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Parity determinations in $^{105-109}$Cd from linearly polarized gamma rays following (^{16}O, xn) reactions

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The linear polarization of γ rays from the deexcitation of Cd isotopes $A = 105$ through 109 following (^{16}O,xn) reactions were measured using a Ge(Li) Compton polarimeter. The linear polarizations are used with γ-ray angular distributions to make unique-parity assignments and to remove ambiguity in angular-momentum values. With these measurements it is possible to identify many states in $^{105-109}$Cd which are similar to states in Pd nuclei that have been interpreted as having one, two, or three quasiparticles coupled to a slightly deformed rotating core.

[NUCLEAR REACTIONS ^{92}Zr(^{16}O, $3n\gamma$), E = 58 MeV; ^{94}Zr(^{16}O, $4n\gamma$), E = 63 MeV; ^{94}Zr(^{16}O, $3n\gamma$), E = 59 MeV; ^{96}Zr(^{16}O, $4n\gamma$), E = 56 MeV; ^{96}Zr(^{16}O, $3n\gamma$), E = 56 MeV. Linear polarization of $^{105-106}$Cd γ rays measured.]

I. INTRODUCTION

The present studies of Cd continue the investigation of the transitional region ($Z < 50, N > 50$) where linear polarization results have recently been reported on Cd ($Z = 48, A = 110$) (Ref. 1) and on Pd nuclei ($Z = 46, A = 101-104, 106$) (Refs. 2–4). These nuclei exhibit distinctly rotational characteristics[5-8] in a region where collective excitations were once thought to be vibrational in nature. Similar rotational structures have also been observed in Ba nuclei ($Z = 56, A = 126, 128, 129, 132$) for which linear polarization experiments have also been performed.[9,10]

In the odd-neutron isotopes ^{101,103,105}Pd strong bands consisting of $\Delta I = 2$ transitions built upon $\frac{11}{2}^-$ states have been identified.[5-7] These, along with $\frac{7}{2}^+$ and $\frac{5}{2}^+$ bands, can be interpreted[11] as one-quasiparticle $h_{11/2}$, $g_{7/2}$, and $d_{5/2}$ states coupled to a slightly deformed rotational core. (For simplicity, shell-model notation will be used to indicate the parentage of the appropriate Nillson orbitals.)

In the even-even isotopes ^{102,104,106}Pd bands consisting of $\Delta I = 2$ transitions are observed[8] built upon the 0^+ ground state. In the region of the 8^+ member, the latter two nuclei experience backbending in the ground-state band. This backbending in ^{104,106}Pd can be attributed to the intrusion of two-quasineutron states (as suggested by Stephens and Simon[12]) which here consist of Coriolis-decoupled $h_{11/2}$ neutrons. In addition to backbending, all three nuclei have strongly fed negative-parity states which are also believed to come from two-quasineutron configurations[8] involving the $h_{11/2}$ neutron. In particular, these bands in ^{104}Pd are in good agreement with a two-quasiparticle Coriolis-coupling calculation performed by Flaum and Cline.[13]

Linear polarization measurements can be used in conjunction with γ-ray angular distributions to identify parity-changing transitions and to remove ambiguity in angular momentum assignments. The present linear polarization measurements are needed to locate states in $^{105-109}$Cd which are expected to be similar to those states in Pd nuclei that have been interpreted as having strong one-, two-, or three-quasiparticle components. Since $h_{11/2}$ neutrons play a crucial role in these interpretations, the recognition of parity-changing transitions is obviously essential; but unambiguous spin assignments are equally important. The γ-ray angular distribution for a highly mixed $\Delta I = 0$ transition can be the same as that for a $\Delta I = 2$ transition.[6] However, the γ-ray linear polarizations for these two cases are very different so that it is possible to determine the angular momentum change. This determination is particularly useful in the case where the energy spacing between states in a band (normally monotonically increasing with respect to I) undergoes a sudden decrease as in the case of a two-quasiparticle and ground-state band crossing. Here, an unambiguous determination of the angular momenta is necessary.

II. PROCEDURE

The Purdue FN tandem Van de Graaff was used to accelerate ^{16}O ions for $^{92,94,96}Zr(^{16}O, xn)^{105-109}Cd$ reactions with isotopically enriched zirconium targets of thickness ~3.6 mg/cm^2. The polarimeter[1,2] was positioned 15 cm below the target and periodically rotated 90° about its vertical axis. This rotation alternately placed the axis connecting the two Ge(Li) crystals of the polarimeter parallel and perpendicular to the reaction plane. Since the cross section for Compton scattering of a γ ray from one crystal of the polarimeter to the other is sensitive to the initial polarization of the γ ray, differences in counting rates for the two orientations could thus be directly related to the polarization of the γ rays. Events of interest were selected by demanding coincidence (to within a time resolution of about 30 nsec) between signals from the two crystals, and the total γ-ray energy was obtained by summing the voltage pulses from the two detectors. Chance coincidences and scattering events in which the γ ray did not stop in the second crystal contributed to a background which was subtracted during analysis. The energy resolution of the summed signals was about 5 keV at 1 MeV a value degraded somewhat from the single-crystal resolutions due to noise summing and nonlinearity in the two channels. Data were stored separately for both of the polarimeter orientations, and normalization was obtained by monitoring the noncoincident γ-ray counts. Figure 1 illustrates partial sample spectra obtained from the two polarimeter orientations. A radioactive source was used for energy calibration and a check on possible instrumental asymmetry due to misalignment of the polarimeter.

The experimental polarization can be calculated from the asymmetry in the observed coincident counts $N(0°)$ and $N(90°)$ for the two polarimeter orientations:

$$P_{\rm exp} = \frac{1}{Q}\frac{N(90°) - N(0°)}{N(90°) + N(0°)}\,, \tag{1}$$

where Q is the efficiency of the polarimeter in detecting linear polarization as determined[4] from γ rays of known polarization. The angular distribution data can be used to predict the *magnitude* of the linear polarization:

$$P_{\rm ad} = \frac{3A_{22}H_2(\delta_{\rm ad}) + 1.75A_{44}}{2 - A_{22} + 0.75A_{44}}\,. \tag{2}$$

Here $H_2(\delta_{\rm ad})$ is a function of the spin sequence and the mixing ratio $\delta_{\rm ad}$ extracted from the *angular distribution* measurements. [Reference 2 presents the standard definition of $H_2(\delta)$, while Ref. 14 presents the definition of δ used here. $H_2 = 1$ for single-multipole transitions.] The relative

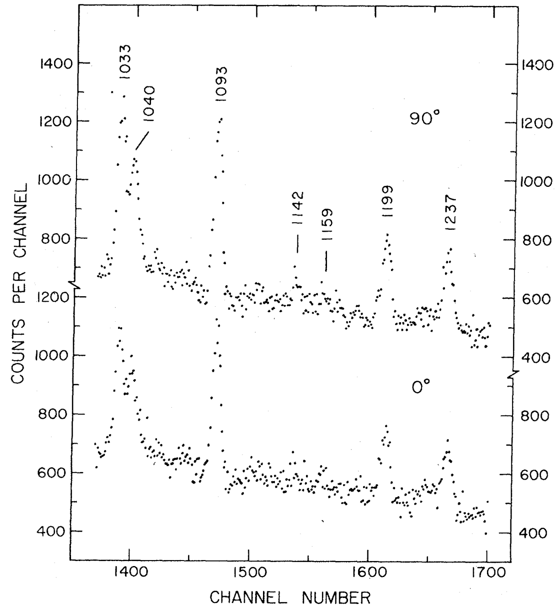

FIG. 1. Partial spectra obtained from the two polarimeter orientations using the $^{96}Zr(^{16}O, xn\gamma)$ reaction at 56 MeV. Peaks of interest from ^{108}Cd and ^{109}Cd are labeled. The energy resolution of the 1093-keV peak is 5.9 keV full width at half maximum.

signs of $P_{\rm exp}$ and $P_{\rm ad}$ are related by

$$P_{\rm exp} = \pm P_{\rm ad}\begin{cases} + \text{ for no parity change} \\ - \text{ for parity change} \end{cases} \tag{3}$$

The ratio $P_{\rm exp}/P_{\rm ad}$ should be +1 for no parity change and −1 for parity change. If the *magnitude* of the ratio is *not* unity, then the spin sequence chosen to calculate H_2 is most likely incorrect. Thus the polarization ratio presents in a simple fashion both of the important results of the polarization measurement: (1) determination of parities of the states, and (2) removal of possible spin-sequence ambiguities arising from the γ-ray angular distribution data.

III. RESULTS

The polarization results are listed in Tables I through V for ^{105}Cd through ^{109}Cd, respectively. The individual transitions are identified in these tables by their energies, with members of each $\Delta I = 2$ cascade generally being grouped together. The γ-ray intensities listed represent the intensities of the individual γ rays. The actual intensities of multiplet peaks observed by the polarimeter can be obtained by dividing the listed intensity by one minus the contaminant percentage given in the table footnotes. The angular distribution coefficients A_{22} and A_{44} presented in the tables were measured previously[15] and are used here

TABLE I. ^{105}Cd linear polarization results.

E_γ (keV)	$I_i \to I_f$	I_γ [a]	A_{22}	A_{44}	P_{ad}	P_{exp}	P_{exp}/P_{ad}	Multipolarity	Mixing ratio δ_{ad}	δ_{pol}
668	$\frac{11}{2}\to\frac{7}{2}$	53.9 (12)	0.212 (10)	−0.041 (14)	0.333 (21)	0.39 (6)	1.17 (19)	$E2$		
887	$\frac{15}{2}\to\frac{11}{2}$	35.7 (9)	0.231 (16)	−0.042 (26)	0.369 (34)	0.50 (10)	1.36 (30)	$E2$		
771	$\frac{9}{2}\to\frac{5}{2}$	9.0 (5)	0.190 (32)	−0.06 (4)	0.28 (6)	0.29 (20)	1.0 (7)	$E2$		
808 [b]	$\frac{13}{2}\to\frac{9}{2}$	21.5 (12)	0.155 (18)	−0.065 (25)	0.21 (4)	0.30 (12)	1.4 (6)	$E2$		
813	$\frac{17}{2}\to\frac{13}{2}$	19.1 (7)	0.128 (22)	−0.005 (31)	0.20 (4)	0.39 (12)	2.0 (7)	$E2$		
832 [c]	$\frac{9}{2}\to\frac{5}{2}$	35.4 (9)	0.267 (12)	−0.088 (17)	0.415 (26)	0.38 (13)	0.92 (32)	$E2$		
539	$\frac{15}{2}\to\frac{11}{2}$	66.2 (14)	0.281 (8)	−0.097 (10)	0.438 (18)	0.38 (4)	0.87 (10)	$E2$		
786	$\frac{19}{2}\to\frac{15}{2}$	55.5 (14)	0.277 (10)	−0.106 (13)	0.425 (22)	0.42 (8)	0.99 (20)	$E2$		
855	$\frac{23}{2}\to\frac{19}{2}$	26.5 (7)	0.331 (16)	−0.113 (23)	0.54 (4)	0.23 (13)	0.43 (25)	$E2$		
905	$\frac{27}{2}\to\frac{23}{2}$	15.9 (6)	0.185 (29)	−0.03 (4)	0.29 (6)	0.34 (20)	1.2 (7)	$E2$		
1044	$\frac{31}{2}\to\frac{27}{2}$	8.3 (5)	0.22 (4)	−0.08 (6)	0.33 (8)	0.32 (48)	1.0 (15)	($E2$)		
260	$\frac{5}{2}\to\frac{5}{2}$	21.4 (6)	0.176 (10)	0.000 (13)	0.25 (6)	0.14 (9)	0.56 (38)	$M1/E2$	$-0.020 \le \delta \le 0.15$	$0.08 \le \delta \le 0.6$
331 [d]	$\frac{11}{2}\to\frac{9}{2}$	36.9 (14)	−0.251 (9)	0.024 (9)	−0.319 [d] (12)	0.31 [d] (8)	−0.97 (25)	$E1$		
392	$\frac{11}{2}\to\frac{9}{2}$	35.6 (8)	−0.239 (12)	0.025 (13)	−0.249 (23)	0.27 (5)	−1.08 (22)	$E1$	$-0.044 \le \delta \le -0.021$	$-0.05 \le \delta \le 0.00$
604	$\frac{7}{2}\to\frac{5}{2}$	13.4 (5)	−0.704 (29)	0.17 (4)	0.14 (11)	0.13 (13)	0.9 (11)	$M1/E2$	$-1.3 \le \delta \le -0.40$	$-1.3 \le \delta \le -0.32$
640	$\frac{9}{2}\to\frac{7}{2}$	34.3 (9)	−0.185 (12)	0.139 (18)	0.159 (4)	0.10 (6)	0.63 (38)	$M1/E2$	$-4.9 \le \delta \le -3.7$	$-4.0 \le \delta \le -0.28$
701	$\frac{9}{2}\to\frac{7}{2}$	7.8 (8)	−0.50 (5)	0.13 (8)	0.207 (13)	0.35 (16)	1.7 (8)	$M1/E2$	$-2.3 \le \delta \le -1.6$	$-26 \le \delta \le -1.6$
705 [e]	$\frac{17}{2}\to\frac{15}{2}$	11.4 (5)	−0.12 (4)	0.05 (5)	{−0.11 (8) or 0.032 (18)}	−0.11 (14)	{1.0 (15) or −3 (5)}	$M1/E2$	{$-0.13 \le \delta \le 0.025$ or $-12 \le \delta \le -4.1$}	f

[a] Normalized to 100 for the 131-keV γ ray.

[b] 8% contamination by 808-keV γ ray (believed to be $E2$) also assigned to ^{105}Cd.

[c] 35% contamination by 835.3-keV $E2$ ^{102}Pd γ ray (resolved in angular distribution measurement but unresolved in polarization measurement).

[d] 24% contamination by 331-keV γ ray. P_{ad} value assumes both transitions have negligible quadrupole admixtures. P_{exp} value shown has been extracted assuming that both γ rays have the same angular distribution and that the contaminating γ ray is $M1$. The uncorrected P_{exp} value is 0.17 (4).

[e] 12% contamination by 705.0-keV $E2$ ^{102}Pd γ ray.

[f] Although P_{exp} overlaps both ranges of δ, the range $-0.13 \le \delta \le 0.025$ is clearly favored.

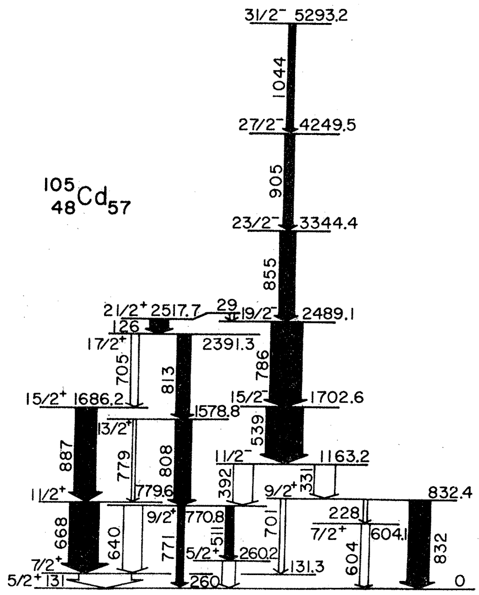

FIG. 2. Partial level scheme for ^{105}Cd showing only those transitions relevant to the present polarization discussion. Solid arrows indicate $E2$ transitions. The widths of the arrows are proportional to the intensities of the transitions.

(along with δ_{ad} where appropriate) to calculate P_{ad} and to distinguish dipole transitions from quadrupoles. The electric or magnetic nature of the transitions is determined from the experimental polarization in accordance with Eq. (3) and the results are shown in the tabulated multipolarity assignments.

The last column of the tables contains the mixing ratio δ_{pol}, which would be necessary to make the magnitudes of P_{ad} [here δ_{pol} replaces δ_{ad} in Eq. (2)] and P_{exp} equal. The accuracy of this measurement of the mixing ratio depends on the uncertainties of the angular distribution coefficients A_{22} and A_{44}, and of the measured polarization P_{exp}. By contrast, the accuracy of δ_{ad}, the mixing ratio extracted exclusively from the angular distribution data, depends on the uncertainties of A_{22} and A_{44} and also on the uncertainties of the orientation coefficients[16] α_2 and α_4. While it is usually possible to determine[6] the α_k values quite accurately, they must sometimes be determined[6] by extrapolation from values known for neighboring states with the possibility of unsuspected uncertainties. While δ_{ad} is usually a more precise measurement than δ_{pol} (due to the large uncertainties in P_{exp}), it is worthwhile to compare the two values as a reassuring check on the methods used to determine the orientation coefficients. Also, for relatively long-lived states, which are deoriented by extra-

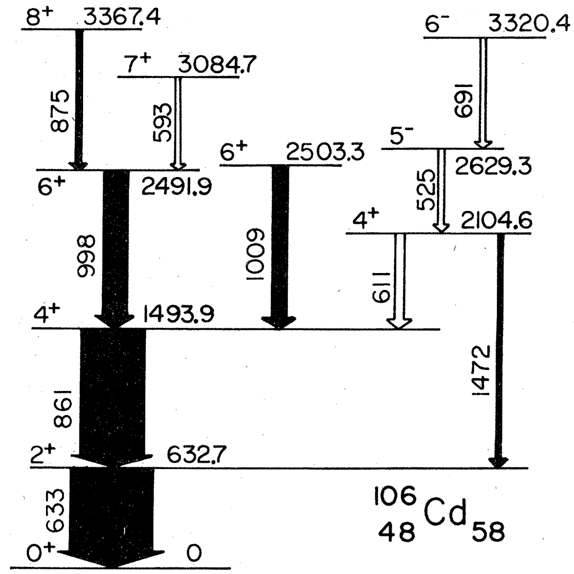

FIG. 3. Partial level scheme for ^{106}Cd.

nuclear perturbations, it is often impossible to make an accurate determination of the α_k values. For these cases δ_{pol} is indeed the best mixing-ratio measurement available. (The mixing-ratio sign convention is that of Krane and Steffen.[14])

Partial decay schemes are shown in Figs. 2 through 6. In these figures darkened arrows are

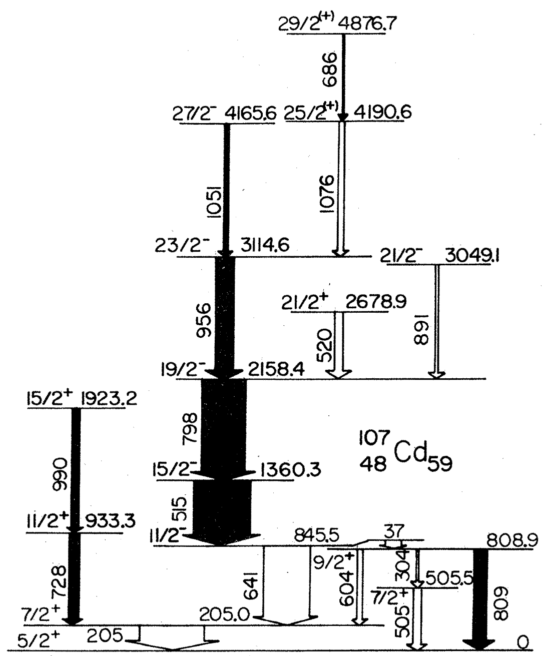

FIG. 4. Partial level scheme for ^{107}Cd.

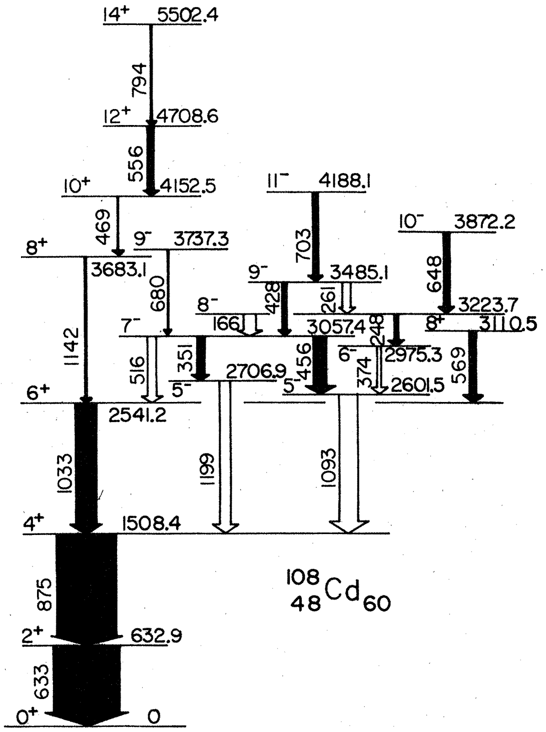

FIG. 5. Partial level scheme for ^{108}Cd.

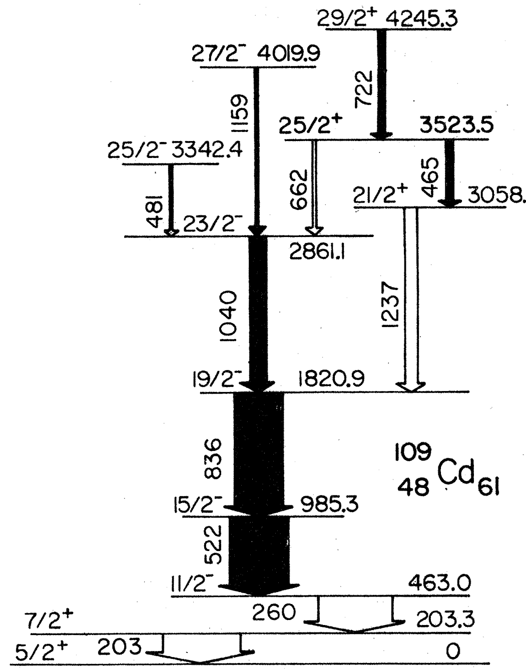

FIG. 6. Partial level scheme for ^{109}Cd.

used to indicate $E2$ transitions and the widths of the arrows are proportional to the transition intensities. More detailed decay schemes will be presented in subsequent publications[15] with only the transitions relevant to the present polarization discussion given here. For each nucleus there are easily identifiable cascades consisting of $E2$ transitions plus other transitions which interconnect these cascades. It is there interconnecting transitions which are of primary importance in polarization measurements since they determine if parity changes exist between the cascades.

In ^{105}Cd the ground state and 131.3-keV state are known[17] to be $\frac{5}{2}^+$ and $\frac{7}{2}^+$, respectively. The transitions which were observed in the present polarization experiment to populate these states are shown in Fig. 2. Spin and parity assignments of $\frac{5}{2}^+$ for the 260.2-keV state, $\frac{7}{2}^+$ for the 604.1-keV state, $\frac{11}{2}^+$ for the 799.6-keV state, and $\frac{15}{2}^+$ for the 1686.2-keV state follow naturally from the angular distribution and polarization data given in Table I. The assignment of $\frac{9}{2}^+$ to the 770.8-keV state from both the $M1/E2$ nature of the 640-keV transition and the $E2$ nature of the 771-keV transition results in the assignment of $\frac{13}{2}^+$ to the 1578.8-keV state and $\frac{17}{2}^+$ to the 2391.3-keV state because the 808- and 813-keV transitions, respectively, are found to the $E2$. Also, the unambiguous $E1$ nature of the 392-keV transition ($\frac{11}{2} \to \frac{9}{2}^+$) requires a negative-parity assignment to the 1163.2-keV state. A confirmation of this spin and parity assignment is available from an alternate route through the 832-keV ($\frac{9}{2} \to \frac{5}{2}^+$) and 331-keV ($\frac{11}{2} \to \frac{9}{2}^+$) transitions. They were found to be $E2$ and $E1$, respectively, thus making the 832.4-keV level $\frac{9}{2}^+$ and the 1163.2-keV level $\frac{11}{2}^-$. (The polarization data for the 331-keV transition in Table I has been corrected for the presence of a 23% $M1$ contamination with an assumed polarization $P = -0.32$. The occurrence of this contaminant was revealed in γ-γ coincidence measurements. The contaminant γ ray is believed to also belong to ^{105}Cd possibly in a cascade feeding the $\frac{21}{2}^+$, 6-μsec isomer at 2517.7 keV. The $M1$ assumption is the only one consistent with all the data.) The extension of negative parity to the states built on the $\frac{11}{2}^-$ level comes from the measured $E2$ characters of the transitions within this cascade.

A partial decay scheme for ^{106}Cd appears in Fig. 3. The ground-band spin and parity assignments as well as the 6^+ assignment to the 2503.3-keV state, the 7^+ to the 3084.7-keV state, and the 8^+ to the 3367.4-keV state are firmly established by the angular distribution and polarization data given in Table II. The 4^+ assignment to the 2104.6-keV state is established by the nonparity changing

TABLE II. ^{106}Cd linear polarization results.

E_γ (keV)	$I_i \rightarrow I_f$	I_γ	A_{22}	A_{44}	P_{ad}	P_{exp}	P_{exp}/P_{ad}	Multipolarity	Mixing ratio δ_{ad}	δ_{pol}
633	2→0	≡100	0.230 (8)	−0.045 (11)	0.365 (17)	0.39 (4)	1.07 (12)	$E2$		
861	4→2	77.4 (9)	0.237 (9)	−0.059 (10)	0.371 (19)	0.43 (5)	1.16 (15)	$E2$		
998	6→4	30.8 (6)	0.276 (14)	−0.079 (17)	0.438 (30)	0.55 (15)	1.26 (35)	$E2$		
1009	6→4	17.2 (6)	0.162 (27)	−0.04 (4)	0.24 (5)	0.42 (15)	1.8 (7)	$E2$		
875 [a]	8→6	7.0 (10)	0.29 (4)	−0.05 (5)	0.48 (9)	0.73 (30)	1.5 (7)	$E2$		
525	5→4	8.5 (4)	−0.239 (31)	−0.03 (4)	−0.31 (7)	0.36 (14)	−1.2 (5)	$E1$	$-0.035 \leq \delta \leq 0.017$	$-0.05 \leq \delta \leq 0.05$
593	7→6	5.0 (5)	−0.61 (10)	0.23 (12)	−0.05 (8)	−0.10 (13)	2.0 (40)	$M1/E2$	$-0.54 \leq \delta \leq -0.24$	$-0.5 \leq \delta \leq -0.15$
611 [b]	4→4	9.5 (6)	0.134 (31)	0.05 (4)	0.60 (19)	0.38 (13)	0.63 (30)	$M1/E2$	$-0.37 \leq \delta \leq -0.26$	$-0.32 \leq \delta \leq -0.08$
691 [c]	6→5	5.9 (6)	c	c		−0.86 (32)		$M1/E2$		$0.35 \leq \delta^{c} \leq 0.8$

[a] 41% contamination by 875.5-keV $E2$ ^{108}Cd γ ray.
[b] 36% contamination by 611.9-keV $E2$ ^{104}Pd γ ray.
[c] Contaminated severely in singles by 691-keV ^{72}Ge (n,n'). The lack of Compton scattering from the 691-keV $E0$ transition in ^{72}Ge and the coincidence requirement, however, allowed determination of P_{exp}. Mixing ratio extracted uses $A_{22} = 0.50$, $A_{44} = 0.12$ estimated from subsequent ^{97}Mo(^{12}C, $3n\gamma$)^{106}Cd angular distribution measurement.

611-keV ($4 \rightarrow 4^+$) transition (its polarization is incompatible with a spin 3 assignment) and by the stretched-$E2$ angular distribution of the 1472-keV ($4 \rightarrow 2^+$) γ ray [$A_{22} = 0.20(6), A_{44} = -0.07(8)$]. The unambiguous $E1$ nature of the 525-keV ($5 \rightarrow 4^+$) transition establishes negative parity to the 2629.3-keV state. This parity assignment is crucial because all remaining transitions (to be presented in a future publication[15]) suspected of being $E1$ are too weak to have their polarization measured and, hence, all remaining negative-parity assignments must be tied to the 2629.3-keV state. The polarization of the 691-keV ($6 \rightarrow 5^-$) γ ray (see footnote Table II) suggests a nonparity changing, highly-mixed dipole-quadrupole transition and thus an $M1/E2$ assignment.

The ^{107}Cd nucleus has received rather extensive investigations including lifetime and magnetic-moment measurements.[18-21] Conversion electron experiments have also been reported using proton (Nyman *et al.*[22]) and α-particle (Hagemann *et al.*[20]) beams in establishing parities for a number of states. The present heavy-ion-beam experiments with γ-ray polarizations provide a check on these results and extend spin and parity assignments in the region of higher angular momenta. A partial decay scheme for ^{107}Cd showing the transitions observed in the present experiments is shown in Figure 4 while the polarization results are given in Table III. In ^{107}Cd the ground state and 205.0-keV state are known[23,22] to be $\frac{5}{2}^+$ and $\frac{7}{2}^+$, respectively. Confirmations of the $\frac{7}{2}^+$ assignment to the 505.5-keV state and the $\frac{9}{2}^+$ to the 808.9-keV state made by both Hagemann *et al.*[20] and Nyman *et al.*[22] follow from the angular distributions and linear polarizations of the 505-keV transition and 604- and 809-keV transitions, respectively. The $E2$ natures of both the 728-keV ($\frac{11}{2} \rightarrow \frac{7}{2}^+$) and 990-keV ($\frac{15}{2} \rightarrow \frac{11}{2}$) γ rays yield assignments of $\frac{11}{2}^+$ and $\frac{15}{2}^+$ to the 933.3- and 1923.2-keV states, respectively. These confirm previous assignments.[20] The contaminant 728-keV γ ray known also to belong to ^{107}Cd (from γ-γ coincidences) appears not to disturb the consistency of either the angular distribution or linear polarization measurement of the more intense 728-keV ($\frac{11}{2}^+ \rightarrow \frac{7}{2}^+$) line, thus indicating that it is also $E2$ in nature.

One of the dominant features of the polarization results in ^{107}Cd is the clearly measured $M2$ nature of the 641-keV ($\frac{11}{2}^- \rightarrow \frac{7}{2}^+$) transition which depopulates the 845.5-keV isomeric state ($T_{1/2} = 67$ nsec) (Refs. 19 and 20). This multipolarity assignment was assumed by Hagemann *et al.*[20] for their internal-conversion calculations, and is in agreement with the results of Nyman *et al.*[22]

Negative parities are assigned to the 1360.3-, 2158.4-, 3114.6-, and 4165.6-keV states in the

TABLE III. ^{107}Cd linear polarization results.

E_γ (keV)	$I_i \to I_f$	I_γ [a]	A_{22}	A_{44}	P_{ad}	P_{exp}	P_{exp}/P_{ad}	Multipolarity	Mixing ratio δ_{ad}	Mixing ratio δ_{pol}
728 [b]	$\frac{11}{2} \to \frac{7}{2}$	11.7 (6)	0.272 (16)	−0.089 (20)	0.424 (35)	0.59 (11)	1.39 (28)	$E2$		
990	$\frac{15}{2} \to \frac{11}{2}$	10.3 (4)	0.21 (4)	−0.08 (6)	0.31 (8)	0.73 (27)	2.4 (11)	$E2$		
809	$\frac{9}{2} \to \frac{5}{2}$	19.4 (4)	0.196 (13)	−0.045 (16)	0.300 (26)	0.13 (8)	0.43 (27)	$E2$		
515	$\frac{15}{2} \to \frac{11}{2}$	85.1 (4)	0.294 (8)	−0.083 (3)	0.473 (17)	0.471 (29)	1.00 (7)	$E2$		
798	$\frac{19}{2} \to \frac{15}{2}$	66.6 (5)	0.291 (9)	−0.082 (10)	0.468 (20)	0.47 (4)	1.00 (10)	$E2$		
956	$\frac{23}{2} \to \frac{19}{2}$	27.2 (4)	0.291 (15)	−0.093 (17)	0.462 (33)	0.48 (9)	1.04 (20)	$E2$		
1051	$\frac{27}{2} \to \frac{23}{2}$	6.9 (5)	0.28 (5)	−0.09 (7)	0.44 (4)	0.54 (29)	1.2 (7)	$E2$		
493 [c]	c	4.9 (3)	0.29 (4)	−0.20 (5)	0.40 (9)	0.40 (19)	1.0 (5)	$E2$		
506	$\frac{7}{2} \to \frac{5}{2}$	12.5 (5)	−0.430 (26)	0.003 (36)	−0.10 (5)	0.01 (7)	−0.1 (7)	$M1/E2$	$-0.35 \le \delta \le -0.20$	$-0.9 \le \delta \le -0.33$
521	$\frac{21}{2} \to \frac{19}{2}$	13.2 (3)	−0.144 (12)	0.000 (17)	−0.201 [d] (19)	0.25 (6)	−1.24 (32)	$E1$	d	$-0.008 \le \delta \le 0.04$
604	$\frac{9}{2} \to \frac{7}{2}$	9.2 (3)	−0.324 (19)	0.111 (25)	0.169 (6)	0.28 (13)	1.7 (8)	$M1/E2$	$-2.6 \le \delta \le -2.0$	$-27 \le \delta \le -1.6$
641	$\frac{11}{2} \to \frac{7}{2}$	70.4 (8)	0.154 (7)	−0.041 (7)	0.226 [e] (13)	−0.200 (33)	−0.89 (16)	$M2$	e	$-0.016 \le \delta \le 0.08$
686	$\frac{29}{2} \to \frac{25}{2}$	4.5 (3)	0.29 (4)	−0.12 (6)	0.44 (9)	0.30 (41)	0.7 (9)	$E2$		
891	$\frac{21}{2} \to \frac{19}{2}$	6.6 (4)	0.445 (34)	0.07 (5)	−0.54 (8)	−0.27 (34)	0.5 (6)	$M1/E2$	$0.6 \le \delta \le 1.2$	$0.6 \le \delta \le 5$
1076	$\frac{25}{2} \to \frac{23}{2}$	7.4 (5)	−0.208 (32)	0.02 (4)	−0.30 (8)	0.17 (43)	−0.6 (15)	$(E1)$	$-0.022 \le \delta \le 0.030$	f

[a] Normalized to 100 for the 205-keV γ ray.
[b] 31% contamination by 728.3-keV $E2$ γ ray also belonging to ^{107}Cd but unplaced in decay scheme.
[c] Not placed in decay scheme.
[d] Deorientation due to 55-nsec half-life precludes δ_{ad} determination. P_{ad} value is that for no significant quadrupole admixture.
[e] Deorientation due to 67-nsec half-life precludes δ_{ad} determination. P_{ad} value is that for no significant $E3$ admixture.
[f] P_{exp} overlaps most values of δ.

cascade above the $\frac{11}{2}^-$ state by the $E2$ nature of the connecting transitions. Finally negative parity is therefore assigned to the 3049.1-keV state because the connecting 891-keV ($\frac{21}{2} \to \frac{19}{2}^-$) transition is found to be highly-mixed $M1/E2$.

A second isomeric state ($T_{1/2} = 55$ nsec) (Ref. 20) is found in ^{107}Cd at 2678.9 keV and can be assigned a spin and parity $\frac{21}{2}^+$ from the clear $E1$ character of the 520-keV ($\frac{21}{2} \to \frac{19}{2}^-$) transition. This assignment confirms the $\frac{21}{2}^+$ assignment of Hagemann *et al.*,[20] which was based upon γ-ray angular distribution and conversion electron measurements.

Two previously unreported states at 4190.6 and 4876.7 keV have been assigned spins of $\frac{25}{2}$ and $\frac{29}{2}$, respectively. The parities of both states depend upon the character of the 1076-keV ($\frac{25}{2} \to \frac{23}{2}^-$) transition which unfortunately is too weak to be measured uniquely. Because its polarization does, however, favor the parity-changing choice, the 1076-keV γ ray is tentatively assigned as $E1$, thus requiring a positive-parity assignment to the 4190.6-keV state. The $E2$ nature of the 686-keV ($\frac{29}{2} \to \frac{25}{2}^{(+)}$) transition then requires positive parity for the 4876.7-keV state.

The structure of ^{108}Cd has been studied with a number of techniques including ^{108}In decay,[24] (^{3}He, d) reactions,[25] (p, p') reactions,[26] and (^{16}O, $4n\gamma$) reactions.[27] Among other low-spin states these studies have identified the ground-state band up to spin 6^+ and have tentatively assigned a state at 2601.5 keV as 5^-. The present heavy-ion experiments and polarization measurements greatly extend the information about spins and parities particularly for states with angular momentum $I \geq 6$. A partial decay scheme for ^{108}Cd is shown in Fig. 5 and the corresponding polarization results are given in Table IV. The ground-band spin and parity assignments up to 6^+ are confirmed. The 1142-keV ($8 \to 6^+$), 469-keV ($10 \to 8$), and 794-keV ($14 \to 12$) transitions are weak but their angular distributions and polarizations are completely consistent with their being $E2$. Although the 556-keV ($12 \to 10$) transition is 51% contaminated by three known $E2$ γ rays, the angular distribution and linear polarization of the composite peak are completely consistent with the ^{108}Cd 556-keV γ ray also being $E2$. Because all connecting γ rays are $E2$ and the ground state has positive parity, all states in this cascade are assigned positive parity.

Two states, one at 2601.5 keV and the other at 2706.9 keV are assigned 5^- on the basis of two $E1$ transitions, 1093 keV ($5 \to 4^+$) and 1199 keV ($5 \to 4^+$), which connect these states to the ground-state band at $I^\pi = 4^+$. Both of these states were found to be fed from a 7^- state at 3057.4 keV by $E2$ transitions of 456 and 351 keV, respectively. This 7^- state also decays into the ground-state band at $I^\pi = 6^+$ by a 516-keV ($7 \to 6^+$) $E1$ transition. The 7^- state is in turn fed by a series of $E2$ transitions forming an odd-spin, odd-parity cascade $11^- \to 9^- \to 7^- \to 5^-$. A second cascade involving even spins up to $I = 10$ is also shown in Fig. 5. The parity of the $I = 6$ state at 2975.3 keV in this cascade is established as negative from the $M1/E2$ nature of the 374-keV ($6 \to 5^-$) transition. The parity of the $I = 8$ state at 3223.7 keV could unfortunately not be determined from polarization measurements but can be inferred to be negative from the highly-mixed nature of the 166-keV ($8 \to 7^-$) transition ($0.18 \leq \delta \leq 0.20$) as determined from its angular distribution [$A_{22} = 0.061$ (16) and $A_{44} = -0.003$ (15)] and the $E2$ nature of the 248-keV ($8 \to 6^-$) transition as determined from its directional correlation with respect to quadrupoles ratio[7,8] [$R_{DCOQ} = 1.07$ (8)]. The $E2$ 648-keV ($10 \to 8^-$) transition extends negative parity to the $I = 10$ state at 3872.2 keV.

Finally, a strongly excited state at 3110.5 keV in ^{108}Cd has been assigned 8^+ based upon the angular distribution and polarization of the 569-keV transition from this state to the 6^+ ground-state band member. Because of the angular distribution coefficients [$A_{22} = 0.353$ (21) and $A_{44} = -0.088$ (27)] of the 569-keV γ ray, the only other allowable assignment is 6^+ where an $M1/E2$ mixing of $0.4 \leq \delta \leq 0.8$ must be assigned to the 569-keV γ ray. The predicted polarization of the 569-keV γ ray for this 6^+ possibility is $P_{ad} = 0.16$ (15) while from Table IV the measured value $P_{exp} = 0.63$ (20) is two standard deviations away. Since $P_{ad} = 0.60$ (5) for an $E2$ assignment to the 569-keV γ ray, and hence an $I^\pi = 8^+$ assignment to the 3110.5-keV state, this assignment has been chosen. (It should be noted that the 16% contamination by the 570.5-keV $E2$ ^{106}Pd γ ray has a negligible effect on these results first because of its weakness and second because it is expected to have a very similar angular distribution and polarization.)

The 8^+ assignment to the 3110.5-keV state in ^{108}Cd arrived at in this work is in disagreement with a 4-7 assignment[24] based upon β^+/EC decay of 58-min ^{108}In^m. (It is assumed that the 3110.5-keV state and 569-keV γ ray observed in β decay are the same as observed here.) From the β-decay studies,[24] the decaying isomer was assigned 5 or 6^+ mostly because transitions depopulating the 2601.5- and 2706.9-keV 5^- states were observed. If, however, γ transitions feeding these two 5^- states were present but not observed, the spin and parity of ^{108}In^m could easily be 7^+ and still be consistent with all of the remaining β-decay data. A 7^+ assignment to ^{108}In^m would be consistent with the systematics for the heavier In nuclei and would also satisfy predictions made from the ground states of neighboring odd-P (In) ($Z = 49, I^\pi = \frac{9}{2}^+$) and

TABLE IV. ^{108}Cd linear polarization results.

E_γ (keV)	$I_i \rightarrow I_f$	I_γ	A_{22}	A_{44}	P_{ad}	P_{exp}	P_{exp}/P_{ad}	Multipolarity	Mixing ratio δ_{ad}	Mixing ratio δ_{pol}
633	2→0	≡100	0.235 (7)	−0.075 (8)	0.358 (15)	0.382 (27)	1.07 (9)	$E2$		
875	4→2	89.7 (12)	0.254 (7)	−0.070 (7)	0.398 (15)	0.46 (4)	1.16 (11)	$E2$		
1033	6→4	29.8 (4)	0.248 (10)	−0.096 (12)	0.371 (21)	0.51 (13)	1.38 (36)	$E2$		
1142	8→6	4.45 (29)	0.27 (5)	−0.13 (5)	0.40 (11)	1.1 (10)	2.8 (26)	$E2$		
469	10→8	3.24 (19)	0.32 (4)	−0.11 (5)	0.52 (9)	0.43 (32)	0.8 (6)	$E2$		
556 [a]	12→10	8.7 (5)	0.271 (27)	−0.100 (22)	0.42 (6)	0.35 (7)	0.83 (21)	$E2$		
794	14→12	4.73 (30)	0.28 (4)	−0.07 (5)	0.45 (9)	0.55 (28)	1.2 (7)	$E2$		
351	7→5	10.29 (22)	0.312 (24)	−0.098 (21)	0.50 (5)	0.50 (24)	1.0 (5)	$E2$		
428	9→7	6.12 (23)	0.330 (25)	−0.086 (22)	0.55 (6)	0.40 (22)	0.7 (4)	$E2$		
456	7→5	17.32 (23)	0.348 (11)	−0.115 (13)	0.575 (26)	0.52 (9)	0.90 (16)	$E2$		
569 [b]	8→6	6.8 (4)	0.353 (21)	−0.088 (27)	0.60 (5)	0.63 (20)	1.05 (35)	$E2$		
648 [c]	10→8	9.4 (7)	0.309 (16)	−0.149 (20)	0.47 (4)	0.47 (13)	1.00 (29)	$E2$		
680	9→7	3.62 (19)	0.36 (5)	−0.17 (6)	0.57 (12)	0.49 (33)	0.9 (6)	$E2$		
703	11→9	7.20 (21)	0.244 (30)	−0.09 (4)	0.37 (6)	0.36 (17)	1.0 (5)	$E2$		
374	6→5	6.40 (20)	0.463 (30)	0.072 (27)	−0.70 (6)	−0.75 (38)	1.1 (5)	$M1/E2$	$0.50 \leq \delta \leq 0.62$	$0.4 \leq \delta \leq 2.0$
516 [d]	7→6	11.36 (32)	−0.227 (14)	0.003 (16)	−0.319 (33)	0.41 (8)	−1.29 (28)	$E1$	$-0.008 \leq \delta \leq 0.017$	$0.010 \leq \delta \leq 0.05$
1093	5→4	29.2 (4)	−0.299 (11)	0.021 (11)	−0.28 (4)	0.34 (10)	−1.2 (4)	$E1/M2$	$-0.06 \leq \delta \leq -0.020$	$-0.05 \leq \delta \leq 0.015$
1199	5→4	15.8 (4)	−0.310 (13)	0.012 (14)	−0.26 (4)	0.35 (19)	−1.3 (8)	$E1/M2$	$-0.07 \leq \delta \leq -0.035$	$-0.12 \leq \delta \leq 0.033$

[a] 25% contamination by 555.8-keV $E2$ ^{104}Pd γ ray, 17% contamination by $E2$ 556.2-keV ^{109}Cd γ ray, and 9% contamination by $E2$ 555.2-keV ^{106}Pd γ ray.
[b] 16% contamination by 570.5-keV $E2$ ^{106}Pd γ ray.
[c] 10% contamination by 648.6-keV γ ray (multipolarity unassigned) also belonging to ^{108}Cd.
[d] 31% contamination by 514.2-keV $M1/E2$ ^{108}Cd γ ray (resolved in angular distribution measurement but unresolved in polarization measurement).

odd-N (Pd and Cd) ($N=59$ or $61, I^\pi=\frac{5}{2}^+$) nuclei. (See rule 2 of Brennan and Bernstein.[28]) In particular the suggestion[24] that spin 6^+ arises from a $(d_{5/2})^{-3}\ \frac{3}{2}^+$ neutron configuration of the ground-state of 18-min ^{109}Sn ($N=59$) is no longer possible because the ground-state spin of ^{109}Sn has subsequently been measured to be $\frac{7}{2}$ using atomic-beam magnetic resonance.[29]

A partial decay scheme for ^{109}Cd is shown in Fig. 6 with the corresponding polarization data being given in Table V. The dominant feature in the decay scheme is a cascade of $E2$ transitions built on the long-lived[30] ($T_{1/2}=11$ μsec) $\frac{11}{2}^-$ state at 463.0 keV. This cascade has been previously reported by Meyer *et al.*[30] in their study of ^{109}Cd using the ^{108}Pd($\alpha, 3n\gamma$)^{109}Cd reaction. The $\frac{19}{2}^-$ 1820.9-keV state in the strong cascade is also fed by a 1237-keV ($\frac{21}{2} \rightarrow \frac{19}{2}^-$) γ ray whose polarization results show that it is $E1$ thus giving positive parity to the $\frac{21}{2}$ state at 3058.1 keV. The parity of this state was not assigned by Meyer *et al.*[30]

The polarization of the 465-keV ($\frac{25}{2} \rightarrow \frac{21}{2}^+$) transition $P_{exp}=0.25$ (9) is two standard deviations away from $P_{ad}=0.48$ (4) but this value is much closer to that expected for an $E2$ than an $M2$ and hence the parity of the $\frac{25}{2}$ state at 3523.5 keV is taken to be positive. [The 662-keV $\frac{25}{2} \rightarrow \frac{23}{2}^-$ transition has an angular distribution consistent with its being $E1$, i.e., $A_{22}=-0.30$ (5), $A_{44}=0.00$ (6), but it is too weak to have its polarization measured.] The 722-keV

TABLE V. ^{109}Cd linear polarization results.

E_γ (keV)	$I_i \rightarrow I_f$	I_γ [a]	A_{22}	A_{44}	P_{ad}	P_{exp}	P_{exp}/P_{ad}	Multipolarity	Mixing ratio δ_{ad}	Mixing ratio δ_{pol}
522	$\frac{15}{2} \rightarrow \frac{11}{2}$	74.9 (17)	0.304 (10)	−0.094 (11)	0.489 (22)	0.49 (4)	1.00 (9)	$E2$		
836	$\frac{19}{2} \rightarrow \frac{15}{2}$	59.4 (13)	0.284 (8)	−0.079 (8)	0.455 (17)	0.51 (4)	1.12 (10)	$E2$		
1040 [b]	$\frac{23}{2} \rightarrow \frac{19}{2}$	19.9 (7)	0.295 (15)	−0.096 (18)	0.468 (33)	0.44 (12)	0.94 (27)	$E2$		
1159	$\frac{27}{2} \rightarrow \frac{23}{2}$	3.5 (4)	0.26 (5)	−0.10 (6)	0.39 (11)	1.3 (9)	3.3 (25)	$E2$		
260	$\frac{11}{2} \rightarrow \frac{7}{2}$	96.1 (16)	0.045 (6)	−0.005 (6)	0.066 [c] (10)	−0.13 (5)	−2.0 (8)	$M2$	c	c
465	$\frac{25}{2} \rightarrow \frac{21}{2}$	8.4 (4)	0.303 (16)	−0.109 (19)	0.48 (4)	0.25 (9)	0.52 (19)	$E2$		
481 [d]	$\frac{25}{2} \rightarrow \frac{23}{2}$	1.9 (5)	−0.25 (4)	0.12 (5)		−0.53 (40)		($M1/E2$)		
722 [e]	$\frac{29}{2} \rightarrow \frac{25}{2}$	6.6 (5)	0.255 (20)	−0.111 (26)	0.38 (4)	0.29 (15)	0.8 (4)	$E2$		
1237	$\frac{21}{2} \rightarrow \frac{19}{2}$	16.3 (7)	−0.257 (15)	−0.005 (17)	−0.258 (33)	0.40 (30)	−1.6 (12)	$E1/M2$	$-0.05 \leq \delta \leq -0.020$	$-0.16 \leq \delta \leq 0.06$

[a] Normalized to 100 for the 203-keV γ ray.
[b] 18% contamination by 1038.0-keV (multipolarity not uniquely assigned) ^{108}Cd γ ray (resolved in angular distribution measurement but unresolved in polarization measurement).
[c] Deorientation due to 11-μsec half-life precludes δ_{ad} determination; also, P_{exp} overlaps most values of δ. P_{ad} value is that for no significant $E3$ admixture.
[d] 32% contamination possibly by 481.0-keV $E2$ ^{105}Pd γ ray.
[e] 25% contamination by 721.7-keV $E2$ ^{108}Cd γ ray and 9% contamination by unknown γ ray.

($\frac{29}{2}\to\frac{25}{2}^+$) γ ray can be assigned $E2$ yielding positive parity to the 4245.3-keV state. Finally, the 481-keV ($\frac{25}{2}\to\frac{23}{2}^-$) γ ray has an anomalously large A_{44} value but has a polarization value like that of a very highly mixed $\Delta I=-1$, $M1/E2$ transition. It therefore has been tentatively assigned as a non-parity-changing transition yielding $I^\pi=\frac{25}{2}^{(-)}$ for the 3342.4-keV state.

IV. DISCUSSION

In the present work, the $\frac{11}{2}^-$ state in ^{105}Cd has been identified, the assignment of the $\frac{11}{2}^-$ state in ^{107}Cd has been confirmed, while the assignment of the $\frac{11}{2}^-$ state in ^{109}Cd has been supported. As expected, decoupled bands built on the $\frac{11}{2}^-$ states are strongly populated in all three odd-neutron Cd nuclei. The position of the $\frac{11}{2}^-$ state is observed to drop rapidly in energy with increasing neutron number (1163.2, 845.5, and 463.0 keV in ^{105,107,109}Cd, respectively). This same systematic trend is observed in ^{101,103,105}Pd and can be attributed to the neutron Fermi surface which is rising toward the low-$\Omega h_{11/2}$ orbits.

The band of states found feeding the $\frac{7}{2}^+$ state at 131.3 keV in ^{105}Cd is of particular interest. Here the $\frac{9}{2}^+$, $\frac{13}{2}^+$, and $\frac{17}{2}^+$ states are above the yrast line and would normally be only weakly populated following a (heavy ion,xn) reaction. In ^{105}Cd, however, these states are strongly populated because the $\frac{17}{2}^+$ state is fed from a strongly populated $\frac{21}{2}^+$ state which happens to lie below the $\frac{19}{2}^+$ member of the $\frac{7}{2}^+$ band. Since this is an unusual situation, it was important to make definite parity assignments to these states.

Since the deformation of the core appears to be small for nuclei in this mass region, a relatively large amount of energy is required to obtain high-angular momentum by core rotation. Thus it should be energetically favorable to form high-angular-momentum states in even-even nuclei by aligning a pair of high-spin quasiparticles. Two-quasiparticle states should appear on the yrast line above 2 MeV (approximately the pairing energy). In Cd and Pd nuclei the high-spin Nilsson orbitals available to valence particles have $h_{11/2}$ and $g_{9/2}$ parentage for neutrons and protons, respectively. In the rotational description $h_{11/2}$ pairs and $g_{9/2}$ pairs would produce 10^+ and 8^+ states, respectively. (The Pauli exclusion principle prevents perfect alignment.) Pairs of $g_{7/2}$ and $d_{5/2}$ quasineutrons would not have enough angular momentum to be on the yrast line. However, $h_{11/2}$-$g_{7/2}$ and $h_{11/2}$-$d_{5/2}$ pairs would produce negative-parity states with relatively high angular momentum. These states could be on the yrast line and hence would be populated following a (heavy ion,xn) reaction.

Positive- and negative-parity bands built on high-spin states have been observed in even-even ^{102,104,106}Pd nuclei.[8] One of the important goals in the present work was to identify the lower levels of these same bands in Cd nuclei. In ^{108}Cd a 10^+ state was identified at 4152.5 keV. (See Fig. 5.) The transition energy from the 10^+ to 8^+ state is obviously too small (469 keV) for the 10^+ state to be a continuation of the ground-state band so this state is an excellent candidate for the $h_{11/2}$ two-quasineutron 10^+ state. The energy of the 10^+ member of the ground-state band would be approximately 4950 keV, so the states shown at 5502.4, 4708.6, and 4152.5 keV would still be on the yrast line if they were a 12^+-10^+-8^+ sequence. The angular distribution of the 469-keV γ ray could be the same for a highly mixed 8^+ to 8^+ transition as it would be for a 10^+ to 8^+ transition. However, for the observed angular distribution, the linear polarization measured here is in excellent agreement with a $\Delta I=2$ transition and does not agree with a $\Delta I=0$ transition. This 10^+ state is therefore a good example of the role that linear polarization measurements can play in firmly establishing angular momentum values. Energy systematics are not sufficient to ensure that the 4152.5-keV state is not an 8^+ state.

Linear polarizations have also provided the basis to identify uniquely three $E1$ transitions from negative-parity states to the ground-state band, 7^- to 6^+ (516 keV), 5^- to 4^+ (1199 keV), and 5^- to 4^+ (1093 keV) in ^{108}Cd. These assignments in turn, have allowed identification of the expected negative-parity bands and additional negative-parity states. These negative-parity states will be discussed in more detail in a separate paper.[15]

The 8^+ state at 3110.5 keV, 573 keV below the 8^+ member of the ground-state band is a candidate for the $(g_{9/2})^2$ two-quasiproton state. As noted above, the linear polarization measurement is especially needed in this case to be sure that the 569-keV transition from this state is $\Delta I=2$ rather than $\Delta I=0$. In ^{102,104,106}Pd the 8^+ member of the ground-state band is the lowest energy 8^+ state that has been observed. This observation is consistent with the calculation of Flaum and Cline[13] which predicts that the 8^+ two-quasiproton state in ^{104}Pd will have higher energy than the 8^+ member of the ground-state band. Two-quasiparticle Coriolis coupling calculations are being performed for ^{108}Cd and it will be interesting to see if the characteristics of the 8^+ state at 3110.5 keV are consistent with that description.

Linear polarization of γ rays from ^{106,107}Cd were measured in the same experiment using ^{94}Zr(^{16}O, $4n$)^{106}Cd and ^{94}Zr(^{16}O, $3n$)^{107}Cd reactions. The $4n$ process was relatively weak compared to the $3n$ reaction, so good results were obtained for only the stronger transitions in ^{106}Cd. Several states were identified which are important in the decay scheme of ^{106}Cd. The expected 5^- state was found at 2629.3 keV. An 8^+ state at 3367.4 keV does not seem to be a simple extension of the ground-state band because the 8^+ to 6^+ transition has less energy (875 keV) than the 6^+ to 4^+ transition (998 keV). The linear polarization was also necessary to definitely assign the angular momentum of a second 6^+ state at 2503.3 keV. Many higher-angular-momentum states have been observed in subsequent experiments using the ^{96}Mo(^{13}C, $3n$) ^{106}Cd and ^{97}Mo(^{12}C, $3n$) ^{106}Cd reactions. A much more complete level scheme and an interpretation of the structure of ^{106}Cd will be given in a paper to be published[15] on the ^{13}C experiments.

The argument given above to explain the intrusion of two-quasiparticle states into the high-angular momentum structure of even-even nuclei also applies to the intrusion of three-quasiparticle states in odd-neutron Cd nuclei. The regular bands built on low-lying one-quasiparticle states are frequently interrupted at high spin by states which have the angular momentum expected for an aligned set of three quasiparticles. In the odd-neutron Cd nuclei the lowest energy three-quasiparticle states would be $(\pi g_{9/2})^2{}_{8^+}$ and $(\nu h_{11/2})^2{}_{10^+}$ coupled to the $(\nu d_{5/2})$ ground state to form $\frac{21}{2}^+$ and $\frac{25}{2}^+$ states, respectively. The $\frac{21}{2}^+$ state at 2678.9 keV in ^{107}Cd has been identified as a three-quasiparticle state.[21] This state decays by a 520-keV, $E1$ transition with $t_{1/2} = 55$ nsec (Ref. 20) so it is retarded by a factor of 10^{-6} from the single-particle estimate. The magnetic moment[21] of this state was found to be in excellent agreement with that expected for a $[(\pi g_{9/2})^2{}_{8^+}(\nu d_{5/2})^1]_{21/2^+}$ configuration. The $\frac{21}{2}^+$ state at 2517.7 keV in ^{105}Cd, which feeds the $\frac{17}{2}^+$ member of the $\frac{7}{2}^+$ band and is also known to be isomeric[31] ($t_{1/2} = 6$ μsec), and the $\frac{21}{2}^+$ state at 3058.1 keV in ^{109}Cd are excellent candidates for this same configuration in these nuclei. The magnetic moments of these states have not as yet been measured, however, so definite structures cannot be assigned. The $\frac{25}{2}^{(+)}$ state at 4190.6 keV in ^{107}Cd and the $\frac{25}{2}^+$ state at 3523.5 keV in ^{109}Cd are possible candidates for the $[(\nu h_{11/2})^2{}_{10^+}(\nu d_{5/2})^1]_{25/2^+}$ three-quasiparticle configuration. These states exhibit the expected energy systematics for states involving $h_{11/2}$ neutrons by dropping 677 keV from ^{107}Cd to ^{109}Cd.

In conclusion, γ-ray linear polarization measurements used in conjunction with γ-ray angular distribution data have not only allowed important $M1/E2$ and $E2$ assignments to be made but also have made it possible to identify important parity-changing transitions in the cadmium isotopes from $A = 105$ through 109. The even-odd and even-even cadmium nuclei are found to exhibit structures very similar to the even-odd and even-even palladium nuclei.

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