Spectroscopy of the ^{108}In nucleus*

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The γ rays following the β decay of 10.30-min ^{108}Sn and from the in-beam ^{108}Cd$(p,n)^{108}$In*(γ) reaction between 6.5 and 10 MeV have been studied in order to determine the properties of the low-lying levels of ^{108}In. Twenty-five γ rays attributed to ^{108}Sn decay were observed. A level scheme of ^{108}In was constructed which contains nine levels, of which only three were previously reported. Spin and parity values are assigned to each level based on angular distribution and excitation function measurements from the $(p,n\gamma)$ reaction and logft values from ^{108}Sn decay. The level properties of ^{108}In are compared to the levels of ^{94}Nb and interpreted within the framework of $j-j$ coupling.

[RADIOACTIVITY ^{108}Sn[from ^{106}Cd$(\alpha,2n)$], enriched target. Measured $t_{1/2}$, E_γ, I_γ, γ-γ coin; deduced ^{108}In levels, J, π, and logft values. Ge(Li) detectors, Ge(Li)-NaI(Tl) anti-Compton spectrometer.]

[NUCLEAR REACTIONS ^{108}Cd$(p,n)^{108}$In*(γ), E_p =6.5–10 MeV, enriched target. Measured E_γ, I, $I_\gamma(\theta)$; deduced ^{108}In levels, $\delta(E2/M1)$, J, π, branching fractions; Ge(Li) detectors, Ge(Li)-NaI(Tl) anti-Compton spectrometer.]

I. INTRODUCTION

The study of the low-lying levels in odd-odd nuclei can provide useful information about neutron-proton residual interactions. Experimental data on the levels of doubly even nuclei are plentiful but similar data for odd-odd nuclei in the mass region around $A \simeq 100$ are quite scarce. Prior to this work the only data on the level scheme of $^{108}_{49}$In$_{59}$ were contained in a brief report of the decay of ^{108}Sn by Kieselev and Burmistrov.[1] In that study five γ rays were observed to decay with a 10.5 ± 0.4-min half-life from an enriched (64%) ^{106}Cd target irradiated with 40-MeV α particles. A decay scheme was proposed for ^{108}In which contained three excited levels based on half-lives and energy summations. The ground state of ^{108}In was assigned as 2^+ which is in disagreement with the reported 3^+ in the later work of Flanagan *et al.*[2] Several inconsistencies exist in the early ^{108}Sn decay study[1] which makes the resultant ^{108}In level scheme questionable.[3]

In this work the level structure of ^{108}In was studied via γ-ray spectroscopy both from the decay of ^{108}Sn and the ^{108}Cd$(p,n)^{108}$In*(γ) reaction. The spin and parity of these levels were also determined on the basis of the estimated logft values in the ^{108}Sn decay study and the angular distributions and excitation functions of these γ rays observed in the in-beam reaction. The level properties are interpreted with the Brennan-Bernstein j-j coupling rules[4,5] and compared with the level properties of ^{94}Nb. During the course of this work Adigamov *et al.*[6] reported 12 γ rays decaying with a half-life of 10.5 min assigned to the decay of ^{108}Sn. Their results are in fair agreement with the γ-ray energy and intensity values from this work, however, no decay scheme was presented in their report.

II. EXPERIMENTAL PROCEDURES

A. Decay of 10.3-min ^{108}Sn

Sources of 10.3-min ^{108}Sn were produced via the ^{106}Cd$(\alpha,2n)$ reaction [$Q = -18.9$ MeV (Ref. 7)] by irradiating an enriched (95.5%) ^{106}Cd target with 30-MeV α particles using the external beam facility of the Washington University sector focused cyclotron. A helium-jet recoil transport system[8] was used to separate and transport the ^{108}Sn nuclei from the irradiation area to the counting site.

The γ-ray spectrum of ^{108}Sn was measured with an 11.7% Ge(Li) detector with energy resolution of 2.2 keV at 1332 keV. γ rays from ^{108}Sn decay were identified by determining the half-life of each line by recording multiple timed spectra from each source with a multichannel analyzer. The γ-ray spectrum recorded in the first 10 min after irradiation is shown in Fig. 1. The energies and intensities of the γ rays attributed to ^{108}Sn decay are listed in Table I. The half-life of ^{108}Sn was determined to be 10.30 ± 0.08 min from the weighted average of the half-lives of the 104.6-,

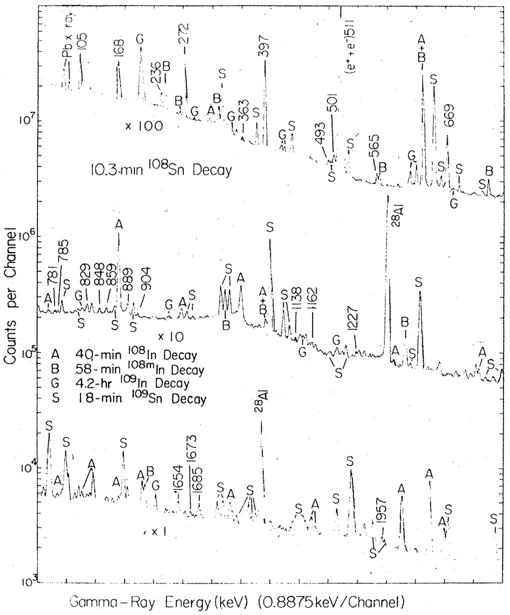

FIG. 1. The γ-ray spectrum of 10.3-min ^{108}Sn produced in 30-MeV α bombardment of ^{106}Cd. The peaks attributed to ^{108}Sn decay are labeled with γ-ray energy only.

167.8-, 272.4-, 396.5-, and 699.2-kev γ rays.

A γ-γ coincidence experiment was performed to aid in the construction of a complete decay scheme for ^{108}Sn. Two Ge(Li) detectors (5.3 and 11.7%) with 2.2-keV energy resolution were placed on opposite sides of the ^{108}Sn sources collected on the Mylar surface of the He-jet system. Standard crossover timing techniques were used and the two-parameter data were stored event by event in related address form on magnetic tapes using a Nuclear Data 50/50 multichannel analyzer. Approximately 2×10^7 events were recorded with a random coincidence rate of ~10%. The individual coincidence spectra were sorted off line with the program SCAN on the Washington University IBM 360/65 computer. The observed coincidence relationships from the decay of ^{108}Sn are summarized in Table II. The relative intensities given in parentheses in that table have been corrected for Compton background, random coincidences and detector efficiency. Several coincidence spectra are shown in Fig. 2. A decay scheme of ^{108}Sn shown in Fig. 3, was constructed on the basis of coincidence relationships as well as γ-ray energies and intensities.

TABLE I. Summary of level energies, γ-ray energies in keV, J^π values, and relative intensities for transitions observed in the 10.3-min ^{108}Sn decay and in the ^{108}Cd$(p,n)^{108}$In$^*(\gamma)$ reaction ($E_p = 8$ MeV).

E_γ	$E_i \to E_f$	^{108}Sn I_γ[a]	$(p,n\gamma)$ I_γ[b]	Ref. 1 E_γ	Ref. 1 I_γ	Ref. 5 E_γ	Ref. 5 I_γ	$J_i^\pi \to J_f^\pi$
104.6 4[c]	272.4 → 167.8	21.5 7	16.8 5	103.5 7	20 1	104.0 3	70 7	$2^+ \to 2^+$
167.8 3	167.8 → 0.0	31.0 6	100 7	168.0 7	36 2	168.6 3	100	$2^+ \to 3^+$
235.7 2	235.7 → 0.0	9.7 4	80.7 10			236.0 3	34 2	$(2-4)^+ \to 3^+$
272.4 3	272.4 → 0.0	70.8 10	52.2 6	271.3 7	67 3	272.6 3	214 13	$2^+ \to 3^+$
363.0 3		1.1 3						
396.5 2	669.2 → 272.4	100 1	20.9 5	399.8 7	100	397.1 3	308 15	$1^+ \to 2^+$
492.8 2	1161.7 → 669.2	1.6 3	1.4 3			493 1	3.8 7	$1^+ \to 1^+$
498.3 3			18.8 5					
501.4 7	669.2 → 167.8	2.7 2	1.1			501 1	4.2 4	$1^+ \to 2^+$
565.2 4	565.2 → 0.0	3.0 4	17.0 9			565 1	6.2 6	$1^+ \to 3^+$
669.2 4	669.2 → 0.0	35.1 6	8.4 5	669.5 7	27 1	669.5 5	84 4	$1^+ \to 3^+$
829.3 5		5.7 6						
847.6 4	847.6 → 0.0	3.3 8	6.6 14					
858.7 6		4.0 10						
889.1 5	1161.7 → 272.4	5.1 5	3.6 5			890 1	7.2 12	$1^+ \to 2^+$
903.5 6		1.0 2						
1161.7 5	1161.7 → 0.0	1.4 4	1.1 3			1162 2	7.4 10	$1^+ \to 3^+$
1231.0 5		1.0 2						
1654.4 5	1926.8 → 0.0	2.8 3						$0^+, 1^+ \to 2^+$
1684.8 6	1957.2 → 272.4	4.3 5						$1^+ \to 2^+$
1957.2 6	1957.2 → 0.0	1.2 3						$1^+ \to 3^+$

[a]Intensity of γ rays relative to 396.5 keV taken as 100 in the ^{108}Sn decay.

[b]Intensity of γ rays relative to 167.8 keV taken as 100 at 8-MeV proton bombardment. Intensities have been corrected for angular correlation effects.

[c]The underlined numbers in each column are estimated uncertainties in the last quoted significant figures.

TABLE II. Summary of γ-, coincidence relationships and relative intensities of coincident γ rays observed in the decay of 10.3-min ^{108}Sn. Numbers in parentheses represent relative intensities and their uncertainties.

γ ray in the gate (keV)	γ-ray energies in keV and relative intensities observed in the Ge(Li) coincidence spectrum [a]
168	105(18 6), 397(16 5), 501(2 1), 889(3 1)
236	397(3 1)
272	397(85 4), 493(2 2), 889(7 2), 1654(2 1), 1685(4 1)
397	105(13 4), 168(15 3), 236(6 3)[b], 272(50 4), 493(2 1)
889	105(3 1), 168(4 1), 273(8 3)

[a] Relative intensities within each gate have been corrected for the efficiency of the gate detector and random coincidences. All intensities are given in arbitrary units.

[b] The placement of 36.7-keV transition between the 272.4- and 235.7-keV levels is based on this coincidence relationship.

B. ^{108}Cd$(p,n)^{108}$In$^*(\gamma)$ reaction spectroscopy

In order to gain more information on the levels populated in ^{108}Sn decay, the levels of ^{108}In were also studied via in-beam ^{108}Cd$(p,n)^{108}$In$^*(\gamma)$ [$\theta = 5.93$ MeV (Ref. 7)] γ-ray spectroscopy. A self-supporting metallic cadmium target (1.4 mg/cm^2) 73.7% enriched in ^{108}Cd was used for this experiment. Because the target contained a large fraction of impurity cadium isotopes, the γ-ray spectra obtained were complicated with transitions resulting from reactions other than the one of interest. Therefore only those γ rays identified in the ^{108}Sn decay were examined in this work. Excitation function measurements between 6.5 and 10 MeV were made using an anti-Compton spectrometer[9] positioned at 55° relative to the beam direction. The spectrometer consisted of a 6.7% Ge(Li) detector with 1.9-keV energy resolution and a NaI(Tl) annulus operated in anticoincidence. A γ-ray spectrum taken at 8-MeV proton bombardment is shown in Fig. 4. The intensities of the

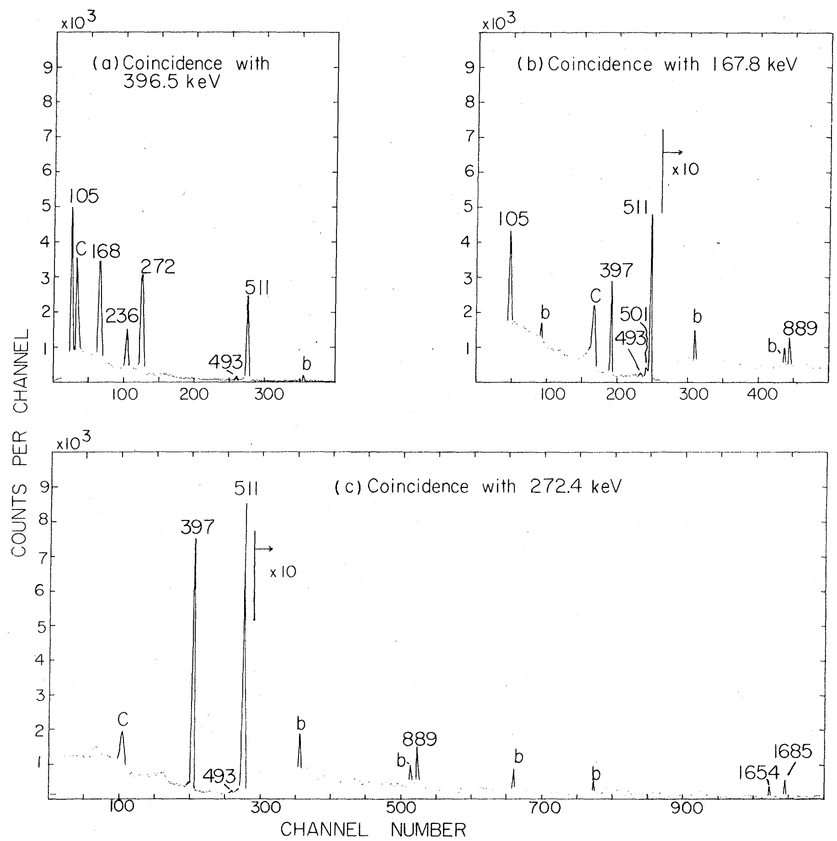

FIG. 2. γ-ray spectra in coincidence with (a) 167.8-, (b) 396.5-, and (c) 272.4-keV γ rays in the decay of ^{108}Sn. Peaks labeled b and c denote background γ rays and backscattering from the 511-keV annihilation radiation, respectively.

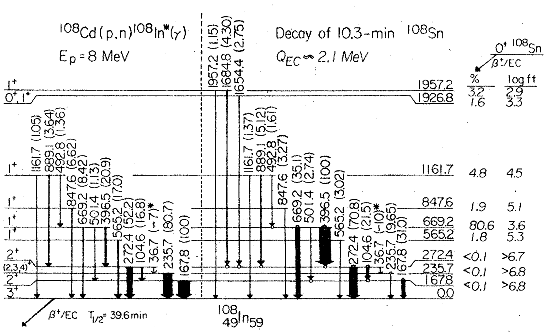

FIG. 3. Proposed level scheme of ^{108}In. γ-ray and level energies and given in keV. The right half of the figure shows the transitions following the β decay of ^{108}Sn. γ-ray intensities in parentheses are relative to the 396.5-keV γ ray taken as 100. The transitions observed in the ^{108}Cd(p, $n\gamma$) reaction at E_p = 8 MeV are shown on the left portion of the figure with γ-ray intensities relative to the 167.8-keV γ ray taken as 100. The intensity of the 36.7-keV transition (labeled with *) was estimated on the basis of coincidence information.

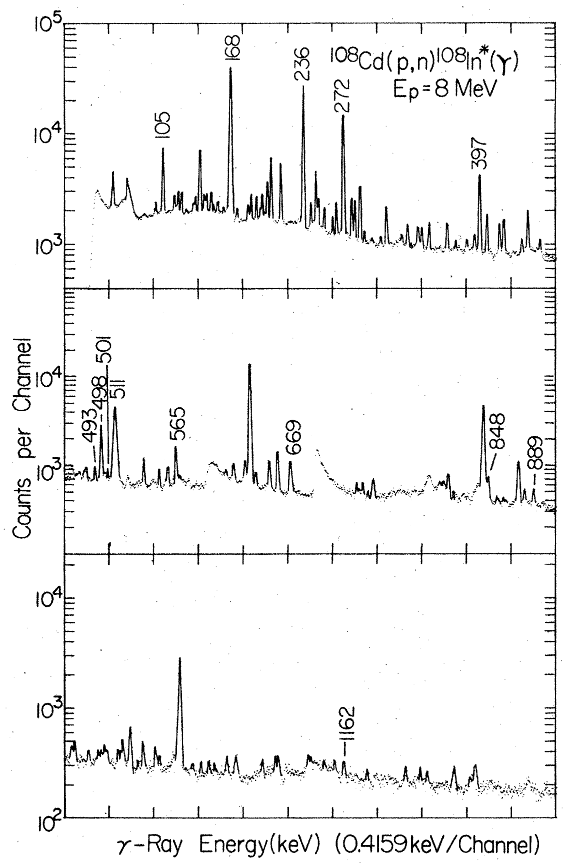

FIG. 4. Anti-Compton γ-ray spectrum obtained in the ^{108}Cd(p, n)^{108}In*(γ) reaction at a proton bombarding energy of 8 MeV and an emission angle of 55°. Peaks attributed to ^{108}In are labeled with the γ-ray energy in keV.

observed γ-ray transitions of ^{108}In in an 8-MeV proton bombardment are given in Table I. The relative excitation function of each level is also shown in Fig. 5 plotted relative to the 167.8-keV level. When several γ rays were observed to deexcite a level, they were found in all cases to have similar excitation functions. These excitation functions give strong evidence for the suggested level sequences as shown in Fig. 4. For example, the appearance of the 565.2- and 847.6-keV γ rays at 7-MeV bombardment but not at 6.5 MeV suggests the existence of two levels with those energies. γ-ray angular distribution measurements at 8 MeV were performed at seven angles between 20° and 90° relative to the beam direction using the anti-Compton spectrometer. γ-ray intensities were normalized to the intensity of the 167.8-keV γ ray measured with a second Ge(Li) detector positioned at 270° relative to the beam direction. The outputs of two pulse generators were separately sent to the monitoring Ge(Li) detector and the anti-Compton spectrometer to correct for system dead time losses. The measured distributions were analyzed by a least squares fit to the data using Eq. (1) below:

$$W(\theta_d) = A_0[1 + A_2Q_2P_2(\cos\theta_d) + A_4Q_4P_4(\cos\theta_d)] . \quad (1)$$

The coefficients A_2 and A_4 can be expressed as

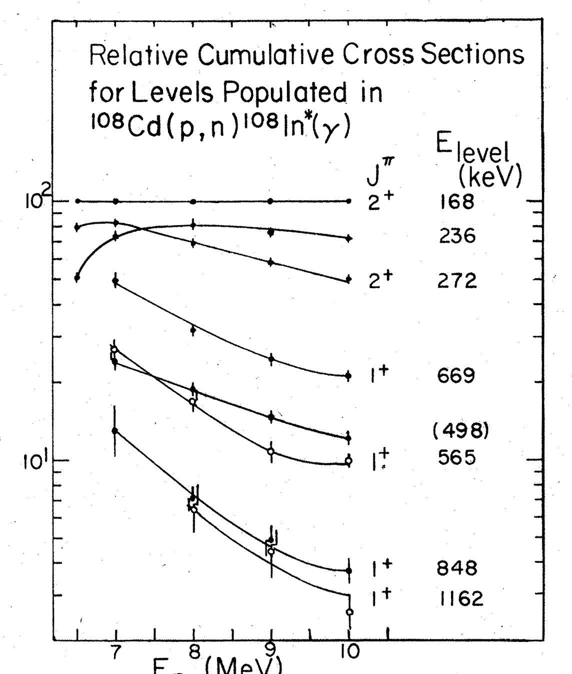

FIG. 5. Excitation functions for the cumulative formation of levels in ^{108}In populated by the ^{108}Cd(p, n)^{108}*(γ) reaction plotted relative to the 2⁺ level at 167.8 keV.

$$A_k(J_1, J_2, \delta) = B_k(J_1)\,\frac{R_k(LLJ_1J_2) + 2\delta R_k(LL'J_1J_2) + \delta^2 R_k(L'L'J_1J_2)}{1+\delta^2}\,, \tag{2}$$

where $B_k(J_1)$ is related to the population parameter for the magnetic substate via the statistical tensor coefficients $\rho_k(J_1M_1)$ as described by Rose and Brink.[10] The $B_k(J_1)$ coefficients were computed using the Hauser-Feshbach theory[11] for nuclear reactions by means of the computer program MANDYS.[12] The proton transmission coefficients required for this calculation were taken from the compilation of Mani, Melkanoff, and Lori[13] and the neutron transmission coefficients were taken from Auerbach and Perey.[14] The phase convention and the tables of Rose and Brink were used for the R_k coefficients. Minimum χ^2 values as a function of δ were determined for each possible spin sequence for a given transition. The resultant A_2, A_4, δ, and χ^2 values are given in Table III. Alternative spin sequences were rejected at the 99% confidence level.[16] The errors quoted for the δ values obtained from this analysis refer to 68% confidence interval by the method outlined by James, Twin, and Butler.[17] The measured angular distributions are shown in Fig. 6. The curve computed using Eq. (2) for the indicated spin sequence with minimum χ^2 is also shown in this figure. These data were useful in determining level spin and parity values as described below.

III. CONSTRUCTION OF THE LEVEL SCHEME AND J^π ASSIGNMENTS

The proposed decay scheme of ^{108}Sn and the level scheme of ^{108}In populated in an 8-MeV proton bombardment are shown in Fig. 3. Log*ft* values, J^π values, and transition multipolarities were also assigned to each proposed level. The log*ft* values were calculated using the tabulations of Gove and Martin.[18] A value of 2100 keV for Q_{EC}, taken from the Wapstra and Gove mass tables,[19] and the intensity balance for each level were used in the calculation of the log*ft* values. The arguments supporting the proposed decay scheme and J^π assignments are summarized below.

39.6-min ^{108}In β-decaying state. ^{108}In has two low-lying $\beta\beta$ decaying states with half-lives of 39.6 and 58 min. It is not known which is the ^{108}In ground state. From this work we conclude that only the 39.6-min state of ^{108}In is populated in the decay of ^{108}Sn. This conclusion is based on the growth of a 10-min component in the decay curves of the 969- and 1529-keV γ rays which follow the decay of the 39.6-min state. On the other hand the 1057-keV γ ray from ^{108}In decay shows a pure 58-min half-life indicating that the 58-min ^{108}In state is not popu-

TABLE III. Summary of angular distribution coefficients, multiple mixing ratios, J^π values, and α_T values for transitions in ^{108}In following the ^{108}Cd$(p,n)^{108}$In$^*(\gamma)$ reactions at a proton energy of 8 MeV.

E_γ	$E_i \to E_f$	$J_i^\pi \to J_f^\pi$	A_2[a]	A_4[a]	$\delta(E2/M1)$[b]	α_T[c]	χ^2_{min}	I_{total}[d]
104.6 4[e]	272.4 → 167.8	$1^+ \to 2^+$	−0.04 1	0.00	-1.4^{+11}_{-53}	1.01	3.1	43.2 14
		$2^+ \to 2^+$	−0.13 3	−0.02 1	0.7^{+15}_{-8}	0.61	1.5	34.6 10
167.8 3	167.8 → 0.0	$2^+ \to 3^+$	−0.11 2	0.00	$M1$	0.17	1.5	36.3 7
		$3^+ \to 3^+$	−0.11 2	−0.04 2	14.3^{+160}_{-24}	0.24	2.0	38.4 7
235.7 4	235.7 → 0.0	$2^+ \to 3^+$	−0.10 1	0.00	−0.21 4	0.05	0.66	10.2 4
		$3^+ \to 3^+$	−0.11 1	−0.02 4	0.82 6	0.08	0.81	10.5 4
		$4^+ \to 3^+$	−0.11 1	0.00	$M1$	0.05	0.71	10.2 4
272.4 3	272.4 → 0.0	$1^+ \to 3^+$	0.02 1	0.00	0.49^{+41}_{-36}	0.04	1.44	73.6 10
		$2^+ \to 3^+$	0.05 1	0.01 1	2.25 24	0.04	0.42	73.6 10
396.5 2	669.2 → 272.4	$1^+ \to 2^+$	−0.07 1	0.00	-0.4^{+6}_{-11}	0.01	1.40	101 1
492.8 2	1161.7 → 669.2	$1^+ \to 1^+$	−0.08 9	0.00	0.53 8		0.14	
669.2 4	669.2 → 0.0	$1^+ \to 3^+$	0.03 2	0.00	$E2$		0.78	
889.1 5	1161.7 → 272.4	$1^+ \to 2^+$	−0.10 4	0.00	-1.33^{+75}_{-167}		0.64	
1161.7 5	1161.7 → 0.0	$1^+ \to 3^+$	0.04 3	0.00	$E2$		0.41	

[a] Uncertainties in A_2 and A_4 obtained from ACORNI program.
[b] Uncertainties in δ values estimated on the basis of 68% confidence level by James *et al.* (Ref. 17).
[c] Estimated based on the obtained δ values and the α_T values from Ref. 26.
[d] The total transition intensity after correcting for conversion electron emission in the decay of 10.3-min ^{108}Sn.
[e] The underlined numbers in each column are estimated uncertainties in the last quoted significant figures.

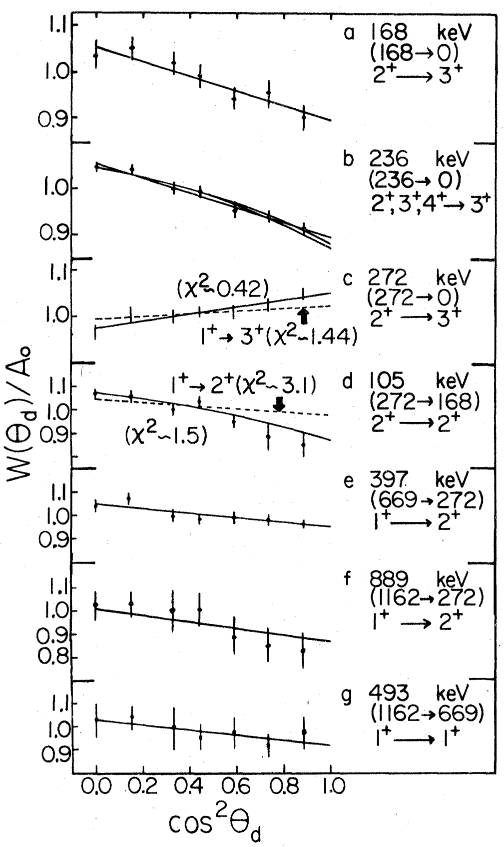

FIG. 6. Single γ-ray angular distributions for transitions in ^{108}In following the ^{108}Cd$(p,n)^{108}$In$^*(\gamma)$ reaction at 8-MeV proton. The solid curves are the theoretical distributions which gave minimum χ^2 fit to the data for the indicated spin sequence.

lated in the β decay of ^{108}Sn. The 39.6-min ^{108}In has been assigned[2] $J^{\pi}=3^+$ based on the fact that it decays to both the 2^+ 633- and 4^+ 1509-keV levels in ^{108}Cd with logft values of 6.4 and 7.1, respectively.

167.8-keV level. The existence of the 167.8-keV level is established on the basis of the coincidence relationships, energy sums, and the fact that the 167.8-keV γ ray has the highest intensity observed in the $(p,n\gamma)$ reaction. This level is assigned a J^{π} of 2^+ based on the angular distribution of the 167.8-keV transition observed in the $(p,n\gamma)$ reaction which is only consistent with a $2^+\rightarrow 3^+$ transition with predominantly $M1$ character (~2% $E2$). The $3^+\rightarrow 3^+$ spin sequence is ruled out due to the large δ value (14.3) obtained. The spin value of 4 is eliminated on the basis of the observed crossover transition of 501.4 keV from the 1^+ 669.2-keV level (the assignment of this level is discussed later) to the 167.8-keV level. The 2^+ assignment of this level is in disagreement with the tentative 3^+ assignment of Ref. 1.

235.7-keV level. The large relative intensity of the 235.7-keV γ ray in the $(p,n\gamma)$ reaction and the lack of coincidence events between this γ ray and more intense γ rays indicate the existence of a level at 235.7 keV. This level is assigned $(2^+,3^+,4^+)$ on the basis of the large $M1$ character of the angular distribution of the 235.7-keV γ ray. This assignment is also in agreement with the reported α_k value[6] (0.041 ± 0.009) for this transition which corresponds to an $M1$ or $M1+E2$ transition.

272.4/keV level. This level is established on the basis of the observed strong coincidence between 104.6- and 167.8-keV γ rays and the existence of an intense 272.4-keV γ ray. This level is assigned as 2^+ on the basis of the angular distribution of the 104.6- and 272.4-keV transitions. The angular distribution of the 104.6-keV γ ray indicated that this transition has an $M1+[(32\pm25)\%\ E2]$ multipole admixture which is in disagreement with the proposed $E2$ multipolarity in Ref. 1. The total intensity of the 104.6-keV transition after correcting for internal conversion is equal within error to the total intensity of the 167.8-keV transition after correcting for internal conversion. A 36.7-keV transition is proposed depopulating this level on the basis of the observed coincidence between the 235.7- and 396.5-keV γ rays. The intensity of this 36.7-keV transition is estimated as ~10% (relative to that of the 396.5-keV γ ray in ^{108}Sn decay) on the basis of the intensities of the 272.4- and 235.7-keV γ rays in coincidence with the 396.5-keV γ ray.

The direct β^+/EC population of the 167.8-, 235.7-, and 272.4-keV levels is estimated to be less than 0.1% on the basis of the intensity balance of each level. Thus the logft values are estimated to be greater than 6.7 which is typical for a second-forbidden nonunique transition $(\Delta J=2,\ \Delta\pi=\text{no})$.[20]

565.2-, 669.2-, 847.6-, *and* 1161.7-keV *levels.* The 565.2- and 847.6-keV levels are proposed based on the lack of coincidences with the 565.2- and 847.6-keV transitions and the observation of a threshold for these transitions in the $(p,n\gamma)$ reaction at 7 MeV (~1 MeV above threshold for ^{108}In ground state formation). The 669.2- and 1161.7-keV levels are established on the basis of coincidence information. All four levels were assigned spin and parity of 1^+ on the basis of logft values ≤ 5.3 and in each case a transition to the 3^+ β decaying state.

1926.8- and 1957.2-keV levels. The existence of these two levels is based on coincidence information and the existence of a 1957.2-keV γ ray. The logft values for these levels limit the J^{π} assignments to 0^+ or 1^+ and 1^+, respectively.

The 10 levels assigned in this work were observed in the ^{108}Sn decay and the in-beam $(p,n\gamma)$

reaction studies. Only four of these levels were assigned in Ref. 1 and most of those results are in disagreement with our observations. There are nine weak γ rays observed with half-lives within 10 ± 3 min in the decay of ^{108}Sn which cannot be incorporated in the proposed decay scheme. A strong 498.2-keV γ ray observed in the in-beam $(p, n\gamma)$ reaction has similar excitation function with most other levels (Fig. 5). This indicates that a 498.2-keV level may exist in ^{108}In; however, no definite assignment can be made.

IV. DISCUSSION

The low-lying level structure of ^{108}In studied in this work is of interest because the relatively simple odd-odd nucleon configurations make it possible to interpret these levels with simple neutron-proton residual interactions. An examination of the ground state of odd-mass indium nuclei reveals that each has a spin and parity of $\frac{9}{2}^+$ arising from the $(g_{9/2})^{-1}$ proton configuration.[21] The situation is not quite so clearcut for the neutron configurations. For $N > 50$ one expects the $2d_{5/2}$ and $1g_{7/2}$ shell model orbitals to be filled. All of the odd-mass $N = 51$, 53, and 55 nuclei have ground-state spins and parities of $\frac{5}{2}^+$. Although it is expected that the $d_{5/2}$ subshell will be full at $N = 56$, odd Pd and Cd nuclei with $N = 57$, 59, or 61 also have ground states with $J^\pi = \frac{5}{2}^+$. This suggests that the pairing energy is very large for the $1g_{7/2}$ neutrons, and hence the low-lying states in ^{108}In and ^{110}In may have a neutron configuration of $(d_{5/2})^{-3}$ and $(d_{5/2})^{-1}$, respectively. The spins and parities of the two β decaying states in ^{110}In were measured to be 2^+ and 7^+ (Ref. 22) which agree with the prediction of the Nordheim[4,5] rules assuming a $(\pi g_{9/2})^{-1}(\nu d_{5/2})^{-1}$ configuration. The Nordheim rule 2 predicts that the lowest-lying states in a hole-hole configuration will be a closely spaced doublet with spins given by $J = j_p \pm j_n$. Other members of the multiplet with $J^\pi = 3^+$, 4^+, 5^+, and 6^+ are also expected from this coupling at slightly higher energies. Little is known about the low-lying levels in ^{110}In so no comparison can be made in this work.

In ^{108}In, the situation is more complex. The three neutron holes in the $2d_{5/2}$ orbital can couple to give neutron configurations with $J = \frac{5}{2}$, $\frac{3}{2}$, and $\frac{9}{2}$. Each of these configurations may in turn couple with the $g_{9/2}$ proton hole giving rise to 6, 4, and 10 states, respectively. Hence a total of 20 low-lying levels will be expected in ^{108}In due to this $(\pi g_{9/2})^{-1}(\nu d_{5/2})^{-3}$ configuration. The spin and parity of the two β decaying states in ^{108}In were determined to be 3^+ and 5^+ or 6^+ in Ref. 2. These J^π values are predicted[3,4] for the configuration $(\pi g_{9/2})^{-1} \times [(\nu d_{5/2})^{-3}{}_{3/2+}]$. Furthermore, the 3^+ state is predicted to be the ^{108}In ground state. More information on high spin low-lying levels of ^{108}In is needed to make further comparisons with the 20 low-lying levels expected from j-j coupling.

An alternative approach is to compare the levels in the hole-hole system with the levels in the corresponding nucleon-nucleon system as carried out by Pandya on ^{38}Cl and ^{40}K.[23] The nucleon-nucleon system equivalent to that of ^{108}In is $^{94}_{41}$Nb$_{53}$ where the low-lying states are thought to be due to the $(\pi g_{9/2})^1(\nu g_{5/2})^3$ configuration. Experimental level energies and J^π values for the low-lying levels in ^{94}Nb are in good agreement with the calculations performed by Bhatt and Ball[24] and Vervier[25] by the use of effective interactions. Comparison of calculated and experimentally observed levels in ^{94}Nb and the observed levels of ^{108}In in this work is shown in Fig. 7. It is clear from this figure that there is a close correspondence between the levels of the nucleon-nucleon and hole-hole configurations, and that the two β decaying states in ^{108}In are due to the same configurations as the low-lying states in ^{94}Nb. Low-lying 4^+, 7^+, and 5^+ states observed in ^{94}Nb are also expected in ^{108}In, however, these levels will not be populated in the 0^+ ground state decay of ^{108}Sn. The energy spacing between 3^+ and 6^+ states in ^{108}In is rather small compared with that in ^{94}Nb which suggests that the p-n residual interaction is smaller in ^{108}In than that in ^{94}Nb. Therefore one would expect levels with similar configurations to be at a lower energy in ^{108}In than in ^{94}Nb. Based on this assumption, the low-lying

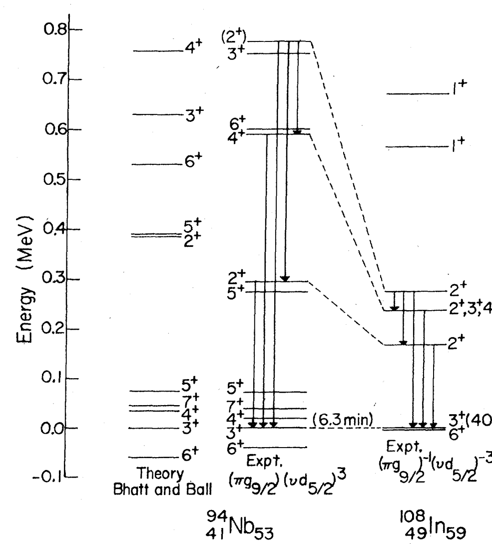

FIG. 7. Comparison of the level structure of ^{108}In with that of ^{94}Nb. The dotted lines indicate the levels with similar configuration. The level energies of both nuclei are normalized to the first 3^+ level.

levels in ^{108}In can be qualitatively interpreted with the j-j coupling configurations of the corresponding levels in ^{94}Nb.

The 39.6-min 3^+ state is analogous to the 6.3-min 3^+ 41-keV isomeric state in ^{94}Nb. Examination of the wave function[27,28] of the 3^+ state in ^{94}Nb indicates that this state consists of 70% $(\nu d_{5/2})^3{}_{5/2^+}$ and 30% $(\nu_{5/2})^3{}_{3/2^+}$ configuration [the proton configuration of $(\pi g_{9/2})$ was used in these cases].

The 2^+ 167.8-keV level may correspond to the 2^+ 334-keV level in ^{94}Nb. Each of these 2^+ levels populate the 3^+ state via a strong $M1$ transition. The wave function of the 334-keV level contains only the $(\nu d_{5/2})^3{}_{5/2^+}$ configuration.[27,28] Thus the 167.8-keV level is expected to contain mainly the $(\nu d_{5/2})^{-3}{}_{5/2^+}$ configuration also.

The 2^+, 3^+, or 4^+ 235.7-keV level may correspond to the 4^+ 632-keV level in ^{94}Nb. The wave function of the 632-keV level consists of 70% $(\nu d_{5/2})^3{}_{3/2^+}$ and 30% $(\nu d_{5/2})^3{}_{5/2^+}$ configuration. The (3^+) 818-keV level in ^{94}Nb may correspond to the 2^+ 272.4-keV level in ^{108}In. Both levels have similar γ-ray decay. The 1^+ 565.2- and 669.2-keV levels in ^{108}In may have the $(\pi g_{9/2})^{-1}[(\nu d_{5/2})^{-3}{}_{9/2^+}]$ configuration. No similar levels have been identified in ^{94}Nb and therefore no conclusion can be drawn about these levels.

The low-lying levels of ^{108}In observed in this work are qualitatively interpreted with the j-j coupling model and by comparison with the corresponding levels in ^{94}Nb. The 3^+ and 6^+ states in both nuclei are predicted on the basis of the $(\pi g_{9/2})^{-1}(\nu d_{5/2})^{-3}$ and $(\pi g_{9/2})(\nu d_{5/2})^3$ configurations, respectively. The level properties of the 167.8-, 235.7-, and 272.4-keV levels in ^{108}In are also quite similar to that of the 2^+, 4^+, and (3^+) levels in ^{94}Nb, hence the same coupling configurations are used in this work to interpret these levels. It is not possible to comment further on the low-lying levels in ^{108}In until the higher-spin levels are characterized.

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