TETRAHEDRAL SHAPES AND OCTUPOLE EXCITATIONS IN THE MASS 160 AND 230 REGIONS

R.A. BARK, E.A. LAWRIE, J.J. LAWRIE
iThemba LABS, National Research Foundation, P.O. Box 722, Somerset West, 7129
South Africa

M.A. STANKIEWICZ, D.G. ASCHMAN, S.N.T. MAJOLA
Department of Physics, University of Cape Town, Rondebosch 7700, South Africa

F. DÖNAU
Research Center Dresden Rossendorf,
01326 Dresden, Germany

T.S. DINOKO, J.F. SHARPEY-SCHAFER
Department of Physics, University of the Western Cape, P/B X17, Bellville, ZA-7535
South Africa

P. PAPKA
Department of Physics, University of Stellenbosch, 7601 Matieland, South Africa

Negative-parity bands in deformed nuclei have traditionally been interpreted in terms of octupole excitations, but interest in these bands has been revived recently by predictions of tetrahedral shape. The level schemes of numerous nuclei in the mass 160 and 230 regions have been studied at iThemba LABS. In particular we look at the results for ^{158}Dy. B(E1)/B(E2) ratios for transitions from the odd and even-spin negative parity bands to the ground bands were measured and are compared with Cranked Random Phase Approximation calculations. The results support an interpretation in terms of aligned octupole vibrations.

1. Introduction

The lowest lying negative parity bands in deformed nuclei have been understood, for some time, in terms of the octupole degree of freedom [1-4]. An odd-spin negative-parity band, interleaving between members of the ground state band, has often been taken as evidence for the existence of a static octupole deformation. The two bands are linked to each other by E1 transitions. Such bands exist for example, in the Ra, Th and U isotopes with neutron numbers less than 136, but with increasing neutron number, the negative parity bands increase in energy so that they are no longer interleaved, an effect which has been understood as a transition to an octupole vibrational structure [1].

In the mass 160 region, interleaved bands are rare – the (odd-spin) negative parity band lies typically 1 MeV above the ground-state band at low-spins – so they have also been understood as octupole vibrations[4] as in the heavy actinide region. Often, the bands have not been observed to low spins ($<9\hbar$) and in many cases, those levels that are known at low spins were identified by their E1 decays to the ground band. The assumption was that the in-band E2 transitions could not compete with the higher energy out-of-band E1 transitions due to the simultaneous decrease of in-band E2 transition energy and increase in out-of-band E1 energy, with decreasing spin.

The lack of observed in-band E2 transitions led to speculation of an alternative explanation for the non-observation of in-band E2 transitions: that these were not octupole vibrational bands, but rather the predicted tetrahedral bands of Dudek and co-workers [5]. The tetrahedral band is characterized as a pure Y_{32} shape, with no Y_{20} contribution, in this way explaining the lack of E2 transitions. Nuclei in the vicinity of predicted tetrahedral shall-gaps, around N=90 and Z=64 and 70 were early candidates for the observation of tetrahedral shapes [6].

2. Results

iThemba LABS began a programme of spectroscopic study in the region, using beams of ^{4}He, ^{12}C and ^{16}O to populate excited states in ^{152,154}Gd, ^{158}Dy, $^{156-160}$Er and ^{160}Yb, using fusion evaporation reactions. Gamma-rays from the decay of excited states in these nuclei were observed using the AFRODITE array of up to 9 Compton suppressed clover detectors. In the actinide region, the nuclei ^{230,232}U were also studied with the AFRODITE array, in conjunction with an ancillary recoil detector. The data obtained by AFRODITE for the mass 160 region allowed a number of new observations. All of the lowest lying negative parity bands in these nuclei have odd-spin and are accompanied by an even spin partner. As an example, we show our results for the nucleus ^{158}Dy, in Figure 1. The energies of the odd and even-spin negative parity partner bands, together with the ground state band are plotted relative to a rigid-rotor reference in the top panel. This pattern of energy difference is typical of the region, for example see Figure 2 of [7]. In the bottom panel, we show the experimental values of

B(E1; I →I)/B(E2; I→I-2) for decays from levels in the even-spin negative-parity band to the ground band, and B(E1; I →I-1)/B(E2; I→I-2)) for decays from levels in the odd- spin negative-parity band. A difference of over an order of magnitude is seen in B(E1)/B(E2) ratios between the even and odd-spin members of the negative-parity bands. In the tetrahedral interpretation, the difference in the ratios would be ascribed largely to differences in quadrupole deformation, implying that the large values for the odd-spin sequence were due to a small quadrupole moment while the much smaller values for the even spin sequence indicated a larger quadrupole moment that could not correspond to the rotation of a pure tetrahedral shape.

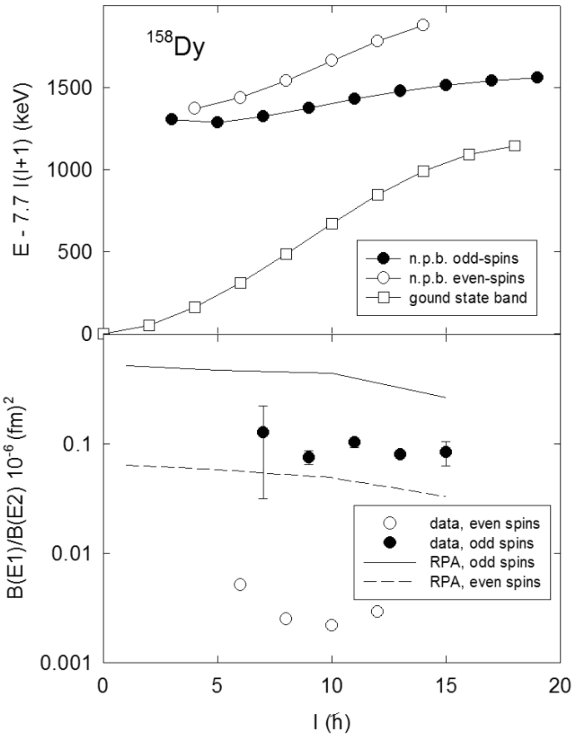

Figure 1. Top: Energies, less a rigid-rotor reference, of the lowest lying negative parity bands and ground state band in ^{158}Dy; Bottom: Experimental B(E1)/B(E2) ratios for decays from the negative parity bands to the ground bands (symbols) compared with RPA calculations (lines) as described in the text.

Fortuitously, in ^{160}Yb, band crossings of the lowest negative parity bands with two-quasiparticle bands allowed the relative quadrupole moments to be deduced using band mixing calculations [7]. Shortly after, B(E2) values were measured in ^{156}Gd by Jentschel et al. [8]. All results indicated that the deformation of the negative-parity bands were similar to the ground band of their respective nuclides. In the mass 230 region, results [9] from iThemba LABS showed that the properties of negative-parity bands in ^{230,232}U were similar to those in ^{226}Ra, for which large quadrupole moments had been established [10].

3. Discussion

With the tetrahedral hypothesis ruled out, we assume a description of these bands in terms of the original understanding of the bands, as octupole vibrators. The aligned angular momenta of the bands support this interpretation. For example, in Figure 2, we show the aligned angular momenta of the bands in ^{158}Dy. They show that at low frequency, the favoured (odd-spin) negative-parity sequence has $2.5\hbar$ - close to what would be expected for an aligned octupole phonon - while the unfavoured (even) sequence has about $1\hbar$ less, as would be expected from the Pauli principle.

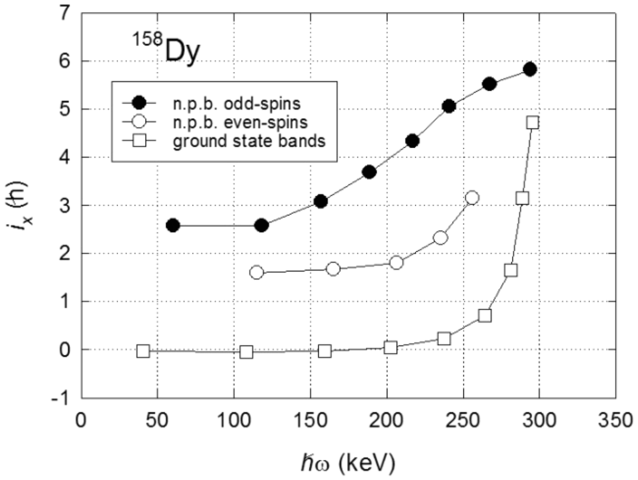

Figure 2. Aligned angular momenta of the lowest lying negative parity bands and ground state band in ^{158}Dy. Reference parameters: $\Im_0$=31 $\hbar^2$/MeV, $\Im_1$ = 140 $\hbar^4$/MeV^3.

What remains mysterious is the large difference in B(E1)/B(E2) ratios for the odd and even-spin sequences. If, as measured for ^{160}Yb [7], the odd and even-spin negative-parity bands correspond, in general, to approximately the same quadrupole deformation as each other, then the difference in B(E1)/B(E2) values – over an order of magnitude between the two bands – must arise from differences in B(E1) values.

Such large differences have also been observed in the mass 170 region between even and odd-spin sequences of negative-parity two-quasiparticle bands. The effect was investigated theoretically by Hamamoto and Sagawa [11], who showed that it is a function of aligned angular momentum and depends sensitively on the location of the Fermi level.

To test whether the large differences in E1 strengths could also be explained in the framework of aligned octupole bands, we have performed Cranked Random Phase Approximation (CRPA) calculations. The quasiparticle energies were derived by using a modified oscillator and by adopting the deformations parameters from Möller et al. [12]. The CRPA used a residual interaction of the multipole-multipole type

$$V = -\frac{1}{2}\sum_{\lambda\mu s=\pm 1} \kappa^{\lambda\mu s}\left(Q_{\lambda\mu} + s\, Q^{*}_{\lambda\mu}\right)^{2}$$

including dipole $(\lambda = 1)$ and octupole $(\lambda = 3)$ octupole terms. The signature branches $r_x = +1$ and $r_x = +1$ of the dipole vibrations can be treated separately which allows the number of unknown strength constants $\kappa^{\lambda\mu s}$ to be reduced to the one needed for the octupole terms. In fact, the remaining constant κ^{3} for a given signature was fitted to reproduce the lowest excitation energy of the respective experimental dipole band. Full details of the calculations will be given elsewhere [13], but the calculated B(E1)/B(E2) values for ^{158}Dy are compared to the data in Figure 1. While the absolute magnitudes of the B(E1) values are overestimated, an order of magnitude difference in B(E1) values is predicted, in qualitative agreement with experiment.

4. Conclusions

In conclusion, low-lying negative-parity bands in the mass 160 and 230 regions have been studied at iThemba LABS using the AFRODITE detector array. In the mass 160 region, the properties of these bands, such as deformations, energies, aligned angular momenta and B(E1) transitions rates are broadly in line with the predictions of CRPA calculations for aligned octupole phonons.

Acknowledgments

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