALL array of charged-particle detectors and an array of 15 neutron detectors. Two collective-like structures were observed, with the most intense structure interpreted as a band built on the $\pi h_{11/2} \otimes \nu h_{11/2}$ configuration. The systematics of yrast bands in odd-odd $_{53}$I isotopes were discussed in comparison to the systematics of the yrast bands in even $_{52}$Te and in odd $_{52}$Te and $_{53}$I isotopes. These comparisons were made relative to the different responses of the underlying core in the odd nuclei for the $\pi h_{11/2}$ or $\nu h_{11/2}$ orbital. The similarity between $\pi h_{11/2} \nu h_{11/2}$ bands in the light odd-odd $_{53}$I isotopes and the $\nu h_{11/2}$ bands in the related odd $_{52}$Te neighbors suggests that the influence of the neutron $h_{11/2}$ valence orbital is larger than that of the proton $h_{11/2}$ valence orbital.

This work was supported in part by the U.S. National Science Foundation and the U.K. Engineering and Physical Sciences Research Council. The authors would like to thank Dr. C. J. Lister, Dr. S. J. Freeman, and the University of Manchester group for setting up the neutron detectors.

[1] D. De Frenne and E. Jacobs, Nucl. Data Sheets **67**, 809 (1992).
[2] T. Faestermann, A. Gillitzer, K. Hartel, P. Kienle, and E. Nolte, Phys. Lett. **137B**, 23 (1984); F. Heine, T. Faestermann, A. Gillitzer, J. Homolka, M. Kopf, and W. Wagner, Z. Phys. A **340**, 225 (1991).
[3] E. S. Paul, P. J. Woods, T. Davinson, R. D. Page, P. J. Sellin, C. W. Beausang, R. M. Clark, R. A. Cunningham, S. A. Forbes, D. B. Fossan, A. Gizon, J. Gizon, K. Hauschild, I. M. Hibbert, A. N. James, D. R. LaFosse, I. Lazarus, H. Schnare, J. Simpson, R. Wadsworth, and M. P. Waring, Phys. Rev. C **51**, 78 (1995).
[4] C.-H. Yu, A. Galindo-Uribarri, S. D. Paul, M. P. Carpenter, C. N. Davids, R. V. F. Janssens, C. J. Lister, D. Seweryniak, J. Uusitalo, and B. D. MacDonald, Phys. Rev. C **59**, R1834 (1999).
[5] A. J. Boston, E. S. Paul, C. J. Chiara, M. Devlin, D. B. Fossan, S. J. Freeman, D. R. LaFosse, G. J. Lane, M. Leddy, I. Y. Lee, A. O. Macchiavelli, P. J. Nolan, D. G. Sarantites, J. M. Sears, A. T. Semple, J. F. Smith, and K. Starosta, Phys. Rev. C **61**, 064305 (2000).
[6] K. Starosta, C. J. Chiara, D. B. Fossan, T. Koike, D. R. LaFosse, G. J. Lane, J. M. Sears, J. F. Smith, A. J. Boston, P. J. Nolan, E. S. Paul, A. T. Semple, M. Devlin, D. G. Sarantites, I. Y. Lee, and A. O. Macchiavelli, Phys. Rev. C **61**, 034308 (2000).
[7] E. S. Paul, K. Starosta, A. J. Boston, C. J. Chiara, M. Devlin, O. Dorvaux, D. B. Fossan, P. T. Greenlees, K. Helariutta, P. Jones, R. Julin, S. Juutinen, H. Kankaanpaa, H. Kettunen, D. R. LaFosse, G. J. Lane, I. Y. Lee, A. O. Macchiavelli, M. Muikku, P. Nieminen, P. Rahkila, D. G. Sarantites, H. C. Scraggs, J. M. Sears, A. T. Semple, J. F. Smith, and O. Stezowski, Phys. Rev. C **61**, 064320 (2000).
[8] K. Starosta, C. J. Chiara, D. B. Fossan, D. R. LaFosse, G. J. Lane, J. M. Sears, J. F. Smith, A. J. Boston, E. S. Paul, M. Devlin, D. G. Sarantites, I. Y. Lee, A. O. Macchiavelli, and S. G. Rohoziński, Contribution to Nuclear Structure ’98, Gatlinburg, 1998, p. 127.
[9] GAMMASPHERE Proposal, LBNL-PUB-5202; I. Y. Lee, Nucl. Phys. **A520**, 361 (1990).
[10] D. G. Sarantites, P.-F. Hua, M. Devlin, L. G. Sobotka, J. Elson, J. T. Hood, D. R. LaFosse, J. E. Sarantites, and M. R. Maier, Nucl. Instrum. Methods Phys. Res. A **381**, 418 (1996).
[11] D. C. Radford, Nucl. Instrum. Methods Phys. Res. A **361**, 297 (1995).
[12] E. S. Paul, H. R. Andrews, T. E. Drake, J. DeGraaf, V. P. Janzen, S. Pilotte, D. C. Radford, and D. Ward, Phys. Rev. C **52**, 1691 (1995).