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SEP 28 1999  
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# 1 LIFETIME MEASUREMENTS AND DIPOLE TRANSITION RATES FOR SUPERDEFORMED STATES IN $^{190}\text{Hg}$

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**Abstract:** The Doppler-shift attenuation method was used to measure lifetimes of superdeformed (SD) states for both the yrast and the first excited superdeformed band of  $^{190}\text{Hg}$ . Intrinsic quadrupole moments  $Q_0$  were extracted. For the first time, the dipole transition rates have been extracted for the inter-band transitions which connect the excited SD band to the yrast states in the second minimum. The results support the interpretation of the excited SD band as a rotational band built on an octupole vibration.

## INTRODUCTION

The first excited SD band in the  $^{190}\text{Hg}$  nucleus has a rather unusual behavior, when compared with excited SD bands in other nuclei of the region [1, 2, 3, 4]. In particular, this SD band decays entirely into the yrast SD band, instead of decaying directly towards the normal deformed states. The inter-band transitions, probably of E1 character, linking this band to the yrast SD band were observed [2, 3] allowing for the excitation energy, spins and possible parity to be determined relative to the yrast SD band. At the point of decay into the yrast SD band, the excitation energy of this excited band is 911 keV, i.e. lower than would be expected for a two quasiparticle excitation. The dynamic moment of inertia  $\mathcal{I}^{(2)}$  for the excited band is essentially flat as a function of rotational frequency and about 20% larger than that of any SD band in the  $A=190$  region of superdeformation. When this excited band and its decay pattern were

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observed for the first time, it was proposed that this could correspond to a rotational band built on an octupole-vibrational phonon in the SD well [3].

The results from the present work provide answers to some of the remaining questions regarding this excited band. First, the dipole transition rates for the linking transitions were determined. Second, the quadrupole moments,  $Q_0$ , were extracted for both the excited and the yrast SD band.

## LIFETIMES AND TRANSITION RATES

Superdeformed states in  $^{190}\text{Hg}$  were populated with the  $^{160}\text{Gd}(^{34}\text{S},4n)$  reaction at a beam energy of 159 MeV. The beam was provided by the 88-Inch Cyclotron at LBNL. A  $^{160}\text{Gd}$  target ( $1.17\text{ mg/cm}^2$ ) evaporated onto a thick ( $13\text{ mg/cm}^2$ ) Au backing was used. The  $\gamma$  rays were detected by the Gammasphere array, which consisted of 87 Compton-suppressed Ge detectors at the time of the experiment. A total of  $1.1 \times 10^9$  events with fold  $\geq 4$  was recorded. The data were sorted into a number of spectra gated by triple coincidence windows placed on combinations of transitions in the SD bands. Spectra corresponding to each of the angular rings of Gammasphere were constructed individually. In order to derive lifetimes and transition rates from the data, a Doppler shift attenuation method (DSAM) analysis was performed. Linear fits of  $\overline{E}_\gamma$  versus  $\cos(\theta)$  were performed using the first-order Doppler shift expression  $\overline{E}_\gamma = E_{\gamma_0}[1 + \beta_0 F(\tau)\cos(\theta)]$  to extract the  $F(\tau)$  values and unshifted  $\gamma$ -ray energies  $E_{\gamma_0}$ . The  $F(\tau)$  values are presented in Fig. 1 as a function of the  $\gamma$ -ray energy for transitions in both bands and for the four linking transitions. The intrinsic quadrupole moments  $Q_0$  of the two SD bands were extracted from the experimental  $F(\tau)$  values using the computer code FITFTAU [6] which requires a velocity profile for the recoiling residues and a model for  $\gamma$ -ray decay of the SD cascade. The velocity profiles of the recoiling Hg ions in the target and the Au backing were calculated using the code TRIM, version 1995, by Ziegler [7]. The following assumptions are made for the decay cascade: (1) the  $Q_0$  values are the same for all SD levels within a band, (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  $\mathfrak{Q}^{(2)}$  moment as the main band, and controlled by a sidefeeding quadrupole moment  $Q_{sf}$  (assumed to remain the same throughout an entire SD band), and (3) a one-step delay at the top of all feeder cascades was parameterized by a single lifetime  $T_{sf}$ . A  $\chi^2$  minimization using the fit parameters  $Q_0$ ,  $Q_{sf}$ , and  $T_{sf}$  was then performed to the measured  $F(\tau)$  values. Results from the fit are illustrated in Fig. 1. It is clear that the  $Q_0$  moments for both SD bands are the same within their respective error bars. Using the lifetimes derived from the present analysis and the branching ratios from ref. [4], absolute transition rates for the dipole inter-band transitions were calculated under the assumption of either  $E1$  or  $M1$  character using the expressions  $B(E1) = 6.288 \times 10^{-16} B.R./\tau E_\gamma^3$  and  $B(M1) = 5.687 \times 10^{-14} B.R./\tau E_\gamma^3$ , respectively. Here  $B.R.$  is the out-of-band

**Figure 1.1** Measured fractional shifts  $F(\tau)$  for  $\gamma$ -rays in the two SD bands (1 and 2) and for the inter-band transitions in  $^{190}\text{Hg}$ . The  $F(\tau)$  values for the linking transitions are plotted at the  $\gamma$ -ray energies of the corresponding in-band transitions of band 2. The solid and dashed curves represent the best fits corresponding to the values of the  $Q_0$  moment given in the figure.

branching ratio,  $E_\gamma$  is the  $\gamma$ -ray energy in MeV, and  $\tau$  is the mean lifetime of the SD level in seconds. The results are presented in Table 1.

**Table 1.1** Information obtained for the dipole transitions linking band 2 and band 1. The reduced matrix elements assuming pure  $E1$  or  $M1$  radiation are given in terms of Weisskopf units.

<i>Transition energy (keV)</i>	<i>Inter-band branching ratio</i>	<i>Lifetime of level (fs)</i>	<i>B(E1) (W.u. <math>\times 10^{-3}</math>)</i>	<i>B(M1) (W.u.)</i>
757	0.23 (8)	110 (20)	1.5 (6)	0.16 (6)
812	0.29 (10)	130 (30)	1.2 (5)	0.13 (5)
864	0.50 (16)	100 (20)	2.3 (9)	0.25 (9)
911	0.67 (27)	110 (20)	2.5 (11)	0.26 (12)

## DISCUSSION

$B(M1)$  values of the magnitude seen in Table 1 have been observed between strongly coupled signature-partner bands in odd-A SD nuclei [3, 4]. However, in the even-A  $^{190}\text{Hg}$  nucleus, the yrast SD band is most likely based on the fully paired vacuum state. Any excited SD band based on a quasiparticle excitation would be very unlikely to decay to the yrast band through  $M1$  transitions of such large strength. Conversely, while the observed  $B(E1)$  rates are orders of magnitude larger than those seen in deformed nuclei, they are of the same order as those reported for  $E1$  inter-band transitions in nuclei with a sub-

stantial dipole moment arising from octupole collectivity, as is the case, for example, in some nuclei of the actinide region [8]. Therefore, the measured  $B(E1)$  rates can be viewed as strong evidence in support of the interpretation of the excited SD band as a rotational band associated with the lowest octupole vibrational mode. In the calculations of ref. [5], the latter is proposed to be the  $K = 2, \alpha = 1$  octupole excitation, although there is considerable mixing with other low-lying octupole excitations in the region of frequency where the band is observed experimentally [3, 4]. It should be pointed out that further support for the assignment of a  $E1$  character to the inter-band transitions comes from the analogy with the situation in  $^{194}\text{Hg}$  where inter-band transitions have recently been observed between bands 3 and 1 and have been shown to have  $E1$  character [9]. In addition, the direct comparison of the quadrupole moments of the two bands as shown in Figure 1, indicates a difference in the quadrupole moments of  $\Delta Q_0 = 0.1 \pm 1.9$  eb. If the difference in  $\mathfrak{S}^{(2)}$  moments between the two bands ( $\Delta \mathfrak{S}^{(2)} \simeq 15\hbar^2/\text{MeV}$ ) was simply due to a difference in deformation, then at a rotational frequency of  $\hbar\omega \simeq 0.28$  MeV, the expected difference in the quadrupole moment would be  $\Delta Q_0 > 5$  eb. Such a difference is well outside the limits imposed by the data. This is consistent with the assumption of equal quadrupole moments used in the RPA calculations of Nakatsukasa *et al* [5]. In summary, the fact that (i) no differences in deformation are found between the two SD bands, and (ii) that the absolute transition rates for the linking dipole transitions are large favors the interpretation of the excited SD band as a rotational band built on an octupole vibration.

This work is supported by the US Department of Energy, Nuclear Physics Division, under contracts no. W-31-109-ENG-38, and DE-FG05-88ER40411.

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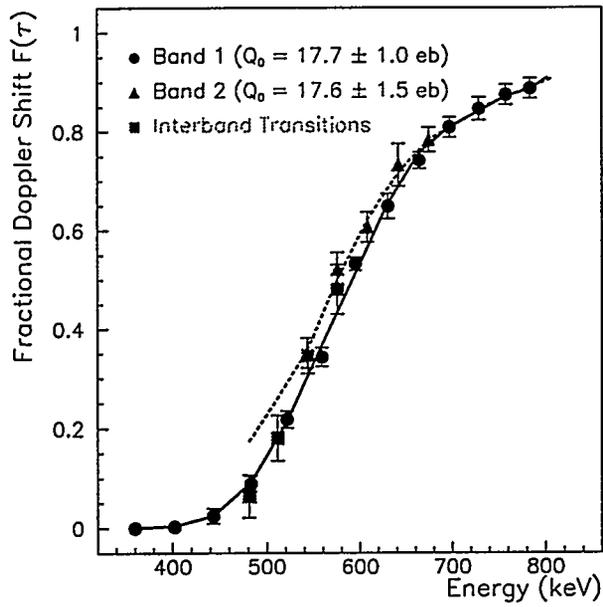


Figure 1.1 Measured fractional shifts  $F(\tau)$  for  $\gamma$ -rays in the two SD bands (1 and 2) and for the inter-band transitions in  $^{190}\text{Hg}$ . The  $F(\tau)$  values for the linking transitions are plotted at the  $\gamma$ -ray energies of the corresponding in-band transitions of band 2. The solid and dashed curves represent the best fits corresponding to the values of the  $Q_0$  moment given in the figure.