Electron conversion coefficients in ^{127}Ba and ^{130}La

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Electron conversion coefficients for nine transitions in ^{127}Ba and ^{130}La have been measured to test the hypothesis that static octupole deformation occurs in the $A = 128$ region. No evidence for alternating parity band or parity doublet structures is observed. Such structures are indicators of static octupole deformation in the $A = 145$ and 225 regions.

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It has been suggested [1] that a number of nuclei in the neighborhood of ^{128}Ba possess stable octupole deformations. In odd-A and odd-odd nuclei, the presence of octupole deformation is indicated by "parity doublets" of states with equal spins and opposite parities and rotational bands of states with alternating parities. In the $A = 145$ and 225 regions, where substantial evidence for static octupole deformations has been found, the states of different parities are often connected by $E1$ transitions as strong as 10^{-2} Weisskopf units (W.u.) [2]. In the $A = 128$ region, the search for parity doublets and alternating parity bands has been hampered by the lack of direct measurements of the multipolarities of transitions using conversion electron spectroscopy or γ-ray polarization measurements. In this work, we report measurements of the electron conversion coefficients of intraband $\Delta J = 1$ transitions in ^{127}Ba and ^{130}La to determine whether they have $E1$ multipolarity. High quality γ-ray data on band structures in these nuclei have recently become available [3, 4]. However, our data are the first direct measurements of the multipolarities of the in-band $\Delta J = 1$ transitions in these nuclei.

Six conversion coefficients were determined for ^{127}Ba and four more for ^{130}La. The ^{118}Sn(^{12}C,3n) reaction at a beam energy of 52 MeV was used to produce ^{127}Ba, and ^{130}La was made via the ^{115}In(^{18}O,3n) reaction at 65 MeV. The experiments were performed using the Florida State University Tandem Van de Graaff and Superconducting Linear Accelerators. The target for the ^{127}Ba experiment consisted of 200 μg/cm^2 of SnO_2 (enriched to 97.8% of ^{118}Sn) evaporated onto a 50 μg/cm^2 carbon backing. For the ^{130}La experiment, a target of 300 μg/cm^2 of natural InO evaporated onto a 50 μg/cm^2 carbon backing was used.

Singles spectra of both γ rays and conversion electrons were collected. The γ-ray and electron spectra collected in the ^{127}Ba experiment are shown in Fig. 1. The γ rays were detected using an n-type HPGe detector of 25% relative efficiency and resolution of 2.1 keV (full width at half maximum) at 1.33 MeV. The Ge detector was located approximately 20 cm from the target and at 90° to the beam axis. Conversion electrons were detected using a miniorange electron spectrometer at 90° to the beam axis. The electron spectrometer included a liquid nitrogen cooled Si(Li) detector of 5 mm thickness and 1 cm diameter. The magnetic filter was similar to that described by Ishii [5], using five thin, flat permanent magnets placed around a central lead plug which shielded the Si(Li) detector from direct exposure to the target. While in-beam, the spectrometer yielded a resolution of 4 keV near 200 keV electron energy. An efficiency curve for the

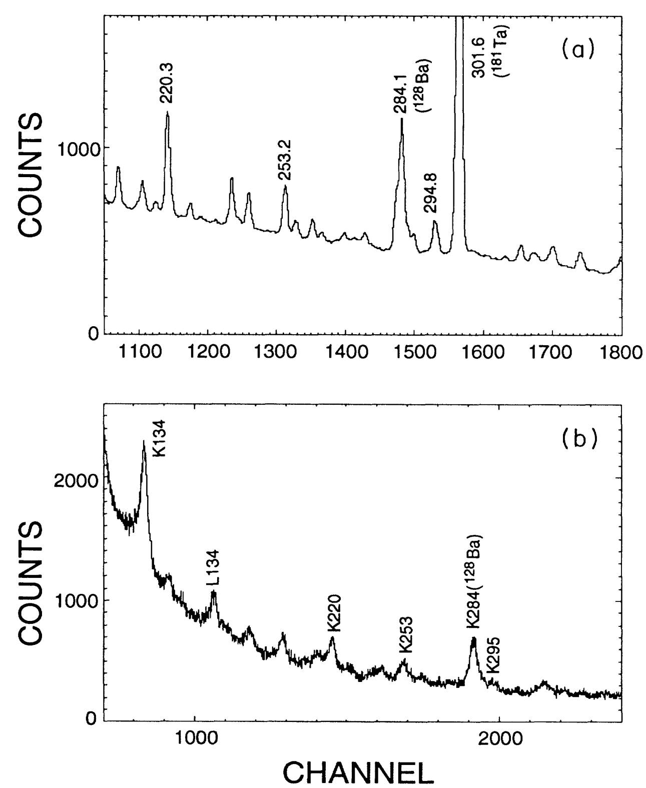

FIG. 1. (a) A portion of the γ-ray spectrum taken in the ^{127}Ba experiment. (b) A portion of the electron spectrum taken in the ^{127}Ba experiment.

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Ge detector was measured with a ^{152}Eu source. The efficiency curve for the electron spectrometer was obtained using open ^{152}Eu and ^{207}Bi sources.

K conversion coefficients for the 221.2, 246.3, and 279.4 keV transitions and the L coefficient for the 118.7 keV transition were determined for ^{130}La. Other conversion lines were too weak to be analyzed. (The K conversion line for the 118.7 keV transition was located at an energy with a large delta electron background.) These coefficients were determined by calculating the ratio of the yield of conversion electrons to the yield of γ rays in the ^{130}La experiment, with each yield corrected for the detectors' relative efficiencies (as measured with the ^{152}Eu and ^{207}Bi sources). This ratio was then multiplied by a normalization factor that was chosen to reproduce the theoretical K conversion coefficient for the 641.9 keV $E2$ transition in ^{129}La, which was also present in the spectrum. The stronger 269.3 and 474.8 $E2$ transitions in ^{129}La were also present in the spectrum; however, they are doublets with transitions in ^{130}La and could not be used for normalization. The ^{130}La results are listed in Table I.

The K conversion coefficients for ^{130}La are plotted with theoretical values [6] for $E1$, $M1$, and $E2$ multipolarities in Fig. 2(a). All three of the K conversion coefficients measured for this nucleus are consistent with $M1$ or $E2$ (or mixed $M1/E2$) multipolarities. The L conversion coefficient for the 118.7 keV transition (0.59±0.14) can be compared with theoretical coefficients [6] of 0.021, 0.466, and 0.0963 for $E1$, $E2$, and $M1$, respectively. Clearly, the L conversion coefficient result favors an E2 multipolarity assignment for the 118.7 keV transition.

In ^{127}Ba, K conversion coefficients for the 134.2, 220.3, 253.2, 294.8 and 483.3 keV transitions and the L coefficient for the 134.2 keV transition are reported here. Other conversion lines were too weak to be analyzed or are members of close doublets in the electron spectrum which could not be separated. Once again, these coefficients were determined by calculating the ratio of the yield of conversion electrons to the yield of γ rays in the ^{127}Ba experiment, with each yield corrected for the detectors' efficiencies. The normalization factor used for determining ^{127}Ba conversion coefficients was the same as that determined in the ^{130}La experiment (from the 641.9 keV $E2$ transition in ^{129}La). We could use the same normalization factor because the physical setup of the ^{127}Ba experiment was unchanged from that used for the ^{130}La measurement. In particular, tight beam collimation was used so that the locations of the beam spots in the two experiments were identical. Results for ^{127}Ba are listed in Table II.

TABLE I. Electron conversion coefficients for ^{130}La.

Transition energy (keV)[a]	Electron shell	α	Multipolarity
118.7	L	0.590(14)	$M1/E2$
221.2	K	0.070(25)	$M1/E2$
246.3	K	0.096(20)	$M1/E2$
279.4	K	0.035(10)	$M1/E2$

[a]Energies taken from [4].

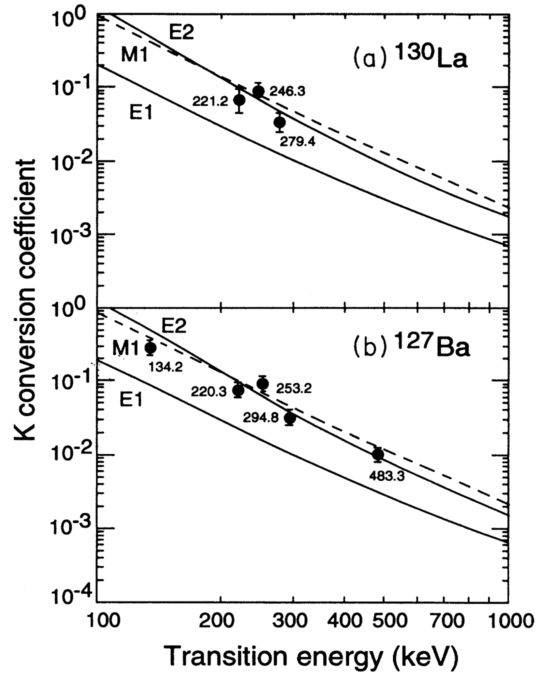

FIG. 2. (a) A comparison of measured K electron conversion coefficients for ^{130}La with theoretical values [6] for $E1$, $M1$, and $E2$ multipolarities. (b) Measured and theoretical K conversion coefficients for ^{127}Ba.

It is worth noting that two of the transitions reported here, at 253.2 and 483.3 keV, are members of doublets. By using γ-γ coincidence data, Ward *et al.* [3] found that these two transitions have doublet partners at 253.0 and 481.7 keV, respectively. However, Ward *et al.* determined that the 253.0 keV γ ray had only 9% of the intensity of the 253.2 keV γ ray, and the 481.7 keV γ ray had 3% of the intensity of the 483.3 keV γ ray. The reaction used for our study, ^{118}Sn(^{12}C,3n) at 52 MeV, is quite similar to the ^{117}Sn(^{13}C,3n) reaction (at 60 MeV) used by Ward *et al.*, so we can conclude that unless the weak doublet partners have octupole or higher multipolarities (and thus very large conversion coefficients) they would not affect the measured conversion coefficients significantly.

The K conversion coefficients for ^{127}Ba are plotted with theoretical values [6] in Fig. 2(b). All of the K

TABLE II. Electron conversion coefficients for ^{127}Ba.

Transition energy (keV)[a]	Electron shell	α	Multipolarity
134.2	K	0.291(67)	$M1/E2$
134.2	L	0.043(10)	$M1/E2$
220.3	K	0.078(18)	$M1/E2$
253.2	K	0.094(22)	$M1/E2$
294.8	K	0.033(8)	$M1/E2$
483.3	K	0.010(2)	$E2$

[a]Energies taken from [3].

conversion coefficients are consistent with $M1$ or $E2$ (or mixed $M1/E2$) multipolarities. The L conversion coefficient for the 134.2 keV transition (0.043 ± 0.010) compares with the theoretical coefficients [6] of 0.014, 0.25, and 0.062 for $E1$, $E2$, and $M1$, respectively. This L conversion coefficient result is closest to the theoretical $M1$ coefficient. This is consistent with the $M1/E2$ assignment given by the K coefficient for this transition.

Godfrey *et al.* [4] have identified two rotational bands in ^{130}La (a partial level scheme is shown in Fig. 3) via their γ-γ coincidence study. From the γ-γ data, the rotational bands appear to include both stretched $E2$ and $\Delta J = 1$ transitions of either $E1$ or mixed $M1/E2$ multipolarity. Godfrey *et al.* assumed that the $\Delta J = 1$ transitions are mixed $M1/E2$ transitions and, therefore, that all of the states in a particular rotational band have the same parity. However, they had no measurements of the intraband $\Delta J = 1$ transitions to support this assumption. In addition, Godfrey *et al.* found a number of transitions linking the two bands at the lowest spins (these transitions are not shown in Fig. 3). However, the information on the linking transitions was insufficient to fix the relative spins and parities of the two bands. The spins shown in Fig. 3 are based on the apparent rotational structure of the bands and the bandhead spin parity assignments made by Godfrey *et al.* on the basis of theoretical arguments.

We measured conversion coefficients for two $\Delta J = 1$ transitions in each band. In band A (as labeled in Fig. 3), we obtained results for the 246.3 and 279.4 keV transitions, and in band B the 118.7 and 221.2 keV transitions were measured. In all four cases, the conversion coefficients are consistent with $M1$, $E2$, or mixed $M1/E2$ character; these transitions clearly do not have $E1$ multipolarities. These results support the proposal of Godfrey *et al.* that all of the states within a particular band indeed have the same parity and do not form alternating parity bands like those found in octupole deformed nuclei in the $A = 145$ and 225 regions. In addition, they suggest that strong $E1$ transitions do not occur among the high spin states of ^{130}La.

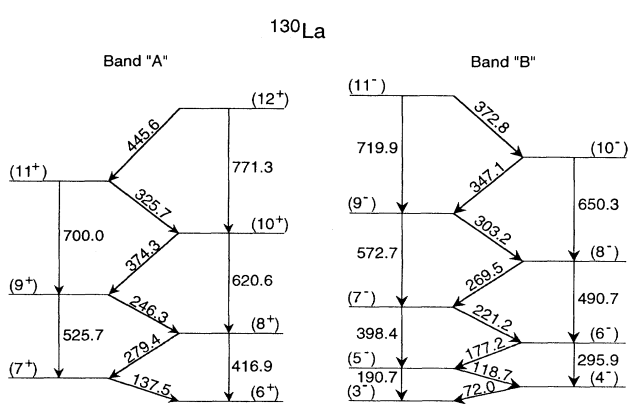

FIG. 3. The low spin part of the level spectrum of ^{130}La reported in [4]. The band heads are shown. Conversion coefficients for the 118.7, 221.2, 246.3, and 279.4 keV transitions are reported in this article.

It is possible that the states in band A form parity doublets with the states in band B. However, until the multipolarities of the linking transitions are confirmed using more sensitive γ-ray polarization or conversion electron measurements, this possibility can neither be confirmed nor excluded.

In their study of high spin states in ^{127}Ba, Gizon and Gizon [7] identified two strong rotational bands that included both stretched quadrupole and $\Delta J = 1$ transitions. As Godfrey *et al.* [4] did for ^{130}La, Gizon and Gizon assumed that the $\Delta J = 1$ transitions have $M1$ or mixed $M1/E2$ character, so that all of the states within a particular rotational band have the same parity. However, they made no measurements to confirm this. In the recent high spin study of Ward *et al.* [3], it was deduced that the bandheads of the two bands seen by Gizon and Gizon are at the same energy to within experimental error. In addition, they carefully measured directional correlation orientation (DCO) ratios to obtain spin and parity information. The DCO ratios for the $\Delta J = 1$ intraband transitions in the two bands seen by Gizon and Gizon fell in the range between 0.32 and 0.51. These values are systematically less than the ratio of 0.56 for a pure stretched dipole transition, and indicate that the $\Delta J = 1$ intraband transitions have either mixed $M1/E2$ or mixed $E1/M2$ character. Because the latter possibility is highly unlikely, Ward *et al.* concluded that within each band all states have the same parity. The $J \leq 21/2$ states of the two strong bands reported in [7] are shown in Fig. 4, along with the spin assignments and excitation energies given by Ward *et al.* [3].

We have measured one $\Delta J = 1$ transition and one $\Delta J = 2$ transition in band A; and three $\Delta J = 1$ transitions in band B. All of the measurements indicate $M1$, $E2$, or mixed $M1/E2$ multipolarity. Therefore, our results confirm the conclusion of [3] that all of the states of band A have a single parity, as do all of the states of band B. Once again, these bands do not have the alternating parity structures characteristic of static oc-

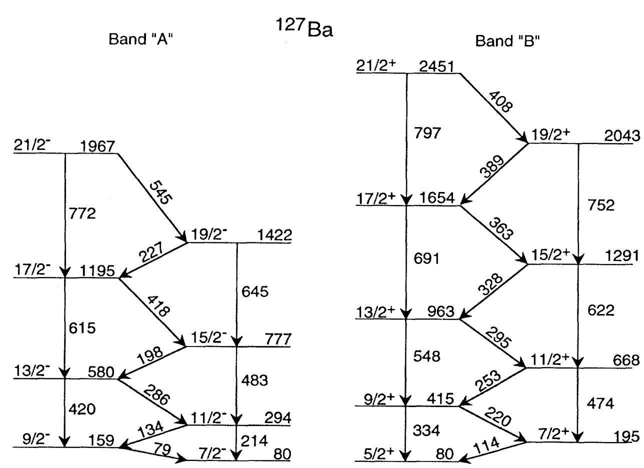

FIG. 4. The low spin part of the strongest bands in ^{127}Ba reported in [7, 3]. The multipolarities of the 134.2, 220.3, 253.2, 294.8, and 483.3 keV transitions are reported in this article.

tupole deformation, and there is no evidence for strong $E1$ transitions.

The possibility that the parity doublets of states in band A are located in band B must be considered, but it is clear from Fig. 4 that this is not the case. The average spacing between a negative parity state in band A and the state of equal spin and opposite parity in band B among the states listed in Fig. 4 is 401 keV. This result can be compared to average parity doublet separations found in a systematic study [8–11] of five odd-A and odd-odd nuclei in the $A = 150$ region which may possess static octupole deformations. In these nuclei, the average parity doublet separations were 71–233 keV. The average separation found here for ^{127}Ba is significantly out of this range.

The present study allows an opportunity to test two different methods for identifying nuclei which are candidates for static octupole deformation. Nazarewicz *et al.* [12] have cited a microscopic argument regarding the origins of octupole collectivity to propose that nuclei with the strongest octupole correlations, and therefore the best candidates for static octupole deformation, occur when the neutron and proton numbers N and Z are equal to what they call "octupole-driving particle numbers" (ODPN's). The ODPN's listed by Nazarewicz *et al.*, which are 34, 56, 88, and 134, are consistent with the two regions where experimental evidence for static octupole deformation exists. In the $A = 145$ region, Z is near 56 and N is near 88. In the $A = 225$ region, Z is near 88 and N is near 134. However, searches for static octupole deformation near $Z = N = 56$ [2] have thus far been unsuccessful.

The assignment of ODPN's by Nazarewicz *et al.* [12] depended on the ordering of single-particle orbits, particularly those involved in octupole correlations. Cottle [13] argued that because the energies of single-particle orbits can change as a function of N and Z, the ODPN's proposed by Nazarewicz *et al.* may not be appropriate everywhere. Instead, Cottle proposed that the best even-even candidates for static octupole deformation are those with the lowest 3_1^- state energies in their respective mass regions. In both the $A = 145$ and 225 regions, the 3_1^- state energies achieve local minima with respect to N and Z.

The suggestion that static octupole deformation occurs in the region near ^{128}Ba [1] was based on the fact that 3_1^- energies are low in the even-even nuclei near ^{128}Ba and also on the observation of alternating parity structures in ^{126,128}Ba and parity doublets in ^{129}Ba. However, the lack of evidence for parity doublet structure in ^{127}Ba and ^{130}La (as reported here) and in a recent study of spins and parities in ^{128,129}La [14] raises the likelihood that the structures seen in ^{126,128,129}Ba are simply fortuitous alignments of states with entirely different origins. Interpretations of the level structures of ^{126,128,129}Ba that do not require static reflection asymmetric shapes have been successful [15–17], and they must be regarded as correct in the absence of any further evidence to the contrary.

In summary, we have measured electron conversion coefficients for a number of intraband $\Delta J = 1$ transitions in ^{127}Ba and ^{130}La and have found no evidence for the alternating parity band or parity doublet structures which are indicators of static octupole deformation in the $A = 145$ and 225 regions. Given the results of this study and a previous study of spins and parities in ^{128,129}La [14], it is unlikely that static octupole deformation occurs in the $A = 130$ mass region.

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[1] P.D. Cottle, Z. Phys. A **338**, 281 (1991).
[2] P.A. Butler, in *Heavy Ions in Nuclear and Atomic Physics*, Proceedings of the 20th Mikolajki Summer School on Nuclear Physics, edited by Z. Wilhelmi and G. Szeflinska (Adam Hilger, Bristol, 1989), p. 295.
[3] D. Ward, H.R. Andrews, V.P. Janzen, D.C. Radford, J.K. Johansson, D. Prevost, J.C. Waddington, A. Galindo-Uribarri, and T.E. Drake, Nucl. Phys. **A539**, 547 (1992).
[4] M.J. Godfrey, Y. He, I. Jenkins, A. Kirwan, P.J. Nolan, D.J. Thornley, S.M. Mullins, and R. Wadsworth, J. Phys. G **15**, 487 (1989).
[5] M. Ishii, Nucl. Instrum. Methods **127**, 53 (1975).
[6] F. Rosel, H.M. Fries, K. Alder, and H.C. Pauli, At. Data Nucl. Data Tables **21**, 109 (1978).
[7] J. Gizon and A. Gizon, Z. Phys. A **281**, 99 (1977).
[8] R.K. Sheline and P.C. Sood, Mod. Phys. Lett. A **4**, 1329 (1989).
[9] R.K. Sheline and P.C. Sood, Prog. Theor. Phys. **81**, 1057 (1989).
[10] R.K. Sheline, Phys. Lett. B **219**, 222 (1989).
[11] P.C. Sood and R.K. Sheline, Phys. Rev. C **40**, 1530 (1989).
[12] W. Nazarewicz, P. Olanders, I. Ragnarsson, J. Dudek, G.A. Leander, P. Möller, and E. Ruchowska, Nucl. Phys. **A429**, 269 (1984).
[13] P.D. Cottle, Phys. Rev. C **42**, 1264 (1990).
[14] P.D. Cottle, T. Glasmacher, and K.W. Kemper, Phys. Rev. C **45**, 2733 (1992).
[15] D. Ward, V.P. Janzen, H.R. Andrews, D.C. Radford, G.C. Ball, D. Horn, J.C. Waddington, J.K. Johansson, F. Banville, J. Gascon, S. Monaro, N. Nadon, S. Pilotte, D. Prevost, P. Taras, and R. Wyss, Nucl. Phys. **A529**, 315 (1991).
[16] U. Neuneyer, H. Wolters, A. Dewald, W. Lieberz, A. Gelberg, E. Ott, J. Theuerkauf, R. Wirowski, P. von Brentano, K. Schiffer, D. Alber, and K.H. Maier, Z. Phys. A **336**, 245 (1990).
[17] K. Schiffer, A.P. Byrne, A.M. Baxter, G.D. Dracoulis, B. Fabricius, and A.E. Stuchbery, Z. Phys. A **336**, 239 (1990).