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# COMPETITION BETWEEN ROTATIONAL AND ALIGNED-PARTICLE HIGH-SPIN EXCITATIONS IN $^{153,154}$Dy

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## Abstract

High-spin level structure of the transitional N = 87,88 $^{153,154}$Dy nuclei have been studied using $^{124}$Sn($^{34}$S,xn) reactions. In both nuclei the lower part of the level scheme includes decoupled rotational bands indicating prolate deformation in yrast structures between I = 17/2 and 41/2 in $^{153}$Dy and up to I = 30 in $^{154}$Dy. Above these collective bands the level structure becomes irregular, very similar to the aligned multiparticle structure in $^{152}$Dy. The yrast 2.3 ns 47/2 isomer at 5591 keV shows that aligned-particle excitations compete successfully with collective rotation above 5 MeV in $^{153}$Dy. The similar change occurs in $^{154}$Dy above 10 MeV after the S-band has crossed with the S'-band. The aligned configurations are connected with the oblate shape of the nucleus and our results show that a transition from a basically prolate to oblate shape occurs in $^{153}$Dy above I = 41/2 and in $^{154}$Dy above I = 32.

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## 1. Introduction

The N = 82-90 nuclei have been studied intensively during recent years and discrete levels are now known up to very high spin in many of these nuclei. The nuclei with N = 82-86 are spherical near the ground state but become oblate at higher energies near the yrast line. This shape transition is caused by the alignment of successive high-j nucleons along the symmetry axis. Many yrast isomers have been observed in these nuclei but no high-spin isomers have been found in N $\geq$ 90 nuclei which are prolate from the ground state up to highest observed discrete levels. Obviously the shell effects causing a deformed prolate shape in these heavier nuclei stay dominant also at high spin. The transitional N = 87 and 88 nuclei have low-lying collective bands indicating a small prolate deformation but it has been suggested$^{1)}$ that these soft nuclei could become oblate at higher angular momenta. Therefore we studied high-spin structures in $^{153}$Dy (N = 87) and $^{154}$Dy (N = 88) and observed a prolate-to-oblate shape transition in both nuclei$^{2,3)}$.

## 2. Level schemes of $^{153,154}$Dy

Levels of $^{153}$Dy and $^{154}$Dy were investigated using $^{124}$Sn($^{34}$Sn, xn) reactions induced by 145-165 MeV $^{34}$Sn beams from the Argonne Tandem-Linac. The experimental in-beam studies included angular distributions, excitation functions, electronic and recoil-distance lifetime measurements and γγ-coincidences. The large NaI detector was used, either as a sum spectrometer or as a multiplicity filter, to enhance $^{153}$Dy or $^{154}$Dy lines. Three Ge-detectors were employed in coincidence experiments.

The level scheme of $^{153}$Dy is shown in Fig. 1. Two strong parallel cascades of streched E2 transitions were observed in

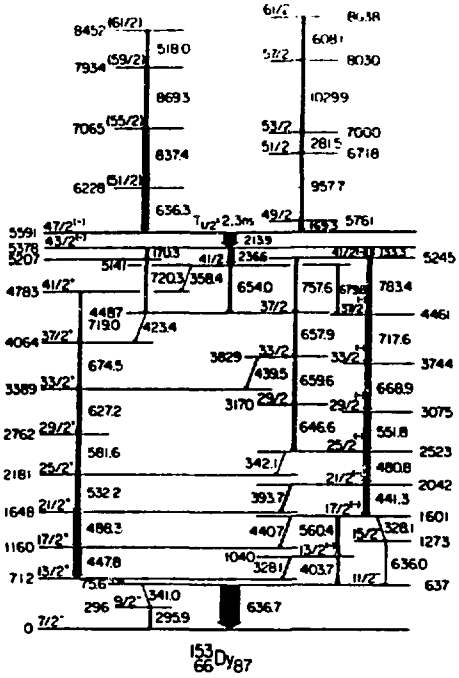

Fig. 1. The level scheme of $^{153}$Dy. The widths of arrows are proportional to transition intensities at 165 MeV.

the lower part of the level scheme. The known $i_{13/2}$ band was extended up to $41/2^{+}$. The more irregular, probably negative-parity band is mainly populated via a high-lying 2.3 ns isomer. The multipolarities of the transitions suggest I = 47/2 for this yrast isomer and the E2 213.9 keV γ-ray was assigned as an isomeric transition. However, it is possible that a strongly converted low-energy (< 50 keV) transition could have escaped notice. Above the isomer the level spacings are irregular and no band structures exist.

Fig. 2 shows the level scheme of $^{154}$Dy. The ground state band was extended up to $(18)^{+}$, the negative-parity band (based on the octupole band) up to $(25^{-})$ continuing as a I-even band up to $(30^{-})$, and the S-band was observed between $14^{+}$ and $(30^{+})$. After the S-band is crossed by a S'-band at *I* = 30 the population of band members

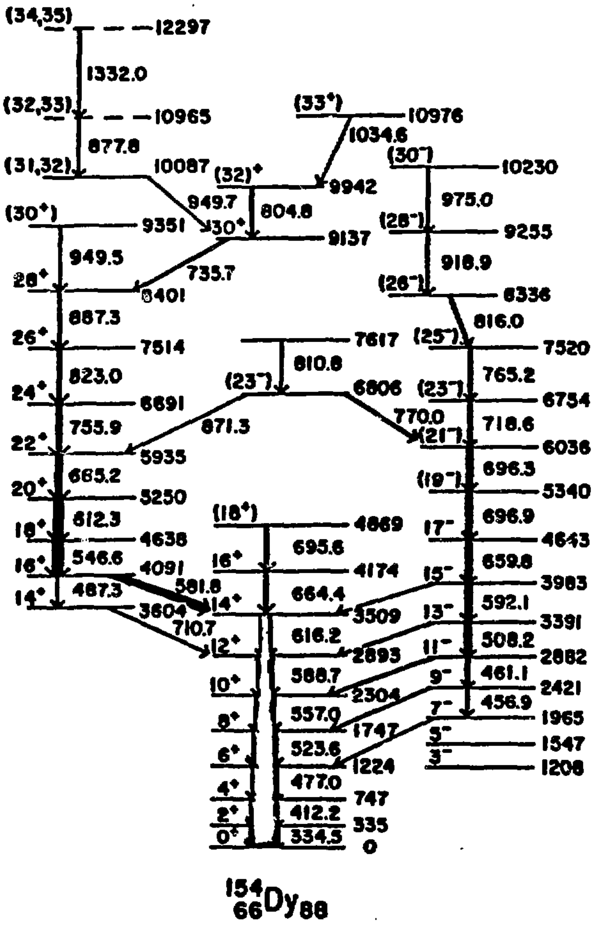

Fig.2. The level structure of $^{154}$Dy from the $^{124}$Sn($^{34}$S,4n) reaction.

terminates and the yrast structure above I = 32 is irregular. The highest part of the level scheme is quite similar to the $^{152}$Dy level structure4,5) above I = 15 and this suggests that aligned-particle configurations dominate the yrast structure of $^{154}$Dy above I = 32. To check the character of these highest levels we measured level lifetimes and feeding times using the recoil distance method. At ANL the recoil velocity was 1.8 % of c and at GSI (using a $^{25}$Mg($^{134}$Xe,5n) reaction) it was v/c = 8 %. Very long feeding times ($t_F$ = 5-50 ps) were observed for the high-spin levels above I > 20 which confirms the aligned-particle character of the highest-spin levels observed in $^{154}$Dy. From the level lifetimes we derived effective intrinsic quadrupole moments3) $Q_0$(eff) which are shown in Fig. 3. In heavier Dy isotopes these values

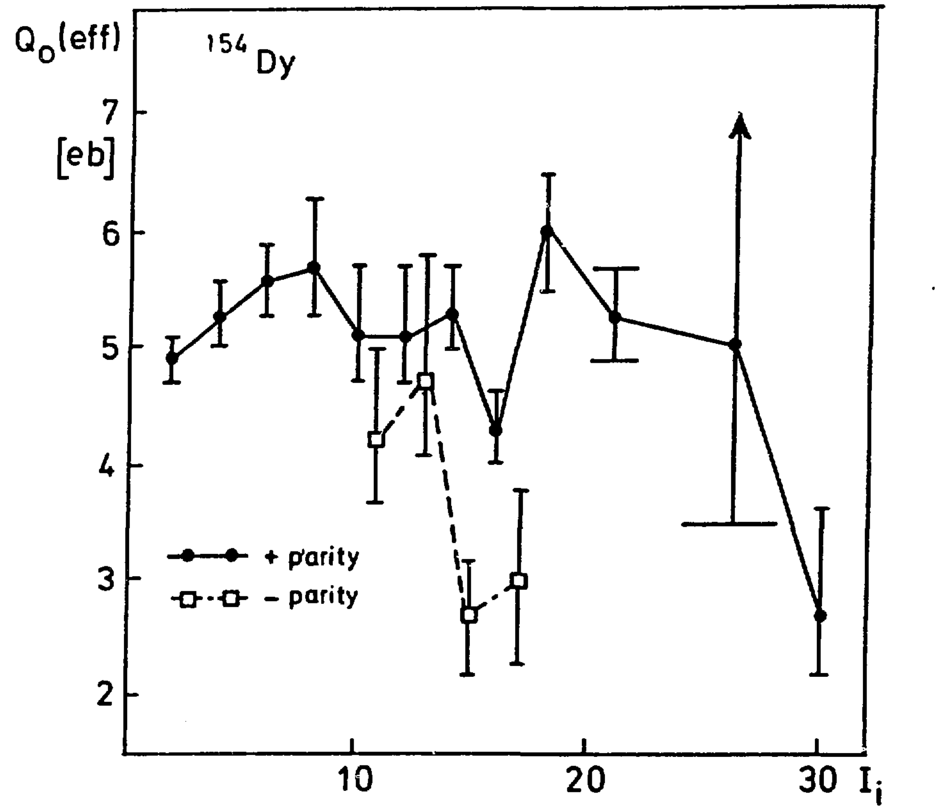

Fig. 3. Effective quadrupole moments $Q_0$(eff) of the E2 transitions in $^{154}$Dy.

go up to 7.5 eb in ground state bands[6]. Although the $Q_0$ is smaller in $^{154}$Dy, between 5 and 6 eb, it means a considerably large deformation of $\beta$ = 0.20-0.25. The long feeding and sidefeeding times of high-spin levels did not allow an accurate determination of lifetimes for the S-band members but a decreasing trend with spin is in agreement with results observed for the N = 90-92 isotopes[6]. Since $Q_0$(eff) is related to deformation parameters $\beta$ and $\gamma$ by the expression

$$Q_0(\mathrm{eff}) \propto \beta \cos(\gamma+30^\circ),$$

the reduced collectivity in the S-band can be explained if the asymmetry parameter $\gamma$ increases with spin. The N = 88 nucleus $^{154}$Dy is the first heavy isotope where the prolate-to-oblate shape transition was observed[3], and the results suggest that it occurs gradually through a series of triaxial shapes.

## 3. Discussion

The experimental results showed that the transitional N = 87 and 88 nuclei are prolate at low energy and spin but become oblate at high spin, above I = 41/2 in $^{153}$Dy and above I = 32 in $^{153}$Dy. Below this transition we observed some bands and it is interesting to test if the cranked-shell model[1,7] can explain some features of these transitional nuclei.

Fig. 4 shows plots of the angular momentum along the rotational axis, $I_x$, versus rotational frequency.

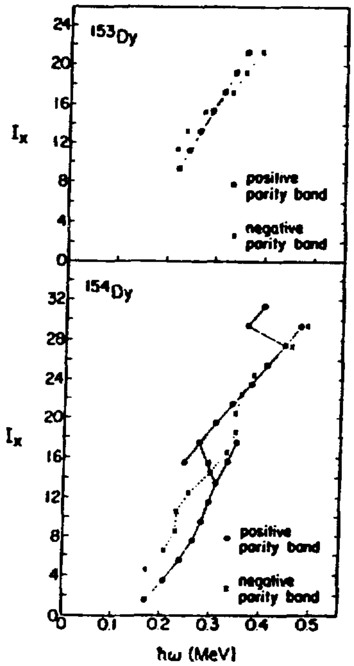

Fig. 4. $I_x$ as a function of ħω for bands in $^{153,154}$Dy.

The $i_{13/2}$ band in $^{153}$Dy is a straight line and no band crossings can be seen. In $^{154}$Dy two crossings occur in positive (ħω = 0.29 and 0.40 MeV) and negative-parity (ħω = 0.23 and 0.35 MeV) bands. In well-deformed nuclei $I_x$ is usually expressed as

$$I_x = i + \mathcal{J}\omega \ , \quad \mathcal{J} = \mathcal{J}_0 + \mathcal{J}_1\omega^2 \ ,$$

where i is the aligned angular momentum of quasiparticles, $J\omega$ is caused by the rotation and $\mathcal{J}_0$ and $\mathcal{J}_1$ are the Harris parameters[7] which can be obtained from the g.s. band or from some reference band having a constant alignment i. In transitional nuclei additional effects can be caused by changes in deformation, and it is probably impossible to find a good reference band (usually the S-band), because negative-parity quasineutrons gradually mix into bands[8], as demonstrated also by Frauendorf in his talk on this conference. For example, no Harris parameter set can give a constant i for the $i_{13/2}$ band in $^{153}$Dy. We used Harris parameters extrapolated from heavier isotopes and the "aligment" $I_x - \mathcal{J}\omega$ curves include these "side effects" in addition to the alignment i (Fig. 5).

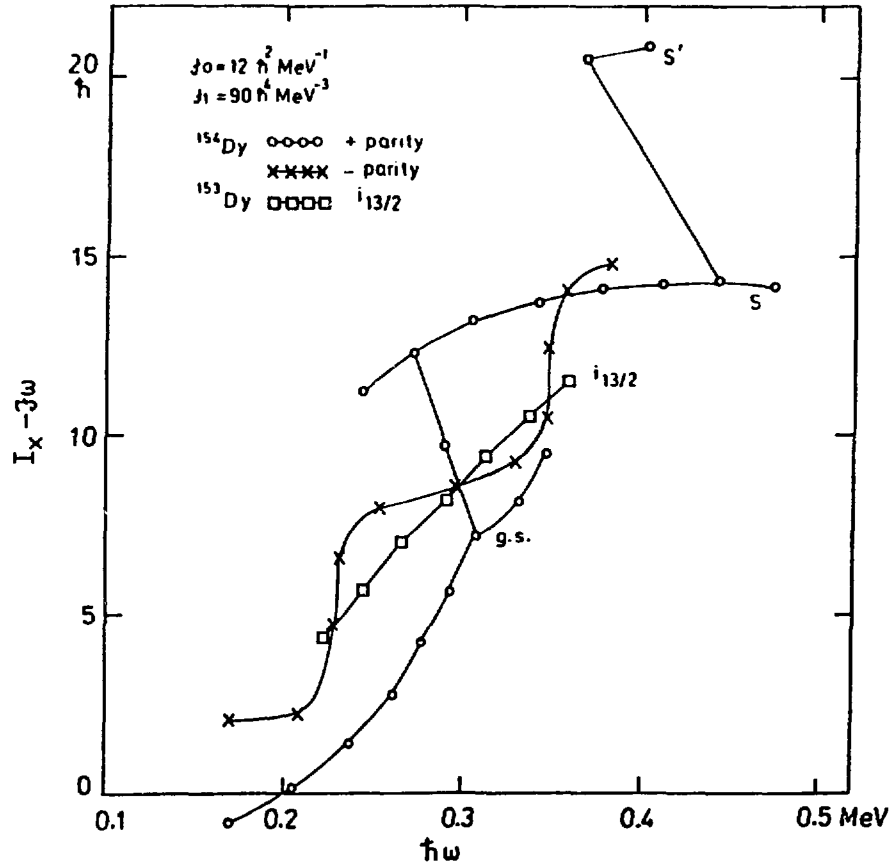

Fig. 5. The "alignment" $I_x - \mathcal{J}\omega$ for bands in $^{153}$Dy and $^{154}$Dy.

The alignments and band crossing frequencies in Fig. 5 can be quite accurately calculated using a γ-dependent CSM[7,9]. For example, the S-band with the $i_{13/2}$ aligned pair crosses with the g.s. band at $\hbar\omega$ = 0.29 MeV which is given by the CSM with deformation parameters $\epsilon_2$ = 0.22 and $\gamma = -10°$; the S'-crossing at 0.40 MeV is reproduced assuming the $h_{11/2}$ proton pair alignment and $\gamma = +30°$. These γ-deformations are also in agreement with transition probabilities mentioned earlier. Frauendorf showed in his talk on this conference that the triaxiality γ for different configurations can be quantitatively extracted from CSM calculations. The total Routhians (a sum of the quasiparticle vacuum and excited quasiparticles) are plotted as a function of the $\gamma$-parameter for different configurations and the minima give equilibrium values of $\gamma$. For $^{154}$Dy at $h\omega$ = 0.38 MeV the vacuum has a minimum at $\gamma = -10°$, a $\nu i_{13/2}$ pair drives $\gamma$ to +10°, and a gradual mixing of negative-parity neutron pairs ($f_{7/2}$, $h_{11/2}^{-1}$, $h_{9/2}$) into the S-band was approximated with a $h_{9/2}$ pair, which gives a wide minimum at $\gamma = +15°$. When the $\pi h_{11/2}$ pair is added it drives the nucleus to an oblate shape $\gamma = +60°$. This is in excellent agreement with our experimental data which show a transition to an oblate shape after the second backbending.

The $i_{13/2}$ band in $^{153}$Dy was observed up to $\hbar\omega$ = 0.36 MeV above which the yrast structure changes to aligned-particle configurations. It is possible that $h_{9/2}$ and other negative-parity neutrons drive this band to an oblate limit already before $(h_{11/2})^2$ proton band crosses the $i_{13/2}$ band (predicted at about 0.4 MeV).

In summary, we have proved that the N = 87 and N = 88 Dy isotopes are prolate at low excitation energies but with increasing angular momenta the nuclear shape becomes triaxial and finally the yrast structure shows a transition to the oblate shape, above I = 41/2 in $^{153}$Dy and I = 32 in $^{154}$Dy. Comparisons with cranked-shell model calculations show that successive aligned-pair excitations cause this prolate-to-oblate transition.

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