# COLLECTIVE EXCITATIONS IN THE SUPERDEFORMED WELL*

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Collective excitations are commonplace features in nuclei at normal deformation. It has been suggested that both in the $A \sim 190$ and 150 superdeformed (SD) nuclei, collective vibrational states might occur in the same excitation energy range as quasi-particle and single-particle excitations. In particular, the large deformation associated with SD nuclei brings together orbitals from many spherical shells and leads to the close proximity of states with opposite parity, favouring octupole shape vibrations. However, to date, $\sim 200$ SD bands have been reported in more than 50 nuclei and in most cases, the excited SD bands have been interpreted as single or quasi-particle excitations. Only in very few cases, has the collective excitation scenario been suggested. Where are the collective states in SD nuclei? The question is particularly relevant in even–even $A = 190$ nuclei in which SD states are observed at lower rotational frequency and hence the additional influence of the pair gap makes the collective excitations more competitive with quasi-particle excitations.

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## 1. Introduction

It has been long predicted that octupole vibrational modes will play an important role in the structure of SD nuclei [1-4]. The results of Random Phase Approximation calculations including an octupole vibrational term in the residual interactions suggest that the Hg SD nuclei should be very soft with respect to octupole vibrations [5]. Of all Hg nuclei, the vibrational states in $^{190}$Hg are expected to be at the lowest excitation energies and therefore to be the most easily accessible experimentally. The lowest excited SD states should be composed of a pure octupole vibrational multiplet at zero rotational frequency. At higher rotational frequency, the effects of the Coriolis force are predicted to mix these states with each other and with the appropriate quasi-particle components and thus one would not expect to observe bands built on pure vibrational states. The expected bands should have specific properties unusual for SD bands, which would allow to identify them as built on collective excitations. The clearest experimental signature for the octupole vibration phenomenon arises from the presence of an anomalously large transition dipole moment associated with the charge asymmetry of this kind of vibration. This is expected to manifest itself in enhanced electric dipole strengths, allowing competiton between inter-band E1 transitions and the highly collective in-band E2 transitions. The extent to which this can take place depends on the $K$ values of the bands involved. Only transitions between SD bands based on the same $K$ values or for which a large degree of mixing with quasi-particle configurations is possible are likely. The lowest excited SD bands in the even–even Hg nuclei are predicted to be based on $K^\pi = 2^-$ octupole vibrations at zero rotational frequency. This $K = 2$ phonon has a significant Coriolis mixing with the $K = 0, 1$ octupole phonons with increasing rotational frequency [5].

Inter-band transitions have been observed between the excited and the yrast SD bands of $^{190}$Hg [6–7], $^{194}$Hg [8] and $^{196}$Pb [9]. In the case of $^{190}$Hg, angular correlations proved the dipole nature of these inter-band transitions [6–7]. Branching ratios and lifetime measurements [10] suggested that they were most likely electric rather than magnetic dipole transitions. For $^{194}$Hg, evidence for the difference in parity between the yrast SD band and the excited band, which decays into the yrast one, arose from the observation of discrete, single-step transitions linking these bands to different parity states in the normal deformed (ND) well [8]. An additional proof for octupole vibrations in the $^{190,194}$Hg nuclei is given by the initial signature splitting of the excited SD bands [11] (the odd spin band being favored) which is well reproduced by the RPA calculations. However, the properties of the excited states in the SD core nucleus of the region, $^{192}$Hg, do not seem to fit in this "octupole paradise" picture. The situation was therefore not so clear since no direct evidence of the electric nature of the inter-band transitions was available in any of these nuclei and the octupole vibration scenario remained questionable.

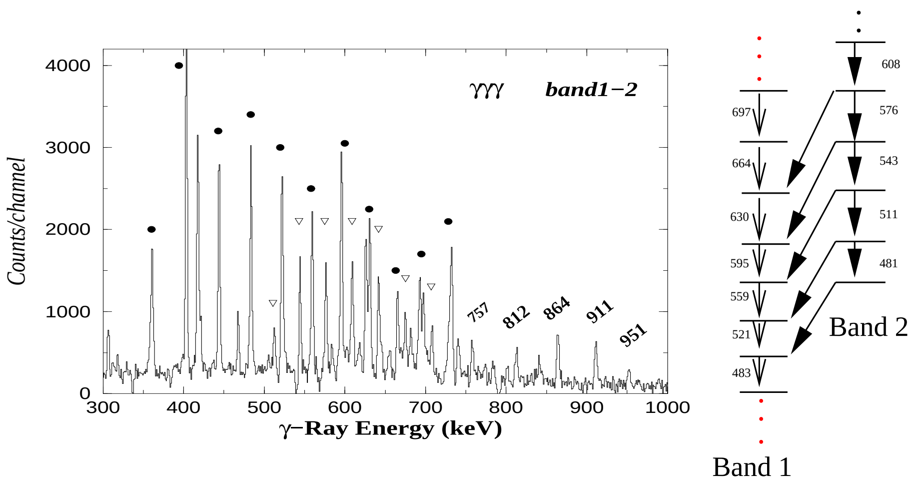


Fig. 1. Spectrum showing $\gamma$ rays in coincidence with at least 3 transitions from either band 1 or band 2. Transitions from band 2 are marked with open triangles and transitions from band 1 with filled cirles. The inter-band transitions are labelled by their energies. On the right is shown a partial level scheme.

We have therefore decided to measure the linear polarisation of the $\gamma$ rays which had been previously observed to link states in band 2 with states in band 1 in SD $^{190}$Hg [6–7] (see Fig. 1).

## 2. Measurements and results

The experiment was performed using the EUROBALL-IV $\gamma$-ray array [12] at Strasbourg. High-spin states in $^{190}$Hg were populated in the $^{160}$Gd($^{34}$S,4$n$) reaction. The beam of $^{34}$S, provided by the Vivitron at an energy of 156 MeV, was incident on a target consisting of a stack of two thin (500 $\mu$gcm$^{-2}$), self-supporting foils of $^{160}$Gd. The array consisted of 30 coaxial, 25 4-element Clover and 15 7-element Cluster Ge-detectors arranged respectively at forward, central and backward angles with respect to the beam direction. An Inner Ball of 210 BGO scintillators designed to provide a measure of the multiplicity and total energy of the reaction was positioned inside the array, around the target. Events were written to tape when a minimum of 5 unsuppressed Ge and 5 elements of the Inner Ball fired in coincidence.

One of the unique capabilities of the EUROBALL-IV array is the possibility to use the Clover detectors as Compton polarimeters [13] and thus measure linear polarisation for the inter-band transitions. These transitions carry only $\sim 0.01\%$ of the intensity of the $^{190}$Hg reaction channel and, thus, a high efficiency was needed. After escape suppression, addback of events Compton scattered between neighbouring elements in the Clover and Cluster detectors and the imposition of prompt time gates, a total of $1.76 \times 10^9$ events of fold 3 and greater were obtained. Of these, $\sim 12$ % contained information concerning $\gamma$ rays which had scattered between neighbouring (non-diagonal) elements in the Clover detectors. The statistics collected was improved compared to previous experiments and allowed a more precise measurement of the angular distributions associated with these transitions.

To measure the linear polarisation one has to determine the number of counts $I_{\rm H}$ and $I_{\rm V}$ of Compton scattered events parallel and perpendicular to a reference plane to which the polarisation $P$ is defined. The experimental asymmetry is defined by the ratio,

$$A(E_\gamma) = \frac{I_{\rm V} - I_{\rm H}}{I_{\rm V} + I_{\rm H}} = Q(E_\gamma)P\,, \qquad (1)$$

where $I_{\rm V}$ and $I_{\rm H}$ represent the number (efficiency corrected) of vertically (Fig. 2(a)) and horizontally (Fig. 2(b)) scattered events, respectively. This ratio is proportional to the degree of polarisation $P$ and depends on the photon energy. The quality factor $Q$ corresponds to the polarisation sensitivity and has been extracted from reference [13].

Indeed, unmixed stretched electric transitions give rise to a positive value of P and magnetic transitions to a negative one. A "calibration" of the polarisation values was performed by analysing known pure magnetic transitions in the level scheme of $^{190}$Hg. The results for $P(E_\gamma)$ are shown in Fig. 2(c).

It is immediately clear that both the in-band and inter-band transitions give positive values of $P$, and that they are clearly separated from the known magnetic transitions which result in a negative value for $P$. This provides the first experimental proof of the electric nature of the inter-band $\gamma$ rays [14].

The angular distribution coefficients obtained in this work are $A_2 = -0.35(12)$ and $A_2 = 0.31(10)$ for the inter- and in-band transitions, respectively. This indicates that the inter-band transitions are pure stretched dipoles, confirming and strengthening the evidence provided by the previous DCO ratios [7]. Based on our results, we assign unambiguously the inter-band transitions as being of stretched electric dipole character.

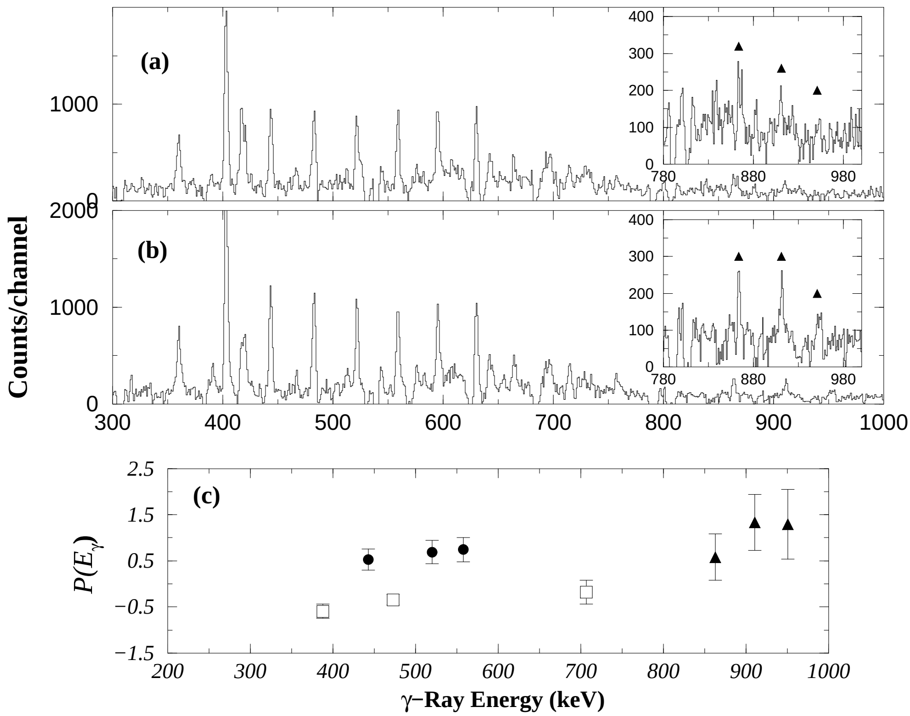


Fig. 2. Spectra showing the $\gamma$ rays in coincidence with at least two transitions which were detected as (a) horizontally and (b) vertically scattered $\gamma$ rays in the Clover detectors. The inter-band transitions are shown in the insets and marked by filled triangles. The lower panel (c) correspond to the measured linear polarisation for in-band and inter-band transitions (circles and triangles) together with the one obtained for known magnetic transitions.

## 3. Conclusion

It is possible to state for the first time that the inter-band transitions connecting the first excited SD band in $^{190}$Hg to the yrast SD band are of electric dipole character. They compete strongly with the in-band E2 transitions: the branching ratios and the previously measured lifetimes [10] indicate transition strengths of the order of $10^{-3}$ W.u corresponding to a significant charge asymmetry in the nucleus. Such large $B$(E1)s occur if there is an octupole component associated with the nuclear wave-function. This is the first time that it has been possible to demonstrate unambiguously that an excited SD band is based on a collective excitation.

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