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Authors
Warden, E.F.
Conway, J.G.
Blaise, J.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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E.F. Worden, J.G. Conway, and J. Blaise

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Energy levels of the second spectrum of curium, Cm II

Earl F. Worden
University of California
Lawrence Livermore National Laboratory
Livermore, California, 94550

John G. Conway
University of California
Lawrence Berkeley Laboratory
Berkeley, California, 94720

Jean Blaise
Laboratoire Aime Cotton
Centre National de la Recherche Scientifique
91405 Orsay, France

ABSTRACT

The curium emission spectrum from electrodeless lamps has been observed from 2400 to 26,500 Å. About 30% of the 14,250 observed lines have been assigned by experimental methods as Cm II lines. The analysis of the spectrum has produced 432 odd levels and 162 even levels of Cm II that combine to classify over 4,100 curium lines. The energy levels are listed and most have Lande g values from Zeeman effect data as well as isotope shift values. Many levels have been assigned to electronic configurations and terms by use of isotope shift and Lande g values. A table containing the lowest level found for each of the eight identified electronic configurations is given. The ground state of the ion is the $^8S^o_{7/2}$ level of the (Rn) $5f^7 7s^2$ configuration. The next electronic configuration is $5f^8 7s$ whose lowest level is the $^8F_{13/2}$ level at 2093.87 cm^{-1}.

INTRODUCTION

In 1976 we reported on the energy levels of the first spectrum of curium, Cm I.[1] References to spectroscopic work on curium up to 1975 are given in that paper. The earliest papers[2,3] gave wavelengths for about 200 lines and ^{244}Cm - ^{242}Cm isotope shifts for 183 lines. In a second paper in 1976 we reported wavelengths, intensities and classifications (when known) for 2034 of the strongest of the over 13,250 curium lines emitted by an electrodeless discharge lamp (EDL) and observed photographically on large grating spectrographs in the 2450 to 11,500 Å region.[4] The curium lines observed in the infrared by a Fourier transform spectrometer were also reported in 1976.[5] Wavenumbers and intensities of 1734 lines between 8400 and 26,500 Å were listed and classification of 87% of the lines were given. A number of new energy levels of Cm I were found.

The energy levels of the Cm II spectrum tabulated here are based on these reported observations and on extensive unpublished isotope shift studies[6] (see experimental). The isotope shift data together with previously measured Zeeman effect data allowed confirmation of a number of levels that were found through searches for constant sums and differences. They also allowed assignment of these levels to electronic configurations with considerable confidence. As a result, levels belonging to the odd configurations $5f^7 7s^2$, $5f^7 6d7s$, $5f^7 6d^2$ and $5f^8 7p$ and to the even configurations $5f^8 7s$, $5f^8 6d$, $5f^7 7s7p$ and $5f^7 6d7p$ were identified. A total of 432 odd and 162 even levels were found and of these 94 have been assigned to the listed odd configurations and 100 to the listed even configurations. An abstract of this work has been published.[7]

Preliminary results were given in abstracts[8,9] and an interpretation of the $5f^{8}7s$ configuration of Cm II was given in a generalized parametric study of f^{n} and $f^{n}s$ configurations in the actinides.[10]

Other published work on the emission spectrum of curium is by the Russian investigators at the I. V. Kurchatov Institute of Atomic Energy.[11,12] One[11] reported 6771 lines between 2424 and 7009 Å emitted by EDLs and observed with large grating spectrographs. Iron lines were used as standards both as iron impurity in the curium lamps and as iron lines photographed adjacent to the curium exposures. Lines of other impurities such as Li, Na, Mg, Al, Ca, Ti, Zn, Cu and Am were identified and eliminated from the list by Russian investigators but we have found that their list still contains over 800 impurity lines belonging to Pu, Ba, La, Ce, Pr, Nd, Sm, Eu and Gd. A number of lines were indicated as neutral or singly-ionized based on their relative intensities from lamps operated at different microwave frequencies (90 and 300 MHz) and power levels. They also indicate that self-reversal was observed in 320 lines. The second paper[12] reported isotope shifts for 97 lines as observed from EDLs with three even isotopes (80.3% ^{244}Cm, 17% ^{246}Cm, 1% ^{248}Cm) and two odd isotopes (1% ^{245}Cm and 0.7% ^{247}Cm). A number of ^{246}Cm - ^{244}Cm shifts were observed in the 2430-6932 Å region. They reported shifts only for the 97 lines where all three even isotope positions were measured. Of these, 38 were measured with an interferometer and are accurate to 0.01 cm^{-1}. The remaining 59 were determined with a large grating spectrograph.

EXPERIMENTAL

Sources

Electrodeless discharge lamps were used exclusively for all our observations of the curium spectrum. The techniques used for preparation of the lamps and employing them to obtain wavelengths, Zeeman effect, spectrum assignment, self-reversal and isotope shift have been discussed.[1,5,13,14] The isotopic composition of the curium samples used to prepare the EDLs is given in Table 1. The type of spectroscopic data obtained with lamps prepared from samples is given in the "Use" column of the table. Approximately 100 to 200 micrograms of curium was used for each lamp preparation. Less than 2 mg total material was used in the investigation and most of the material was recovered for other uses.

Wavelengths

The method of recording the curium spectra has been described fully in Ref. 1. Briefly the spectra were photographed on the Argonne National Laboratory (ANL) 9.15 m Paschen-Runge spectrograph in the wavelength region 2400 to 9100 Å. Additional spectra were photographed on a 3.4 m Ebert spectrograph using a grating with 300 lines/mm at angles near 59^{0} (2400-3200 Å) and 30^{0} (8900-11500 Å). Line positions were measured on semiautomatic comparators with an accuracy of ±1 micron. The photographic wavelength list contained about 13,250 lines due to ^{244}Cm. The wavenumber precision or internal consistency from the level analysis is ±0.02 cm^{-1} or better throughout the line list. The near infrared region was investigated using a Fourier transform spectrometer. A total of 1734 lines were measured with an accuracy of 0.005 cm^{-1}.[5] Because of the overlap, the infrared measurements added about 1000 lines to the list.

Spectrum assignment

When operated at low metal-atom pressures, EDLs tend to enhance the second spectrum and at high metal-atom pressures the first spectrum is predominant. In the region 2400 to 9400 Å 51% of the lines were assigned Cm I and 30% to Cm II while the remaining 19% were mostly weak lines. Details of spectrum assignment procedures are given in Refs. 1 and 14.

Zeeman effect

The Zeeman effect was photographed from 2400 to 9000 Å with the ANL 9.15 m spectrograph at a field of 2.4 T (24,000 gauss). Figure 1 shows Zeeman patterns obtained for two Cm II lines. The patterns were measured with a semiautomatic comparator and the data reduced by computerized least-squares methods.[1] The accuracy of the g-values derived from resolved Zeeman patterns like 3962.7 Å in Figure 1 is ±0.003 Lorentz units. Level g values obtained from such measurements are given to three significant figures after the decimal point in Tables 2 and 3. Level g values reported to two places after the decimal are accurate to ±0.02 Lorentz units. These values were derived from measurements on unresolved patterns or on patterns where only a measure of the interval between adjacent components (delta g) could be obtained. A more detailed description of how g values were derived is given in Ref. 1.

Isotope shift

Spectra of Cm isotopes using lamps with isotopic compositions given in Table 1 were recorded on the 9.15 m ANL spectrograph and measured with a semiautomatic comparator. Figure 2 is a sample portion of the spectrum obtained with these isotopic mixtures. The advantage of using lamps with three isotopic compositions is evident from this figure. Shifts of over 6000 lines were measured. The shifts are the wave number of the heavy isotope minus the wave number of the light isotope. Shifts of clearly resolved lines, for example the three lines with wavelength identified in Figure 2, have a precision of ±0.005 cm^{-1} or better. Level shifts obtained from these lines are reported to three significant figures in Tables 2 and 3. Level shifts reported in the tables to two places are precise to about ±0.02 cm^{-1}. The isotope shift of the ground state was assumed to be zero. Lines with shifts less than 0.1 cm^{-1} are precise to only about ±0.01 cm^{1}, a few shifts less than 0.1 cm^{-1} are precise to only about ± 0.05 cm^{-1}. Line isotope shifts less than 0.1 cm^{-1} were obtained from values measured for ^{248}Cm - ^{244}Cm shifts. They were converted to ^{246}Cm - ^{244}Cm shifts by use of the relative isotope shift (RIS) factor of 1.945 for (^{248}Cm - ^{244}Cm)/(^{246}Cm - ^{244}Cm) derived from lines that have large isotope shift and that are unblended. The RIS for ^{245}Cm was measured using lines with small or no ^{245}Cm hyperfine structure: ^{245}Cm has a nuclear spin of 7/2. These Cm RIS values are shown in Figure 3 together with a RIS for ^{242}Cm derived from ^{244}Cm - ^{242}Cm shift data of Conway and McLaughlin.[3]

RESULTS

The energy levels of singly-ionized curium atoms are listed in Tables 2 (odd levels) and 3 (even levels). Column 1 lists the value of the energy level in cm^{-1}, columns 2 and 3 give the J and g values. Column 4 is the isotope shift in units of cm^{-1}. The isotope shifts are ^{246}Cm - ^{244}Cm shifts relative to the $5f^7 7s^2\ ^8S^o_{7/2}$ ground state as zero shift. Column 5 gives the configuration designation followed by the term, usually in LS coupling notation. In some cases the $J_1 j$ coupling notation is used. We follow the configuration notation used in Atomic Energy Levels-The Rare-Earth Elements.[15]

In Figure 4 is shown the level structure of the lowest terms of Cm II. The electronic configurations and LS designations are indicated. The level structure of the ^8F and ^6F terms of the $5f^8 7s$ configuration found at the beginning of Table 3 is more clearly illustrated in this figure. Figure 5 shows the range of isotope shifts for levels assigned to identified configurations of Cm II. Note that there is overlap of observed shift for a number of configurations. In these cases, theory, Lande g values, transition intensities and other factors are important for assigning the level to the appropriate configuration. As seen in the figure, we report the shifts relative to the ground state as X. For the shifts in Tables 2 and 3, the X is zero. The value of X is approximately +1.2 cm^{-1} for Cm II. In heavy elements the largest isotope shifts are found for levels belonging to configurations with largest number of penetrating s electrons and smallest number of shielding f or d electrons. The smallest isotope shifts are for levels of configurations with no penetrating electrons. Thus in the case of Cm II, the configuration $5f^8 6d$ is expected to have a shift close to zero. As can be seen from Table 4, this leads to a value of approximately +1.2 cm^{-1} for levels of $5f^7 7s^2$. The levels of the still unidentified $5f^6 6d7s^2$ configuration are expected to have larger shifts.

Table 4 lists the lowest level of the identified configurations of Cm II along with their designations, g values and isotope shifts. We have identified levels belonging to all the configurations expected below 50,000 cm^{-1} except the $5f^9$ configuration predicted to start around 26,000 cm^{-1} according to Brewer.[16]

A parametric study has been made of only the $5f^8 7s$ configuration.[10] The parametric study was made before the more complete isotope shift data were available. As a result, several levels identified as $5f^8 7s$ were reassigned to other configurations or removed. At the same time, new levels with the correct isotope shift have been assigned to $5f^8 7s$. These corrected assignments are included in Table 3. The levels of $5f^8 7s$ below 18000 cm^{-1} did not change. Since these levels strongly influence the fit, the parameters in Ref. 10 will not be changed significantly.

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FIGURE CAPTIONS

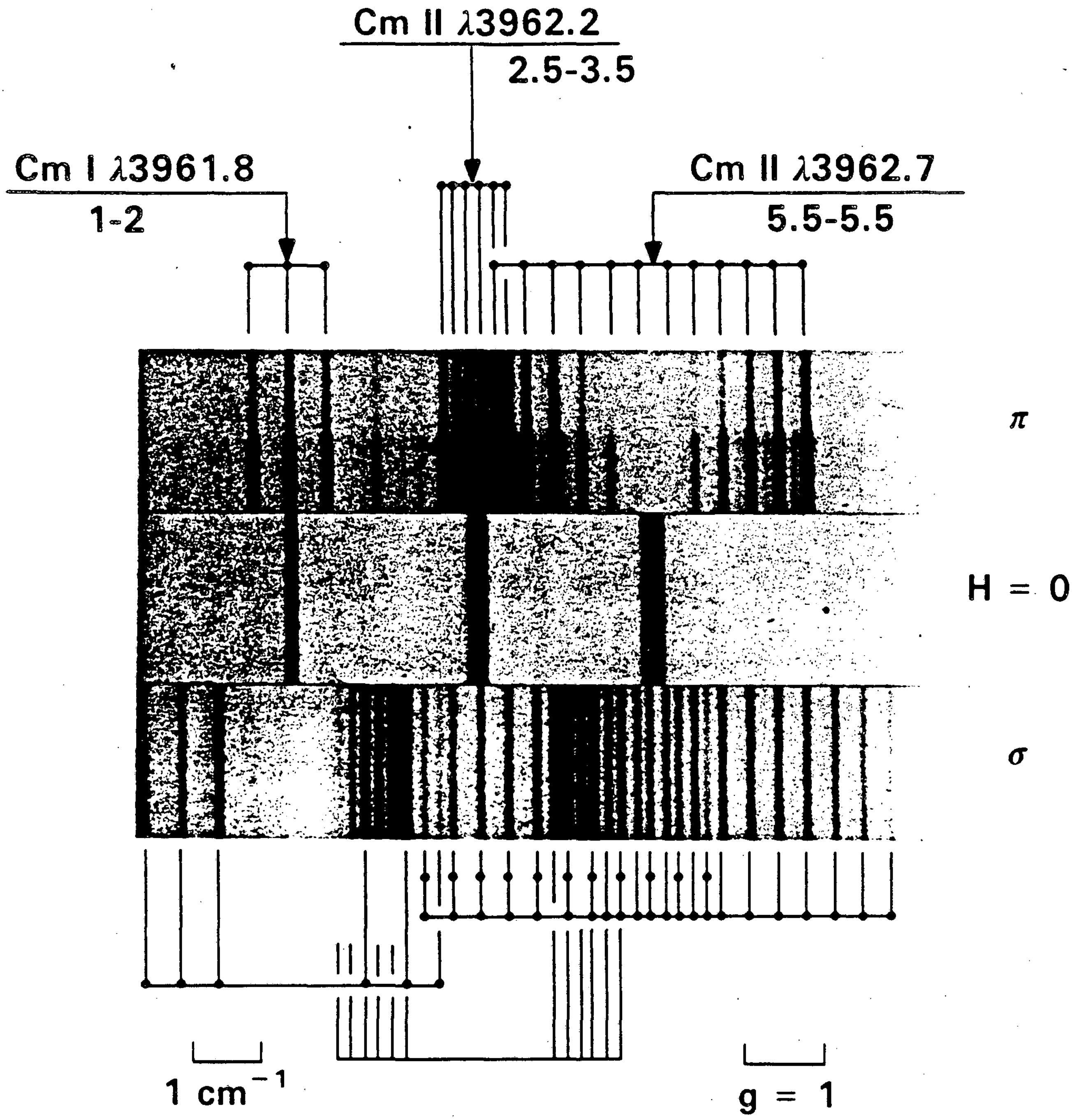
Figure 1. Zeeman patterns of one Cm I and two Cm II lines at 2.4 T photographed on the ANL 9.15 m spectrograph.

Figure 2. Three Å region of the curium spectrum showing the isotope shift for four isotopes. Spectra of three isotopically different samples are shown. Photographed on the ANL 9.15 m spectrograph.

Figure 3. Relative isotope shift of five isotopes of curium from atomic emission spectra.

Figure 4. Low lying energy levels of singly-ionized curium. The electronic configurations and LS term designations are given.

Figure 5. Range of observed isotope shifts for several electronic configurations of curium II. The value of x is about +1.2 cm^{-1} (see text).



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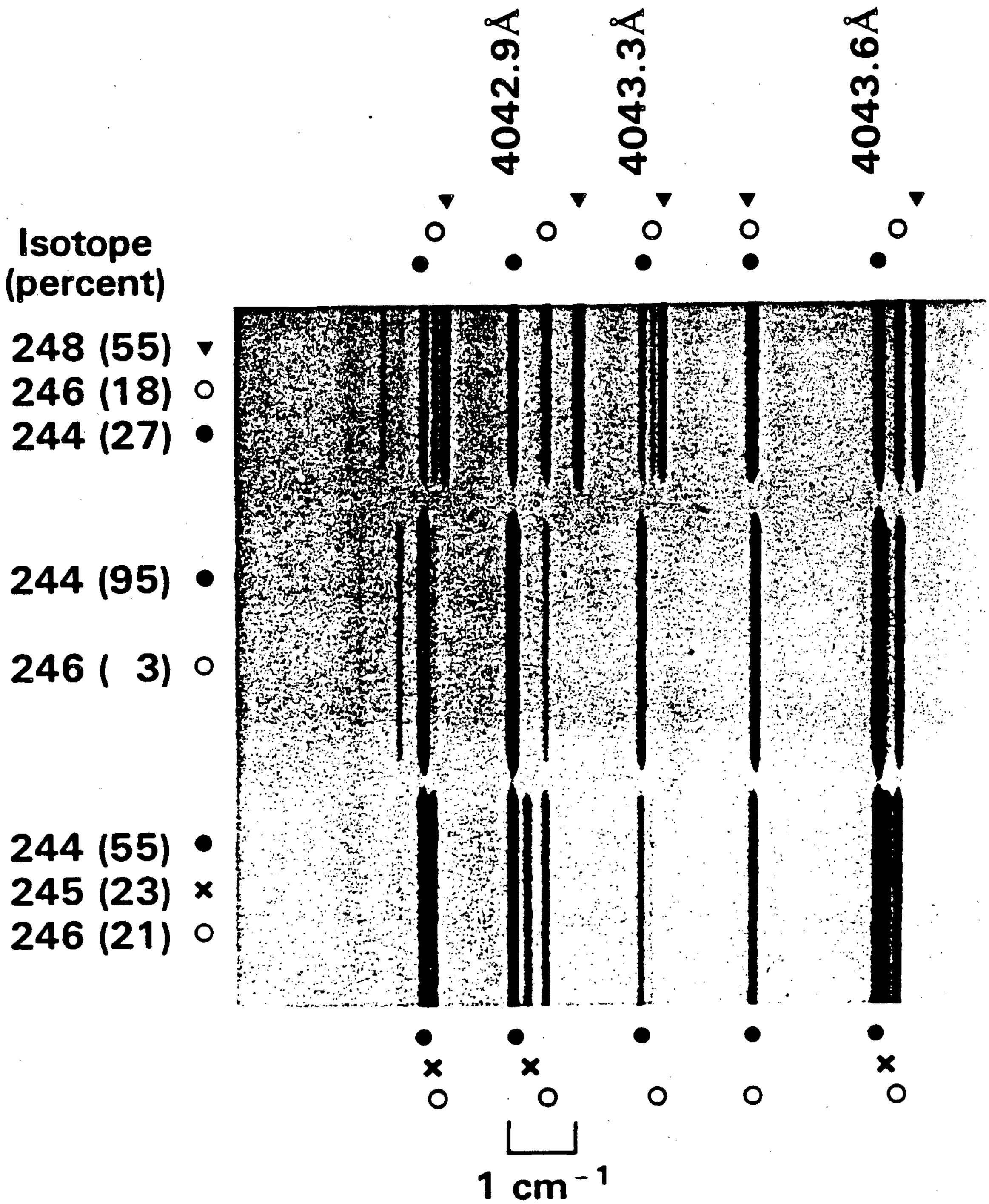

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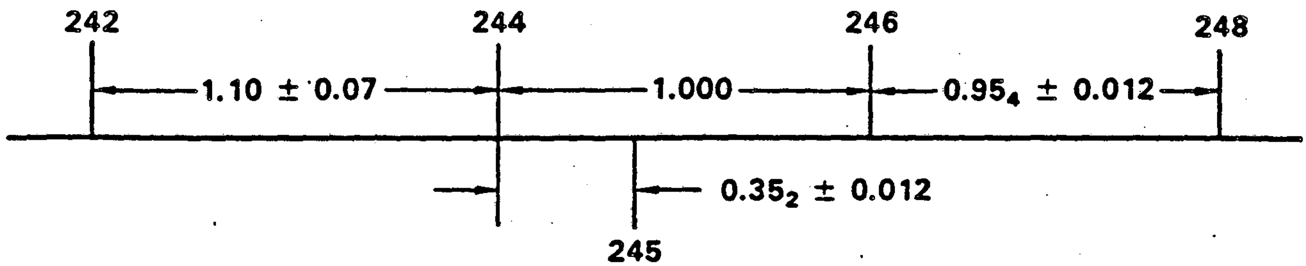

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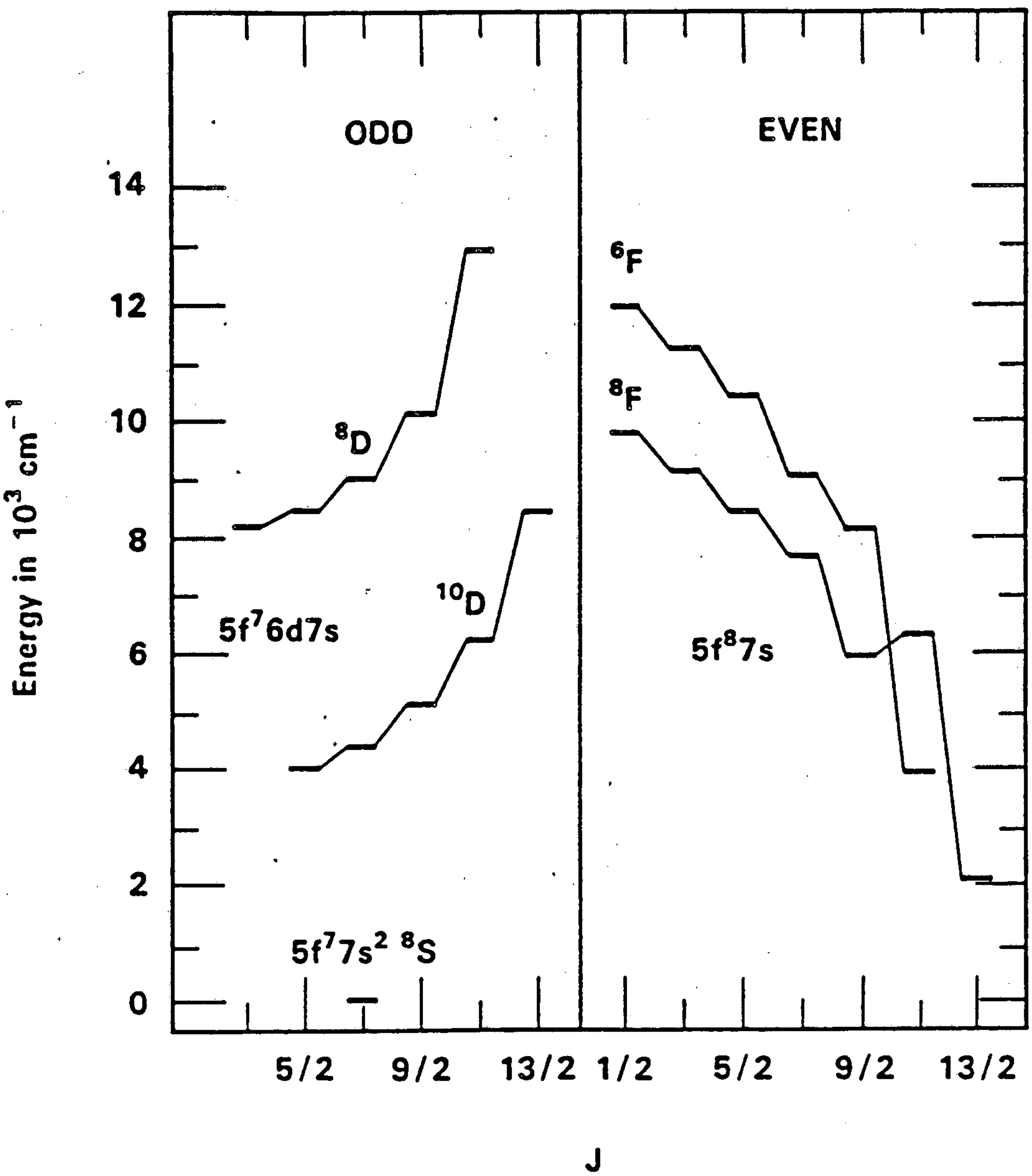

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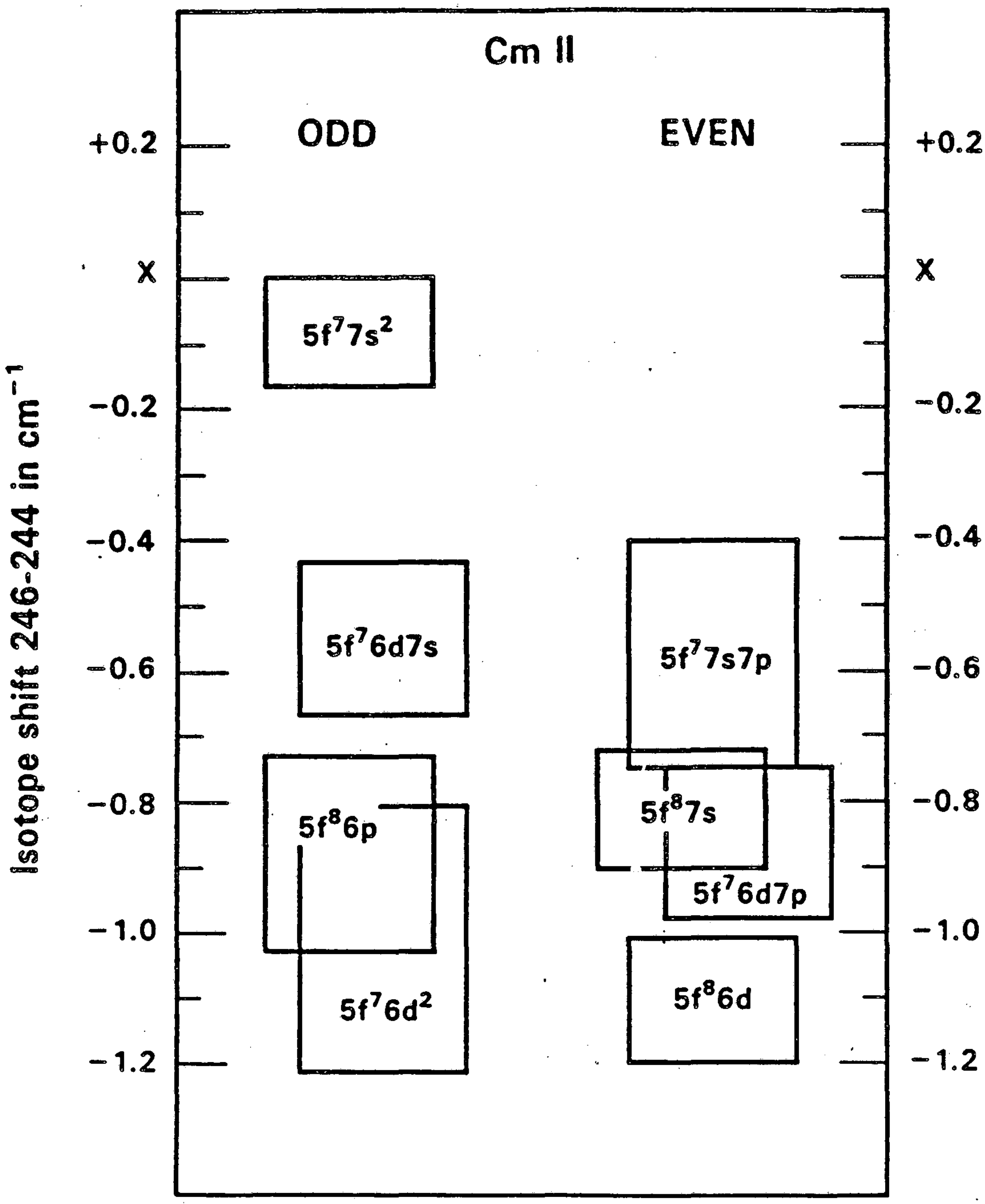

Figure 5. Range of observed isotope shifts for several electronic configurations of curium II. The value of x is about +1.2 cm^{-1} (see text).

Captions;

Table 1. Isotopic composition of curium samples used for lamp preparation.

Table 2. The odd parity energy levels of the curium ion, Cm II.

Table 3. The even parity energy levels of the curium ion, Cm II.

Table 4. Lowest levels of identified configurations in Cm II.

Table 1. Isotopic Composition of Curium Samples Used for Lamp Preparation.

Sample	Composition >1%				Use
	244	245	246	248	
1	95	1.5	3		Wavelength, Zeeman effect Spectrum assignment, Self-reversal Isotope shift
2	27		16	55	Isotope shift
3	55	23	21		Isotope shift

Table 2. The odd parity energy levels of the curium ion, Cm II.

Energy Level (cm^{-1})	J odd	g odd	IS (cm^{-1})	Configuration	
0.000	7/2	1.935	0.000	$5f^7 7s^2$	$^8S^o$
4010.645	5/2	2.492	-0.496	$5f^7 6d7s$	$^{10}D^o$
4411.540	7/2	2.028	-0.496	$5f^7 6d7s$	$^{10}D^o$
5067.900	9/2	1.826	-0.494	$5f^7 6d7s$	$^{10}D^o$
6202.430	11/2	1.716	-0.492	$5f^7 6d7s$	$^{10}D^o$
8199.890	3/2	2.666	-0.559	$5f^7 6d7s$	$^8D^o$
8425.360	13/2	1.655	-0.480	$5f^7 6d7s$	$^{10}D^o$
8474.775	5/2	1.952	-0.557	$5f^7 6d7s$	$^8D^o$
9012.480	7/2	1.722	-0.554	$5f^7 6d7s$	$^8D^o$
10134.785	9/2	1.638	-0.555	$5f^7 6d7s$	$^8D^o$
12913.101	11/2	1.599	-0.547	$5f^7 6d7s$	$^8D^o$
14830.150	3/2	3.009	-0.962	$5f^7 6d^2$	$^{10}F^o$
15092.768	5/2	2.109	-0.934	$5f^7 6d^2$	$^{10}F^o$
15457.514	7/2	1.800	-0.867	$5f^7 6d^2$	$^{10}F^o$
15559.133	9/2	1.650	-0.659	$5f^7 6d7s$	$^8D^o$
15737.548	11/2	1.603	-0.600	$5f^7 6d7s$	$^8D^o$
16956.223	7/2	1.595	-0.429	$5f^7 6d7s$	$^6D^o$
17013.379	9/2	1.633	-0.800	$5f^7 6d^2$	$^{10}F^o$
17430.189	7/2	1.435	-0.158	$5f^7 7s^2$	$^6P^o$
17485.491	5/2	1.93	-0.584	$5f^7 6d7s$	$^8D^o$
17853.291	7/2	1.63	-0.621	$5f^7 6d7s$	$^8D^o$
18122.430	3/2	2.710	-0.606	$5f^7 6d7s$	$^8D^o$
18205.773	9/2	1.585	-0.634	$5f^7 6d7s$	$^6D^o$
18222.515	11/2	1.635	-0.972	$5f^7 6d^2$	$^{10}F^o$
18230.266	5/2	1.705	-0.565	$5f^7 6d7s$	$^6D^o$
18376.367	3/2	1.810	-0.515	$5f^7 6d7s$	$^6D^o$
18847.318	1/2		-0.517	$5f^7 6d7s$	$^6D^o$

19596.910	13/2		-0.998	$5f^7 6d^2$	$^{10}F^o$
21426.120	15/2	1.60	-0.99	$5f^7 6d^2$	$^{10}F^o$
21816.865	7/2		-0.481	$5f^7 6d7s$	
22280.885	7/2		-0.840	$5f^7 6d^2$	$^{10}P^o$
22430.420	9/2	1.42	-0.493	$5f^7 6d7s$	
22577.590	7/2		-0.654	$5f^7 6d7s$	
23794.020	9/2		-0.987	$5f^7 6d^2$	$^{10}P^o$
24078.900	11/2	1.720	-0.978	$5f^7 6d^2$	$^{10}P^o$
24533.055	11/2	1.365	-0.514	$5f^7 6d7s$	
26087.144	7/2	1.56	-0.991	$5f^7 6d^2$	
26234.985	3/2		-0.962	$5f^7 6d^2$	
26272.380	5/2		-0.901	$5f^7 6d^2$	
26525.110	9/2	1.49	-0.832		
27065.085	11/2	1.51	-0.972	$5f^8(^7F_6)7p_{1/2}$	
27700.945	13/2	1.42	-1.022	$5f^8(^7F_6)7p_{1/2}$	
27853.520	13/2	1.355	-0.473	$5f^7 6d7s$	
28079.390	11/2	1.320	-0.757	$5f^7 6d7s$	
28555.840	11/2	1.170	-0.593	$5f^7 6d7s$	
28587.400	9/2	1.185	-0.499	$5f^7 6d7s$	
29169.595	11/2	1.050	-0.571	$5f^7 6d7s$	
29617.815	9/2	1.425	-0.972	$5f^7 6d^2$	$^8F^o$
29925.300	11/2	1.425	-0.974	$5f^7 6d^2$	$^8F^o$
30011.710	7/2	1.335	-0.75	$5f^7 6d7s$	
30166.000	9/2	1.055	-0.526	$5f^7 6d7s$	
30252.500	13/2	1.49	-1.000	$5f^7 6d^2$	$^8F^o$
30297.135	7/2	1.290	-0.700	$5f^7 6d7s$	
30386.005	5/2	1.335	-0.910	$5f^7 6d^2$	$^8G^o$
30550.820	3/2	1.045	-0.955	$5f^7 6d^2$	$^8G^o$
30692.380	9/2	1.49	-0.675	$5f^7 6d7s$	
30740.115	5/2	1.925	-0.950	$5F^7 6d^2$	$^8P^o$
30745.000	1/2	-1.05	-0.990	$5f^7 6d^2$	$^8G^o$
30797.630	7/2	1.49	-0.595	$5f^7 6d7s$	
30800.555	11/2	1.200	-0.528	$5f^7 6d7s$	
30805.760	7/2	1.58	-0.742		
30997.995	7/2	1.175	-0.504	$5f^7 6d7s$	
31134.310	11/2	1.09	-0.522	$5f^7 6d7s$	

Table 2.

31166.675	9/2	1.43	-0.800	$5f^8(^7F_5)7p_{1/2}$
31259.795	9/2	1.352	-0.619	$5f^7 6d7s$
31333.385	3/2	2.42	-0.83	
31357.880	9/2		-0.580	$5f^7 6d7s$
31455.540	11/2	1.279	-0.082	$5f^7 7s^2$
31734.470	15/2	1.331	-0.471	$5f^7 6d7s$
31777.160	11/2	1.226	-0.536	$5f^7 6d7s$
31788.195	9/2	1.246	-0.565	$5f^7 6d7s$
31890.645	7/2		-0.508	$5f^7 6d7s$
31933.755	11/2	1.274	-0.635	$5f^7 6d7s$
31947.675	7/2	1.478	-0.859	$5f^8(^7F_4)7p_{1/2}$
32106.235	11/2	1.230	-0.528	$5f^7 6d7s$
32195.825	11/2	1.337	-1.017	$5f^7 6d^2$
32354.785	9/2	1.265	-0.498	$5f^7 6d7s$
32417.800	11/2	1.280	-0.582	$5f^7 6d7s$
32527.285	9/2	1.305	-0.233	
32654.875	15/2	1.22	-0.575	$5f^7 6d7s$
32705.055	9/2		-0.575	
32728.135	11/2	1.145	-0.525	
32775.870	9/2	1.287	-0.956	
32816.105	7/2	1.167	-0.553	$5f^7 6d7s$
32867.720	9/2	1.340	-0.701	$5f^7 6d7s$
32923.880	13/2	1.39	-1.008	$5f^7 6d^2$
33055.015	9/2	1.368	-0.610	
33090.820	7/2	1.46	-0.734	
33209.090	7/2	1.49	-0.650	
33235.225	9/2	1.312	-0.573	
33265.480	11/2	1.382	-0.830	$5f^8(^7F_5)7p_{1/2}$
33401.800	13/2	1.060	-0.534	
33680.490	13/2		-1.205	$5f^7 6d^2$
33749.175	11/2	1.44	-0.966	
33766.240	7/2	1.315	-0.723	
33767.090	11/2	1.645	-0.540	
33802.330	9/2	1.38	-0.925	$5f^8(^7F_4)7p_{1/2}$
33948.555	15/2		-0.643	
33988.535	3/2		-0.615	
34023.550	5/2	1.385	-0.595	
34099.075	7/2	1.121	-0.550	
34277.980	3/2	1.504	-0.716	
34304.385	5/2	1.619	-0.806	$5f^8(^7F_3)7p_{1/2}$

34332.340	15/2		-0.505	
34337.385	13/2	1.295	-0.457	
34382.990	9/2	1.150	-0.545	
34678.910	7/2	1.274	-0.622	
34683.930	9/2	1.474	-0.80	
34701.770	5/2	1.405	-0.716	
34750.645	1/2	-0.665	-0.605	
34816.785	3/2	0.696	-0.579	
34821.815	9/2	1.250	-0.717	
34857.050	5/2	1.353	-0.580	
34888.905	11/2	1.38	-0.734	$5f^8(^7F_6)7p_{3/2}$
34926.680	13/2	1.39	-0.830	$5f^8(^7F_6)7p_{3/2}$
34945.405	7/2	1.193	-0.571	
34986.555	9/2	1.315	-0.579	
35050.860	5/2	1.416	-0.531	
35178.905	3/2	1.552	-0.866	$5f^8(^7F_2)7p_{1/2}$
35226.355	9/2	1.32	-0.661	
35291.395	7/2	1.382	-0.774	$5f^8(^7F_3)7p_{1/2}$
35319.115	5/2	1.223	-0.726	$5f^8(^7F_2)7p_{1/2}$
35335.025	11/2	1.240	-0.578	
35368.750	13/2		-0.334	
35390.740	11/2	1.195	-0.727	
35397.720	9/2	1.172	-0.75	
35431.385	15/2		-0.542	
35571.395	11/2		-0.538	
35575.055	5/2	1.145	-0.68	
35591.550	9/2	1.33	-0.652	
35593.180	3/2	0.902	-0.569	
35611.250	7/2	1.284	-0.68	
35730.540	5/2	1.510	-0.629	
35820.665	11/2	1.237	-0.857	
35932.290	3/2	1.092	-0.68	
35972.365	7/2	1.187	-0.358	
35981.305	13/2		-0.467	
36008.790	7/2	1.215	-0.632	
36063.090	3/2	1.27	-0.843	
36083.640	1/2	3.098	-0.958	$5f^8(^7F_1)7p_{1/2}$
36128.375	9/2	1.245	-0.488	
36178.220	3/2	1.221	-0.828	
36200.780	9/2	1.22	-0.487	
36223.420	5/2	1.25	-0.869	
36226.140	15/2	1.172	-0.516	
36330.280	11/2	1.212	-0.597	
36413.100	13/2	1.233	-0.360	
36447.545	7/2	1.288	-0.627	
36464.155	9/2	1.229	-0.666	
36500.930	3/2	1.271	-0.705	$5f^8(^7F_1)7p_{1/2}$

Table 2.

36592.945	13/2	1.342	-0.229	
36596.380	9/2	1.215	-0.919	
36710.135	11/2	1.085	-0.765	
36812.230	11/2	1.28	-0.838	
36908.125	3/2	0.831	-0.65	
36957.800	5/2	1.273	-0.73	
36968.780	7/2	1.274	-0.69	
37046.885	9/2	1.32	-0.653	
37101.190	13/2		-0.778	
37113.725	3/2	1.134	-0.73	
37118.775	7/2	1.255	-0.524	
37179.780	11/2		-0.71	
37225.120	13/2	1.165	-0.516	$5f^7 6d7s$
37310.010	3/2	1.007	-0.73	
37315.470	11/2	1.25	-0.641	
37359.605	5/2	1.41	-0.75	
37393.790	7/2	1.225	-0.730	
37417.815	11/2		-0.668	
37504.720	7/2	1.18	-0.77	
37528.470	1/2	-0.280	-0.854	$5f^8(^7F_0)7p_{1/2}$
37648.630	11/2		-0.640	
37656.630	5/2	1.025	-0.515	
37717.275	1/2	0.416	-0.76	
37789.685	3/2	1.226	-0.81	
37815.545	9/2	1.121	-0.634	
37829.305	7/2	1.20	-0.913	
37924.220	9/2	1.293	-0.605	
37958.835	11/2	1.163	-0.590	
37992.800	7/2	1.205	-0.75	
37999.680	13/2	1.251	-0.567	
38042.165	1/2	1.30	-0.609	
38188.050	7/2	1.425	-0.850	
38259.945	11/2		-0.540	
38316.115	1/2	2.93	-0.72	
38327.135	9/2	1.242	-0.557	
38457.830	7/2	1.39	-0.71	
38472.695	15/2	1.34	-0.692	
38627.120	13/2		-0.692	
38634.830	11/2	1.279	-0.696	
38685.550	7/2	1.257	-0.632	
38759.425	9/2		-0.75	
38771.070	15/2	1.23	-0.580	
38793.695	5/2	1.05	-0.75	
38794.960	1/2	1.79	-0.590	
38949.170	9/2	1.135	-0.601	
38973.940	7/2		-0.591	
38980.505	13/2		-0.645	
39078.555	9/2	1.225	-0.605	
39082.665	11/2	1.007	-0.75	
39165.195	9/2		-0.71	
39195.735	11/2	1.254	-0.580	
39204.165	5/2	1.245	-0.636	

39336.155	3/2	0.785	-0.659	$5f^8 7p$
39369.570	5/2		-0.588	
39381.485	7/2	1.29	-0.572	
39458.235	9/2	1.24	-0.645	
39465.845	13/2		-0.650	
39466.380	11/2	1.095	-0.661	
39474.990	9/2		-0.603	
39507.215	11/2	1.30	-0.574	
39537.265	7/2	1.34	-0.707	
39566.445	15/2	1.12	-0.533	
39643.640	3/2	1.420	-0.63	
39681.090	9/2		-0.70	
39690.790	13/2		-0.587	
39739.615	7/2	1.21	-0.71	
39772.100	11/2		-0.643	
39817.225	5/2	1.18	-0.68	
39843.060	5/2	1.195	-0.430	
39909.880	13/2		-0.122	$5f^7 7s^2$
39914.725	7/2		-0.585	
39918.670	9/2		-0.620	
39997.135	11/2		-0.864	
40081.950	13/2		-0.531	
40097.095	9/2		-0.70	
40113.560	11/2	1.260	-0.437	
40252.565	7/2		-0.595	
40275.325	11/2		-0.607	
40285.940	5/2	1.16	-0.570	
40337.475	7/2		-0.71	
40350.040	9/2		-0.73	
40378.520	11/2		-0.67	
40446.285	5/2	1.44	-0.66	
40494.100	9/2		-0.560	
40534.325	13/2	1.156	-0.579	
40632.180	1/2	-0.01	-0.633	
40651.520	5/2	1.172!	-0.648	
40671.600	9/2		-0.563	
40673.045	3/2	1.11	-0.569	
40700.530	5/2		-0.521	
40761.165	11/2		-0.445	
40805.300	7/2		-0.578	
40821.695	13/2		-0.622	
40892.880	7/2		-0.626	
40932.805	7/2	1.106	-0.629	
40962.600	13/2		-0.597	
40968.520	9/2		-0.630	
40976.960	5/2	1.30	-0.603	
40978.500	7/2		-0.73	
41070.930	9/2		-0.310	
41134.885	11/2	1.145	-0.655	
41148.045	11/2		-0.663	
41154.810	13/2		-0.694	
41178.630	5/2	1.283	-0.597	
41188.750	7/2		-0.68	

Table 2.

41239.850	9/2		-0.597
41241.095	11/2		-0.557
41259.200	5/2	1.505	-0.76
41268.575	13/2		-0.670
41316.950	7/2		-0.512
41368.835	3/2		-0.570
41383.570	15/2	1.18	-0.431
41418.670	11/2	1.33	-0.339
41469.590	5/2		-0.613
41482.680	13/2	1.18@	-0.682
41563.230	9/2		-0.629
41616.075	11/2		-0.557
41708.685	7/2		-0.850
41733.900	9/2	1.231	-0.582
41736.575	7/2	1.334	-0.73
41737.535	3/2	1.481	-0.646
41766.730	5/2		-0.414
41772.330	9/2		-0.580
41794.705	7/2		-0.647
41812.210	13/2		-0.74
41854.125	15/2		-0.544
41886.530	11/2		-0.510
41902.410	9/2		-0.640
41902.810	7/2		-0.642
41950.950	7/2		-0.538
41989.340	13/2	1.125	-0.755
42019.890	15/2		-0.768
42065.795	11/2		-0.71
42085.530	7/2		-0.555
42087.685	5/2		-0.75
42088.400	3/2	1.120	-0.576
42097.955	13/2	1.11	-0.734
42133.915	11/2		-0.820
42144.600	9/2		-0.76
42148.185	5/2		-0.75
42200.040	1/2		-0.73
42200.960	7/2		-0.505
42215.605	11/2	1.220	-0.673
42252.785	3/2		-0.466
42259.185	9/2		-0.554
42265.225	15/2		-0.668
42365.340	13/2		-0.76
42368.930	11/2	1.21	-0.658
42425.245	7/2		-0.687
42498.445	9/2	1.251	-0.68
42502.850	7/2	1.36	-0.75
42510.470	13/2		-0.552
42550.840	3/2		-0.73
42571.570	5/2	1.122	-1.066
42598.070	5/2	1.17	-0.82
42616.250	7/2	1.246	-0.613
42631.425	13/2	1.176	-0.570
42655.350	3/2,5/2		-0.617
42725.675	11/2	1.22	-0.75

42734.955	9/2		-0.393
42771.475	7/2		-0.566
42833.290	9/2		-0.552
42847.780	11/2		-0.728
42928.330	5/2		-0.70
42949.100	13/2	1.23	-0.589
42984.425	5/2		-0.69
42988.980	11/2		-0.628
42998.340	9/2		-0.630
43006.845	7/2	1.172	-0.635
43063.225	11/2		-0.530
43106.235	5/2		-0.74
43137.075	7/2		-0.568
43153.145	9/2	1.21	-0.628
43176.710	3/2		-0.68
43179.390	11/2		-0.378
43217.790	13/2		-0.644
43273.530	7/2		-0.74
43297.960	1/2	2.11	-0.75
43300.105	9/2		-0.64
43317.145	3/2		-0.74
43319.155	11/2	1.252	-0.693
43328.370	9/2		-0.79
43358.390	5/2		
43422.935	7/2		-0.537
43456.525	13/2	1.30	-0.582
43518.515	5/2		-0.68
43555.140	5/2		-0.653
43577.835	7/2		-0.75
43662.765	3/2		-0.75
43678.565	5/2		-0.75
43679.580	9/2		-0.79
43729.950	7/2		-0.592
43752.815	13/2		-0.639
43795.175	9/2		-0.81
43822.005	3/2		-0.825
43828.010	7/2		-0.673
43841.315	11/2		-0.603
43867.360	5/2		-0.68
43891.750	1/2	0.67	-0.67
43915.005	11/2		-0.857
43920.365	9/2		-0.74
43958.690	1/2		-0.67
43978.320	11/2		-0.530
44019.480	9/2		-0.74
44061.855	11/2	1.23	-0.853
44094.895	3/2		-0.631
44170.500	9/2		-0.723
44207.775	3/2		-0.69
44333.105	9/2		-0.75
44363.825	5/2		-0.71
44385.055	13/2		-0.572
44452.095	11/2		-0.641
44502.475	9/2		-0.638

Table 2.

44549.030	9/2		-0.74
44578.420	3/2		-0.77
44613.720	11/2		-0.625
44655.485	7/2		-0.75
44693.660	11/2	1.285	-0.626
44693.840	5/2		-0.648
44770.785	7/2		-0.76
44805.710	7/2		-0.74
44841.920	11/2		-0.412
44865.395	5/2		-0.556
44937.350	9/2		-0.77
44975.660	5/2		-0.66
45005.235	3/2		-0.77
45015.440	11/2		-0.569
45051.520	9/2		-0.567
45063.385	5/2		-0.67
45074.245	7/2		-0.76
45128.260	11/2		-0.72
45135.420	3/2		-0.72
45149.295	7/2		-0.710
45185.190	3/2		-0.75
45188.390	7/2		-0.75
45239.465	9/2		-0.77
45336.555	9/2		-0.579
45378.565	5/2	1.180	-0.605
45420.905	11/2		-0.74
45466.885	7/2		-0.658
45507.100	1/2	0.76	-0.76
45538.690	9/2		-0.69
45577.985	7/2		-0.640
45593.880	7/2		-0.569
45821.335	11/2		-0.584
46025.105	1/2		-0.73
46125.435	7/2		-0.82
46207.615	7/2		-0.615
46367.130	1/2		-0.638
46415.550	7/2		-0.76
46479.765	5/2		-0.576
46668.675	7/2		-0.75
46744.710	5/2		
46777.145	3/2		-0.645
46785.185	7/2		-0.75
46815.755	9/2		-0.71
46838.795	7/2		-0.81
46915.165	5/2		-0.574
46917.670	7/2		-0.641
46983.055	9/2		-0.646
47027.350	5/2		-0.74
47606.925	5/2		-0.77
47648.725	3/2		-0.75
47794.205	5/2		-0.73
47845.070	9/2,7/2		
48001.690	3/2	1.02	-0.70
48089.385	3/2		-0.76

48142.335	3/2		-0.597
48210.480	11/2		-0.593
48231.405	7/2		-0.515
48321.740	1/2		-0.601
48373.330	7/2		-0.665
48429.520	3/2		-0.73
48454.540	5/2		-0.75
48670.48	11/2	1.16	
48706.080	11/2		-0.784
48831.755	7/2		-0.77
49183.995	11/2		-0.67
49227.275	11/2		-0.72
49334.035	3/2		-0.74
49566.770	13/2		-0.600
50029.210	5/2		-0.74

! possibly, g=1.428
@ possibly, g=1.26

Table 3. The even parity energy levels of the curium ion, Cm II.

Energy Level (cm^{-1})	J even	g even	IS (cm^{-1})	Configuration
2093.870	13/2	1.500	-0.738	$5f^8 7s$ ^8F
3941.439	11/2	1.424	-0.765	$5f^8 7s$ ^6F
5919.263	9/2	1.527	-0.736	$5f^8 7s$ ^8F
6347.900	11/2	1.500	-0.744	$5f^8 7s$ ^8F
7067.133	7/2	1.485	-0.748	$5f^8 7s$ ^8F
8144.306	9/2	1.400	-0.765	$5f^8 7s$ ^6F
8436.099	5/2	1.656	-0.733	$5f^8 7s$ ^8F
9073.572	7/2	1.444	-0.753	$5f^8 7s$ ^6F
9127.847	3/2	1.834	-0.733	$5f^8 7s$ ^8F
9801.305	1/2	3.740	-0.729	$5f^8 7s$ ^8F
10433.776	5/2	1.300	-0.763	$5f^8 7s$ ^6F
11250.886	3/2	1.167	-0.759	$5f^8 7s$ ^6F
11978.441	1/2	-0.420	-0.760	$5f^8 7s$ ^6F
15918.045	9/2	1.489	-0.731	$5f^8 7s$ ^6D
16938.940	13/2	1.225	-0.750	$5f^8 7s$ ^4H
17126.590	7/2	1.34	-0.750	$5f^8 7s$ ^6D
17150.790	13/2	1.415	-1.177	$5f^8 6d$ ^8G
17468.095	11/2	1.35	-1.070	$5f^8 6d$ ^8G
17511.400	11/2	1.16	-0.867	$5f^8 7s$ ^4H
18255.735	15/2	1.425	-1.187	$5f^8 6d$ ^8G
18919.640	9/2	1.562	-1.188	$5f^8 6d$ ^8G
20340.960	7/2		-1.007	$5f^8 6d$ ^8G
20544.775	7/2		-0.885	$5f^8 7s$
20704.725	9/2		-1.159	$5f^8 6d$ ^8D
21044.030	11/2		-1.165	$5f^8 6d$ ^8D
21150.090	5/2		-1.165	$5f^8 6d$ ^8G
22175.940	3/2		-1.171	$5f^8 6d$ ^8G

22305.430	7/2	1.66	-1.180	$5f^8 6d\ ^8D$
22572.665	1/2		-1.185	$5f^8 6d\ ^8G$
23105.645	5/2		-1.156	$5f^8 6d\ ^8D$
23186.855	13/2		-1.182	$5f^8 6d\ ^8F$
23239.970	17/2		-1.174	$5f^8 6d\ ^8H$
23560.020	11/2		-1.178	$5f^8 6d\ ^8F$
24046.385	7/2	2.098	-0.403	$5f^7(^8S^o_{7/2})7s7p(^3P^o_0)\ ^{10}P$
24113.725	9/2	1.505	-1.158	$5f^8 6d\ ^8F$
24265.300	15/2		-1.178	$5f^8 6d\ ^8H$
25207.260	13/2		-1.184	$5f^8 6d\ ^8H$
25402.410	11/2		-1.186	$5f^8 6d$
25436.470	9/2	1.240	-0.726	$5f^8 7s$
25579.725	9/2	1.781	-0.485	$5f^7(^8S^o_{7/2})7s7p(^3P^o_1)\ ^{10}P$
25783.365	11/2		-1.174	$5f^8 6d\ ^8H$
26328.020	9/2	1.290	-1.085	$5f^8 6d$
26490.795	11/2		-1.190	$5f^8 6d$
27404.255	9/2	1.445	-1.162	$5f^8 6d$
27446.760	9/2		-0.903	$5f^8 7s$
27539.800	9/2	1.37	-1.002	$5f^8 6d$
27625.715	5/2	1.596	-0.717	$5f^8 7s$
27980.085	5/2	2.024	-0.513	$5f^7(^8S^o_{7/2})7s7p(^3P^o_1)\ ^8P$
27983.940	15/2		-1.183	$5f^8 6d\ ^6H$
28191.535	7/2	1.744	-0.476	$5f^7(^8S^o_{7/2})7s7p(^3P^o_1)\ ^8P$
28232.670	7/2	1.543	-0.741	$5f^8 7s$
29247.870	7/2	1.63	-1.172	$5f^8 6d$
29477.200	5/2	1.389	-0.738	$5f^8 7s$
29814.140	9/2		-1.154	$5f^8 6d$
30442.315	11/2			$5f^8 6d$
30457.640	13/2		-1.180	$5f^8 6d$
30701.540	5/2	1.620	-1.139	$5f^8 6d$
30850.570	7/2	1.58	-1.179	$5f^8 6d$
31816.660	5/2	1.293	-1.130	$5f^8 6d$
32034.430	3/2	2.933	-0.923	$5f^7 6d7p\ ^{10}F$
32411.310	5/2	2.070	-0.924	$5f^7 6d7p\ ^{10}F$

32436.980	7/2	1.458	-1.149	$5f^8 6d$
32605.690	5/2		-1.165	$5f^8 6d$
32617.405	3/2	1.695	-1.124	$5f^8 6d$
32845.490	9/2	1.383	-1.163	$5f^8 6d$
32984.770	7/2	1.746	-0.942	$5f^7 6d7p\ ^{10}F$
33576.600	7/2	1.318	-0.722	$5f^8 7s$
33577.195	11/2	1.765	-0.465	$5f^7(^8S^o_{7/2})7s7p(^3P^o_2)\ ^{10}P$
33670.005	5/2		-0.893	
33852.565	9/2	1.629	-0.926	$5f^7 6d7p\ ^{10}F$
34171.395	7/2	1.545	-1.149	$5f^8 6d$
34532.400	11/2	1.32	-1.138	$5f^8 6d$
34893.775	5/2	1.65	-1.163	$5f^8 6d$
35280.665	5/2	2.255	-0.762	$5f^7 6d7p\ ^{10}D$
35378.325	11/2	1.366	-1.041	$5f^7 6d7p + f^8 d$
35397.790	9/2	1.768	-0.458	$5f^7(^8S^o_{7/2})7s7p(^3P^o_2)\ ^8P$
35456.915	11/2	1.367	-1.042	$5f^7 6d7p\ ^{10}F$
35556.240	7/2	1.858	-0.743	$5f^8 6d7p\ ^{10}D$
35778.500	7/2	1.13	-1.106	$5f^7 6d7p + f^8 d$
36039.980	9/2		-0.721	
36124.590	7/2		-0.406	
36415.100	7/2	1.05	-0.723	$5f^8 7s$
36526.985	9/2	1.723	-0.805	$5f^7 6d7p\ ^{10}D$
36618.270	7/2		-0.708	
36695.555	9/2	1.128	-1.148	
36866.530	7/2	1.655	-0.578	$5f^7(^8S^o_{7/2})7s7p(^3P^o_2)\ ^6P$
37263.590	13/2		-1.158	
37493.235	5/2		-0.741	$5f^8 7s$
37730.880	5/2	1.710	-0.548	$5f^7(^8S^o_{7/2})7s7p(^3P^o_2)\ ^6P$
38548.615	3/2	2.245	-0.489	$5f^7(^8S^o_{7/2})7s7p(^3P^o_2)\ ^6P$
39336.800	11/2		-0.48	
39464.980	11/2	1.689	-0.894	$5f^7 6d7p\ ^{10}D$
39568.525	13/2	1.559	-0.920	$5f^7 6d7p\ ^{10}F$
40592.510	5/2	2.240	-0.654	$5f^7(^8S^o_{7/2})7s7p(^1P^o_1)\ ^8P$
40966.185	7/2	1.778	-0.743	$5f^7(^8S^o_{7/2})7s7p(^1P^o_1)\ ^8P$
41006.550	9/2		-0.855	
41098.265	7/2		-1.075	

41130.390	9/2	1.70	-0.698	$5f^7(^8S^o_{7/2})7s7p(^1P^o_1)$ ^8P
42112.135	5/2		-0.676	
42223.500	3/2	2.49	-0.968	$5f^76d7p$ ^8D
42261.415	5/2	1.990	-0.947	$5f^76d7p$ ^8D
42277.220	7/2	1.50	-0.867	$5f^76d7p$ ^8D
42286.200	3/2	1.243	-0.959	
42295.745	7/2		-0.833	
42332.445	9/2		-0.944	$5f^76d7p$ ^8D
42534.980	9/2		-0.973	
42647.650	7/2		-1.015	
42691.920	9/2		-0.804	$5f^87s$
42775.855	11/2	1.64	-0.958	$5f^76d7p$ ^8D
43272.010	9/2	1.28	-0.775	
43285.755	7/2		-1.027	
43377.225	5/2		-0.777	$5f^87s$
43490.765	3/2		-0.56	
43513.325	1/2	3.59	-0.944	$5f^76d7p$ ^8F
43526.900	5/2		-0.959	
43545.040	3/2		-0.56	
43703.945	7/2		-1.065	
43774.785	5/2		-0.819	
43819.750	7/2		-0.971	
43888.380	7/2		-0.750	
43995.330	9/2		-0.989	
44036.965	5/2		-0.720	
44085.290	9/2	1.38	-0.977	
44117.435	9/2		-1.013	
44384.100	7/2	1.227	-0.694	
44400.270	13/2	1.615	-0.959	$5f^76d7p$ ^{10}D
44535.315	9/2	1.160	-1.235	
44680.910	7/2	1.995	-0.929	$5f^76d7p$ ^{10}P
44725.925	11/2		-1.085	
44900.620	11/2	1.464	-0.970	
45538.930	9/2		-1.054	
45631.340	9/2	1.583	-0.995	
45685.045	9/2		-1.122	
46095.890	15/2	1.56	-0.951	$5f^76d7p$ ^{10}F
46339.190	7/2	1.29	-0.955	
46401.315	7/2	1.387	-0.699	
46510.315	7/2		-1.010	
46572.450	5/2		-1.026	
46603.555	7/2	1.35	-0.745	
46789.130	5/2	1.785	-0.895	
47071.970	9/2	1.45	-0.937	
47133.630	9/2		-0.967	
47277.720	11/2		-0.942	
47728.745	9/2		-0.931	

Table 3.

47866.300	5/2		-0.987
47868.975	9/2		-0.912
47910.130	9/2	1.30	-0.697
47916.005	5/2		-0.750
47936.880	13/2,11/2		-0.968
48003.625	11/2,9/2		-0.888
48083.445	5/2		-0.944
48193.975	5/2		-0.870
48310.650	11/2		-0.993
48312.535	7/2	1.465	-0.929
48397.810	13/2		-0.957
48430.080	5/2		-0.65
48509.010	11/2		-1.036
48956.270	3/2		-0.90
49196.710	7/2		-0.914
49507.150	7/2		-1.059
51071.625	5/2		-0.84
51936.210	9/2		-0.980
52103.525	5/2		-0.701
53493.295	9/2,7/2		-0.810
53638.865	11/2		-0.948
54860.915	13/2		-0.834
55233.760	7/2		-0.833
56656.735	5/2		-0.62
58041.765	9/2		-0.725

Table 4. Lowest levels of identified configurations in Cm II.

Energy Level (cm^{-1})	g value	Isotope Shift (cm^{-1})	Configuration Designation	
Odd				
0.000	1.935	x	$5f^7 7s^2$	$^8S^o_{7/2}$
4010.645	2.492	x-0.496	$5f^7 6d7s$	$^{10}D^o_{5/2}$
14830.150	3.009	x-0.962	$5f^7 6d^2$	$^{10}F^o_{3/2}$
27065.085	1.51	x-0.972	$5f^8 7p$	$^8F^o_{11/2}$
Even				
2093.870	1.500	x-0.739	$5f^8 7s$	$^8F_{13/2}$
17150.790	1.415	x-1.177	$5f^8 6d$	$^9G_{13/2}$
24046.385	2.098	x-0.403	$5f^7 7s7p$	$^{10}P_{7/2}$
32034.430	2.933	x-0.923	$5f^7 6d7p$	$^{10}F_{3/2}$

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720