High Spin States in the Transitional Nucleus $^{156}$Er

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High-spin states in $^{156}$Er have been populated using the ($\alpha$, 8$n$) and ($^{16}O$, 4$n$) reactions. In the ground state band a strong backbending effect was observed at $I^\pi = 12^+$. Four states of a second $K=0$ band with spins 9, 11, 13 and 15 were found. This second band depopulates completely into the $8^+$ and $10^+$ members of the ground state band. This is explained by the fact that the upper states of this second band are yrast states and that this band crosses the (gsb)-line at $I \simeq 11$.

1. Introduction

It is now experimentally well established that in the ground-state rotational bands (gsb) of some doubly-even rare earth nuclei in the mass range $A = 158 - 168$ the nuclear moment of inertia $\theta$ increases dramatically as high-spin members of the gsb are reached [1–3]. Plots of the moment of inertia defined by

$$\frac{2\theta}{\hbar^2} = \frac{4I - 2}{E_I - E_{I-2}}$$

as a function of the square of the rotational frequency defined by

$$\hbar^2 \omega^2 = \frac{I^2 - I + 1}{(2I - 1)^2} [E_I - E_{I-2}]^2$$

result in "backbending" curves for many of these nuclei [4]. Here the quantity $I$ denotes the spin of the initial state, and $[E_I - E_{I-2}]$ is the transition energy.

Of particular interest is the fact that the isotopes $^{162,160,158}$Er whose highest known gsb levels have spins of $20^+$, $18^+$ and $18^+$ respectively [1, 3, 5], all show backbending behaviour. The degree of backbending increases with decreasing neutron number [4], which can be understood qualitatively from theoretical models based either on the Coriolis anti-pairing (CAP) effect [6–8], or alternatively, on that of Stephens and Simon [9, 10] in which the effect of the Coriolis decoupling of one (or
two) pairs of $i_{13/2}$ neutrons from the core are treated. The present investigation was initiated to find out whether this trend already established in $^{162,160,158}$Er is continued in the transitional nucleus $^{156}$Er.

An earlier study on $^{156}$Er conducted at Berkeley using $^{40}$Ar-induced reactions established the gsb as far as the $10^+$ level [11, 12].

### 2. Experiments and Results

An $^{160}$Dy oxide target ($\approx 7 \text{ mg/cm}^2$), enriched to 96.6% on the mass separator facility at the KFA Jülich, was bombarded with an 108 MeV external $\alpha$-particle beam from the Jülich isochronous cyclotron JULIC so that the final nucleus under investigation, namely $^{156}$Er, was produced via the ($\alpha$, $8n$) reaction. The nuclei $^{157}$Er and $^{158}$Er were also produced in considerable amounts via the ($\alpha$, $7n$) and ($\alpha$, $6n$) reactions respectively. Using Ge (Li) spectrometers, in-beam measurements of $\gamma$-singles spectra, $\gamma$-$\gamma$ coincidence spectra, $\gamma$-spectra time-related to the cyclotron beam bursts and $\gamma$-ray angular distributions were performed. Explicit details of the experimental techniques used have already been published [3].

Furthermore a study of the angular distribution of $\gamma$-rays following the $^{144}$Nd($^{16}$O, $4n$)$^{156}$Er reaction was conducted on the cyclotron of the University of Louvain-La-Neuve. In this experiment a self-supporting metallic $^{144}$Nd target ($\approx 3.7 \text{ mg/cm}^2$) enriched to 97.5% was irradiated with 100 MeV oxygen ions. Since this reaction is more specific to produce the final nucleus $^{156}$Er than the ($\alpha$, $8n$) reaction, considerably cleaner $\gamma$-spectra were obtained.

To establish the level scheme of $^{156}$Er $\gamma$-$\gamma$ coincidences were studied. These $\gamma$-$\gamma$ coincidence spectra were measured using a pair of large volume ($60 \text{ cm}^3$ and $66 \text{ cm}^3$) Ge (Li) detectors and were event-mode recorded on magnetic tape. Coincidence spectra were obtained by successively setting gates on all $\gamma$-lines of interest. In addition to the five gsb $\gamma$-transitions in $^{156}$Er known previously, seven new $\gamma$-transitions appeared in the coincidence spectra. A comprehensive examination of the individual coincidence spectra gated with each of the twelve $\gamma$-rays was performed. In Fig. 1 a background-corrected summed coincidence spectrum is shown, where gates were simultaneously set on all the gsb transitions in $^{156}$Er up to the $10^+ \rightarrow 8^+$ transition. Taking into account all coincidence relationships and $\gamma$-intensities in each individual coincidence spectrum, the level scheme shown in Fig. 2 was constructed. In addition to the gsb in $^{156}$Er, a second band is apparent which depopulates into the gsb by means of two interband transitions.

In order to determine $\gamma$-ray multipolarities and to obtain thereby spin assignments, $\gamma$-ray angular distributions were measured using the ($\alpha$, $8n$) and ($^{16}$O, $4n$) reactions. In Jülich these measurements were simul-