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Spectroscopy of ^{123}I

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The level scheme of ^{123}I has been studied by in-beam gamma-ray spectroscopy in the fusion evaporation reaction ^{121}Sb$(\alpha,2n\gamma)^{123}$I. Gamma-gamma coincidences and gamma-ray angular distributions have been measured with large-volume high-resolution germanium detectors. The multipolarities and multipole mixing ratios have been determined for some of the transitions. Several new levels and transitions are observed and assigned to ^{123}I. A revised decay scheme is presented showing new levels and transitions associated with various bands in ^{123}I. The band structure of ^{123}I is discussed and interpreted in the light of theoretical predictions and evidence is presented for possible coexistence of different shapes in this nucleus.

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I. INTRODUCTION

The neutron-deficient odd-mass nuclei in the $Z>50$ transition region show collective features which have generated considerable theoretical interest. The traditional theoretical approaches used for the interpretation of the collective properties of these nuclei are based on models of deformed rotors [1] or anharmonic vibrators [2]. Recently microscopic theory [3] and the interacting boson-fermion model [4] have been applied for a more detailed understanding of the collectivity of transitional nuclei. Iodine nuclei with $Z=53$ form an important link in the systematics of the transitional region between the primarily spherical Sn nuclei and the well-deformed La and Ce nuclei. Two collective features observed systematically in odd-proton nuclei with $Z>50$ are (i) occurrence of a $\Delta J=1$ band characterized by $M1$ cascade and $E2$ crossover transitions, and (ii) $\Delta J=2$ bands with level spacings closely following those of the corresponding even-even cores. The levels of the $\Delta J=2$ bands are connected by stretched $E2$ transitions. The $\Delta J=1$ band has been interpreted as a sequence of rotational states built on a low-lying deformed $g_{9/2}$ proton-hole state. The $\Delta J=2$ bands, on the other hand, have been explained as arising from the coupling of the odd proton to the collective motion of the core. In ^{123}I, three $\Delta J=2$ case structures built on the first $\frac{5}{2}^+$, $\frac{7}{2}^+$, and $\frac{11}{2}^-$ states have been reported up to states with $J^\pi=(\frac{21}{2}^+)$, $(\frac{15}{2}^+)$, and $\frac{23}{2}^-$, respectively, and a $\Delta J=1$ structure based on a low-lying $\frac{9}{2}^+$ state up to $J^\pi=(\frac{17}{2}^+)$ in Refs. [5,6]. In a later work [7] the negative-parity $\Delta J=2$ sequence has been extended to $J^\pi=\frac{27}{2}^-$. Several levels in ^{123}I, however, are reported as uncertain in Ref. [5], and some $\Delta J=1$ transitions expected to occur in analogy with the neighboring iodine isotopes are not known in ^{123}I. A recent spectroscopic study [8] of the structure of the neighboring odd-mass iodine nuclei ^{119,121}I shows band structures with coexisting prolate and oblate deformed shapes in these nuclei. Theoretical calculations [5] of equilibrium deformation with the Strutinsky shell-model correction method [9] show that the nucleus ^{123}I is very soft against deformation, and coexistence of different shapes can be expected in this nucleus also at low excitation energies. With these points in mind, and to search for new levels and transitions as well as higher spin members of various bands, the level structure of ^{123}I has been investigated by spectroscopic measurements in the present work.

II. EXPERIMENTAL PROCEDURE

The level scheme of ^{123}I has been studied by in-beam gamma-ray spectroscopy in the fusion-evaporation reaction ^{121}Sb$(\alpha,2n\gamma)^{123}$I with a beam energy of 30 MeV, using an enriched ^{121}Sb target of ~ 3 mg/cm^2 thickness. The experiments were carried out at the Variable Energy Cyclotron Centre, Calcutta. Gamma-ray singles, $\gamma\gamma$ coincidence, and γ-ray angular distributions were measured using two HPGe detectors of 10% efficiency and energy resolution of 2 keV at 1.33 MeV. The target-detector distance was 25 cm for γ-ray singles and angular distribution measurements, and about 5 cm for $\gamma\gamma$ coincidence experiments. The γ-ray energies and relative intensities were determined from the singles measurements at 90° and 55°, respectively, relative to the beam axis. The coincidence data were recorded event by event on magnetic tape in a list mode configuration using a CAMAC-based data acquisition system with an ND 560 computer, suitably interfaced to Northern Scientific Nuclear analog-to-digital converters (ADC's). The full width at half maximum (FWHM) of the $\gamma\gamma$ prompt time spectrum was 19 nsec with integral γ-ray energies >50 keV. The energy-gated spectra were generated with a time window of 50 nsec, and the contributions of the Compton and random events were subtracted from the projected spectra. The γ-ray angular distributions were measured with one detector placed at 55° to the beam axis serving as the monitor and the other detector positioned at angles of 35°, 45°, 70°, 80°, and 90° with respect to the beam direction. The angular distribution coefficients were determined from the least-squares fit of the normalized data at various angles with the Legendre expansion

$$W(\theta)=A_0+A_2P_2(\cos\theta)+A_4P_4(\cos\theta) .$$

The mixing ratios δ for some of the $\Delta J=1$ transitions were determined from $\chi^2(\delta)$ analysis using the computer code THDST [10].

III. EXPERIMENTAL RESULTS

The present work confirms most of the previously reported [5,7] levels and transitions in ^{123}I. In addition, several new results have been obtained. The level scheme of ^{123}I based on the spectroscopic measurements in the present work is shown in Fig. 1. The gamma-ray energies measured at 90°, and the relative intensities at 55° to the beam direction are given in Table I along with the angular distribution coefficients and multipolarity assignments for some of the transitions. The placement of the gamma rays in the level scheme is based on their coincidence relations with other gamma rays, and on consideration of their energies and relative intensities. A few representative coincidence spectra are shown in Figs. 2–4.

Some of the prominent sequences of transitions in ^{123}I are labeled (A), (B), (C), (D), (E), and (F) in Fig. 1. A new level at 2567.2 keV is observed to be connected by two new gamma-ray transitions of energies 990.7 and 696.0 keV to the previously reported [5,7] $\frac{15}{2}^+$ and $\frac{17}{2}^+$ states, respectively. Two other levels at 2466.1 and 2790.1 keV are also observed to decay to the above-mentioned states via 889.6 and 919.0 keV transitions, respectively. The level at 2466.1 keV has been reported as uncertain in Ref. [5], whereas the other level at 2790.1 keV has not been reported before. Also, a cascade of two new $\Delta J=1$ transitions of energies 294.7 and 420.4 keV is observed between the 1871.1 keV ($\frac{17}{2}^+$), 1576.5 keV ($\frac{15}{2}^+$), and 1155.9 keV ($\frac{13}{2}^+$) states. Two more new transitions of energies 985 and 943 keV are tentatively shown to populate the $\frac{21}{2}^+$ and $\frac{19}{2}^+$ states in sequences (A) and (B), respectively, as they were observed in the coincidence spectra with gates set on the lower members of the respective cascades, but the reverse gates on these transitions were not conclusive due to their poor intensities. Most of the above-mentioned new transitions can be seen in the coincidence spectra with energy gates set on the 603.7 and 782.4 keV transitions shown in Fig. 2.

It is worth mentioning that the 603.7 and 715.2 keV transitions of sequence (A) are very near in energy to the 605.9 and 711.0 keV transitions, respectively, of sequence (C), forming close doublets. Consequently, the energy gates set on the 603.7 and 605.9 keV peaks include a small contribution from the other partner of the doublet, as indicated by the changes in intensities of the 715.2 and 711.0 keV gamma rays in the coincidence spectra shown in Figs. 2(a) and 2(b). A new quadrupole transition of 856.3 keV is observed to populate the previously reported $\frac{15}{2}^+$ state of the $\Delta J=2$ sequence labeled (C) in Fig. 1. Likewise, a new 766.4 keV transition ($\frac{13}{2}^+\rightarrow\frac{9}{2}^+$) from a new level at 1437.2 keV to the previously known 670.9 keV state is found to be a member of the cascade (D) in Fig. 1. Incidentally, the 766.4 keV transition is doubly

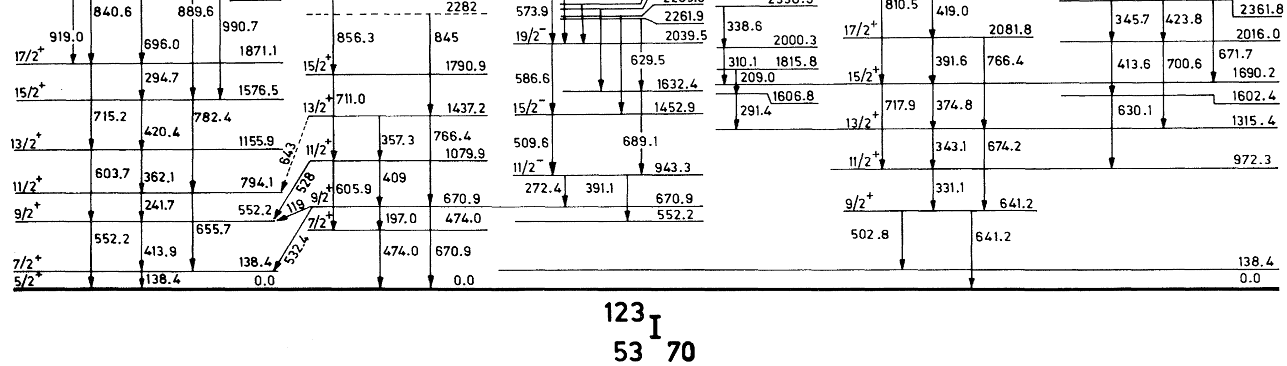

FIG. 1. Energy levels and transitions in ^{123}I deduced from this work. Prominent sequences of transitions are labeled (A), (B), (C), (D), (E), and (F). All energies are in keV.

TABLE I. Energies E_γ, relative intensities I_γ, and angular distribution results for transitions assigned to ^{123}I via the reaction ^{121}Sb$(\alpha,2n\gamma)^{123}$I at 30 MeV.

E_γ[a] (keV)	Initial state (keV)	I_γ[b]	A_2/A_0[c]	A_4/A_0[c]	Multipolarity[d]
119	670.9	1			
138.4	138.4	210	−0.28(1)	−0.03(1)	$M1/E2$
197.0	670.9	4			
209.0	1815.8	2			
241.7	794.1	7			
272.4	943.3	100	−0.19(2)	−0.02(5)	$E1$
291.4	1606.8	4			
294.7	1871.1	3			
298.0	2659.8	13			
310.1	2000.3	13			
329.8	2369.3	10			
331.1	972.3	113	0.08(2)	0.03(4)	$M1/E2$
338.6	2338.9	4			
343.1	1315.4	53	0.07(3)	0.05(4)	$M1/E2$
345.7	2361.8	11			
357.3	1437.2	4			
362.1	1155.9	10			
374.8	1690.2	37	0.08(4)	0.06(6)	$M1/E2$
391.1	943.3	25	−0.11(6)	0.09(7)	D
391.6	2081.8	14			
409	1079.9	2			
413.6	2016.0	14	−0.53(2)	−0.01(4)	$M1$
413.9	552.2	89			
419.0	2500.8	8	−0.08(16)		$(M1/E2)$
420.4	1576.5	3			
423.8	2439.8	6			
474.0	474.0	75	−0.59(3)	−0.05(4)	$M1$
502.8	641.2	61	−0.53(3)	−0.08(5)	$M1$
509.6	1452.9	105			
528	1079.9	2			
532.4	670.9	25	−0.32(4)	0.08(6)	D
552.2	552.2	68	0.30(4)	−0.06(5)	$E2$
573.9	2613.4	39	0.31(7)	−0.10(8)	$E2$
586.6	2039.5	75	0.37(4)	−0.04(5)	$E2$
603.7	1155.9	104	0.35(7)	0.00(7)	$E2$
605.9	1079.9	40	0.33(8)	0.04(8)	$E2$
629.5	2261.9	3			
630.1	1602.4	19			
641.2	641.2	79	0.15(4)	−0.08(6)	$E2$
643	1437.2	2			
655.7	794.1	82	0.33(4)	−0.07(6)	$E2$
670.9	670.9	125	0.23(3)	−0.03(4)	$E2$
671.7	2361.8	15			
674.2	1315.4	17	0.32(11)	−0.13(16)	$E2$
687	(2319)	2			
689.1	1632.4	10			
696.0	2567.2	6			
700.6	2016.0	11			
711.0	1790.9	28			
715.2	1871.1	66	0.40(7)	−0.04(7)	$E2$
717.9	1690.2	18			
766.4	1437.2	20	0.32(10)	−0.06(13)	$E2$
766.4	2081.8	9			
782.4	1576.5	45	0.33(4)	0.00(6)	$E2$
810.5	2500.8	4			
812.7	2265.6	11			
840.6	2711.7	24	0.29(9)	0.09(13)	Q

TABLE I. (*Continued*).

E_γ [a] (keV)	Initial state (keV)	I_γ [b]	A_2/A_0 [c]	A_4/A_0 [c]	Multipolarity[d]
845	(2282)	10			
856.3	2647.2	15	0.35(10)		Q
889.6	2466.1	17	0.40(10)		Q
898.5	3511.9	18	0.24(12)		Q
908.2	2947.7	6			
919.0	2790.1	8			
943	3409	4			
985	3697	4			
990.7	2567.2	8			

[a]Typical energy errors are 0.1–0.3 keV depending on the energy, intensity, and the complexity of the spectrum, except in a few cases where the errors are 1 keV and the energy values are quoted without a decimal place.

[b]The relative intensities I_γ are measured at an angle of 55° with respect to the incident beam. Typical errors are 5 to 20%.

[c]Errors in the A_2/A_0 and A_4/A_0 values are given in parentheses in units of the last decimal place.

[d]Letters D and Q denote dipole and quadrupole assignments, respectively.

placed on the basis of the results of the present work as shown in Fig. 1. Previous work [5,7] shows a transition of this energy connecting the $\frac{17}{2}^+$ and $\frac{13}{2}^+$ states of the positive-parity band labeled (F) in Fig. 1. The present work confirms this placement, but also shows at the same time that this transition is a member of an unresolved doublet whose major intensity belongs to the $\frac{13}{2}^+ \rightarrow \frac{9}{2}^+$ transition from the 1437.2 keV level of sequence (D) in Fig. 1. The 1437.2 keV level is further confirmed in the present work by the observation of new cascade transitions of 357.3 and 409 keV connecting the previously known 1079.9 and 670.9 keV states, and a weak 643 keV transition to the 794.1 keV state. Another new transition of 845 keV energy is observed to populate the above-mentioned 1437.2 keV state. A weak 528 keV transition is observed in this work from the $\frac{11}{2}^+$ state of sequence (C) to the $\frac{9}{2}^+$ state of sequence (A).

The energy gate set on the composite peak of 670.9 and 671.7 keV transitions depopulating the 670.9 and 2361.8 keV states, given in Fig. 3(c), shows, in addition to some of the above-mentioned new transitions, a fairly prominent 766.4 keV peak which cannot arise from the $\frac{17}{2}^+ \rightarrow \frac{13}{2}^+$ transition of band (F), according to the level scheme. The reverse gate on the 766.4 keV peak given in Fig. 4(c) shows not only the expected transitions of band (F) but also the 532.4, 670.9, and 845 keV transitions, supporting the double placement of the 766.4 keV transition, as shown in Fig. 1.

The cascade of $\Delta J = 2$ transitions connecting the negative-parity states labeled (E) in Fig. 1 has been reported up to $\frac{23}{2}^-$ state in Ref. [5] and extended to the $\frac{27}{2}^-$ state in Ref. [7]. The present work confirms all these transitions and shows them to be quadrupole in nature. The 908.2, 812.7, and 689.1 keV transitions reported [5] to populate the negative parity states are also confirmed. In addition, new transitions of 329.8, 629.5, and 687 keV are observed and placed in the level scheme as shown in Fig. 1. The gated spectra of Figs. 3(a)–3(c) show the various transitions associated with the negative-parity states.

The sequence of positive-parity levels labeled (F) in Fig. 1, forming a $\Delta J = 1$ band based on the 641.2 keV $\frac{9}{2}^+$ state, has been previously reported [5–7] up to the $\frac{17}{2}^+$ state. An uncertain level at 2481.7 keV has been reported [5] as the next higher member depopulated by a 399.5 keV transition to the $\frac{17}{2}^+$ state of the band. No crossover transition has been reported from the proposed 2481.7 keV state. A search for the transitions populating the $\frac{17}{2}^+$ state of the band in the present work does not show any evidence of the 399.5 keV transition. The present work shows, however, the next higher level of this band at 2500.8 keV, which depopulates via two new cascade and crossover transitions of 419.0 and 810.5 keV, respectively. The doubly placed 766.4 keV transition appears in this band as the $\frac{17}{2}^+ \rightarrow \frac{13}{2}^+$ transition.

The levels and transitions shown on the left and right of band (F) include a few levels which were previously reported to be uncertain [5]. They are all observed in the present work in good agreement with the results of Ref. [5]. In addition, the present work shows a new transition at 423.8 keV which populates the 2016.0 keV level, which in turn decays to the $\Delta J = 1$ band mentioned above.

The energy gate on the 343.1 keV ($\frac{13}{2}^+ \rightarrow \frac{11}{2}^+$) transition given in Fig. 4(a) shows the above-mentioned new transitions of 419.0, 810.5, and 423.8 keV, as well as various other transitions associated with the $\Delta J = 1$ band (F). A part of the spectrum of Fig. 4(a) is shown on an expanded scale in Fig. 4(b) for clear display of the region of closely spaced lines.

The A_2/A_0 and A_4/A_0 values of the angular distributions given in Table I from the present work are, in general, in good agreement with the corresponding results for the previously known transitions given in Ref. [5,7]. A new transition at 856.3 keV, placed in sequence (C) of Fig. 1, shows a large positive A_2/A_0 value indicating the quadrupole nature of this transition. Similarly, the 889.6 keV transition of sequence (B), previously reported with uncertain placement, is found to be a quadrupole. The A_2/A_0 and A_4/A_0 values for the 766.4 keV unresolved doublet show characteristics of a stretched quadrupole transition. As mentioned earlier, a major component of its intensity arises from the decay of a new level at 1437.2 keV. In view of this fact, the corresponding 766.4 keV transition from the stated level is shown to be a quadrupole. It is assigned an $E2$ multipolarity considering its competition with the other new transitions observed from the same level. The second component of the 766.4 keV doublet arising from the decay of the

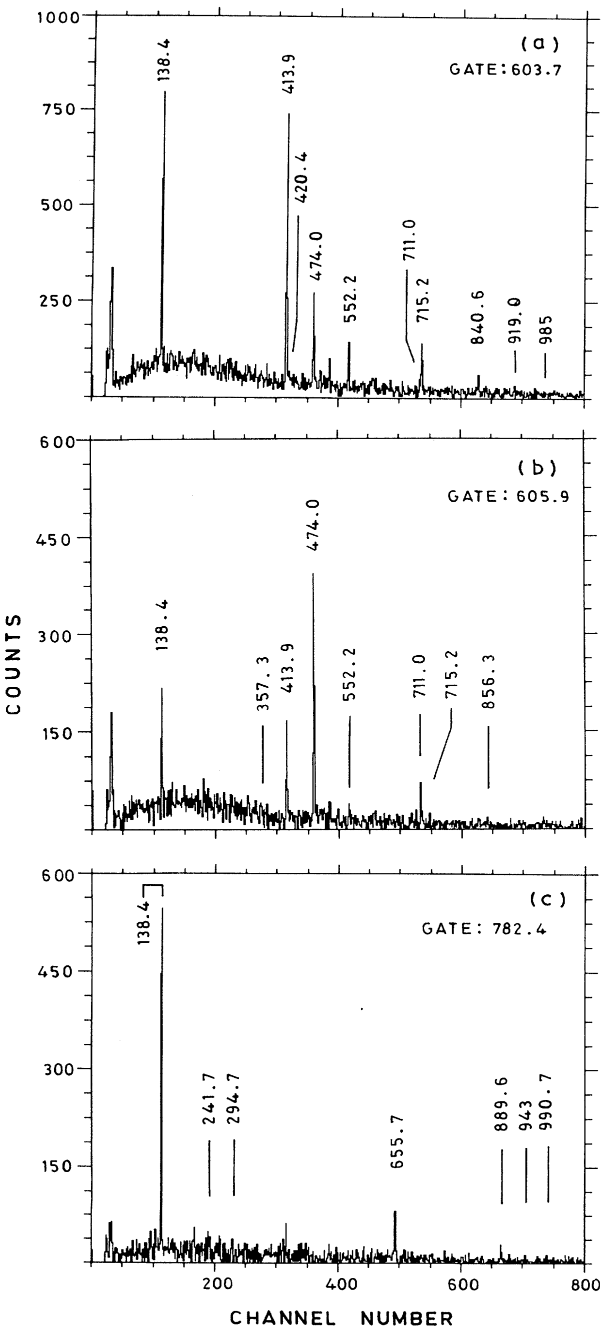

FIG. 2. Coincidence spectra showing gamma rays of ^{123}I with gates on (a) 603.7, (b) 605.9, and (c) 782.4 keV transitions, belonging to the sequences (A), (C), and (B) in the decay scheme of Fig. 1. The energies are given in keV.

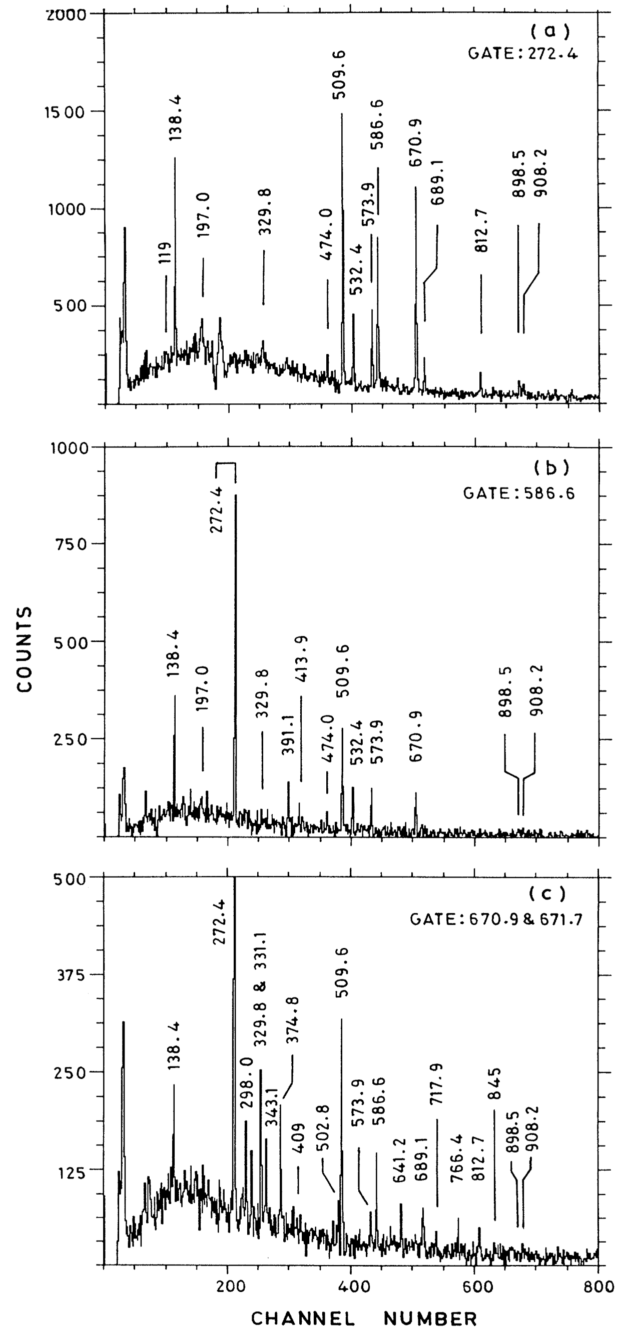

FIG. 3. Coincidence spectra showing the gamma-ray transitions associated with the negative parity levels, as well as other transitions in ^{123}I with gates on (a) 272.4, (b) 586.6, and (c) 670.9 and 671.7 keV.

2081.8 keV level was assigned as $E2$ in a previous report [7]. This assignment is also supported by theoretical considerations of the characteristics of the $\Delta J = 1$ band based on the 641.2 keV $\frac{9}{2}^+$ state.

The 419.0 keV transition assigned to band (F) in this work is found to be a dipole from angular distribution measurements. The transitions belonging to the $\Delta J = 1$ cascade of band (F) show small A_2/A_0 values implying a positive $E2/M1$ mixing ratio for these transitions. The $E2/M1$ mixing ratios for the stronger members of this cascade, viz., 331.1, 343.1, and 374.8 keV, are found to be $\sim +0.2$, in fair agreement with the previously reported results [7].

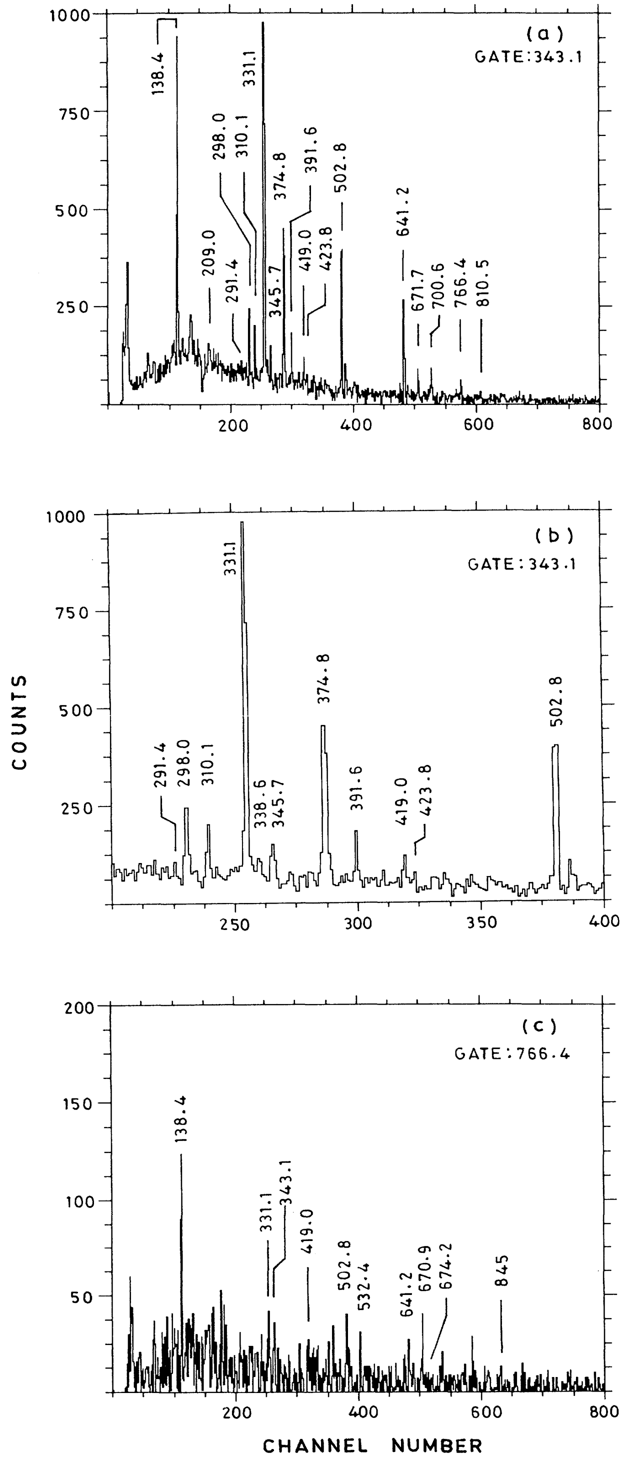

FIG. 4. Coincidence spectra with gates on (a), (b) 343.1 and (c) 766.4 keV gamma rays of ^{123}I. A part of the spectrum in (a) having close-lying lines is displayed on an expanded scale in (b).

IV. DISCUSSION

Odd-mass iodine nuclei with proton Fermi surface near the $Z = 50$ closed shell are predicted to be soft against deformation [5]. The deformation softness of these transitional nuclei makes them sensitive to various effects associated with shape variations. A consequence of the softness of these nuclei is the significant variation of the deformation with the odd particle occupying different orbitals. The Nilsson diagram for protons in this region of nuclei shows negatively sloping orbitals at both prolate and oblate shapes. The positive-parity $\pi d_{5/2}$ and $\pi g_{7/2}$ proton orbitals with small oblate deformation give rise to the low-lying positive-parity states. The calculations [8] of the low-lying single quasiparticle states for I isotopes at both prolate and oblate deformations within the Strutinsky formalism using a Woods-Saxon potential show that for neutron number $N > 66$ the oblate states for the $\pi d_{5/2}$ and $\pi g_{7/2}$ orbitals are lower than the related prolate states, and the ground-state configuration is predicted to involve these orbitals with small oblate deformation. Two high-Ω Nilsson orbitals near the Fermi surface which contribute to this configuration are the $\pi d_{5/2}[402]\frac{5}{2}^+$ and $\pi g_{7/2}[404]\frac{7}{2}^+$ orbitals with oblate deformation. The unique parity $\pi h_{11/2}[550]\frac{1}{2}^-$ intruder orbital gives rise to a low-lying $\frac{11}{2}^-$ state with prolate deformation. The $\Delta J = 2$ sequences of quadrupole transitions terminating on the first $\frac{5}{2}^+$ (g.s.), $\frac{7}{2}^+$, and $\frac{11}{2}^-$ states in ^{123}I, labeled (A), (B), and (E) in Fig. 1, may be interpreted [5,7] as "decoupled bands" resulting from the coupling of the odd particle in the $d_{5/2}$, $g_{7/2}$, or $h_{11/2}$ orbital, with the collective motion of the core. This interpretation is based on the observation that the transition energies in these sequences are fairly close to the corresponding energy-level separations in the ^{122}Te core. However, the agreement is not as good in the case of the positive-parity sequences (A) and (B) as for the negative-parity sequence (E). This difference is understandable in view of the fact that the decoupled bandlike structure can be best achieved with the odd particle in a high-j orbital such as $h_{11/2}$, with its angular momentum aligned with that of the core. The positive-parity sequences (A) and (B) in ^{123}I can be interpreted alternatively by considering the neighboring odd-mass iodine isotope ^{121}I. In a recent work [8] on the structure of ^{121}I, $\Delta J = 2$ sequences of quadrupole transitions between positive-parity states, ending on the first $\frac{5}{2}^+$ and $\frac{7}{2}^+$ states, closely similar to the sequences (A) and (B) in ^{123}I, have been observed along with interconnecting $\Delta J = 1$ dipole transitions between the lower members of the two sets of levels involved. These positive-parity levels in ^{121}I have been collectively interpreted as forming a $\Delta J = 1$ band based on the $\frac{5}{2}^+$ ground state with oblate deformation. By analogy, the corresponding positive-parity levels belonging to sequences (A) and (B) in ^{123}I, with new $\Delta J=1$ transitions observed in the present work, may also be interpreted as forming together a $\Delta J=1$ band in view of their strikingly close similarity to ^{121}I and the predicted [5,8] oblate deformation for the ground state of ^{123}I. The observed staggering in the energy-level spacings of this band is similar to that in ^{121}I, and may be explained as due to the mixing of the $d_{5/2}$ and $g_{7/2}$ configurations. It has been shown [8] that in this mass region the sign of the $E2/M1$ mixing ratio δ for the in-band $\Delta J=1$ transitions is directly related to the sign of the quadrupole moment. The experimental $E2/M1$ mixing ratios reported [7] for the $\frac{13}{2}^+\rightarrow\frac{11}{2}^+$, $\frac{9}{2}^+\rightarrow\frac{7}{2}^+$, and $\frac{7}{2}^+\rightarrow\frac{5}{2}^+$ transitions in this band in ^{123}I have a negative sign. Large negative A_2/A_0 coefficients in the angular distribution of the $\frac{9}{2}^+\rightarrow\frac{7}{2}^+$ and $\frac{7}{2}^+\rightarrow\frac{5}{2}^+$ transitions in the present work are also consistent with a negative $E2/M1$ mixing ratio for these transitions. This implies a negative sign of the quadrupole moment and hence supports the interpretation of the levels of sequences (A) and (B) in ^{123}I as forming a $\Delta J=1$ band with oblate deformation.

The $\Delta J=2$ sequence labeled (C) in Fig. 1 has been extended to the $\frac{19}{2}^+$ state with the observation of a new 856.3 keV ($\frac{19}{2}^+\rightarrow\frac{15}{2}^+$) transition with quadrupole assignment in the present work. The sequence (D) contains two new transitions at 766.4 and 845 keV. Although the multipolarity of the former transition is deduced to be a quadrupole in the present work, that of the latter could not be established. Two other new transitions, 357.3 keV ($\frac{13}{2}^+\rightarrow\frac{11}{2}^+$) and 409 keV ($\frac{11}{2}^+\rightarrow\frac{9}{2}^+$), form a $\Delta J=1$ cascade with the previously known transitions between the lower-lying states. There is a close resemblance of transition energies and spacings of the levels involved in the sequences (C) and (D) with those of the sequences (A) and (B). Thus there is an indication of another $\Delta J=1$ band involving the levels of the sequences (C) and (D). Proper interpretation of these levels, however, would require more experimental information regarding the higher members, multipole character of the 845 keV transition, and the mixing ratios for the $\Delta J=1$ transitions.

The sequence of levels labeled (F) in Fig. 1 includes a cascade of $\Delta J=1$ transitions, as well as $\Delta J=2$ crossover transitions. This sequence has been extended to the ($\frac{19}{2}^+$) state with the observation of new cascade as well as crossover transitions at 419.0 and 810.5 keV, respectively. On the basis of the deexcitation properties and the spacings of the levels, this sequence may be explained as a rotational structure built on a deformed $\frac{9}{2}^+$ state. From the Nilsson scheme a $\frac{9}{2}^+$ bandhead associated with the $\pi g_{9/2}[404]\frac{9}{2}^+$ proton-hole orbital with a prolate deformation of $\beta\sim0.2$ may be expected at low excitation energy [5,8]. Excitation of one proton from the pairwise filled $g_{9/2}$ proton orbital across the $Z=50$ gap gives rise to a strong tendency towards deformation, and leads to deformed minima in the potential energy of the nucleus [5]. The J^π assignment of $\frac{9}{2}^+$ to the 641.2 keV bandhead has been confirmed from the angular distribution measurements in the present work, which indicate the 502.8 keV transition to the first $\frac{7}{2}^+$ state and the strongly competing 641.2 keV crossover transition to the $\frac{5}{2}^+$ ground state to be dipole and quadrupole, respectively. The rotational interpretation of the band is supported by the angular distributions of the in-band transitions connecting the band members. These results are consistent with $J\rightarrow J-1$ $M1/E2$ cascade transitions corroborated by the systematic occurrence of $J\rightarrow J-2$ crossover transitions for which only an $E2$ can effectively compete. The small values of A_2/A_0 coefficients (close to zero) in the angular distributions of the 331.1 keV ($\frac{11}{2}^+\rightarrow\frac{9}{2}^+$), 343.1 keV ($\frac{13}{2}^+\rightarrow\frac{11}{2}^+$), and 374.8 keV ($\frac{15}{2}^+\rightarrow\frac{13}{2}^+$) transitions imply positive $E2/M1$ mixing ratios for these transitions and hence a prolate deformation for this band in agreement with the above interpretation. The small A_2/A_0 coefficient for the new 419.0 keV transition is also consistent with the observed characteristics of this band.

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