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Differential lifetime measurements and identical superdeformed bands in ^{192,194}Hg

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High-precision lifetime measurements have been performed in superdeformed (SD) bands of ^{192,194}Hg with the Doppler-shift attenuation method. Intrinsic quadrupole moments Q_0 were extracted for three SD bands in ^{194}Hg and for the yrast SD band in ^{192}Hg. Within experimental uncertainties, all four SD bands have equal Q_0 values. These results provide constraints on differences in Q_0 values between the ''identical'' SD bands ^{194}Hg(3) and ^{192}Hg(1). [S0556-2813(97)51005-3]

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The observation of rotational bands in different nuclei with moments of inertia nearly identical to each other has been among the most exciting recent discoveries in nuclear structure physics [1]. In superdeformed (SD) nuclei, many cases of rotational bands consisting of 10–20 transitions with either the same energies, or with energies obeying a fixed relation with respect to a SD band in a neighboring nucleus, have been reported [1]. The remarkable degeneracies in transition energies have spurred many theoretical explanations, but at present there is no generally accepted one. One (so-called heroic) class of explanations speculates that the degeneracies are due to some new underlying symmetry. The other (unheroic) class attributes them to accidental cancellations of several effects, such as changes in deformation, alignment, and/or pairing which compensate for a change in mass. Further progress in understanding this striking phenomenon clearly depends on experimental information beyond transition energies: spins, parities, and quadrupole moments must also be measured. With the completion of the new generation of γ-ray spectrometers, substantial progress is being made toward this goal. Excitation energies, spins, and parities have been established very recently in a few SD nuclei near $A=190$ [2–5], and intrinsic quadrupole (Q_0) moments (which probe the quadrupole deformation) are beginning to be determined with sufficient accuracy using the Doppler shift attenuation method (DSAM) [6–8]. Here, we report on measurements of the Q_0 moments of a pair of identical SD bands in ^{192,194}Hg.

These nuclei are of central importance to the understanding of SD bands because they include the first cases for which the spins, parities, and excitation energies are known (bands 1 and 3 in ^{194}Hg [2,3]). Furthermore, band 3 (using the notation of Ref. [9]) of ^{194}Hg is ''identical'' to the yrast SD band of ^{192}Hg, i.e., the γ-ray transition energies of ^{194}Hg(3) are equal to those in ^{192}Hg(1) to within two keV over nearly the entire energy range. The equality of the γ-ray energies requires that both bands have equal moments of inertia $\Im^{(2)}$. In the framework of the Strutinsky method, the moment of inertia is given by a sum of a macroscopic and a shell-correction term (where the latter would include the effects of pairing and particle alignment). To get a sense of the change in deformation required to compensate for the change in mass for identical bands, let us consider only the macroscopic term. The $A^{5/3}$ scaling of the rigid body moment of inertia would lead to an expected difference in deformation $\beta_2(^{192}\mathrm{Hg})-\beta_2(^{194}\mathrm{Hg})\simeq 0.04$. This difference corresponds to a value of $\delta Q_{0,\mathrm{mac}}\equiv \mathrm{Q}_0(^{192}\mathrm{Hg})-Q_0(^{194}\mathrm{Hg})\simeq 1.7\ e$ b (using the expression for the quadrupole moment given in Ref. [10]). A difference of 1.7 e b is well within the sensitivity of the differential DSAM technique and is in contrast with the much smaller differences in Q_0 values recently found for identical bands in the $A=150$ region [7,8].

In order to compare DSAM measurements for SD bands in neighboring nuclei, great care must be taken to ensure that all bands are populated under nearly identical conditions in terms of angular momentum input and excitation energy, so that the sidefeeding into the states of interest is as similar as possible. Furthermore, the uncertainties associated with stopping powers must be minimized by choosing the same stopping material and making the recoil velocity profiles as close as possible. These considerations form the basis of the so-called ''differential'' DSAM measurements as they minimize the systematic uncertainties, allowing differential Q_0 values to be precisely measured. First measurements of this type have recently been reported in ^{131,132}Ce by Clark *et al.* [6], in ^{148,149}Gd and ^{152}Dy by Savajols *et al.* [7], and in ^{151,152}Dy and ^{151}Tb by Nisius *et al.* [8].

Motivated by these considerations, DSAM measurements were performed with the Gammasphere spectrometer [11] in two experiments, when 55 and 85 Compton-suppressed Ge detectors were present. Excited states in ^{192}Hg were popu-

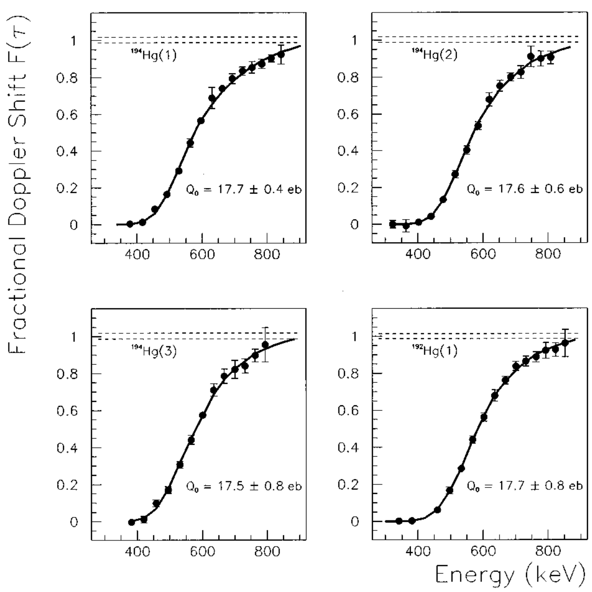

FIG. 1. Measured fractional shifts $F(\tau)$ for SD bands in ^{192,194}Hg. The curves represent the best fit corresponding to the value of the Q_0 moment given. The dashed lines indicate the spread in full shift due to the slowing down of the beam across the target. See text for a detailed discussion.

lated with the ^{148}Nd(^{48}Ca,4n) reaction at a beam energy of 205 MeV, while states in ^{194}Hg were populated using the ^{150}Nd(^{48}Ca,4n) reaction at a beam energy of 202 MeV. In each case, the targets consisted of $\sim$1 mg/cm^2 Nd evaporated onto thick Au backings (13 mg/cm^2) in which the recoiling nuclei were stopped. The beams were supplied by the 88 inch cyclotron at Lawrence Berkeley National Laboratory. In the first beam time, approximately 1×10^9 three- and higher-fold coincidence events were recorded for each of the two reactions. In the second experiment, $\sim 1.8\times 10^9$ four- and higher-fold events were recorded for the ^{150}Nd(^{48}Ca, 4n) reaction. In all cases, the recoiling Hg nuclei were slowed down and brought to rest in the Au backings.

Spectra sorted by angle were constructed by combining data with double coincidence gates placed on stopped and nearly stopped transitions at the bottom of each of the SD bands. Particular care was taken to ensure that consistent gating conditions were applied to each of the SD bands studied, i.e., similar combinations of gates were used for each spectrum. The data analysis consisted of both centroid shift and individual line shape fits. Fractions of the full Doppler shift $F(\tau)$ were obtained for transitions in three SD bands of ^{194}Hg and in the yrast SD band of ^{192}Hg. The $F(\tau)$ values were determined from the centroid of the γ-ray peak at each angle using the first-order relation $F(\tau) = (\langle E_\gamma\rangle - E^0_\gamma)/E^0_\gamma \beta_0 \cos\theta$, where E^0_γ is the nominal (i.e., unshifted) γ-ray energy, and $\langle E_\gamma\rangle$ is the corresponding energy derived from spectra measured in the detectors located at an angle θ with respect to the beam direction. The factor β_0 refers to the initial velocity (v_0/c) of the recoiling nucleus assuming formation at the center of the target. The $F(\tau)$ values are presented in Fig. 1 as a function of the transition energy.

In order to extract the intrinsic quadrupole moments Q_0 from the experimental $F(\tau)$ values, the computer code FITFTAU [12,13] was used. To compute the average recoil velocity at which the decay from a particular SD state occurs, the following assumptions are made: (1) The Q_0 values are the same for all SD levels within a band, and the transition probability T (in ps^{-1}) of a band member of spin I is described within the rotational model by the expression $T(I\rightarrow I-2) = 1.22 E^5_\gamma Q^2_0 \langle IK20|(I-2)K\rangle^2$, where E_γ is the γ-ray energy in MeV. (2) The sidefeeding into each SD state is approximated by a single rotational cascade (with the number of transitions in the sidefeeding cascade proportional to the number of transitions in the main band above the state of interest), having the same $\mathfrak{I}^{(2)}$ moment as the main band, and controlled by a sidefeeding quadrupole moment Q_{sf} (assumed to remain the same throughout an entire SD band). (3) A one-step delay at the top of all feeder cascades was parametrized by a single lifetime T_{sf}.

The code takes into account the measured γ-ray intensities and also includes a correction for the internal conversion process. The detailed slowing-down histories in both the target and the Au backing were calculated with electronic and nuclear stopping powers provided by the code TRIM, version 1995, by Ziegler [14] which uses the most recent evaluation of existing stopping-power data. In the fit of the $F(\tau)$ values, a χ^2 minimization was performed with Q_0, Q_{sf}, and T_{sf} as parameters. The quality of the fits to the data can be judged from Fig. 1 (solid lines) where the derived Q_0 values are also given. The results of the centroid shift analysis are summarized in Table I. The quoted errors include the covariance between the three parameters Q_0, Q_{sf}, and T_{sf}.

In order to investigate the possibility of changes in the in-band Q_0 values with rotational frequency, a line shape analysis of several transitions in each of the SD bands was performed. Such an analysis was possible for SD transitions in the energy range $430 \leqslant E_\gamma \leqslant 700$ keV; transitions of lower energy are completely stopped and those above this range exhibit sharp Doppler-shifted peaks (for which the analysis reduces to that of a centroid shift). Lifetimes of individual levels were extracted from the line shapes with the code LILIFI [15] which also uses the TRIM stopping powers. For each nucleus, some 10^4 recoiling ions were traced in a Monte Carlo simulation. The feeding model as described above was also used in the line shape calculations with the in-band Q_0 and sidefeeding quadrupole moment Q_{sf} as free parameters for each level (for those transitions above $\sim$700 keV in each band, lifetimes obtained from the centroid shift analysis were used).

For each line shape, both the state lifetime and sidefeeding parameter are derived from the fit. The results have been obtained from fits to the angle combinations available in the Gammasphere data: for bands ^{192}Hg(1) and ^{194}Hg(1), fits were performed on spectra obtained at eleven independent angles. Due to lower statistical accuracy, fits to ^{194}Hg(2) and ^{194}Hg(3) were performed for spectra at five different angles which were obtained by the summation of spectra from adjacent angular rings. Simultaneous fits to successive transitions were performed in order to determine correlations between fit parameters. Examples of comparisons between experimental and calculated line shapes are shown in Fig. 2; it is apparent that the data are well reproduced.

The transition quadrupole moments were derived from the level lifetimes using the rotational formula, as described

TABLE I. Summary of centroid shift analysis results for SD bands in ^{192,194}Hg. The uncertainties quoted do not include the systematic stopping power uncertainties, which could be as large as 10–15%. The fifth column lists the β_2 values derived from the experimental data (see text for details). The last column presents results from previous measurements, all of which represent average Q_0 values derived from the analysis of DSAM line shapes.

Band	Q_0 (e b)	Q_{sf} (e b)	T_{sf} (fs)	β_2	Previous Q_0 (e b)
^{192}Hg(1)	17.7±0.8	$11.0^{+0.8}_{-0.6}$	9^{+10}_{-9}	0.48±0.02	20.0±2.0[a] 18.7±2.0[b]
^{194}Hg(1)	17.7±0.4	$11.8^{+3.2}_{-1.3}$	19^{+22}_{-18}	0.48±0.01	17.2±2.0[c]
^{194}Hg(2)	17.6±0.6	11.6±1.2	28^{+3}_{-6}	0.48±0.01	17.6±3.0[c]
^{194}Hg(3)	17.5±0.8	$10.8^{+1.3}_{-0.6}$	1^{+16}_{-1}	0.48±0.02	

[a]Moore *et al.* [17].
[b]Willsau *et al.* [18].
[c]Hughes *et al.* [16].

above. The individual Q_0 values for all four SD bands are plotted against E_γ in Fig. 3. The average values for ^{194}Hg bands 1 and 2 are $Q_0=18.1\pm1.3\,e$ b and $Q_0=18.1\pm2.1\,e$ b, respectively. For the identical bands, the average values are $Q_0=17.6\pm1.0\,e$ b for ^{192}Hg(1) and $Q_0=17.5\pm2.4\,e$ b for ^{194}Hg(3). These values agree with the results of the centroid shift analysis. Furthermore, the individual Q_0 values are essentially constant with rotational frequency, indicating that the constant Q_0 assumption used in the centroid shift analysis is indeed reasonable.

Due to the scatter in the individual Q_0 values and the relatively large error bars obtained from the line shape analysis, the results of the centroid shift analysis will be used in the comparison of the differential Q_0 values. At this point, the following details concerning the error analysis and sidefeeding assumptions used in the centroid shift analysis deserve further discussion: (1) The uncertainties in the Q_0 values are dominated by correlations with the sidefeeding parameter Q_{sf} (i.e., for fixed Q_{sf} values, the statistical uncertainties on the Q_0 values are only about $0.1-0.2\,e$ b). The observation that the Q_{sf} values are considerably smaller than the in-band Q_0 values is consistent with the results of previous measurements [16,17]. (2) When comparing the uncertainties in differential Q_0 measurements in the $A\sim190$ region with those from recent measurements in the $A\sim150$ region [7,8], it should be kept in mind that the sidefeeding in the lighter mass region occurs over a range of transitions for which the $F(\tau)$ values are not changing very rapidly

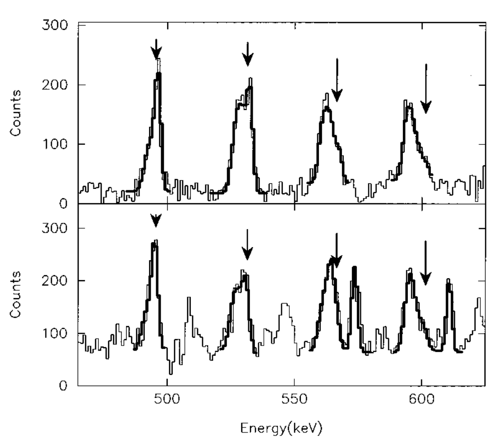

FIG. 2. Sample line shapes for spectra obtained in detectors at backward angles of Gammasphere, the thicker lines correspond to the calculated line shapes. Transitions in ^{192}Hg(1) are shown in the top panel and the lower panel shows the same region for ^{194}Hg(3). The arrows indicate the unshifted γ-ray energies. Note the presence of several contaminant γ rays in the ^{194}Hg(3) data, two of which were taken into account in fitting this particular spectrum.

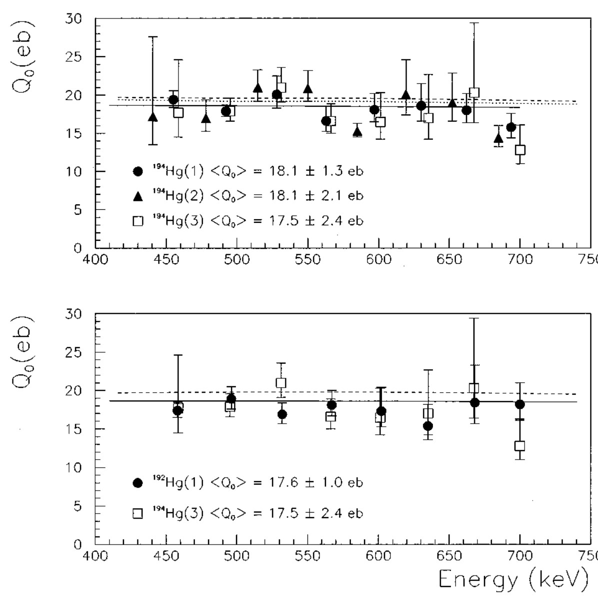

FIG. 3. Experimental transition quadrupole moments Q_0 as a function of transition energy, derived from line shape fits. The top panel presents the results for the three SD bands in ^{194}Hg. The solid line corresponds to the Q_0 values calculated in Ref. [24] for the yrast SD band in ^{194}Hg. The dashed (dotted) lines represent the results of calculations by Satuła *et al.* [23] for the yrast (excited) SD bands of ^{194}Hg. The lower panel presents a comparison of the Q_0 values for ^{192}Hg(1) and the identical SD band ^{194}Hg(3). The calculated Q_0 values of Gall *et al.* [24] and Satuła *et al.* [23] for the yrast SD band of ^{192}Hg are represented by solid and dashed lines, respectively. The average Q_0 value for each SD band is shown in the figure (see the text for details).

TABLE II. Experimental and calculated intrinsic quadrupole moments for SD bands in ^{192,194}Hg. The calculated results are taken from Chasman [22], Satuła *et al.* [23], Gall *et al.* [24], Girod *et al.* [25], Krieger *et al.* [26], Bonche *et al.* [27], Meyer *et al.* [28], and Heenen [29]. The Q_0 values presented for the calculations of Chasman were derived from the values of the ν_2 and ν_4 deformation parameters given in the original paper. All quadrupole moment values are in e b.

Band	Expt.	Chasman	Satuła	Gall	Girod	Krieger	Bonche	Meyer	Heenen
^{192}Hg(1)	17.7±0.8	19.2	19.9	18.6		18.0	18.5^{b} 17.5^{c}	18.2	18.5
^{194}Hg(1)	17.7±0.4	19.3	19.5	18.5	18.4		18.5^{b} 18.0^{c}	18.5	18.6
^{194}Hg(2)	17.6±0.6		19.3^{a}						18.6^{a}
^{194}Hg(3)	17.5±0.8		19.3^{a}						18.6^{a}

^{a}Calculated for the $\nu([512]5/2\otimes[624]9/2)$ configuration.
^{b}Obtained from Hartree-Fock+BCS calculations.
^{c}Obtained from generator coordinate method calculations.

$[F(\tau)\geqslant 0.9]$. As a result, there is less sensitivity to the sidefeeding properties. In contrast, the sidefeeding in the $A\sim 190$ region persists down to $F(\tau)$ values as low as 0.4, and there is a larger sensitivity to the Q_{sf} fit parameter. (3) Finally, it should be emphasized that since the same decay model and feeding assumptions were consistently applied to all bands, the *relative differences* in the Q_0 values are valid even if the model used in the analysis is simplified.

The results of the present analysis are compared with those of previous measurements in Table I: good agreement between all Q_0 values is obvious. In particular, the agreement between our results and the most recent measurements in ^{194}Hg [16] is excellent. It should be noted that for the case of band 1 in ^{192}Hg, the previous measurements [17,18] were performed using ^{36}S induced reactions and detector arrays with lower sensitivity; therefore, the associated uncertainties are larger.[1] Recent recoil distance method (RDM) measurements for ^{192,194}Hg [18,20,21] also indicate similar Q_0 values of about 18e b near the bottom of the bands. Since the RDM results do not depend on stopping power formulations, the agreement between the latter measurements and the DSAM results gives us further confidence in the stopping powers used in the analysis.

Table II compares the results of recent calculations using a variety of theoretical models with the values extracted from our measurements. In cases where the evolution of the SD minimum in deformation space is calculated as a function of the rotational frequency $\hbar\omega$, the values computed at $\hbar\omega\simeq 0.3$ MeV are listed in the table. The Q_0 values given for Chasman [22] were derived from the corresponding deformation parameters; those presented for Satuła *et al.* [23] were derived from the calculated β_2 and β_4 values using the relationship given by Nazarewicz *et al.* [10]. The other calculated quadrupole moment values were taken directly from the corresponding references.

From an inspection of Table II, it is clear that the agreement between experiment and theory is quite satisfactory, although there is a tendency for theory to give somewhat larger Q_0 values.[2] The most important conclusion to be drawn from this comparison is that the similarity in Q_0 values seen in the data is also present in the calculations, reflecting the fact that the additional neutron orbitals occupied in ^{194}Hg (with respect to ^{192}Hg) are not shape driving. In contrast, for SD bands in the $A\sim 150$ region [7,8], some pronounced differences in Q_0 values have been measured, which are correlated with the number of occupied intruder orbitals. Remarkably, the results of those studies also indicate that bands that are identical to the yrast band of ^{152}Dy have the same Q_0 values. In the case of the excited bands in ^{194}Hg, the calculations of Satuła *et al.* [23] and Heenen [29] were performed for the lowest SD neutron excitation (the [512]5/2⊗[624]9/2 configuration suggested in [9]), which is not expected to be strongly shape driving. However, from recent calculations, Nakatsukasa *et al.* [30] propose that bands 2 and 3 in ^{194}Hg correspond to the $K=2$ octupole vibration rather than to the neutron excitation proposed in Ref. [9]. While Q_0 values were not calculated for these bands in Ref. [30], changes in Q_0 values, if any, are anticipated to be small and it is not possible to distinguish between the two interpretations on the basis of our measurements.

Using the results shown in Table I, one can investigate the *maximal differences* in quadrupole moment and deformation allowed by the data for the different SD bands. (The β_2 values given in Table I were computed from the experimental Q_0 values using the expression of Ref. [10], under the assumption that the β_4 values are the same for each band.) Within experimental uncertainties, all four bands have the same quadrupole moment and deformation. The difference in Q_0 between the yrast and excited SD bands in ^{194}Hg is $\delta Q_{0,\mathrm{exp}}=0.1\pm 0.7e$ b and $0.2\pm 0.9e$ b for bands 2 and 3, respectively.

For the identical bands, the difference in Q_0 values be-

[1]Similar results were obtained by Korichi *et al.* [19] in a Eurogam experiment where an average value of $Q_0\simeq 19e$ b was measured for the yrast SD band in ^{192}Hg (see Fig. 2 of Ref. [19]).

[2]The discrepancies between the data and some of the calculations are not considered serious since the experimental errors do not include the systematic uncertainties associated with stopping powers, which are estimated to be of the order of 10–15%. Furthermore, uncertainties in parameters used in the theoretical calculations (such as r_0) limit the accuracy with which absolute Q_0 values can be compared.

TABLE III. Comparison of differences in the Q_0 values calculated for equal moments of inertia ($\delta Q_{0,\mathrm{mac}}$) and the experimental values ($\delta Q_{0,\mathrm{exp}}$) for identical SD bands in different mass regions.

Bands	$\delta Q_{0,\mathrm{mac}}$ (e b)	$\delta Q_{0,\mathrm{exp}}$ (e b)
^{192}Hg(1), ^{194}Hg(3)	1.7	0.2±1.1
^{152}Dy(1), ^{149}Gd(4)	1.9	0.0±0.7[a]
^{152}Dy(1), ^{148}Gd(3)	2.7	0.3±1.3[a]
^{152}Dy(1), ^{151}Dy(4)	0.9	0.0±0.7[b]
^{132}Ce(1), ^{131}Ce(2)	0.7	1.1±0.5[c]
^{131}Ce(1), ^{132}Ce(2)	−0.7	0.1±0.5[c]

[a]Savajols *et al.* [7].
[b]Nisius *et al.* [8].
[c]Clark *et al.* [6].

tween ^{192}Hg(1) and ^{194}Hg(3) is $\delta Q_{0,\mathrm{exp}}=0.2\pm 1.1\,e$ b. This difference is smaller than the $\delta Q_{0,\mathrm{mac}}=1.7\,e$ b (see Table III) estimated from the change in mass in the macroscopic term. Hence, further compensation for the mass change must come from a shell-correction effect (e.g., from changes in alignment and/or pairing). Table III gives the values of $\delta Q_{0,\mathrm{mac}}$ and $\delta Q_{0,\mathrm{exp}}$ for several other identical SD bands. With the exception of the [^{132}Ce(1), ^{131}Ce(2)] pair, the measurements indicate that contributions from shell-correction terms are needed to compensate for the mass change. This is consistent with the conclusions of Ref. [31] that individual valence orbitals do contribute to the quadrupole moment. However, it is not clear if one can deduce the contribution of the shell-correction term with sufficient accuracy using the simple approach discussed above. In any event, our results define the allowed difference in quadrupole moments for theories which attempt to explain identical bands.

In summary, we have measured precise lifetimes in SD bands of ^{192,194}Hg. In contrast to the $A\sim 150$ region (in particular), very little variation in the Q_0 values was found. The smaller variations probably reflect the stronger influence of pairing correlations in the SD bands of the $A\sim 190$ region, which tend to ''wash out'' the individuality of the occupied orbitals. (However, the implications of a recent differential DSAM measurement for bands in ^{192,193}Hg [32], where possible differences between the Q_0 values of ^{192}Hg(1) and several bands in ^{193}Hg were found, need to be evaluated.) The results of theoretical calculations also indicate that the SD minimum in this mass region is very stable with respect to neutron number and orbital occupation. For theories which explain the origin of identical bands, our results place tight constraints on allowed changes in quadrupole moment for offsetting mass changes. Alternatively, the theories can assume from the start the small measured difference in quadrupole moments.

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[1] C. Baktash, B. Haas, and W. Nazarewicz, Annu. Rev. Nucl. Part. Sci. **45**, 485 (1995).
[2] T.L. Khoo *et al.*, Phys. Rev. Lett. **76**, 1583 (1996).
[3] G. Hackman *et al.*, Proceedings of the Conference on Nuclear Structure at the Limits, Argonne, IL, 1996, ANL Report No. ANL/PHY-97/1 (unpublished), p. 11.
[4] A. Lopez-Martens *et al.*, Phys. Lett. B **380**, 18 (1996).
[5] K. Hauschild *et al.* [3], p. 11.
[6] R.M. Clark *et al.*, Phys. Rev. Lett. **76**, 3510 (1996).
[7] H. Savajols *et al.*, Phys. Rev. Lett. **76**, 4480 (1996).
[8] D. Nisius *et al.*, Phys. Lett. B **392**, 18 (1997).
[9] M.A. Riley *et al.*, Nucl. Phys. **A512**, 178 (1990).
[10] W. Nazarewicz, R. Wyss, and A. Johnson, Nucl. Phys. **A503**, 285 (1989).
[11] I.Y. Lee, Nucl. Phys. **A520**, 641c (1990).
[12] E.F. Moore *et al.*, in *Proceedings of Workshop on Gammasphere Physics*, Berkeley, CA, 1995, edited by M. A. Deleplanque, I. Y. Lee, and A. O. Macchiavelli (World Scientific, Singapore, 1996), p. 137.
[13] D. Nisius, Ph.D. thesis, Purdue University, 1996 (unpublished); D. Nisius *et al.* (unpublished).
[14] J.F. Ziegler, J.P. Biersack, and U. Littmark, *The Stopping and Range of Ions in Solids* (Pergamon, New York, 1985); J.F. Ziegler (private communication).
[15] H. Emling *et al.*, Phys. Lett. B **217**, 33 (1989).
[16] J.R. Hughes *et al.*, Phys. Rev. Lett. **72**, 824 (1994).
[17] E.F. Moore *et al.*, Phys. Rev. Lett. **64**, 3127 (1990).
[18] P. Willsau *et al.*, Nucl. Phys. **A574**, 560 (1994).
[19] A. Korichi *et al.*, Phys. Lett. B **345**, 403 (1995).
[20] I-Y. Lee *et al.*, Phys. Rev. C **50**, 2602 (1994).
[21] R. Kuhn *et al.*, Phys. Rev. C **55**, R1002 (1997).
[22] R.R. Chasman, Phys. Lett. B **219**, 227 (1989).
[23] W. Satuła, S. Ćwiok, W. Nazarewicz, R. Wyss, and A. Johnson, Nucl. Phys. **A529**, 289 (1991).
[24] B. Gall, P. Bonche, J. Dobaczewski, H. Flocard, and P.-H. Heenen, Z. Phys. A **348**, 183 (1994).
[25] M. Girod, J.P. Delaroche, J.F. Berger, and J. Libert, Phys. Lett. B **325**, 1 (1994).
[26] S. Krieger, P. Bonche, M.S. Weiss, J. Meyer, H. Flocard, and P.-H. Heenen, Nucl. Phys. **A542**, 43 (1992).
[27] P. Bonche, J. Dobaczewski, H. Flocard, P.-H. Heenen, S.J. Krieger, J. Meyer, and M.S. Weiss, Nucl. Phys. **A519**, 509 (1990).
[28] M. Meyer, N. Redon, P. Quentin, and J. Liebert, Phys. Rev. C **45**, 233 (1992).
[29] P.-H. Heenen (private communication); (unpublished).
[30] T. Nakatsukasa, K. Matsuyanagi, S. Mizutori, and Y. Shimizu, Phys. Rev. C **53**, 2213 (1996).
[31] W. Satuła, J. Dobaczewski, J. Dudek, and W. Nazarewicz, Phys. Rev. Lett. **77**, 5182 (1996).
[32] F.S. Stephens *et al.* [5], p. 47.