# Spreading widths for superdeformed states in $^{194}$Hg and $^{194}$Pb

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Using several theoretical models, we have obtained estimates for the spreading widths $\Gamma^{\downarrow}$ for the decay out of a superdeformed (SD) band. We pay particular attention to the statistical model by Gu and Weidenmüller. Our results for $^{194}$Hg and $^{194}$Pb are compared to other theoretical predictions and to experimental upperbounds for $\Gamma^{\downarrow}$. We find that the models of Gu and Weidenmüller and of Vigezzi *et al.* yield a consistent description of the data. We relate $\Gamma^{\downarrow}$ to the strength $v$ of the interaction that couples the normally deformed levels to the SD level at which the decay out of the SD band occurs. Using an exponential spin dependence of $v$, we are able to reproduce the intraband intensities in the SD bands in $^{194}$Hg and $^{194}$Pb.

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The sudden disappearance of the intensity of the $\gamma$ decay within a superdeformed (SD) band has posed a puzzle that has received much experimental and theoretical attention. We mention here the theoretical models put forward in Refs. [1–9], the measurements of lifetimes of the lowest observable SD states in Refs. [10–17] [these are sensitive to the interaction between SD and normally deformed (ND) states], and the study of the quasicontinuum of $\gamma$ rays linking SD and ND states [18]. A major breakthrough has occurred only recently with the first observation of discrete transitions linking the SD bands 1 (SD-1) and 3 (SD-3) in $^{194}$Hg [19,20] and the SD band 1 (SD-1) in $^{194}$Pb [21–23] with the ND levels in the same nuclei. These novel results have made it possible for the first time to determine the excitation energies, spins, and parities of SD states in the mass 190 region.

The intensity attenuation of the $\gamma$ decay within a SD band is due to the mixing of SD and ND states. Properties of the barrier separating these groups of states can be deduced from the spreading widths $\Gamma^{\downarrow}$ of the SD states. Do the theoretical models yield the same information on $\Gamma^{\downarrow}$? If not, which should be preferred? With these questions in mind, we apply in this paper various models to data on the decay out of SD bands in $^{194}$Hg and $^{194}$Pb. We pay particular attention to the model by Gu and Weidenmüller [7] as this model is derived under controlled approximations from the underlying statistical theory. Additionally, we are able to reproduce the intraband intensities in the SD bands in $^{194}$Hg and $^{194}$Pb using an exponential spin dependence of $v$.

The model of Ref. [7] is based on a statistical treatment. The ND states are described in terms of the Gaussian orthogonal ensemble of random matrices. Within the model the intensity $\overline{I_{\text{in}}}$ for $\gamma$ decay within the SD band is the sum of two parts,

$$\overline{I_{\text{in}}}=I_{\text{av}}+\overline{I_{\text{fluc}}}. \tag{1}$$

Here, $I_{\text{av}}$ is the square of the ensemble average of the intraband transition amplitude while $\overline{I_{\text{fluc}}}$ is the ensemble average of the square of the fluctuating part of the same amplitude. The first term is given by

$$I_{\text{av}}=\frac{1}{1+\dfrac{\Gamma^{\downarrow}}{\Gamma_S}}. \tag{2}$$

Here, $\Gamma_S$ stands for the $E2$ decay width within the SD band, and the spreading width $\Gamma^{\downarrow}=2\pi v^2/D$ describes the mixing between the SD state and the ND states of the same spin and parity due to barrier penetration where $v$ is the root-mean-square nuclear matrix element.

The quantity $I_{\text{av}}$ dominates over $\overline{I_{\text{fluc}}}$ whenever the ND levels overlap (average ND level spacing $D$ smaller than or similar to the average $\gamma$-decay width $\Gamma_N$ of the ND states) while $\overline{I_{\text{fluc}}}$ is important or even dominant in the opposite case where $\Gamma_N < D$. This latter case is typical of most heavy nuclei for which decay out of a SD band has been observed. In Ref. [7], the term $\overline{I_{\text{fluc}}}$ is given in closed form [7], and $\overline{I_{\text{fluc}}}$ is seen to depend only on the two dimensionless parameters $\Gamma^{\downarrow}/\Gamma_S$ and $\Gamma_N/D$. In the sequel, we do not use the closed-form expression but a fit formula for $\overline{I_{\text{fluc}}}$ also given in Ref. [7],

$$\overline{I_{\text{fluc}}}=\left[1-0.9139\left(\frac{\Gamma_N}{D}\right)^{0.2172}\right]\times\exp\left\{-\frac{\left[0.4343\ln\left(\dfrac{\Gamma^{\downarrow}}{\Gamma_S}\right)-0.45\left(\dfrac{\Gamma_N}{D}\right)^{-0.1303}\right]^2}{\left(\dfrac{\Gamma_N}{D}\right)^{-0.1477}}\right\}. \tag{3}$$

We recall that within the statistical model of Ref. [7], $I_{\text{fluc}}$ carries sizable statistical errors because the intraband intensity is sensitive to the relative positions of SD and ND states that are coupled by $v$. Figure 2 of Ref. [7] shows that as a result, the values of $\Gamma^{\downarrow}$ have an uncertainty of about an order of magnitude. Within these uncertainties, the fit formula (3) is a reasonable approximation to the analytical result for $\overline{I_{\text{fluc}}}$. We have smoothed the sum $\overline{I_{\text{in}}}=I_{\text{av}}+\overline{I_{\text{fluc}}}$ so that it does not rise above intensity values of 100% that might otherwise

 

TABLE I. Intraband intensity $I_{\mathrm{in}}$, width $\Gamma_S$ of SD states (calculated using average quadrupole moments), calculated $E1$ width $\Gamma_{E1} = \Gamma_N$, and average level spacing $D$ of the ND states for states in SD bands in $^{194}$Hg and $^{194}$Pb. The intraband intensity $I_{\mathrm{in}}$ is defined as that fraction of the occupation probability of a SD state at spin $J$ that decays to the lower-lying SD state at spin $(J\text{-}2)$.

| SD band | $J$ ($\hbar$) | $E_\gamma$ (keV) | $I_{\mathrm{in}}$ (%) | $\Gamma_S$ (meV) | $\Gamma_{E1}$ (meV) | $D$ (eV) |
|---|---|---|---|---|---|---|
| $^{194}$Hg-1 | 12 | 255 | 58 | 0.097 | 4.8 | 16.3 |
| | 10 | 212 | $<9$ | 0.039 | 4.1 | 26.2 |
| $^{194}$Hg-3 | 15 | 303 | 90 | 0.230 | 4.0 | 26.5 |
| | 13 | 262 | 84 | 0.110 | 4.5 | 19.9 |
| | 11 | 222 | $<7$ | 0.048 | 6.4 | 7.2 |
| $^{194}$Pb-1 | 10 | 214 | 90 | 0.045 | 0.08 | 21 700 |
| | 8 | 170 | 62 | 0.014 | 0.50 | 2200 |
| | 6 | 124 | $<9$ | 0.003 | 0.65 | 1400 |

happen because of the approximate nature of the fit formula (3). (The result of the full theory by Gu and Weidenmüller always stays below or at 100%.) The difference between the smoothed fit formula and the exact result remains below 20% and is thus small compared to the statistical error, see Fig. 3 of Ref. [7].

Because of the large fluctuations of the intensity, it is not sufficient to work only with $\overline{I_{\mathrm{fluc}}}$. The variance of $I_{\mathrm{in}}$ must also be taken into account. In our analysis, we assume that the experimental intensity patterns are close to the average behavior. This assumption is supported by the observation that the intensity patterns of all observed SD bands in the mass 190 region are fairly similar although the excitation energies of the bands differ. This is a somewhat surprising feature that is not understood at present. We cannot expect that the intensity pattern of every SD band follows exactly the calculated average intensities. Therefore, the extracted values for $\Gamma^{\downarrow}$ have to be seen as estimates rather than exact values.

For the determination of $\Gamma^{\downarrow}$ we have calculated $\Gamma_S$ from the average SD quadrupole moments (17.3 $e$ b for $^{194}$Hg and 18.3 $e$ b for $^{194}$Pb). These average quadrupole moments were extracted from the results of experiments using the recoil distance method [15,16] and the Doppler-shift attenuation method [24,25]. The width $\Gamma_N$, was calculated under the assumption that statistical $E1$ transitions will dominate the decay of the ND states ($\Gamma_N$, $\approx \Gamma_{E1}$) at the high excitation energy of the SD states. We have used the approach outlined by Døssing and Vigezzi [26] to calculate the level density $\rho(U)$ and the $E1$ width $\Gamma_{E1}$ at the excitation energy $U = E_x - 2\Delta$. The $E1$ width is approximated by the analytical expression [26] $\Gamma_{E1} = c_{E1} T^5$, with $T \approx \sqrt{a/U}$. The parameters in Ref. [10] were used to calculate the factor $c_{E1}$ [26] and the level density parameter $a = 22.58$ MeV$^{-1}$. A backshift parameter of $2\Delta = 1.4$ MeV was used for $^{194}$Hg and $^{194}$Pb, which is based on the analysis of the continuum $\gamma$-ray spectra of the decay out of the SD band in $^{194}$Hg [27]. The experimentally known excitation energies at each spin were used for the SD [19,20,22,23] and ND [28] states.

Table I shows the calculated values for $\Gamma_S$, $\Gamma_N$, and $D$ for the levels of interest in $^{194}$Hg and $^{194}$Pb. We note that because of the small excitation energy of the SD states in $^{194}$Pb, the approximation $\Gamma_N \approx \Gamma_{E1}$ may not quite suffice here. This is also indicated by the observation of $M1/E2$ transitions in the decay out of the yrast SD band in $^{194}$Pb.

The spreading width $\Gamma^{\downarrow}$ can be determined numerically by using Eq. (1). Our analysis shows that in the present case, $I_{\mathrm{av}}$ contributes at most 4% to $\overline{I_{\mathrm{in}}}$ while $\overline{I_{\mathrm{fluc}}}$ is dominant. Thus we can neglect $I_{\mathrm{av}}$ in Eq. (1) and calculate $\Gamma^{\downarrow}$ analytically from the data. The difference between the numerical result for $\Gamma^{\downarrow}$ and this approximation is at most 6%. This value is small in comparison with the statistical error expected from Fig. 2 of Ref. [7] and comparable to the error of the fit formula (3).

In Table II we compare the results for $\Gamma^{\downarrow}$ obtained from the model of Ref. [7] as just described (fourth column) with results obtained from several other models [2,4,5]. We also compare with the upper limits for $\Gamma^{\downarrow}$ extracted from lifetime measurements [16] (last column). The values determined from the data in the weak-mixing limit of the model by Vigezzi *et al.* [2] (third column) are of the same order of magnitude as our results. This is expected since according to Ref. [7], both models should give similar results if $\Gamma_N \ll D\Gamma^{\downarrow}/\Gamma_S$. This condition is met for those states in the mass 190 region for which decay out of the SD band has been observed. (Some deviations between the two approaches are expected due to the approximations used in Ref. [2]. The most significant differences appear when $I_{\mathrm{in}}$ drops below 10%.) The results in both columns meet the constraints imposed by the experimental data. The $\Gamma^{\downarrow}$ values given in Ref. [5] (column 3) are much smaller than all other values. This is due to the fact that in Ref. [5] only $I_{\mathrm{av}}$ was considered and $\overline{I_{\mathrm{fluc}}}$ was neglected ($\overline{I_{\mathrm{in}}} \approx I_{\mathrm{av}}$). As noted above and as already pointed out in Ref. [7], this approximation is not reasonable in the mass 190 region. We conclude that in this mass region, a consistent analysis of the data is possible in the framework of both Refs. [2,7], while Ref. [5] is not applicable.

The model of Ref. [8] is based on a two-level mixing model for resonant states and reports values for $\Gamma^{\downarrow}$ that are equal to those of Ref. [5]. At first sight it is not clear why this mixing model should give results that differ so strongly from, say, the weak-mixing limit of Ref. [2]. A closer look at Refs. [2,7,8] shows that all models come to very similar results for the interaction strength $v$ (see Table III). However,

TABLE II. Average spreading width $\Gamma^{\downarrow}$ determined in this work using the framework of various models for states in SD bands in $^{194}$Hg and $^{194}$Pb. The maximum spreading widths $\Gamma^{\downarrow}_{max}$ determined from lifetime measurements [15,16] are presented in the last column.

| Band | $J$ ($\hbar$) | $\Gamma^{\downarrow}$ (meV) | | | | $\Gamma^{\downarrow}_{max}$ (meV) |
|---|---|---|---|---|---|---|
| | | Ref. [4] | Refs. [5,8] | Ref. [2] | This work[a] | Ref. [16] |
| $^{194}$Hg-1 | 12 | 6800 | 0.097 | 37 | 25 | 270 |
| | 10 | 27 500 | $>$0.890 | $>$132 | $>$800 | |
| $^{194}$Hg-3 | 15 | 84 200 | | 10 | 6 | 110 |
| | 13 | 111 000 | | 8 | 4 | 120 |
| | 11 | 147 000 | | $>$30 | $>$300 | |
| $^{194}$Pb-1 | 10 | 15 100 | 0.011 | 79 000 | 390 000 | 1 710 000 |
| | 8 | 131 000 | 0.009 | 5600 | 3200 | 42 200 |
| | 6 | 1 130 000 | | $>$3400 | $>$103 000 | |

[a]Based on the framework of Ref. [7].

Ref. [8] uses a relation connecting the spreading width $\Gamma^{\downarrow}$ and the interaction strength $v$ that differs from that of all other work. The quantity $\Gamma^{\downarrow}$ introduced in Ref. [8] is defined as $\Gamma^{\downarrow}=2\overline{\Gamma}v^2/(\Delta^2+\overline{\Gamma}^2)$, with $\overline{\Gamma}=(\Gamma_S+\Gamma_N)/2$. This quantity is not related to the spreading width $\Gamma^{\downarrow}$ used in this work; the two quantities should, therefore, not be compared.

The model by Shimizu *et al.* [3,4] differs from the ones discussed so far, in that it *predicts* values for $\Gamma^{\downarrow}$. In this model, the action $A$ for the superfluid tunneling through the potential barrier separating the SD and ND potential wells is calculated. The model also predicts the dependence of the action on the spin of the state for which decay out of the SD band occurs. The action $A$ is related to $\Gamma^{\downarrow}$ by $\Gamma^{\downarrow}=(\hbar\omega_s/2\pi)\exp(-2A)$, with $\hbar\omega_s\approx 0.6$ MeV [10]. For most states, the predicted values for $\Gamma^{\downarrow}$ (column 2) are seen to be significantly larger than the results of Refs. [2,7]. The $\Gamma^{\downarrow}$ values of Refs. [3,4] are also inconsistent with the upper limits for $\Gamma^{\downarrow}$ shown in the last column. The large overestimate of $\Gamma^{\downarrow}$ by the model of Refs. [3,4] is not understood so far.

We conclude the first part of this paper by summarizing our results. Whenever $\overline{I_{\rm fluc}}$ dominates over $I_{\rm av}$, the models of Refs. [2,7] yield, within the expected statistical error, equivalent values for $\Gamma^{\downarrow}$. These values lie within the bounds given by lifetime measurements. We expect that similar statements apply even when $\overline{I_{\rm fluc}}$ and $I_{\rm av}$ are comparable. In the regime $\overline{I_{\rm fluc}}\geqslant I_{\rm av}$, the result of Ref. [5] cannot be used to analyze the data. The work of Ref. [8] uses a nonequivalent definition of $\Gamma^{\downarrow}$. The estimates given in Refs. [3,4] are far too large. This fact calls for a deeper theoretical understanding of the barrier penetration mechanism.

In the second part of this paper we study the possibility to use the model by Gu and Weidenmüller [7] to reproduce the experimentally observed intensity patterns. It has been shown in the recent paper by Krücken [9] that one needs an exponential spin dependence of the interaction to account for the sudden decay out of the SD bands. This fact was already pointed out in a number of papers [2,4,6,29]. In Ref. [9] a Monte Carlo simulation on the basis of a two-level mixing model was compared with predictions based on the model by Gu and Weidenmüller. It was shown that for the same spin dependent interaction both approaches predicted similar average intraband intensities. In this paper we elaborate more on the results within the framework of the model by Gu and Weidenmüller.

TABLE III. Comparison of the interaction strength $v$ obtained from several models for the decay out of SD bands in $^{194}$Hg and $^{194}$Pb. The values in the last column are calculated from the $\Gamma^{\downarrow}$ values in Ref. [8] by the relation $\Gamma^{\downarrow}=2\pi v^2/D$.

| SD band | $J$ ($\hbar$) | $v$ (eV) | | |
|---|---|---|---|---|
| | | Ref. [2] | This work[a] | Ref. [8] modified |
| $^{194}$Hg-1 | 12 | 0.31 | 0.26 | 0.49 |
| | 10 | $>$0.74 | $>$2.6 | $>$2.2 |
| $^{194}$Hg-3 | 15 | 0.20 | 0.16 | 0.51 |
| | 13 | 0.16 | 0.18 | 0.33 |
| | 11 | $>$0.19 | $>$0.68 | 0.63 |
| $^{194}$Pb-1 | 10 | 522 | 1150 | 1130 |
| | 8 | 44 | 43 | 71 |
| | 6 | $>$27 | $>$280 | $>$78 |

[a]Based on the framework of Ref. [7].

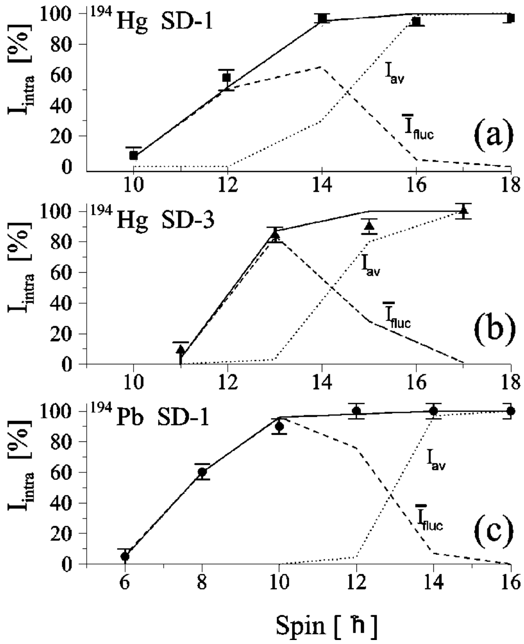


FIG. 1. Experimental intraband intensities (in percent) in the SD band $^{194}$Hg-1 (a), $^{194}$Hg-3 (b), $^{194}$Pb-1 (c), in comparison to the calculated average intraband intensity $\overline{I_{\rm in}}=I_{\rm av}+\overline{I_{\rm fluc}}$ as given by Eq. (1) [7]. An exponential parametrization of $v(J)=v_0e^{-\alpha J}$ was used for the interaction strength. Values of $v_0=50$ keV ($v_0=100$ keV) and $\alpha=1$ were used for $^{194}$Hg ($^{194}$Pb). The two components ($I_{\rm av}$, $\overline{I_{\rm fluc}}$ contributing to $\overline{I_{\rm in}}$ are shown as well.

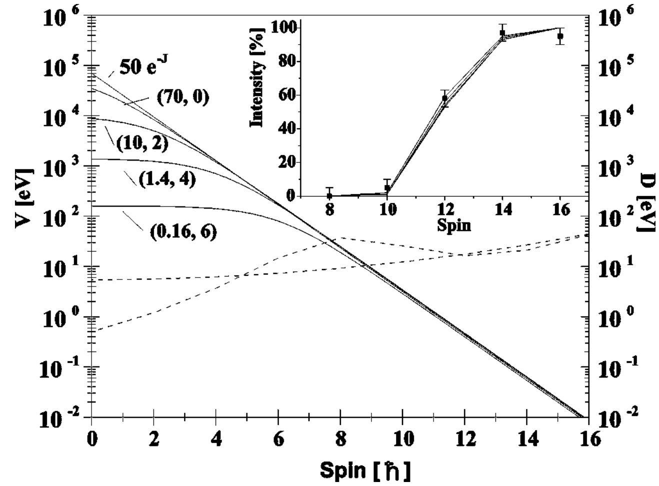


FIG. 2. The interaction strength versus spin for the parametrizations of Eqs. (4) and (5) (solid lines). The curves are labeled by the parameter values [$v_0$ (keV), $J_0$ ($\hbar$)]. The curves nearly coincide in the region where the decay out of the SD band in $^{194}$Hg occurs. The dashed lines show the estimates of the mean level spacing $D$ of the ND states at the excitation energy of the SD states in the yrast SD band in $^{194}$Hg as explained in the text. The inset shows the intensity patterns for $^{194}$Hg SD-1 calculated with the various parametrizations for $v(J)$ in comparison to the experimental intensities.

We will start by using a spin dependent interaction of the form

$$v(J)=v_0e^{-\alpha J}. \tag{4}$$

This parametrization corresponds to a linear spin dependence of the action integral for the tunneling through the barrier separating superdeformed and normal deformed potential minima [3,4,10]. As in the example of Fig. 1 in Ref. [9] we use parameters of $v_0=50$ keV and $\alpha=1$ for the SD bands SD-1 and SD-3 in $^{194}$Hg. Figures 1(a) and 1(b) show the calculated average intraband intensities $\overline{I_{\rm in}}=I_{\rm av}+\overline{I_{\rm fluc}}$ as a function of angular momentum in comparison to the experimental data in $^{194}$Hg bands SD-1 and SD-3. Also shown are the individual components $I_{\rm av}$ and $\overline{I_{\rm fluc}}$. Figure 1(c) shows the same for SD band SD-1 in $^{194}$Pb but here the intensities were calculated using $v_0=100$ keV. One can see that the calculated intensities closely follow the experimental intensities. However, we would emphasize again that for purposes of practicality we have assumed that the experimental intensities are a good representation of the average behavior expected for each band. We feel that this assumption is supported by the fact that the Monte Carlo simulations by Krücken [9] find that the parameters used here are within the set of parameters that provide the maximum probability to reproduce the experimental data in $^{194}$Hg.

The figure also shows that at the point of the decay out the fluctuating part $\overline{I_{\rm fluc}}$ is clearly the dominant contribution to $\overline{I_{\rm in}}$. Our results support the findings of Ref. [9] that the yrast and excited SD band in $^{194}$Hg can be described by the same interaction function. For $^{194}$Pb we have used an interaction of $v_0=100$ keV leading to significantly larger interactions at the point of the decay out as compared to $^{194}$Hg.

It is important to ask the question what role possible fluctuations play and if one even should expect the calculated average intraband to agree with the experimental intensities of a single band. It was shown in Ref. [9] that fluctuations of the separation between the mixing SD and ND will have an influence on the observed intensity pattern. For clarity let us consider the example of band SD-1 in $^{194}$Hg. Figure 2 in Ref. [9] shows that the intensity at spin $12\hbar$ can have almost any value and is very sensitive to the exact separation between the SD and ND states. However, from this figure it is also evident that at spin $14\hbar$ independent of the level separation the intraband intensity is larger than 90%. Similarly, at spin $10\hbar$ the intraband intensity is below 10%. Therefore, we can conclude that the point of the decay out is defined by the spin dependence of the interaction alone while the exact intensity for the intermediate spin depends on the exact level separation. In a similar way we expect that fluctuations of the transition strength $\Gamma_{E1}$, such as Porter-Thomas fluctuations, have a similar effect on the detailed intensity pattern but do not determine the point of the decay out. However, the exact role of these fluctuations has not yet been studied in detail. We would conclude this discussion by remarking that the exact reproduction of the experimental intensity pattern, while possible, is not the main goal of this investigation. We are using the experimental intensities mostly as a guideline that defines the point of the decay out.

Another experimental observable that can be used to test the theoretical description of the decay out is the transition quadrupole moment of the intraband transitions in the spin range of the decay out. While Ref. [7] does not provide an explicit prediction for the quadrupole moments we can use the near equivalence of the model by Gu and Weidenmüller and the two-level mixing model used by Vigezzi *et al.* and Krücken. In particular, the Monte Carlo simulations of Ref. [9] show that the experimental intensity pattern and quadrupole moments are simultaneously reproduced using the same the exponential spin dependence of the interaction as used in this paper for the model by Gu and Weidenmüller. We would point out that an explicit calculation of quadrupole moments within the framework of the full statistical model by Gu and Weidenmüller would be desirable for the future.

Finally, we would discuss if the assumed exponential spin dependence is unique or if other solutions for the spin dependence of the interaction are possible. Extrapolation of $v$ in Eq. (4) down to $J=0$ yields values of $v=v_0 \sim 50-100$ keV. This figure is comparable to the strength of the interaction that couples collective excitations in nuclei and, thus, seems somewhat large. We have to bear in mind, however, that we are sensitive to $v$ only in the spin range where the decay out of the SD band happens. In the absence of a reliable microscopic model for the spin dependence of the interaction (tunneling action) one has to consider other parametrizations that gives similar values for $v$ and its spin dependence in the experimentally accessible spin range. Until there is a better microscopic understanding of the interaction or other experimental observables constraining the possible parametrizations we have to consider deviations from the simple exponential spin dependence. One could, for example, consider saturation of the interaction (or equivalent the action of the tunneling through the barrier) at low spin values as given by the parametrization

$$v(J)=\frac{v_0}{1+e^{(J-J_0)}}. \tag{5}$$

Figure 2 displays this parametrization for various combinations of the parameters $v_0$ and $J_0$ (solid curves). For the SD bands in $^{194}$Hg, the results are very similar in the spin region where the decay out of the bands occur. The inset shows the average intraband intensities derived for these interactions. They all yield a very satisfactory description of the data for the band $^{194}$Hg SD-1. Thus we see that the value of $v_0$ cannot be uniquely extracted from the data. In Fig. 2, we also show the average level spacing $D$ (dashed curves). These curves were calculated for the ND states at the excitation energy of the SD states of the yrast SD band in $^{194}$Hg. The nonmonotonic curve for $D$ is obtained from the experimental ND yrast line. The smooth curve is based on a smooth ND yrast line fitted to the experimental ND states in the spin range from $16\hbar$ to $24\hbar$. Our results for the interaction strength and spreading do not depend sensitively on the use of either curve. From Fig. 2 it is apparent that the interaction strength in the critical spin range $(10\hbar-14\hbar)$ is much smaller than the mean level spacing.

Recently it has been suggested by Åberg [6] that the enhancement of the decay out of the SD band is due to the onset of chaos. This would explain the exponential dependence of $v(J)$. However, the close similarity of the interaction strengths for the states in the yrast and excited SD bands in $^{194}$Hg seem to contradict this suggestion. If the onset of chaos in the ND states would play a role for the yrast SD band in $^{194}$Hg one would expect that the ND states in the vicinity of the states in the excited SD bands would be already more chaotic, resulting in a larger interaction or a decay out of the band at higher spin values. This is not seen in the data.

In summary, we have been able to reproduce the spin dependence of the experimental intensity patterns by using an exponential parametrization for the spin dependence of the interaction strength. An extrapolation of this strength to spin zero is not possible. Several parametrizations for $v(J)$ describe the experimental data well but differ in their values at spin zero by several orders of magnitude. The interaction strength in the region of the decay out of the SD band is typically much smaller than in cases where coexisting shapes interact and where typical values of tens of keV are found. This indicates that the interaction between the SD states and the ND states is suppressed by the tunneling barrier.

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