High-spin rotational bands in ^{123}I

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High-spin states in ^{123}I were populated in the reaction ^{80}Se(^{48}Ca,$p4n$)^{123}I at a beam energy of 207 MeV and γ-ray coincidence events were measured using the Gammasphere spectrometer. Three weakly populated, high-spin rotational bands have been discovered with characteristics similar to those of the long collective bands recently observed in other nuclei of this mass region. Configuration assignments are proposed based on calculations within the framework of the cranked Nilsson-Strutinsky approach.

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The nuclei in the $A = 125$ mass region, with a limited number of valence nucleons outside the ^{114}Sn core, undergo a transition from weakly prolate deformation at low spin to an oblate shape at medium spin. The shape change is induced by the successive alignment of nucleons along the rotation axis and, finally, the level sequences terminate in maximally aligned oblate states [1–6]. In addition, several high-spin rotational bands have recently been observed in ^{120}Te [7], ^{124}Ba [6], ^{125}I [8], ^{125}Xe [9], and ^{126}Xe [10], which extend far beyond the noncollective oblate states. Only some of these sequences are firmly connected to lower-lying levels; they feed normal-deformed states in the spin range of $I \simeq 25$ at excitation energies around 10 MeV.

In the present work, the results of a further analysis of the data from the experiment to investigate the high-spin structure of ^{123}I [2] are reported. This investigation revealed three highly deformed bands in this nucleus. Their properties are similar to those of the long bands observed in neighboring nuclei. Cranked Nilsson-Strutinsky (CNS) calculations have been employed to propose configurations for the new bands.

High-spin states in ^{123}I were populated using the reaction ^{80}Se(^{48}Ca,$p4n$)^{123}I. The beam with an energy of 207 MeV was provided by the ATLAS accelerator at ANL. The target consisted of a ^{80}Se layer with a thickness of 0.6 mg/cm^2. Gamma-ray coincidence events were recorded with the Gammasphere spectrometer [11]. Further details on the experiment and the data analysis are given in previous publications by the present collaboration [2,7].

The three rotational sequences with large moments of inertia discovered in ^{123}I are displayed in Fig. 1. Their intensities are <1% of the channel strength. Bands a and b are about equal in intensity, while band c is weaker. Such small intensities preclude a measurement of directional correlations. However, the regularity of the bands and their similarity with high-spin bands in neighboring nuclei suggests that the in-band transitions are of $E2$ multipolarity. It was not possible to establish linking transitions into known ^{123}I levels. Excitation energies and spins of the new bands were estimated on the basis of the observed coincidences. These values were varied within reasonable limits to give agreement with theoretical predictions for the suggested configurations. The adopted values are similar to those of the connected bands in the neighboring nuclei ^{125}I [8], ^{125}Xe [9], and ^{126}Xe [10].

Triple-gated γ-ray coincidence spectra for the three new bands are presented in Fig. 2. Although no linking transitions between the bands and the lower-spin states could be established, transitions between the positive- and negative-parity states of ^{123}I [2] up to $I \simeq 30$ are visible in the three spectra.

The spins assigned to the three new bands are plotted as a function of transition energies in Fig. 3. A comparison with the high-spin bands in the neighboring nuclei ^{120}Te [7], ^{125}I [8], and ^{125}Xe [9] demonstrates the similarity of their behavior. At high frequencies, above $\hbar\omega = 0.95$ MeV, the slopes of the curves for the ^{123}I bands change, however, not as drastically as for band L4 in ^{125}Xe. These irregularities are indicative of band crossings, probably caused by neutron alignments.

Since firm spin assignments are missing, a comparison with theoretical predictions to assign configurations can only be viewed as tentative. In the following, suggestions for the configurations are made. Calculations were performed within the framework of the CNS formalism [12–14]. For details of the parameters used in these calculations see Ref. [2]. The configurations are labeled relative to the ^{100}Sn core as $[p_1 p_2,n_1(n_2 n_3)]$, which is a shorthand notation for

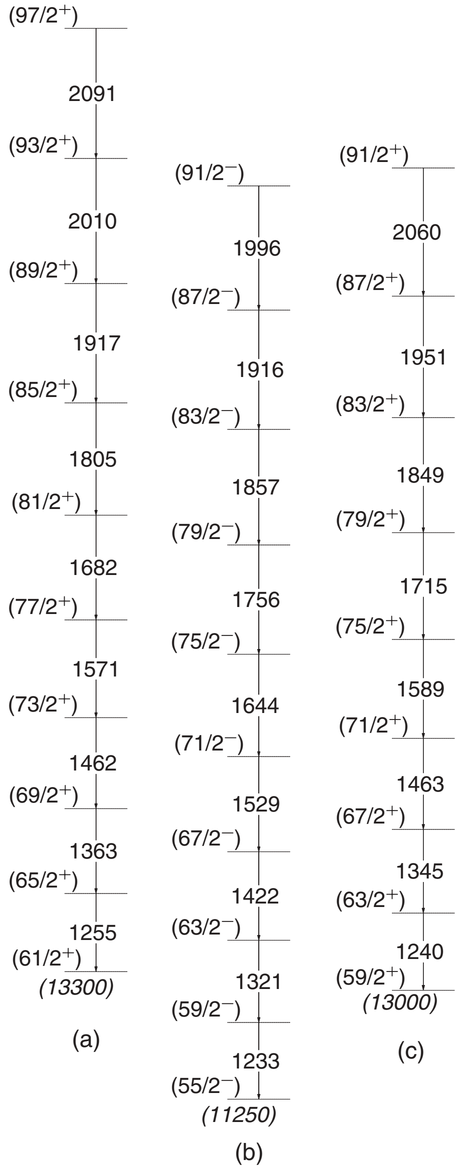

FIG. 1. The three new rotational bands in ^{123}I.

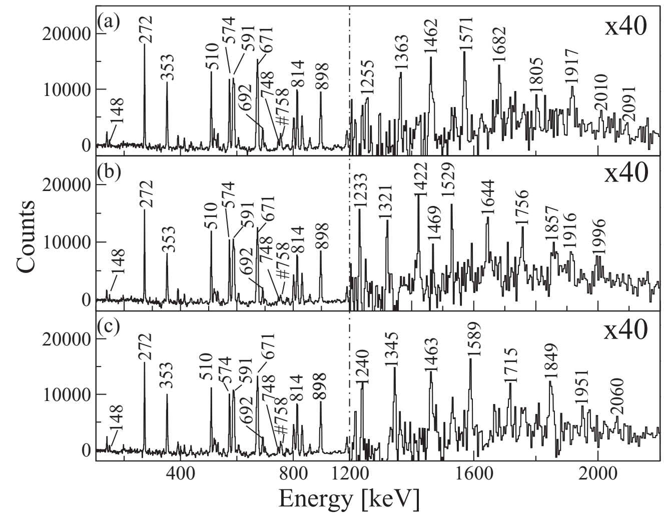

FIG. 2. Triple-gated background-subtracted γ-ray coincidence spectra showing transitions of (a) band a, (b) band b, and (c) band c. The spectra are separated into the two energy ranges: 100 keV – 1 MeV and 1.2–2.2 MeV, respectively. The labeled photopeaks below 1 MeV correspond to low-lying states in ^{123}I. The peak at 758 keV is an unresolved doublet. The spectra were produced from the hypercube by requiring two γ rays from a list of all transitions of the negative-parity sequence 6 in ^{123}I from 272 to 801 keV, see Ref. [2], and one γ ray from the list of all transitions of bands a, b, and c, respectively.

$\pi[(g_{9/2})^{-p_1}(h_{11/2})^{p_2}]\otimes\nu[(h_{11/2})^{n_1}(h_{9/2}f_{7/2})^{n_2}(i_{13/2})^{n_3}]$. The remaining particles outside the core are located in the mixed $d_{5/2}$, $g_{7/2}$, $s_{1/2}$, and $d_{3/2}$ orbitals.

Studies of neighboring nuclei [6–10] as well as the present calculations for ^{123}I, see below, indicate that the high-spin bands in the $A \simeq 125$ region are built on configurations with two proton holes in the $g_{9/2}$ subshell. Representative potential energy surfaces (PES) for such configurations with parity and signature $(\pi, \alpha) = (+, 1/2)$ are displayed in Fig. 4. The PES for the other (π, α) combinations show a similar behavior. At low spin, the lowest-energy minimum corresponds to a well-developed prolate shape at $\varepsilon_2 \simeq 0.28$. With increasing spin, at $I \simeq 30$, it splits into two minima. The one that develops towards smaller deformation ($\varepsilon_2 \simeq 0.2$) corresponds to configurations with proton excitations from the $g_{9/2}$ subshell, but without neutron excitations across the $N = 82$ shell gap. The recently observed highly deformed bands in ^{120}Te were associated with this minimum [7]. The minimum at $\varepsilon_2 \simeq 0.3$ results from neutrons excited across the $N = 82$ gap. Such a deformation has been associated with high-spin bands in ^{125}Xe [9] and ^{126}Xe [10] on the basis of measured transition quadrupole moments.

A systematic investigation has been performed to search for configurations, associated with these two minima, that may be assigned to the bands in ^{123}I. It turns out that configurations

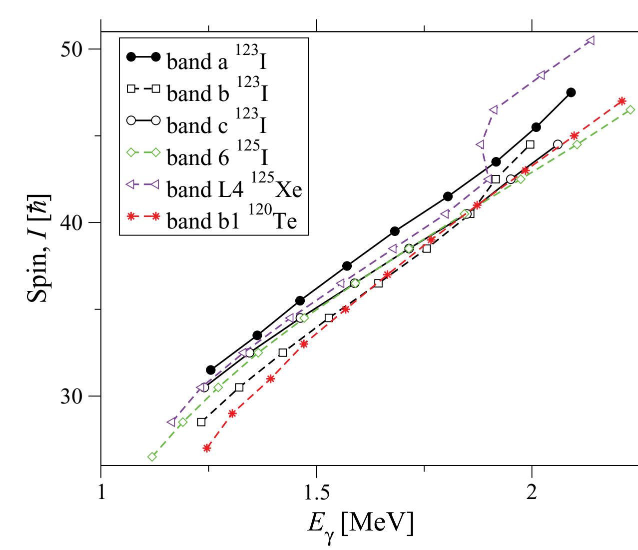

FIG. 3. (Color online) Spins as a function of γ-ray energy depopulating the states for the new bands in ^{123}I and for the connected bands in ^{120}Te, ^{125}I, and ^{125}Xe.

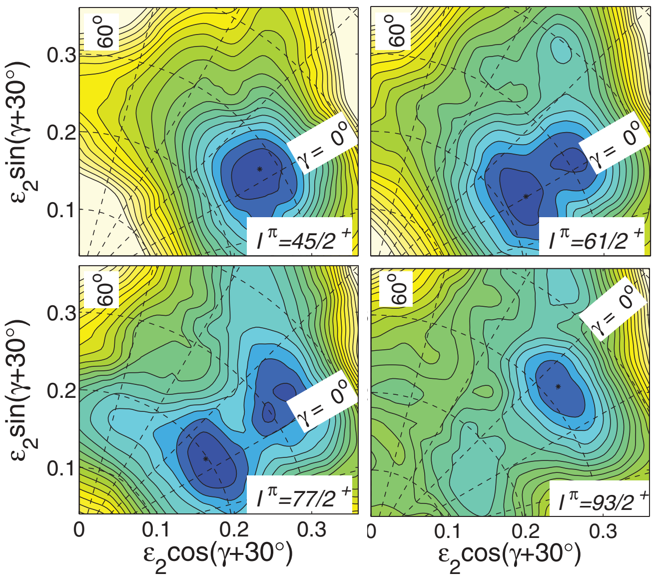

FIG. 4. (Color online) Potential energy surfaces for ^{123}I with parity and signature $(\pi, \alpha) = (+, 1/2)$, with the additional constraint of two proton holes in $g_{9/2}$ orbitals, in the spin range $I^\pi = 45/2^+$–$93/2^+$. The contour line separation is 0.25 MeV.

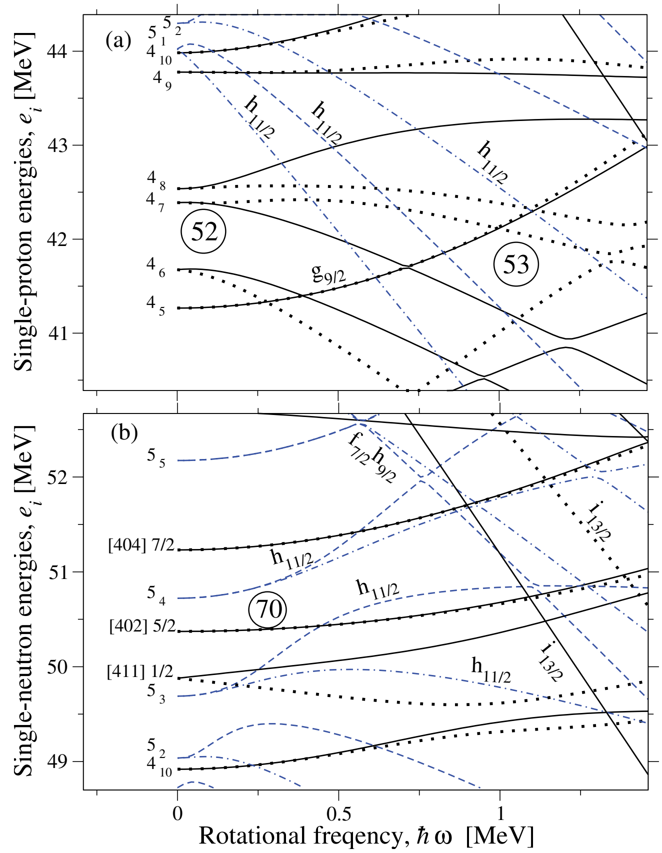

FIG. 5. (Color online) Single-particle (a) proton and (b) neutron energies as a function of rotational frequency at a deformation of $\varepsilon_2 = 0.20$. The orbitals are labeled at $\hbar\omega = 0$ by the oscillator quantum number, N_{osc}, with the ordering within the N_{osc} shell as a subscript or by their Nilsson quantum numbers. A few orbitals important for the present interpretation are labeled by their dominating j shell. Note that the [404]7/2 and [402]5/2 neutron orbitals are of $g_{7/2}d_{5/2}$ character while [411]1/2 is of $d_{3/2}s_{1/2}$ character. The line types distinguish between different (π, α) combinations: solid lines represent $(+, +1/2)$, dotted lines $(+, -1/2)$, dashed lines $(-, +1/2)$, and dash-dotted lines $(-, -1/2)$.

located in the minimum at $\varepsilon_2 \simeq 0.2$ give a better agreement with experiment than those corresponding to the one at larger deformation.

In order to understand the single-particle occupancy of the orbitals for these configurations, calculated Routhians for the appropriate deformation are displayed in Fig. 5. For protons, in the frequency range of $\hbar\omega \simeq 0.6$–1.0 MeV, configurations with two $g_{9/2}$ holes and one or two $h_{11/2}$ particles are favored; i.e., the $\pi(g_{9/2})^{-2}(g_{7/2}d_{5/2})^3(h_{11/2})^2$ configuration, or [22,..] in the shorthand notation, and the $\pi(g_{9/2})^{-2}(g_{7/2}d_{5/2})^4(h_{11/2})^1$ configuration, or [21,..], respectively. Note that similar configurations based on two-particle-two-hole (2p-2h) excitations across the $Z = 50$ shell gap have been suggested [8] for the high-spin bands in neighboring ^{125}I and ^{126}Xe. The favored neutron configurations have five or six particles in the $h_{11/2}$ subshell. In addition, the number of neutrons excited across the spherical $N = 64$ shell gap from the orbitals of $g_{7/2}d_{5/2}$ to orbitals of $d_{3/2}s_{1/2}$ character has to be considered. The neutron configuration $\nu(g_{7/2}d_{5/2})^{-2}(h_{11/2})^6(d_{3/2}s_{1/2})^2$, or [..,6(00)] in the shorthand notation, is favored in a large frequency range. This configuration with $(\pi, \alpha) = (+,0)$, coupled to the $(\pi, \alpha) = (+,1/2)$ proton configuration [22,..] mentioned above, forms the [22,6(00)] band with $(\pi, \alpha) = (+,1/2)$. It is yrast in the spin range of $I \simeq 30$–40 with a maximum spin value of $I_{max} = 105/2$ and is the most likely candidate for band a. At this spin, the potential energy minimum lies close to $\gamma = 60^\circ$, corresponding to termination in a noncollective state. However, if only the number of $h_{11/2}$ particles is fixed in the neutron configuration, the band can be followed up to $I_{max} = 113/2$ corresponding to the configuration $(g_{7/2}d_{5/2})^{-4}(h_{11/2})^6(d_{3/2}s_{1/2})^4$.

Another low-lying configuration can be obtained by changing the signature of the $N_{osc} = 4$ protons in the configuration just discussed; i.e., the [22,6(00)] configuration with $(\pi, \alpha) = (+,-1/2)$. This configuration with $I_{max} = 103/2$ (or 111/2 with four $N_{osc} = 4$ neutrons excited across the $N = 64$ gap) may be associated with band c.

A favored negative-parity configuration can be formed by combining the neutron configuration [..,6(00)] with the proton configuration [21,..] to give the $(\pi, \alpha) = (-,-1/2)$ [21,6(00)] band with $I_{max} = 99/2$ (or 107/2 with more $N_{osc} = 4$ neutrons excited). This configuration may be associated with band b, provided it has negative parity.

It is worth noting that, at the deformation used in Fig. 5, the neutron orbitals emerging from the $i_{13/2}$ and $h_{9/2}f_{7/2}$ subshells above the $N = 82$ gap become energetically competitive only around $\hbar\omega = 1.2$ MeV. Therefore, they are not active in the calculated high-spin bands of ^{123}I.

The tentatively assigned experimental energies of the bands, relative to the rotating liquid-drop energy, are displayed in panel (a) of Fig. 6. The calculated energies of the configurations assigned to these bands are presented in panel (b). In

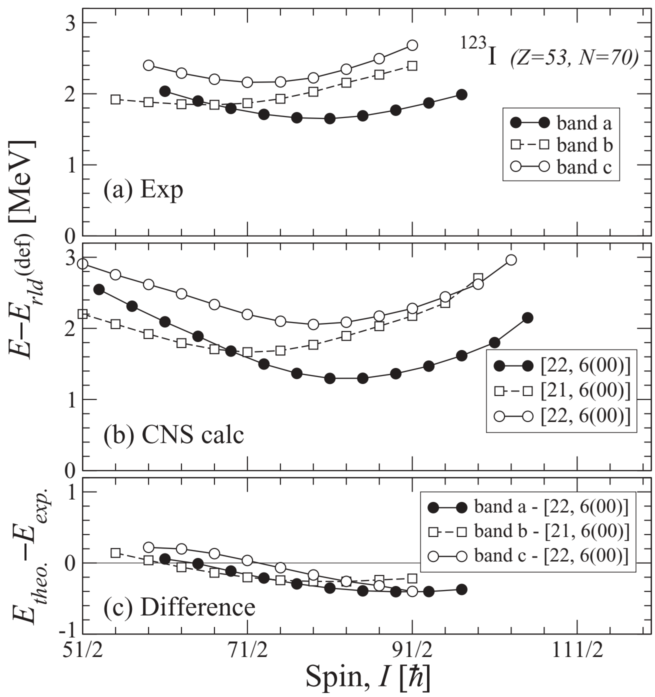

FIG. 6. Comparison between the experimentally observed rotational bands in ^{123}I (a) and the CNS predictions for the [22,6(00)] and [21,6(00)] configurations (b). Panel (c) shows the energy difference between theory and experiment.

panel (c), the differences between calculated and experimental energies are plotted. With the present tentative spin and parity assignments, good agreement between theory and experiment is achieved. For these configuration assignments the observed bands in ^{123}I reach spins close to the $I_{\max}$ value of the respective configurations. However, these configurations are calculated to remain somewhat collective at the highest spins [15].

Furthermore, it is interesting to note that, although almost all the highly deformed bands in the mass $A \sim 125$ region have the same proton configuration; i.e., they involve two holes in the $g_{9/2}$ subshell, the neutron configurations appear to be different. Whereas the bands in ^{120}Te ($N = 68$) and ^{123}I ($N = 70$) may be assigned to configurations without neutron excitations across the $N = 82$ shell gap, the bands in ^{125}Xe ($N = 71$), ^{125}I ($N = 72$), and ^{126}Xe ($N = 72$) have been suggested to be based on configurations involving such excitations. Note, however, the problems with the description of several of the collective bands in the latter nuclei, as pointed out in Ref. [8]. These inconsistencies should be addressed in further theoretical investigations.

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