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DOUBLE BLOCKING IN THE SUPERDEFORMED ^{192}Tl NUCLEUS

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Abstract: Six superdeformed bands have been found in the nucleus ^{192}Tl. For two of the bands, the dynamic moment of inertia $J^{(2)}$ is found to be constant with the rotational frequency $\hbar\omega$. This result can be understood in terms of Pauli blocking of quasiparticle alignments in intruder orbitals, and represents the first experimental evidence that the alignment of these intruders is responsible for the smooth rise in $J^{(2)}$ seen in other superdeformed nuclei of this mass region.

One of the most intriguing aspects of superdeformed (SD) nuclei in the A = 190 regions is that the vast majority of SD bands displays a smooth pronounced increase of $J^{(2)}$ as a function of the rotational frequency $\hbar\omega$. The occupation of specific high-N intruders cannot account for this rise[1-4]. An explanation in terms of changes in deformation with $\hbar\omega$ has been ruled out from the available lifetime measurements[5]. It has been suggested that the combined quasiparticle alignments of a pair of N = 6 ($i_{13/2}$) protons and a pair of N = 7 ($j_{15/2}$) neutrons, and the resulting changes in pairing play an essential role in such a rise[3-7]. Experimental evidence for this alignment picture is at present circumstantial. Clearly, the study of the behavior of $J^{(2)}$ in the SD bands of an odd-odd nucleus should be particularly revealing. If both the odd proton and the odd neutron occupy the high-N intruder orbitals, the alignments should be blocked and, as a result, the moments of inertia should be constant with frequency. Here, we report on a study of ^{192}Tl where six SD bands have been located. Two of these bands are characterized by constant moments of inertia, thereby providing the first strong evidence that the alignment of quasiparticles occupying the high-N intruder orbitals indeed plays an essential role in the evolution of $J^{(2)}$ with $\hbar\omega$.

The states in ^{192}Tl were populated with the ^{160}Gd(^{37}Cl, 5n) reaction at beam energies of 178 and 181 MeV. The γ-γ coincidence data were recorded using the Argonne-Notre Dame BGO γ-ray facility consisting of 12 Compton-suppressed Ge detectors and an inner array of 50 BGO elements. A detailed analysis of the data revealed the presence of six superdeformed bands in ^{192}Tl[7]. Fig. 1 presents spectra for these bands. The bands are very weak and in some cases difficult to discriminate from contaminants, the coincidence relationships between the γ rays were also studied carefully by observations of regular grid patterns in the two dimensional γ-γ matrix using the code BANDAID[9,10]. For a few clean γ rays, multipolarity information obtained from angle-sorted matrices[11] indicates that the

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transitions involved are of stretched E2 character. As some of the γ rays discussed here are close in energy to SD transitions in ^{191}Tl[12], care was taken to ensure that the assignment into ^{192}Tl is correct by checking that (1) the relative variation of the γ-ray intensities between the beam energies and (2) the fold distributions at each beam energy follow the pattern exhibited by the ^{192}Tl transitions. Finally, in analogy with the neighboring ^{191,193,194}Tl isotopes[12,13,14], these six bands can be grouped into three strongly coupled signature pairs (bands 1-2, 3-4, 5-6).

The dynamic moments of inertia for the six bands are presented as a function of the rotational frequency $\hbar\omega$ in fig. 2. From this figure, several observations can be made. First, it is clear that $J^{(2)}$ remains constant with $\hbar\omega$ for bands 3 and 4 (fig. 2a), while the other four SD bands display the more typical rise with $\hbar\omega$ (fig. 2b). Second, a comparison between the $J^{(2)}$ values for bands 3 and 4 and those of the odd-even neighboring nuclei ^{191}Hg (band 1)[4] and ^{191}Tl[12] (fig. 2a) indicates that, at the lowest frequencies, the value of $J^{(2)}$ is lower in the odd-even neighbors than in the two new SD bands. In order to understand these results, we have performed cranked shell model calculations with the Warsaw-Lund code which uses a Wood-Saxon potential[15] with the universal parameters given in ref. 16. While specific results depend on the deformation and the pairing gaps used, the following general conclusions can be drawn: (i) An alignment of an N=7 neutron pair, which is calculated to occur in ^{191}Tl (and ^{192}Hg) within 0.15< $\hbar\omega$ <0.3 MeV is blocked in ^{192}Tl (and ^{191}Hg) when the odd neutron occupies the second $j_{15/2}$ orbital involved. (ii) An alignment of a pair of N=6 protons is calculated to occur between 0.25< $\hbar\omega$ <0.4 MeV in ^{191}Hg (and ^{192}Hg). This alignment is also blocked in ^{192}Tl (and ^{191}Tl) when the proton occupies the third intruder $i_{13/2}$ orbital. (iii) At low values of $\hbar\omega$, our calculations show that the occupation of both the $\pi i_{13/2}$ and $\nu j_{15/2}$ orbitals will result in an additional contribution to $J^{(2)}$ with respect to the odd-even neighboring nuclei. The calculated value (107 $\hbar^2 MeV^{-1}$) for the double-blocked configuration discussed above, is also shown in fig. 2a, and agrees well with the data. On the basis of this discussion, we propose that bands 3 and 4 correspond to a configuration built on the favored (r=i) signature of the $\nu j_{15/2}$ orbital coupled to the two signatures (r=$\pm$i) of the $\pi i_{13/2}$ orbital, i.e., $\pi i_{13/2}(r=\pm i)\otimes\nu j_{15/2}(r=i)$. (It has been shown in ref. 4 that the unfavored (r=$-$i) signature of $\nu j_{15/2}$ orbital is located too high in energy to be observed experimentally.) In fact, the data on bands 3 and 4 represent the first case where constant values of $J^{(2)}$ have been observed in SD bands near A = 190.

The discussion above also serves as a starting point for the interpretation of the four other SD bands in ^{192}Tl. From fig. 2b it is apparent that the four bands all exhibit a rise in $J^{(2)}$ with $\hbar\omega$. Furthermore, this rise is similar to that seen over the same frequency range in the odd-even neighbors and is significantly smaller than that observed in the even-even ^{192,190}Hg nuclei. This suggests that only one pair of high-N intruders is aligning in these four ^{192}Tl bands. (This argument is also consistent with the observation that the $J^{(2)}$ values at the lowest frequencies are smaller here than in bands 3 and 4, as discussed above.) The question then remains whether it is possible to identify the odd intruder particle as a proton or a neutron.

We propose that the four bands are associated with the intruder $\pi i_{13/2}[642]5/2$ configuration coupled to the lowest neutron excitation identified in ^{191}Hg (bands 2 and 3 in ref. 4), i.e. the $\nu i_{11/2}[642]3/2$ orbital. This assignment is based on the following considerations. (1) Both pairs of SD bands show increasing signature splitting as a function of $\hbar\omega$ as expected for the $\pi i_{13/2}[642]5/2$ and $\nu i_{11/2}[642]3/2$ orbitals, and these splittings have been observed experimentally in the SD bands of ^{191,193}Tl[12,13] and ^{191}Hg[4]. (2) Recently, Stephens et al.[17] have proposed to compare SD bands near A = 190 by examining the evolution with $\hbar\omega$ of the incremental alignment Δi. Striking patterns of incremental alignment values cluster around Δ i = 1, +0.5, 0 over a wide $\hbar\omega$ range have been shown to occur, particularly when the SD bands being compared are characterized by configurations involving the same number of high-N intruder orbitals[1,13,14,18]. We have computed Δi values for the ^{192}Tl SD bands using ^{190,191,192}Hg and ^{191,193}Tl as possible references. Only when one of the ^{191}Tl SD bands[12] is the reference does Δi exhibit behavior of this type. We obtained Δi (band 2) $\simeq$ 0 relative to band 1 of ^{191}Tl, and Δi (band 5) $\simeq$ 1 relative to band 2 of ^{191}Tl over the entire $\hbar\omega$ range, respectively. This suggests that bands 2 and 5 share the same $\pi i_{13/2}$ (r=$\pm$i) intruder content as ^{191}Tl. Furthermore, the signature partners (band 1 and 6 respectively) show smoothly decreasing values of Δi with $\hbar\omega$ in analogy to that seen in SD bands associated with the $\nu i_{11/2}[642]3/2$ orbital in ^{191}Hg[4]. Thus, one of the two pairs of bands (1-2 or 5-6) corresponds to $\pi i_{13/2}[642]5/2(r=i)\otimes\nu i_{11/2}[642]3/2(r=\pm i)$ configuration while the other is associated with the unfavored (r=$-$i) $\pi i_{13/2}$ partner coupled to the same neutron configuration. Unfortunately, the available data do not provide an unambiguous way to determine which of the pairs should be associated with the r=+i or the r=$-$i proton configuration.

It is worth pointing out that a similar classification can be proposed for the SD bands in ^{194}Tl of ref. 14. A pair of SD bands labeled as bands 3a & 3b in ref. 14, has a higher $J^{(2)}$ at low $\hbar\omega$ and displays a smaller rise with $\hbar\omega$. This pair is most likely associated with a configuration where the two odd particles occupy high-N intruder orbitals. The small rise in $J^{(2)}$ would then have to be the result of second order effects (such as small changes in deformation with $\hbar\omega$ and/or small changes in higher order pairing corrections....) The two other signature partner pairs (marked 1a & 1b and 2a & 2b in ref. 14) can then be understood as being based on the intruder proton configuration coupled to neutron excitations observed in the ^{193}Hg SD bands.

In conclusion, six SD bands have been found in ^{192}Tl. Two of these bands are characterized by a dynamic moment of inertia $J^{(2)}$ which remains constant with rotational frequency. This result can be understood within the framework of cranked shell model calculations with pairing as being due to Pauli blocking of high-N intruder orbitals. This is the first evidence that pairing is indeed carried to a large extent by these intruder orbitals in the SD nuclei near A = 190. Configurations have been proposed for all six SD bands. They involve proton and neutron excitations which have been observed in the odd-even neighboring SD nuclei ^{191}Tl and ^{191}Hg.

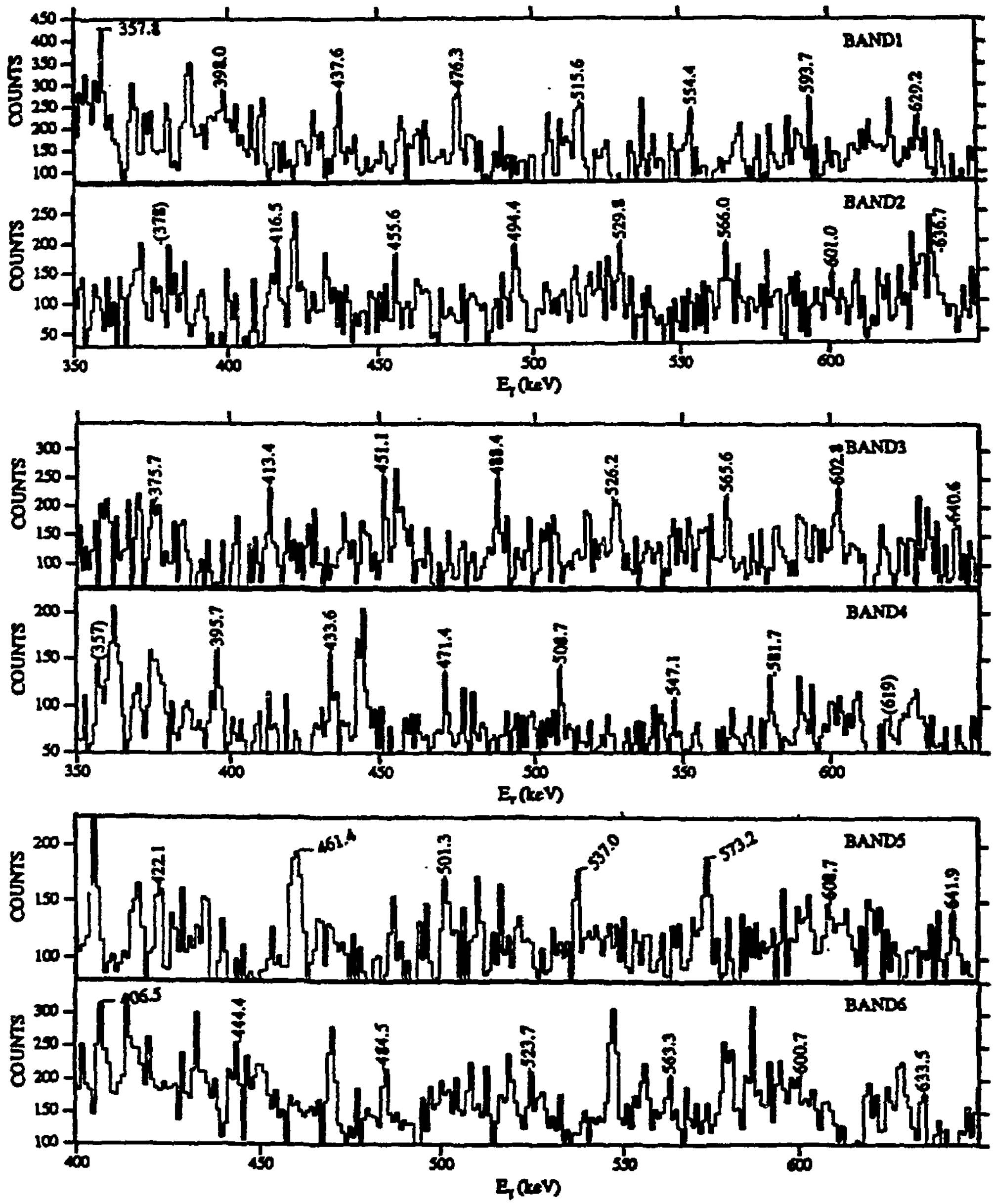

Figure 1: *γ-ray spectra obtained for the six SD bands in ^{192}Tl by summing cleanest coincidence gates. The SD band energies are indicated. The errors are on the order of 0.5 keV for the strongest transitions and up to 1 keV for the weakest γ rays. Transitions for which the placement is not certain are given in parenthesis. Several contaminants are also present in the spectra.*

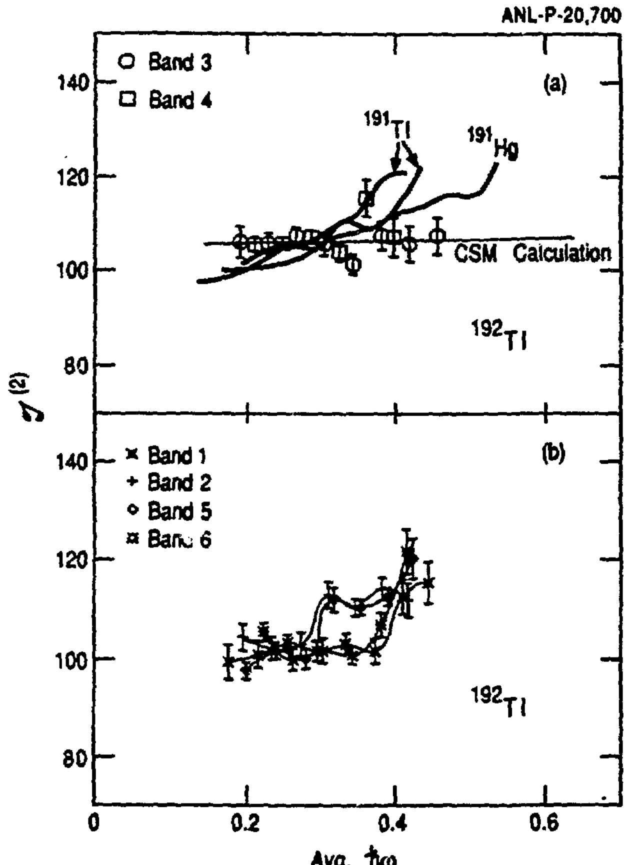

Figure 2: *Dynamic moments of inertia $\mathcal{J}^{(2)}$ for the six SD bands in ^{192}Tl. (a): the $\mathcal{J}^{(2)}$ values for bands 3 and 4 are compared with those of the two SD bands in ^{191}Tl[1] and with the first SD band in ^{191}Hg[4] (thick lines). The result of a cranked shell model calculation discussed in the text is given as the thin line. (b): dynamic moments of inertia for bands 1, 2, 5 and 6. The lines joining the points have been drawn to guide the eye.*

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