Collective excitations in ^{246}Cm and the decay of $^{246}Am^{m}$†

L. G. Multhauf, K. G. Tirsell, and R. A. Meyer
Lawrence Livermore Laboratory, University of California, Livermore, California 94550
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Intense sources of ^{246}Pu have been produced (through double neutron capture by ^{244}Pu) for making detailed electromagnetic and conversion-electron measurements of the decay of $^{246}Am^{m}$ to levels of ^{246}Cm. γ rays from ^{246}Pu decaying to ^{246}Am levels were identified in a chemical milking experiment. Of the 260 ^{246}Cm γ rays observed, 97 are new and 64 have been assigned multipolarities from Si(Li) conversion-electron measurements. Some transitions were found to have strong $E0$ components, and two pure $E0$ transitions were observed. High-resolution γ-γ-time coincidence measurements were used to establish 54 levels, from which the low-energy band structure of ^{246}Cm was determined. The investigation confirmed previous assignments of $K^{\pi}=0^-$, 1^-, and 2^- octupole bands, and a $K^{\pi}=0^+$ band at 1175 keV. We have also identified the probable $K^{\pi}=3^-$ octupole band, and a second $K^{\pi}=0^+$ band at 1289 keV. The two $K^{\pi}=0^+$ bands are discussed in terms of possible collective excitations. Other identified bands are discussed in terms of two-quasiparticle and multipole-phonon excitations.

[RADIOACTIVITY $^{246}Am^{m}$ (from β decay of ^{246}Pu produced by double neutron capture on ^{244}Pu); measured E_γ, I_γ, $\gamma\gamma$ coin, I_{ce}; deduced levels, J, π, logft.]

I. INTRODUCTION

The heaviest even-even nucleus whose structure has been examined in considerable detail is ^{246}Cm. In a previous study,[1] we identified a number of the known energy levels and collective bands by studying the decay of an $^{246}Am^{m}$ source (in equilibrium with ^{246}Pu). (We denote the 25-min isomer by "$^{246}Am^{m}$," though it is not established whether it is the ground state (g.s.) of ^{246}Am or an isomer.) The source was obtained directly from the debris of a nuclear detonation designed to produce heavy elements, and was used to make γ-ray singles measurements. However, the source was not of sufficient intensity to permit measurements for determining transition multipolarities, and hence, for firmly establishing spin and parity assignments. We were also unable to obtain evidence for $K^{\pi}=0^+$ bands, which have been identified in lighter mass nuclei. We subsequently produced a source of sufficient intensity to permit conversion-electron and γ-γ-coincidence studies, as well as improved γ-ray singles measurements. We thus verified most of our previous assignments, and have identified several new bands, including one with $K^{\pi}=0^+$.

II. EXPERIMENTAL PROCEDURES

A. Source production and preparation

The ^{246}Pu activity was produced through double neutron capture on ^{244}Pu at the ORNL (Oak Ridge National Laboratory) high-flux reactor (HIFR). The ^{244}Pu target material was obtained from fused cavity debris of the Hutch event[2]: an underground nuclear detonation designed to produce heavy elements. The plutonium sample from the HIFR irradiation was chemically isolated from fission products and other heavy elements with chemical procedures outlined in Ref. 1. This procedure produced ^{246}Pu sources of considerably greater intensity than those used in our first study.[1] Some of the sources were electroplated on platinum planchets to allow the study of conversion electrons and low-energy γ rays.

B. Separation of Am

Sources in all previous studies have contained ^{246}Pu in equilibrium with $^{246}Am^{m}$, and this has resulted in ambiguity in the γ-ray data below 400 keV. To identify γ rays from ^{246}Pu decay, an experiment was performed in which the Am component was periodically removed and counted. In addition to positively assigning many strong γ rays to either ^{246}Pu or $^{246}Am^{m}$ decay, we detected some previously unobserved low-energy lines.

C. Singles spectra

Singles spectra were obtained with thin-window, coaxial, and Compton-suppression Ge(Li) spectrometers. The Compton-suppression system (described in Ref. 3) was particularly useful below 1 MeV in reducing the large Compton background present in our unsuppressed spectra. Energies and intensities of the more intense γ rays were obtained with the thin-window and coaxial detectors. The two thin-window diodes had volumes of 1 cm^3 and resolutions of 600 eV at 60 keV. The 40-cm^3 coaxial detector gave a 1.9-keV resolution at 1.3 MeV. Other detectors used included 6- and 19-cm^3 planar Ge(Li) diodes. Conventional low-noise electronics and 4096-channel pulse-height analyzers were used.

Peak locations and areas were determined using the GAMANAL computer code,[4] which subtracts a smoothed-step-function background and uses a Gaussian and tailing function for least-squares fitting of the data.

Sources for efficiency calibration included standard International Atomic Energy Agency (IAEA) sources and lines of well-measured relative intensity in ^{56}Co and ^{182}Ta (Refs. 5 and 6, respectively). In general, errors were below 2%.

The sources used to measure efficiencies were also used to generate an energy-channel nonlinearity curve for each of the spectrometers. The availability of accurate energy values for the high-energy ^{56}Co lines permitted a significant improvement in accuracy over our previous measurements[1] in the region above 1.3 MeV. High precision was achieved by simultaneously accumulating data from the calibration sources and the ^{246}Pu sample. The procedure is described in more detail in Ref. 7.

D. Coincidence data

Coincidence data were taken with two large Ge(Li) coaxial diodes viewing the source in a 90° geometry. A thick graded shield of lead, cadmium, and copper was placed between the detectors to minimize scattering effects. Plastic absorbers eliminated β-γ coincidences. Data were accumulated over a 96-h period in a three-parameter energy-energy-time mode using a $4096\times4096\times512$ channel buffer-tape system controlled by a PDP-7.[8] In total, 10^7 coincident events were stored on tape for analysis. The energy ranges were 0–1 and 0–2 MeV, corresponding to axes designated low and high energy, respectively. A standard start-stop time-to-amplitude converter measured time differences between coincident pulses.

A data reduction routine was used to obtain γ-ray spectra in coincidence with each of the strong lines on the low- and high-energy axes. Each spectrum was corrected for the γ-ray distribution from Compton photons underlying the gated peak with appropriately chosen background windows. In addition, optimum use of the time difference information was made to correct each spectrum for accidental coincidences. Equal-width true- and random-coincidence time windows were selected for each of 256 regions of the energy-energy data matrix (a 16 by 16 array). Most of the windows were from 5 to 9 times narrower than the window width that would have been required if the experiment were performed in a two-parameter configuration. The large reduction in random coincidences and the corresponding improvement in the true-to-random ratio made possible the use of stronger sources with much higher coincidence rates.

E. Conversion-electron measurement

Conversion-electron spectra were measured with a 1-cm^2 Si(Li) detector that was 2-mm thick and had a resolution of approximately 2 keV. The electron energy scale was established with ^{207}Bi and ^{137}Cs sources. The detector's relative efficiency was calibrated with standard sources,[9] primarily ^{180}Hf^m and ^{207}Bi; it was found to be almost independent of energy below 700 keV.

The electron spectra were analyzed with the Vista shape-fitting program,[10] running in an interactive mode on the LBL CDC-6600 computer. Peak-shape parameters used in the program were determined from ^{207}Bi spectra accumulated before and after the ^{246}Pu data were taken. The fitting procedure gave relative conversion-electron intensities that were used with relative γ-ray intensities to calculate K- and L-shell conversion coefficients.

For normalization of the conversion-electron to γ-ray intensity ratios, we used the 1036-, 1062-, and 1079-keV transitions. The 1062-keV transition is known to be pure $E1$ from the conversion-electron measurements of Orth,[11] and because it feeds the 0^+ ground state.[1] Also, from the measurements of Orth, the 1036- and 1079-keV transitions are known to be predominately $E1$. We assumed all three to be pure $E1$ transitions and obtained intensity normalization factors by requiring their K-conversion coefficients to be equal to the theoretical values calculated by Hager and Seltzer.[12] The weighted average of these three normalization constants was then used to obtain the remaining conversion coefficients listed in Table I and shown in Fig. 1. (This procedure results in a large number of coefficients falling on the theoretical line for $M1$ transitions.)

III. EXPERIMENTAL RESULTS AND DECAY SCHEME

We selected portions of the spectra obtained in this study to illustrate data quality improvements over our previous work[1] that were made possible

TABLE I. γ rays and conversion electrons for transitions in $^{246}Am^{m}$ decay.

Energy [a] (keV)	Relative γ-ray intensity	Assignment	Relative K-electron intensity	α_K (10^{-3})	Multipolarity
34.76 [b]	216(20) [b]	876–842			
42.9(2)	~2	43–0			
46.87 [b]	3.5(8) [b]	923–876			
81.63 [b]	5.5(12) [b]	923–842			
99.2(2)	6.7(5)	142–43			
150.81(14)	0.32(6)				
152.9(2)	0.18(6)				
171.02(11)	2.0(8)	1250–1079 [c]			
227.4(2)	0.6(2)				
228.71(7)	1.5(3)	1478–1250			
237.23(4)	5.8(3)	1079–842 [c]			
238.64(3)	5.9(3)	1367–1128 [c]			
244.03(3)	27.5(10)	1349–1105 [c]			
244.9(2)	0.25(15)	1594–1349 [c]			
251.50(10)	0.11(2)	1128–876			
261.73(5)	6.3(2)	1367–1105 [c]			
263.17(5)	1.35(9)	1105–842			
267.3(5)	0.2(1)	(1478–1211)			
		(1634–1367)			
270.07(3)	41.2(13)	1349–1079 [c]	K: 55.2(12)	α_K: 1340(64)	$M1$
			L: 14(4)	α_L: 340(100)	
271.1(2)	0.2(1)	1983–1712			
277.0(2)	0.08(3)	1452–1175			
287.78(3)	5.20(18)	1367–1079 [c]			
289.3(2)	0.19(5)	(1165–876)			
		(1509–1220)			
293.37(15)	0.18(5)	(1594–1300)			
		(1634–1340)			
302.96(5)	0.28(3)				
306.0(3)	0.05(3)	1526–1220			
321.07(4)	0.75(5)	1621–1300			
325.61(8)	0.24(4)	1947–1621			
327.81(17)	0.12(4)	1452–1124			
329.87(14)	0.13(4)				
343.93(4)	1.04(4)	1594–1250			
347.26(4)	0.97(5)	(1857–1509)	4.2(8)	4400(800)	$M1+E0(M2)$
354.45(6)	0.26(4)	1604–1250			
360.39(4)	2.29(9)	1526–1165 [c]	2.3(9)	1000(400)	$M1$
361.85(9)	0.49(6)	(1983–1621)			
370.81(13)	0.17(4)	(2032–1662)			
373.36(5)	0.84(5)	1250–876			
377.2(2)	0.11(4)	1300–923			
381.0(3)	0.06(2)	(1509–1128)			
		(1601–1220)			
383.73(6)	0.75(8)	1634–1250	0.51(6)	680(100)	$M1$
398.14(12)	0.33(5)	1526–1128 [d]			
401.68(3)	10.7(3)	1526–1124 [c]	<0.3	<30	$E1$
407.99(6)	0.41(4)	1250–842			
414.16(6)	0.42(5)	1781–1367			
421.08(5)	0.89(7)	1526–1105 [d]			
423.4(5)	0.16(7)	(1300–876)			
		(1634–1211)			
434.92(13)	0.35(11)	1887–1452	0.32(5)	900(300)	$M1+E0(M2)$
443.25(18)	0.14(4)	1367–923			
446.8(5)	0.05(4)	1526–1079			

TABLE I *(Continued)*

Energy [a] (keV)	Relative γ-ray intensity	Assignment	Relative K-electron intensity	α_K (10^{-3})	Multipolarity
451.2(2)	0.10(4)	(1662–1211)			
		(1671–1220)			
456.11(6)	0.56(7)	1621–1165 [d]			
461.2(2)	0.13(5)	(1681–1220)			
465.61(5)	1.03(8)	1594–1128 [d]			
469.71(8)	0.41(5)	1594–1124			
472.33(5)	1.47(7)	1349–876			
476.89(5)	0.86(6)	1601–1124 [d]	0.29(7)	340(80)	$M1$
487.2(3)	0.37(8)	1662–1175			
488.82(4)	3.70(14)	1594–1105 [c]	K: 1.04(7)	α_K: 280(20)	$M1$
			L: 0.21(7)	α_L: 60(20)	
493.46(4)	4.34(15)	1621–1128 [c]	K: 1.52(7)	α_K: 350(20)	$M1$
			L: 0.33(7)	α_L: 75(15)	
505.61(13)	0.49(9)	(1634–1128) }			
		(1671–1165) }	170(20)	50(10)	
507.10(5)	2.70(12)	1394–842 [d] }			
514.79(4)	3.48(15)	1594–1079 [c]	0.80(21)	230(60)	$M1$
516.60(13)	0.40(10)	1621–1105			
522.53(5)	1.85(8)		0.41(11)	220(60)	$M1$
524.92(4)	2.95(11)	1367–842 [c]	0.71(12)	240(40)	$M1$
528.69(7)	0.60(6)	1634–1105	0.19(5)	310(90)	$M1$
542.92(5)	1.6(2)	1671–1128 [c]	0.29(6)	180(45)	$M1$
554.4(2)	0.89(7)	1659–1105 }	0.26(8)	170(60)	{ $M1$
554.68(6)	0.59(6)	1634–1079 }			{ $M1$
566.12(5)	1.72(10)	1671–1105 [c]	0.31(7)	180(40)	$M1$
577.9(3)	0.34(9)	(2171–1594)			
580.9(3)	0.34(9)	(1870–1289)			
		(2032–1452)			
602.54(6)	9.4(5)	1526–923 [c]	0.35(8)	37(8)	$E2+8\%M1$
609.98(9)	1.8(3)	1452–842	<0.02	<12	$E1$
636.72(12)	0.48(11)	1478–842			
649.48(4)	14.8(5)	1526–876 [c]	0.67(7)	45(5)	$E2+18\%M1$
656.35(14)	0.47(11)	1781–1124	0.30(5)	630(180)	$M1+E0$
670.1(2)	0.33(12)	1594–923			
677.86(6)	1.81(15)	1601–923			
684.28(5)	23.6(8)	1526–842 [c]	K: 1.42(9)	α_K: 60(4)	$E2+39\%M1$
			L: 0.28(5)	α_L: 12(2)	
698.27(5)	4.7(3)	1621–923 [c]	0.59(6)	125(14)	$M1$
717.24(5)	10.2(4)	1594–876 [c]	1.08(6)	106(7)	$M1$
724.79(4)	8.6(3)	1601–876 [c]	<0.06	<7	$E1$
732.5(2)	0.61(17)	(1857–1124)			
		(1898–1165)			
734.41(4)	47.1(14)	876–142 [c]	K: <0.35	α_K: <7	$E1$
			L: 1.1(3)	α_L: 24(6)	
745.05(4)	9.5(3)	1621–876 [c]	1.37(17)	144(18)	$M1+E0$
747.74(8)	1.0(2)	1671–923			
751.0(3)	1.4(5)	(1876–1124)			
		(2100–1349)			
752.06(4)	33.0(12)	1594–842 [c]	4.72(13)	143(6)	$M1+E0$
759.59(4)	25.9(8)	1601–842 [c]	<0.16	<6	$E1$
776.3(3)	0.16(5)				
779.76(8)	2.7(4)	1621–842 [c]	0.24(5)	76	$M1$
781.28(6)	6.8(5)	923–142 [c]			
791.5(2)	2.6(5)	1634–842 [c]			

TABLE I *(Continued)*

Energy [a] (keV)	Relative γ-ray intensity	Assignment	Relative K-electron intensity	α_K (10^{-3})	Multipolarity
798.80(4)	1000	842–43 [c]	K: 5.2(2)	α_K: 5.2(2)	$E1$
			L: 0.93(18)	α_L: 0.93(18)	
810.2(3)	0.25(11)	2100–1289	0.10(4)	400(200)	$M1+E0$
820.7(3)	0.15(9)				
829.37(8)	0.72(14)	1671–842			
833.60(4)	72(2)	876–43 [c]	0.31(6)	4.3(8)	$E1$
904.42(5)	2.31(9)	1781–876 [c]	<20	<9	$E1$ or $E2$
925.0(3)	0.37(13)	2100–1175			
939.15(5)	3.1(2)	1781–842 [c]	<0.03	<9	$E1$ or $E2$
960.2(3)	0.22(9)	1837–876			
962.9(4)	0.02(2)	1105–142			
982.73(15)	0.7(2)	1124–142			
986.03(4)	38.6(12)	1128–142 [c]	<0.35	<9	$E1$ or $E2$
1023.44(7)	1.6(2)	1165–142			
1036.00(4)	512(15)	1079–43 [c]	1.82(5)	3.6(1)	$E1$
1045.08(6)	0.73(12)	1887–842			
1045.66(6)	0.73(12)				
1062.04(4)	691(14)	1105–43 [c]	2.25(7)	3.3(1)	$E1$
1078.86(4)	1120(40)	1079–0 [c]	3.29(14)	2.94(13)	$E1$
1081.40(6)	~10	1124–43 [c]			
1085.15(6)	61.6(19)	1128–43 [c]	0.15(1)	2.4(10)	$E1$
1102.5(2)	0.14(4)				
1105.0(5)	0.03(2)	(Sum peak)			
1113.6(2)	0.27(5)				
1122.64(6)	4.0(2)	1165–43 [c] }	0.13(3)	9(2)	{ $E2$
1124.29(4)	10.5(4)	1124–0 [c] }			{ $E2$
1131.88(7)	0.44(5)	1175–43			
1148.62(6)	0.74(6)				
1158.47(6)	0.50(4)	1300–142			
1167.74(5)	1.01(6)	1211–43	K: 0.72(15)	α_K: 710(150)	$E0+(M1, E2)$
			L: 0.17(3)	α_L: 710(30)	
1174.72 [e]	0.8(2) [e]	1175–0	K: 0.80(3)		$E0$
			L: 0.19(2)		
1177.2(2)	0.15(4)	1220–43			
1198.19(6)	1.24(6)				
1203.2(2)	0.20(7)				
1206.96(4)	6.0(2)	1250–43	<0.03	<5	$E1$
1210.35(9)	0.45(7)	1211–0			
1237.2(2)	0.29(4)	1379–142			
1249.79(4)	6.0(2)	1250–0 [c]	0.11(2)	18(4)	
1257.62(6)	1.57(10)	1300–43			
1274.72(4)	10.8(3)	(1318–43) [d]	K: 0.30(10)	α_K: 28(10)	$M1(+E0)$
			$L1$: 0.06(2)	α_{L1}: 6(2)	
1289.4 [e]	0.070(10) [e]	1289–0	0.07(1)		$E0$
1297.34(9)	0.42(5)				
1303.20(11)	0.35(4)				
1306.8(2)	0.25(4)				
1323.77(8)	1.0(2)	1367–43			
1336.38(7)	0.74(5)	(1379–43)			
		(1478–142)			
1348.81(4)	4.84(17)	1349–0 [c]	<0.02	<5	$E1$
1367.9(2)	0.63(11)	1509–142			
1379.3(4)	0.07(4)				
1383.94(17)	0.22(4)	1526–142			
1409.12(8)	1.35(7)	1452–43	0.050(19)	37(14)	
1435.59(6)	1.04(10)	1478–43			

TABLE I *(Continued)*

Energy [a] (keV)	Relative γ-ray intensity	Assignment	Relative K-electron intensity	α_K (10^{-3})	Multipolarity
1451.91(4)	1.83(8)	1452–0	0.035(16)	19(9)	$M1$
1459.32(6)	0.38(4)	1601–142			
1466.33(6)	0.30(4)	1509–43			
1479.43(4)	9.2(3)	1621–142	<0.03	<3	$E1$
1483.09(9)	0.83(7)	1526–43			
1486.90(7)	0.08(6)	1629–142			
1497.0(4)	0.024(15)				
1509.0(4)	0.030(15)	(1509–0)			
1526.30(15)	0.55(11)	(Sum peak)			
1529.00(7)	9.0(4)	1671–142 }	0.045(14)	4.5(14)	$\left\{\begin{pmatrix}E1\\M1\end{pmatrix} \text{or} \begin{pmatrix}E2\\E2\end{pmatrix}\right.$
1530.7(5)	1.0(2)	1574–43 }			
1538.9(2)	0.055(19)	1681–142			
1540.6(2)	0.03(2)				
1545.0(5)	0.09(4)				
1550.0(2)	2.1(10)		<0.02	<10	$E1$ or $E2$
1550.94(9)	11.0(10)	1594–43	<0.03	<3	$E1$
1552.22(16)	2.1(10)		<0.02	<10	$E1$ or $E2$
1558.35(10)	0.68(7)	1601–43			
1561.30(5)	3.84(15)	1604–43	<0.02	<5	$E1$ or $E2$
1570.46(7)	0.62(5)	1712–142			
1573.74(5)	1.95(8)	1574–0	0.027(10)	14(5)	$M1$
1578.62(5)	3.12(12)	1621–43	<0.015	<5	$E1$ or $E2$
1586.1(2)	0.2(1)	1629–43			
1590.68(5)	21.0(15)	1634–43	0.042(13)	2.0(6)	$E1$
1601.8(3)	0.11(5)				
1604.14(5)	4.11(15)	1604–0	<0.02	<5	$E1$ or $E2$
1616.3(2)	0.12(3)	1659–43			
1618.80(4)	4.64(18)	1662–43	0.06(1)	14(2)	$M1$
1628.17(5)	2.21(11)	1671–43	<0.01	<5	$E1$ or $E2$
1637.95(5)	6.5(8)	1681–43	0.088(9)	14(2)	$M1$
1659.18(10)	0.51(4)	1659–0			
1661.63(5)	9.1(3)	1662–0	0.09(1)	10(1)	$M1(+E2)$
1669.50(5)	0.63(4)	1712–43			
1680.69(18)	0.043(8)	1681–0			
1690.15(16)	0.05(2)				
1714.61(9)	0.087(9)	1857–142			
1737.94(5)	4.5(3)	1781–43	0.06(1)	13(2)	$M1$
1756.1(2)	0.057(9)	1898–142			
1759.30(5)	0.86(7)	1901–142			
1764.2(2)	0.036(8)	1906–142			
1769.47(7)	0.079(14)				
1778.92(6)	0.90(5)	1822–43			
1780.5(2)	0.16(4)	1781–0			
1794.7(4)	0.015(5)	1837–43			
1801.53(6)	0.38(4)				
1804.8(2)	0.037(9)	1947–142			
1813.73(6)	0.110(10)	1857–43			
1821.70(12)	0.059(12)	1822–0			
1827.39(5)	0.77(6)	1870–43			
1832.6(3)	0.019(9)	1876–43			
1836.71(6)	0.19(2)	1837–0			
1843.86(5)	0.36(3)	1887–43			
1855.34(12)	0.06(2)	1898–43			
1858.7(2)	0.031(5)	1901–43			

TABLE I *(Continued)*

Energy [a] (keV)	Relative γ-ray intensity	Assignment	Relative K-electron intensity	α_K (10^{-3})	Multipolarity
1863.19(18)	0.038(6)	1906–43			
1866.48(6)	0.20(3)	1909–43			
1869.81(15)	0.040(8)	1870–0			
1875.56(12)	0.034(8)	1876–0			
1881.70(5)	0.30(3)	1925–43			
1886.80(5)	0.50(3)	1887–0			
1897.8(2)	0.018(4)	1898–0			
1904.26(10)	0.049(6)	1947–43			
1909.27(9)	0.057(6)	1909–0			
1924.56(5)	0.33(3)	1925–0			
1940.43(18)	0.022(4)	1983–43			
1944.79(15)	0.014(7)				
1953.6(5)	0.004(2)				
1974.2(3)	0.012(4)				
1983.2(3)	0.012(4)	1983–0			
1989.63(8)	0.042(8)	2032–43			
2000.3(5)	0.005(3)				
2029.39(8)	0.047(5)	2171–142			
2032.49(11)	0.041(15)	2032–0			
2058.18(6)	0.058(4)				
2065.0(2)	0.017(4)				
2068.69(8)	0.061(4)				
2083.1(2)	0.013(3)				
2091.4(3)	0.008(2)				
2103.18(7)	0.063(6)	2146–43			
2123, 66(7)	0.105(7)				
2128.57(9)	0.052(5)	2171–43			
2140.2(3)	0.009(2)				
2146.05(7)	0.123(7)	2146–0			
2149.5(2)	0.019(3)				
2156.05(17)	0.014(3)				
2168.33(7)	0.044(4)				
2184.79(15)	0.011(2)				
2203.4(5)	0.003(1)				
2234.4(3)	0.006(2)				
2259.2(4)	0.004(2)				
2287.0(6)	0.002(1)				

[a] Numbers in parentheses indicate standard deviation of least significant digits.
[b] These transitions were determined indirectly (see text). Intensity values give total transition intensities.
[c] Indicates that placement is confirmed by coincidence data.
[d] Refers to a weak coincidence line.
[e] The $E0$ transitions were observed in conversion-electron spectra. Intensity values give electron intensities normalized to 1000 units for the 798-keV γ-ray intensity.

by higher source activities. Figure 2 shows a region of a Compton-suppression spectrum revealing numerous weak lines not previously reported. The value of the high-resolution (1.9 keV) coaxial detector is illustrated by the data in Fig. 3, where a 1081-keV line is revealed on the edge of the intense 1079-keV line. Adequate study of the high-energy region (Fig. 4) required the high efficiency of a large coaxial detector and 11 days of continuous counting time. Within the same energy region in spectra obtained in our previous work, only the 1925- and 2146-keV lines appeared above background.

The γ rays observed in ^{246}Am^m decay are listed in Table I. This table is a summary of γ-ray singles data obtained with Ge(Li) planar, coaxial, and Compton-suppression spectrometers. γ rays assigned to Pu decay were identified in data taken with a separated Pu source and are given in Ref. 13. Measured conversion coefficients are shown in the table along with the derived transition multipolarities. Pure *E*0 transitions at 1174.72 and 1289.4 keV are included and their total conversion intensities are given. Measured *K*-to-*L* electron intensity ratios for both transitions are in agreement with predictions of Bell *et al.*[14] As indicated in Table I, many of the γ-ray assignments have been established by means of Ge(Li)-Ge(Li) coincidence results. Coincidence data also established that the 244-keV line is a doublet and revealed low-energy transitions at 34.76, 46.87, and 81.63 keV. Coincidence results are summarized in Table II.

The number of γ rays observed and assigned in this work is greatly increased from our earlier work[1]; hence a single complete decay scheme has become quite cumbersome. It is more instructive to examine partial decay schemes, which we present for those levels that can be assigned to bands, or for which the data otherwise warrant a detailed discussion. Table III contains a list of all the levels identified, along with corresponding log*ft* values. Note that for levels above ~1800 keV, log*ft* values are very uncertain because of the possibility of large effects from weak unobserved transitions. The known band structure of ^{246}Cm is summarized in Fig. 5.

A. $K^{\pi}=2^{-}$ band at 842 keV

In addition to previously observed[1,10,17] γ rays that depopulate levels of the 842-keV band, intense intraband transitions (Fig. 6) have been revealed by coincidence data. In coincidence with the 602- and 698-keV γ rays that directly populate the 923-keV level, we observe γ rays deex-

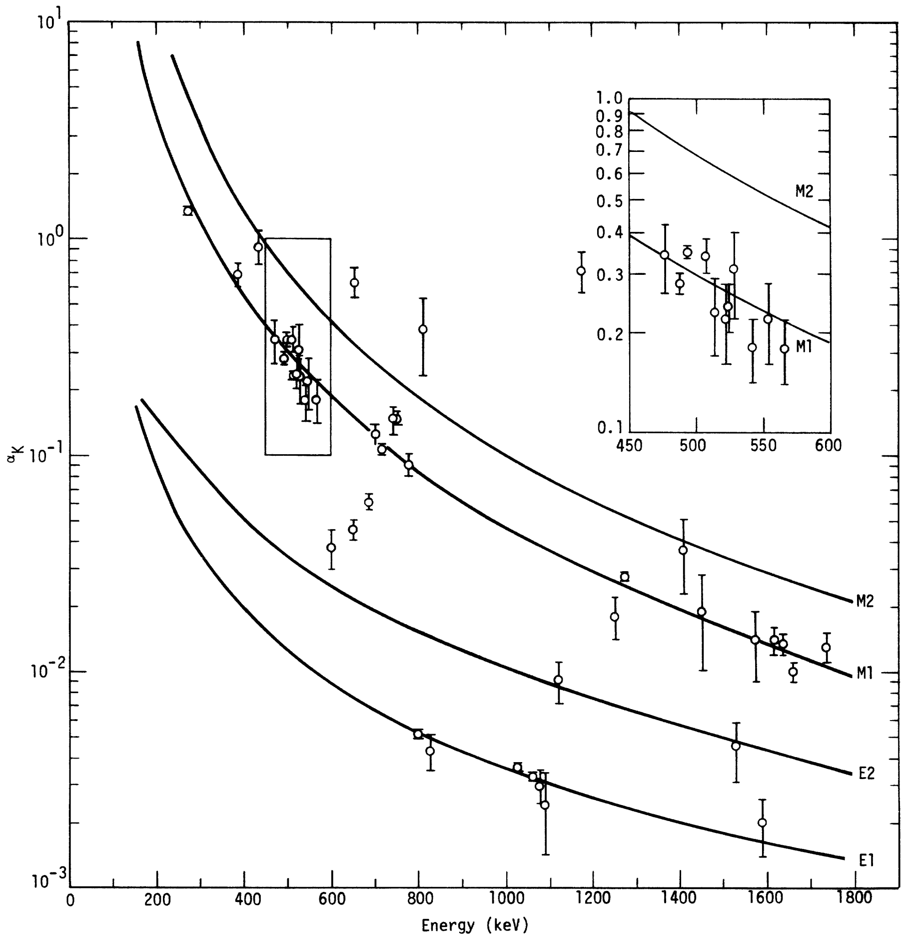

FIG. 1. *K*-shell conversion coefficients of ^{246}Cm γ transitions. Experimental values are normalized to theoretical value of Hager and Seltzer (Ref. 12), indicated by solid lines. Error bars reflect statistical errors in measured electron and γ-ray peak areas and in electron and γ-ray relative-efficiency curves.

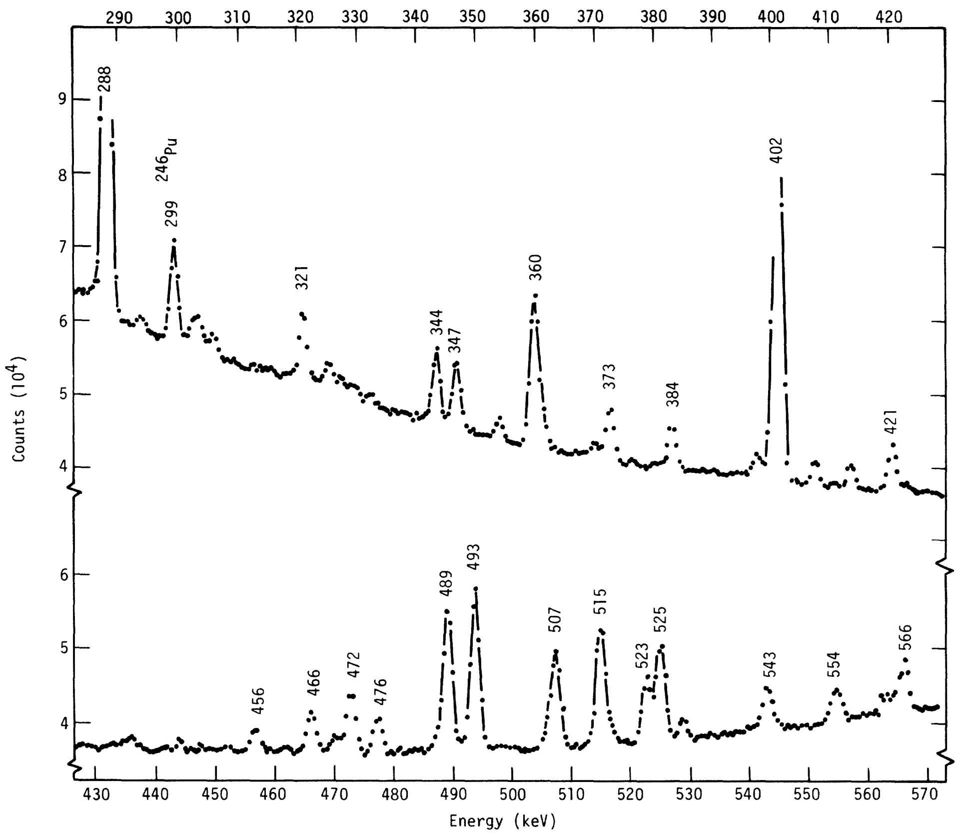

FIG. 2. High Compton background region from Compton-suppressed spectrum.

citing not only the 923-keV level, but also the two lower-energy levels of the band. Similarly, in coincidence with γ rays populating the 876-keV level (at 649, 717, 725, and 745 keV), we observe the 799-keV γ ray from the 842-keV level. By comparing the intensities of transitions to the ground-state band, we obtain intensities of the intraband transitions, all of which should be highly converted, and hence, unidentifiable in γ-ray spectra.

Conversion data firmly establish negative parity assignments, as summarized in Fig. 6. Conversion electrons were observed for several of the $E1$ transitions because of their large transition intensities.

B. Negative parity bands at 1079, 1250, and 1349 keV

Negative parity bands at 1079, 1250, and 1349 keV (Figs. 7, 8, and 9), having K values of 1, 0, and 1, respectively, are well known from other studies.[1,17,18] Our conversion and coincidence results firmly establish spin and parity assignments for each of the observed levels. Coincidence results verify the placements of intense transitions between the 1079-keV and ground-state bands and between the 1349- and 1079-keV bands. Singles data have revealed previously unobserved transitions from the 2^- level at 1105 keV to the 0^+ and 4^+ levels of the ground-state band. The low in-

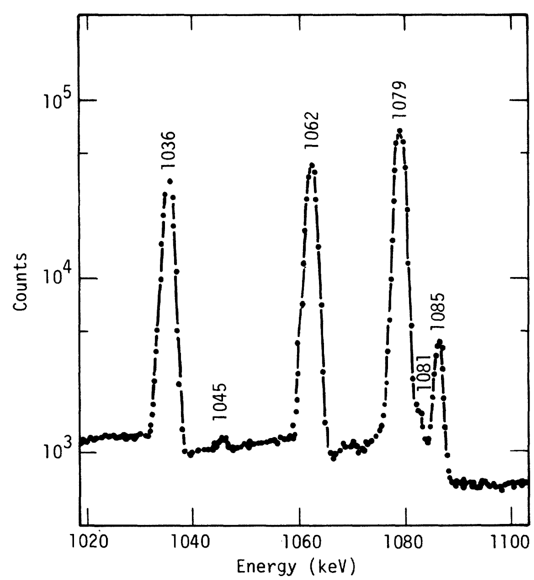

FIG. 3. High-resolution data revealing 1081-keV line.

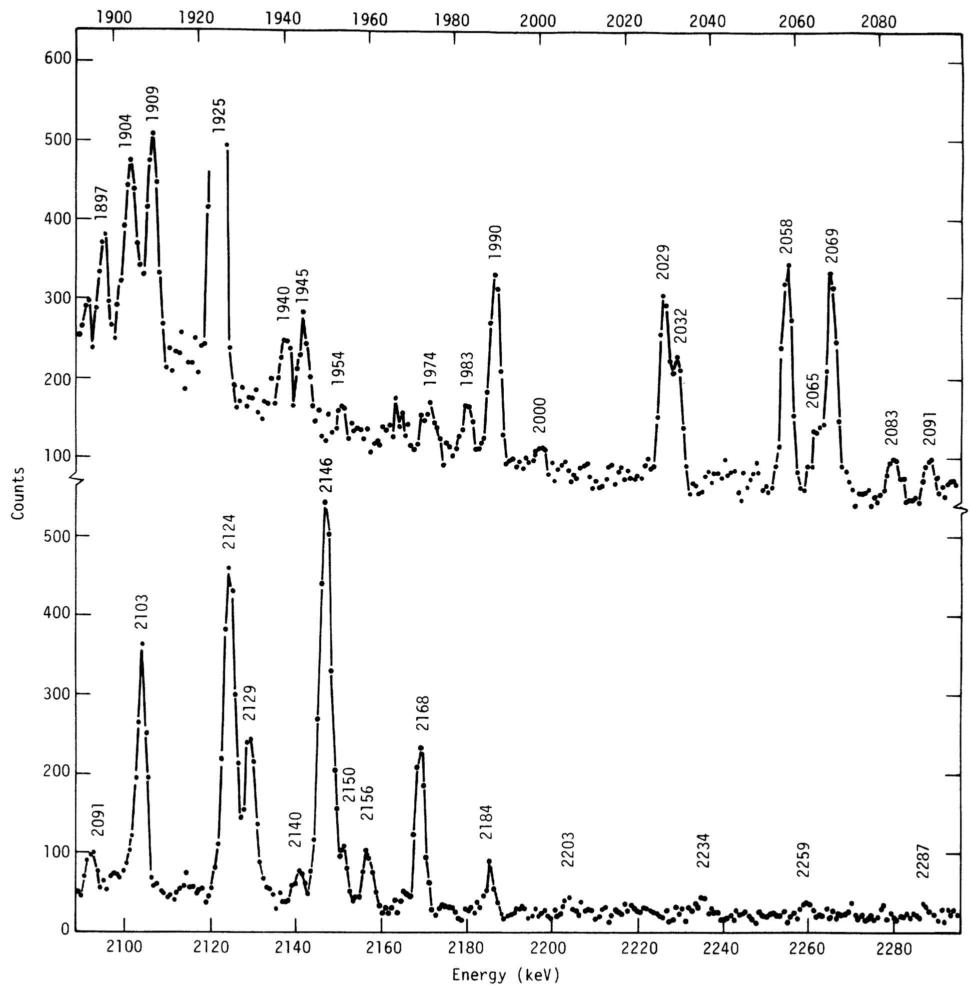

FIG. 4. High-energy data from 11-day run on high-efficiency detector.

TABLE II. γ-ray coincidence results.

Gated E_γ	γ-ray observed in coincidence gate (Numbers enclosed in parentheses refer to a weak coincidence)	Gated E_γ	γ-ray observed in coincidence gate (Numbers enclosed in parentheses refer to a weak coincidence)
244.0	244.9, 1062.0	798.8	237.2, (507.1), 524.9, 649.4, 684.2, 717.3, 724.8, 752.1, 759.6, 779.9, 791.5, 939.2
244.9		833.6	649.4, 717.3, 724.8, 745.1, 904.4
270.1	237.2, 244.9, 1036.0, 1078.8	986.0	237.2, (398.1), (465.6), 493.5
287.8	237.2, 1036.0, 1078.8	1036.0	171.1, 270.1, 287.8, 514.8, (554.7)
401.7	1081.4, 1124.3	1062.0	244.0, 261.8, (421.1), 488.8, 566.1
602.5	781.3, 798.8, 833.6	1078.8	171.1, 244.0, 270.1, 287.8, 514.8, 798.8
649.4	734.4, 798.8, 833.6	1085.2	238.6, 493.5, 542.9
684.2	(524.9), 798.8	1122.6	360.4, (456.1)
698.3	734.4, 781.3, 798.8, 833.6	1124.3	401.7, (476.9)
717.3	734.4, 798.8, 833.6	1198.2	None
724.8	734.4, 798.8, 833.6	1249.8	None
734.4	649.4, 717.3, 724.8, 745.1, 904.4	1274.7	None
745.1	734.4, 798.8, 833.6	1348.8	None
752.1	798.8		
759.6	798.8		

TABLE III. β decay of $^{246}Am^m$.

Level Energy [a] (keV)	$I^{\pi}K$	% of total	Log*ft* [b]	Level Energy [a] (keV)	$I^{\pi}K$	% of total	Log*ft* [b]
0	0^+0	~0 [c]		1604.16(4)	1^-1	0.210	7.7
42.83(2)	2^+0	7 [c]	8.0	1621.49(4)	3^-2	1.01	7.0
141.99(3)	4^+0	1.1	9.9	(1628.90(7))		≤0.007	≥9.2
841.67(2)	2^-2	16.0	7.0	1633.51(4)	2^-1	0.70	7.1
876.43(2)	3^-2	6.94	7.3	1659.19(9)	(1^-)	≤0.038	≥8.4
923.30(3)	4^-2	~0		1661.64(4)	1^+1	0.36	7.4
1078.84(2)	1^-1	37.2	6.3	1670.99(4)	3^-1	0.45	7.3
1104.85(2)	2^-1	14.0	6.7	1680.81(5)	2^+1	0.170	7.6
1124.26(2)	2^+2	0.29	8.4	1712.37(5)	3^+1	≤0.025	≥8.4
1128.01(3)	3^-1	0.82	7.9	1780.80(5)	2^+	0.281	7.2
1165.47(3)	3^+2	≤0.060	≥8.9	1821.75(6)		0.024	9.4
1174.72(7)	0^+0	~0		(1836.73(6))		0.0107	8.4
1210.52(5)	2^+0	≤0.036	≥8.9	1856.53(5)		0.044	7.7
1219.91(10)	4^+2	~0		(1870.19(5))		≤0.029	≥7.9
1249.77(2)	1^-0	0.62	7.9	(1875.55(12))		0.036	7.8
1289.4(2)	0^+0	≤0.002	≥10.8	1886.76(5)	1^+	0.058	7.5
1300.44(4)	3^-0	≤0.015	≥9.4	1898.06(9)	(2^+)	≤0.0186	≥8.0
1317.55(4)	(2^+0)	0.268	8.1	1901.31(6)		0.0221	7.9
1348.85(4)	1^-1	5.85	6.8	(1906.10(14))		0.0017	9.0
1366.62(4)	2^-1	1.54	7.3	1909.31(5)		0.0065	8.4
1379.22(7)	(4^+0)	≤0.025	≥9.5	1924.56(5)		0.0156	8.0
1451.88(4)	1^+1	0.113	8.3	(1947.07(7))		≤0.0082	≥8.2
1478.44(5)	(2^+1)	0.108	8.4	1983.34(8)		≤0.0186	≥7.6
1509.24(5)	(3^+1)	≤0.0144	≥9.1	2032.48(6)		≤0.0062	≥7.9
1525.92(4)	3^-3	1.71	7.0	(2099.75(18))		≤0.053	≥6.5
1573.74(5)	1^+	~0.073	~8.3	2146.04(5)		0.0047	7.2
1593.69(4)	2^-2	1.88	6.8	2171.41(6)		0.0109	6.7
1601.22(4)	3^+3	0.96	7.1				

[a] Numbers in parentheses indicate standard deviation of least significant digits.
[b] Calculated using the tabulation of Gove and Martin (Ref. 16).
[c] Given in Ref. 15.

tensities are consistent with the expected $M2$ multipolarities. From levels of the 1250-keV band we observe transitions to the 842-keV band in addition to the previously observed transitions to the ground-state and the 1079-keV bands.

C. $K^{\pi}=2^+$ band at 1124 keV

In previous studies,[1,11] the 1124- and 1165-keV levels were identified as the 2^+ and 3^+ members, respectively, of the γ-vibrational band (Fig. 10). We added a 962.9-keV transition between the 1124-keV level and the 4^+ member of the ground-state band, giving added confirmation to the 2^+ assignment. The 2^+ and 3^+ assignments are also supported by the $E2$ multipolarities deduced for ground-state-band transitions from measured conversion coefficients. Orth[11] has previously deduced an $E2$ value for the 1124-keV transition. In our conversion-electron spectra, the 1123- and 1124-keV lines form an unresolved doublet; however, when γ-ray and conversion intensities are analyzed together, agreement with the theoretical conversion coefficient for $E2$ transitions is very good.

Besides the 2^+ and 3^+ levels, we now have evidence for the 4^+ member of the 1124-keV band. Based on an $I(I+1)$ level spacing, we calculate for the 4^+ level an energy value of 1220.5 keV. In this work we added a level nearby at 1219.91 keV. This level is based on an 1177-keV transition to the 2^+ level of the ground-state band, and on five γ rays by which it is populated: from two 3^+, two 3^-, and one 2^+ level. When considered together with the lack of a transition to the 0^+ ground state and with the high apparent log*ft* for β decay (≥10.0), a 4^+ spin and parity assignment is entirely reasonable, though not definitely established by model-independent arguments.

D. $K^{\pi}=0^{+}$ bands at 1175 and 1289 keV

A level at 1211 keV was suggested in our previous work.[1] Improved singles and conversion-electron data confirm the 1211-keV-level placement and add an associated level at 1175 keV (Fig. 11). Both levels are populated by γ transitions, and decay by transitions to the 0^{+} and 2^{+} members of the ground-state band. Strong $E0$ contributions to the decay provide definite spin and parity assignments and a K value of zero. The 1175-keV level is assigned a spin value of 0^{+} based on the observed pure $E0$ decay to the ground state. A 2^{+} value is indicated for the 1211-keV level by the $E0$ contribution in the transition to the 2^{+} level of the ground-state band. The assigned K value is consistent with the large measured $\log ft$ value for β decay to the 2^{+} level (≥ 8.9), which is expected for a $\Delta K=2$ forbiddenness. A separation energy of 35.8 keV (compared with 42.83 keV for the 0^{+} and 2^{+} members of the ground-state band) provides additional evidence

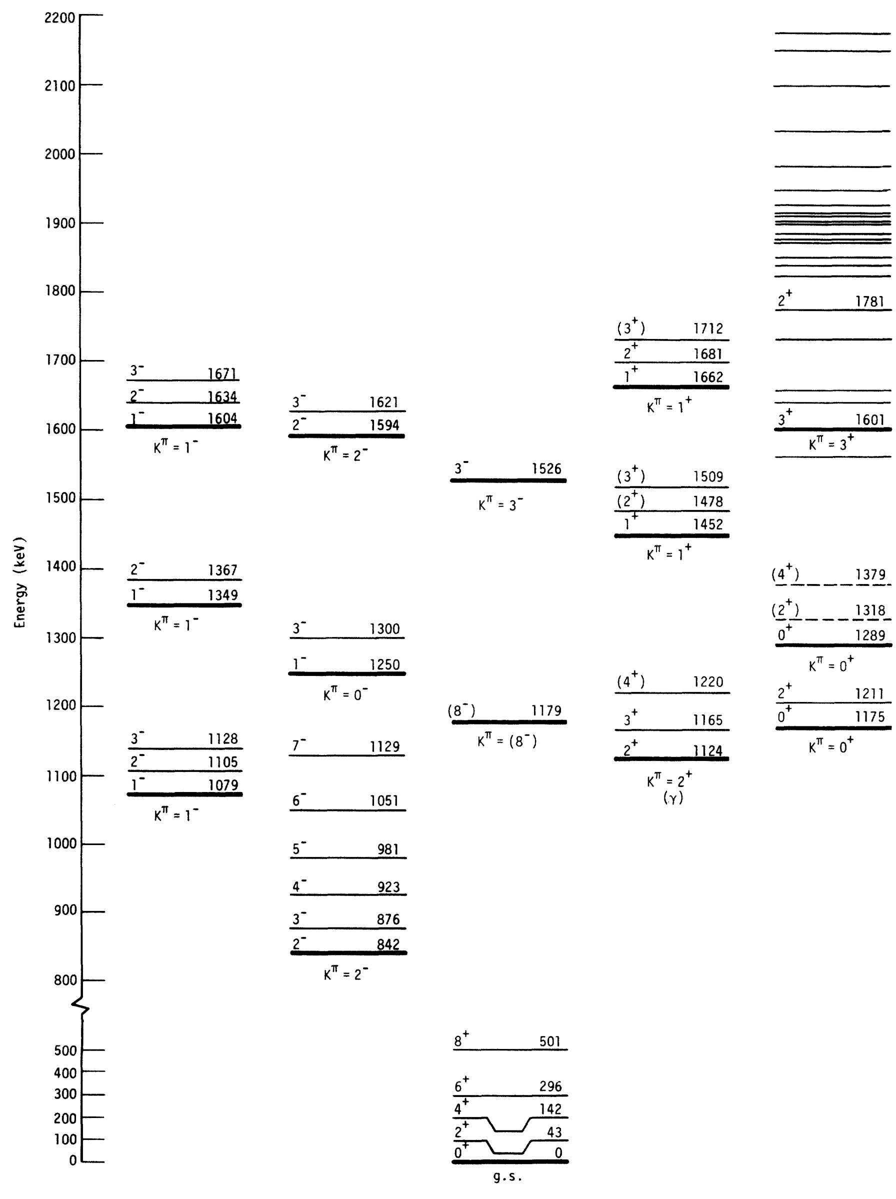

FIG. 5. Band structure and levels in ^{246}Cm based on the present investigation and on previous studies (Refs. 1, 11, 17, and 18). High-spin levels ($I>4$) are taken from Refs. 1 and 17.

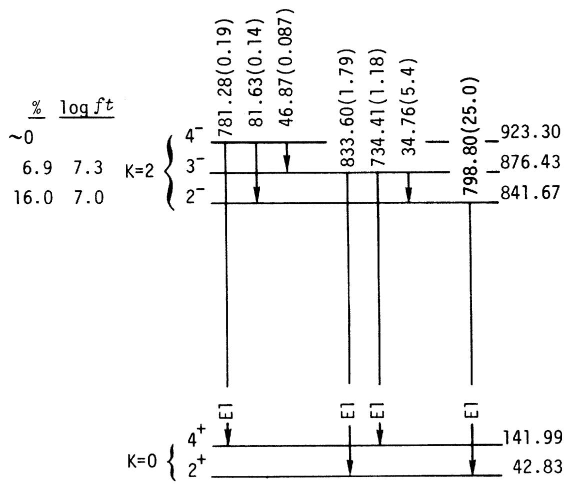

FIG. 6. Decay of the $K^\pi=2^-$ band at 842 keV.

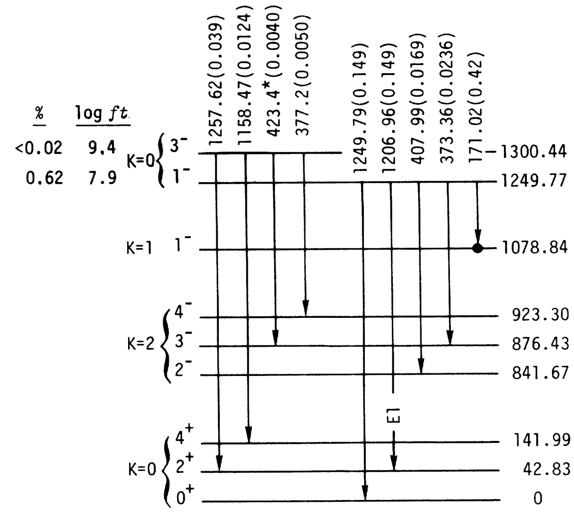

FIG. 8. Decay of the $K^\pi=0^-$ band at 1250 keV. * = γ ray used elsewhere in the ^{246}Cm decay scheme. ● = γ ray observed in coincidence with a γ ray deexciting the indicated level.

for identifying the 1175- and 1210-keV levels as the 0^+ and 2^+ members of a $K^\pi=0^+$ band. This is in agreement with Maher *et al.*[19] who also identified this band and have established the 0^+ assignment from (p, t) studies.

We propose another $K^\pi=0^+$ band with $I^\pi=0^+$, 2^+, and 4^+ members at 1289, 1318, and 1380 keV, respectively (Fig. 12). In conversion-electron spectra we observe the ground-state $E0$ decay of the 1289-keV band head. The associated $E2$ transition to the ground-state 2^+ level is, however, masked in γ-ray spectra by an intense 1250-keV line.

The proposed 2^+ member is based on a strong 1275-keV transition to the ground-state 2^+ level for which the measured conversion coefficient indicates a probable $M1$ multipolarity with $E0$ admixture. We attempted to find other transitions that would establish the 1275-keV placement; however, none appeared in singles or coincidence data. Therefore, the existence and $I^\pi K$ values of the 1318-keV level are based on the following arguments:

(i) The 1275-keV transition cannot feed any states above the 4^+ level of the ground-state band because it does not appear in coincidence spectra.

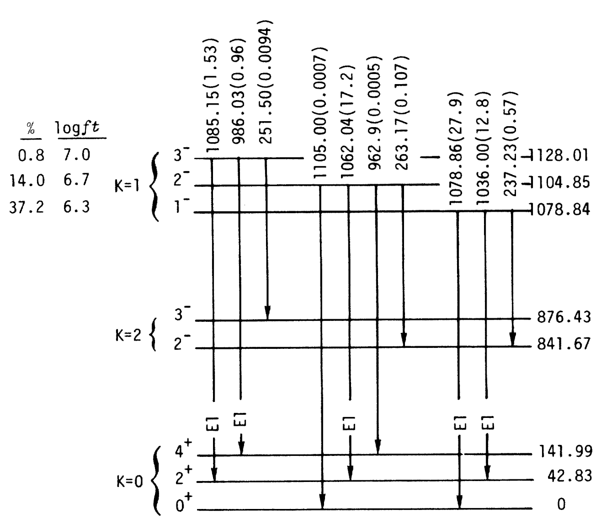

FIG. 7. Decay of the $K^\pi=1^-$ band at 1079 keV.

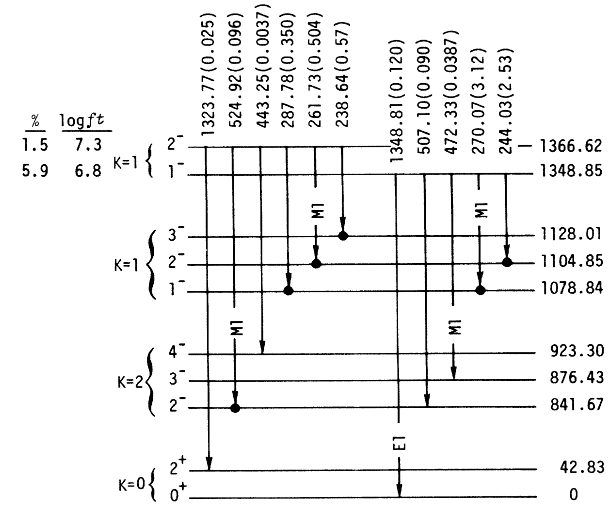

FIG. 9. Decay of the $K^\pi=1^-$ band at 1349 keV. ● = γ ray observed in coincidence with a γ ray deexciting the indicated level.

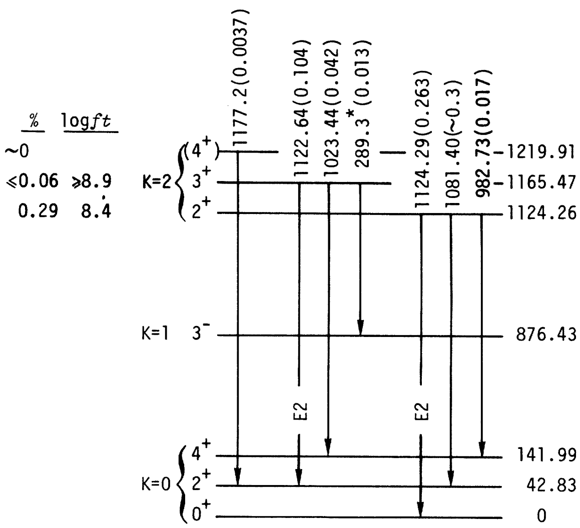

FIG. 10. Decay of the $K^\pi = 2^+$ band at 1124 keV. * = γ ray used elsewhere in the ^{246}Cm decay scheme.

(ii) The 1275-keV γ ray must come from a level fed by β decay because nothing appears in coincidence with it.

(iii) The intensity of the 1275-keV γ ray requires that the level it deexcites be fed by an allowed or first-forbidden β decay, and hence have a spin value of <4.

(iv) The measured multipolarity of $M1$ ($+E0$) (or possibly $E2+E0$) requires that the level have spin >0 and have positive parity.

Hence, by strong arguments we determine that the 1275-keV transition populates the 0^+, 2^+, or 4^+ members of the ground-state band and that it deexcites a 1^+, 2^+, or 3^+ level. Further arguments characterizing the new level are model dependent and are as follows:

(v) The $M1$ multipolarity of the 1275-keV transition rules out a K value of 2 or greater because a transition to the ground-state band would be K forbidden.

(vi) If the 1275-keV γ ray depopulates a level with $K=1$ and $I^\pi = 1^+$, 2^+, or 3^+, then the two other members of the triplet should be observed—that is, if one level is strongly fed by β decay, then the other two levels should be fed with comparable $\log ft$ values.

This leaves us with only one placement possibility, namely, an $I^\pi = 2^+$ level at 1318 keV from a $K=0$ band having a 1275-keV transition to the 2^+ level of the ground-state band. From the proximity of the 1289-keV level and the absence of any other unassigned levels, we assign the 1318-keV level as the 2^+ member of the 1289-keV band. The two levels then define a $K=0$ band having a higher moment of inertia than the 1124-keV band.

Because the 0^+ member of the 1289-keV band is populated by β decay, we might expect to see also the 4^+ member. We do find a candidate for this level at 1379.3 keV, which is near the 1383.2-keV energy calculated with the $I(I+1)$ relationship for this level. Its presence is based only on two weak γ rays, so it must be regarded as a very tentative assignment. However, the pattern of γ decay and the $\log ft$ of β decay (≥ 9.5) are consistent with a 4^+ spin and parity. Also, the experimental $2^- \to 4^+/2^- \to 0^+$ ft ratio of 0.050 agrees reasonably well with the theoretical value of 0.072.

E. $K=1$ bands at 1452, 1604, and 1662 keV

Bands at 1452 and 1604 keV were identified in our previous study,[1] and a band at 1662 keV was suggested. In this work we added several γ rays to the decay scheme and confirmed the presence

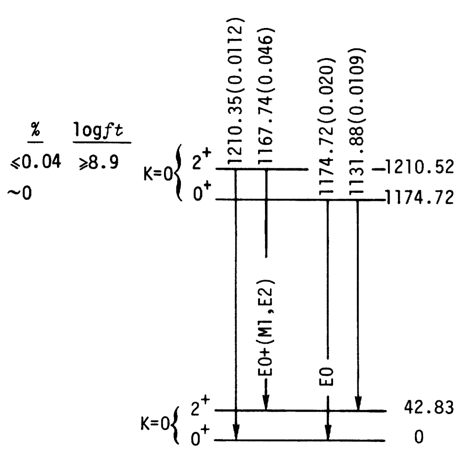

FIG. 11. Decay of the $K^\pi = 0^+$ band at 1175 keV.

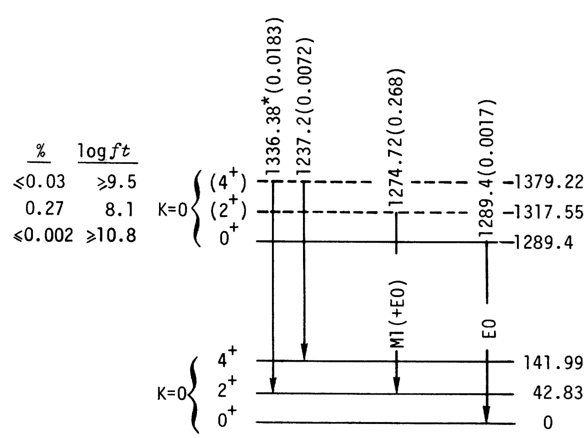

FIG. 12. Decay of the $K^\pi = 0^+$ band at 1289 keV. * = γ ray used elsewhere in the ^{246}Cm decay scheme.

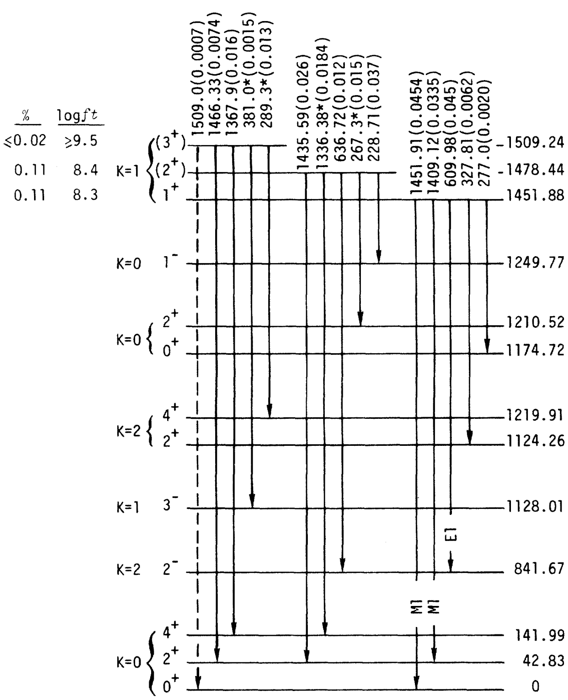

FIG. 13. Decay of the $K^{\pi}=1^{+}$ band at 1452 keV. $*=\gamma$ ray used elsewhere in the ^{246}Cm decay scheme.

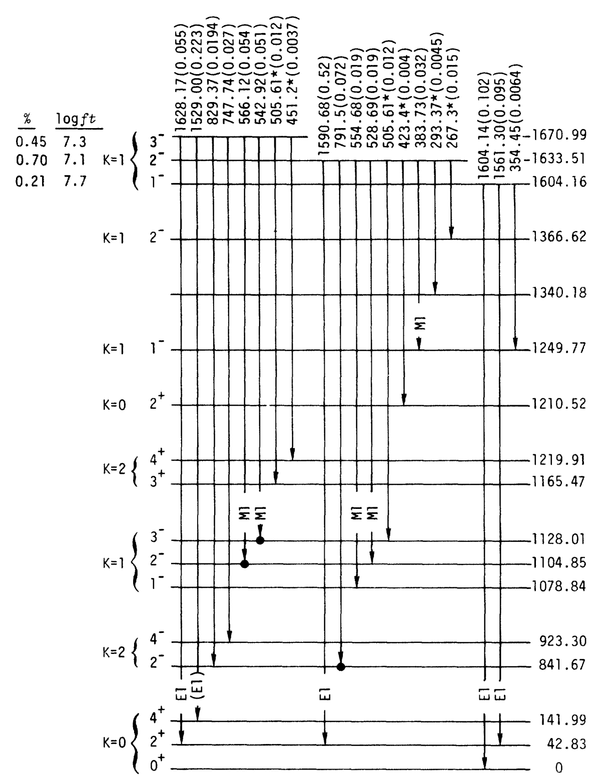

FIG. 14. Decay of the $K^{\pi}=1^{-}$ band at 1604 keV. $*=\gamma$ ray used elsewhere in the ^{246}Cm decay scheme. $\bullet=\gamma$ ray observed in coincidence with a γ ray deexciting the indicated level.

of levels identified previously (Figs. 13, 14, and 15). Conversion-electron results establish spin and parity values, and hence K^{π} values of 1^{+}, 1^{-}, and 1^{+} for the 1452-, 1604-, and 1662-keV levels, respectively.

Members of the 1452-keV band (Fig. 13) at 1452, 1478, and 1509 keV are weakly populated by β decay ($\log ft$ values of 8.3, 8.4, and ≥ 9.1, respectively). As a result, conversion-electron intensities of transitions deexciting the 1478- and 1509-keV levels were too weak to be measured. Hence, spin and parity assignments could not be definitely established.

The 1604-keV band (Fig. 14) is the most strongly populated of the three ($\log ft$ values of 7.7, 7.1, and 7.2 for levels at 1604, 1634, and 1661 keV, respectively). The two higher-energy levels are firmly established by numerous deexcitation γ rays and by coincidence results. Conversion data establish the spin and parity assignments.

We previously suggested[1] a $K^{\pi}=1^{-}$ assignment for the 1662-keV band (Fig. 15). A positive parity is now indicated by conversion data. Transitions to the 0^{+}, 2^{+}, and 4^{+} levels of the ground-state band restrict the 1681-keV level to a spin and parity of 2^{+}. The 1712-keV level has a probable spin of 3, based on the essentially equal transition intensities to the 2^{+} and 4^{+} levels of the ground-state band. The high β-decay intensities to levels of the 1662-keV band ($\log ft$ values of 7.4, 7.6, and ≥ 8.4) are similar to intensities to the 1^{+} band at 1452 keV, and significantly higher than intensities to the 1^{-} band at 1604 keV.

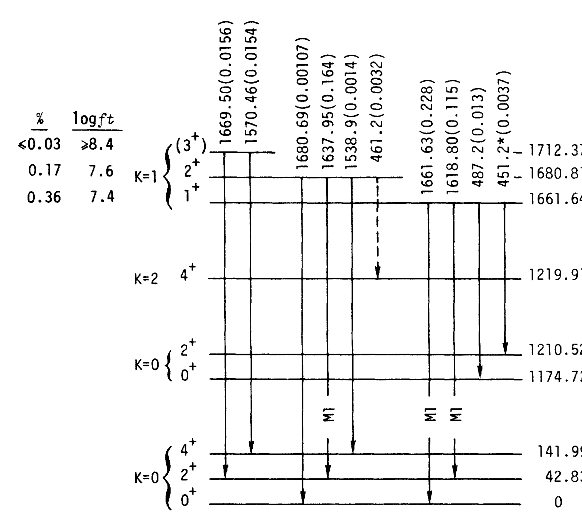

FIG. 15. Decay of the $K^{\pi}=1^{+}$ band at 1661 keV. $*=\gamma$ ray used elsewhere in the ^{246}Cm decay scheme.

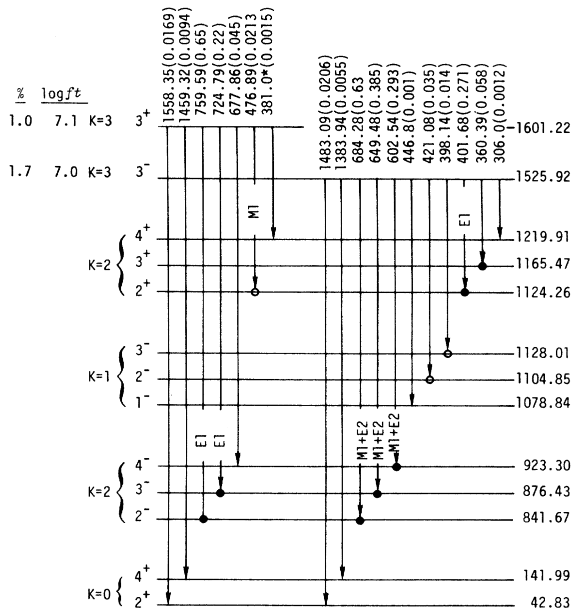

FIG. 16. Decay of the $K^\pi=3^-$ and 3^+ levels at 1526 and 1601 keV, respectively. * = γ ray used elsewhere in the ^{246}Cm decay scheme. ● = γ ray observed in coincidence with a γ ray deexciting the indicated level. ○ = coincidence which is probable, but not certain.

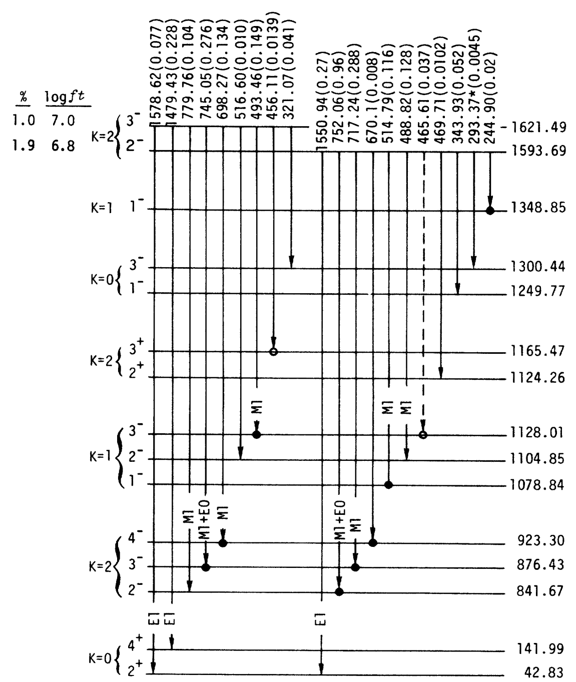

FIG. 17. Decay of $K^\pi=2^-$ band at 1594 keV. * = γ ray used elsewhere in the ^{246}Cm decay scheme. ● = γ ray observed in coincidence with a γ ray deexciting the indicated level. ○ = coincidence which is probable, but not certain.

F. $K^\pi=3^-$, 2^-, and 3^+ bands at 1526, 1595, and 1601 keV

Earlier we reported[1] bandheads with spin 3 at 1526 and 1601 keV. Results of this work (Figs. 16 and 17) confirm the spin assignments, and conversion-electron data establish a negative parity value for the 1526-keV level and a positive value for the 1601-keV level. Weak γ transitions from each level were added and coincidence data confirmed the strong transitions to the $K=2$ bands at 842 and 1124 keV.

The $K^\pi=2^-$ band at 1594 keV (Fig. 16) was also identified in our previous work.[1] Spin, parity, and K value assignments are confirmed by coincidence and conversion-electron results. In particular, $E0$ admixtures in transitions to levels of the 842-keV band confirm the $K=2$ assignment. We assigned several additional weak transitions to the decays of both the 2^- and 3^- levels.

G. Other high-energy levels

Several high-energy levels (Fig. 5) not correlated to form bands were identified. A spin and parity assignment of 1^+ for a weakly populated level at 1574 keV is based on the measured $M1$ multipolarity of the 1574-keV transition to the ground state. A level at 1659 keV is based on the observation of transitions to the ground state, 2^+ at 43 keV and 2^- at 842 keV. Conversion-electron results indicate a probable $M1$ multipolarity for the 554-keV transition to the 1105-keV level, giving a corresponding spin and parity of 1^-. A level of 2^+2 at 1781 keV (Fig. 18) is rather strongly populated ($\log ft=7.2$). Its presence is confirmed by

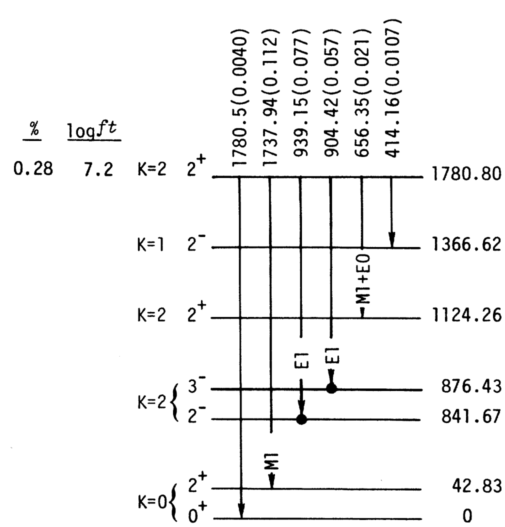

FIG. 18. Decay of the 2^+ level at 1781 keV. ● = γ ray observed in coincidence with a γ ray deexciting the indicated level.

coincidence data and its spin and parity are established by conversion-electron results. A K value of 2 is indicated by the $E0$ mixture in the 656-keV transition to the γ-vibrational band. A level at 1887 keV is assigned a spin and parity of 1^+ on the basis of an $M1+E0$ multipolarity mixture for a 435-keV transition to the 1^+ level at 1452 keV. Conversion-electron results allow either an $M2$ or $M1+E0$ assignment. An $M2$ would imply a spin change of 2, suggesting a 3^+ assignment for the level. This, however, is inconsistent with the observed transition intensity to the 0^+ ground state. The 2^+ assignment for the 1898-keV level is based on transitions to the 0^+, 2^+, and 4^+ levels of the ground-state band.

There are several other levels with energies above 1600 keV that have been identified on the basis of the energy relationships between deexciting γ rays. Many of these clearly have low-spin values, as they are observed to decay to the 0^+ ground state. However, data is insufficient to characterize them further.

IV. DISCUSSION

A. Octupole bands

Experimental evidence from previous studies[1,11,18] points to a probable collective interpretation for $K^\pi=0^-$, 1^-, and 2^- bands at 1250, 1079, and 842 keV, respectively. In our current work we observed transitions between members of the 842-keV band that provide a measure of the hindrance of $E1$ transitions to the ground-state band ($\approx 10^7$). This is due in part to K hindrance ($\Delta K=2$); but is also to be expected from quasiparticle forbiddenness if the dominant configurations are those suggested by Soloviev and Siklos[20] in their collective interpretation of the 842-keV band. Also, note that intraband transitions provide a measure of the enhancement over single-particle estimates of the ratio of $E2$ to $M1$ strengths ($\approx 10^4$).

In this work we identified, at 1526 keV, a candidate for the 3^- member of the octupole quadruplet. Supporting the assignment are intense transitions to the 842-keV band ($K^\pi=2^-$), and transitions to the 1079-keV band ($K^\pi=1^-$) that are similarly intense in spite of the K hindrance. There are few two-quasiparticle candidates for $K^\pi=3^-$ bands in the region of $N=146$, $Z=100$. The only candidates expected to lie below a few MeV excitation energy are the $\frac{9}{2}[734]\uparrow-\frac{3}{2}[622]\downarrow$ and the $\frac{7}{2}[743]\uparrow-\frac{1}{2}[620]\uparrow$ two quasineutron configurations. The second of these would couple to configurations included in calculations of Soloviev and Siklos[20] for the 842- and 1124-keV bands only by quasiparticle-forbidden transitions. In view of the strong observed

TABLE IV. Experimental and theoretical octupole bandhead energies.

	Bandhead energies (keV)				
K^π	Experimental	CRPA [a]	SDI [b]	SIF [b]	POF [b]
0^-	1250	1220	1250	1340	1260
1^-	1079	820	1360	1270	1340
2^-	842	760	1020	1500	1160
3^-	1526	1290	1809	1890	1900

[a] Random-phase approximation with corrections made due to particle-phonon interactions, calculated by Neergaard and Vogel (Ref. 22).

[b] Surface δ interaction (SDI), pairing-plus-state-independent-octupole force (SFI), and pairing-plus-octupole force (POF), calculated by Faessler and Plastino (Ref. 21).

γ-ray coupling, it becomes probable that the dominant configuration in the 1526-keV band is the $\frac{9}{2}[734]\uparrow-\frac{3}{2}[622]\downarrow$.

Several models have been used to calculate octupole states. Faessler and Plastino[21] have calculated bandhead energies with a pairing-plus-state-independent-octupole force (SIF), a pairing-plus-octupole force (POF), and a surface δ interaction (SDI). More recently, Neergaard and Vogel[22] calculated level energies in the random-phase approximation with corrections made for particle-phonon interactions (CRPA). In Table IV we compare calculated and experimental bandhead energies for the bands indicated above. Note that the inclusion of particle-phonon interactions in Neergaard and Vogel's results appears to lower bandhead energies and is in good agreement with experimental results for the $K^\pi=0^-$ and 2^- bands. The $K^\pi=1^-$ and 3^- bands are approximately 250 keV above CRPA predictions and 300 keV below those of Faessler and Plastino.

B. $K^\pi=0^+$ bands

The nature of 0^+ bands in deformed nuclei has been of special interest in recent years. Properties of low-energy 0^+ bands often correspond poorly to predictions for β-vibrational states. This has led[23] to the development of the pairing-vibration[24] and spin-quadrupole[25-27] models. Spin-quadrupole 0^+ states are associated with β vibrations, but in most cases have comparatively small $E0$ and $E2$ ground-state decay strengths.[26] Pairing vibrations are also characterized by low $E0$ and $E2$ decay strengths, and are strongly excited in two-nucleon-transfer reactions.[28] Calculations including both quadrupole- and pairing-field fluctuations[29] indicate that significant mixing of these configurations can occur.

In the actinide region, Maher *et al.*[19] have studied 0^+ levels with the (p,t) two-nucleon-transfer reaction and have found that measured cross sections are not consistent with either the β- or pairing-vibrational picture, and that they cannot be explained in terms of Nilsson-level systematics. Griffin *et al.*[30] attempted to explain these 0^+ states in terms of a modified pairing-force theory for which matrix elements between prolate and oblate states are considerably weaker than are matrix elements between like states. However, calculations of Chasman[31] using this model have failed to consistently predict 0^+ level energies. Bes, Broglia, and Nilsson[32] proposed that the observed 0^+ states can be explained in terms of quadrupole-pairing-correlation effects.

In this work, we identified a 0^+ state in ^{246}Cm at 1175 keV that corresponds to the 0^+ level observed by Maher *et al.*[19] We also identified a second low-energy 0^+ state at 1289 keV. Two-nucleon-transfer results suggest a pairing-vibration mixture in the 1175-keV state, but no similar mixture in the 1289-keV state. Several other quantities derived from observed transition multipolarities and intensities are given below. These parameters, however, do not provide a sensitive means of discriminating between models.

For the 1175-keV band, we measured the intensity ratio $B(E2, 2^+ \to 0^+ \text{ g.s.})/B(E2, 2^+ \to 2^+ \text{ g.s.})$, obtaining a value of 0.20. This compares with an Alaga ratio of 0.70. The discrepancy may indicate an $M1$ admixture in the 1167-keV transition. It could also be explained by a ground-state-band-mixing ratio of −0.077. We were unable to obtain a measure of this ratio for the 1289-keV band due apparently to the weakness of the $E2$ strength.

Next, we consider the $E0$-to-$E2$ intensity ratios that we have determined for both the 0^+ and 2^+ levels of the 1175-keV band. This ratio has been calculated for different models, but is not found to be a sensitive means of differentiating between them. The values obtained for different levels of a band should, however, be nearly equal (exactly equal if states are identical in their internal structures). Experimental values for the 0^+ levels give

$$0^+[B(E0)/B(E2)]/2^+[B(E0)/B(E2)] = 0.23 \pm 0.08 .$$

Comparing the $E0$-to-$M1$ transition intensity ratio for the 2^+0-to-2^+0-g.s. transition for both levels, we find that the ratio is a factor of 10 smaller for the 1175-keV band. Either transition could have an $E2$ component, thus changing the ratio; however, a relative $E0$ weakness in the 1289-keV band would still be present. Both bands have larger moments of inertia than that of the ground-state band ($\mathscr{I}_{1175} = 1.20\mathscr{I}_{\text{g.s.}}$ and $\mathscr{I}_{1289} = 1.52\mathscr{I}_{\text{g.s.}}$).

C. Possible higher vibrational states

In deformed nuclei, both quadrupole- and octupole-vibrational states are commonly observed. Based on the Bohr model, one expects to also find multiple phonon states. These, however, are rarely observed. One of the few examples is ^{154}Gd, for which a coupled phonon $(\beta - \gamma)$ band was identified in decay studies.[33,34] The coupled band was observed to have favored $E0$ transitions[35] to the γ-vibrational band and to have weak $E2$ strength[33] to the ground-state band as compared to β-band transitions. Even more rare than coupled quadrupole-quadrupole excitations, however, is the identification of octupole-quadrupole states. Their properties have been calculated in a phenomenological framework by Lipas,[36] and in a microscopic treatment by Raduta, Sandulescu, and Lipas.[37]

There are three bands in ^{246}Cm with properties that may be associated with multiple-phonon characteristics; their bandhead energies (K^π values) are 1526 (3^-), 1594 (2^-), and 1781 (2^+) keV. The 1526-keV state is a good candidate for the one-phonon octupole state, as discussed in Sec. IV A. Note that it also deexcites strongly to the γ-vibrational band, as would be expected of a coupled octupole-γ band. However, the 1.5×10^{-3} hindrance of transitions to the ground-state band relative to transitions to the γ-vibrational band would seem to be small for a $\Delta K = 3$, two-phonon jump.

Both the 1594-keV $K^\pi = 2^-$ and 1780-keV $K^\pi = 2^+$ bands are characterized by $E0$ strength in some of their deexcitations to collective bands. This could result from two-phonon bands having a collective $K^\pi = 0^+$ component. However, we did not observe transitions to either of the $K^\pi = 0^+$ bands.

D. Two-quasiparticle bands

In addition to the two 0^+ levels, we identified three other low-energy positive parity bands—two with $K^\pi = 1^+$ and one with $K^\pi = 3^+$. At low energies, there are few two-quasiparticle configurations that will give rise to positive parity bands. Further, if we require that β feeding not be quasiparticle forbidden, we find that positive parity two-quasineutron states are only present at high energies, because allowed configurations must include the $\frac{9}{2}[734]\uparrow$ quasineutron, and because all of the nearby Nilsson levels are of positive parity. In addition, the quasiproton level density is low in the region of 96 protons. This allows us to derive probable quasiparticle configurations for positive parity bands.

The most notable feature of the 1^+ bands at 1452 and 1662 keV is the virtual absence of γ decay to the 842- and 1079-keV bands. If this is a result of quasiparticle forbiddenness, then the probable configurations for these bands are $\frac{5}{2}[523]\downarrow-\frac{3}{2}[521]\uparrow$ and $\frac{5}{2}[523]\downarrow-\frac{7}{2}[547]\downarrow$, for which bandhead energies are calculated to be about 1.3 and 1.8 MeV, respectively.[20] Both can be fed by β decay if the ^{246}Am 25-min decay is from the 2^+2, $\frac{5}{2}^-[523]\uparrow p-\frac{9}{2}^-[734]\uparrow n$ state.

In examining the 3^+ band at 1601 keV, we find no configurations that would be fed by β decay among those calculated by Soloviev and Siklos.[20] The only additional two-quasiparticle configuration that could produce a low-energy 3^+ state is the two-quasiproton $\frac{5}{2}[523]\downarrow-\frac{11}{2}[505]\uparrow$. It must be emphasized, however, that this configuration, as well as those given above for the 1^+ levels, are probable only in the absence of a strong collective character for these bands.

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