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Conversion-Coefficient Measurements and Spin-Parity Assignments for Excited Levels in ^{133,135,136}Xe, ^{135,137,139}Cs, and ^{138}Ba†

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Solid-state detectors have been used to perform on-line measurements of γ-ray and conversion-electron intensities in ^{133,135,136}Xe, ^{135,137,139}Cs, and ^{138}Ba. Conversion coefficients were determined for 37 transitions. Logft values were calculated on the basis of reported level schemes. The deduced multipolarities and logft values were combined with published reaction and angular-correlation results to assign spins and parities to 24 excited levels of the mentioned nuclei. The obtained $J\pi$ contributed 13 new experimentally-well-defined β-transition probabilities to the systematics of this magnitude. In ^{136}Xe and ^{138}Ba, three levels with known half-lives were determined to be depopulated by pure-$E2$ transitions; the retardation factors as compared to the Weisskopf estimate were calculated. Apart from $J\pi$ assignments, some additional minor contributions were made to the knowledge of the level structure in ^{138}Ba and ^{139}Cs. The number of possible spins and parities for some of the excited levels in the nuclei studied was reduced by analyzing the systematic trends of measured $J\pi$ values in their neighborhood. No modelistic considerations were taken into account for this purpose.

I. INTRODUCTION

The conveniences of studying properties of (short-lived) nuclei far from the β-stability line have been discussed repeatedly during the last years in a number of papers and, particularly, at several international conferences.[1-4] Among those properties, spins and parities of the excited levels are fundamental, their correct prediction being one of the strongest validity tests of any nuclear model. A straightforward means to obtain these parameters is through the determination of the multipolarities of transitions connecting the levels with others having a previously assigned spin-parity. Thus, since internal-conversion coefficients depend heavily on the multipole order and on the electric or magnetic character of the transitions, their measurement generally leads to well-supported spin-parity assignments. However, up to now, few measurements of this type have been reported on short-lived isotopes, either by the modern on-line technique or by conventional nuclear-spectroscopy methods, in the latter case due to the difficulties in collecting a reasonable amount of information.

At the Buenos Aires isotope-separator on-line facility (IALE project), a program was started some time ago to determine internal-conversion coefficients in the region of the "heavy" fission-produced isotopes, for which the protons occupy the $g_{7/2}$ shell and the neutrons, close to $N=82$, are in the $d_{3/2}$ or $f_{7/2}$ shells. The characteristics of the setup used (Sec. II) limited the scope of our investigations to isotopes originated in the decay of rare-gas or halogen nuclides. In the present work, we have determined multipolarities of transitions appearing in the decays of $^{133, 135, 136m}$I, $^{133m, 135m, 135, 137, 139}$Xe, and ^{138}Cs (Sec. III). Although neutron-rich, not all these nuclei are short-lived, their $T_{1/2}$ actually ranging from 40 sec to 53 h. Our results on the conversion electrons from the decay of $^{134m, g}$I have been published[5] recently. A study of the decay of 14.2-min ^{138}Xe is close to completion.

Of the 37 K conversion coefficients presented in this paper, only those of 3 long-lived transitions have been reported earlier. Each of these previous determinations led to a definite $J\pi$ proposal for the levels being depopulated. The bulk of our results allowed us to assign spins and parities to 21 additional excited levels of the nuclei being studied. Previous information existing on each of these levels is reviewed in Sec. IV, specifically dealing with each of the nuclei. In Sec. V, the firmly established $J\pi$ assignments are utilized to deduce 13 β-transition probabilities; in the same section, three γ-ray transition probabilities are compared to the Weisskopf estimate. In order to reduce the number of possible spins and parities for some of the levels, concluding Sec. VI contains a limited study of the systematic trends of measured $J\pi$ values in the mass region we are concerned with.

As a by-product to the main aim of this paper, a few details of the level structures of ^{138}Ba and ^{139}Cs have been studied.

II. EXPERIMENTAL PROCEDURES

A. Source Production

The several radioactive sources we investigated were produced as follows. A target of uranl stearate containing 16 g of uranium enriched to 90% in ^{235}U and enclosed in a stainless-steel container was exposed to a flux of about 10^8 thermal neutrons/cm^2 sec. The rare-gas and halogen fission products were continuosly fed into the ion source of a magnetic mass separator through a short (50-cm) pipe. Isotopes of other fission products did not reach the ion source in measurable quantities. The ion beam corresponding to the mass of interest was then collected on a small piece of 5-mg cm^{-2} aluminium foil. In this way, a very thin source having a diameter of about 4 mm was obtained, with almost no self-absorption for internal-conversion electrons of the energies dealt with in this work. The contamination due to hydrides of mass $A-1$ was kept at about 5×10^{-4} of the mass $A-1$ line intensity. At the collector position, the tail of the intensity distribution corresponding to mass $A+1$ had a height of about 10^{-4} of its maximum. A complete description of the experimental setup will be published elsewhere.

B. Experimental Arrangement and Efficiency Calibrations

Our experimental determination of internal-conversion coefficients is based on the simultaneous measurement of the rates of emission of internal-conversion electrons and γ rays belonging to the same transition.

The internal-conversion coefficient corresponding to the K line of a given transition can be expressed as

$$\alpha_K = \eta A_K \epsilon_\gamma / A_\gamma , \quad (1)$$

where A_K is the area of the K conversion electron peak; A_γ is the area of the corresponding γ-ray photopeak; $\epsilon_\gamma(E_\gamma)$ is, for a given geometry, the relative photopeak-detection efficiency of the Ge(Li) detector; $\eta(E_e)$ is, for the same geometry, an experimentally obtained normalization function by which Eq. (1) gives the absolute internal-conversion coefficient α_K. It includes the electron-detection efficiency of the Si(Li) detector (see below).

The geometry of the experimental arrangement we used is shown schematically in Fig. 1. A Si(Li) detector, providing high electron-detection efficiency, is mounted inside a small chamber, connected to the exit of the mass separator through a tube provided with suitable diaphragms. The chamber has a 3-mm-thick Lucite wall, in front of which an externally mounted Ge(Li) detector is placed, facing the electron detector. The collector, as well as calibration sources, can be introduced into the vacuum chamber through a conventional airlock. The distances from the collected activity to the Si(Li) and the Ge(Li) detectors were about 1 and 5 cm, respectively. The vacuum was provided by the main vacuum of the mass separator. Masses neighboring the one of interest were stopped on lead blocks placed about 80 cm before the Al collector, and additional lead shieldings were interposed between them and the detectors. The γ-ray background due to neutron reactions in the detectors, and in the materials surrounding them, was reduced by lead and boric acid shieldings.

The 1-cm^2 area and 3-mm-depletion-depth Si(Li) detector was operated at liquid-N_2 temperature. Its resolution was of 8.0 keV for the 976-keV conversion line in ^{207}Bi. The electron detection was not affected by the stray magnetic field of the mass separator. However, due to the presence of the ion beam, on-line electron spectra generally had a high noise level below $E_e = 100$ keV. To

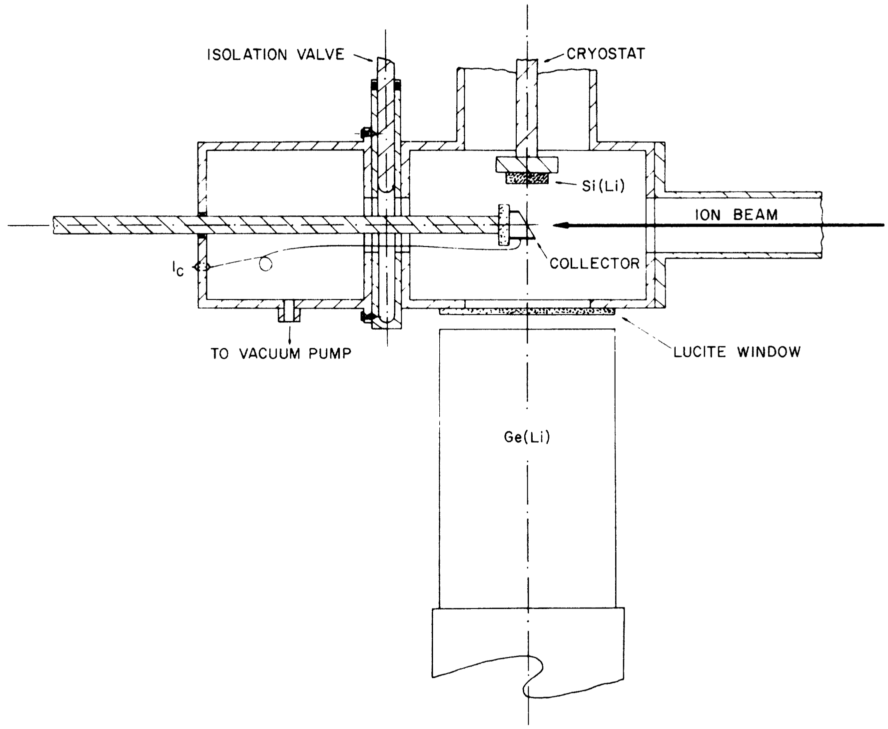

FIG. 1. Schematic top view of the collection-detection system. The main vacuum is supplied from the mass separator chamber. (The auxiliary vacuum connection shown is only used when replacing collectors or calibration sources.)

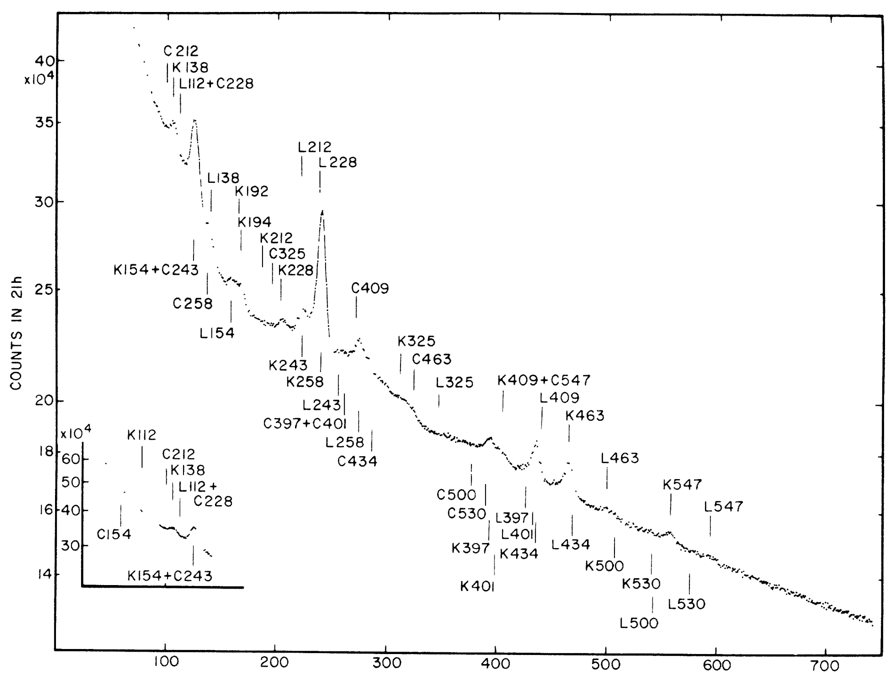

FIG. 2. Partial on-line electron spectrum of the decays of ^{138}Cs and ^{138}Xe, recorded with a 1-cm^2 area and 3-mm depletion-depth Si(Li) detector. The ^{138}Cs lines and Compton edges are identified above the spectrum. The values given below the spectrum correspond to transitions belonging to the ^{138}Xe decay.

decrease this effect, we placed a permanent magnet outside the collection chamber. It generated a field weak enough not to affect the measured intensity relations of the conversion electrons, but sufficient to prevent the secondary electrons generated by the ion beam on the collector from reaching the Si(Li) detector. In this way it was possible to shift the upper limit of the noise to about 50 keV. The magnet was specially effective when the Xe gas used to sustain the discharge in the ion source of the mass separator did not contribute a stable isotope to the isobar being collected, since then the current on the collector was low.

Figures 2 and 3 show typical on-line recorded conversion-electron spectra. The analysis of the spectrum of Fig. 2 became somewhat difficult owing to the presence of peaks from 14.2-min ^{138}Xe and from its 32.2-min daughter ^{138}Cs, having similar energies and intensities. As the energy region corresponding to the K electrons of the 112.44-keV transition coincides with that of the Pb x rays, the latter were suppressed by lining the inner walls of the shielding with a thin Fe sheet. Figure 3 shows the electron spectrum due to the decay of 48-sec ^{136}I. The over-all intensity is much lower than in the preceding example, a fact which, together with the significant presence of long-lived Xe contaminants, illustrates the difficulties related to the extraction of iodine isotopes from the stearate and to their conveyance to the mass-separator ion source.

The γ-ray spectra were recorded with a 35-cm^3 Ge(Li) detector. In the normally long runs, lasting up to 25 h, the resolution for the 1332-keV line in the ^{60}Co was about 2.5 keV. This figure improved to 2.0 keV when the system was operated over short periods at a high gain corresponding to 0.3 keV/channel. Figure 4 shows a partial on-line γ-ray spectrum of the decay of ^{139}Xe.

The outputs of both the electron and the γ-ray detection systems were recorded simultaneously in an analyzing system, using 2048 channels for each detector. The analyzer, as well as several fast read-out and plotting peripherals, were under the control of a 16 000-word memory computer.

Electron- and γ-ray-peak areas were evaluated by manual methods. The background was defined as a straight extrapolation of the spectral distribution at the high-energy side of the peak. The number of channels from which counts were added was determined by the intersections of the background line with the extrapolations of the low- and high-energy straight sides of the peak. The procedure consistently excludes from the area computations the tails on both sides of the peaks. This effect is a convenient one, since those tails would contribute with only a small fraction of the

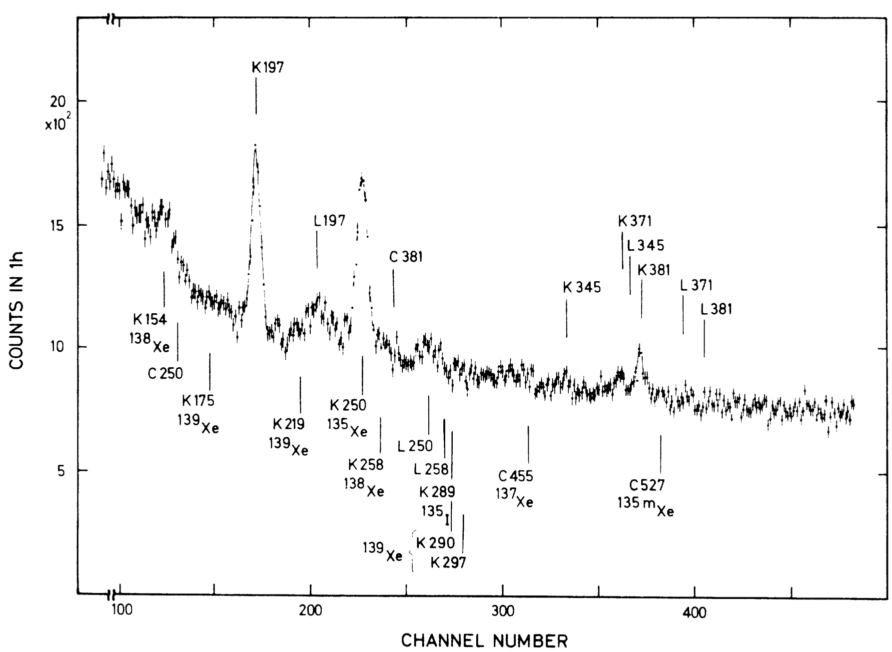

FIG. 3. Partial on-line electron spectrum of the decay of ^{136}I, recorded with a 1-cm^2 area and 3-mm depletion-depth Si(Li) detector. Values given below the spectrum correspond to transitions in isotopes contained in the tails of higher-mass isobars. The K 249.7-keV line of ^{135}Xe decay has been superposed intentionally (see text), to be used as a normalization standard for the α_K. Collecting time was kept short in order to obtain a fair resolution.

total area, affected however by a rather large relative error.

The relative photopeak-detection efficiency ϵ_γ of the Ge(Li) detector was determined over the range 250–1800 keV according to the method described by Kane and Mariscotti.[6] The standard sources used were ^{88}Y, ^{108}Ag, and ^{110m}Ag, with the relative intensities given in the works of Lederer, Hollander, and Perlman,[7] Kane and Mariscotti,[6] and Brahamavar *et al.*[8] The curve thus obtained was then extended down to 100 keV, utilizing the relative intensities of ^{75}Se.[9] In this way, the efficiency was defined to ±10% between 100 and 200 keV, to ±7% between 200 and 300 keV, and to ±5% at higher energies.

The normalization function η accounts for the full-energy absorption efficiency of conversion electrons, correcting simultaneously for effects

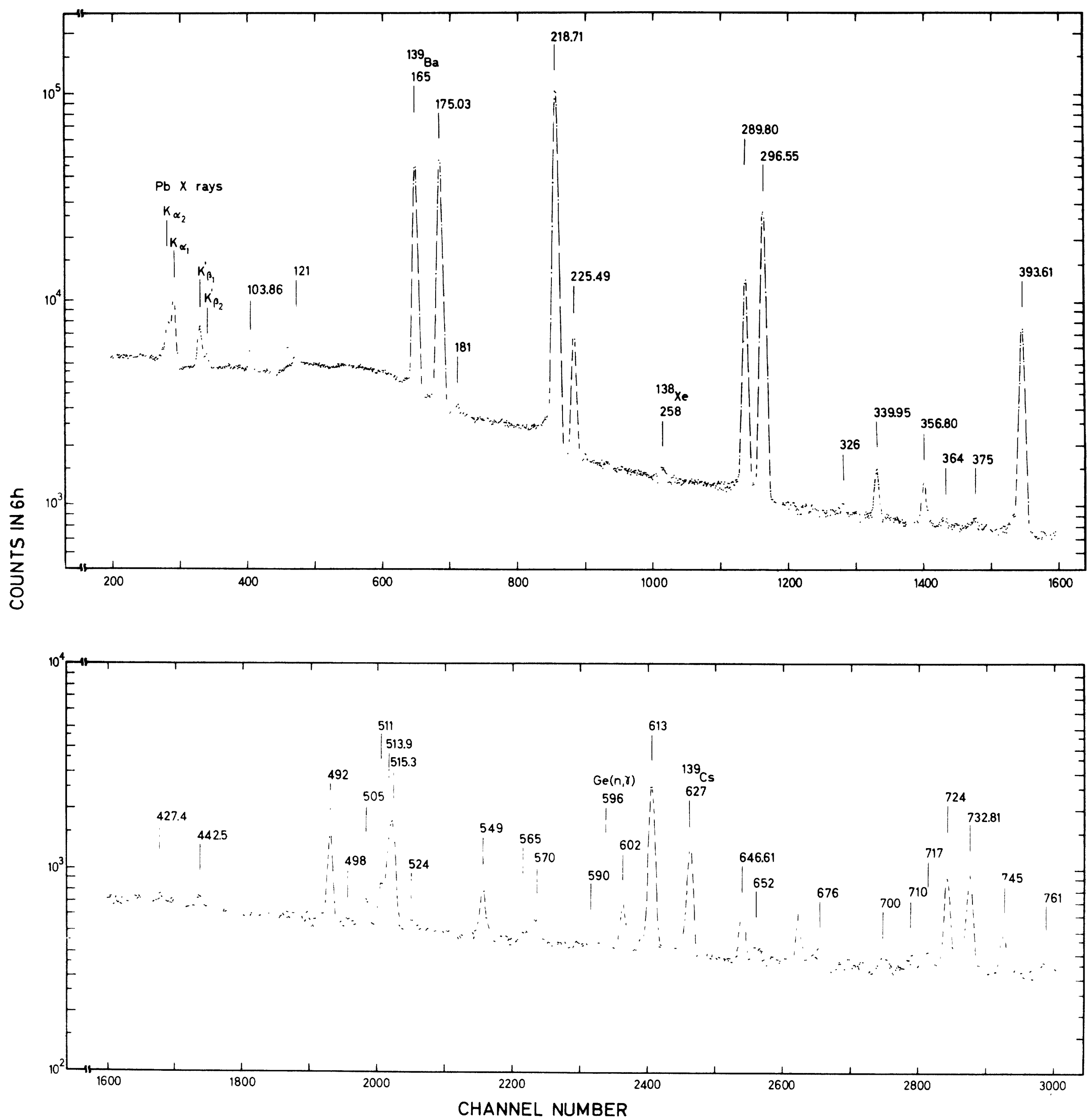

FIG. 4. Partial on-line γ-ray spectrum of the decay of ^{139}Xe, recorded during 6 h with a 35-cm^3 Ge(Li) detector operated at 0.25 keV/channel. The transitions for which the energies are indicated with a precision better than 1 keV are those used in the energy-sum relations of Table V. The transition at 667 keV could not be assigned to any isotope.

depending on the geometry used, such as the distortion of K line areas by the summing of K electrons with their corresponding X_K x ray. It was determined experimentally as a function of the electron energy E_e through Eq. (1), using several transitions with well-established internal-conversion coefficients. The long-lived standard sources[10] employed were ^{137}Cs, ^{203}Hg, and ^{207}Bi, properly placed at the position of the collector. Shorter-lived standard transitions, such as the 165-keV γ ray in 83-min ^{139}Ba decay, were produced as described in Sec. A. Actually, ^{139}Ba was obtained as a decay product of the collected 40-sec ^{139}Xe; its α_K value was taken from Ref. 10. A good quality standard was also furnished by the strong 250-keV transition in 9.1-h ^{135}Xe decay. The experimental value 0.061 ± 0.004 we obtained in a preliminary run for its K conversion coefficient showed that it ought to have $M1$-$E2$ multipolarity, in agreement with Bergström[11] and with Graham and Bell.[12] Thus, this transition was included as a standard with an α_K obtained as an average between the close-lying theoretical values[13] 0.0636 for $E2$ and 0.0624 for $M1$.

The standards mentioned in the preceding paragraph determine the normalization function up to about 1 MeV. In order to extend this range, at an early stage of the present work we experimentally determined the K conversion coefficient of the 1436-keV γ ray in the 32-min decay of ^{138}Cs. This was done using a graphical extrapolation of the function η up to 1.5 MeV. The obtained $\alpha_K = 0.000\,62 \pm 0.000\,15$ determined the multipolarity to be $E2(+M1)$. As this transition depopulates the first excited state of ^{138}Ba to its 0+ ground state,[14] the 1436-keV transition was also included as a standard having the theoretical[13] $\alpha_K(E2)$ conversion coefficient.

Within the rather large errors involved, the function η could be represented over the range of interest by a straight line. Its magnitude was defined to about ±10% and it had a slope of about 0.8% per 100 keV. The permanency of these figures was checked over several weeks of measurement and enough confidence was acquired to use the function for obtaining absolute conversion coefficients from those spectra not containing any transitions with a well-established multipolarity ($A = 133$, 136, and 137).

As said above, the γ-ray detection efficiency was obtained using only off-line-produced standard sources, and also the determination of the electron-detection efficiency included the use of some of these sources. As a consequence, we had to reduce the areas of all on-line-detected peaks, since not all of the activity stuck onto the Al collector and because of the incomplete shielding of the activities deposited on the diaphragms defining the ion beam. For γ rays the correction was about 4% below 600 keV, slowly changing to about 7% at 1.7 MeV. For the conversion electrons it was below 1% over the whole energy range.

C. Energy Calibrations

The procedure used for γ-ray energy calibrations was the conventional one: Standard transitions were recorded simultaneously with the spectrum under investigation and the most prominent peaks of the latter were calibrated against the standards. These peaks were subsequently used for internal calibration of the spectra taken without the standard sources. In some cases, we could use peaks which appeared prominently in the spectra and had energies well known from previous works.

III. EXPERIMENTAL RESULTS

Our measurements give information on the K conversion coefficients of 37 transitions in nuclei having masses from 133 to 139. For only three of these coefficients did there exist previous determinations.[11,12,15,16] Only a small number of $K/(L+\cdots)$ ratios have been determined in the present work. This is due to poor statistics and to the overlapping of the $L+\cdots$ peaks with K peaks of the same isobar or from contaminants (see Fig. 2).

All α_K values obtained in this work are collected in Table I, together with the $K/(L+\cdots)$ ratios and the corresponding γ-ray energies and intensities resulting from our measurements. The error quoted for each α_K is the result of combining the errors arising from area evaluations, efficiency curves, and normalization procedures.

In order to assign the multipolarities proposed in the last column of Table I, we have compared the experimental results of the preceding column with the theoretical values given by Hager and Seltzer.[13] For the K conversion coefficients the comparison is shown graphically in Figs. 5–7, where the $E5$ curve has been drawn from the theoretical data published by Sliv and Band.[17] Since highly hindered $E1$ transitions are not frequent outside deformed regions and, besides, from α_K and $K/(L+\cdots)$ measurements alone nothing may be stated about eventual $E1+M2$ mixtures, these have not been considered in the present paper. The conventions used for the proposed multipolarities are as follows: (a) $M1$-$E2$-$E1$ indicates that any of the three multipolarities may correspond to the transition, the preference being in the given order; (b) $M1, E2, E1$ is used when no preference can be established, the order being the one cor-

TABLE I. Results of γ-ray and conversion-electron measurements.

Parent nucleus	E_γ (keV)	I_γ [a] relative	$10^3 \alpha_K$ [b] $\langle K/(L+\cdots)\rangle$	Multipolarity
^{133}I 20.8 h [c]	529.83 ± 0.25	···	8.0 ± 1.0	$M1$ (≤80% $E2$)
^{133m}Xe 52.6 h [d]	233.2 ± 0.4	···	7400 ± 1400 ⟨2.54 ± 0.20⟩	$M4$ (≤7% $E5$) [e]
^{135}I 6.7 h [f]	220.3 ± 0.3	6.9 ± 1.4	70 ± 30	$M1$-$E2$
	417.5 ± 0.4	11.9 ± 2.0	15 ± 9	$M1$, $E2$
	1038.6 ± 0.3	25.7 ± 1.4	≤0.7	$E1$
	1131.5 ± 0.3	78 ± 4	1.18 ± 0.24	$E2$-$M1$
	1260.3 ± 0.3	100 ± 5	0.90 ± 0.14	$E2$ (≤70% $M1$)
	1457.5 ± 0.3	32.3 ± 1.7	0.70 ± 0.24	$E2$-$M1$
	1678.1 ± 0.3	32.1 ± 1.8	0.56 ± 0.14	$M1$-$E2$
^{135m}Xe 15.2 min [d]	526.5 ± 0.3	···	198 ± 12	$M4$ (≤8% $E5$)
^{135}Xe 9.14 h [d]	249.7 ± 0.2	100 ± 5	63.0 [g]	$M1$+$E2$
	358.2 ± 0.3	0.23 ± 0.02	≤42	$M1$, $E2$, $E1$
	407.9 ± 0.3	0.37 ± 0.03	≤25	$M1$, $E2$, $E1$
	608.0 ± 0.3	2.90 ± 0.25	8.4 ± 2.2	$M1$ (≤20% $E2$)
^{136}I 48 sec [h]	197.2 ± 0.2	72 ± 4	158 ± 25 ⟨3.8 ± 0.8⟩	$E2$
	381.3 ± 0.2	100 ± 6	18 ± 4	$M1$, $E2$
^{137}Xe 3.82 min [i]	455.3 ± 0.2	···	9.0 ± 1.1 ⟨4.2 ± 0.8⟩	$E2$ (≤10% $M1$)
^{138}Cs 32.2 min [i]	112.44 ± 0.10	0.26 ± 0.10	≤830	$E2$, $M1$, $E1$
	138.02 ± 0.10	2.05 ± 0.20	400 ± 90	$E2$-$M1$
	212.38 ± 0.10	0.14 ± 0.05	210 ± 50	$E2$, $M1$
	227.75 ± 0.10	1.86 ± 0.07	89 ± 10	$M1$, $E2$
	324.90 ± 0.12	0.32 ± 0.03	≤34	$M1$, $E2$, $E1$
	408.98 ± 0.08	5.41 ± 0.25	21 ± 4	$M1$ (≤45% $E2$)
	462.82 ± 0.12	36.7 ± 1.5	10.5 ± 1.3	$E2$ (≤50% $M1$)
	546.87 ± 0.15	12.7 ± 0.5	10.5 ± 1.4	$M1$ (≤4% $E2$)
	871.66 ± 0.07	7.1 ± 0.5	2.8 ± 0.8	$M1$-$E2$
	1009.78 ± 0.07	37.2 ± 1.5	2.2 ± 0.4	$M1$ (≤55% $E2$)
	1435.72 ± 0.07	100 ± 3	0.743 [j]	$E2$
^{139}Xe 39.7 sec [i]	103.86 ± 0.10	0.72 ± 0.23	730 ± 130 [k]	$M1$ (≤45% $E2$)
	175.03 ± 0.08	34 ± 3	122 ± 15 ⟨10 ± 4⟩	$M1$ (+$E2$)
	218.71 ± 0.08	100 ± 4	82 ± 12 ⟨4.1 ± 0.4⟩	$E2$, $M1$
	289.80 ± 0.10	17.9 ± 1.8	31 ± 6	$M1$, $E2$
	296.55 ± 0.10	40 ± 3	36 ± 5	$E2$-$M1$

TABLE I *(Continued)*

Parent nucleus	E (keV)	I_γ [a] relative	$10^3\alpha_K$ [b] $\langle K/(L+\cdots)\rangle$	Multipolarity
	338.95 ± 0.10	1.23 ± 0.10	16 ± 12	$E2$, $E1$-$M1$
	356.80 ± 0.20	1.03 ± 0.10	79 ± 25	$M2$, $E3$
	393.61 ± 0.08	12.8 ± 1.0	15 ± 3 ⟨3 ± 1⟩	$E2$ (≤70% $M1$)
	732.81 ± 0.25	3.77 ± 0.20	≤4.8	$M1$, $E2$, $E1$

[a] The errors stated for the intensities normalized to 100 have not been included in the errors of the other intensities.
[b] Previously reported values are quoted in sections specifically dealing with each of the nuclei entered in column 1.
[c] Reference 19.
[d] Reference 15.
[e] Fransson and Erman (Ref. 24), by a recent determination of the $L_{\mathrm{I}}:L_{\mathrm{II}}:L_{\mathrm{III}}$ ratios, set an upper limit of 2% for the $E5$ admixture.
[f] Reference 7.
[g] We obtained an experimental value $\alpha_K = 0.061 \pm 0.004$ for the 249.7-keV transition. As explained in Sec. II B, the average between the theoretical values $\alpha_K(E2) = 0.0636$ and $\alpha_K(M1) = 0.0624$ was adopted and used as a normalization standard.
[h] Reference 42.
[i] Reference 34.
[j] We obtained an experimental value $\alpha_K = 0.000\,62 \pm 0.000\,15$. As explained in Sec. II B, we adopted the theoretical value 0.000 743, corresponding to an $E2$ multipolarity, and used it as a normalization standard.
[k] For this transition we obtained too low a value for the $K/(L+\cdots)$ ratio; we attribute this to the contribution of the γ line, since, at this energy, the γ-ray efficiency of the Si(Li) detector is significant.

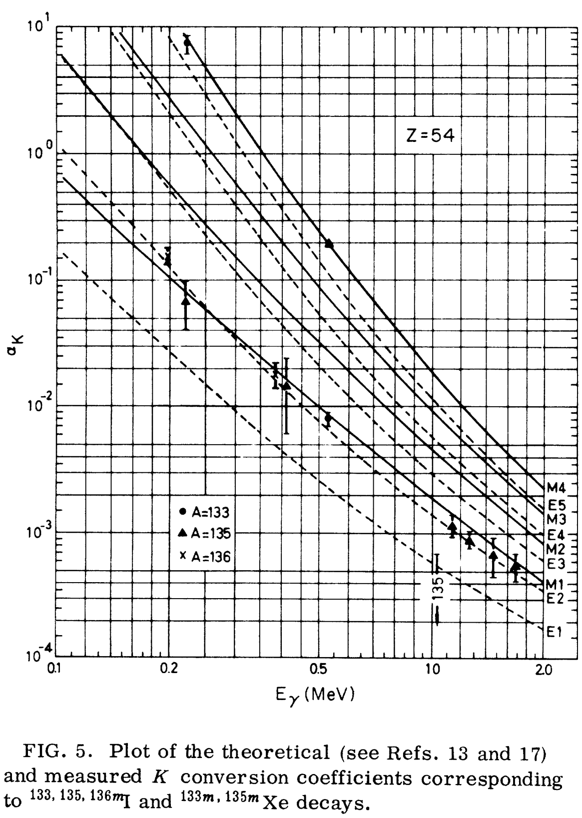

FIG. 5. Plot of the theoretical (see Refs. 13 and 17) and measured K conversion coefficients corresponding to ^{133,135,136m}I and ^{133m,135m}Xe decays.

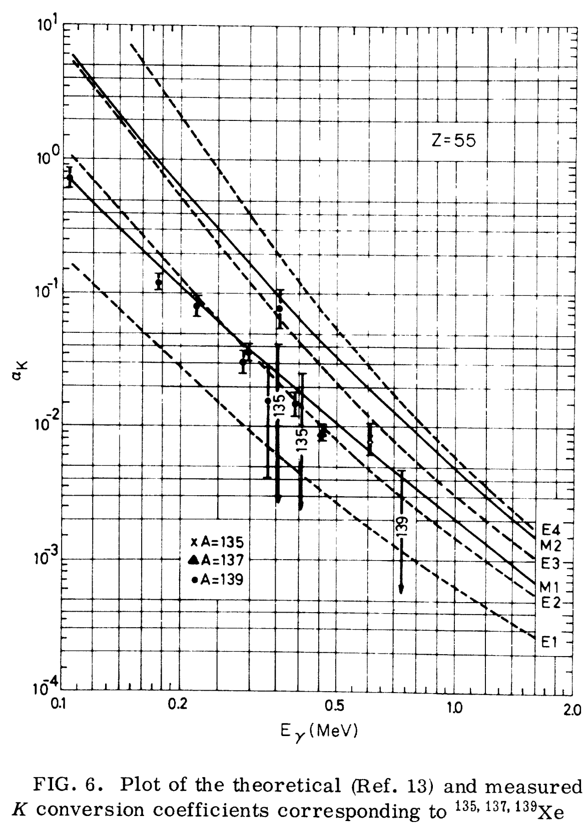

FIG. 6. Plot of the theoretical (Ref. 13) and measured K conversion coefficients corresponding to ^{135,137,139}Xe decays.

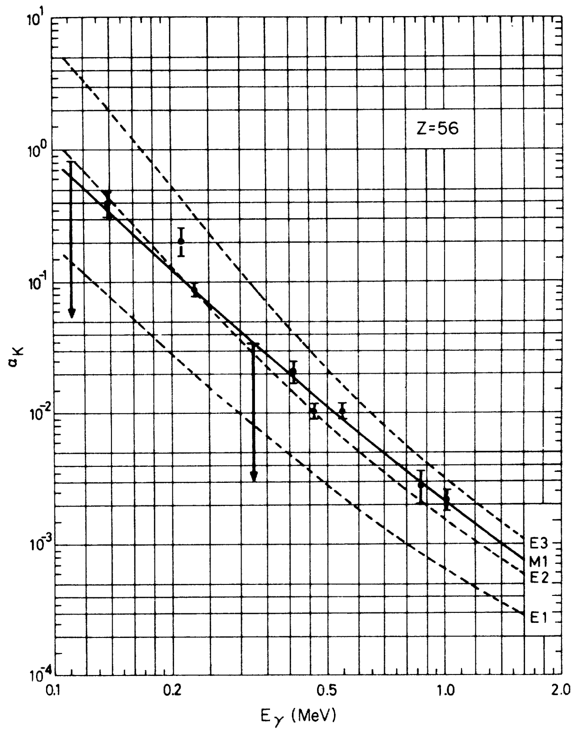

FIG. 7. Plot of the theoretical (Ref. 13) and measured K conversion coefficients corresponding to ^{138}Cs decay.

responding to decreasing values of α_K ; (c) the upper limit for the percentage of admixture has been evaluated using not the experimental value itself, but the appropriate end of the corresponding error bar.

IV. SPIN AND PARITY ASSIGNMENTS

In this section we discuss the $J\pi$ values of the excited levels of seven nuclei. The corresponding level schemes were taken from published works and have been checked by the energy-sum relations and the transition intensities obtained in the present investigation. In some cases, transitions have been eliminated from proposed level schemes, owing to the higher precision of our energy values, or some levels have been removed because of the nonexistence of the transitions presumptively supporting them.

In order to establish spins and parities of excited levels, we have combined the information given by the multipolarities reported in Table I with the information arising from deduced $\log ft$ values, as well as from published angular-correlation and reaction studies. In no case did we use the information available from the systematics of $J\pi$ values of excited nuclear states. For the deduction of spins and parities from $\log ft$ values, we have followed the criteria established[18] by the Nuclear Data Group. Accordingly, since all the β rays which feed levels for which we propose $J\pi$ values have $5.8 \leq \log ft \leq 10.6$, they were assumed to be allowed or first forbidden. Moreover, because there exists for none of them information on the spectral-shape factor, the first-forbidden unique type was excluded only when the corresponding $\log f^1 t \leq 7.6$. Conversely, the validity of these criteria is confirmed by the bulk of our results which, by univocally fixing the spin-parity of some levels, yield several well-based data for the systematics of $\log ft$ values.

All γ-ray, internal-conversion-electron, and level energies, as well as relative γ-ray intensities and $\log ft$ values, given in this section have been determined in the present work, except in the few cases where we explicity mention other sources.

A. Odd-A Nuclei

1. *Levels of* ^{133}*Xe*

The $J\pi$ value of the ground state of ^{133}I has been measured[14] to be $\frac{7}{2}+$. Its 20.8-h decay has been studied mainly by Eichler, Chase, Johnson, and O'Kelley[19] and by Saxena and Sharma,[20] who assigned spins and parities for the excited levels of ^{133}Xe by combining deduced $\log ft$ values with observed depopulation branchings.

TABLE II. Results from conversion-electron measurements on the 233-keV transition in ^{133}Xe.

	Energy (keV)	α_K	$K/(L+\cdots)$
Bergstrom (Refs. 11 and 23)	232.8 ± 0.3	4.4 ± 1.4	2.32 ± 0.15
Alexander and Lau (Ref. 15)	233.4	7.68 ± 0.25	2.04 ± 0.12
Present work	233.2 ± 0.4	7.4 ± 1.4	2.54 ± 0.20
Hager and Seltzer (Ref. 13)	···	$M4$: 6.40	$M4$: 2.48
Sliv and Band (Ref. 17)	···	$M4$: 6.30 $E5$: 4.04	$M4$ < 3.07 [a] $E5$ < 0.59 [a]

[a] The stated value corresponds to K/L.

TABLE III. Spins and parities proposed for levels of ^{135}Xe.

Level energy Present work (keV)	Spin and parity assignments ^{136}Xe(*d*, *t*) reaction [a]	log*ft* and log$f^{1}t$ [b]	Conversion coefficients [c] Present work	Proposed spins and parities
0.0	$\frac{3}{2}+$	...	...	$\frac{3}{2}+$
288.4 ± 0.3	$\frac{1}{2}+$	...	...	$\frac{1}{2}+$
526.5 ± 0.3	$\frac{11}{2}-$	$\frac{5}{2}+$ to $\frac{9}{2}+$ $\frac{3}{2}-$ to $\frac{11}{2}-$	$\frac{11}{2}^-$	$\frac{11}{2}-$
1131.5 ± 0.3	...	$\frac{5}{2}+$ to $\frac{9}{2}+$ $\frac{3}{2}-$ to $\frac{11}{2}-$	$\frac{1}{2}+$ to $\frac{7}{2}+$	$(\frac{7}{2})+$
1260.4 ± 0.2	$(\frac{5}{2}+)$	$\frac{5}{2}\pm$ to $\frac{9}{2}\pm$	$\frac{1}{2}+$ to $\frac{7}{2}+$	$\frac{5}{2}+$
1457.4 ± 0.2	$(\frac{5}{2}+)$	$\frac{5}{2}\pm$ to $\frac{9}{2}\pm$	$\frac{1}{2}+$ to $\frac{7}{2}+$	$\frac{5}{2}+$
1565.1 ± 0.4	...	$\frac{5}{2}\pm$ to $\frac{9}{2}\pm$	$\frac{9}{2}+$ to $\frac{13}{2}+$	$\frac{9}{2}+$
1677.9 ± 0.2	...	$\frac{5}{2}\pm$ to $\frac{9}{2}\pm$	$\frac{1}{2}+$ to $\frac{7}{2}+$	$(\frac{7}{2})+$

[a] References 21 and 26.
[b] The log*ft* values were taken from Ref. 27.
[c] The transition multipolarities used for the spin-parity assignments are collected in Table I. The conversion-electron data for the 526.5-keV transition have also been determined earlier (Ref. 16).

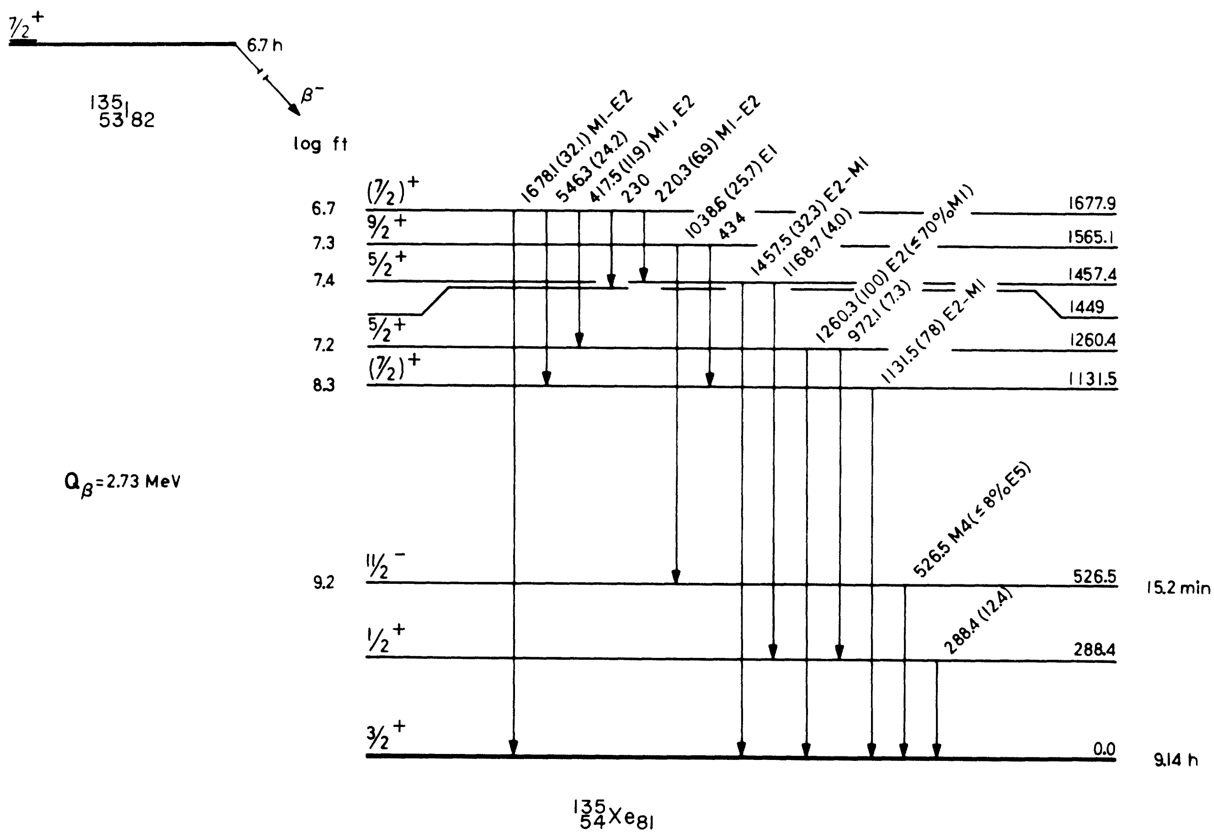

FIG. 8. Partial level scheme for ^{135}Xe, based on Ref. 27. Shown are all the transitions for which we determined the indicated multipolarities, as well as others supporting the location of the levels for which we propose spins and parities. Q_β and log*ft* values, as well as energies for the 230- and 434-keV transitions, and for the 1449-keV level, were taken from Ref. 27. Relative γ-ray intensities are given within parentheses.

The ground state of ^{133}Xe has a half-life[15] of 5.3 days, and its spin and parity $\frac{3}{2}+$ were obtained by studing the ^{134}Xe(d, t) reaction,[21] and the characteristics of the β decays[22] from ^{133}I to ^{133}Xe, and from the latter to ^{133}Cs.

For the 2.2-day[15] isomeric level at 233.2 keV, spin and parity $\frac{11}{2}-$ have been established in previous works[15,23] by combining $\log ft$ values with results from measurements of the conversion coefficients of the ground-state transition. Table II collects the previously measured coefficients, those obtained in this work, and the theoretical values[13,17] for $M4$ and $E5$ multipolarities. The data clearly indicate the predominant $M4$ character of the transition. The $M4$ multipolarity is strongly supported by a determination of the $L_{\text{I}}: L_{\text{II}}: L_{\text{III}}$ ratios by Fransson and Erman,[24] who deduced and upper limit of 2% for the $E5$ admixture.

From their (γ, γ) coincidence measurements, Eichler *et al.*[19] established that the half-life of the 529.83-keV level should be significantly shorter than 200 nsec. Moreover, based on the $\log ft$ of 6.8 for the β branch feeding the level, they assumed the latter to be of the allowed type (disregarding the first-forbidden nonunique shape, which also fits). On these bases, they restricted the possible $J\pi$ assignments to $(\frac{5}{2}+, \frac{7}{2}+)$. In agreement with this proposition is the total conversion coefficient of the ground-state transition measured by Jha, Friedman, Patniak, and Power.[25] These authors obtained a value of 0.008 ± 0.002, which corresponds to an $M1, E2$ multipolarity. In Ref. 20, $J = (\frac{7}{2})$ is disregarded because of the existence of a weak γ ray connecting this level with one which the authors established at 263.4 keV, and to which they assigned $J\pi = \frac{1}{2}+$, taking as definite the tentative proposition made for this level by Schneid and Rosner.[21] The α_K coefficient determined in the present work (see Table I) allows identification of the transition as $M1(\leq 80\% E2)$. This new result, when combined with the $\frac{5}{2}\pm$ to $\frac{9}{2}\pm$ possibilities allowed by the $\log ft$ value for the 529.83-keV level, unequivocally establishes $J\pi = \frac{5}{2}+$ for it.

We were unable to determine other conversion coefficients in this decay, since all other transitions are very weak.

2. *Levels of* ^{135}*Xe*

Schneid and Rosner[21] and Moore *et al.*,[26] studying the reaction ^{136}Xe$(d, t)^{135}$Xe, assigned spin-parity $\frac{3}{2}+$, $\frac{1}{2}+$, and $\frac{11}{2}-$ for the ground state and the first two excited levels at 288.4 and 526.5 keV, respectively. In Ref. 21, tentative spin-parity values were also proposed for five higher placed levels. The multipolarity of the 526.5-keV isomeric transition has been determined to be $M4$ from measurements[16] of the internal-conversion coefficient and the level half-life. This multipolarity is in agreement with the $J\pi$ assignments obtained from the (d, t) reaction.

More recently, studying the 6.7-h decay of ^{135}I, Macias, Op de Beeck, and Walters[27] proposed a level scheme for ^{135}Xe. They established γ-ray locations and level energies by means of (γ, γ) and (β, γ) coincidence measurements, energy-sum relations, and relative γ-ray intensities. These authors considered the tentative $l = (2)$ determined in Ref. 21 for the levels at 1.28 ± 0.03 and 1.47 ± 0.03 MeV as good enough to ensure the positive parity of their levels at 1260.5 and 1458.1 keV. Combining this tentative assignment with their deduced $\log ft$ values and measured relative γ-ray intensities, Macias *et al.* assigned, however, definite $J\pi = \frac{5}{2}+$ to both levels. They also proposed $J\pi$ values for eight additional new levels that they established.

In Table III, columns 2 and 3, values are given for $J\pi$ obtained from the (d, t) measurements,[21,26] and those which we deduced as possible from the published[27] $\log ft$ values. The first column contains the level energies as given from our γ-ray energy sums which, being in good agreement with the level energies reported by Macias *et al.*,[27] furnish additional support to the level scheme proposed by these authors. Our γ-ray energies themselves are also in very good agreement with the values reported by Macias *et al.*, Heath,[28] and Wakat.[29]

The partial level scheme of Fig. 8 shows those levels for which we propose $J\pi$ values, as well as all the transitions proceding between them.

Levels at 1131.5, 1260.4, 1457.4, and 1677.9 keV. For these levels, the multipolarities we determined for the corresponding ground-state transitions (see Fig. 8) define positive parity without using the above-mentioned inconclusive (d, t) reaction results.[21,26] The multipolarities of the 220.3- and 417.5-keV transitions give additional support to the parity of the 1677.9-keV level. Consequently, we removed the negative parities associated (according to the reported $\log ft$ values of 8.3, 7.2, 7.4, and 6.7, respectively) with the possible first-forbidden β decay from the $\frac{7}{2}+$ ground state[14,30] of ^{135}I.

Combining the results of $\log ft$ determinations and conversion-coefficient measurements leads to $\frac{5}{2}$, $\frac{7}{2}$ spins for all four levels. For the 1260.4- and the 1457.4-keV levels we have preferred $\frac{5}{2}$, because of the rather strong 972.1- and 1168.7-keV deexcitations to the 288.4-keV $\frac{1}{2}+$ state. For the 1131.5- and 1677.9-keV levels we preferred a $(\frac{7}{2})$ assignment, since they do not decay to the 288.4-keV level and, since for the case of the 1677.9-keV level, this assignment gives more plausible ΔJ differences for the 220.3- and the 417.5-keV transitions. These $(\frac{7}{2})+$ assignments imply $(E2)$ as the most probable multipolarity of the respective ground-state transitions.

Level at 1565.1 keV. The positive parity of this level is determined by the $E1$ multipolarity of the 1038.6-keV transition depopulating it via the $\frac{11}{2}-$ isomeric state. Combining the value $\log ft = 7.3$ with the multipolarity of the 1038.6-keV transition, the only possible $J\pi$ turns out to be $\frac{9}{2}+$. This assignment implies that the ground-state transition should be practically undetectable. In connection with this, we point out that our more precise energy determinations confirm the statement of Macias *et al.* that a γ ray having almost the energy of the level is not the cross-over transition: We obtained 1565.1 ± 0.4 keV for the level and 1566.7 ± 0.6 keV for the γ ray. Although Macias *et al.* specifically stated that they could not rule out a $\frac{9}{2}\pm$ assignment for this level, their final proposition was $(\frac{7}{2}-)$, based on $\log ft$ values, relative γ-ray intensities, and modelistic considerations.

Note added in proof: Recently, Macias and Walters[30a] performed angular correlations on γ transitions in ^{135}Xe and determined spins for several levels. From these, the only one discussed by us is the 1131.5-keV level, for which they obtained $(\frac{5}{2}, \frac{7}{2})$, in agreement with our results.

3. *Levels of ^{135}Cs*

Level schemes for ^{135}Cs have been proposed independently by Op de Beeck and Walters[31] and by Alexander and Lau[15] studying the decay of 9.14-h ^{135}Xe. There are no contradictions between both groups, although two levels in the 1-MeV region have been reported only in Ref. 15. The levels at 249.7 and 608.0 keV were established earlier by Thulin.[32] Energy-sum relations, (γ, γ) coincidence measurements,[15,31] and (e, γ) and (β, γ) studies[32] were used to place the transitions in the ^{135}Cs level scheme. These experiments also allowed the deduction of $\log ft$ values for all known levels.

According to ^{136}Xe(d, t) reaction studies,[21,26] the ground state of ^{135}Xe has $J\pi = \frac{3}{2}+$. The ground-state spin and parity of ^{135}Cs have been measured[14] to be $\frac{7}{2}+$ by atomic-beam magnetic-resonance methods.

Bergström[11] and Graham and Bell[12] determined that the 249.7-keV transition had an $M1+E2$ multipolarity by measuring its K conversion coefficient and its $K/(L+M)$ ratio. Combining this result with the $\log ft = 5.9$ for the β feeding from ^{135}Xe, a $J\pi = \frac{5}{2}+$ was proposed[15,31] for the 249.7-keV level.

The $\log ft$ values corresponding to the β feedings to the 407.8- and 608.0-keV excited levels (Refs. 15, 31, 32, and the present work; see Fig. 9) are consistent with both allowed and first-forbidden nonunique decays. However, Op de Beeck and Walters[31] proposed positive parity only on the ba-

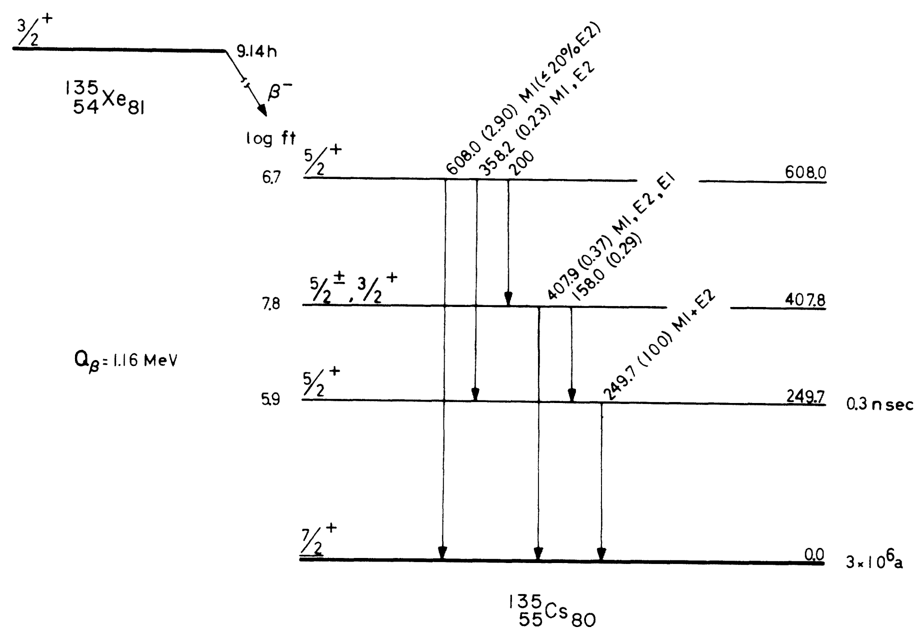

FIG. 9. Partial level scheme for ^{135}Cs including information from the present and previous works. The 200-keV transition energy was taken from Ref. 15. Since the 608.0-keV level has a well-established positive parity, the $E1$ possibility has been eliminated for the 358.2-keV transition (see Table I). Relative γ-ray intensities are given within parentheses.

sis of the systematic behavior of odd-Z nuclei in the region. In this way they restricted the possible $J\pi$ values to those related to allowed decays, namely, $\frac{1}{2}+$ to $\frac{5}{2}+$. A further selection was performed by Op de Beeck and Walters, based on the existence of the ground-state transition and on comparisons made with the well-established level scheme of ^{133}Cs. Their final propositions are ($\frac{5}{2}+$) for the 407.8-keV level and ($\frac{3}{2}+$) for the 608.0-keV level.

Table IV collects the $J\pi$ assignments we deduced as possible from the logft and conversion-coefficient determinations. The given level energies were established from our γ-ray energy determinations and are in good agreement with those of Refs. 15 and 31. The $M1$($\leq$20%) multipolarity we obtained for the 608.0-keV transition definitely sets positive parity for the level at that energy and, in disagreement with Ref. 31, spin $\frac{5}{2}$.

For the 407.8-keV level our measurements only furnished an upper limit for the α_K of the corresponding ground-state transition. The multipolarities consistent with this limit reduce by half the possibilities allowed by the logft value alone. Nevertheless, the final result is still inconclusive, as shown in Table IV. Figure 9 shows the details related to the levels for which we propose $J\pi$ values.

4. Levels of ^{137}Cs

The only detailed level scheme for ^{137}Cs proposed so far is the one obtained by Holm[33] studying the 3.82-min[34] decay of ^{137}Xe. This author quotes all previous measurements, which essentially only establish a single level at 455.3 keV. As determined by Holm, all the other numerous transitions present in the decay have γ-ray intensities lower than 2% of the 455.3-keV γ-ray intensity. Alväger, Naumann, Petry, Sidenius, and Darrah Thomas,[35] in their on-line measurements of ^{252}Cf spontaneous-fission-produced sources, only report the existence of the 455.3-keV level.

From the proton angular distribution observed in the ^{136}Xe(d,p) reaction, Schneid and Rosner[21] and Moore *et al.*[26] assigned spin-parity $\frac{7}{2}-$ to the ground state of ^{137}Xe. Thus, the logft = 6.7 obtained by Holm for the β decay to the 455.3-keV level leads to a $\frac{5}{2}\pm$ to $\frac{9}{2}\pm$ assignment for it. The ground state of ^{137}Cs has a measured[14] spin-parity of $\frac{7}{2}\pm$.

Due to the weakness of all the other transitions, we could only determine the multipolarity of the ground-state transition from the 455.3-keV level. As it turned out to be $E2$($\leq$10% $M1$), the negative parity is eliminated as a possibility for the level. Our 455.3 ± 0.3-keV energy value is in good agreement with the 455.1 ± 0.5 keV obtained in Ref. 35.

After our work on this nucleus had been completed, Wildenthal *et al.*[36] published their recent proton-transfer experiments on ^{136}Xe. For the 455.3-keV level they obtained $l_p = 2$, consequently giving $J\pi = \frac{5}{2}+$.

5. Levels of ^{139}Cs

Level energies. Using on-line techniques at the Stockholm mass separator, Holm, Borg, Fägerquist, and Kropff[37] studied the decay of 40-sec ^{139}Xe as a gaseous fission product of ^{235}U. Based on γ-ray singles and coincidence measurements, they were the first to propose a level scheme for ^{139}Cs, extending it up to 1007 keV. Alväger *et al.*[35] obtained ^{139}Xe from the spontaneous fission of

TABLE IV. Spins and parities proposed for levels of ^{135}Cs.

Level energy Present work (keV)	Spin and parity assignments: Atomic beam and conversion electrons	logft and logf^1t [a]	Conversion coefficients [b] Present work	Proposed spins and parities
0.0	$\frac{7}{2}+$ [c]	...	...	$\frac{7}{2}+$
249.7 ± 0.2	$\frac{5}{2}+$ to $\frac{9}{2}+$ [d]	$\frac{1}{2}\pm$ to $\frac{5}{2}\pm$	$\frac{3}{2}+$ to $\frac{11}{2}+$	$\frac{5}{2}+$
407.8 ± 0.3	...	$\frac{1}{2}\pm$ to $\frac{5}{2}\pm$	$\frac{3}{2}+$ to $\frac{11}{2}+$ $\frac{5}{2}-$ to $\frac{9}{2}-$	$\frac{3}{2}+$, $\frac{5}{2}\pm$
608.0 ± 0.3	...	$\frac{1}{2}\pm$ to $\frac{5}{2}\pm$	$\frac{5}{2}+$ to $\frac{9}{2}+$	$\frac{5}{2}+$

[a] The logft values were obtained combining our relative transition intensities with the Q_β = 1.16 MeV reported by Thulin (Ref. 32).

[b] The transition multipolarities used for the spin-parity assignments are collected in Table I.

[c] Spin measured by the atomic-beam magnetic-resonance method. Positive parity assigned because the magnetic dipole moment belongs to the $g_{7/2}$ Schmidt group (Ref. 14).

[d] α_K and K/L determinations (Refs. 11 and 12).

TABLE V. Energy-sum relations for ^{139}Cs levels.

E_i (keV)	E_j (keV)	E_{i+j} (keV)	E_{level} (keV)
...	393.61 ± 0.08	393.61 ± 0.08	
218.71 ± 0.08	175.03 ± 0.08	393.74 ± 0.11	393.65 ± 0.06
289.80 ± 0.10	103.86 ± 0.10	393.66 ± 0.14	
...	515.3 ± 0.3	515.3 ± 0.3	
218.71 ± 0.08	296.55 ± 0.10	515.26 ± 0.13	515.28 ± 0.09
289.80 ± 0.10	225.49 ± 0.10	515.29 ± 0.14	
...	646.61 ± 0.20	646.61 ± 0.20	
218.71 ± 0.08	427.4 ± 0.7	646.1 ± 0.7	646.58 ± 0.15
289.80 ± 0.10	356.80 ± 0.20	646.60 ± 0.22	
...	732.81 ± 0.25	732.81 ± 0.25	
218.71 ± 0.08	513.9 ± 0.3	732.6 ± 0.3	732.60 ± 0.10
289.80 ± 0.10	442.53 ± 0.25	732.3 ± 0.3	
393.65 ± 0.06	338.95 ± 0.10	732.60 ± 0.12	

^{252}Cf and published a level scheme based only on energy-sum relations. This scheme is essentially that of Ref. 37, although it has two levels less and the order of the 225.49-, 289.80-keV cascade is reversed; this reversal, however, is incompatible with the transition-intensity balance. Moreover, through a private communication, W. L. Talbert also proposed a level scheme which, reaching up to about 2.2 MeV, at lower energies is coincident with that of the Stockholm group. On the other hand, Talbert added two levels below 1 MeV, for which he gave energies of 646.5 and 891.7 keV.

All the transitions for which we were able to determine the multipolarity are placed below the 732.60-keV level. In order to ensure their location in the adopted[37,38] level scheme, a special effort was made to obtain precise energy-sum relations up to that energy and, simultaneously, to better resolve a multiplet at about 515 keV. The γ-ray spectrum was recorded several times with a gain corresponding to 0.25 keV/channel and a resolution of 2.2 keV at 515 keV (Fig. 4). Energy calibration was performed as explained in Sec. II C, using the values given by Marion[39] for the ^{241}Am, ^{139}Ce, ^{203}Hg, ^{137}Cs, and ^{88}Y standards. For the analysis of the 510–515-keV region we used a peak shape which we obtained by interpolation from a phenomenological function giving the variation of full-energy-peak shape versus γ-ray energy.

Our γ-ray energy-sum relations (Table V) and relative intensities confirm, up to 732.60 keV, the level scheme proposed by Holm *et al.*, as well as the additional 646.58-keV level proposed by Talbert. The γ-ray energies resulting from the above

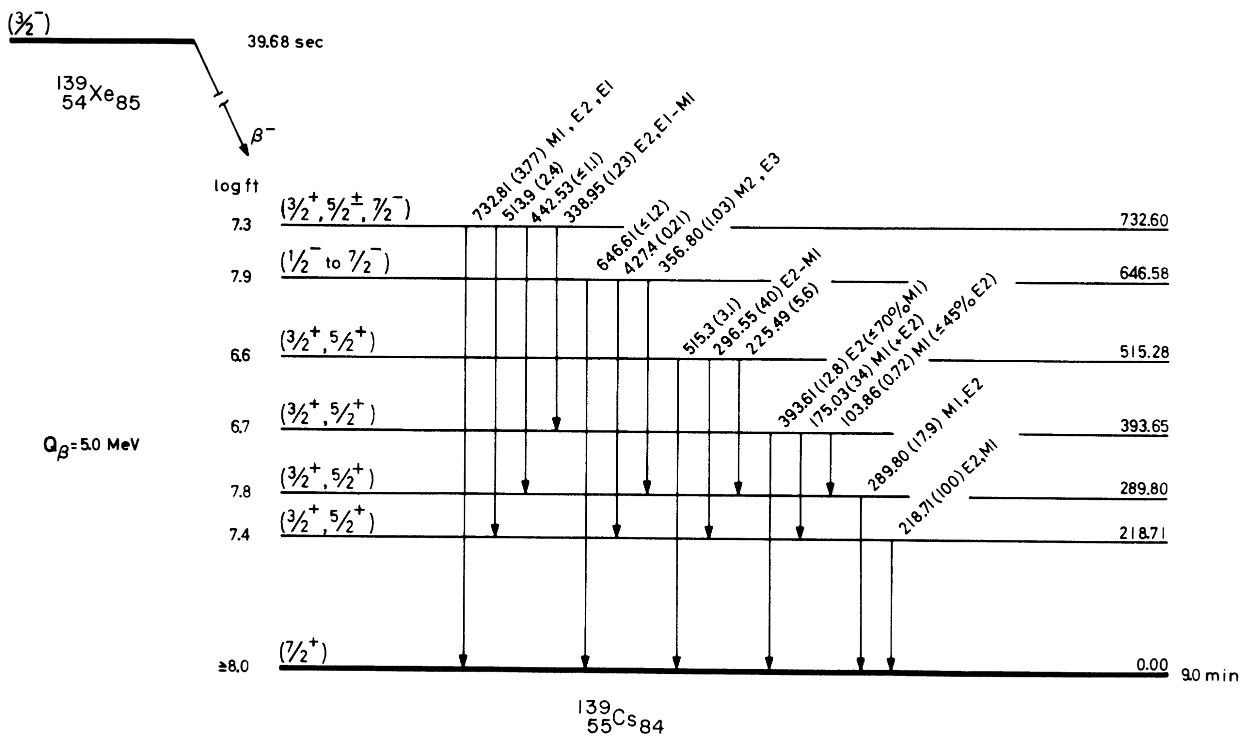

FIG. 10. Partial level scheme for ^{139}Cs. Shown are the transitions for which we determined multipolarities as well as others supporting the location of those levels for which we propose spins and parities. Only upper limits are given for the relative intensities of the 442.53- and 646.61-keV γ rays, since these are likely to be complex peaks.

mentioned analysis are 513.9 ± 0.3 and 515.3 ± 0.3 keV. These values coincide very well with the corresponding level-energy differences of 513.89 ± 0.13 and 515.27 ± 0.10 keV obtained when excluding from the energy-sum relations the two transitions we are dealing with. Although the Stockholm group[37] did not resolve these two γ rays, from their coincidence measurements they already suggested the present locations.

The three proposed[35, 37, 38] level schemes include, between the 515.28- and the 393.65-keV levels, a γ ray for which we obtained an energy of 121.37 ± 0.10 keV. For the corresponding level-energy difference we got 121.63 ± 0.11 keV, which differs from the former by 2.5 times the standard error. This leads us to suggest the possibility that this γ ray might have to be placed somewhere else in the level scheme. Two transitions of 103.86 and 442.5 keV, not reported by Holm *et al.*, but communicated by Talbert, were detected in the present work and found to fit properly into the proposed level scheme (see Table V). Finally, from our γ-ray spectra we can state, as did Holm *et al.*, that the 647-keV peak is probably complex.

Although in additional measurements we detected ^{139}Xe γ rays up to about 3 MeV, this information has not yet been analyzed thoroughly. However, a preliminary analysis was sufficient to deduce the log*ft* values corresponding to the β branches feeding the ^{139}Cs levels below 800 keV (see Fig. 10).

Spin and Parity Assignments. Since the ground-state spins and parities of ^{139}Xe and ^{139}Cs have not been determined experimentally, they have to be based on systematic nuclear trends in the region we are dealing with.

Although the systematics of ground-state $J\pi$ values[14] for $N=85$ nuclei is scarce, it suggests a $\frac{3}{2}-$ assignment for ^{139}Xe. On the other hand, by analogy with ^{137}Xe, a $\frac{7}{2}-$ state is also possible for this nucleus.

Concerning the ground state of ^{139}Cs, $J\pi$ systematics[14] for $Z=55$ and N odd, strongly suggests a $\frac{7}{2}+$ assignment, by analogy with $^{133, 135, 137}$Cs. Although the spin and parity of the ground and first-excited levels of ^{139}Ba are well established,[40] the β decay from ^{139}Cs to them yields little information, since the log*ft* values have been inferred[41] only roughly. Anyhow, they are not in contradiction with the possible $\frac{7}{2}+$ assignment for the ^{139}Cs ground state.

Consequently, the most plausible ground-state assignments are ($\frac{3}{2}-$, $\frac{7}{2}-$) for ^{139}Xe and ($\frac{7}{2}+$) for ^{139}Cs. Further information is furnished by the results of (β,γ) coincidence measurements performed by Holm *et al.*[37] They observed that the end point of the β distribution from ^{139}Xe, recorded when the γ gate accepted the 393.61-keV ray, was only 100 keV below the end point of the singles β distribution. From this result they concluded that the ground-state feeding was weak,

TABLE VI. Spins and parities proposed for levels in ^{139}Cs.

Level energy Present work (keV)	Spin and parity assignments: log*ft* and logf^1t [a]	Spin and parity assignments: Conversion coefficients [b] Present work	Proposed spins and parities
0.00	...	...	($\frac{7}{2}+$) [c]
218.71 ± 0.08	($\frac{1}{2}+$ to $\frac{5}{2}+$) ($\frac{1}{2}-$ to $\frac{7}{2}-$)	($\frac{5}{2}+$ to $\frac{9}{2}+$)	($\frac{3}{2}+$, $\frac{5}{2}+$)
289.80 ± 0.10	($\frac{1}{2}+$ to $\frac{5}{2}+$) ($\frac{1}{2}-$ to $\frac{7}{2}-$)	($\frac{3}{2}+$ to $\frac{11}{2}+$)	($\frac{3}{2}+$, $\frac{5}{2}+$)
393.65 ± 0.06	($\frac{1}{2}\pm$ to $\frac{5}{2}\pm$)	($\frac{3}{2}+$ to $\frac{7}{2}+$)	($\frac{3}{2}+$, $\frac{5}{2}+$)
515.28 ± 0.09	($\frac{1}{2}\pm$ to $\frac{5}{2}\pm$)	($\frac{1}{2}+$ to $\frac{9}{2}+$)	($\frac{3}{2}+$, $\frac{5}{2}+$)
646.58 ± 0.15	($\frac{1}{2}+$ to $\frac{5}{2}+$) ($\frac{1}{2}-$ to $\frac{7}{2}-$)	($\frac{1}{2}-$ to $\frac{11}{2}-$)	($\frac{1}{2}-$ to $\frac{7}{2}-$)
732.60 ± 0.10	($\frac{1}{2}+$ to $\frac{5}{2}+$) ($\frac{1}{2}-$ to $\frac{7}{2}-$)	($\frac{3}{2}+$ to $\frac{9}{2}+$) ($\frac{5}{2}-$, $\frac{7}{2}-$)	($\frac{3}{2}+$, $\frac{5}{2}\pm$, $\frac{7}{2}-$)

[a] The log*ft* values were obtained combining our relative γ-ray intensities and conversion coefficients with the $Q_\beta = 5.0$ MeV reported by Holm *et al.* (Ref. 37). Spin-parity $\frac{3}{2}-$ was assumed for the ground state of ^{139}Xe (see text).
[b] The transition multipolarities used for the spin-parity assignments are collected in Table I.
[c] From systematic trends (see text).

since otherwise a shift of about 400 keV should have been observed (Fig. 10). They were thus led to propose a $\log ft \gtrsim 8$ for this feeding, which implies $\log f^1 t \gtrsim 9$ and most probably characterizes it as a first-forbidden unique transition. Accordingly, we finally select the pair $(\frac{3}{2}-)$, $(\frac{7}{2}+)$ for the ^{139}Xe and ^{139}Cs ground states, respectively. The total β-disintegration energy Q_β has been measured by the Stockholm group to be about 5.0 MeV.

As mentioned before, a preliminary evaluation of the bulk of our γ-spectra results was enough to deduce the $\log ft$ values (see Fig. 10) of those β branches feeding levels for which information from the conversion-electron measurements was also available. It is worthwhile to mention that we obtained feedings to the first two excited levels of only 5.7 and 2.6%, respectively, which is significantly less than those reported by Holm *et al.*

In columns 2 and 3 of Table VI we give the spin-parity assignments obtained from the $\log ft$ values and from our multipolarity determinations. The latter, for each of the levels up to 646.58 keV, eliminate one of both parities compatible with the $\log ft$ values. For the 732.60-keV level, the parity is not definite. Combining the data of both columns we have deduced the possible $J\pi$ values proposed in the last column. Spin $\frac{1}{2}$ has been disregarded for the 515.28-keV level because of the presence of the ground-state transition.

Reasoning in a similar way as we did above, Holm *et al.* gave for the ^{139}Xe and ^{139}Cs ground states the same $J\pi$ possibilities we propose. Then, making the assumption that all β feedings were first-forbidden nonunique transitions, they established positive parity and suggested spins for the excited levels. However, with the new $\log ft$ values we have obtained, unique decays cannot be excluded for the β feedings to the 218.71- and the 289.80-keV levels. Moreover, one cannot exclude either unique decays to the 646.58- and 732.60-keV levels.

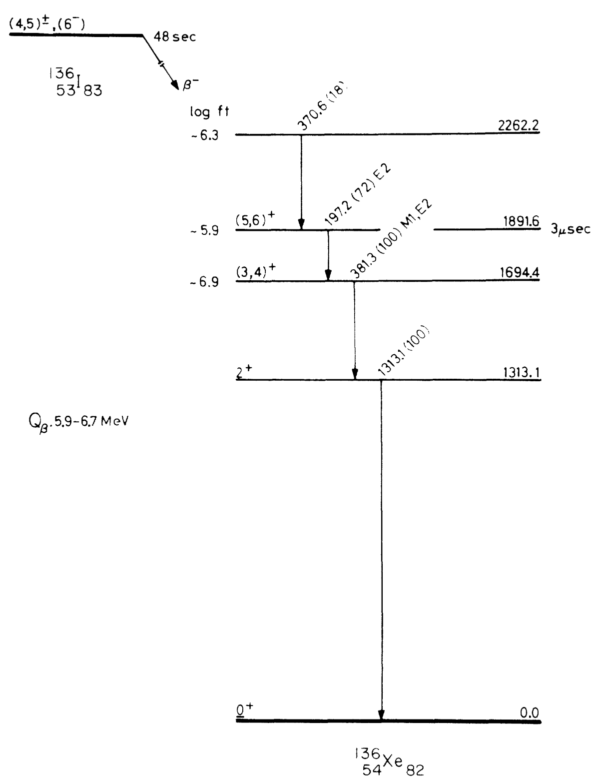

FIG. 11. Spin-parity assignments for the ^{136}Xe levels fed (Refs. 42 and 43) in the β decay from 48-sec ^{136}I. Relative γ-ray intensities are given within parentheses.

B. Even-*A* Nuclei

1. *Levels of ^{136}Xe*

Two extensive studies concerning the β decays of ^{136}I isomers formed in the fission of ^{235}U were published[42, 43] recently. Carraz, Blachot, Monnand, and Moussa[42] performed measurements of (γ, γ), (β, γ), and delayed (β, γ) coincidences. Lundán[43] made singles and coincidence γ-ray measurements and, in addition to the two previously known isomers of 48 and 83 sec, reported the existence of a third isomer with a half-life of 100 sec. No isomeric transitions connecting them have been detected.

The most intense γ rays appearing in the singles spectra are those fed from the 48-sec isomer: 370.6, 197.2, 381.3, and 1313.1 keV which, in that

TABLE VII. Energies and relative γ-ray intensities following ^{138}Cs decay.

E_γ (keV)	I_γ (relative)	E_γ (keV)	I_γ (relative)
112.44 ± 0.10	0.26 ± 0.10	1009.78 ± 0.07	37.2 ± 1.5
138.02 ± 0.10	2.05 ± 0.20	1147.06 ± 0.13	1.75 ± 0.20
191.94 ± 0.12	0.52 ± 0.03	1343.31 ± 0.15	1.52 ± 0.11
193.86 ± 0.12	0.46 ± 0.05	1415.5 ± 0.3	0.42 ± 0.03
212.38 ± 0.10	0.14 ± 0.05	1435.72 ± 0.07	100 ± 3 [b]
227.75 ± 0.10	1.86 ± 0.07	1444.7 ± 0.3	1.14 ± 0.06
324.90 ± 0.12	0.32 ± 0.03	1555.0 ± 0.3	0.41 ± 0.08
364.3 ± 0.6	a	1779.0 ± 1.0	0.18 ± 0.03
408.98 ± 0.08	5.41 ± 0.25	2217.76 ± 0.07	20.6 ± 1.5
421.72 ± 0.10	0.48 ± 0.05	2582.2 ± 0.6	0.34 ± 0.05
462.82 ± 0.12	36.7 ± 1.5	2639.37 ± 0.07	10.1 ± 1.5
516.65 ± 0.20	0.48 ± 0.17	2730.9 ± 0.5	0.20 ± 0.03
546.87 ± 0.15	12.7 ± 0.5	2807.0 ± 0.5	0.13 ± 0.03
782.3 ± 1.0	0.41 ± 0.04	3338.7 ± 0.3	0.25 ± 0.04
871.66 ± 0.07	7.1 ± 0.5	3367.09 ± 0.20	0.37 ± 0.06

[a] Due to the presence of an unidentified contaminant, this peak appears double in our spectra.

[b] The error stated for the intensity normalized to 100 has not been included in the errors of the other intensities.

order, cascade from a level at 2262.2 keV to the ground state (see Fig. 11). Except for the 1313.1-keV level, the other levels of the cascade are not fed from the 83- and 100-sec isomers, neither directly nor through γ rays from higher-lying ^{136}Xe states. Carraz *et al.*[42] established that the level at 1891.6 keV has a half-life of 2.8 ± 0.2 μsec. This isomeric state was also reported[44] with $T_{1/2} = 3.10 \pm 0.25$ μsec by a team working at the Jülich reactor.

No experimental information on the $J\pi$ of the ^{136}I isomeric states has been reported so far. The ground-state spin of ^{136}Xe has been measured[14] by optical-spectroscopy methods to be 0. Moore, Riley, Jones, Mancusi, and Foster[45] observed 36 excited levels in a study of proton-inelastic scattering from ^{136}Xe. They assigned $J\pi = 2+$ to the 1313.1-keV level, this being the only level below 3.3 MeV for which they could determine spin and parity.

The conversion coefficient of the 1313.1-keV $E2$ transition lends itself to be used as an internal normalization for the conversion coefficients of this nucleus. However, with our setup it was not possible to obtain good enough statistics for doing so in a reasonable collecting time. Consequently, we choose to record the 249.7-keV standard line of 9-h ^{135}Xe (see Sec. IIB) simultaneously with the decay of ^{136}I. The activity of ^{135}Xe was first collected during a few minutes and then, using the same collector, ^{136}I was measured on line for about 21 h. Shorter runs, having a better resolution in the electron spectrum, were also recorded. In Fig. 3 one of these spectra is shown. Besides the K lines of the 197.2- and 381.3-keV transitions, we detected peaks with energies corresponding to the K lines of the weaker 370.6-keV transition and of a 345-keV transition, the second of which appears only[42, 43] in the decay of the two longer-lived isomers. For the last two transitions the experimental data gave conversion coefficients corresponding to $E3(+M2)$ multipolarities. Moreover, as will be seen in the discussion following below, the 370.6-keV transition is most probably complex. On the other hand, the 345-keV γ ray clearly appears as complex in all our spectra. Due to their complexity, there may exist transitions of these energies having a multipolarity even higher than $E3(+M2)$. For this reason, the 345- and the 370.6-keV transitions were not included in Table I. We ascertained that there were no contaminations which could contribute to the intensities of the 345- and 370.6-keV K lines.

Positive parity is established unambigously for the 1694.4- and 1891.6-keV levels from the multipolarities determined in the present work for the 381.3- and 197.2-keV transitions, respectively.

As far as spin assignments are concerned, our multipolarities establish 0 to 4 for the 1694.4-keV level, and 0 to 6 for the 1891.6-keV level. Spins lower than 3 for the 1694.4-keV level and lower than 4 for the 1891.6-keV level are disregarded in view of the lack of the ground-state transitions and of the transition linking the latter to the 2+ state. Moreover, the pure $E2$ character proposed for the 197.2-keV transition led us to prefer J

TABLE VIII. Energy-sum relations for ^{138}Ba levels.

E_i (keV)	E_j (keV)	E_{i+j} (keV)	E_{level} (keV)
···	2217.76 ± 0.07	2217.76 ± 0.07	2217.76 ± 0.07
1435.72 ± 0.07	782.3 ± 1.0	2218.0 ± 1.0	
1435.72 ± 0.07	871.66 ± 0.07	2307.38 ± 0.10	2307.36 ± 0.08
1898.54 ± 0.14	408.98 ± 0.08	2307.32 ± 0.16	
1898.54 ± 0.14	516.65 ± 0.20	2415.19 ± 0.24	2415.30 ± 0.10
2090.48 ± 0.18	324.90 ± 0.12	2415.38 ± 0.22	
2202.92 ± 0.21	212.38 ± 0.10	2415.31 ± 0.15	
1435.72 ± 0.07	1009.78 ± 0.07	2445.50 ± 0.10	2445.45 ± 0.07
1898.54 ± 0.14	546.87 ± 0.15	2445.41 ± 0.21	
2217.76 ± 0.07	227.75 ± 0.10	2445.51 ± 0.14	
2307.36 ± 0.08	138.02 ± 0.10	2445.38 ± 0.13	
···	2582.2 ± 0.6	2582.2 ± 0.6	2582.71 ± 0.14
1435.72 ± 0.07	1147.06 ± 0.13	2582.78 ± 0.15	
2217.76 ± 0.07	364.3 ± 0.6	2582.1 ± 0.6	
···	2639.37 ± 0.07	2639.37 ± 0.07	2639.38 ± 0.07
2217.76 ± 0.07	421.72 ± 0.10	2639.48 ± 0.12	
2445.45 ± 0.07	139.86 ± 0.12	2639.31 ± 0.14	

= (5, 6) for the 1891.6-keV level.

In order to calculate the log*ft* values given in Fig. 11, we had to rely on two conclusions reached in Refs. 42 and 43: (a) The 48-sec ^{136}I isomer does not feed either the ground state or the 1313.1-keV level in ^{136}Xe, and (b) the disintegration energy Q_β from the 83-sec isomer is 6.3 MeV. From our γ-ray intensities and α_K coefficients we then obtained the log*ft* corresponding to the β decay from the 48-sec isomer by assuming that the Q_β might differ from 6.3 MeV by not more than 0.4 MeV.

If the tentative $J\pi$ assignments proposed above for ^{136}Xe are accepted, combining them with the log*ft* values and with the $\log f^1t \sim 7.5$ for the 1694.4-keV level, leads to (4, 5), (6−) as possible $J\pi$ values for the 48-sec isomeric state. This result is not affected by allowing the Q_β to vary between the mentioned limits of 5.9 and 6.7 MeV. On the other hand, it agrees with the absence of β feeding to the 2+ level at 1313.1-keV which, as Carraz *et al.*[42] have already pointed out, suggests $J \geq 4$ for the isomer. (Any consideration based on log*ft* values is, however, subject to error, because of the eventual existence of significantly strong, but undetected, low-energy isomeric transitions.)

As mentioned in a previous paragraph, the α_K of the 370.6-keV transition corresponds to an $E3(+M2)$ multipolarity. The shortest half-life of the level which it depopulates may thus be about 10 μsec, which corresponds[46] to a pure $M2$ multipolarity. On the other hand Carraz *et al.* using a circuit having a $2\tau = 0.1$ μsec, found that a γ ray of this energy was in coincidence with a β branch. Comparing their coincidence spectrum with the singles γ-ray relative intensities, the conclusion is reached that almost the whole intensity of the 370.6-keV γ ray has to be in coincidence with the mentioned β feeding. Finally, Lundán established that the 370.6-keV transition populates the 3.0-μsec isomeric state in ^{136}Xe by performing delayed (γ, γ) coincidences between the 197.2-keV γ ray and a 0–390-keV region. From the bulk of the previous results we conclude that: (a) Almost the whole intensity of the 370.6-keV peak comes from the transition depopulating the 2262.2-keV level in ^{136}Xe; (b) this transition has a low ($E1$, $M1, E2$) multipolarity; (c) consequently, there is another transition with very low γ intensity and an energy very close to 370.6 keV, having a high multipolarity ($M2, E3$, higher). This latter transition could be the one proposed by Lundán to be in coincidence with the 345-keV transition (see Fig. 5 of Ref. 43). Alternatively, it might be an isomeric transition in ^{136}I.

According to Carraz *et al.* and to Lundán, the 345-keV γ ray has no 48-sec half-life component. As we stated above, this peak is complex and at least one of its components appears to have high multipolarity. This high-multipolarity component cannot be the one Lundán proposes to be in prompt coincidence with part of the 370.6-keV γ intensity. It might also turn out to be an isomeric transition in ^{136}I.

From what precedes it is clear that the decays

TABLE IX. Spins and parities proposed for levels of ^{138}Ba.

Level energy Present work (keV)	Spin and parity assignments: ^{139}La(d, ^{3}He) and angular correlation	log*ft* and $\log f^1t$ [a]	Conversion coefficients [b] Present work	Proposed spins and parities
0.00	0+ [c]	···	···	0+ [d]
1435.72 ± 0.07	2+ [c]	1+ to 5+ 2− to 4−	2+	2+
1898.54 ± 0.14	4+, 6+ [c]	1+ to 5+ 2− to 4−	2+ to 4+	4+
2217.76 ± 0.07	···	1+ to 5+ 2− to 4−	1+ to 5+	1+, 2+
2307.36 ± 0.08	···	1+ to 5+ 2− to 4−	2+ to 4+	3+, 4+
2445.45 ± 0.07	3 [e]	2± to 4±	1+ to 3+	3+

[a] The log*ft* values were obtained combining our relative γ-ray intensities and conversion coefficients with the $Q_\beta = 5.04$ MeV reported by Carraz *et al.* (Ref. 47).
[b] The transition multipolarities used for the spin-parity assignments are collected in Table I.
[c] (d, ^{3}He) reaction (Ref. 50).
[d] Spin measured by the optical-spectroscopy method (Ref. 14).
[e] Angular correlation (Ref. 52).

of the ^{136}I isomers still present some challenging problems. Furthermore, in the singles γ-ray spectra of Carraz *et al.*, of Lundán, and of ourselves a 750-keV ray appears whose origin is not established.

2. *Levels of* ^{138}*Ba*

Level energies. Recently Carraz, Monnand, and Moussa[47] studied extensively the decays of ^{138g}Cs populated by fission-produced ^{138}Xe and of the 2.90-min ^{138m}Cs isomer formed in the ^{138}Ba(n,p) reaction. They performed singles and coincidence measurements, involving both γ rays and β transitions. This group also reviewed in detail relevant previously published results obtained from the decay of 32.2-min ^{138g}Cs and from (d,p), (p,p'), (d,d'), (α,α'), and (n,γ) reactions. Including the preexisting information, a level scheme of ^{138}Ba as fed from ^{138m,g}Cs was presented[47]; logft values were calculated and $J\pi$ assignments proposed and discussed. In a private communication W. L. Talbert furnished us with the results of his on-line

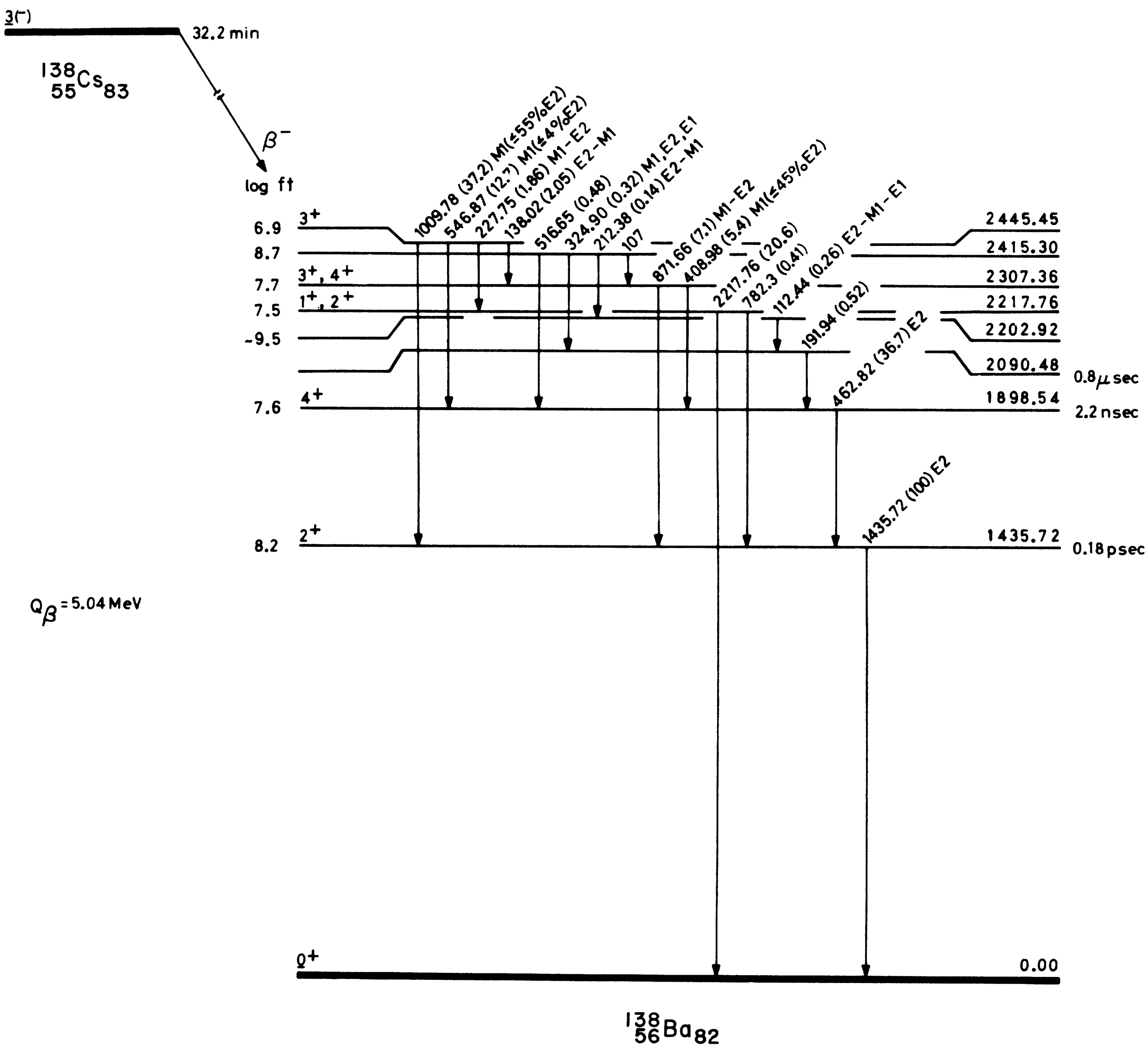

FIG. 12. Partial level scheme for ^{138}Ba, based on Ref. 47. Shown are the transitions for which we determined multipolarities as well as others supporting the location of levels for which we propose spins and parities. The 107-keV transition has not been detected by us. The logft values were calculated using the $Q_\beta = 5.04$ MeV obtained in Ref. 47. Since the spins of the 1435.72- and 1898.54-keV levels differ by two units, the possibility of an $M1$ admixture has been eliminated for the transition of 462.83 keV (see Table I). Relative γ-ray intensities are given within parentheses.

measurements on this nucleus. His γ-ray energies and intensities are in good general agreement with the values reported by Carraz *et al.*[47] and by Heath.[28] The energy values obtained by Mariscotti, Gelletly, Moragues, and Kane[48] in their (n,γ) work and by Nagahara, Miyaji, Kurihara, Miguno, and Ishizuka[49] in their study of ^{138g}Cs decay are of less precision. In a recent single-proton-transfer study[50] using the ^{139}La$(d,{}^3$He) reaction, spins and parities were proposed for the ground state and the first and second excited states of ^{138}Ba.

Since, besides the present conversion-coefficient work, we are also performing a detailed study[51] of the ^{138}Xe decay, many singles γ-ray spectra corresponding to fission-produced mass-138 activity were recorded during this investigation. From them we obtained accurate energy and intensity values for the γ rays in both ^{138}Cs and ^{138}Ba, as well as their assignment to either of the decays. Our energy and intensity values (Table VII) coincide best with those communicated by Talbert.[38]

The spectra we recorded do not show a weak 773.3-keV γ ray which, though reported in Refs. 38, 48, and 49, was not included in the published level schemes. We have not been able to detect a very weak γ ray of 107.5 keV reported in Refs. 28 and 38. The somewhat stronger 240-keV (Refs. 38 and 49) and 2499-keV (Refs. 28 and 47) transitions could not be resolved from ^{138}Xe decay lines of similar energy present in our spectra. Our analysis of the 193-keV doublet led to the values 191.94 ± 0.12 and 193.86 ± 0.12 keV. The lower of these coincides well with those values given in Refs. 38 and 47. The higher one, on the other hand, coincides very well with the value given by Talbert,[38] but differs appreciably from the 193.3 $\pm$ 0.2-keV value obtained by Carraz *et al.*[47] with a γ-ray energy resolution better than ours. However, our energy, when added to that of the 2445.45 $\pm$ 0.07-keV level yields 2639.31 ± 0.14 keV, in very good agreement with the average value of 2639.40 $\pm$ 0.08 keV one obtains for the level if the 193.86-keV transition is excluded from the energy-sum relations collected in Table VIII.

Nagahara *et al.* reported that in their coincidence measurements on the ^{138g}Cs decay they detected weak transitions of 834, 1040, and 1477 keV. Previously, these γ rays had only been found in the ^{137}Ba(n,γ) work by Mariscotti *et al.*,[48] who placed them as depopulating levels at 3051.4 and 3921.7 keV. Transitions of the stated energy have not been seen in our singles γ-ray spectra, this giving some support to the arguments by which Carraz *et al.* suggested that the mentioned levels are not fed from ^{138g}Cs.

Nagahara *et al.* also tentatively proposed two levels at 2442.7 and 2681.8 keV, supported only by the two corresponding ground-state transitions, having similar intensities. Carraz *et al.* reported the existence of a 2444 ± 1-keV γ ray, also with the same intensity. In our measurements, these transitions were not observed; if they exist at all, they should have at most an intensity one third of the one reported. However, when we recorded singles γ-ray spectra using a geometry in which the Ge(Li) detector subtended a larger solid angle, peaks appeared at 1899 and 2445 keV. Since they were clearly identified as due to the summing-up of intense transitions (1435.72 + 462.82 keV and 1435.72 + 1009.78 keV), we assume that at least the level proposed[49] at 2442.7 keV was based on a misinterpretation of summing effects.

The energy-sum relations entered in Table VIII, strongly support, up to 2639.38 keV, the level scheme proposed in Ref. 47. In this scheme, each of the eight higher-lying levels is depopulated by only one γ ray, none of them having a relative intensity larger than 1.5%. Moreover, all these levels had also been proposed by Nagahara *et al.* Besides that, three of them appear to be generated in the ^{137}Ba(n,γ) reaction[48] and three others in the (d,p) reaction. Consequently, we based our $\log ft$ calculations (see Fig. 12) on the level scheme given by Carraz *et al.*[47] and on our relative γ-ray intensities and conversion coefficients.

Spin and parity assignments. The spin of ^{138g}Cs has been measured[14] to be 3, whereas no direct determination for its parity exists. We adopted a negative parity, since all those measured for $N = 83$ nuclei belong to this type, in agreement with quite general shell-model predictions for the Z region under consideration. Still, in connection with the discussion following below, it may be worthwhile to point out that our final $J\pi$ assignments for the excited levels of ^{138}Ba actually do not depend on the ^{138g}Cs parity.

The ground state of even-even ^{138}Ba itself has an experimentally determined[14] spin 0. Jones *et al.*[50] determined positive parity for it, based on the $l_p = 4$ momentum of the proton transferred when it is populated in the ^{139}La$(d,{}^3$He) reaction.

In assigning the $J\pi$ values for the levels shown in Fig. 12, we proceeded in the following sequence. As discussed in Sec. II B, our conversion-coefficient measurements established $E2(+M1)$ multipolarity for the ground-state transition from the 1435.72-keV level, univocally characterizing it as 2+. This assignment is in agreement with the result obtained in Ref. 50.

For the 2445.45-keV level, the combination of angular-correlation results[52] and the present conversion-coefficient measurements univocally lead to $J\pi = 3+$ (see Table IX). This assignment is in agreement with the absence of the ground-state transition. Positive parity had been inferred earlier[49] only on the basis of excluding the possibility that the β feeding might be allowed, although this alternative is quite compatible with its $\log ft = 6.9$ (6.7 as reported in Ref. 52).

The $M1$ character of the 546.87-keV transition now restricts the possible spin-parity values for the 1898.54-keV level to 2+, 3+, 4+. Moreover, Jones *et al.*[50] also measured $l_p = 4$ for the momentum of the proton transferred when this level is populated in the $(d,{}^3He)$ reaction and, on this basis, made a $J\pi = 4+, 6+$ assignment. Consequently, spin 4 and positive parity are experimentally established for the 1898.54-keV level. Thus, the multipolarity of the 462.8-keV transition (see Fig. 12) ought to be pure $E2$.

TABLE X. β-decay transition probabilities.

Parent nucleus	$E_{\beta^-,max}$ (MeV)	E_{level} (keV)	Spin-Parity Parent	Daughter	$\log_{10} ft$
Allowed transitions: $\Delta J = 0, 1$; $\Delta\pi$ = No					
^{133}I	1.23	529.83	$\frac{7}{2}+$ [a]	$\frac{5}{2}+$	6.8
^{135}I	1.60	1131.5	$\frac{7}{2}+$ [b]	$\frac{5}{2}+$, $\frac{7}{2}+$	8.3
	1.47	1260.4		$\frac{5}{2}+$	7.2
	1.27	1457.4		$\frac{5}{2}+$	7.4
	1.16	1565.1		$\frac{9}{2}+$	7.3
	1.05	1677.9		$\frac{5}{2}+$, $\frac{7}{2}+$	6.7
^{135}Xe	0.91	249.7	$\frac{3}{2}+$ [c]	$\frac{5}{2}+$	5.9
	0.55	608.0		$\frac{5}{2}+$	6.7
First-forbidden nonunique transitions: $\Delta J = 0, 1$; $\Delta\pi$ = Yes					
^{137}Xe	3.70	455.3	$\frac{7}{2}-$ [d]	$\frac{5}{2}+$	6.7
^{138}Cs	3.60	1435.72	3(−) [e]	2+	8.2
	3.14	1898.54		4+	7.6
	2.73	2307.36		3+, 4+	7.7
	2.59	2445.45		3+	6.9
First-forbidden unique transitions: $\Delta J = 2$; $\Delta\pi$ = Yes					
^{133}I	1.53	233.2	$\frac{7}{2}+$ [a]	$\frac{11}{2}-$	8.7 [f]
^{135}I	2.20	526.5	$\frac{7}{2}+$ [b]	$\frac{11}{2}-$	9.3 [f]

[a] Spin and parity measured by atomic-beam magnetic-resonance methods (Ref. 14).

[b] Spin measured by atomic-beam magnetic-resonance methods (Ref. 14). Parity determined in a study of the reaction $^{136}Xe(d, {}^3He)^{135}I$ (Ref. 30).

[c] Spin and parity determined in studies of the reaction $^{136}Xe(d, t)^{135}Xe$ (Refs. 21 and 26).

[d] Spin and parity determined in studies of the reaction $^{136}Xe(d, p)^{137}Xe$ (Refs. 21 and 26).

[e] Spin measured by atomic-beam magnetic-resonance methods (Ref. 14). Parity based on systematic trends for $N = 83$ nuclei.

[f] The stated value corresponds to $\log_{10} f^1 t$.

Next we considered the 2307.36-keV level. The combined multipolarities of the 408.98- and of the 871.66-keV transitions establish positive parity and spins 3, 4. This result is in agreement with the multipolarity of the 138.02-keV transition and with the absence of the ground-state transition. Although, based on the deexcitation pattern of the level, other authors[47, 48] suggested the same $J = 3, 4$ as we do, they were unable to establish the positive parity determined in our α_K measurements.

Finally, for the 2217.76-keV level only a broad range of possible J values is obtained from the multipolarity of the 227.75-keV transition, which, nevertheless, shows the parity to be positive. The presence of the intense 2217.76-keV γ ray eliminates $J \geq 3$. Positive parity had been suggested earlier[48, 52] only on the basis of assuming that the $\log ft = 7.5$ (7.2 as reported in Ref. 52) defined the β branch feeding this level as being of the first-forbidden nonunique type, excluding the "allowed" possibility which also fits.

We shall now consider the levels which, as reported by Carraz *et al.*,[47] are strongly fed from 2.90-min ^{138m}Cs, namely, those at 2090.48, 2202.92, and 2415.30 keV. Since the feeding from ^{138g}Cs is comparatively weak, and since the 2.90-min isomer is not significantly formed in ^{235}U fission nor fed from the ^{138}Xe there produced, the intensities of the transitions taking place between these levels were very low in our experiments (see Fig. 12). Due to this weakness, we could obtain an α_K value only for the 212.38-keV transition, whereas for the α_K of the 112.44- and 324.90-keV transitions the measurements gave only an upper limit (see Table I). There are two more transitions depopulating the levels we are dealing with, namely, those of 191.94- and 516.65-keV. However, it was not possible to determine their multipolarities, since the K line of the first one overlaps other conversion lines and that of the second one is too weak to be detectable (Fig. 2). The $E2, M1$ multipolarity we obtained for the 212.38-keV transition indicates that the 2202.92- and 2415.30-keV levels should have the same parity. This result is in contradiction with what is suggested by Carraz *et al.*, who proposed, respectively, (5−) and (4+), based mainly on a rather weak argument, as are analogies with the ^{140}Ce level scheme.

It may be worthwhile to point out that further studies of the decay of ^{138m}Cs should be welcome,

TABLE XI. γ-ray transition probabilities.

Transition	E_γ (MeV)	$T_{1/2}$ (sec)	$\log_{10}(\tau_\gamma A^{4/3} E_\gamma{}^5)$	$\frac{(T^\gamma_{1/2})_{exp}}{(T^\gamma_{1/2})_W}$
${}^{136}_{54}Xe_{82}$	0.197	3.0×10^{-6}	−6.0	78
${}^{138}_{56}Ba_{82}$	0.463	2.2×10^{-9}	−7.3	4
	1.436	1.8×10^{-13}	−8.9	0.08

since the following analysis of data published by Carraz *et al.* shows that they cannot be combined very coherently. As stated in the preceding paragraph, the tentative (5−) and (4+) assignments given by them for the 2202.92- and 2415.30-keV levels, respectively, are only weakly supported. The (6−) spin-parity of the ${}^{138m}Cs$ isomer feeding these levels is itself proposed only on the basis of a weak analogy with ${}^{140}La$ levels and the probable $M3$ character of the isomeric transition. Furthermore, the proposed $J\pi$ values cannot be fitted satisfactorily with the $J\pi=\underline{3}(-)$ of ${}^{138g}Cs$ and with the $\log ft$ values[53] of 8.7 and 7.1 corresponding to the β feedings to the 2415.30-keV level from ${}^{138g}Cs$ and ${}^{138m}Cs$, respectively. This set of $J\pi$ values, would indeed indicate a very weak first-forbidden nonunique feeding from ${}^{138g}Cs$, and a strong unique feeding from ${}^{138m}Cs$, the character of the latter being incompatible with a $\log ft$ value of 7.1 ($\log f^1t=7.2$).

Assuming that ${}^{138g}Cs$ and ${}^{138m}Cs$ have spin-parity 3− and 6−, respectively, a 5+ assignment for the 2415.30-keV level turns out to be the only one in agreement with the $\log ft$ values of both β decays feeding it, one of them being a first-forbidden non-

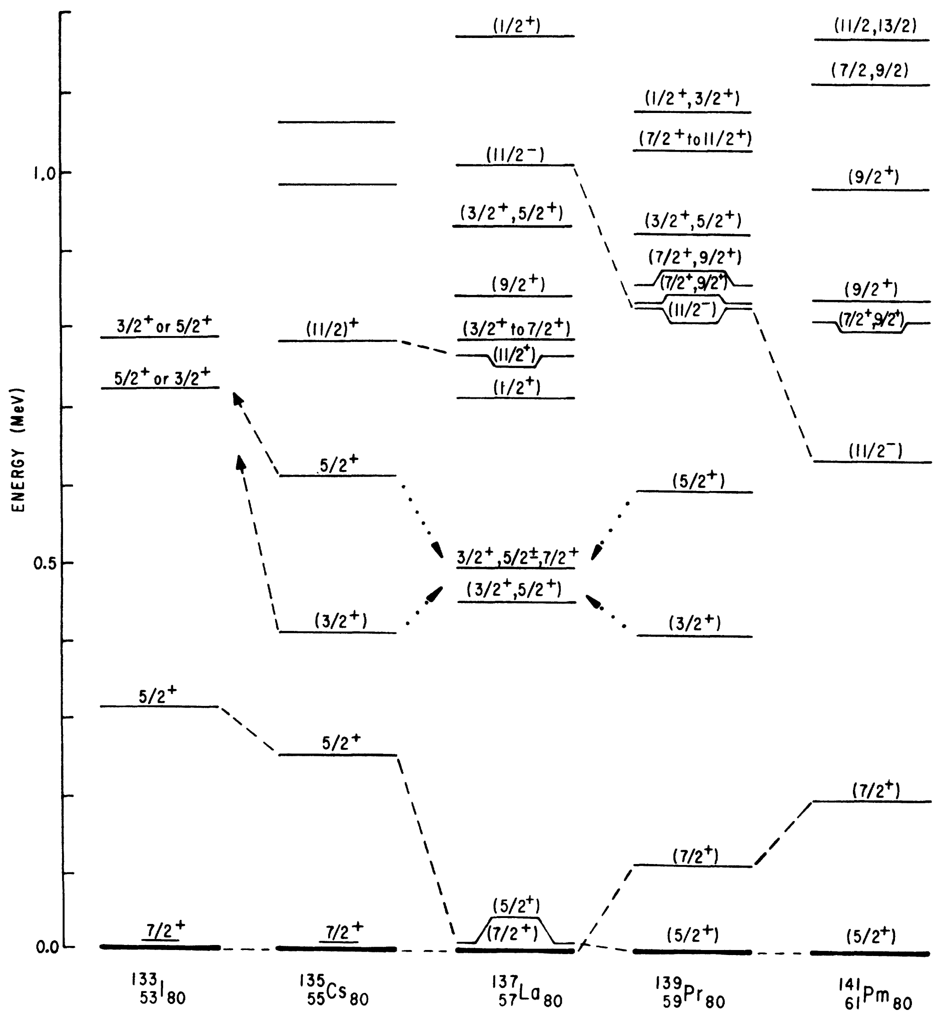

FIG. 13. $J\pi$ systematics for $N=80$ nuclei. Clear correspondences are indicated by dashed lines; more dubious ones by dotted lines. Data for excited levels were obtained from the following sources: ${}^{133}I$: Refs. 60 and 61; ${}^{135}Cs$: Refs. 15, 31, 62, and 63; ${}^{137}La$: Refs. 64 and 65; ${}^{139}Pr$: Refs. 66 and 67; ${}^{141}Pm$: Ref. 68.

unique transition and the other a first-forbidden unique one. The not well-defined multipolarity of the 324.90-keV transition would be compatible with the mentioned $J\pi$ assignment, if for the 2090.48-keV level one accepts $J\pi = 6+$, as was reasonably proposed by Carraz *et al.*

For the β decay feeding the 2202.92-keV level from ^{138g}Cs, we obtained $\log ft \sim 9.5$ ($\log f^1t \sim 9.9$). From the β-ray energies and γ intensities reported by Carraz *et al.*, the $\log ft$ of the branch feeding the mentioned level from ^{138m}Cs is[53] ~7.4 ($\log f^1t$ ~7.6). Combining these data with the same assumption made above regarding the $J\pi$ values for ^{138m,g}Cs, a 4+, 5+ assignment is obtained for the 2202.92-keV level. The parity receives some support from the already mentioned fact that the $E2$, $M1$ multipolarity of the 212.38-keV transition requires it to be equal to the parity of the 2415.30-keV level. The multipolarity range for the 112.44-keV transition furnishes no additional restriction. One should keep in mind that the preceding line of thought is tied to the weakly sustained 6− assignment for ^{138m}Cs.

C. Reviewing Comments

Spins and parities for the excited levels of ^{133,135}Xe and ^{135,137}Cs were established in the preceding sections by combining only experimentally obtained data, such as ground-state $J\pi$, transition multipolarities, $\log ft$ values, results from

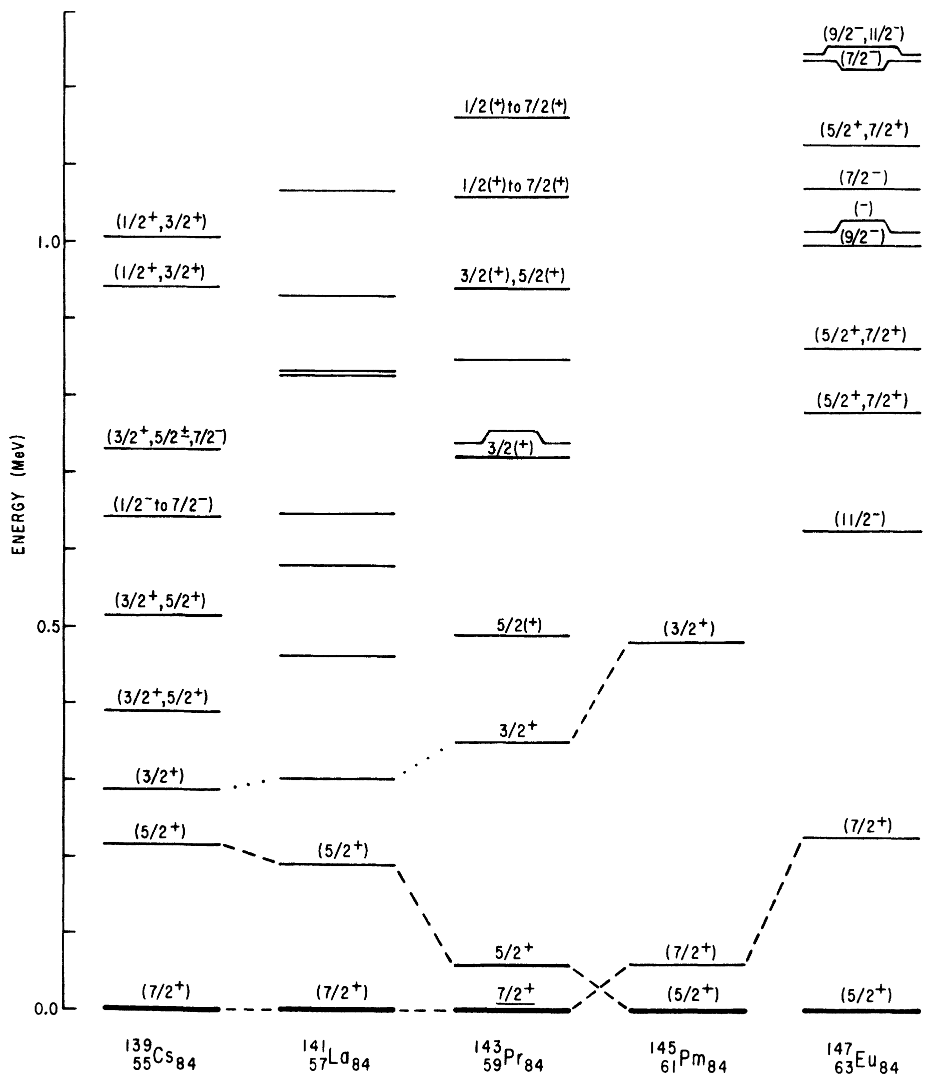

FIG. 14. $J\pi$ systematics for $N = 84$ nuclei. Data for excited levels were obtained from the following sources: ^{139}Cs: Ref. 37; ^{141}La: Refs. 69 and 70; ^{143}Pr: Ref. 71; ^{145}Pm: Ref. 72; ^{147}Eu: Refs. 73 and 74.

nuclear reactions, and, to a lesser degree, the presence or absence of certain transitions. Assignments in ^{135}Xe, based on the absence of transitions, have been given as tentative.

For the even-*A* nuclei investigated, ^{136}Xe and ^{138}Ba, the conditions were somewhat different. For the first one, log*ft* values were not applicable at all, since the $J\pi$ for 48-sec ^{136}I was unknown. In the case of ^{138}Ba, the spin of the parent nucleus has been measured, whereas for its parity we adopted (−); however, our $J\pi$ determinations for this nucleus turned out to be independent of the ^{138}Cs parity.

The situation was less favorable for ^{139}Cs, since its ground-state spin-parity and that of its parent nucleus ^{139}Xe had to be based on the systematic trends in the region. Actually, for odd-*A* cesium isotopes, this trend is quite definite: ^{133,135,137}Cs have all been measured[14] to be $\frac{7}{2}+$. A less conservative approach would thus allow removing the parentheses from our assignments for the ground state and, further, the excited states in ^{139}Cs.

Consequently, for all the investigated nuclei but ^{139}Cs, the proposed $J\pi$ values have been obtained without resorting either to the information available from the systematics of $J\pi$ values of nuclear ground or excited states, or to any prediction related to models.

V. β- AND γ-RAY TRANSITION PROBABILITIES

The spin-parity assignments made in Sec. IV, led to several log*ft* values which we consider an experimentally well-based contribution to the systematics of this magnitude.[54,55] The pertinent information is collected in Table X, where the only "parent" parity not directly[14] measured is that of ^{138g}Cs, although, as described in Sec. IV B 2, the evidence for it is rather strong. The only "daughter" $J\pi$ which have been firmly established in pre-

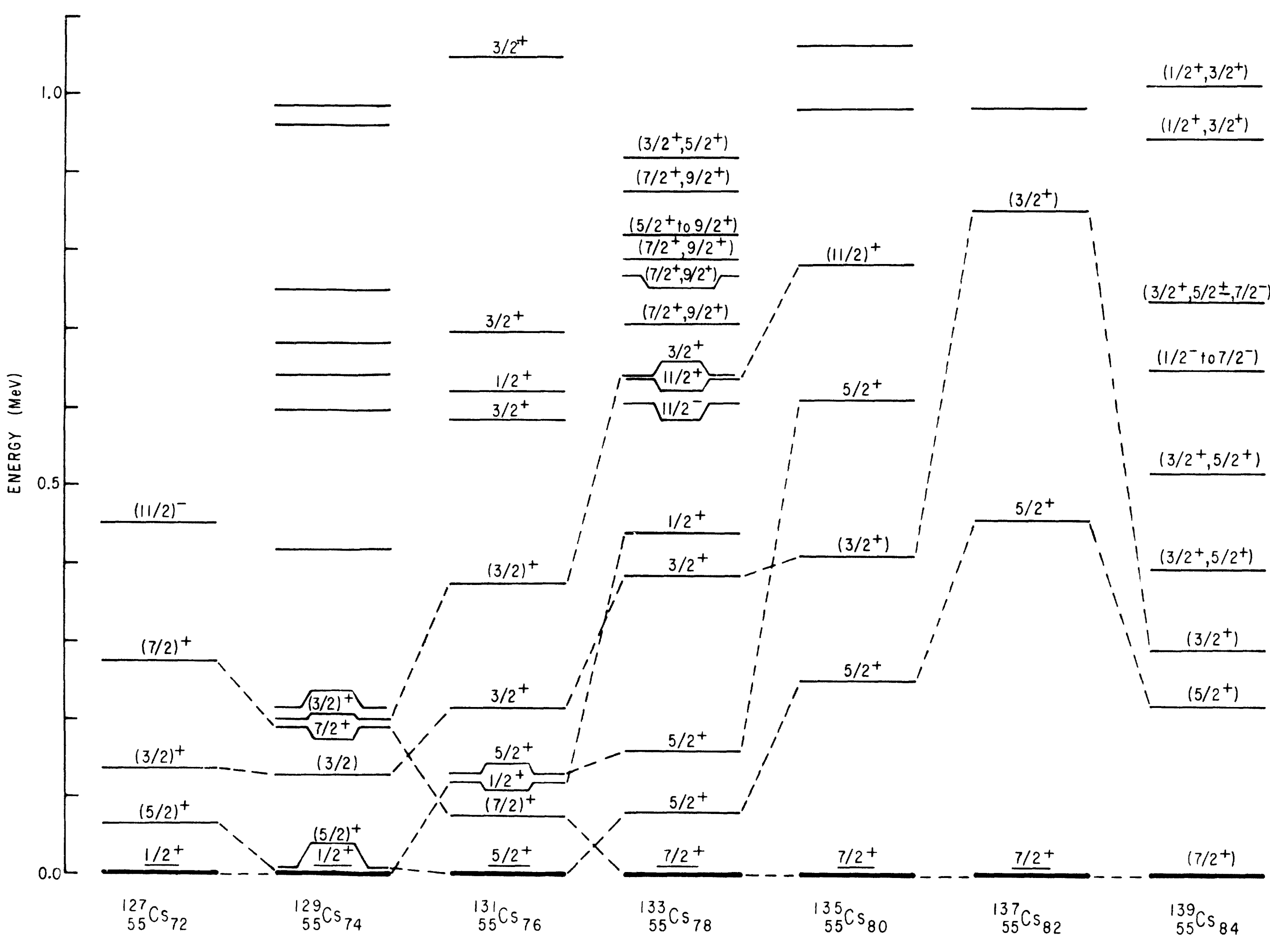

FIG. 15. $J\pi$ systematics for cesium isotopes. Data for excited levels were obtained from the following sources: ^{127}Cs: Ref. 75; ^{129}Cs: Ref. 76; ^{131}Cs: Refs. 77 and 78; ^{133}Cs: Refs. 79–81; ^{135}Cs: Refs. 15, 31, 62, and 63; ^{137}Cs: Refs. 33 and 36; ^{139}Cs: Ref. 37.

vious works are those corresponding to the levels of 233.2 keV in ^{133}Xe (Refs. 15 and 23) and of 526.5 keV in ^{135}Xe (Refs. 16, 21, and 26), as well as the one recently obtained[36] for the 455.3-keV level in ^{137}Cs. The logft values of the β decays from ^{135}Xe and ^{138g}Cs have been determined in the present work, whereas those characterizing the decays of ^{133,135}I and ^{137}Xe were taken from Refs. 19, 27, and 33, respectively. In Sec. IV A 2, when discussing the spin assignments for the 1131.5- and 1677.9-keV levels of ^{135}Xe, we eliminated the $\frac{5}{2}$ possibility because of the absence of some transitions. Table X shows that even when this possibility is taken into account, the classification of the decays feeding these levels is not modified.

As a whole, our data for allowed transitions decaying from $\frac{7}{2}+$ parents tend to cluster in the 6.7 to 7.4 logft region, whereas the only two cases proceeding from a $\frac{3}{2}+$ parent tend to have lower logft. All values fall within the limits of the histogram given in Ref. 55 for allowed transitions in the mass region $120 \leq A \leq 169$. Our data for first-forbidden nonunique transitions contribute to the prominent peak shown by the corresponding histogram.

Among the transitions collected in Table I, there are several having a well-defined multipolarity. However, apart from the well-known $M4$ transitions in ^{133,135}Xe, the only other ones depopulating levels with measured half-lives are the $E2$ transitions of 197.2 keV in ^{136}Xe, and of 1435.72 keV in ^{138}Ba. To these should be added the 462.82-keV transition in ^{138}Ba, which in Sec. IV B 2 was shown to be pure $E2$. The comparative lifetime $\log_{10}(\tau_\gamma A^{4/3}E_\gamma{}^5)$, and the ratios of the experimental half-lives $T_{1/2}^\gamma$ to the Weisskopf estimate,[46] are given in Table XI.

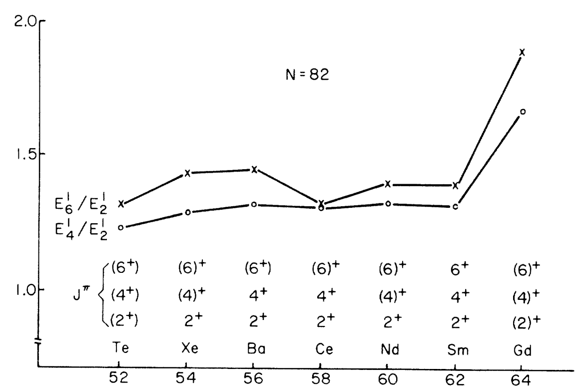

FIG. 16. Systematics of the E_6^1/E_2^1 and E_4^1/E_2^1 ratios as a function of proton number for $N=82$ nuclei. The data were obtained from the following sources: ^{134}Te: Refs. 83 and 84; ^{140}Ce: Refs. 57 and 85; ^{142}Nd: Refs. 50, 86, and 87; ^{144}Sm: Refs. 56 and 59; ^{146}Gd: Ref. 88.

As will be discussed in Sec. VI, the 197.2-keV transition in $^{136}_{54}$Xe most probably proceeds between a 6+ and a 4+ level. Our information regarding this transition has already been used[56] to include it in a systematics of hindrance factors for similar 6+ → 4+ transitions in $N=82$ nuclei, in which the existence of highly retarded $E2$ transitions at half-filled $g_{7/2}$ and $d_{5/2}$ proton subshells is stressed. This result is to be expected, since transitions between seniority-2 states should be largely hindered in the middle of the shell.

The ratio between the retardation factor 7.6 of the 4+ → 2+ 487-keV transition[57,58] in $^{140}_{58}$Ce and that of the corresponding transition in $^{138}_{56}$Ba is ~2. This figure may be compared with the ratio of ~0.1 existing,[56] in the same nuclei, between the retardation factors of corresponding 6+ → 4+ transitions. The different behavior might be explained by the existence of an admixture of a collective two-phonon 4+ state in the seniority-2 4+ states of the nuclei being considered. (This admixture could be less dependent on the occupation number of the shell than the transition rates between seniority-2 states.)

Finally, the enhancement factor 12 of the 1435.72-keV transition in $^{138}_{56}$Ba is similar to those of the transitions depopulating the first excited 2+ levels in $^{140}_{58}$Ce and $^{144}_{62}$Sm: 16 (1597 keV)[57,58] and 15 (1660 keV),[59] respectively.

VI. SYSTEMATICS FOR $J\pi$ ASSIGNMENTS

We shall now make use of the systematic trends of reported $J\pi$ determinations in order to reduce the span of our own assignments for some of the excited levels discussed. The information collected for the cesium isotopes is shown in Figs. 13–15.[60-81] For all those ground-state spin-parity values which are not directly[14] measured, we have looked up the systematic trend of known values corresponding to each of the elements involved.[14,82] The sources from which we extracted the experimental data concerning the excited levels are given in the figure captions. To keep uniformity in the presentation of these data, we have gone through the papers referred to and reevaluated the information given there. In doing so, systematic trends and modelistic considerations have been taken as only weak arguments for assigning $J\pi$ values, or for rejecting assignments otherwise possible from experimental results. For most of the nuclei shown, there exists information at energies higher than the limits established in the figures. Clear correspondences have been indicated by dashed lines, whereas more dubious ones are indicated by dotted lines.

Figure 13 stresses the fact that for odd-A nuclei neighboring ^{135}Cs, the four lowest levels are one $\frac{7}{2}$+, one $\frac{3}{2}$+, and two $\frac{5}{2}$+ states. In ^{133}I, the sequence of the $\frac{3}{2}$+ and $\frac{5}{2}$+ levels at about 750 keV is not well known. A similar situation occurs in ^{137}La, at about 500 keV. As in ^{135}Cs we had already univocally identified two $\frac{5}{2}$+ states, the 407.8-keV level is most probably characterized as ($\frac{3}{2}$+). In that case, the ground-state transition would be of the pure $E2$ type, and the corresponding logft value would belong to an allowed β decay.

For the low-lying levels of ^{139}Cs, the information furnished by the neighboring nuclei is rather well defined but scarce (Fig. 14). The first excited state most probably has $J\pi = (\frac{5}{2}+)$, this assignment being strengthened by the over-all tendencies for cesium isotopes shown in Fig. 15. The evidence for the second excited state being a ($\frac{3}{2}$+) level is somewhat weaker. If this assignment were correct, the 289.80-keV transition would be characterized as pure $E2$. The appearance in Fig. 15, of $\frac{1}{2}$+ ground states for ^{127,129}Cs is associated with the known fact that in this region stable deformations are likely to exist,[75] ^{131}Cs being the transitional nucleus.

The isomeric levels at 1891.6 and 2090.48 keV in ^{136}Xe and ^{138}Ba, respectively, most reasonably are[42] 6+ states. If this is correct, the 197.2-keV transition in the first of these nuclei would define the level at 1694.4 keV as having $J\pi = 4+$. Figure 16[83-88] shows a plot of E_6^1/E_2^1 and E_4^1/E_2^1 for $N = 82$ nuclei, which includes the levels just mentioned. The general trend is quite reasonable. The decrease in the E_6^1/E_2^1 ratio for $Z = 58$ is probably related to the closing of the $g_{7/2}$ subshell.

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