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Decay of ^{129}Cs and ^{131}I to the Levels in ^{129}Xe and ^{131}Xe†

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The decay schemes of ^{129}Cs and ^{131}I have been investigated using Ge(Li) and Si(Li) semiconductor detectors as well as various coincidence techniques. Gamma-ray energies and relative gamma-ray intensities were determined as well as conversion coefficients for many transitions. In ^{129}Xe, levels at 322.0 and 904.9 keV were proposed, which have not been reported earlier. The spin and parity assignments for the 322.0-keV level are probably $\frac{5}{2}+$. In ^{131}Xe, a level at 404.8 keV has been found which was not previously known. The spin and parity assignments for this level are $\frac{1}{2}+$ or $\frac{3}{2}+$. Beta-gamma coincidence measurements were used to indicate that the 503-keV γ ray in ^{131}I decay feeds the 11/2− isomer of ^{131}Xe. Decay schemes for both ^{129}Cs and ^{131}I consistent with our observations have been constructed. The levels of ^{129}Xe and ^{131}Xe are compared with each other and with current theoretical calculations.

I. INTRODUCTION

The low-lying levels of ^{129}Xe and ^{131}Xe have been recently investigated by a number of investigators by studying the radiations associated with the decay of 32-h ^{129}Cs[1,2] and 8.06-day ^{131}I.[3–6] A composite of the energy levels determined by these investigations is shown in Fig. 1. Although the structures of the two nuclei should be similar, the wide difference in the spins of the radioactive parents (^{129}Cs, $J\pi=\frac{1}{2}+$; ^{131}I, $J\pi=\frac{7}{2}+$) coupled with the β-decay selection rules have made it difficult to observe analogous levels in the two nuclei. Although the pairing-model calculations of Kisslinger and Sorensen[7] account well for a number of observed levels in nearby odd-Z nuclei, the limited number of spins observed in any one nucleus made comparison with the calculations difficult for the odd-mass Xe nuclei.

We have re-investigated the decay of ^{129}Cs and ^{131}I using high-resolution semiconductor detectors and coincidence techniques in the hope of observing additional levels in ^{129}Xe and ^{131}Xe, some of which may not be populated directly in β decay. We have also sought to check the presence of the low-lying negative-parity levels indicated in ^{131}Xe.[3,5] Odd-parity levels have been also observed in ^{125}Te,[8] ^{129}Te,[9] but not in ^{133}Xe.[10] A theoretical characterization has recently been suggested by Kisslinger to account for the presence of these negative-parity states.[11]

II. EXPERIMENTAL PROCEDURE

A. Procurement and Preparation of the Sources

Radioactive cesium was produced by irradiating LiI powder with 30-MeV ^{4}He ions in the MIT cyclotron. To be sure that the radiations observed were from ^{129}Cs, two different chemical procedures were used to isolate cesium from the LiI target. In the first, the target was dissolved in water and Cs_2PtCl_6 precipitated by the addition of a 10% solution of H_2PtCl_6. The mixture was filtered and the precipitate washed and mounted for counting. The counting was delayed until 5 h after the irradiation to allow ^{130}Cs ($t_{1/2}=30$ min) that was also produced in the irradiation to decay away.

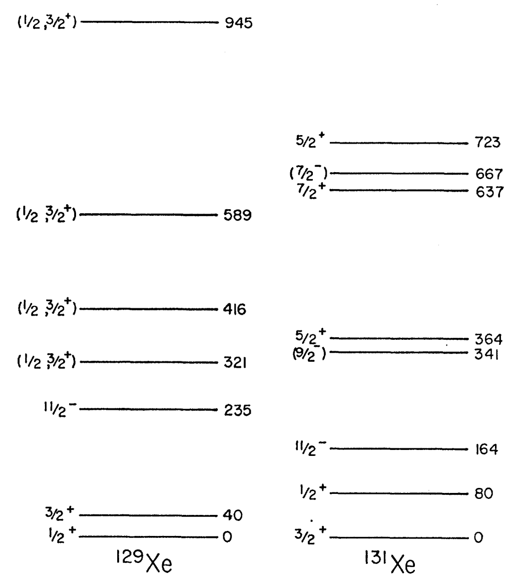

FIG. 1. The level schemes for ^{129}Xe and ^{131}Xe obtained from previous works (Refs. 1 and 3–6).

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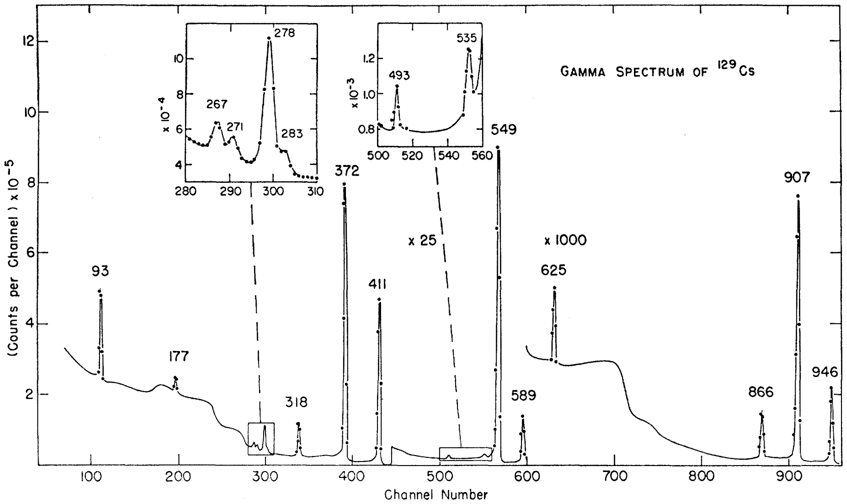

FIG. 2. Spectrum of γ rays from ^{129}Cs observed with Ge(Li) detector. For clarity, the regions around 270 and 500 keV are expanded in the insets. Numbers above the peaks correspond to γ-ray energies in keV.

In the other chemical procedure, the target material was dissolved in a weak HNO_3 solution which was passed through an ammonium molybdophosphate (AMP) ion-exchange column.[12] Only cesium remained on the column after an elution with a solution which was 1*N* in both HNO_3 and NH_4NO_3. For most of the measurements, the column itself was used for counting. Carrier-free thin sources suitable for electron or low-energy photon counting were prepared by eluting the cesium from the column with a saturated NH_4NO_3 solution. The ammonium salt was then destroyed by aqua regia and the solution evaporated on a glass backing for counting.

The γ rays reported for ^{131}I were observed from sources obtained from two commercial suppliers,[13] and were in the same intensity ratios from both sources before and after chemical purifications. In order to purify the ^{131}I, the carrier-free commercial solution was made basic prior to adding KI and KBr carriers. The iodine was then oxidized to iodate by the addition of NaOCl solution. The mixture was acidified with HNO_3 and the iodate reduced to I_2 by the addition of more KI. The solution was neutralized with NaOH and the *p*H adjusted to a value of 4.0 with acetic acid. Elemental I_2 was extracted into CCl_4 and washed with hydroxylamine sulfate. The iodine was then back extracted into a solution of sodium bisulfite as I^- ion. Silver nitrate was added in order to precipitate AgI, which was then used for counting. Thin sources were prepared by slowly evaporating the carrier-free solution on a glass backing.

B. Equipment and Spectroscopic Methods

Gamma-ray singles spectra were obtained using a Ge(Li) detector that had a surface area of 1.5 cm^2 and a sensitive thickness of 0.8 cm. The pulses were amplified using a commercial preamplifier and amplifier[14] and stored in a 4096-channel analyzer. The full width at half maximum (FWHM) for the 662-keV γ ray associated with the decay of ^{137}Cs was 2.3 keV. The mounting and cooling of the detector have been described earlier.[15]

Electrons were counted using a Si(Li) detector whose area was 0.5 cm^2 and sensitive thickness 0.5 mm. Counting was done in a chamber similar to the one used to mount the Ge(Li) detector. The sources were mounted inside the chamber which was then evacuated and the detector cooled to dry-ice temperature prior to the start of counting. For 350-keV conversion electrons, the FWHM was 6 keV.

The spectra of γ rays in coincidence with specific γ rays were accumulated in the memory of the 4096-channel analyzer using a 7.6- ×7.6-cm NaI(Tl) detector and an eight-channel digital gating unit in conjunction with the Ge(Li) detector. It was possible to accumulate, simultaneously, eight 512-channel Ge(Li) spectra in coincidence with eight digitally-selected areas of the NaI(Tl) spectrum. The γ-γ coincidence measurements were usually taken at an angle of approximately 120° with lead shielding between the detectors. In some instances, however, to achieve better statistics, the two detectors were nearly in contact with the source and the detectors were not shielded from each other. In the latter case, seen in Fig. 9(d), large Compton scattering peaks may occur. Electron-gamma coincidence measurements were made by replacing the NaI(Tl) detector in the above system with a Si(Li) detector. Coincidence resolving times (2τ) of 60 to 100 nsec were used except when very low- and high-energy events were involved, during which times resolving times as high as 300 nsec were used.

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[12] J. von R. Smit, W. Ross, and J. J. Jacobs, J. Inorg. Nucl. Chem. **12**, 107 (1959).

[13] Isotopes Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee and New England Nuclear Corporation, Boston, Massachusetts.

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TABLE I. Transitions obtained in the decay of ^{129}Cs.

Energy (keV)	Relative γ-ray intensity	Measured α_K	$\alpha_K/(\alpha_L+\alpha_M)$
39.4 ± 0.3	9.2 ± 0.5	10.7 ± 1.1	
93.5 ± 0.3	2.40 ± 0.15	0.72 ± 0.07	5.3 ± 0.5
177.2 ± 0.5	0.94 ± 0.06	0.14 ± 0.2	3.0 ± 0.6
266.6 ± 0.5	0.90 ± 0.08	$(4.5\pm1)\times10^{-2c}$	
270.5 ± 0.5	0.56 ± 0.05		
278.0 ± 0.5	4.4 ± 0.3	$(4.1\pm0.6)\times10^{-2c}$	
282.6 ± 0.5	0.81 ± 0.07		
317.9 ± 0.6	7.8 ± 0.4	$(2.94\pm0.3)\times10^{-2}$	
322.0 ± 0.8	0.15 ± 0.06[a]		
371.9 ± 0.5	100	$(1.89\pm0.2)\times10^{-2}$	4.6 ± 0.7
411.3 ± 0.6	69 ± 2	$(1.51\pm0.15)\times10^{-2}$	5.5 ± 0.6
492.8 ± 0.7	0.04 ± 0.006		
534.8 ± 0.6	0.10 ± 0.01		
549.3 ± 0.4	10.3 ± 0.04	$(5.8\pm0.6)\times10^{-3}$	5.8 ± 1.0
588.8 ± 0.5	1.75 ± 0.1		
624.5 ± 0.8	0.09 ± 0.01		
865.5 ± 0.8	0.11 ± 0.01		
907.0 ± 0.7	0.72 ± 0.05		
946.3 ± 0.8	0.21 ± 0.02		
x ray	360 ± 25[b]		

[a] Obtained from coincidence measurements.
[b] Fluorescence yield correction already included.
[b] Fluorescence yield correction already included.

The γ-ray energies reported were measured by counting the ^{129}Cs or ^{131}I source simultaneoulsy with a number of sources whose γ-ray energies are well known. The centroids were determined for each peak and for the peaks of interest energies were calculated by linear interpolation between nearby standard peaks. The relative γ-ray intensities were obtained by correcting the photopeak areas for the efficiency using a curve determined experimentally for this detector in a manner described earlier.[15,16]

The reported electron-conversion coefficients were obtained by counting with both the Si(Li) and the Ge(Li) detectors a source that contained ^{203}Hg as well as ^{129}Cs. Using the known conversion coefficient of ^{203}Hg,[17] it was possible to calculate the conversion coefficients reported for the ^{129}Cs transitions, excepting that of the 39.4-keV transition.

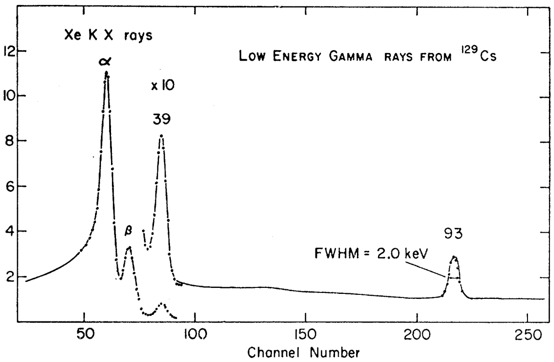

FIG. 3. Low-energy gamma-ray spectrum from a thin ^{129}Cs source obtained with the Ge(Li) detector. Numbers above the peaks correspond to γ-ray energies in keV.

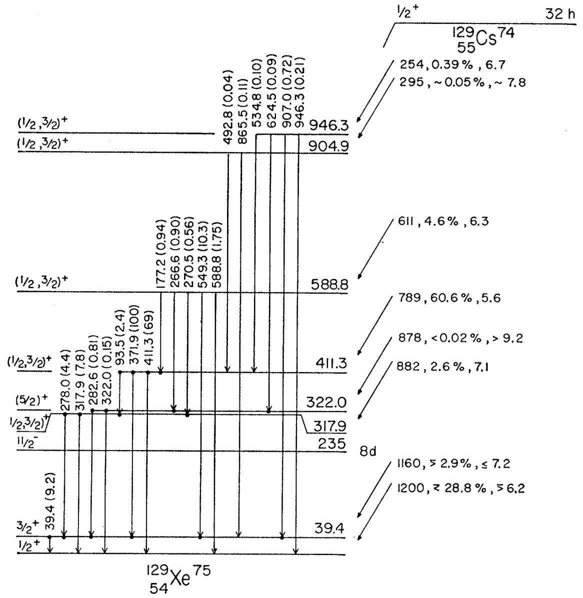

FIG. 4. Decay scheme of ^{129}Cs. Conventions used are those of Ref. 17, except that all energies are given in keV.

III. RESULTS

A. ^{129}Cs

A γ-ray spectrum of ^{129}Cs is shown in Fig. 2 and the intensities, conversion coefficients, and $K/(L+M)$ ratios that we have determined are tabulated in Table I for the observed transitions. The seven γ rays whose energies are 266.6, 282.6, 322.0, 492.8, 534.8, 624.5, and 865.5 keV were not reported by Shera and Burson,[1] though γ rays with energies of ~623 and ~864 keV (and several others that we do not see) have been reported.[2] Two different chemical procedures were used as well as the half-life determinations to ensure that the weak γ rays reported were from the decay of ^{129}Cs. The intensities of the x rays and the 39.4-keV γ ray were determined from spectra similar to the one shown in Fig. 3 for which a thin source was used. The x-ray intensity was measured relative to K x rays from the 662-keV transition following the decay of ^{137}Cs. By measuring both the x rays and 662-keV γ rays and using the known 662-keV conversion coefficient,[17] it was possible to account accurately for fluorescence yield, detector efficiency, and x-ray and γ-ray absorption in the detector housing.

Our proposed decay scheme is shown in Fig. 4, including levels at 322.0 and 904.9 keV that have not been previously reported. Because the majority of our coincidence spectra only served to confirm the decay scheme of Shera and Burson,[1] we show in Fig. 5 only those coincidence spectra related to the placement of new level at 322 keV.

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[16] W. B. Walters, C. E. Bemis, Jr., and G. E. Gordon, Phys. Rev. **140**, B268 (1965).

[17] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C., 1964).

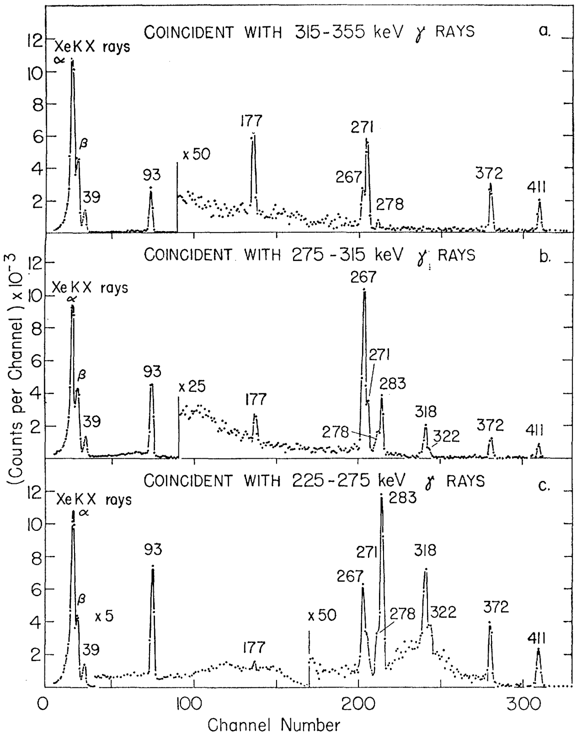

FIG. 5. Gamma-ray spectra of ^{129}Cs observed with Ge(Li) in coincidence with three different regions of the spectrum obtained with NaI(Tl). Numbers above the peaks correspond to γ-ray energies in keV. No corrections for random events have been made.

The presence in the singles spectrum of two new γ rays, whose energies are 266.6 and 282.6 keV and whose sum of 549.2 keV is equal (within the limits of our errors) to the energy of a well-known 549.3-keV γ ray suggests a new level at either 306 or 322 keV. That such is the case is clearly indicated by the coincidence spectrum shown in Fig. 5(c), where the 283-keV γ ray is seen in coincidence with the gate region that includes the 267-keV photopeak. The presence of a γ ray at 322 keV in that coincidence spectrum serves to indicate that the new level is at 322 keV and is fed from the 588.8-keV level by the 267-keV γ ray. This is confirmed in Fig. 5(a), where the 267-keV γ ray is seen in coincidence with the gate region that includes the 322-keV photopeak. A weak γ peak at 282 keV was also seen in coincidence with the gate region that includes the 624.5-keV γ ray. Because the difference between the levels at 946.3 and 322.0 keV is close to 624.5, we have shown the 624.5-keV γ ray feeding the level at 322.0 keV. Within the limits of our errors, the sum of the intensities of the γ rays feeding the level at 322 keV is equal to the sum of the intensities of the γ rays leading away from that level.

Because the energy of the 534.8-keV γ ray corresponds closely to the energy difference between the levels at 946.3 and 411.3 keV, we have shown the 534.8-keV γ ray as feeding the 411.3-keV level.

The remaining low-intensity γ rays at 492.8 and 865.5 keV were not observed in any coincidence spectrum with photons >50 keV.

In view of the total estimated electron-capture decay energy of 1.2 MeV,[17] the 865.5-keV γ ray is restricted to feeding into one of the five levels below 335 keV. Because feeding to either of the levels at 322 and 318 keV would require a new level near 1180 keV whose log*ft* would be about 3, those placements are unlikely.

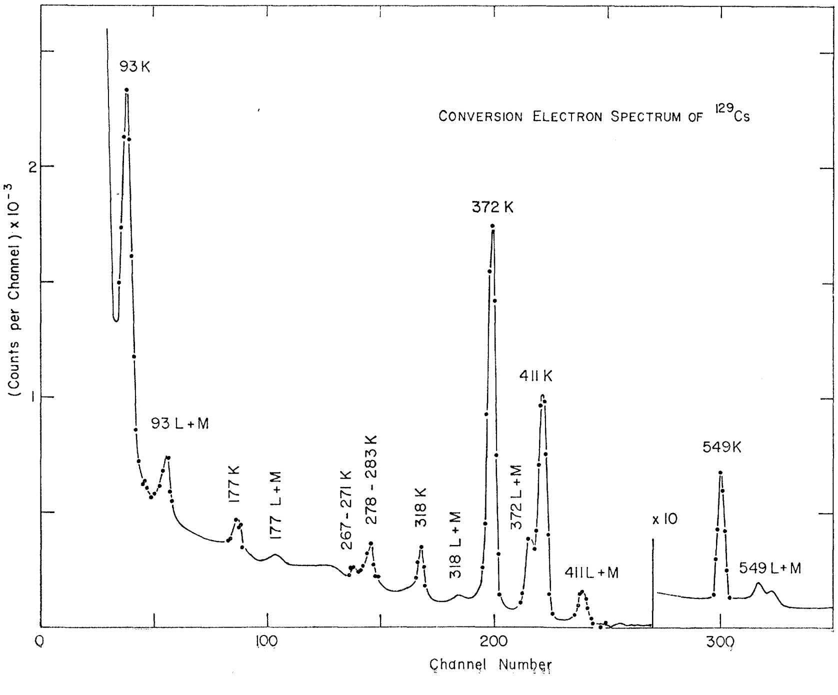

FIG. 6. Electron spectrum of ^{129}Cs observed with the 50-mm^2 area, 0.5-mm thick Si(Li) detector. Numbers above the peaks correspond to the transition energies in keV.

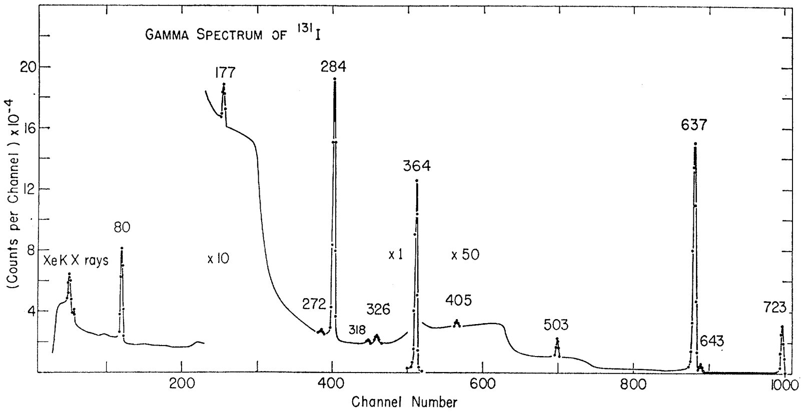

FIG. 7. Spectrum of γ rays from ^{131}I observed with the Ge(Li) detector. Numbers above the peaks correspond to γ-ray energies in keV.

Equally unlikely would be the decay to the 11/2− level as 5 units of angular momentum would have to be transferred in only two steps. Thus the only realistic possibilities are that it must decay either to the ground state or to the 39.4-keV state. The latter possibility is more attractive since it indicates the existence of a new level at 904.9 keV, which could also give rise to the 492.8-keV γ ray in a decay branch to the level at 411.3 keV. A single additional level can thus accomodate these two weak γ rays.

A singles conversion-electron spectrum is shown in Fig. 6, and the conversion coefficients obtained from such measurements are tabulated in Table I. The values indicated for the 371.9- and 411.3-keV γ rays are in good agreement with the results of Jha, Friedman, and Patniak.[18] The absolute values were obtained by counting a source which contained ^{203}Hg as well as ^{129}Cs. Where coefficients could be obtained, multipolarities of $M1$, $M1+E2$, or $E2$ were indicated.

The K-shell conversion coefficient for the 39.4-keV transition was obtained by measuring the ratio of x-ray intensity to 39.4-keV γ-ray intensity in coincidence with a 310- to 490-keV gate region. The value of 10.7±1.1 was obtained by correcting the coincidence ratio for the x rays produced in the electron-capture process which populates the ^{129}Xe levels and for fluorescence yield. The former correction was made assuming allowed transitions to those levels associated with γ rays in the 310- to 490-keV region.[19]

The logft values shown in Table II were obtained by utilizing the conversion coefficients, the K x-ray intensities, and the γ-ray intensities. From γ-ray intensities and conversion coefficients it is possible to determine the relative populations of the upper six levels. From these data it is possible to determine the number of K x rays associated with the β decay to the upper 6 levels. The remaining K x rays are associated with K capture to the lower two levels and K conversion of the 39.4-keV transition. Using the measured α_K for the 39.4-keV transition, we can determine only the number of K conversions of the 39.4 transition. However, without the knowledge of total conversion coefficient α_T, we cannot precisely determine whether the observed K x rays arise from K capture to the two lowest levels or from conversion process in 39.4-keV transition. If we know the multipolarity for 39.4-keV transition then we can determine the fraction of K x rays associated with direct β decay to the ground state.

If we use the measured α_K to determine the $M1+E2$ mixing, the value which follows is $\sim$30 for α_T.[20,21] With that value, no feeding to the ground state is indicated. On the other hand, if we assume no feeding to the 39.4-keV level and calculate the total intensity of the transitions into the 39.4-keV level and compare that to γ-ray intensity out of this level we get for α_T a value of 11.9±0.7 for the 39.4-keV transition, which already is higher than the extrapolated α_T value of 11.1 for a pure $M1$ transition.[20,21] This also suggests mixing of $M1+E2$ for 39.4-keV transition. Our limits for the two lowest levels have been calculated using the measured value for α_K and extrapolated $\alpha_K/(\alpha_L+\alpha_M)$ ratio for a pure $M1$ transition.[20,21] It should be noted

TABLE II. Levels obtained in the decay of ^{129}Cs.

Energy (keV)	Electron-capture energy (keV)	Percent of disintegrations	log ft
0	1200[a]	$\geqq$28.8	$\geqq$6.2
39.4	1160	$\leqq$ 2.9	$\leqq$7.2
317.9	882	2.6	7.1
332.0	878	< 0.02	>9.2
411.3	789	60.6	5.6
588.8	611	4.6	6.3
904.9	295	0.05	$\sim$7.8
946.3	254	0.39	6.7

[a] Energy value taken from Ref. 17.

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[18] S. Jha, M. Friedman, and B. Patniak, in *Internal Conversion Processes*, edited by J. H. Hamilton (Academic Press Inc., New York, 1965), p. 329.

[19] A. H. Wapstra, G. J. Njgh, and R. Van Lieshout, *Nuclear Spectroscopy Tables* (North-Holland Publishing Company, Amsterdam, 1959).

[20] L. A. Sliv and I. M. Band, in *Alpha-, Beta-, and Gamma-ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1965), Vol. 2, App. 5.

[21] M. E. Rose, in *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

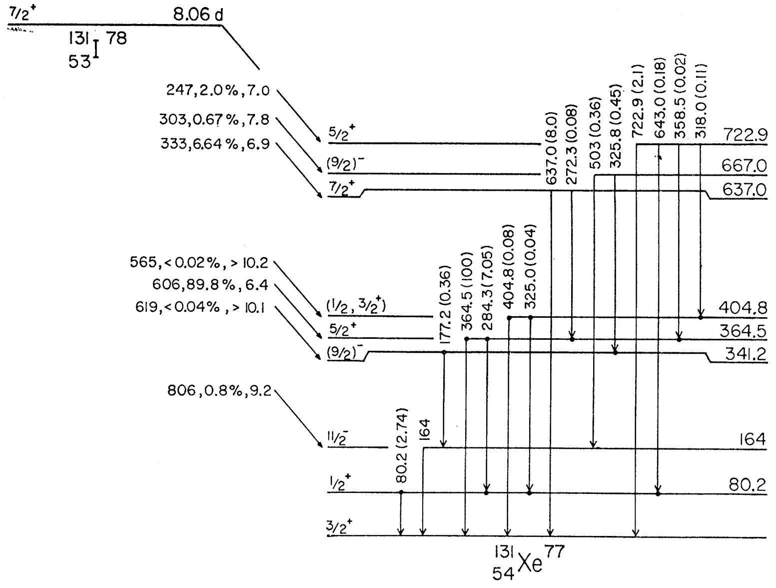

FIG. 8. Decay scheme of ^{131}I. Conventions used are those of Ref. 17, except that all energies are in keV.

that the total fraction of the electron capture to these levels, 31.7%, is not heavily dependent on these assumptions.

B. ^{131}I Decay

A γ-ray singles spectrum of 8-day ^{131}I is shown in Fig. 7. For the γ rays observed, the energies, relative intensities, and some conversion data, calculated using our data and that of Wolfson, Park, and Yaffe,[4] are tabulated in Table III. The proposed decay scheme for ^{131}I that is shown in Fig. 8, includes γ rays at 272.3, 318.0, 325.0, 358.5, and 404.8 keV which have not been previously reported. The γ ray at 643.0 keV, which was suggested by Jungclaussen *et al.*,[3] was observed in the singles spectrum. The observed γ rays and their intensities were the same for sources obtained from both suppliers both before and after chemical purification.

Coincidence spectra which relate to the placement of the new γ rays are shown in Fig. 9. The new γ rays at 272.3 and 358.5 keV are seen in Fig. 9(b) to be in strong coincidence with the gate area that includes the 364.5-keV γ ray. Their energies are the differences between the levels at 637.0 and 364.5 keV and between the levels at 722.9 and 364.5 keV, respectively. Thus both the energies and the coincidence relationships support the proposal that these γ rays directly feed the 364-keV level.

The remaining spectra in Fig. 9 support the proposed level at 404.8 keV which is fed from the 722.9-keV level by the 318.0-keV γ ray and decays by 325.0- and 404.8-keV γ rays to the 80.2-keV level and ground, respectively. A 318.0–404.8-keV cascade is clearly indicated in Fig. 9(a) where the gate area includes the 404.8-keV photopeak. The 404.8-keV γ ray is seen

TABLE III. Transitions obtained in the decay of ^{131}I.

Energy (keV)	Relative γ-ray intensity	K-line intensity by Wolfson *et al.* (Ref. 4)	Calculated α_K[a]	Intensity ratios by Wolfson *et al.* (Ref. 4) K/L	L_I/L_{II}	L_I/L_{III}
80.164±0.009[b]	2.72 ±0.15	2.0 ±0.22	1.33 ±0.16			
163.98 ±0.02[b]				1.83±0.09	6.1±0.7	1.2±0.1
177.23 ±0.03[b]	0.36 ±0.02	0.031±0.002	0.155±0.016	5.1 ±0.5	1.8±0.7	2.7±1.3
272.3 ±0.5	0.08 ±0.01					
284.307±0.049[b]	7.05 ±0.40	0.160 ±0.008	0.041 ±0.004	5.5 ±0.5	2.9±0.4	3.4±0.5
318.0 ±0.4	0.11 ±0.015					
325.0 ±0.4	0.04 ±0.01					
325.78 ±0.05[b]	0.45 0.03[c]	0.0059±0.0005	0.0236±0.0028	6.2 ±1.3		
358.5 ±0.5	0.02 ±0.004[c]					
364.467±0.050[b]	100	1.000	0.018±0.001	6.3 ±0.6	4.5±0.8	5.0±0
404.8 ±0.5	0.080±0.007					
502.99 ±0.08[b]	0.36 ±0.02	0.0017±0.0002	0.0085±0.0013	>5		
636.99 ±0.09[b]	8.0 ±0.4	0.019±0.0013	0.0043±0.0004			
643.0 ±0.4	0.18 ±0.015					
722.89 ±0.10[b]	2.10 ±0.15	0.0043±0.0005	0.0037±0.00035			

[a] Based on $\alpha_K = 0.018 \pm 0.001$ for 364-keV transition (Ref. 17) and γ-ray intensities obtained in this work (column 2).
[b] The energy value taken from the work of Wolfson *et al.* (Ref. 4).
[c] Obtained from coincidence measurements.

clearly in Fig. 9(c) where the gate area includes the 318.0- and 325.0-keV γ rays. Furthermore, since the two γ rays are in coincidence with each other, both appear with nearly equal intensities in the same spectrum. In Fig. 9(e), both are also seen in coincidence with the 80.2-keV γ ray but the 404.8-keV γ ray is absent. Within the limits of our errors, the intensity of the 318.0-keV γ ray feeding into the 404.8-keV level is equal to the sum of the intensities of the two γ rays decaying from the 404.8-keV level.

The 177.2-, 325.8-, and 503.0-keV γ rays have received considerable attention in recent attempts to carefully characterize these transitions and determine their positions in the ^{131}I decay scheme. The precise energy measurements of Wolfson, Park, and Yaffe[4] indicated that the three γ rays arise from the decay of a single level by a cascade and a crossover. Since no other coincidence relationships with these three γ rays were observed, the level fed in β decay must either be at 503 keV and decay to the ground state or it must be at 667 keV and decay to the 164-keV isomer. Beta-gamma coincidence experiments in which an attempt is made to gate on the 503-keV γ ray suffer from the disadvantage that the 503-keV γ-ray photopeak is in the midst of the Compton plateau of the 723-keV γ ray and near the Compton edge of the 637-keV γ ray. Careful corrections are necessary to account for the effects of these Compton events. More convincing are experiments in which a β discriminator is set at an energy above the point where the 667-keV level could be populated. By setting a series of β gates of increasing energy, the 503-keV γ ray should disappear at the point where the gate is above 303 keV. Jungclaussen *et al.*[3] made such measurements using a NaI(Tl) γ-ray detector and the results indicated that the 503-keV shoulder did disappear when the β gate was above approximately 250 keV. We have made a similar measurement using a Ge(Li) γ-ray detector and a Si(Li) electron detector. The results in Fig. 10 indeed show the disappearance of the 503-keV γ ray as the β gate is raised above 300 keV.

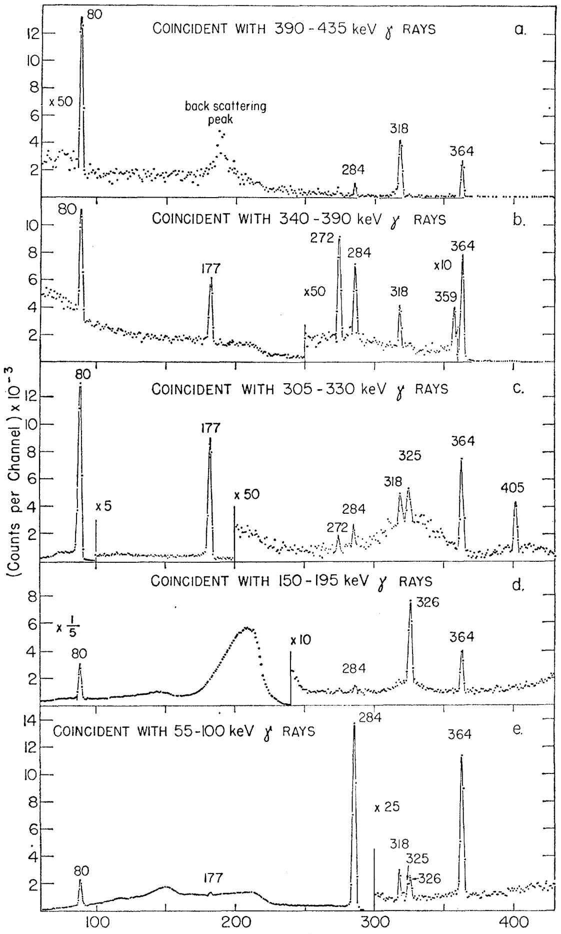

FIG. 9. Gamma-ray spectra of ^{131}I observed with Ge(Li) in coincidence with five different regions of the spectrum observed with NaI(Tl). Numbers above the peaks correspond to γ-ray energies in keV. No corrections for random events have been made.

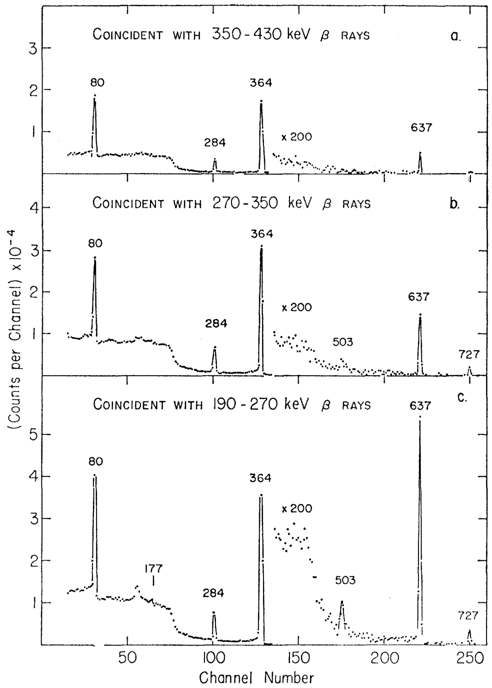

FIG. 10. Gamma-ray spectra of ^{131}I observed with Ge(Li) in coincidence with three different regions of the β spectrum observed with Si(Li) detector. Number above the peaks correspond to γ-ray energies in keV.

Though these experiments leave little doubt that the 503-keV γ ray arises in the decay of a level at 667 keV, they give little indication as to the position of the intermediate level. When our γ-ray intensity measurements are corrected for electron conversion, the intensities of the 177.2- and 325.8-keV γ rays are equal within the limits of our error. This is a surprising result in view of the moderate β decay to a similar intermediate-energy negative-parity level observed in the decay of ^{127}Sb.[9]

The log*ft* values were calculated from the γ-ray intensities, the conversion coefficients, and the assumption that 0.8% of the β decay feeds the 12-day 11/2− isomer directly.[17]

IV. ASSIGNMENT OF SPINS AND PARITIES

A. ^{129}Xe

We have retained the spin and parity assignments of Shera and Burson[1] for the levels of ^{129}Xe shown in Fig. 1. Though the log*ft* values for decay to the levels at 317.9, 588.8, and 946.3 keV, and perhaps also one of the two lower levels, may be higher than expected for allowed transitions, the presence of low-lying negative-parity states of spin less than $\frac{7}{2}$, required if the transitions were first forbidden, would be difficult to understand. Since the conversion coefficients that we have determined indicate *M*1 and/or *E*2 multipolarity for the transitions to the $\frac{1}{2}+$ ground state, the β decay must be of the allowed type, which restricts the spins and parities of those levels populated to being $\frac{1}{2}+$ or $\frac{3}{2}+$.

The β transition to the new level that we have proposed at 322.0 keV has a log*ft* value above 9.2, suggesting either a first-forbidden or second-forbidden transition. Because our resolution was not good enough to permit separation of the conversion electron lines for 267- and 271-keV transitions, we could not measure the conversion coefficient of the individual lines. The combined coefficient, however, indicates that they are both *M*1 and/or *E*2. Because the 271-keV γ ray is certainly *M*1 and/or *E*2 and because the 267-keV level is the more intense, it must also be *M*1 and/or *E*2. The level at 322 keV is thus fed from a known positive parity level by a transition in which there is no parity change, and must itself be a positive parity level. As the level at 589 keV has a spin no greater than $\frac{3}{2}$, the level at 322 keV could have a spin no greater than $\frac{7}{2}$. Because the level at 322 keV decays to the $\frac{1}{2}+$ ground state, its spin can be no greater than $\frac{5}{2}$.

In view of the above data, the level at 322 keV is most likely a $\frac{5}{2}+$ level, though it could be a $\frac{1}{2}+$ or $\frac{3}{2}+$ level with an abnormally high log*ft*. Though such high log*ft* values are rare, they have been observed for $\frac{1}{2}+$ and $\frac{3}{2}+$ levels in the decay of ^{127}Te to levels of ^{127}I.[22]

The log*ft* value of 7.8 indicated in Fig. 4 and Table II for electron capture to the level at 904.9 keV is based on a total decay energy of 1200 keV taken from Ref. 17 and thus an electron-capture energy of 295 keV for electron capture to the 904.9-keV level. If the more recent total decay energy of 1100 keV estimated by Mattauch, Thiele, and Wapstra[23] is used, the electron-capture energy is reduced to ~200 keV and the log*ft* to 7.2. The log*ft* value of 7.8 is enough to open the possibility that the transition is first forbidden. Since this value represents the upper limit to be expected for the transition and since the presence of a $\frac{1}{2}-$ or $\frac{3}{2}-$ level at this low energy would be difficult to account for, the transition is likely allowed but hindered somewhat. The level at 904.9 keV is thus restricted to spin and parity values of $\frac{1}{2}+$ or $\frac{3}{2}+$.

B. ^{131}Xe

The spins and parities for the previously known positive parity levels of ^{131}Xe are quite well known[3] and our results support these assignments.

The log*ft* value for the β decay to the new level at 404.8-keV indicates that the level is likely fed by a second-forbidden transition indicating a spin $\leq\frac{3}{2}+$ or $>11/2+$. Because it decays to the $\frac{1}{2}+$ level at 80 keV, its spin is no higher than $\frac{5}{2}$. Thus the assignment is either $\frac{3}{2}+$ or $\frac{1}{2}+$ for the level.

The conversion-electron measurements of Wolfson, Park, and Yaffe[4] indicated an *E*2 multipolarity for the 177.2-keV transition and either an *E*2 or *M*2 multipolarity for the 325.8-keV transition. The values for α_K that we have obtained by combining their relative *K*-electron intensities with our relative γ-ray intensities definitely rule out the *M*2 possibility for the 325.8-keV transition and the 503.0-keV transition. This assures negative parity for the levels at 341.2 and 667.0 keV. The log*ft* of 7.8 for decay to the 667.0-keV level is low for a first-forbidden unique transition and indicates that the level at 667.0 keV is most likely $\frac{7}{2}-$ or $\frac{9}{2}-$. The high log*ft* for the β decay to the 341.2-keV level leaves open a wide variety of spins ranging from $\frac{7}{2}$ up to 13/2 with negative parity. The assignment of $\frac{9}{2}-$ is based on analogy with the levels of ^{125}Te[8] and ^{127}Te[9] as well as on the calculations of Kisslinger.[11]

V. DISCUSSION

With our new data, it is possible to discuss a number of interesting features of the decay of ^{129}Cs and ^{131}I, especially in regard to several recent theoretical attempts to describe nuclei in this region.[7,11,24] The principal points that we will discuss concern the systematic variations in level positions of odd xenon and tellurium levels, the fit to the experimental levels given by the various calculations, the high log*ft* values observed for several allowed transitions, and the low-lying negative-parity levels observed in this region.

The shell model suggests that, in this region just below the closed neutron shell at 82 neutrons, the $d_{3/2}$, $s_{1/2}$, and $h_{11/2}$ levels are being filled. This is the case for odd-tellurium and odd-xenon levels in this region. The $d_{3/2}$ level is the ground state near the shell closure, but as neutrons are removed, the $s_{1/2}$ level is lowered and is the ground state in ^{129}Xe and ^{125}Te.[17] The large rela-

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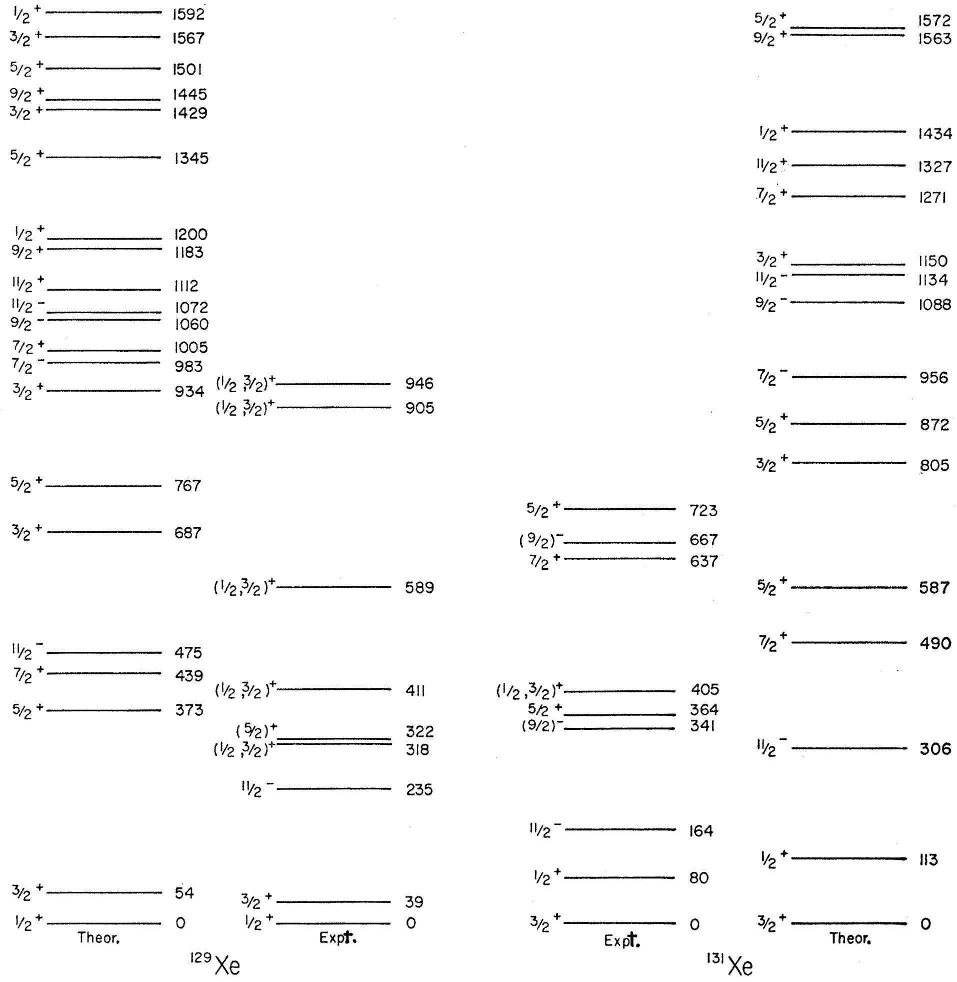

FIG. 11. Comparison of ^{129}Xe and ^{131}Xe levels predicted by Kisslinger and Sorensen (theor.) (Ref. 7) with those observed in this work (expt.).

tive change in the position of the $s_{1/2}$ level is accounted for by the pairing-model calculations of Kisslinger and Sorensen[7] (KS). The $s_{1/2}$ level rises rapidly as the shell closing is neared and, for example, could not be identified by Eichler *et al.* in a recent study of ^{133}Xe levels.[10] In both tellurium and xenon, the $h_{11/2}$ level lies somewhat above the $d_{3/2}$ level and is usually a long-lived isomeric level.

Prior to present studies, there was little opportunity for observations of the systematic behavior of energy levels other than the three shell-model levels in ^{129}Xe and ^{131}Xe, as no other levels whose spins were above $\frac{3}{2}$ in ^{129}Xe and no other levels whose spins were below $\frac{5}{2}$ in ^{131}Xe were observed. In spite of the failure to observe such levels, there was reason to expect that $\frac{5}{2}+$ and $\frac{7}{2}+$ levels exist below 1 MeV in ^{129}Xe and that $\frac{1}{2}+$ and $\frac{3}{2}+$ levels are present in ^{131}Xe. With the observation of the $\frac{5}{2}+$ level at 322 keV in ^{129}Xe and the $\frac{1}{2}+$ or $\frac{3}{2}+$ level at 405 keV in ^{131}Xe it is now possible to observe the variation of the lowest $\frac{5}{2}+$ level from ^{129}Xe through ^{133}Xe and the first excited $\frac{1}{2}+$ or $\frac{3}{2}+$ level in ^{129}Xe and ^{131}Xe. In Fig. 11, we show the levels of ^{129}Xe and ^{131}Xe as determined experimentally and as calculated by KS.[7] Experimentally, the positions of the levels are seen to rise with increasing neutron number, though not as much as the positions of the calculated levels.

Prior to our study, the extent to which the KS calculations accounted for the levels of odd-mass even-Z nuclei in this region depended upon which nucleus was under discussion. Stone *et al.*[8] indicated a fairly good fit for the levels of ^{125}Te where primarily levels with spins $\frac{5}{2}$ and above were observed. Similar conclusions could be drawn about the levels of ^{131}Xe where the $\frac{5}{2}+$ and $\frac{7}{2}+$ levels were concerned. Shera and Burson,[1] however, noted that the fit in ^{129}Xe was not as good, where primarily $\frac{1}{2}+$ and $\frac{3}{2}+$ levels were concerned. It can be seen for ^{129}Xe in Fig. 11 that the $\frac{1}{2}+$ and $\frac{3}{2}+$ levels (except for ground-state and 39-level) are lower than expected by the KS calculation while the calculated positions of the $\frac{5}{2}+$ level is closer to the experimentally observed $\frac{5}{2}+$ level in ^{129}Xe than in ^{131}Xe (a more rapid rise is predicted than is observed in the position of the $\frac{5}{2}+$ level). The possibility of the onset of large collective interactions in ^{129}Xe which are not accounted for by KS calculation might explain the lowering of the $\frac{1}{2}+$ and $\frac{3}{2}+$ levels. Since deformed nuclei have been suggested in cesium and barium for $A \leq 129$,[25] ^{129}Xe might be thought of as a borderline nucleus. If ^{129}Xe is to be so characterized, however, then ^{131}Xe must also be described in the same manner as the level structure for the two nuclei are quite similar below 500 keV. Because ^{131}Xe is not thought of as deformed, it is not likely that ^{129}Xe can be described by the presence of static nuclear deformation. The lowest $\frac{1}{2}+$ or $\frac{3}{2}+$ level is $\sim$320 keV above the $s_{1/2}$ level in both nuclei and $\sim$380 keV below the KS predicted position in both nuclei. The question that we leave unanswered concerns the positions of the other $\frac{1}{2}+$ or $\frac{3}{2}+$ levels in ^{131}Xe analogous to the 411- and 589-keV levels in ^{129}Xe. If those levels do not show a larger rise in position than the 318-keV level in ^{129}Xe to 405 keV in ^{131}Xe has shown, then the over-all fit of the KS calculation to the levels in ^{129}Xe or ^{131}Xe will not be good for this particular calculation. Since many of the predicted levels are higher than the observed levels, a similar calculation with a lower phonon-energy parameter might give a better fit. It should be noted that rather good fits are found in ^{129}I [26] and ^{131}I.[16]

The high logft values observed for a number of β transitions in the decay of ^{129}Cs is another indication of the unusual nature of the $\frac{1}{2}+$ and $\frac{3}{2}+$ levels in this area. Hindrances are also observed for decay to odd proton levels in ^{127}I,[22] ^{129}I,[26] ^{131}I,[16] ^{123}Sb,[27] and ^{125}Sb [27] whose spins are $\frac{1}{2}+$ or $\frac{3}{2}+$. The hindrances are larger than can be accounted for by odd-jumping or even-jumping as described by KS.[7] It is possible that the same hitherto unaccounted-for interaction that brings down a number of $\frac{1}{2}+$ and $\frac{3}{2}+$ levels in ^{129}Xe to positions below 1 MeV also contributes to the hindrance observed in β decay, although in the odd-proton case of ^{127}I, the KS calculation accounts well for the positions of the lower $\frac{1}{2}+$ and $\frac{3}{2}+$ levels whose logft values are quite high.[22] It should be noted that the three principal β groups in the decay of ^{131}I have logft values somewhat higher than would be expected for allowed transitions and all three involve $\frac{5}{2}+$ and $\frac{7}{2}+$ levels.

The low-lying negative-parity levels observed in ^{131}Xe as well as ^{125}Te[8] and ^{127}Te[9] are also not accounted for by phonon coupling to the single quasiparticle 11/2 level. Recently, Kisslinger[11] has suggested that the coupling of three quasiparticles to $j-1$, where j is the quasiparticle orbital spin, would lead to a level whose energy would not be too much higher than the single quasiparticle level j itself. Such an interaction would be observed when the parity of the orbital was opposite to the parities of the nearby single quasiparticle levels. One of the characteristics of such a level of spin $j-1$ would be a highly hindered $M1$ transition probability to the level of spin j. In ^{131}Xe, a level of spin $\frac{9}{2}-$ is thought to exist only 177 keV above the $11/2-$ level and the 177-keV transition between the two levels has been shown by Wolfson *et al.*[4] to be nearly pure $E2$. Even if the 326-keV γ ray represents the transition to the 11/2 level, it, too, is mostly an $E2$ transition.

Similar levels might exist in ^{129}Xe but would be difficult to observe in the decay of the $\frac{1}{2}+$ ground state of ^{129}Cs. Since ^{133}I has a spin of $\frac{7}{2}+$ similar to ^{131}I, it should be possible to observe such levels in ^{133}Xe, if they are present. The failure to observe these levels[10] may be understood by noting that ^{133}Xe is only three neutrons below the closed shell of 82 neutrons. To form a three-quasiparticle state would thus require the other orbitals to be totally occupied. Although such a configuration is possible for ^{133}Xe, it is likely to be considerably higher in energy than a similar configuration in ^{131}Xe where occupancy of the $h_{11/2}$ orbital is 0.75.[7] The occupancy of 0.75 indicates an average occupancy of 4.5 pairs and 1.5 holes, a situation which might be approximated by considering the orbital occupied by 4 pairs of neutrons 50% of the time. With 4 pairs of neutrons present, a three-quasiparticle level is formed by exciting the odd particle into the 11/2 orbital, breaking a pair that is already present, and excluding the fifth pair of neutrons. The position of the levels will depend upon the energy required for each of these three processes. As the occupancy is raised, more energy is required to exclude the fifth pair. This is the trend observed in ^{125}Te[8] and ^{127}Te[9] levels where the energy difference between the 11/2 and $\frac{9}{2}$ levels rises from 176 to 250 keV as the extra pair of neutrons are added. It is likely that the energy required to exclude the fifth and sixth pairs of neutrons in ^{133}Xe is considerably higher than the energy required to exclude these neutrons in ^{131}Xe.

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