Octupole Correlation and Collective Coupling in the Rare Earth Nucleus ^{154}Dy

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Abstract. The low spin states of ^{154}Dy were studied with the AFRODITE spectrometer array equipped with 9 clover High Purity Germanium ($HPGe$) detectors at iThemba LABS Western Cape. The reaction ^{155}Gd (^{3}He, 4n)^{154}Dy at 37.5 MeV was used to populate these states. A first observation of enhanced E1 transitions in the in the transitional isotones ^{150}Sm and ^{152}Gd from the levels in the first excited 0^+ band to the lowest negative parity band was reported [3]. Here, we report on experimentally observed fingerprint of octupole deformation [19], [20]. And we also give a brief description of our results of the low spin structure of ^{154}Dy.

1. Introduction

The dysprosium (^{154}Dy) nucleus offers an opportunity to study nuclear structures in a transitional region [1], thus the ^{154}Dy nucleus has a rapidly changing shape from spherical to quadrupole deformed. In even-even nuclei, strong deformation is observed at N = 60 and lighter isotopes with N < 59 are spherical [2]. The N = 88 isotones in low-lying spins display a variety of properties, rapidly changing shape, strong E3, and quadrupole and octupole deformations. The strong E1 properties, from the bands built on $0^+_2 \rightarrow 3^-_1$ are mostly caused by octupole vibrations which have been described and explained as due to the proximity of Δj^{π}=3^- shell model orbits to the Fermi surface [19]. This behavior was observed in ^{152}Gd and ^{150}Sm by [3]. The ^{154}Dy nucleus has 6 neutrons and 2 protons outside the closed shell which is nearly spherical and has very common quadrupole phonon states. ^{154}Dy has a quadrupole deformation in the ground state which consists of levels connected by stretched E2 transitions above the 0^+ ground state.

In a microscopic representation, the origin of octupole collectivity can be explained by the interplay of the unique parity orbit in each major shell and a common parity orbit that differ by angular momentum and total spin $l = j = 3$ [15], [16] and can be described through condensation of single-particle energy level sequence for a harmonic oscillator potential [12]. In certain cases, an orbit is lowered into next lowest major shell by the l^2 and $l.s$ terms. These intruder orbits lie close in energy to orbits with $l = l_{int} = 3$ and $j = j_{int} = 3$. We will refer to to the lowest-lying negative parity band as the ocutpole band. Observations by [9], [10] have shown that the interpretation of the first excited 0_2^+ as β - vibrations are unfounded, He suggests are shown to result from the $[505]\frac{11}{2}$ Nilsson orbit closeness to the Fermi surface hence forming two particle two hole (2p-2h) states. Therefore we will not refere to the bands built on the 0_2^+ as β - vibrations.

2. Experimental Details and Results

The ^{154}Dy nucleus was studied at iThemba LABS Cape Town using the modern state of the art AFRODITE spectrometer array [18] equipped with 9 clover detectors. The low-lying excited states of ^{154}Dy were populated via the ^{155}Gd (^{3}He, 4n) reaction at 37.5 MeV, the thickness of the ^{155}Gd target was 3.2 mg/cm^2. The trigger condition was such that two Compton-suppressed HPGe detectors fired in prompt time coincidence.

The data were sorted into two dimensional matrix using MTsort and analyzed using Radware software package [4]. Calibrations were performed using a standard ^{152}Eu source. The lUrbanWevel scheme deduced from gamma-gamma($\gamma - \gamma$) coincidence relationship is shown in Figure 1.

3. Discussion

3.1. New levels and γ rays observed

A new band-head at 2345.8 keV has been found with spin-parity 6^-. Two new γ rays 340 keV and 419 keV have been observed in the low-lying negative parity band. These two γ rays connect levels $3^- \rightarrow 5^-$ and $7^- \rightarrow 5^-$ respectively. These levels were reported in National Nuclear Data Center [5] database but the γ rays connecting them were not observed. The odd and even γ positive-parity bands built on 3^+ and 2^+ were only reported up to 7^+ and 4^+ respectively [5]. The two bands have since been observed up to 13^+ and 12^+ respectively. The level at 3290.6 keV, 12^+ was the last level on the band built on 0_2^+ is now the new band head for the band with former band head at 3681.1 keV, 14^+.

The were no observed E3 transitions from the ground state band to the lowest lying negative parity band. It is suggested that no transitions were observed between the two bands because the lowest lying negative parity band in ^{154}Dy has a high excitation energy and the lowest lying negative parity band becomes yrast at a low spin. Figure 2 shows the the E1 transitions in three N = 88 isotones and the relative positions of the band head of the ocutpole band is shown to increase with an increase in proton number. Strong E1 were observed for ^{150}Sm and ^{152}Gd by Bvumbi et al [3], from the first excited 0^+ band to the low lying negative-parity band. In ^{154}Dy, we observed E1 transitions from the lowest lying negative parity band to the first excited 0^+.

3.2. Alignment properties of bands

The Figure 3(a) and (b) show the excitation energies (minus 7.7 keV) against rotational frequency. In Figure 3(a), it can be seen that the band built on 12^+ cross the ground state band (0_1^+) at 15 $\hbar\omega$. This behavior has been previously observed in [11] and suggests that this crossing is caused by an aligned $i_{\frac{13}{2}}$ S band which crosses the 0_1^+ band. The new extended bands, the bands built on 2^+ and 3^+ are shown to have a split up to spin 10 $\hbar\omega$ when the two bands come together, this is shown in the negative parity bands where the bands built on 7^- and 6^- have the same behavior but no splitting is observed, see Figure 3(a). The band built on 6^- is seen to cross both the band built on 7^- and 6^- at 15 $\hbar\omega$. The band built on 0_1^+ and 3^- are seen to track the 0_1^+ band.

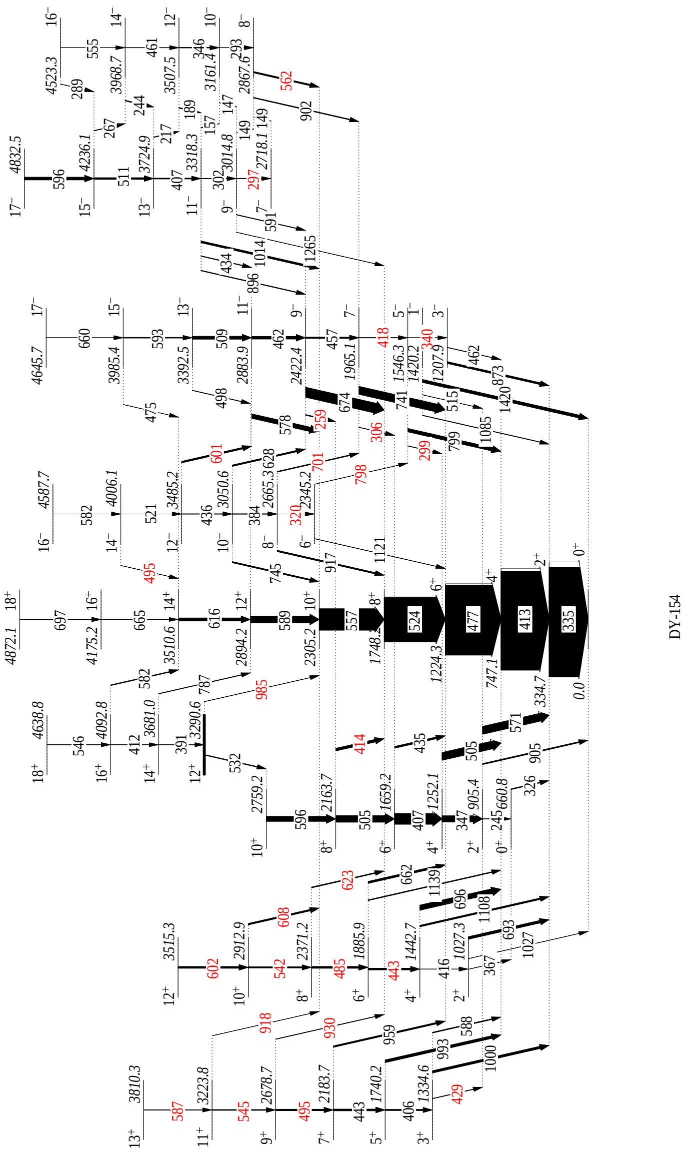

Figure 1. The new level scheme for ^{154}Dy obtained from our ^{155}Gd (^{3}He, 4n)^{154}Dy reaction at 37.5 MeV. The new γ rays are shown in red.

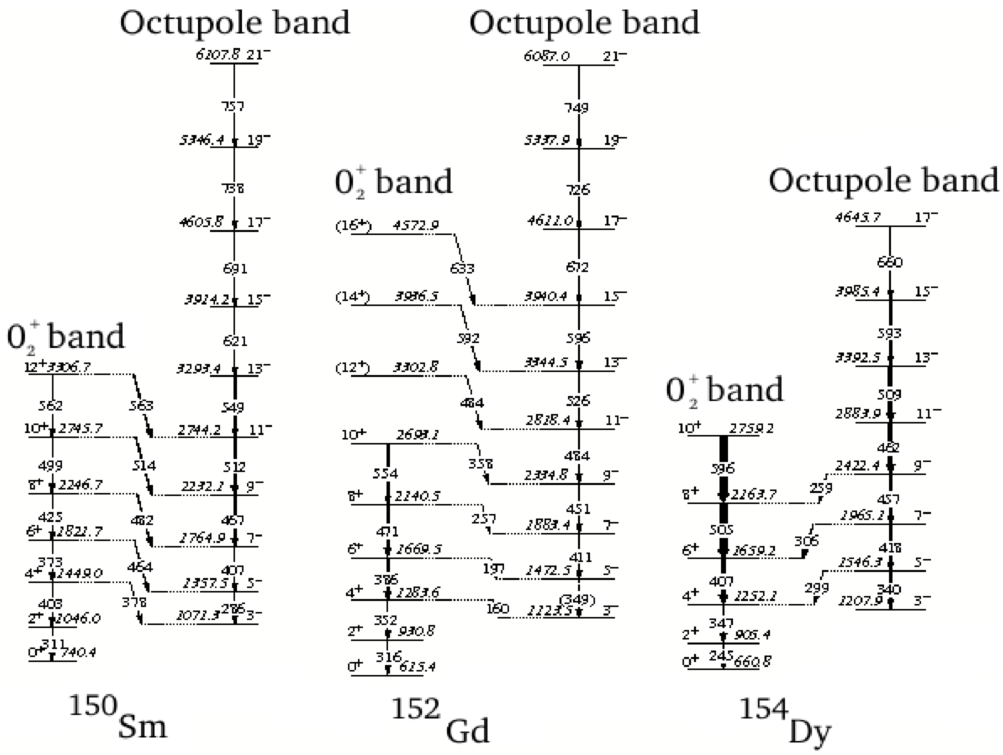

Figure 2. Shows the $0_2^+ \rightarrow 3_1^-$ for ^{152}Gd and ^{150}Sm [3] and the first observation of $3_1^- \rightarrow 0_2^+$ observed in ^{154}Dy.

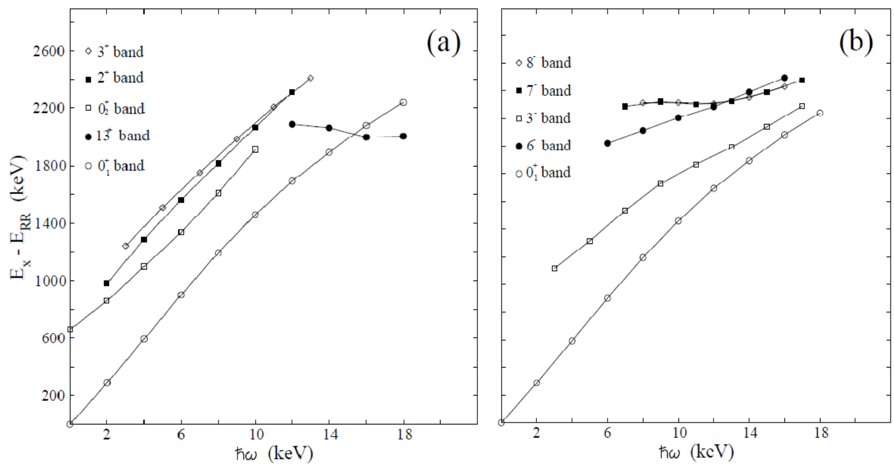

Figure 3. Shows excitation energies minus 7.7 keV against rotational frequency($\hbar\omega$) of the positive-parity bands (a) and the negative-parity bands (b).

The alignment(i_x) of the two new γ bands built on 3^+ and 2^+ positive states and the 0_2^+ positive state bands were plotted as a function of rotational frequency($\hbar\omega$), the ground state band was also plotted to compare their behavior, see Figure 4(a) and the negative parity bands are shown in Figure 4(b).

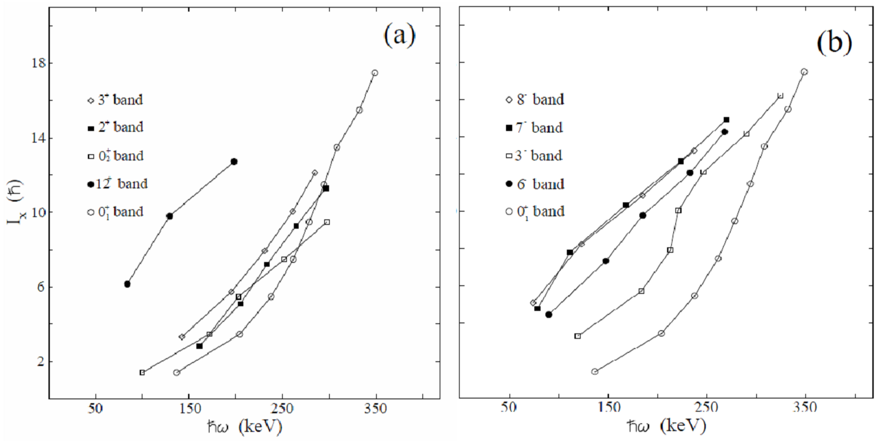

Figure 4. The alignment(i_x) against rotational frequency ($\hbar\omega$) of the positive-parity bands (a) and the negative-parity bands (b).

The change in slopes in Figure 4(a) and 4(b) represents specific positions of different energies at the same rotational frequencies. Rees et al. states that the changes in slope represent a rotational alignment of specific quasi-particle pair [7]. The newly extended odd γ band carries more aligned angular momenta than the even γ band. The 0_2^+ band slope is reduced at rotational frequency of 200 keV which makes it cross the even γ band and ground state bands, 0_1^+. The ground state band has a gradual aligned angular momenta increase with an increase in rotational frequency up to 310 keV when the slope sharply increases.

4. Conclusion

The experiment showed that $3_1^- \rightarrow 0_2^+$ is present in low-lying states of ^{154}Dy and therefore there is a need to explain why this behavior is opposite to that observed in other rare earth isotones ^{150}Sm and ^{152}Gd as shown in [3]. Spear and Catford [17] showed that there is a maximum in strength in E3 transitions between the ground state band and the lowest lying negative parity band at neutron number N = 88 and proton number Z = 62 but these E3 transitions were not observed in N = 88 Dy. Bands built on the 3^+, 2^+ and 0_2^+ states have been established and other new transitions. We therefore conclude that calculations along those of [6] and [14] are needed in order to explain the interaction between the 0^+ and 3^- in the N = 88 transitional region.

Acknowledgments

We would like to thank the AFRODITE group and students for their participation in the experiment and for their help during the analysis of the data.

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