experimental values in Sm^{147} and Sm^{149}. The *magnitude* of $\mu(Nd^{147})$ is also in fair agreement (it is $0.58\,\mu_N$), but the sign is unknown

In Table I we have listed several states whose magnetic moments place them in the wrong Schmidt group for single-particle character. Most of these have been discussed in detail elsewhere,[14–16] but often in contexts that did not emphasize the simple three-qp interpretation of the anomalous magnetic moments. We have included in Table I magnetic-moment estimates based on the empirical g factors of single-qp states in neighboring nuclei. Characterization of these levels as simple $|j^n\rangle_{j-1}$ three-qp states is in some cases an oversimplification, and is no substitute for a detailed treatment (as given, for example, in Ref. 15). Still, the good agreement between the measured and estimated magnetic moments in Table I supports the value of the "wrong-Schmidt-group" rule as a diagnostic guide for finding three-qp states.

[14] J. Vervier, Phys. Letters **7**, 200 (1963).
[15] J. F. Mc Cullen, B. F. Bayman, and Larry Zamick, Phys. Rev. **134**, B515 (1964).
[16] H. Ikegami and M. Sano, Phys. Letters **21**, 323 (1966), and references therein.

We could only speculate on whether the $f_{1/2}-$ qp-plus-phonon or the three-qp $|f_{1/2}{}^3\rangle_{5/2}$ structure is correct for the lowest $\frac{5}{2}-$ states in $N=85$ and 87 nuclei. Both are in agreement with the magnetic moments' being in the wrong Schmidt group for a single-qp state of the same spin and parity. Both would lead to small $M1$ transition matrix elements. Both are also consistent with the sudden appearance of the $\frac{5}{2}-$ state at $N=85$, but not at $N=83$. Further work will be necessary to decide between these two interpretations.

ACKNOWLEDGMENTS

Mrs. Winifred Heppler contributed materially to the success of this work by carrying out many careful ion-exchange separations of promethium. Judd Haverfield and Dr. N. J. Stone kindly took the γ-ray and electron spectra that allowed us to estimate the conversion coefficient in Nd^{143}. One of us (DAS) wrote part of this manuscript while a National Science Foundation Senior Postdoctoral Fellow at Mullard Cryomagnetic Laboratory, Clarendon Laboratory, Oxford. The support of the Foundation and the hospitality of his hosts are acknowledged.

PHYSICAL REVIEW VOLUME 184, NUMBER 4 20 AUGUST 1969

Ge(Li)-Ge(Li) Study of the ^{134}I Decay*

W. G. WINN AND D. G. SARANTITES
Department of Chemistry, Washington University, St. Louis, Missouri 63130
(Received 2 January 1969)

The levels in ^{134}Xe were investigated from the decay of 53-min ^{134}I by means of Ge(Li) γ-ray spectrometry. From γ-ray energy and intensity measurements employing a high-resolution Ge(Li) detector, and from coincidence relationships determined by γ-γ coincidence measurements using two Ge(Li) detectors, it was established that levels at 846.95, 1613.4, 1731.0, 1919.8, 2136.3, 2271.7, 2303.0, 2352.8, 2408.5, 2547.4, 2588.1, 2653.1, 2773.4, 2867.3, 3084.3, 3256.0, 3300.8, 3314.4, 3359.9, 3375.3, 3475.6, and 3493.0 keV are populated in the decay of ^{134}I. Possible levels at 2704.7, 3160.4, 3190.0, 3463.1, 3790.3, and 3874.5 keV are discussed on the basis of energy sums. From the logft values obtained, limits for the J^π values of many levels in ^{134}Xe were placed. No evidence for the population of the 7^- isomer of ^{134}Xe was found in ^{134}I decay.

I. INTRODUCTION

In recent years, the lower-lying energy levels of the even xenon isotopes with $A=126$–136 have been discussed in terms of the vibrational model for the collective motion in these nuclei.[1,2] On the other hand, the existence of transitions from the second 2^+ state to the 0^+ ground state in each of these nuclei indicates that a pure vibrational model is not applicable.[1] A lack of experimental evidence for the 0^+ state of the "vibrational triplets" in these nuclei has motivated recent studies of ^{128}Xe and ^{130}Xe by Julian *et al.*[3,4] In these experiments, the 0^+ members of the "vibrational triplets" in ^{128}Xe and ^{130}Xe could be populated via allowed β transitions in the decay of ^{128}I, ^{128}Cs, and ^{130}Cs; however, no evidence was found for these 0^+ states. The absence of this 0^+ state in other even xenon isotopes has not been established at the present time.

Recently, the discovery[5,6] of "quasirotational" bands

* Work supported in part by the U.S. Atomic Energy Commission under Contract Nos. AT(11-1)-1530 and AT(11-1)-1760.
[1] *Nuclear Data Sheets*, edited by K. Way *et al.* (Academic Press Inc., New York, 1965), p. 1097.
[2] N. R. Johnson, E. Eichler, G. D. O'Kelley, J. W. Chase, and J. T. Wasson, Phys. Rev. **122**, 1546 (1961).
[3] G. M. Julian, S. Jha, and A. S. Johnston, Phys. Rev. **163**, 1323 (1967).
[4] T. E. Fessler, G. M. Julian, and S. Jha, Phys. Rev. **174**, 1472 (1968).
[5] H. Morinaga and N. L. Lark, Nucl. Phys. **67**, 315 (1965).
[6] J. E. Clarkson, R. M. Diamond, F. S. Stephens, and I. Perlman, Nucl. Phys. **A93**, 272 (1967).

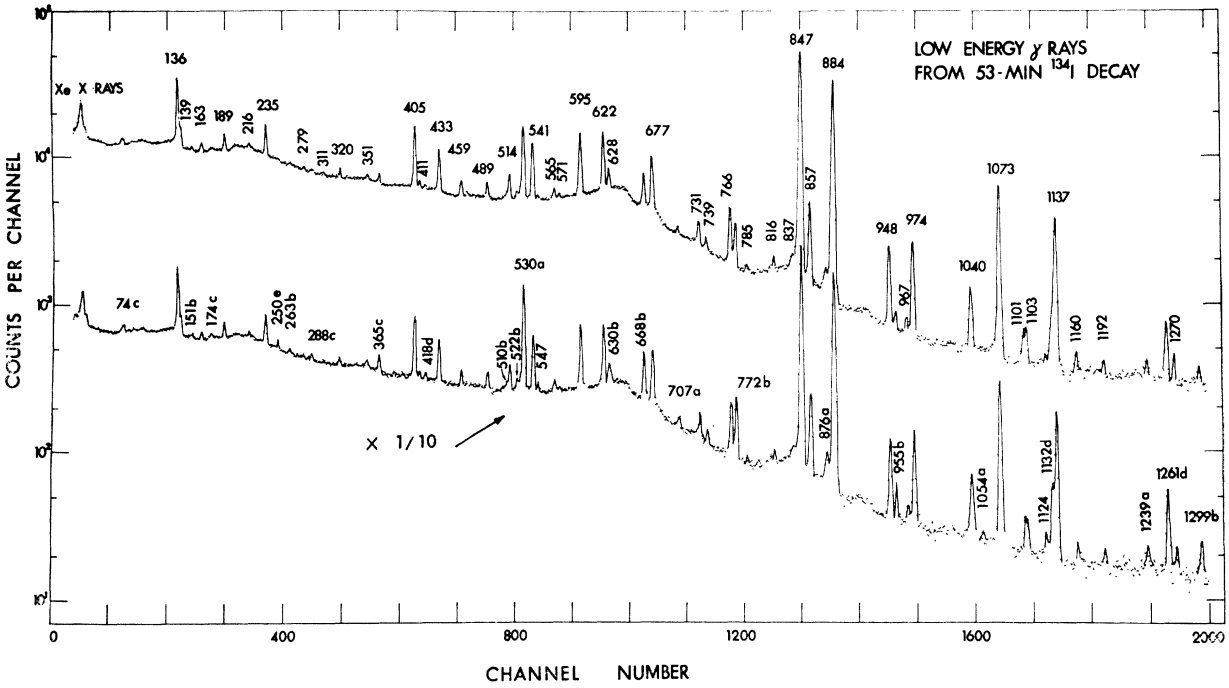

FIG. 1. Singles spectra from 20 to 1300 keV recorded with the 20-cm^3 Ge(Li) detector. The upper spectrum labels the γ rays of ^{134}I and the lower spectrum displays the background 50 min later. Backgrounds are (a) ^{133}I, (b) ^{132}I, (c) ^{131}I, (d) ^{135}I, and (e) ^{135}Xe.

in even nuclei of $^{120-130}$Xe has led Peker[7] to suggest that the low-lying 4^+ levels of these nuclei are not two-phonon states. Also, Peker points out that a strong hindrance factor ($F\sim10^{11}$) in the decay of a two-neutron excitation in ^{132}Xe implies a strongly K-forbidden transition to a state in a deformed nucleus. From this fact and the continuity of the level trends from ^{130}Xe to ^{132}Xe, he indicates that the low-lying 4^+ level in ^{132}Xe may also be nonvibrational. When such a treatment is extended to ^{134}Xe, it is found that a two-neutron 7^- isomer decays directly to the low-lying 4^+ state with only a small retardation factor ($F\sim15$), indicating a sudden change in the nuclear properties with respect to the nature ascribed to $^{120-132}$Xe. A comparison of the isomeric decay of ^{134}Xe with similar $7^-\rightarrow4^+$ decays in other $N=80$ isotones (^{140}Nd, ^{138}Ce, and ^{136}Ba) indicates that the retardation factor ($F\sim3$) for these isomers is somewhat smaller than that for ^{134m}Xe, and suggests that these $N=80$ isotones are nondeformed. As the 7^- level ($\sim$1960 keV) of ^{134}Xe satisfies the level trends of the other $N=80$ isotones whereas the 4^+ state ($\sim$1740 keV) does not, it has been considered[7,8] that the discrepancy in the retardation factor of ^{134}Xe is due to the nature of its 4^+ state ($\sim$1740 keV). On the other hand, a more analogous level ($\sim$1920 keV) by energy trends does exist, and the discrepancy in the retardation factor could be explained by a small branch decay to this state, provided its angular momentum and parity were 4^+. Winn and Clark[8] have determined that the branch, if it exists, is less than 2% of the observed decay; however, since the postulated transition to this level was only known to be 40 ± 30 keV, an examination of the associated retardation factor was inconclusive.[8]

In the present work, it was desired to establish more accurate levels in ^{134}Xe by examining the decay of ^{134}I with Ge(Li) detectors in both singles and coincidence measurements. From this information, it was hoped that a more definite comparison of the characteristics of the ^{134}Xe levels could be made with respect to those of the "quasirotational" xenon nuclei and also the $N=80$ isotones. In particular, a more accurate energy value for the postulated 40-keV isomeric branch transition would give some insight concerning the nature of the two low-lying 4^+ states. Also, as previous work had associated γ rays of 230, 890, and 848 keV with the decay of ^{134}I it was hoped that the 7^- isomer of ^{134}Xe could be studied.[2,8]

II. EXPERIMENTAL PROCEDURE

A. Preparation of ^{134}I Samples

The ^{134}I samples were produced from 30-MeV ^{4}He-ion–induced fission on natural uranium foils, at the Washington University cyclotron. From the fission products the tellurium activities were separated and purified 15 min after the end of bombardment. The 43-min ^{134}Te was allowed to decay to ^{134}I for a period

[7] L. K. Peker, Bull. Akad. Sci. USSR **31**, 1624 (1968).
[8] W. G. Winn and D. D. Clark, Bull. Am. Phys. Soc. **11**, 775 (1966); and (to be published).

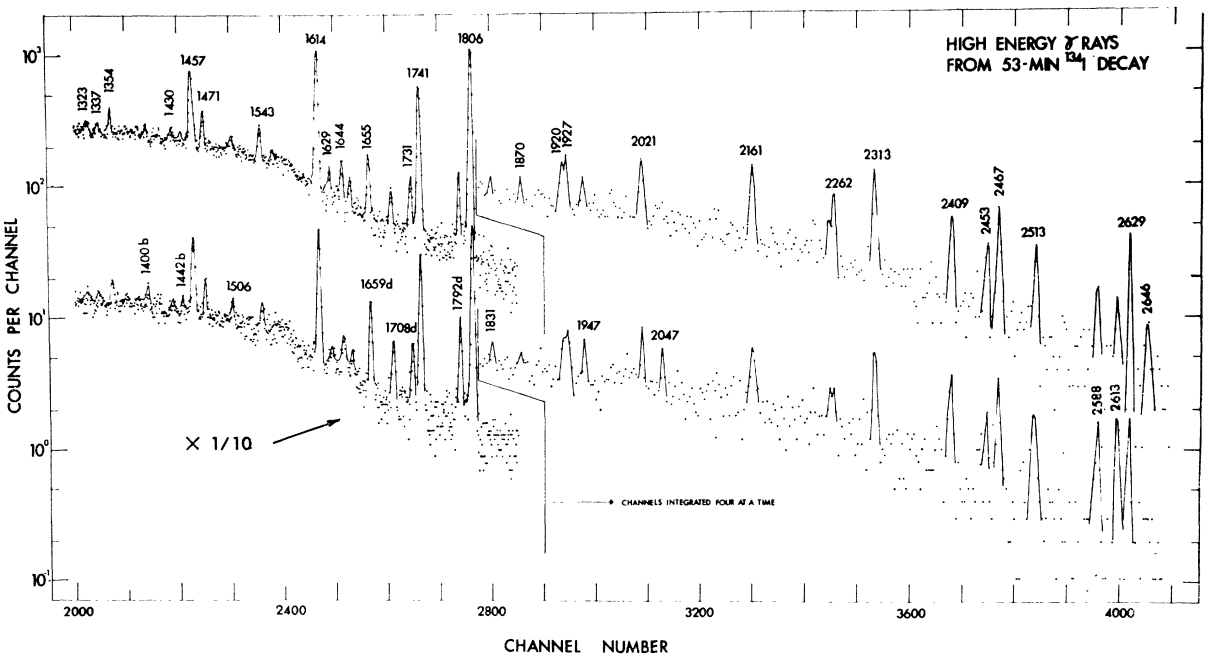

FIG. 2. Singles spectra from 1300 to 2700 keV recorded with the 20-cm³ Ge(Li) detector. The upper spectrum labels the γ rays of ^{134}I and the lower spectrum displays the background 50 min later. Backgrounds are (a) ^{133}I, (b) ^{132}I, (c) ^{131}I, (d) ^{135}I, and (e) ^{135}Xe.

of about 50 min and the iodine activity was separated and purified from tellurium and the other fission products. This method gives ^{134}I samples with very little ^{135}I and only a few percent of ^{132}I and ^{133}I activities.[2]

The uuranim foils were dissolved in 10 ml of concentrated HCl containing a few drops of concentrated HNO_3. $Te^{IV,VI}$ and I^- carriers were added and elemental tellurium was precipitated by bubbling SO_2. The tellurium was redissolved in concentrated HNO_3 and the precipitation was repeated. This sample was allowed to decay for about 50 min, after which the tellurium was dissolved in concentrated HNO_3; then the I^- carrier was added and oxidized to IO_4^- with excess of 5% NaOCl solution. The IO_4^- was reduced to I_2 with 1M NH_2OH and then extracted into CCl_4. The I_2 was back-extracted by reduction to I^- with a few ml of 1M $NaHSO_3$. The extraction cycle was repeated and the final I^- was precipitated as AgI and mounted as such for counting.

B. Detection Equipment and Methods of Counting

For γ-ray counting, two Ge(Li) detectors were employed. These detectors had active volumes of 20 and 30 cm³ with full widths at half-maximum of 2.4 and 3.0 keV, respectively, for the 662-keV γ ray from ^{137}Cs. These detectors were used in two different configurations for γ-γ coincidence measurements. In one experiment the two Ge(Li) detectors were positioned at ~90° and $\frac{3}{8}$ in. of Pb absorber was placed between them to minimize the "cross-talk" from Compton scattering. In a second experiment, the solid angle was increased by sandwiching the source between the detectors positioned at 180°. In this latter configuration, the "cross-talk" was minimized by placing the source between two $\frac{3}{16}$-in. Pb absorber plates with a $\frac{1}{4}$-in. hole at the center. The resolving times used were ~100 nsec. Two Ortec model-437 base line restorers were employed in these experiments. Under these conditions the total coincidence counting rate varied between 500–1000 counts/sec without significant loss in resolution.

For pulse-height analysis a 4096-channel two-parameter pulse-height analyzer was used. This system has been described elsewhere.[9] A 60-counts/sec pulser was fed to the preamplifier of the 30-cm³ Ge(Li) detector during the coincidence experiment. From the resulting coincidences with the pulser, the random events were estimated and found to be negligible. The coincidence data were recorded in a 256×1024-channel configuration covering an energy range 1900×2300 keV. The coincidence spectra presented in Figs. 3–8 were obtained with the 20-cm³ Ge(Li) detector and correspond to 7.8-keV windows selected from the 30-cm³ Ge(Li) spectrum.

III. EXPERIMENTAL RESULTS

A typical singles spectrum of the γ rays following 52.8-min ^{134}I decay is shown in Fig. 1 (lower-energy part of the spectrum) and Fig. 2 (high-energy part of the spectrum). The upper spectra shown in these figures were obtained by counting for 40 min imme-

[9] W. G. Winn and D. G. Sarantities, Nucl. Instr. Methods **66**, 61 (1968).

TABLE I. Energies and relative intensities of γ rays following 53-min ^{134}I decay.

Measured E_γ (keV)	Relative intensity	E_γ from scheme (keV)	Measured E_γ (keV)	Relative intensity	E_γ from scheme (keV)
135.55±0.15	4.97±0.11	135.44	974.6±0.2	4.96±0.25	974.67
138.5±0.5	0.88±0.12	138.86	1039.5±0.6	2.32±0.10	1039.69
162.65±0.5[a]	0.38±0.04	(162.59)	1072.85±0.15	15.63±0.16	1072.86
188.75±0.4	0.92±0.06	188.83	1100.8±0.5[a]	0.71±0.11	(1101.1)
216.95±0.5	0.30±0.05	217.10	1102.4±0.7	1.06±0.20	1103.6
235.3±0.4	2.60±0.16	235.32	1136.6±0.4	8.52±0.26	1136.27
279.0±0.7	0.16±0.05	279.16	1159.9±0.5	0.30±0.07	1159.93
311.0±0.7	0.10±0.05	311.00	1191.6±0.7[a]	0.21±0.06	(1191.4)
319.85±0.5	0.48±0.07	319.89	1270.15±0.3[a]	0.49±0.10	(1270.2)
350.5±1.0	0.53±0.07	350.16	1323.0±0.9[b]	0.14±0.07	...
405.3±0.25	7.71±0.15	405.30	1336.9±0.9[b]	0.16±0.08	...
410.9±0.7	0.56±0.10	411.08	1353.7±0.7	0.37±0.06	1353.37
433.2±0.2	4.44±0.12	432.96	1429.6±0.9[a]	0.17±0.08	(1429.4)
458.75±0.15	1.49±0.28	458.75	1456.7±0.7	2.82±0.13	1456.0
488.7±0.3	1.38±0.11	488.69	1470.6±0.6	0.79±0.09	1470.9
514.4±0.3	2.27±0.13	514.48	1542.9±1.0[a]	0.54±0.08	(1543.4)
540.65±0.25	7.88±0.23	540.74	1613.7±0.5	4.80±0.32	1613.42
565.3±0.4	0.92±0.12	564.30	1628.9±1.5	0.22±0.06	1628.9
571.2±0.7	0.35±0.14	571.97	1643.8±1.0	0.38±0.06	1644.3
595.2±0.2	11.52±0.18	595.53	1654.6±1.5[a]	0.16±0.04	(1654.0)
621.6±0.2	11.07±0.21	621.79	1741.1±0.7	3.00±0.22	1741.14
627.85±0.35	2.21±0.20	627.55	1806.1±0.8	6.03±0.10	1806.16
677.4±0.5	7.84±0.78	677.52	1870.3±0.9[a]	0.06±0.03	(1870.5)
730.5±0.3	1.76±0.12	730.97	1927.5±1.8	0.20±0.07	1926.4
739.2±0.4	0.80±0.15	739.35	2021.2±1.0	0.22±0.04	2021.3
766.4±0.2	4.45±0.17	766.47	2160.7±1.5[b]	0.23±0.03	...
784.85±0.5[a]	0.42±0.10	(784.85)	2262.4±1.5[a]	0.06±0.03	(2261.1)
816.1±0.5	0.56±0.11	816.38	2313.0±1.3[a]	0.22±0.03	(2313.4)
837.3±0.5[a]	0.66±0.13	(837.2)	2409.0±1.4	0.10±0.02	2409.0
846.95±0.15	100.00	846.95	2453.3±1.3	0.05±0.02	2453.3
857.25±0.2	6.73±0.16	857.11	2467.4±1.3	0.12±0.02	2467.7
884.05±0.15	68.12±0.60	884.03	2512.8±1.6	0.06±0.02	2512.9
948.0±0.4	4.02±0.20	947.44	2628.6±1.8	0.07±0.02	2628.6
967.6±0.4	0.29±0.15	966.8	2646.0±2.0	~0.02	2646.0

[a] γ rays that could be accommodated in the scheme by means of levels based only on energy sums.

[b] γ rays not assigned in the decay scheme.

diately after separation; the lower spectra, obtained from a 40-min count beginning 50 min from the time of the ^{134}I separation, are shown after division by a factor of 10 for graphical clarity. These spectra are actually the sums of the spectra obtained from four samples counted as described. By comparison of the intensities of the corresponding peaks in these two timed spectra it is possible to identify the peaks with half-lives different from 53 min. For graphical simplicity, in the upper spectrum the energies of the peaks associated with ^{134}I decay are shown, while in the lower spectrum the energies of the peaks with other half-lives are given. The energies and relative intensities of the γ rays determined from four dif-

TABLE II. Summary of observed coincidence

Fig.[a] No.	20 cm³ / 30 cm³	136	139	189	217	235	279	320	405	411	433	459	489	514
3(B)	136				S				S					
3(C)	139	W											S	
	189										S			
	217	S												
	235	W									S			
	279													
	320													
4(A)	405	S								S				
4(B)	411								S					
	433			S		S								S
	459													
	489													
	514										S			
	541													
	565								S					
	595	S							S					
	622					S								S
	628							S						
	677		S											
	731								S					
	766													
5(A)	847	S	S	S		S			S		S	S	S	S
5(B), (C)	857													
5(D)	884	S	S	S		S			S					
	948													
	975						S							
	1040													
6(B)	1073	W	W		S					S	S			S
	1101	W		S										
	1102	W		S										
	1137													
	1457													
7(B)	1614													
	1741													
	1806													

[a] Because of the large number of recorded coincidence spectra, only the most representative spectra are shown in the figures.

ferent spectra are shown in Table I. The energies and relative intensities were determined from the centroids of the peaks and the peak areas employing standard sources as described elsewhere.[10] The last column in Table I gives the energy values for the various transitions based on the proposed scheme. Comparison with the values listed in the last column shows the consistency of the decay scheme with the measured energy values. Energies in parentheses denote those transitions that could be accommodated in the scheme by means of energy sums only and do not correspond to transitions between the more firmly established levels shown in the final decay scheme. On the other hand, a discussion of possible assignments for these γ rays has been included in the text that follows. We note that only three of the γ rays listed could not be assigned to the scheme on any basis.

The coincidence relationships among many γ rays from ^{134}I decay were established by means of Ge(Li)$\times$Ge(Li) two-parameter experiments. The results are summarized in Table II. Here the strong coincidences observed are indicated by *S* and the weak coincidences by *W*. Figures 3–7 illustrate the spectra obtained in coincidence with some of the most intense γ rays. Figure 8(A) illustrates the singles spectrum obtained with the gating 30-cm³ Ge(Li) detector by sampling singles for 2.0% of the time. A 60-counts/sec pulser was fed to the preamplifier of the 30-cm³ Ge(Li) detector and the spectrum recorded with the 20-cm³ Ge(Li) detector in coincidence with this pulser peak is shown in Fig. 8(B). When this spectrum is normalized to the area of each singles peak in the 30-cm³ detector, a measure of the chance events is obtained. From this, it is seen that the chance coincidence spectrum was negligible.

IV. CONSTRUCTION OF DECAY SCHEME

The earlier work of Johnson *et al.*[2] has assigned a number of the low-lying levels in ^{134}Xe that are presented in the scheme of Fig. 9. In particular, the 847- and 1731-keV levels were established on the basis of the intensities and the observed coincidence of the 847- and 884-keV γ rays. In the spectrum coincident with the 847-keV γ ray [Fig. 5(A)], peaks are seen at 766, 1073, 1457, 1741, and 1806 keV, which are

[10] E. J. Hoffman and D. G. Sarantites, Phys. Rev. **177**, 1647 (1969).

relationships of the γ rays from ^{134}I decay.

541	565	595	622	628	677	731	766	847	857	884	948	975	1040	1073	1101	1102	1137	1457	1614	1741	1806
		S						S		S											
					S			S		S											
								S		S											
			S				S	S		S				S							
		S				S		S		S											
								S						S							
								S													
								S						S							
			S					S		S				S							
		S					S	S		S					S	S					
																		S			
S								S		S											
								S		S											
														S							
								S	S	S											
S												S	S								
S	S	S	S		S		S		S	S	S	S		S	S	S	S	S		S	S
								S		S											
S	S	S	S		S			S	S						S	S	S				
							S	S											S		
							S														
				S				S			S										
S								S		S							W				
S								S		S							W				
								S		S											
	S							S				S	W	W							
								S													
								S													

not seen in the spectrum coincident with the 884-keV γ ray [Fig. 5(D)]. This suggests the presence of levels at 1613, 1920, 2303, 2588, and 2653 keV, which is further supported by other evidence. For example, the observed γ ray at 1613.7 keV confirms the level at 1613.4 keV. Also, the 189-keV γ ray is in strong coincidence with the 884- and 433-keV γ rays, but not with the 1073-keV γ ray [Figs. 5(D) and 6(B)]; this strongly supports the assignment of the 189-keV γ ray between the 1920- and 1731-keV levels. The 1457-keV γ ray was seen in strong coincidence with the 565- and 847-keV γ rays, but since it is more intense than the 565-keV γ ray, it must populate the 847-keV level directly. Energy difference considerations motivated the assignment of the rather weak 571-keV γ ray as a transition from the 2303- to 1731-keV level. Transitions from the 2588-keV level to the 1731- and 1613-keV levels have been assigned on the basis of the observed strong coincidence of the 975-keV γ ray with the 766- and 1614-keV γ rays [Fig. 7(A)], and of the 857-keV γ ray with the 884-keV γ ray [Fig. 5(D)]. A 351-keV transition from the 2653-keV level to the 2303-keV level has been assigned on the basis of energy sums. Also, a 1040-keV transition from the 2653-keV level to the 1614-keV level is based on the observed coincidence of the 1040-keV γ ray with the 766- and 1614-keV γ rays [Fig. 7(A)].

Additional levels at 2136 and 2272 keV are established from the following evidence. The 217- and 405-keV γ rays are in coincidence with the 1703- and 884-keV γ rays, respectively [Figs. 6(B), 5(D)]. The four last-mentioned γ rays are in strong coincidence with the 136-keV γ ray, and the 405-keV γ ray is further in coincidence with the weak 411- and 731-keV γ rays [Figs. 3(B), 4(A), 4(B)]. This evidence establishes levels at 2136 and 2272 keV and suggests the presence of levels at 2547 and 2867 keV. The levels at 2272 and 2867 keV are further confirmed by the observed coincidence of the 541- and 1137-keV γ rays with the 884-keV γ ray [Fig. 5(D)]. The level at 2547.4 keV is firmly established from the following strong coincidences: the 627-keV γ ray with the 1073-keV γ ray [Fig. 6(B)], the 411- with the 405-keV γ ray [Figs. 4(A) and 4(B)], and the 139- with the 677- and 844-keV γ rays [Fig. 3(C)]. The weak 816-keV γ ray is assigned by difference as a transition between the 2547- and 1731-keV levels.

The presence of a level at 2353 keV is established from the observed coincidences between the 433- and

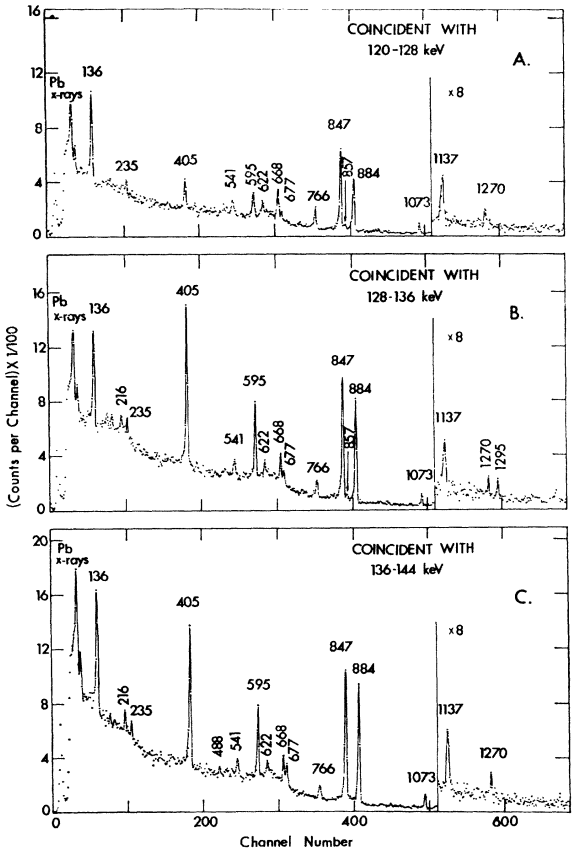

FIG. 3. Spectra of the γ rays from ^{134}I observed with the 20-cm^3 Ge(Li) detector in coincidence with the indicated energy regions in the 30-cm^3 detector. (A) and (B) display the spectra coincident with the 136- and 139-keV γ rays and (C) gives the corresponding Compton background.

622-keV γ rays with the 1073- and 884-keV γ rays, respectively [Figs. 6(B) and 5(D)]. Using energy differences the 739-keV γ ray was assigned as a transition between the 2353- and 1613-keV levels.

A level at 2409 keV is firmly established on the basis of the observed strong coincidence of the 489- and 677-keV γ rays with the 1073- and 884-keV γ rays, respectively, (Table II); and of all of these with the 139-keV γ ray [Fig. 3(C)].

A level at 2773 keV is based on previously observed NaI(Tl) coincidences between the 1614- and 1160-keV γ rays.[2] Although the NaI(Tl) resolution was not sufficient to discriminate between the 1136- and 1160-keV γ peaks, the fact that the present decay scheme does not permit a coincidence between the 1614- and 1136-keV γ rays supports the above conclusion. Also, the assignment of the 1928-keV γ ray as a transition from this level to the 847-keV level further establishes the 2773-keV level. By similar arguments, a level at 3084 keV is based on previously observed NaI(Tl) coincidences between the 1613- and 1471-keV γ rays,[2] and supported by assignable γ transitions of 311.0 and 1353.7 keV from this level to the 2773- and 1731-keV levels, respectively.

Transitions to the 0^+ ground state from levels directly populated by β decay are not expected to occur here. The transitions of 2409, 2453, 2467, 2513, 2629, and 2646 keV are too energetic to populate any level other than the one at 847 keV. This establishes levels at 3256.0, 3300.8, 3314.4, 3359.9, 3475.6, and 3493.0 keV.

Finally, a level at 3375.3 keV is supported by the observed coincidence between the 541- and the 1102-keV γ ray, and by the assignment of 967.6-, and 1643.8-keV transitions from this level which populate the 2409- and the 1731.0-keV levels, respectively. A weak coincidence of the 1073-keV γ ray with the 1457-keV γ ray was observed and it is possible that this is due to a weak 1072.3-keV transition between the 3375- and 2303-keV levels.

The proposed decay scheme of Fig. 9 accommodates 98.7% of the total γ-ray intensity associated with ^{134}I decay. Not included are a number of possible levels that are based on energy sums alone. For example, a level at 2704.7 keV could accommo-

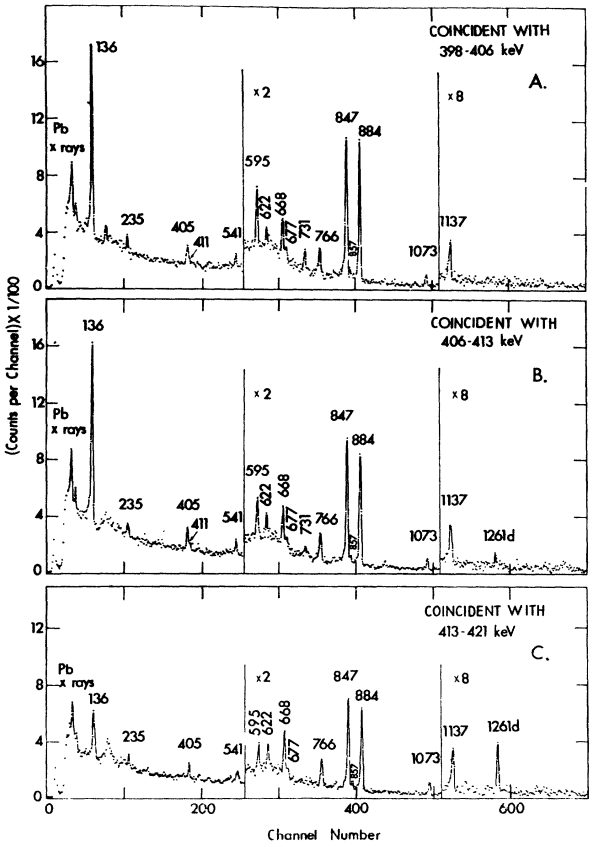

FIG. 4. Spectra of the γ rays from ^{134}I observed with the 20-cm^3 Ge(Li) detector in coincidence with indicated energy regions in the 30-cm^3 detector. (A) and (B) display the spectra coincident with the 405- and 411-keV γ rays, and (C) gives the corresponding Compton background.

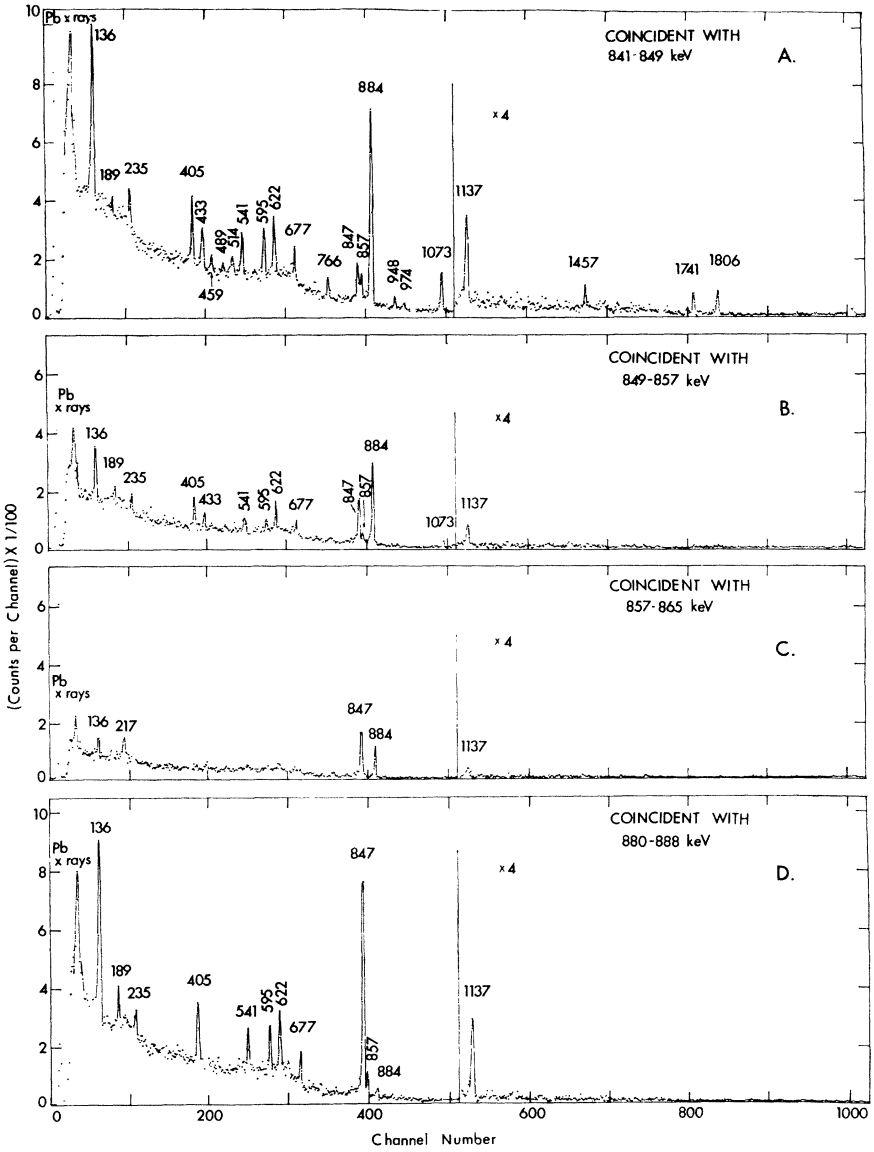

FIG. 5. Spectra of the γ rays from ^{134}I observed with the 20-cm^3 Ge(Li) detector in coincidence with indicated energy regions in the 30-cm^3 detector. (A) and (D) display the spectra coincident with the 847- and 884-keV γ rays, respectively. (B) and (C) give the Compton backgrounds for the above spectra, as well as the spectra coincident with the 857-keV γ ray.

date the 163-keV γ ray populating it and the 785-keV γ ray deexciting it. Other possible levels E_L are supported by respective γ transitions of energy γ_1 and γ_2 to well established levels E_1 and E_2, such that E_L is given by $(E_1+\gamma_1=E_2+\gamma_2)$; accordingly, the following levels (in keV) are suggested: 3160.4 (847+2313=1731+1430), 3190.0 (2353+837=1920+1270), 3463.1 (2272+1192=1920+1543), 3790.3 (2136+1655=1920+1870), and 3874.5 (2773+1101=1613+2262). The 7$^-$ isomer at 1963 keV is reported[8] to decay by a 233.0±1.5-keV γ-ray transition. With this large uncertainty in the transition energy it is possible that the isomeric transition overlaps substantially with the 235.3-keV transition which is shown from the present work to populate the 2352.8-keV level. From our singles and coincidence data it is not possible to exclude a weak population of the 7$^-$ isomer, but an upper limit of 0.4 for the 233-keV isomeric transition relative to the 847 taken as 100 can be placed from our spectra and from the intensity of the observed but unassigned γ rays. After these additional assignments, there are only three remaining γ rays which are not assigned to the scheme. (See Table I.)

V. ASSIGNMENT OF J^π VALUES

The logft values given in Fig. 9 were obtained from the percent β^- population on the basis of the decay scheme shown in Fig. 9, utilizing the Q_{β^-} value of 4150 keV of Johnson *et al.*[2] The presence of additional levels based on energy sums discussed earlier would only slightly affect the logft values of some of the higher-lying levels and were therefore ignored here.

From arguments similar to those given in Ref. 2 the J^π value for the ^{134}I ground state is likely to be

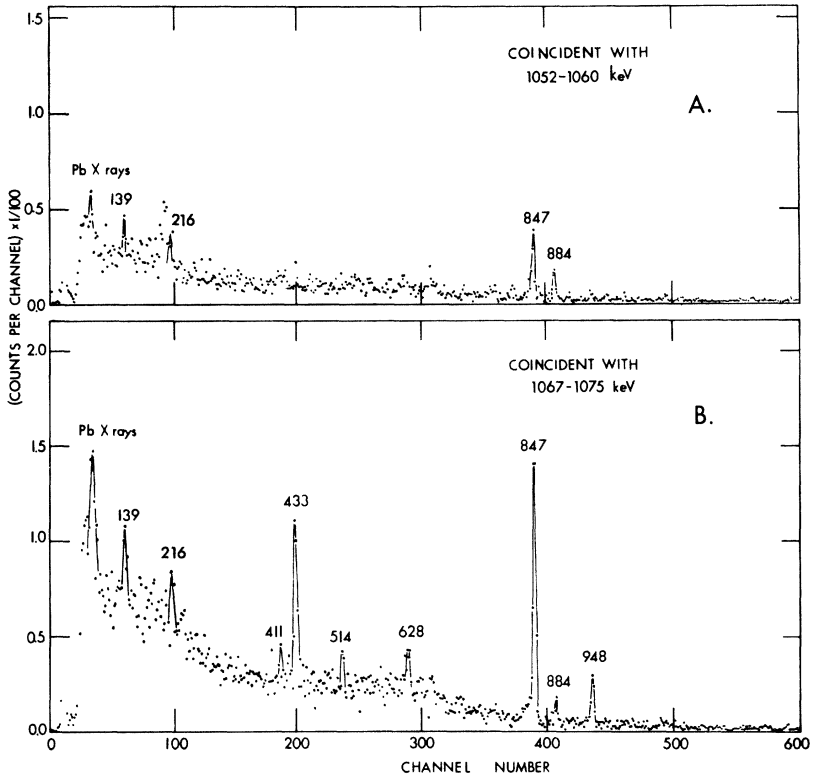

FIG. 6. Spectra of the γ rays from ^{134}I observed with the 20-cm^3 Ge(Li) detector in coincidence with indicated energy regions in the 30-cm^3 detector. (B) displays the spectrum coincident with the 1073-keV γ ray and (A) gives the corresponding Compton background.

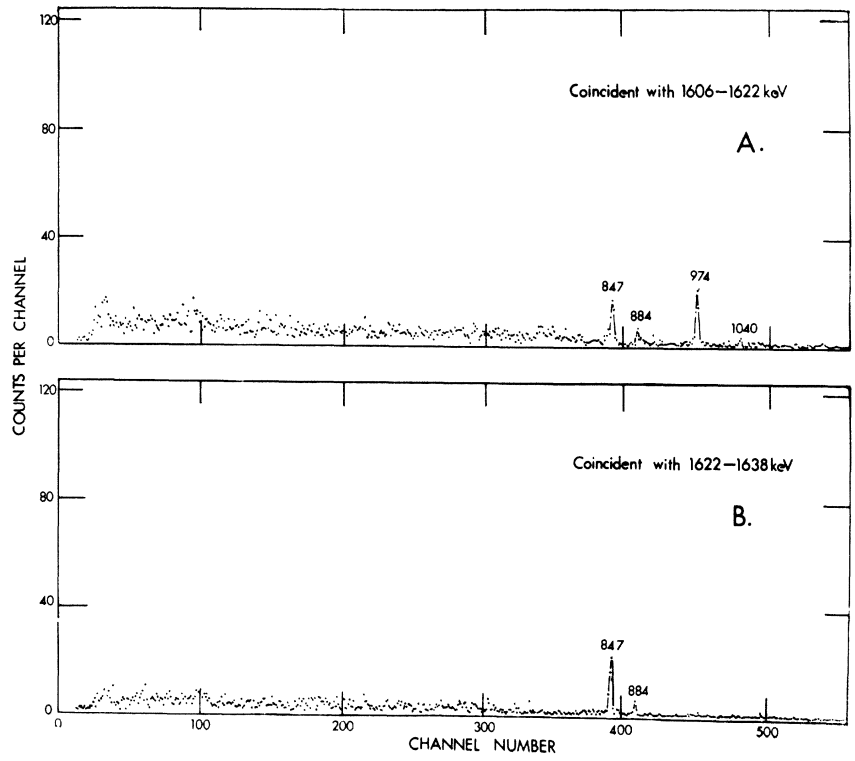

FIG. 7. Spectra of the γ rays from ^{134}I observed with the 20-cm^3 Ge(Li) detector in coincidence with indicated energy regions in the 30-cm^3 detector. (A) displays the spectrum coincident with the 1614-keV γ ray and (B) gives the corresponding Compton background.

$(4, 5)^+$, and the J^π values for the first three excited states in ^{134}Xe are 2^+, 2^+, and 4^+. Of the two J^π values for the ^{134}I ground state we favor the 4^+, since a 5^+ ^{134}I would populate most likely some 6^+ states in ^{134}Xe which would have populated the 7^- isomeric state at 1964.0 keV in ^{134}Xe and this was not observed.

Parity assignments for the levels in ^{134}Xe can be made on the basis of the log ft values. However, in this region first forbidden transitions with log ft values as low as 6.5 have been observed.[1] This makes it difficult to exclude negative parity as a possibility from many of the levels in ^{134}Xe. For β^- decays with log ft values less than 6.7 we favor the allowed character of the decay. The levels at 1920, 2303, 2773, 3084,

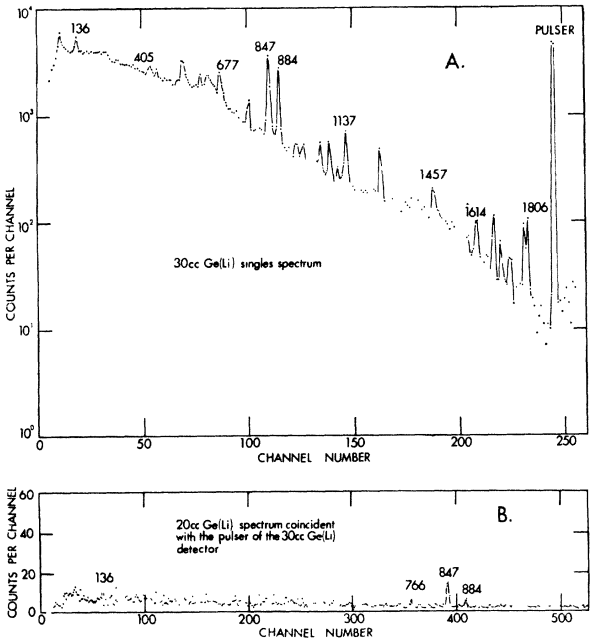

FIG. 8. Spectra illustrating the magnitude of the random events. (A) displays the 30-mc^3 singles spectrum of ^{134}I sampled 2% of the time in a coincident experiment. (B) is the corresponding spectrum of the 20-cm^3 detector in coincidence with the pulser in the 30-cm^3 Ge(Li) detector.

3256, 3301, 3314, 3475, and 3493 are only weakly populated by β^- decay and all decay to populate 2^+ states below. This is consistent with a limitation of the possible J^π values to $3^\pm$ or 4^+ for these levels. The levels at 2588 and 2653 keV are rather strongly populated by β^- decay and they populate 2^+ levels below. This supports a $(3, 4)^+$ assignment for these levels. The level at 2867 keV is considered to be $(4, 5)^+$, as it is strongly populated by β^- decay and it deexcites to a wealth of levels below, including the 2^+ level at 847 keV. The level at 3375 keV is considered to be $(4, 5, 6)^+$ as it is strongly populated by β^- decay and it populates 3^+, 4^+ or 5^+ levels below. The 2353- and 3360-keV levels are not populated strongly by β^- decay and they populate 2^+ and 4^+ levels below. This favors a $(3, 4)^\pm$ assignment. Finally, the levels at 2136, 2272, 2409, and 2547 keV are only weakly populated by β^- decay and they populate only $J=3$ or 4 states below. This is consistent with a $(4, 5, 6)^\pm$ assignment for these levels.

TABLE III. Systematics of energy levels in Xe isotopes.

Isotope	E_2^+ (keV)	E_4^+/E_2^+	E_6^+/E_2^+
^{122}Xe	337	2.49	4.40
^{124}Xe	355	2.48	4.38
^{126}Xe	390	2.44	4.22
^{128}Xe	444	2.35	3.94
^{130}Xe	529	2.28	3.69
^{132}Xe	668	2.15	3.06[a]
^{134}Xe	847	2.27[a] 2.04[b]	3.17 or 3.52[a] 2.52, 2.68, 2.84 } [b] 3.00 or 3.98 }

[a] Values obtained from level schemes of Ref. 7.
[b] Values obtained from present considerations (see text).

VI. DISCUSSION

In the treatment of the ^{134}Xe levels by Peker,[7] an ^{134}I decay scheme "reconstructed" from earlier data was used to facilitate the discussion; however, the present results disagree with some of the assignments of this "reconstructed" scheme. In particular, we find no evidence for the 2333-, 2712-, 3008-, and 3117-keV levels invoked by Peker, as the γ rays that would define these levels are assigned elsewhere in Fig. 9. Also, the level at 2874 keV that Peker assigns as 5^- is certainly the 2867-keV level which in the present work is assigned as $(4, 5)^+$ as discussed earlier.

The above discrepancies do not involve the lower-lying states utilized in comparing ^{134}Xe levels with those of the $N=80$ isotones; however, the "reconstructed" 6^+ levels of 2712 and 3008 keV are involved in the level systematics of the even xenon isotopes considered by Peker.[7] These 6^+ states are generally higher than the possible 6^+ states in the present work

TABLE IV. Systematics of the energy levels in $N=80$ isotones.

Isotone	$E_{2_1}^+$ (keV)	"Normal" 4^+ $E_4^+/E_{2_1}^+$	"Anomalous" 4^+ $E_4^+/E_{2_1}^+$	$E_7^-/E_{2_1}^+$
$_{62}{}^{142}$Sm$_{80}$	(750)[a]	(2.36)[a]	...	(3.05)[a]
$_{60}{}^{140}$Nd$_{80}$	770	2.33	...	2.87
$_{58}{}^{138}$Ce$_{80}$	790	2.30	3.33	2.68
$_{56}{}^{136}$Ba$_{80}$	818	2.28	2.51	2.51
$_{54}{}^{134}$Xe$_{80}$	847	2.26	2.04	2.31
$_{52}{}^{132}$Te$_{80}$	(880)[a]	(2.24)[a]	(1.80)[a]	(2.12)[a]

[a] Values assumed from systematic extrapolation.

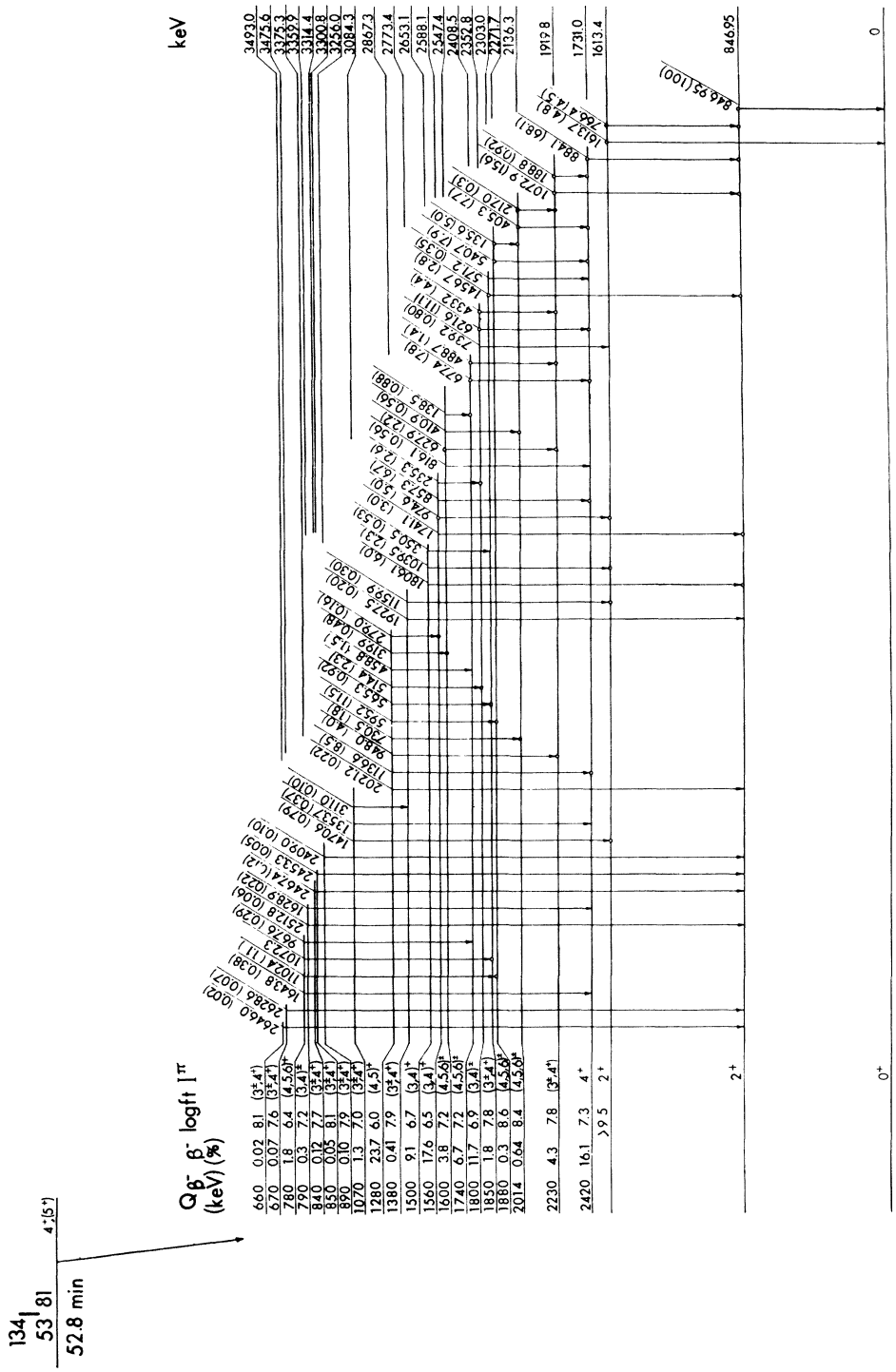

FIG. 9. Decay scheme of ^{134}I. All energies are given in keV and the intensities given in parentheses are relative to the 847-keV γ ray taken as 100.

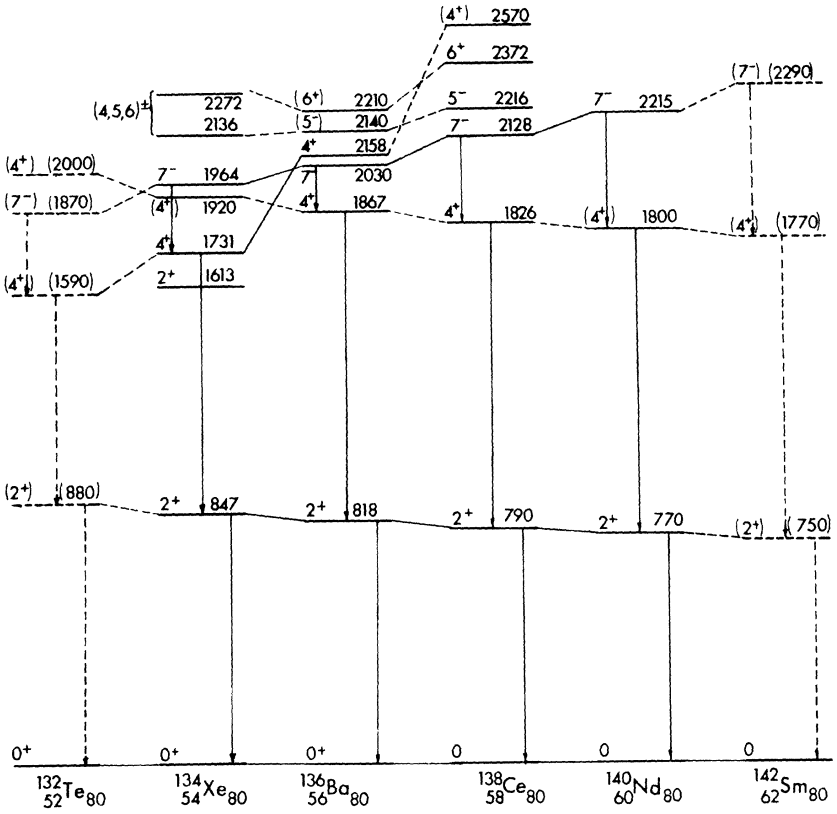

FIG. 10. Level systematics of the $N=80$ isotones ^{132}Te, ^{134}Xe, ^{136}Ba, ^{138}Ce, ^{140}Nd, and ^{142}Sm.

(see Fig. 9), and consequently the E_{6+}/E_{2+} value for ^{134}Xe may be lower. The E_{6+}/E_{2+} and E_{4+}/E_{2+} values for the isotopes $^{122-134}$Xe are given in Table III, as calculated from the data from Refs. 5, 7, and 11. Here we note that most of our values of E_{6+}/E_{2+} for ^{134}Xe satisfy the systematic trends better than that assumed from Peker's "reconstructed" level scheme of ^{134}Xe. It is also interesting to note that the E_4^+/E_2^+ systematics are satisfied similarly when the 1731-keV level of ^{134}Xe is used for E_{4+} rather than the 1920-keV level used by Peker. Thus, the transition from the "quasirotational" nuclei $^{120-130}$Xe to the "spherical" nucleus ^{134}Xe is not necessarily accompanied by a sharp departure from the level trends, and thus suggests that a deformation in the lower levels of ^{132}Xe may not be identified by level trends (see Sec. I).

A 0^+ state of the "vibrational triplet" could not be assigned from the present data because such 0^+ levels of ^{134}Xe are not likely to be formed in the decay of $4^+(5^+)$ ^{134}I. The intensity ratio of the $2_2^+\rightarrow 0^+$ and $2_2^+\rightarrow 2_1^+$ transitions from the 2_2^+ state of the "vibrational triplet" is 1.08 ± 0.10 which is in reasonable agreement with earlier results.[2]

In Fig. 10, the systematics of the $N=80$ isotones are displayed. Here we see that the first 2^+ state rises slowly in energy with decreasing proton number. The same effect is observed with the first 4^+ state for $^{140}_{60}$Nd, $^{138}_{58}$Ce, and $^{136}_{66}$Ba. For the level at 1920 keV in ^{134}Xe a J^π value of $3^\pm$ or 4^+ is consistent with our data. If this level is indeed 4^+, then it follows the trend of the first 4^+ level in the Ba, Ce, and Nd isotones. As it was pointed out by Peker,[7] the first 4^+ level in ^{134}Xe follows a different trend, and it appears that in these nuclei this is an "anomalous" level as its energy is rapidly increasing with increasing Z. For purposes of systematic extrapolation the ratios E_{4+}/E_{2+} and E_{7-}/E_{2+} for the $N=80$ isotones are given in Table IV. Values given in parentheses were obtained by linear extrapolation. If the nature of the 1731-keV 4^+ level is indeed different from that of the 1920-keV 4^+ level, then this should be reflected in the values of the reduced transition probabilities.[8] The reduced half-life for $E3$ transitions defined as

$$D=(t_{1/2})_{\text{expt}}E_\gamma^7(1+\alpha_{\text{tot}}),$$

with $(t_{1/2})_{\text{expt}}$ in sec and E_γ in MeV, varies smoothly with Z. If the values for D obtained from the experimental data for the 7^- isomeric levels in ^{140}Nd, ^{138}Ce, and ^{136}Ba are extrapolated to the ^{134}Xe case, a value of 4.65×10^{-6} results, which gives a partial half-life of 7.5 sec for the branch to the 1920-keV level. This corresponds to a fraction of 0.039 for the decay of the 7^- isomer in ^{134}Xe to the 1920-keV level as compared with the experimental upper limit of 0.02 of Winn and Clark.[8] In Table V, we summarize

[11] R. Henck, L. Stab, P. Siffert, and A. Coche, Nucl. Phys. A93, 597 (1967).

TABLE V. Systematics of the decay properties of the 7^- isomers in the $N=80$ isotones.

Isotone	$E(J^\pi=7^-)$ (keV)	$E_\gamma(E3)$ (keV)	$(t_{1/2})_{expt}$ (sec)	α_{total}	$D\times10^6$ (sec MeV^7)	$(t_{1/2})_{sp}$ (sec)	$F=(t_{1/2})_{expt}/(t_{1/2})_{sp}$
^{142}Sm	(2290)[a]	(529)[a]	($\sim5\times10^{-5}$)[a]	...	(~0.5)[a]	...	...
^{140}Nd	2215[b]	413	6×10^{-4} [c]	0.063	1.30	4.8×10^{-4}	1.25
^{138}Ce	2128[d]	303	9.2×10^{-3} [e]	0.20	2.59	3.8×10^{-3}	2.4
^{136}Ba	2035[f]	164[f]	0.307[g]	2.7	3.49	9.7×10^{-2}	3.2
^{134}Xe	1964[g,h]	44[h]	(7.5)[a]	1900	(4.65)[a]	1.84	(4.1)[a]
^{134}Xe	1964	44	>14.5[i]	1900	>9.0[i]	1.84	>7.9[i]
^{134}Xe	1964	233[g]	0.290[g]	0.5	16.2	2.02×10^{-2}	14.4
^{132}Te	(1870)[a]	(280)[a]	(~0.08)[a]	...	...	...	...

[a] Values based on extrapolation from systematics.
[b] Reference 7.
[c] V. V. Remaev, V. T. Gritsyna, and A. P. Klyucharev, Zh. Eksperim. i Teor. Fiz. **42**, 408 (1962) [English transl.: Soviet Phys.—JETP **15**, 283 (1962)].
[d] R. Babadzhanov, J. Vrzal, K. Ya. Gromov, J. Liptak, V. A. Morozov, F. N. Mukhatsimov, and J. Urbanets, Bull. Acad. Sci. USSR **31**, 1763 (1968).
[e] A. M. Morozov, V. V. Ramaev, and P. A. Yampol'skii, Zh. Eksperim. i Teor. Fiz. **39**, 973 (1960) [English transl: Soviet Phys.—JETP **12**, 674 (1961)].
[f] R. Reising and B. D. Pate, Nucl. Phys. **65**, 609 (1965).
[g] Reference 8.
[h] Present work.
[i] Values based on upper limit of 2% for branch to the 1920-keV level from Ref. 8.

the decay properties of the 7^- isomers in the $N=80$ isotones. Columns 2, 3, and 4 give the level energies in keV, the transition energies in keV, and the observed half-lives in sec. Column 5 gives the total conversion coefficient used (α_K and α_L values from Ref. 12 and α_M values from Ref. 13). Column 6 gives the calculated reduced half-lives as defined earlier. The single-proton estimates[14] are given in column 7 and the retardation factors F over the single-proton estimates are given in the last column as $(t_{1/2})_{exp}/(t_{1/2})_{sp}$. The values in parentheses in Table V are predicted values from systematic extrapolation.

It is interesting to note that the lower limit of 7.9 for the retardation factor for the branch to the 1920-keV level when compared with the value of 14.4 for the decay to the 1731-keV level is not sufficient to prove the assertion that the 1920- and 1731-keV 4^+ states are of different nature. Also, this result ($F>7.9$) does not agree well with the value ($F=4.1$) expected from the level systematics. Consequently, the present results are inconclusive with regard to identifying the 1920-keV level as analogous to the low-lying 4^+ levels of the other $N=80$ isotones.

Little can be said about the states above 2100 keV because the present experimental evidence does not allow unique J^π assignments. Although a number of levels in Fig. 9 are candidates for a 5^- or 6^+ assignment, we find it difficult to make meaningful comparisons with the levels in ^{136}Ba and ^{138}Ce. The level at 2136 keV may be considered as the possible 5^- level, while the 2272-keV level may be considered for a 6^+ assignment in analogy with the corresponding levels in ^{136}Ba and ^{138}Ce (see Fig. 10).

[12] L. A. Sliv and I. M. Band, in *Alpha-, Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Co., Amsterdam, 1965), see Appendix.
[13] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Co., Amsterdam, 1958).
[14] S. A. Moszkowski, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited K. Siegbahn (North-Holland Publishing Co., Amsterdam, 1965), p. 881.

ACKNOWLEDGMENTS

The authors are grateful for the continued cooperation of J. Hood and the operating crew of the Washington University cyclotron during the course of this investigation. The authors wish to thank Dr. T. Gallagher and the personnel of the Washington University computing facilities for their cooperation in processing the data from this work.