High-Spin Structure in $^{154}$Er

F.A. Beck, J. Dudek, B. Haas, J.C. Merdinger, A. Nourreddine, Y. Schutz, and J.P. Vivien
Centre de Recherches Nucléaires, Strasbourg, France

Ph. Hubert and D. Dassié
Centre d'Etudes Nucléaires de Bordeaux-Gradignan, Gradignan, France

G. Bastin, L. Nguyen, and J.P. Thibaud
Centre de Spectroscopie Nucléaire et de Spectrométrie de masse, Orsay, France

W. Nazarewicz
Lund Institute of Technology, Lund, Sweden and Institute of Physics, Technical University of Warsaw, Warsaw, Poland

Received April 11, 1984; revised version August 13, 1984

High spin states in the nucleus $^{154}$Er have been reinvestigated using the $^{123}$Sb($^{35}$Cl, 4$n$) reaction and a variety of spectroscopic techniques including excitation functions, $\gamma$-$\gamma$ coincidences, $\gamma$ angular distribution and linear polarization measurements. From the measured energies, relative intensities and transition multipolarities a new level scheme has been deduced up to an excitation energy of $\sim 12$ MeV and spin 36. An interpretation of the experimental results is given in terms of the deformed Woods-Saxon orbitals. Gigantic backbending (superdeformation) effect is studied theoretically within the cranking model.

I. Introduction

It is well known by now that prolate-deformed nuclei can generate very high angular momenta when rotating around an axis perpendicular to the symmetry axis. However, in spherical or weakly deformed oblate-shape nuclei, large total spin values can also be generated by an alignment of a few single particle angular momenta along the symmetry axis. In such nuclei hindered gamma transitions and even long-lived isomeric states are expected. An island of high spin isomers has indeed been observed in the region $N \sim 82$, $Z \sim 64$ Ref. [1] and this has prompted studies of, in particular, nuclei with a few particles outside $Z=64$ and $N=82$ shell closures. An equatorial shape polarisation due to the presence of a few “valence” particles is considered to be a microscopic reason for the oblate shape configurations there. Moreover, increasing number of “valence” nucleons results in softening the nuclear response to deformation thus lowering the energies of the corresponding collective vibrational motion. The latter mechanism is expected to increase gradually a possibility of a coherent (collective) excitation of several nucleons and enhance some of the high-spin transitions considerably due to increasing “softness” with respect to deformation. As a result an interplay between typical single-particle (particle-hole) and enhanced (collective) transitions is expected in the high-spin regime of nuclei with 2-4 protons and especially 4-6 neutrons outside closed shells. Among those nuclei $N=86$ isotones have been studied extensively. The dominant single particle character of the high-spin Yrast states in $^{154}$Er Refs. [2,3], $^{155}$Dy Ref. [4] and $^{153}$Ho Ref. [5] is supported by the observed irregular deexcitation pattern including long-lived isomers and by measurements of $E2$ transition strengths in the range 0.1-10 Weisskopf units [5-8]. In the case of $^{154}$Er there are, however, serious discrepancies in the level ordering cf. [3, 6, 7] and in the lifetime measurements [6, 7] reported by different authors. As a consequence the deduced $E2$ transition rates seem uncertain. Although the average $E2$ transition strength is $\sim 5$ W.u. suggesting
that collective degrees of freedom (presumably vibrational) may also be involved in the description of the high-spin Yrast states [6], the observation of one very fast transition interpreted originally as $E2$ ($E_1 = 318$ keV, $B(E2) \sim 80$ W.u.) was very unusual and this has led Ward et al. [7] to question its $E2$ character. In view of the discrepancies we have reinvestigated the decay scheme and multipolarities of the $\gamma$-ray transitions above the $I^+ = 11^-$ isomer [9] using variety of experimental techniques including excitation function, $\gamma - \gamma$ coincidence, angular distribution and linear polarization measurements. Special care was taken to identify the $^{154}$Er evaporation residues in order to reject $\gamma$-ray transitions which belong to neighbouring nuclei.

We also performed theoretical calculations aiming at:

i. interpreting the experimental results in terms of the deformed shell model (Woods-Saxon) orbitals;

ii. examining the spin range in which the single-particle type of the excitation pattern of $^{154}$Er terminates giving rise to a collective rotational motion;

iii. investigating the possible behaviour of $^{154}$Er in the very high-spin ($I \sim 40-80$) range.

In fact, as expected, a special role of only a few-particle few-hole configurations with maximum alignment of angular momenta possible at the given configurations is dominating in the theoretical decay scheme. An extremely strong $\nu(N=86)$ shell structure present in the single-particle spectrum over a broad range of frequencies and corresponding to $\beta_2 \sim 0.65$, $\gamma \sim 0^\circ$, acts as a very selective mechanism of producing a strong superdeformation effect in $^{154}$Er (and much weaker effects in heavier Erbium isotopes).

II. Experimental Procedure

The experiments were performed at the Strasbourg M.P. tandem accelerator using the $^{123}$Sb($^{35}$Cl,4$n$)$^{154}$Er fusion evaporation reaction. The energy of the projectiles was varied between 140 and 160 MeV. We used enriched (>98%) targets of 1 mg/cm$^2$ thickness evaporated onto 0.1 mm Pb backings.

The decay scheme of $^{154}$Er is known to exhibit a long lived high spin isomer $T_{1/2} = 35$ ns, at about 3 MeV excitation energy [9]. We have taken advantage of this isomer in order to select prompt $\gamma$-rays from the $4n$ exit channel by using a pulsed beam (FWHM $\sim 3$ ns and repetition rate 400 ns) and a “timing filter” array of NaI counters. The experimental set-up is shown in Fig. 1. The “timing filter” array consisted of two halos of 6 NaI detectors (5.1 cm $\times$ 5.1 cm$^2$ each) located above and below the reaction chamber, at $\sim 6$ cm from the target. Quasi-singles and quasi-coincidence $\gamma$ spectra from one or two Ge(Li) detectors were recorded in a delayed coincidence arrangement with the array so that only events in which Ge(Li) pulses prompt with the beam burst ($\pm 6$ ns) and followed by a delayed NaI pulse during a given time period were recorded. Dead time in the computer and ADC’s was minimized by electronically suppressing coincidences due to prompt $\gamma$-rays detected in the NaI counters. With the arrangement we have measured the angular distributions of the $\gamma$-rays feeding the long lived isomer using four Ge(Li) detectors located at $0^\circ$, $45^\circ$, $90^\circ$ and $150^\circ$ relative to the beam direction at about 10 cm from the target. Detailed computer calculations were performed to investigate how the $\gamma$-angular distributions should be affected by $\gamma-\gamma$ correlations in our detector geometry. These calculations, which involved trials with different assumed multipolarities for the prompt and delayed $\gamma$ transitions, have shown that the effect of the delayed coincidence requirement on the measured $a_2$-coefficients is extremely small, less than 5%. The data were fitted to an expansion of even Legendre polynomials (up to fourth order) and the deduced intensities used in the ordering of the $\gamma$-ray transitions.

The Ge(Li) detectors were simultaneously used for the $\gamma-\gamma$ coincidence measurement. Six pairs of $\gamma-\gamma$ quasi-coincidences were thus recorded event by event. In order to measure the $\gamma$-ray linear polarization of the transitions feeding the isomer we have used a five Ge Compton polarimeter [10] placed at 10 cm from the target. A conical lead shield (5 cm thick) was used a collimator so that $\gamma$-rays emitted from the target could only be detected by the central crystal (scatterer). Again only those events were ac-