CONF-9607156--15

Systematic Description of Superdeformed Bands in the Mass-190 Region

Yang Sun[1,2,3], Jing-ye Zhang[2], and Mike Guidry[2,3]
[1] *JIHIR, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831*
[2] *Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996*
[3] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831*

Abstract

Superdeformed bands for the mass-190 region are described by the Projected Shell Model. Even–even, odd mass and odd–odd nuclei are equally well described. Good agreement with available data for all isotopes studied is obtained. Our calculation of electromagnetic properties and pairing correlations provides an understanding of the observed gradual increase of dynamical moments of inertia with angular momentum observed in many bands in this mass region.

In the superdeformed (SD) mass-190 region, data show that both kinematical ($\mathcal{J}^{(1)}$) and dynamical ($\mathcal{J}^{(2)}$) moments of inertia (MoI) for many SD bands exhibit a gradual increase as a function of increasing rotational frequency, with a more pronounced increase in $\mathcal{J}^{(2)}$. The usual explanation using the cranking model is that this behavior is caused by a gradual rotation alignment of pairs from high-j intruder orbitals [1]. Although the role played by high-j intruders for many phenomena in a normally deformed system is well understood, it is not obvious that such knowledge translates simply to the SD case for at least two reasons: (1) At the static level, high-j intruder orbitals are no longer of unique parity at larger deformation as they are in the normally deformed case [2,3]. (2) At the dynamical level, the larger quadrupole moment for a SD band implies more mixing among different configurations through the two-body hamiltonian, which includes explicitly a quadrupole–quadrupole term. This mixing will reduce the influence from any particular orbital.

In order to further understand the issues raised above, we have performed calculations using the projected shell model. The calculations that we describe provide a full description of the SD spectrum, electromagnetic properties, and pairing properties. We shall demonstrate that all the observed quantities are reproduced by this calculation, and that a gradually decreasing pairing caused by the Coriolis Antipairing (CAP) effect acting on both low and high-j orbitals is responsible for the observed smooth increase of the MoI.

Our theoretical analysis for SD nuclei is based on the Projected Shell Model (PSM) [4], which has been generalized from its description of normally deformed systems [5]. The configuration space and the interaction strengths in the Hamiltonian used for the description of the SD mass-190 region are given in Ref. [2].

In Fig. 1, we compare calculated transition energies E_γ and dynamical MoI $\mathcal{J}^{(2)}$ with the available measurements for yrast SD bands in even–even $^{188-196}$Hg isotopes. The agreement

DISCLAIMER

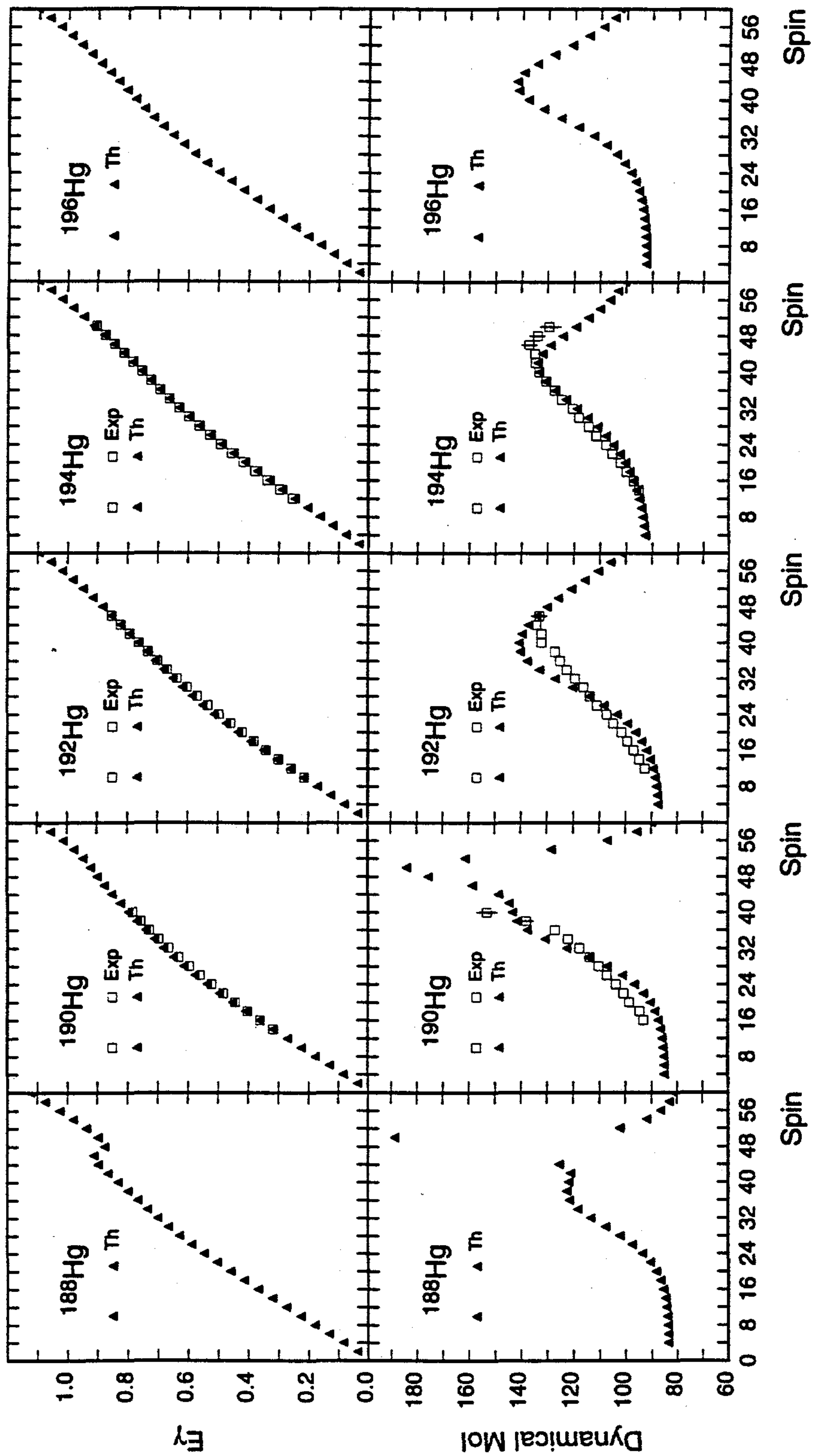

FIG. 1. Comparison of calculations with experimental data for even–even $^{188-196}$Hg: a) γ-ray energies defined by $E_\gamma(I) = E(I) - E(I-2)$ (MeV); b) Dynamical MoI defined by $\mathcal{J}^{(2)}(I) = 4/[E_\gamma(I) - E_\gamma(I-2)]$ ($\hbar^2$MeV^{-1}).

with data is extremely good, with even the sensitive dynamical MoI being reproduced well. The MoI rises gradually with angular momentum for all nuclei in this mass region; however, the rate of increase (slope of $\mathcal{J}^{(2)}$) varies from nucleus to nucleus. The calculations reproduce these variations well without adjustment of parameters, indicating the potential of the model to give a quantitative description of SD nuclei. The differences in slope arise from the variation of effective interaction strengths and band crossing spin for different nuclei, which is a common occurrence in normally deformed bands [6,7]. It is clear that extension of data in known SD nuclei by even a few spin units, or observation of SD states in Hg isotopes 2 neutron numbers larger or smaller than presently known, could provide strong tests of these calculations. We predict a backbending at $I = 48\hbar$ in ^{188}Hg.

Generally, we predict a gradually decreasing $\mathcal{J}^{(2)}$ for the highest spins. The whole pattern forms a smooth bump with the maximum at about $I = 42\hbar$. At this spin the SD ground-state band (g-band) crosses, simultaneously, a 2-qp proton band and a 2-qp neutron band. After the crossing, the 2-qp proton band is lower in energy and thus has larger weight in the yrast band for $I > 42\hbar$. We note that changing the quadrupole pairing will shift the band crossing, thereby shifting the peak in the $\mathcal{J}^{(2)}$ curve. If the quadrupole pairing employed in Fig. 1 is decreased (increased) by 30%, the $\mathcal{J}^{(2)}$ peak for ^{194}Hg is shifted to $I = 38\hbar$ ($I = 46\hbar$), but the E_γ values are displaced by only a few keV. Thus, the location of the maximum in $\mathcal{J}^{(2)}$ is sensitive to the quadrupole pairing strength, but our other results do not depend significantly on this parameter. In particular, the quadrupole pairing force is not found to be responsible for the gradual increase behavior of $\mathcal{J}^{(2)}$, as claimed in Ref. [8].

The angular momenta for experimental states in Fig. 1 are those proposed by the corresponding experimentalists, but only for ^{192,194}Hg are these measured quantities. For ^{192,194}Hg the agreement with data is excellent, with the experimental and theoretical E_γ values virtually indistinguishable on the scale of the plot. This provides strong theoretical support for recently-measured spin values in these nuclei. This indicates also that the present model could be a powerful tool to predict unknown spins for SD nuclei.

Comparisons of our results with data for odd-mass nuclei are shown in Fig. 2, where we take the recent SD measurements for ^{193}Pb and ^{193}Tl as representative examples for odd-N and odd-P nuclei, respectively. In the left part of Fig. 2, the calculated $\mathcal{J}^{(2)}$ for the $[761]\frac{3}{2}$ band in ^{193}Pb starts at a higher value, deceases rapidly until $I = 16\hbar$, and finally increases again at $I = 36\hbar$. Thus, $\mathcal{J}^{(2)}$ is observed to be approximately constant for the spin region $I = 16 - 36\hbar$, but predict that it should increase at higher spins. One observes also that for the signature partner bands 1 and 2, our calculation predicts a larger $\mathcal{J}^{(2)}$ for band 1 until $I = 36\hbar$, as found in the data. After that spin, $\mathcal{J}^{(2)}$ for band 2 has a larger value. Very good agreement with data for the E_γ's is obtained, particularly for higher spins, and the signature splitting between the partners is also reproduced. Thus, our calculations support the present spin assignment.

The right part of Fig. 2 shows our results, together with data, for the $[642]\frac{5}{2}$ band of ^{193}Tl. The present data stop at the point where the theoretical $\mathcal{J}^{(2)}$ curve turns downward at $I = 44\hbar$. Again, extension of the data to higher spins will test our prediction. For the E_γ's, there is good overall agreement between data and calculations, with the right phase and amplitude in the splitting of signature partners.

Fig. 3 compares the same data [9] with two sets of calculations. A nearly constant $\mathcal{J}^{(2)}$ is observed in the measured spin interval. In the left part of Fig. 3, we performed a calculation by using the configuration proposed in Ref. [9], $\nu[761]\frac{3}{2} + \pi[642]\frac{5}{2}$. However, we obtained a decreasing $\mathcal{J}^{(2)}$. The other configuration, $\nu[642]\frac{3}{2} + \pi[642]\frac{5}{2}$, reproduces the data much

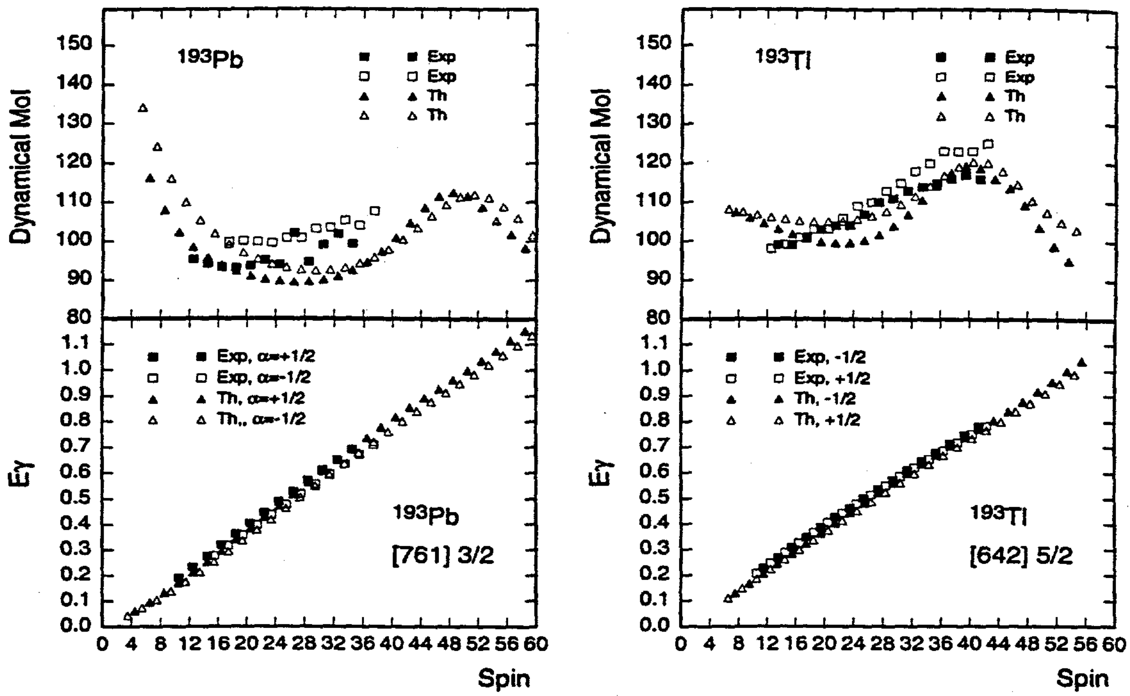

FIG. 2. Comparison of calculations with experimental data for ^{193}Pb (left part), and for ^{193}Tl (right part).

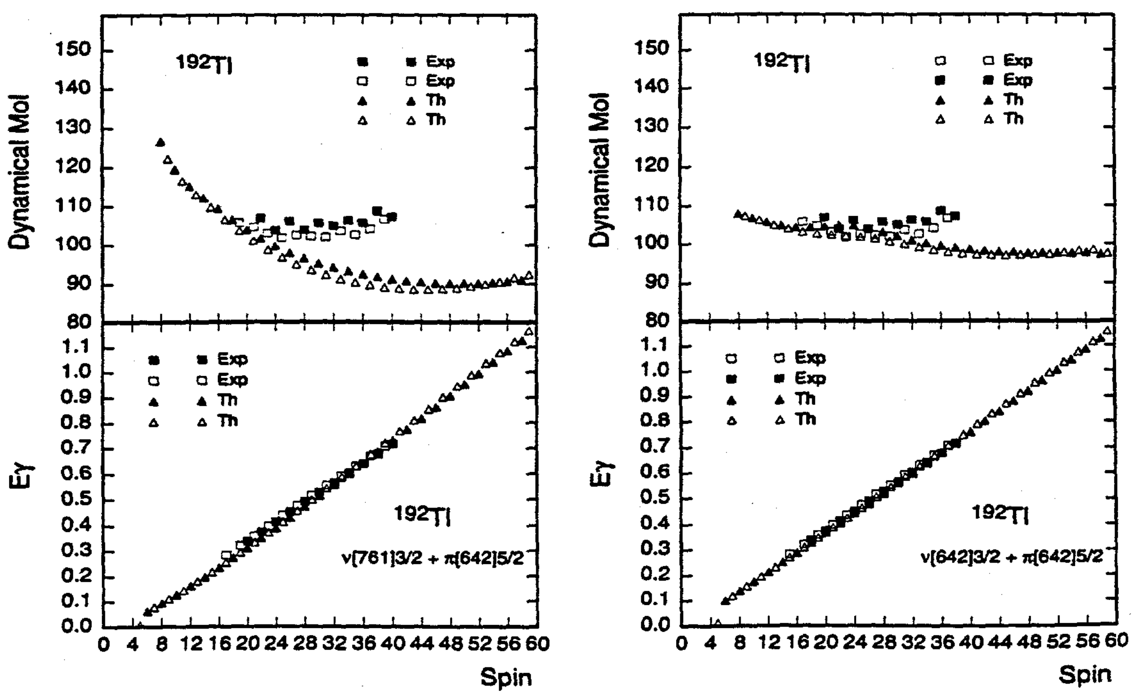

FIG. 3. Comparison of calculations with experimental data for ^{192}Tl. See text for theoretical configurations.

better, with excellent agreement in $\mathcal{J}^{(2)}$ up to $I = 32\hbar$ — see the right part of Fig. 3. (The deviation beyond that spin is due to the absence of 4-qp states in our odd–odd calculations.) A better agreement in E_γ for the latter configuration is also observed.

Since our wavefunctions are eigenfunctions of angular momentum, we can calculate unambiguously the transition quadrupole moment Q_t, g-factor, and pairing gaps (Δ_n and Δ_p), as a function of angular momentum. These quantities are defined in Ref. [10]. In Fig. 4 we show the theoretical values of these quantities for the SD yrast band in ^{194}Hg. Rather constant Q_t (Fig. 4a) is found up to $I \approx 24\hbar$, with a value of 16.8 eb that is comparable to the measured average Q_t of 17.2 ± 2.0 eb. Above that spin, the theoretical values are gradually and smoothly quenched because of gradual alignment processes that lead to a small reduction of collectivity. Therefore, this calculation indicates that stretching in deformation is negligible for the range of measured angular momenta in the ^{194}Hg yrast band.

The calculated g-factors are presented in Fig. 4b. There are as yet no experimental data available for comparison. These quantities are sensitive to the alignment of individual nucleon pairs. Proton and neutron g-factors are plotted separately, as is their sum. We observe a rather constant, small, and negative value for neutrons. The behavior of the total g-factor is governed by that of the protons, which shows a gradual increase with angular momentum in the range $I = 24 - 44\hbar$. At $I = 44\hbar$, the total g-factor reaches $Z/A \approx 0.41$ and saturates thereafter. The g-factors suggest that the rotation alignment of high-j orbitals enhances the MoI, but the alignment contribution seems insufficient to cause the pronounced increase in the MoI seen in Fig. 1 for ^{194}Hg. In particular, this cannot easily explain the increase in the MoI before $I = 24\hbar$, where the high-j pair alignment is small.

We show calculated pairing gaps in Fig. 4c. Note that the quantities displayed are not BCS gaps; they are computed from the many-body wavefunctions, which incorporate dynamical effects in the pair field [10]. We observe steady quenching of proton and neutron pairing with increasing spin across the entire spin range. This smooth decrease of Δ corresponds to a collective CAP effect that enhances the MoI with increasing angular momentum. A somewhat steeper decrease in the gap is found for protons in the range $I = 24 - 44\hbar$. This additional contribution comes from the increasing importance of high-j pair alignment, in accord with discussions given above.

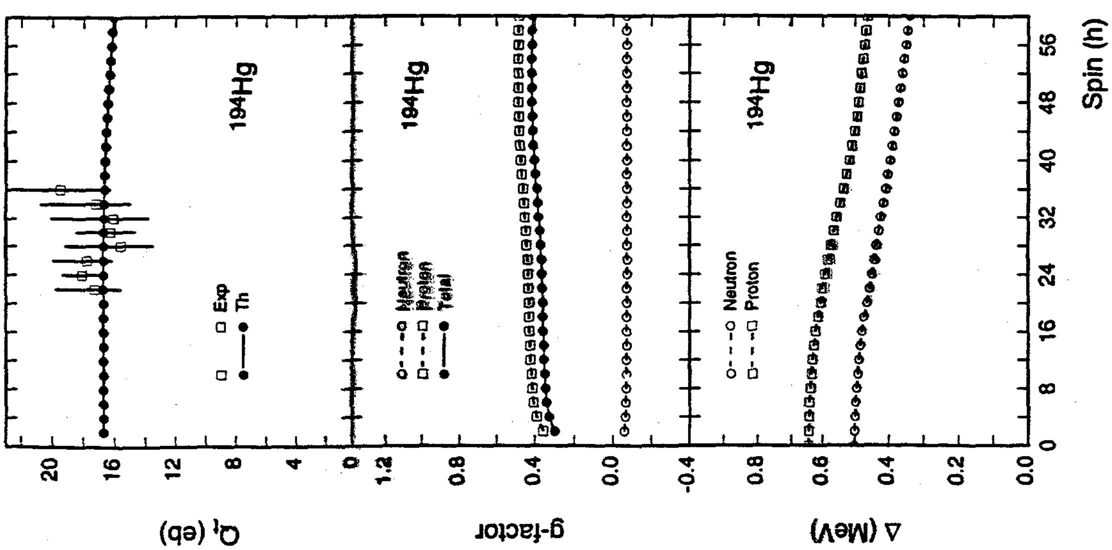

FIG. 4. For ^{194}Hg: a) Comparison of the calculated transition quadrupole moments (in eb) with the data. b) Theoretical g-factors; c) Theoretical pairing gaps (in MeV).

Thus we conclude that the gradual increase of the MoI for SD bands in the mass-190 region is due to smooth quenching of pairing correlations by the CAP effect, which receives contributions from all orbitals and only becomes dominated by gradual rotation alignment of high-j particles at higher spins. In previous discussions [1,8], the gradual rotation alignment of quasiparticles from high-j orbitals was stressed, but the important average contribution of *all orbitals* through the CAP effect has not been emphasized. This observation is implicit in previous studies where it was noticed [1] that treatment of the collective motion in a cranking model with shell-correction calculations could have difficulties for a quantitative description of the MoI of a SD band.

In conclusion, the Projected Shell model has been used to provide the first comprehensive theoretical description of the SD bands in the mass-190 region that simultaneously describes all observables, including the angular momentum. The increase of the MoI is caused by a smooth decrease of the pairing correlation within the nucleus due to a combination of the CAP effect and rotation alignment of high-j pairs, with no evidence of deformation stretching. These conclusions are supported by calculations of transition quadrupole moments, g-factors, and pairing gaps. We notice in this connection the recently observed relative transition quadrupole moments for SD bands in ^{132}Ce and ^{131}Ce [11], indicating a negligible polarization effect induced by the high-j particles. Finally, these calculations provide a variety of predictions that could be tested by extension of existing SD data to somewhat higher spins and to other nuclei in this region, and by measurement of g-factors.

ACKNOWLEDGMENTS

The Joint Institute for Heavy Ion Research has as member institutions the University of Tennessee, Vanderbilt University, and the Oak Ridge National Laboratory; it is supported by the member institutions and by the U. S. Department of Energy through Contract No. DE–AS05–76ER04936 with the University of Tennessee. Theoretical nuclear physics research at the University of Tennessee is supported by the U. S. Department of Energy through Contract No. DE–FG05–87ER40361 and DE–FG05–93ER40770. Oak Ridge National Laboratory is managed by Lockheed Martin Energy Research Corp. for the U. S. Department of Energy under Contract No. DE–AC05–96OR22464.

REFERENCES

[1] M.A. Riley, *et al.*, Nucl. Phys. **A512**, 178 (1990)

[2] Yang Sun, Jing-ye Zhang, and M. Guidry, subm. Phys. Rev. Lett. April, 1996.

[3] C.-L. Wu, D. H. Feng, and M. W. Guidry, Ann. Phys. **222**, 187 (1993)

[4] Y. Sun and M. Guidry, Phys. Rev. **C52**, R2844 (1995)

[5] K. Hara and Y. Sun, Int. J. Mod. Phys. **E4**, 637 (1995)

[6] R. Bengtsson, I. Hamamoto, and B. Mottelson, Phys. Lett. **73B**, 259 (1978)

[7] Y. Sun, P. Ring and R.S. Nikam, Z. Phys. **339**, 51 (1991)

[8] W. Satula and R. Wyss, Phys. Rev. **C50**, 2888 (1994); R. Wyss and W. Satula, Phys. Lett. **B351**, 393 (1995)

[9] S.M. Fischer, *et al.*, Phys. Rev. **C53**, 2126 (1996)

[10] Y. Sun and J.L. Egido, Phys. Rev. **C50**, 1893 (1994); Nucl. Phys. **A580**, 1 (1994)

[11] R.M. Clark, *et al.*, Phys. Rev. Lett. **76**, 3510 (1996).