Decay-Scheme Studies of ^{125}Xe and ^{127}Xe

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High-resolution conversion-electron studies have been made of the ^{125}Xe and ^{127}Xe decay schemes. The energies in KeV and multipolarities of the transitions seen in ^{125}I are 54.960±0.015, $M1+(0.05\pm0.03)\%E2$; 74.86±0.02, $E2+<15\%M1$; 113.57±0.03, $M1+(1.4\pm0.4)\%E2$; 188.43±0.03, $M1+(11.3\pm0.5)\%E2$; 210.43±0.04; 243.40±0.04, $E2+<4\%M1$; 372.08±0.06 and 453.83±0.05; while those in ^{127}I are 57.60 ±0.02, $M1+(0.7\pm0.1)\%E2$; 145.22±0.03, $E2+<25\%M1$; 172.10±0.03, $M1+<1\%E2$; 202.84±0.03, $M1+(21\pm3)\%E2$; and 374.96±0.05, $E2+<30\%M1$. The γ rays associated with the ^{125}Xe decay have been studied using (NaI(Tl)-NaI(Tl) coincidence techniques and Ge(Li) γ-ray spectrometers. Transitions of energies 511, 553.9, 635.8, 717.1, 726.8, 809.4, 819.3, 846.5, 901.5, 937.3, 992.5, 1007.5, 1021.5, 1075.3, 1089.9, 1108.5, 1138.4, 1181.0, 1193.6, 1253.6, 1318.3, 1327.9, 1383.7, 1442.1, and 1560.4 keV are seen in addition to the ones observed in internal conversion. Angular-correlation measurements verify that the 511-keV quanta result from positron annihilation. A ^{125}I level scheme is given which accounts for all transitions. The γ54.960–γ188.43 and γ54.960–e_K188.43 angular correlations have been measured. The correlation results together with the measured transition multipolarities are consistent only with respective spin values of $\frac{3}{2}$ and $\frac{1}{2}$ for the 188.43- and 243.40-keV levels in ^{125}I.

I. INTRODUCTION

THE decay schemes of ^{125}Xe and ^{127}Xe received relatively little attention for some 10 years following the original studies of Bergström.[1] During that period the quality of the instrumentation available for conversion-electron studies improved dramatically. This made feasible the detailed determination of the γ transition properties for these decays. High-resolution conversion-electron studies were undertaken to this end in 1962 using the Chalk River iron-free $\pi\sqrt{2}$ β spectrometer. The work was concentrated on establishing the relative intensities and multipolarity mixing ratios of the γ transitions depopulating the low-lying level structure of the respective daughter nuclides ^{127}I and ^{125}I. These studies were augmented by both γ-γ and γ-conversion-electron angular correlation measurements to elucidate the detailed properties of the level schemes. The ^{127}Xe angular correlation studies provided evidence for a sign error in the conversion-electron-γ angular correlation theory and were described in an earlier publication.[2] A brief account of the ^{125}Xe angular-correlation studies was presented at the Warsaw conference on the Role of Atomic Electrons in Nuclear Transformations.[3]

The mean lives of the first- and second-excited states of both ^{125}I and ^{127}I have been measured by the delayed-coincidence method. These results in combination with the transition intensity and multipolarity data from the conversion-electron work yield absolute transition rates for four $M1$ and six $E2$ transition components. These lifetime measurements and the resulting transition rates have been described in the literature.[4,5]

The present paper summarizes the high-resolution internal-conversion studies of the ^{125}Xe and ^{127}Xe decays. The results of the angular-correlation studies on the ^{125}Xe decay are presented. The information on the higher excited states of ^{125}I gained from γ-γ coincidence studies with NaI(Tl) detectors and from Ge(Li) γ-ray spectra[6] are included.

II. ^{125}Xe INTERNAL-CONVERSION-ELECTRON STUDIES

The internal-conversion-electron studies were carried out using the Chalk River $\pi\sqrt{2}$ β spectrometer[7] at momentum resolutions of 0.06 to 0.1%. A flow-type proportional counter was used as the electron detector. Data were taken with the counter operating with an ~1-mg/cm² Mylar window and atmospheric gas pressure and also with it operating with an ~100-μg/cm² laminated VYNS window and ~9-cm Hg gas pressure. The counter window transmission curve used to correct the data taken with the ~1-mg/cm² Mylar window is given in Fig. 1 of Geiger *et al.*[8] (their curve D). The transmission of the ~100-μg/cm² VYNS window was taken to be constant in the electron-energy range from 20 to 100 keV.

The ^{125}Xe and ^{127}Xe activities were produced by irradiating samples of natural xenon gas in neutron fluxes in the range 6×10^{13}–2.5×10^{14} n/cm² sec. Sources were prepared from the activated gas samples using the Chalk River electromagnetic mass separator.[9] The ~40-keV accelerating potential used in most of these

[1] I. Bergström, Arkiv Fysik **5**, 191 (1952).
[2] J. S. Geiger, Phys. Letters **7**, 48 (1963).
[3] J. S. Geiger and F. Brown, in *Proceedings of the International Conference on the Role of Atomic Electrons in Nuclear Transformations* (Nuclear Energy Information Center, Warsaw, 1965).
[4] J. S. Geiger, R. L. Graham, I. Bergström, and F. Brown, Nucl. Phys. **68**, 352 (1965).
[5] J. S. Geiger and R. L. Graham, Nucl. Phys. **89**, 81 (1966).
[6] J. S. Geiger and R. L. Graham, in Proceedings of the International Conference on Nuclear Structure, Gatlinburg, Tennessee, 1966 (unpublished).
[7] R. L. Graham, G. T. Ewan, and J. S. Geiger, Nucl. Instr. Methods **9**, 245 (1960).
[8] J. S. Geiger, R. L. Graham, and G. T. Ewan, Nucl. Phys. **16**, 1 (1960).
[9] The author is indebted to Dr. F. Brown and J. Tole for arranging the sample irradiations and preparing the mass-separated sources.

separations imbeds the mass-separated Xe ions to a mean depth of $\sim$10 μg/cm^2 in the $\sim$20-mg/cm^2 Al backing foils used.[10] The beam focusing was such as to produce a line source $\sim$2-mm wide and $\sim$1-cm high.

This study was directed toward the detailed investigation of the properties of the known γ transitions in the ^{125}Xe and ^{127}Xe decays. While searches were made over restricted electron-energy regions for the conversion lines of transitions which might be present on simple permutations of the accepted level sequence, no complete and detailed survey of the entire energy range was made.

The L-shell internal conversion line spectra of the 54.96-, 74.86-, 113.57-, 188.43-, and 243.40-keV transitions in ^{125}I are presented in Figs. 1–5; the plotted data are not corrected for counter window transmission or decay. The relative line intensities have been deduced by determining first the relative line areas $\int N(B\rho)d(B\rho)/(B\rho)_0$ under each component and then applying a mean correction for counter window transmission and for decay to each of the line areas thus deduced. In all cases except that of the 113.57-keV data, the spectrum was resolved into its L_{I}, L_{II} and L_{III} components by fitting a common line shape to the three peaks on a semilogarithmic plot of the net L-line data.[7] The background subtracted from the observed counting rates was taken as the rate observed

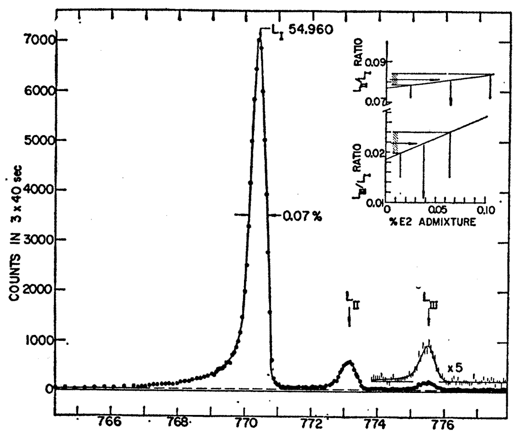

FIG. 1. The L-shell internal conversion line spectrum of the 54.960-keV transition in ^{125}I.

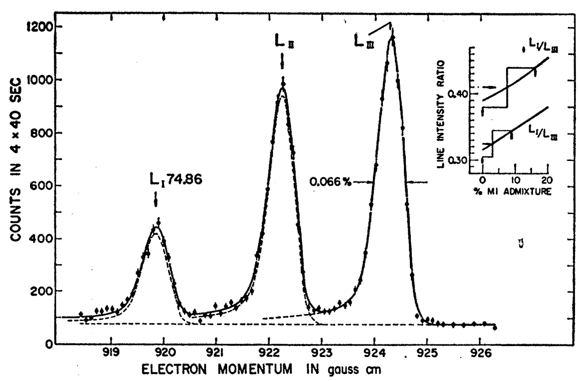

FIG. 2. The L-shell internal conversion line spectrum of the 74.86-keV transition in ^{125}I.

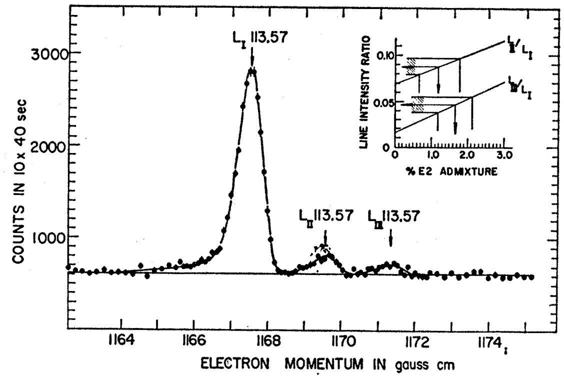

FIG. 3. The L-shell internal conversion line spectrum of the 113.57-keV transition in ^{125}I.

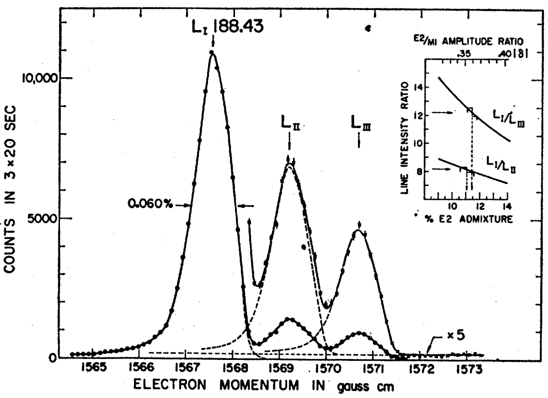

FIG. 4. The L-shell internal conversion line spectrum of the 188.43-keV transition in ^{125}I.

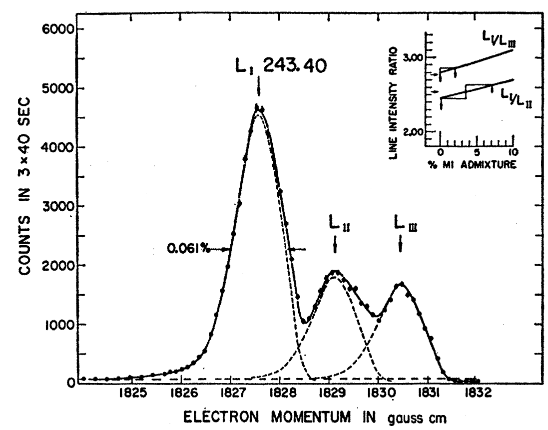

FIG. 5. The L-shell internal conversion line spectrum of the 243.40-keV transition in ^{125}I.

[10] I. Bergström, F. Brown, J. A. Davies, J. S. Geiger, R. L. Graham, and R. Kelley, Nucl. Instr. Methods **21**, 249 (1963).

above the L_{III} line. In Figs. 2, 4, and 5, the dashed curves give the respective line components as determined from the semilogarithmic plot. The solid curve is the sum of the background rate observed above the lines and the three component contributions at each point. The L lines of the 54.96-keV transition are essentially completely resolved and only the component curves are given, in this case by the solid lines. The multipolarity assignments have been made by comparing the experimental L-line intensity ratios, after correction for window transmission and decay, with those calculated from the conversion coefficient tables of Sliv and Band.[11] These comparisons are given in the upper right of the respective figures.

The L-subshell intensity ratios and the transition multipolarities deduced from them are given in columns 2 and 3 of Table I. Theoretical K-shell internal conversion coefficients appropriate to the respective transition energies and multipolarities have been deduced from the tables of Sliv and Band and are given in column 4. The relative conversion line intensities are given in columns 5–8. Relative photon intensities for the transitions have been deduced from the relative K conversion line intensities and the theoretical K conversion coefficients listed in column 4. These relative photon intensities are given in column 9 and the relative total transition intensities in column 10. The uncertainties assigned to the latter intensities make no allowance for possible errors introduced by the particular choice of the theoretical K conversion coefficient values as listed in column 4.

The K conversion lines of 3 transitions not previously seen in internal conversion were studied. The relative K line intensities for these 210.43±0.04-, 372.08±0.06-, and 453.83±0.05-keV transitions are included in Table I. Searches were made for the K lines of six other transitions with negative results. The intensity limits set in these searches are included in the table. There is no evidence for the first four of these transitions and they are not expected on the level ordering established by this investigation. While 511-keV quanta are observed in the ^{125}Xe decay, angular-correlation measurements described in Sec. IV demonstrate that these result from positron annihilation. The 636-keV transition is seen in both the direct and the coincidence γ-ray spectra.

III. DIRECT AND COINCIDENCE γ-RAY SPECTRA

Our initial studies of the γ-ray spectrum from the mass-separated ^{125}Xe sources were made using 3 in. ×3 in.-NaI(Tl) scintillation detectors. Subsequently, the author had the opportunity to study the spectrum with the 18-mm-diam by 3.5-mm-deep Ge(Li) detector

TABLE I. Conversion line and transition intensities in ^{125}I.

Transition energy (keV)	Relative L line intensities L_I	L_{II}	L_{III}	Multipolarity	α_K (Sliv)	I_K	$I\Sigma_L$	$I\Sigma_M$	$I\Sigma_{N+O}$	I_γ[a]	I_{tot}
54.960±0.015	≡1	0.081±0.003	0.022±0.002	$M1+(0.05\pm0.03)\%E2$	3.72	4.0±0.2	0.57±0.02	0.115±0.006	0.026±0.003	1.1	5.8±0.15
74.86±0.02	≡1	2.44±0.18	3.08±0.19	$E2$, <15% $M1$	2.90	0.054±0.002	0.032±0.002	0.0063±0.0006	0.0015±0.0004	0.019	0.113±0.005
113.57±0.03	≡1	0.088±0.009	0.046±0.008	$M1+(1.4\pm0.4)\%E2$	0.456	0.034±0.001	0.0048±0.0003	0.0011±0.0001		0.075	0.115±0.003
188.43±0.03	≡1	0.123±0.004	0.082±0.002	$M1+(11.3\pm0.5)\%E2$	0.116	≡1	0.145±0.004	0.0295±0.0012	0.0066±0.0008	8.62	9.8
210.43±0.04						0.0011±0.0001					
243.40±0.04	≡1	0.393±0.012	0.360±0.012	$E2$, <4% $M1$	0.0665	0.302±0.007	0.055±0.002	0.0113±0.0004	0.0024±0.0003	4.54	4.9±0.1
372.08±0.06						0.00048±0.00003					
453.83±0.05						0.0082±0.0002					
K 340						<0.0004					
K 129.8						<0.0002					
K 165.8						<0.0003					
K 265.3						<0.001					
K 511						<0.0003					
K 636						<0.0007					

[a] Deduced from the experimental K conversion line intensities using α_K values of Sliv (Ref. 11).

[11] L. A. Sliv and I. M. Band, *Alpha-, Beta-, and Gamma-Ray Spectroscopy* (North-Holland Publishing Company, Amsterdam, 1965), Vol. 2, Appendix 5.

GLO9Q of Ewan and Tavendale.[12] The low-energy region of the γ-ray spectrum as seen in this Ge(Li) detector is shown in Fig. 6. The shape of the full-energy peaks of the 75- and 114-keV γ transitions are affected by the Compton edges of the intense 188- and 243-keV transitions. The γ75 peak suffered a further distortion from lead x rays incident on the detector from lead shielding blocks left near the detector during this measurement. These complications make it impossible to deduce meaningful intensity values for these two transitions from this spectrum. All of the ^{125}I γ transitions identified in this spectrum have also been seen in internal conversion.

The Ge(Li) spectrum of the higher-energy ^{125}I γ transitions is shown in Fig. 7. The experimental geometry and the absorbers used for the measurement are indicated in the inset. Gamma-ray energies were deduced from this spectrum using a calibration based on ^{60}Co, ^{22}Na, and ^{137}Cs γ-ray spectra taken both before and after the ^{125}Xe run and on the energies of the 453.83- and 511-keV γ rays which occur in the ^{125}Xe spectrum. The linearity of the detector system was determined using a mercury relay pulser and showed a marked compression at the high-energy end of the spectrum (above about channel 330). The energies obtained from these measurements showed a systematic deviation of $\sim$3 keV from values subsequently reported by Lessard and Moore.[13] This discrepancy prompted both groups to reexamine the spectrum. We used a large-volume (30-cc) Ge(Li) detector and a 1024-channel analysis system for the new study. In addition to following the calibration procedures outlined above, we accumulated composite γ-ray spectra by having the detector view both the ^{125}Xe source and calibration γ-ray sources of ^{137}Cs and ^{60}Co simultaneously. The γ transition energies obtained from the analysis of these more recent data are in good agreement with our original values. ^{125}Xe γ-ray spectra observed with the large-volume Ge(Li) detector are shown in Fig. 8. Nine ^{125}Xe γ rays are seen in these spectra which were either unresolved or indistinguishable from background in the spectra taken with the smaller detector; six of these are of higher energy than any of the previously observed γ transitions. The energies for these transitions given in our preliminary report of this work[6] were obtained by extrapolating the calibration curve obtained from the less energetic ^{125}Xe γ rays. Discrepancies between these results and recent values obtained by Lessard and Moore[14] prompted a re-analysis of the data. Two of the background peaks appearing in the lower spectrum of Fig. 8 have accurately known energies. White and Groves give the energy of the ^{41}Ar γ ray as 1293.76

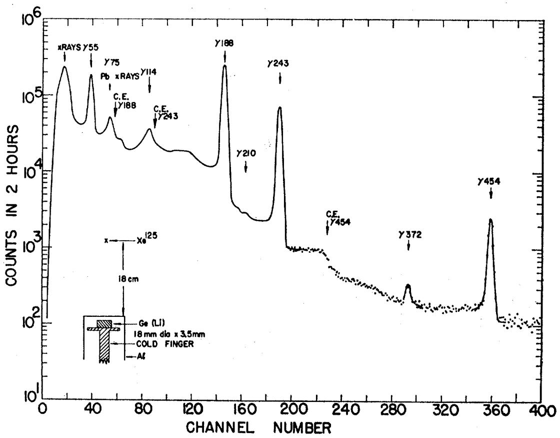

FIG. 6. The low-energy region of the ^{125}Xe γ-ray spectrum seen using a small-volume Ge(Li) γ-ray detector.

$\pm$0.14 keV.[15] The background peak appearing in channel 559 of this spectrum is the second escape peak of the 2614.47$\pm$0.10 keV[16] γ transition in ^{208}Pb. The revision of the calibration curve called for by these additional calibration points results in a lowering of the energy values for the most energetic ^{125}Xe γ rays by $\leq$1.3 keV. The transition energies and the assigned errors are summarized in Table II.

The relative γ-ray intensities have been deduced primarily from data taken with the small-volume Ge(Li) detector using the full-energy-peak efficiency curve for this detector given by Ewan and Tavendale [Fig. 14(a) of Ref. 12]. The backgrounds under the lines were obtained from smooth curves drawn under the peaks. In assessing uncertainties in the γ-ray intensities, differences between the results obtained by a peak-height analysis and the peak-area analysis were considered. The intensity of γ188 was taken to be 8.6

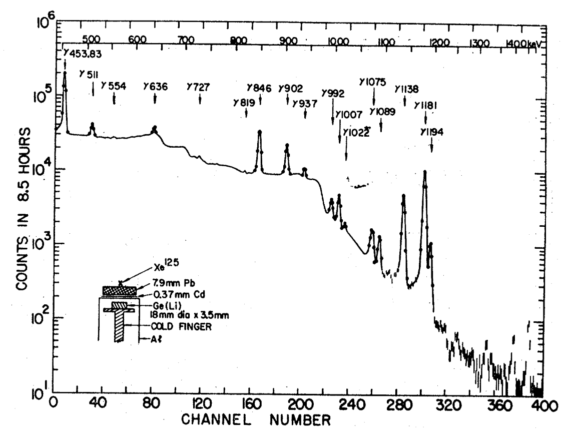

FIG. 7. The high-energy portion of the ^{125}Xe γ-ray spectrum seen using a small-volume Ge(Li) γ-ray detector.

[12] G. T. Ewan and A. J. Tavendale, Can. J. Phys. 42, 2286 (1964).

[13] L. Lessard and R. B. Moore, in The Annual Congress of the Canadian Association of Physicists, Sherbrooke, Quebec, 1966 (unpublished).

[14] J. Lessard and R. B. Moore (private communication).

[15] D. H. White and D. J. Groves, Nucl. Phys. A91, 453 (1967).

[16] G. Murray, R. L. Graham, and J. S. Geiger, Nucl. Phys. 63, 353 (1965).

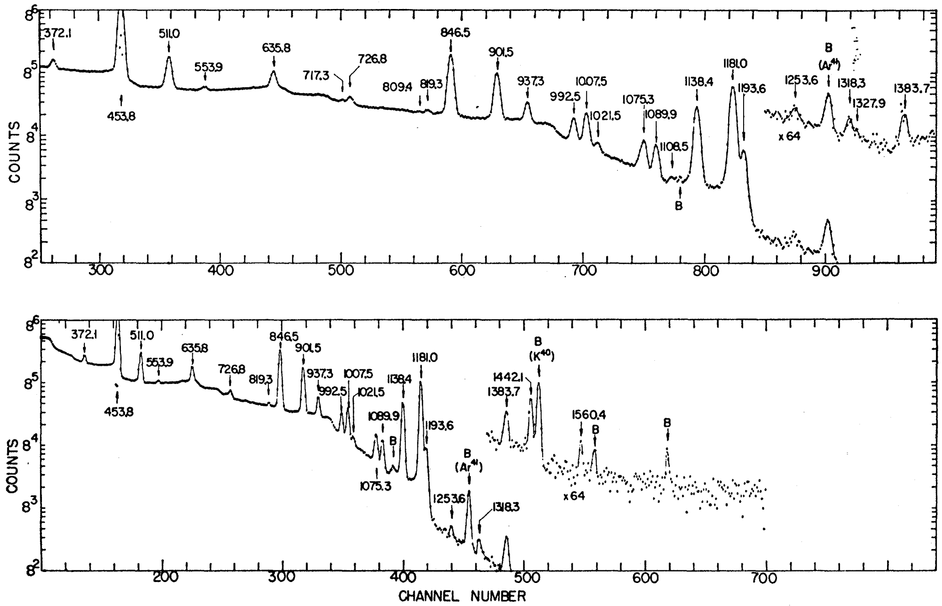

FIG. 8. The ^{125}Xe γ-ray spectrum over ~300 keV as seen with an ~30-cc Ge(Li) detector.

units, so that the γ intensity scale would be consistent with the scale used in the conversion-electron work (Table I). The uncertainty arising from the detector efficiency calibration has been taken as ±5% for transitions near γ188 and ±10% for all transitions above 511 keV. The γ-ray intensity information is included in Table II. Conversion coefficient values deduced from the data of Tables I and II by normalizing to $\alpha_K(\gamma 188)\equiv 0.116$ are given in Table III. Comparison of the experimental K conversion coefficients for the 210-, 372-, and 454-keV transitions with the theoretical values of Sliv and Band indicates that all three of these transitions are most probably $M1$, $E2$, or some $M1$-$E2$ mixture. The small discrepancy which exists between the experimental and theoretical α_K values for the 55-keV $M1$ transition is attributed to error in the photon intensity determination rather than to either the conversion-electron measurements or the theoretical conversion coefficient.

A ^{125}I level sequence incorporating all of the higher-energy γ transitions can be constructed from energy-sum considerations alone. This level scheme is shown in Fig. 9. Confirmation of the correct positioning of some of the more intense γ transitions in this level sequence has been obtained from γ-γ coincidence measurements made using 3-in.×3-in. NaI(Tl) scintillation detectors. These γ-γ coincidence measurements are summarized in Fig. 10. The gating counter spectrum and gate are shown by the curves on the right and the corresponding coincidence spectra are shown on the left. The upper left coincidence spectrum confirms that the 636- and 729-keV transitions feed the 454-keV level. The middle coincidence spectrum shows the expected γ847, γ937, and γ1138 feeds to the 243-keV level as well as a 511-keV γ peak. The 243-keV level decays 54% of the time to the 188-keV level. Hence we expect to find these same γ peaks in the spectrum coincident with γ188 which is given by the lower left spectrum. The dashed curve is the appropriately normalized γ243 coincidence spectrum and represents the contribution to the γ188 coincidence spectrum arising from the cross feeding by the 55-keV transition. Subtraction of this component from the spectrum coincident with γ188 yields the open-circle spectrum which exhibits clearly resolved peaks of γ902, γ1194, and γ511. These are direct feeds to the 188-keV level. These coincidence results are fully consistent with the level scheme of Fig. 9. An angular-correlation measurement has confirmed that the 511-keV quanta are annihilation

TABLE II. Relative photon intensities from Ge(Li) γ spectra.

Transition energy (keV)	Photon intensity $I_{\gamma 188}\equiv 8.62$	Transition energy (keV)	Photon intensity $I_{\gamma 188}\equiv 8.62$
54.960[a]	0.93±0.09	937.3±0.4	0.025±0.003
74.86[a]		992.5±0.4	0.016±0.002
113.57[a]		1007.5±0.4	0.024±0.004
188.43[a]	≡8.62	1021.5±0.6	0.004±0.001
210.43[a]	0.007±0.002	1075.3±0.5[b]	0.012±0.002
243.40[a]	4.5±0.2	1089.9±0.4	0.009±0.002
372.08[a]	0.032+0.003	1108.5±0.7	0.0007±0.0003
453.83[a]	0.67±0.05	1138.4±0.4	0.055±0.005
511.0		1181.0±0.4	0.12±0.01
553.9±0.6	0.0045±0.0009	1193.6±0.6	0.015±0.003
635.8±0.4	0.040±0.006	1253.6±1.0	0.00038±0.00010
717.1±0.7	0.0021±0.0007	1318.3±1.0	0.00029±0.00010
726.8±0.5	0.0091±0.0014	1327.9±1.6	0.00016±0.00006
809.4±0.7	0.0009±0.0004	1383.7±0.8	0.0008±0.0002
819.3±0.6	0.0029±0.0006	1442.1±0.8	0.0014±0.0003
846.5±0.4	0.19±0.02	1560.4±1.1	0.00025±0.00006
901.5±0.4	0.11±0.01		

[a] Energy values from conversion-electron studies.
[b] Peak complex.

TABLE III. Experimental K conversion coefficients and multipolarity assignments.

Transition energy (keV)[a]	K conversion line intensity	α_K	Theoretical α_K values[b] $E1$	$M1$	$E2$	Assignment
54.960	4.0±0.2	4.3±0.4		3.72		Table I
74.86	0.054±0.002					Table I
113.57	0.034±0.001					Table I
188.43	≡1	≡0.116	0.030_7	0.112	0.150	Table I
210.43	0.0011±0.0001	0.16±0.04	0.0224	0.082	0.104	$M1$, $E2$
243.40	0.302±0.007	0.067±0.003	0.0152	0.056	0.066	Table I
372.08	0.00048±0.00003	$0.015_0 \pm 0.001_8$	0.0049	0.0184	0.0170	$E2$, $M1$
453.83	0.0082±0.0002	$0.012_2 \pm 0.001_0$	0.00307	0.0111	0.0096	$M1$, $E2$
635.8	<0.0007	<0.02				

[a] Energy values from conversion-electron work.
[b] Theoretical values of Sliv and Band (Ref. 11).

radiation associated with weak positron feeds to the 188- and 243-keV levels.

IV. ANGULAR-CORRELATION MEASUREMENTS

The γ511-γ511 angular correlation is given in Fig. 11 together with the γ511-γ511 correlation observed from a ^{22}Na source. The counter arrangement used is shown in the inset. The gating window used and the coincidence spectra observed at $\theta=180°$ and $\theta=135°$ are shown on the right. The close similarity of the ^{125}Xe correlation with that produced by positron annihilation from the ^{22}Na source confirms that the γ511's in the ^{125}Xe spectrum are annihilation radiation. The cause of the low-intensity tails on the correlation which extend to large angles has not been investigated. A γ511–γ511–γ triple coincidence measurement confirmed that weak positron branches feed the 188- and 243-keV levels as previously inferred from Fig. 10.

The γ54.96-γ188.43 and γ54.96-K188.43 angular correlations were measured as a part of the investigation of the correct sign for the interference term in electron-γ angular correlations involving mixed $M1$-$E2$ radiations.[2,3] The γ188.43-γ54.96 angular correlation is shown in Fig. 12. A copper absorber was used on the gating counter to suppress the low-energy radiations and thus reduce the over-all rate in this counter. The spectrum in the gate counter is shown in the lower right. The solid points give the γ188 gate used for the angular-correlation measurement. The γ spectrum coincident

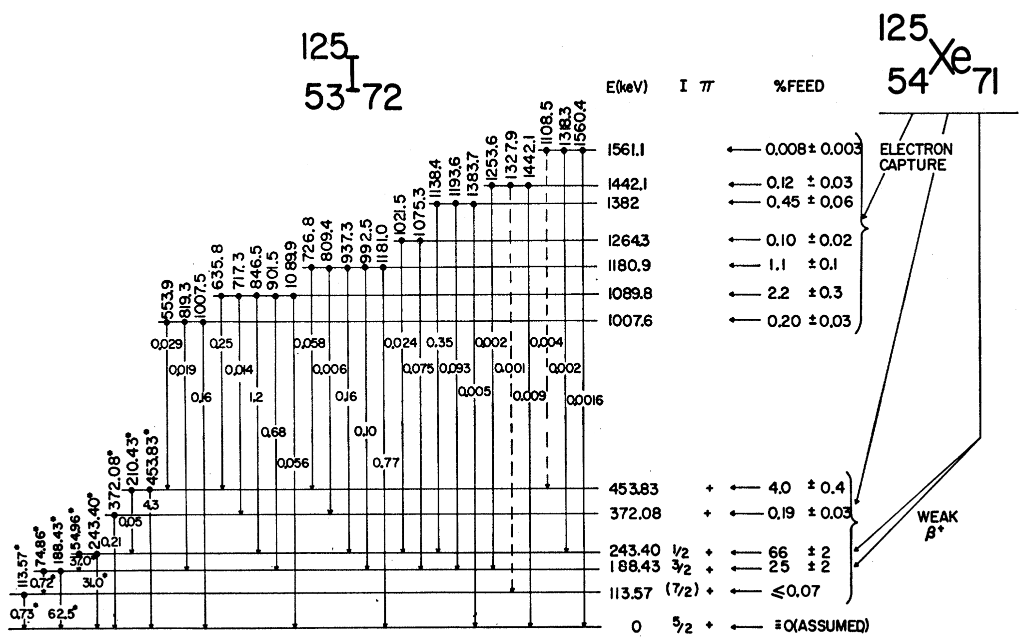

FIG. 9. A ^{125}I level scheme which accounts for all transitions excited in the ^{125}Xe decay. The energies and intensities identified with asterisks are based on the conversion-electron measurements. The conversion-electron and γ-ray intensity scales were normalized using the theoretical α_K value for the 188.43-keV transition. The K-capture feeds have been inferred from the total γ-transition intensities and the intensity scale has been normalized to percentage per ^{125}Xe disintegration assuming no direct decay branch to the ^{125}I ground state. The 1075.3-keV peak in the γ spectra appears to be complex and may include a contribution from a transition between the 1442.1- and 372.08-keV levels.

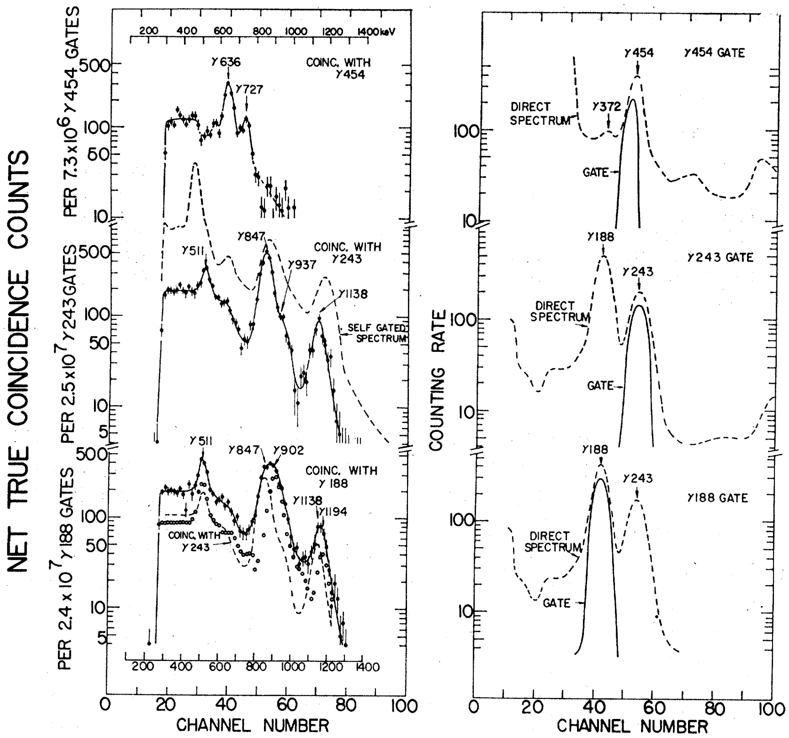

FIG. 10. γ-γ coincidence spectra taken using 3-in.×3-in. NaI(Tl) scintillation detectors. These results provide confirmation for the more intense γ cascades shown in Fig. 9.

with this γ188 gate is given in the upper right. The γ188-γ55 angular correlation was determined from the counts in channel 36 through 43 of the coincident γ-ray spectrum while the γ188–K x-ray correlation was determined from the counts in channels 18 through 25 of the coincident spectrum. Both correlations are given on the right. The least-squares-fitted coefficients of the γ188–K x-ray angular correlation, corrected for the finite counter solid angles, are $A_0=1$, $A_2=+0.012\pm0.007$, and $A_4=0.008\pm0.012$, while those for the γ188-γ55 correlation are $A_0=1$, $A_2=0.235+0.014$, and $A_4=-0.01\pm0.02$.

The γ55-K188, γ-conversion-electron angular correlation was measured using a silicon p-n junction as electron detector. The arrangement is indicated schematically in the inset of Fig. 13. The active area of the silicon p-n junction was a rectangular area ~15 mm ×3 mm. The detector was oriented so that its long dimension was in a plane perpendicular to that in which the correlation was measured. The conversion-electron spectrum as seen in this cooled detector is shown in the lower right of Fig. 13. The K188 gate used for the correlation measurements is shown by the X's. The γ-ray spectrum coincident with this electron gate is given by the solid points of the upper right-hand spectrum. The K188–K x-ray and K188-γ55 correlations were evaluated from the counts in channels 21 through 25 and channels 36 through 43 of the coincident spectra, respectively. The K188–K x-ray correlation shows no anisotropy. The least-squares-fitted coeffi-

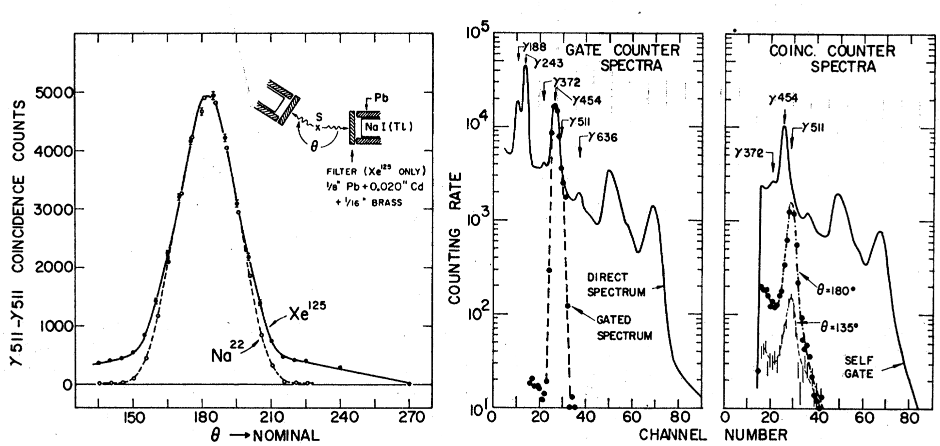

FIG. 11. The angular correlation of the 511-keV γ quanta observed in the ^{125}Xe γ-ray spectrum. These results show that this radiation results from positron annihilation.

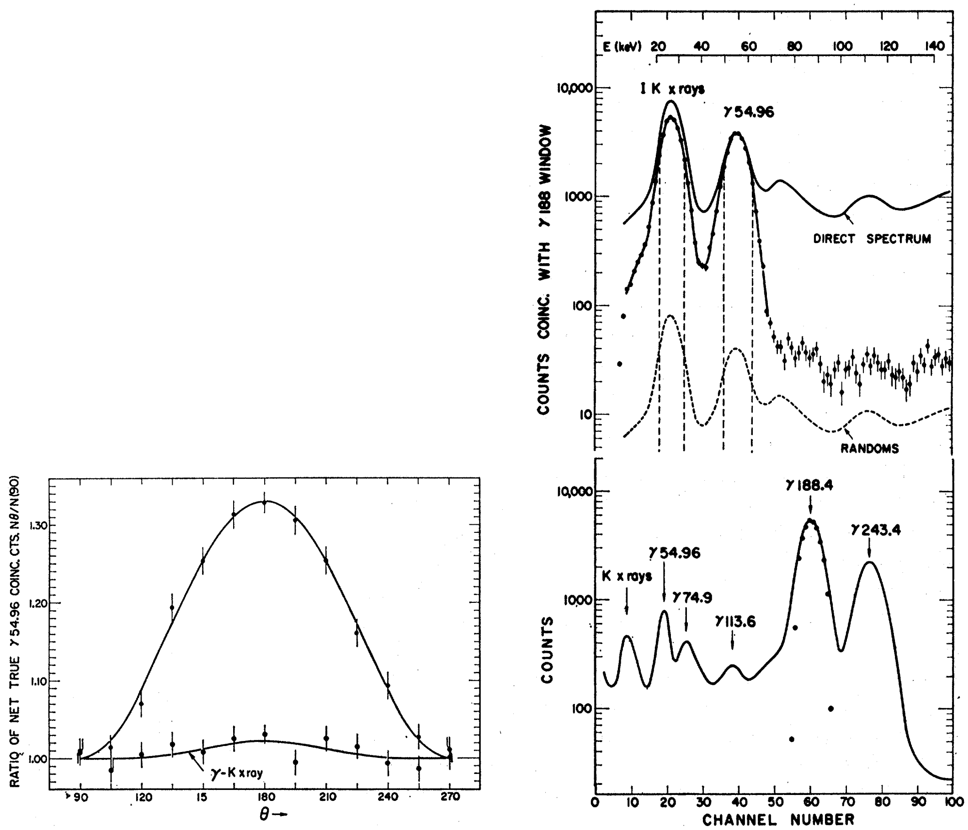

FIG. 12. The angular correlations of γ188.43 with γ54.96 and the iodine K x rays. The least-squares-fitted coefficients for these correlations, corrected for the finite solid angles subtended by the counters are $A_0\equiv1$, $A_2=+0.235\pm0.014$, $A_4=-0.01\pm0.02$, and $A_0\equiv1$, $A_2=+0.012\pm0.007$, $A_4=+0.008\pm0.012$, respectively.

cients for the K188-γ55 correlation, corrected for the finite solid angles subtended by the detectors, are $A_0=1$, $A_2=+0.082\pm0.012$, and $A_4=-0.02\pm0.025$.

V. INTERPRETATION OF ANGULAR-CORRELATION RESULTS FOR THE γ55–γ188 CASCADE

The ground-state spin of ^{125}I is known to be $\frac{5}{2}$.[17] The $E2/M1$ mixing ratios for the 55- and 188-keV γ transitions are known from the L-subshell conversion-line intensity measurements described earlier in this paper. These are $\delta(55)=\pm(0.022\pm0.008)$ and $\delta(188)=\pm(0.357\pm0.009)$. Only the spins of the two excited states in the cascade and the signs of the two mixing ratios remain to be determined. The multipolarities of the cascade γ transitions restrict the number of possible spin sequences to nine. The dominantly dipole character of the transitions in the cascade results in a negligible

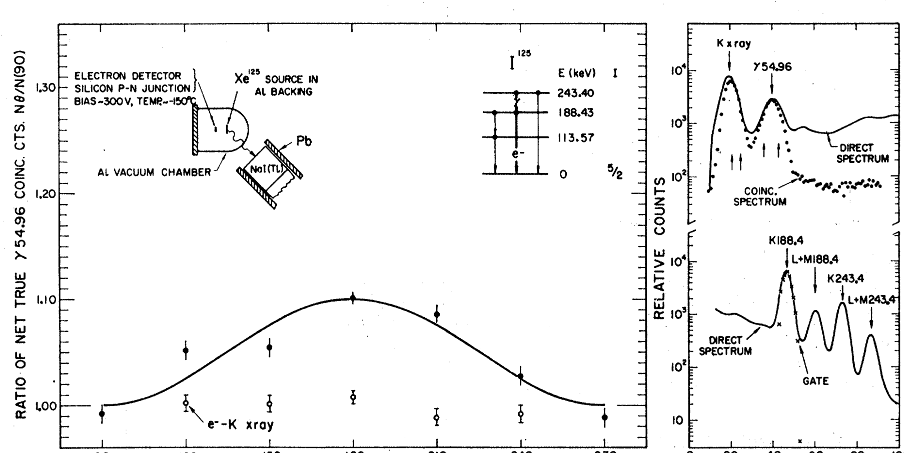

FIG. 13. The K188.43–γ54.96 and K188.43–K x-ray electron-gamma angular correlations. The corrected coefficients for the K188.43–γ54.96 correlation are $A_0\equiv1$, $A_2=+0.082\pm0.012$, and $A_4=-0.02\pm0.025$.

[17] P. C. Fletcher and E. Amble, Phys. Rev. 110, 536 (1958).

A_4 coefficient for all of these cases. Four of the sequences can be excluded since they lead to predicted A_2 coefficients for the γ-γ correlation of less than $+0.12$, i.e., less than one-half the experimental value. The predicted A_2 values which are >0.12 are plotted on the left-hand scale of Fig. 14 and are labelled according to spin sequence. The experimental A_2 value is indicated by the cross-hatched region on the scale. The prediction for the spin sequence $\frac{1}{2}\rightarrow\frac{3}{2}\rightarrow\frac{5}{2}$ is in agreement with the experimental result. The predicted A_2 coefficients for the γ-e correlation were evaluated using the point nucleus particle parameters of Biedenharn and Rose.[18] The values used in the calculations were $b_2(M1)=+0.246$, $b_2(E2)=+1.884$, and $b_2(M1,E2)=+0.204$. The sign attached to the latter parameter is the corrected one.[2,19,20] The ratio $A_2(\gamma,\gamma)/A_2(\gamma,e)$, plotted on the right-hand scale of Fig. 14, depends only on properties of the 188-keV transition and of the lower two levels of the cascade. Furthermore, this ratio is independent of any attenuation of the correlations which may result from nuclear precession occurring within the lifetime of the intermediate state. As seen from the figure, the $A_2(\gamma,\gamma)/A_2(\gamma,e)$ comparisons restrict the intermediate level spin to $\frac{7}{2}$ or $\frac{3}{2}$. A $\frac{7}{2}$ spin value results in predicted γ-γ and γ-e correlations significantly smaller than those observed experimentally. The intermediate state spin is therefore $\frac{3}{2}$. Of the cascades having intermediate and ground-state spins $\frac{3}{2}$ and $\frac{5}{2}$, respectively, only those for the $\frac{1}{2}\rightarrow\frac{3}{2}\rightarrow\frac{5}{2}$ sequence have $A_2(\gamma,\gamma)$ coefficients >0.12. The theoretical value of $A_2(\gamma,e)$ for the $\frac{1}{2}\rightarrow\frac{3}{2}\rightarrow\frac{5}{2}$ sequence, evaluated using the phases required to fit $A_2(\gamma,\gamma)$, is in agreement with the experimental result. Hence the spins of the 188- and 243-keV levels are uniquely determined by the measurements. If

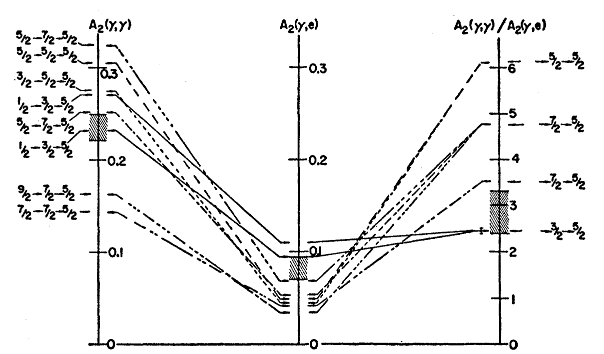

FIG. 14. Comparison of the least-squares-fitted A_2 coefficients of the γ54.96–γ188.43 and γ54.96–e_K188.43 angular correlations with theoretical predictions. The latter have been evaluated using the $E2/M1$ mixing ratios established by the internal-conversion-electron work. The ratio $A_2(\gamma,\gamma)/A_2(\gamma,e)$ depends on properties of the 188.43-keV transition only. The comparisons presented here show the spin sequence to be $\frac{1}{2}\rightarrow\frac{3}{2}\rightarrow\frac{5}{2}$.

[18] L. C. Biedenharn and M. E. Rose, Rev. Mod. Phys. **25**, 729 (1953).
[19] E. L. Church, A. Schwarzschild, and J. Weneser, Phys. Rev. **133**, B35 (1964).
[20] L. C. Biedenharn and M. E. Rose, Phys. Rev. **134**, B8 (1964).

TABLE IV. Conversion line and transition intensities in ^{127}I.

Transition energy (keV)	Relative L line intensities L_I	L_{II}	L_{III}	Multipolarity	α_K (Sliv)	I_K	$I\Sigma_L$	$I\Sigma_M$	$I\Sigma_{(N+O)}$	I_γ[a]	I_{tot}
57.60±0.02	≡1	0.118±0.004	0.068±0.004	$M1+(0.7\pm0.1)\%E2$	3.13	0.632±0.025	0.093±0.003	0.020±0.002	0.0037±0.0014	0.202	0.950
145.22±0.03	≡1	0.76±0.10	0.87±0.11	$E2$, $<25\%M1$	0.360	0.226±0.004	0.063±0.004	0.0129±0.0013	0.0030±0.0007	0.628	0.933
172.10±0.03	≡1	0.066±0.003	0.016±0.004	$M1$, $<1\%E2$	0.142	0.554±0.010	0.073±0.003	0.0152±0.0010	0.0038±0.0005	3.901	4.55
202.84±0.03	≡1	0.160±0.015	0.121±0.013	$M1+(21\pm3)\%E2$	0.0965	≡1.000	0.154±0.003	0.028±0.002	0.012±0.001	10.36	11.6
374.96±0.05	≡1	0.26±0.05	0.17±0.05	$E2$, $<30\%M1$	0.0168	0.0457±0.0010	0.0085±0.0006			2.72	2.77

[a] Deduced from the experimental K conversion line intensities using α_K values of Sliv (Ref. 11).

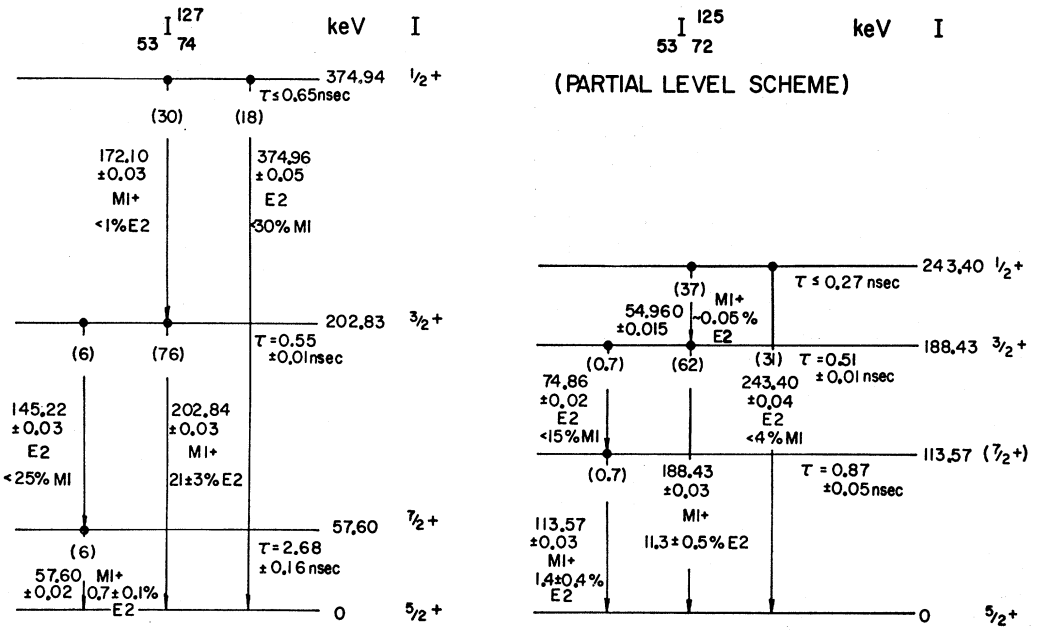

FIG. 15. The level structure of ^{127}I populated by the decay of ^{127}Xe is shown on the left. The corresponding level structure of ^{125}I populated by the decay of ^{125}Xe is given on the right. The total transition intensities in percent per disintegration are given by the bracketed numbers and assume no direct β^+ or K-capture decay component to the respective ground states. The complete ^{125}Xe decay scheme is given in Fig. 9. The intensity values given in Ref. 5 are slightly higher than those given here. They included no allowance for feeding to the higher-lying ^{125}I levels.

attenuations of the correlations arising from nuclear precession in the intermediate state are present in the measurements, their effect is only to alter the phases inferred for the mixing ratios. On the assumption that the observed correlations do not suffer from attenuation and in the theoretical formulation of Biedenharn and Rose,[18] the signs of the mixing ratios inferred from the analysis are both positive.

VI. ^{127}Xe STUDIES

The internal-conversion-electron spectrum from the ^{127}Xe decay has been studied and analyzed using the techniques described in Sec. II. The L conversion lines of the 57.60-keV transition in ^{127}I are shown in Fig. 5 of Ref. 4. The L lines of the 202.83-keV transition are shown in Fig. 1 of Ref. 2. The results of the conversion line studies are summarized in Table IV. The relative L-subshell line intensities and the deduced multipolarities are given in columns 2 and 3 of Table IV. The theoretical K conversion coefficient of Sliv appropriate to the respective transition energies and multipolarities are given in column 4. In deducing these, the multipolarities of the 145.22-, 172.10-, and 374.96-keV transitions are assumed to be pure $E2$, $M1$, and $E2$, respectively. The relative K and L line intensities are based on two, and in some cases, three measurements. The errors have been assigned on the basis of the statistical counting uncertainties and the scatter of the two or more measurements. The quantum intensities given in column 9 were obtained from the K conversion line intensities using the theoretical K shell conversion coefficients given in column 4. The estimated uncertainties in the total transition intensities listed in column 10 make no allowance for uncertainty in these coefficients.

The γ-γ, γ-e, and e-γ correlation studies on the ^{127}Xe decay and the time-correlation measurements on this decay have been described in earlier publications.[2,4,5]

VII. DISCUSSION

The ^{125}I level structure populated by the decay of ^{125}Xe is shown in Figs. 9 and 15. The latter figure summarizes the detailed properties of the low-lying states and the γ transitions which de-excite them. Moore and his collaborators have carried out studies of the ^{125}Xe decay concurrently with those reported here. Five of the seven transitions shown in Fig. 15 were seen by Moore with a permanent magnet spectrograph.[21] While his results agree with those presented here with regard to the multipole character of the transitions, his energy values are systematically lower than those obtained in this investigation. Horowitz, Moore, and Barton[22] have recently reported mean lives for the 188.43- and 243.40-keV states of $\tau_{188.43}=0.49\pm0.03$ nsec and $\tau_{243.40}=0.30$

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[21] R. B. Moore, Bull. Am. Phys. Soc. **5**, 338 (1960).

[22] Y. S. Horowitz and R. B. Moore, in Proceedings of the Conference on the Bases for Nuclear Spin-Parity Assignments, Gatlinburg, Tennessee, 1965 (unpublished); Can. J. Phys. **45** 101 (1967).

±0.03 nsec. These results are consistent with our values[5] which are given in Fig. 15.

The spins of $\frac{3}{2}$ and $\frac{1}{2}$ for the 188.43- and 243.40-keV states are uniquely determined by the measurements presented in this paper. The multipole order of the γ transitions, shell-model considerations, and level systematics in this mass region all support a $\frac{7}{2}$ spin assignment for the 113.57-keV level. The parity of these three states is the same as that of the ground state, i.e., positive.

The currently available information on the higher-lying levels of ^{125}I is summarized in Fig. 9. The transition-energy and intensity values labeled with asterisks result from the internal-conversion-electron work. The internal-conversion coefficients of the 372.08-, 210.43-, and 453.83-keV transitions summarized in Table III indicate $M1+E2$ character for these transitions and consequently positive parity for the 372.08- and 453.83-keV levels. No firm conclusion regarding spins and parities of the higher lying levels can be drawn from the present study. The K-capture feeds and logft values given in Fig. 9 have been deduced from the total transition intensities assuming no direct component to the ^{125}I ground state. The agreement between the transition-energy values reported in this paper and the recent results of Lessard and Moore[14] is, in general, excellent. While there is qualitative agreement between the groups as to the relative intensities of the γ rays, a quantitative comparison of results has not been possible to date. The respective studies lead to the same ^{125}I level structure.

The ^{127}I level structure populated by the decay of ^{127}Xe is shown on the left side of Fig. 15. The spins of $\frac{3}{2}$ and $\frac{1}{2}$ for the 202.83- and 374.94-keV states are uniquely determined by angular-correlation measurements.[2] Additional correlation measurements by Leisi determine the spin of the 57-keV level to be $\frac{7}{2}$.[23] Leisi gives a detailed discussion of the interpretation of our measurements in terms of theory, with particular emphasis on the fact that the conclusions drawn from these correlations concerning the sign of the particle parameter for the interference term and concerning the level spins are unaffected by any attenuation which may be present in the observed correlations because of nuclear precession in the intermediate state.

The mean life given in Fig. 15 for the 57-keV level in ^{127}I was measured in this laboratory[4] and is supported by the work of Thieberger[24] and of Tandon and Devare.[25] Jha and Leonard[26] have reported a somewhat smaller value (1.8±0.3 nsec). The mean life of the 202.83-keV level shown here is in excellent agreement with a resonance fluorescence measurement by Langhoff and collaborators.[27]

The detailed information now available on transition properties between the low-lying states in ^{125}I and ^{127}I has permitted detailed comparisons of experimental transition rates with those predicted on the Kisslinger-Sorensen model. Such comparisons are presented and discussed in Refs. 4, 5, and 28.

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[23] H. J. Leisi, Nucl. Phys. **76**, 308 (1966).

[24] P. Thieberger, Arkiv Fysik **22**, 127 (1962).

[25] H. G. Devare (private communication).

[26] S. Jha and R. Leonard, Phys. Rev. **136**, B1585 (1964).

[27] L. Frevert, W. Schott, H. Langhoff, and A. Flammersfeld, Z. Physik, **194** 248 (1966).

[28] H. Langhoff, Nucl. Phys. **63**, 425 (1965).