Z. Phys. A 359, 5–6 (1997)

ZEITSCHRIFT FÜR PHYSIK A

Short note

High-K band structures in ^{164}Er

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Received: 11 June 1997
Communicated by B. Herskind

Abstract. Several of the known rotational bands in ^{164}Er are extended considerably (to around $35\hbar$). In addition, a new coupled band is established and found to decay by an isomeric transition with $t_{1/2} \geq 170$ nsec, to the 11^- state of the known $K^\pi = 7^-$ two-quasi-proton band. The new band is interpreted as a four-quasi-particle structure, with measured values of B(M1)/B(E2) consistent with the configuration $[7^-] \otimes \nu i_{13/2}[642\ 5/2^+] \otimes \nu h_{9/2}[523\ 5/2^-]$, i.e. $[7^-] \otimes$ [AE,AF]. This is supported by the observation of a crossing which resembles the second $i_{13/2}$ neutron crossing, BC, associated with the two-quasi-neutron band built on the configuration, [AE,AF]. The routhian of the new band is close to the sum of the individual routhians of [AE,AF] and $[7^-]$. The cause of a small gain in energy of 130-272 keV is discussed.

PACS: 21.10.-k; 21.60.-n; 27.70.+q

The well deformed nucleus ^{164}Er ($Z = 68, N = 96$) is one of the best known in the rare-earth region, being an early example of a nucleus in which there exist several side bands in addition to the ground-state band [1]. Recently, multitudes of rotational bands have been revealed in many nuclei in this region and the interest is now focused on the structure of these bands, their configurations and interactions [2, 3].

In high-K bands in this region, a two-quasi-proton state (2-qp), $\pi h_{11/2}[523\ 7/2^-] \otimes \pi g_{7/2}[404\ 7/2^+]$ coupled to $[K^\pi = 7^-]$, plays an important role. The $[7^-]$ configuration is observed in several nuclei in the Er, Yb and Hf region with neutron numbers between 90 and 96 [4]. Furthermore, it contributes, for example, to the interpretation of high-K rotational bands in ^{163}Er [2]. Here we report the observation of a four-quasi-particle isomer, formed by the addition of a pair of neutrons to the $[7^-]$ configuration.

Levels in ^{164}Er were populated using the ^{150}Nd(^{18}O,4n) reaction at a beam energy of 87 MeV on a 700 μg target. A Au-backed target to stop the recoils was also employed. At this beam energy, around 20 % of the fusion cross-section lead to ^{164}Er through the 4n channel. Results for the main channel, ^{163}Er, have already been reported [2, 3]. The experiment was performed with the tandem accelerator at Laboratori Nazionali di Legnaro (Padova) using the 4π-detector system GASP. A total of $\sim 10^9$ $\gamma - \gamma - \gamma$ coincidences were obtained in ^{164}Er.

The triples data were sorted into a 3D-cube. For the analysis of the cube, programs of the Radware package were used [5]. A partial level scheme is shown in Fig. 1. The bands AB, AE and AF are now extended higher in spin.

Furthermore, a new, weakly populated band, labelled in Fig. 1 as $[7^-] \otimes$ [AE,AF], is introduced as a result of studies of prompt-delayed coincidence relationships of the backed target data, as demonstrated in Fig. 2. The spectra show that the new band is depopulated by a delayed transition that feeds the well known $[7^-]$ band [6] at the 11^- level.

The band head of the new band most likely has I(= K) $\geq$ 12. The two possible low-lying 4-quasi-particle structures with K = 12 are: $[7^-] \otimes \nu i_{13/2}[642\ 5/2^+] \otimes \nu h_{9/2}[523\ 5/2^-]$, i.e. $[7^-] \otimes$ [AE, AF] and the 4-quasi-neutron configuration: $\nu h_{11/2}[505\ 11/2^-] \otimes \nu f_{7/2}[521\ 3/2^-] \otimes$ [AE, AF]. Ratios of B(M1,I→I–1) to B(E2,I)→I–2), deduced from the branching ratios of the $\Delta I = 1$ and $\Delta I = 2$ γ-decays, are plotted in Fig. 3A. The jump in B(M1)/B(E2) values near spin 24 is indicative of a bandcrossing, which can also be seen on the plot of routhians in Fig. 3B, near $\hbar\omega = 0.3$ MeV. This crossing is most likely the BC crossing, as no proton crossing can be observed in the S-band (labelled AB in Fig. 3B). Values of B(M1)/B(E2), calculated using a generalisation of the semi-classical method [7], are shown in Fig. 3A. The agreement with the values calculated for the $2\pi 2\nu$-configuration is seen clearly, in contrast to the 4ν-configuration, especially after the BC crossing, (forming a 6-quasi-particle band). This enables the $[7^-] \otimes$[AE,AF] configuration to be assigned.

The half-life of the band head is similar to the coincidence window of the GASP array ($\sim$ 150 nsec), and therefore only an approximate value $t_{1/2} \geq 170$ nsec can be estimated. The K-hindrance from the observed half-life is reasonable. Taking a standard reduction of the K-allowed E1 strength over the Weisskopf-estimate of 10^4 the result is $f_\nu \geq 10$, in accordance with systematics [8].

From Fig. 3B it can be deduced that the sum of the routhians of the bands, [AE,AF] and $[7^-]$, is close to the observed routhian of the new band, in ageement with the present assignment, although there is a small gain in energy of 130–230 keV with decreasing frequency. When adding 2-quasi-particle ex-

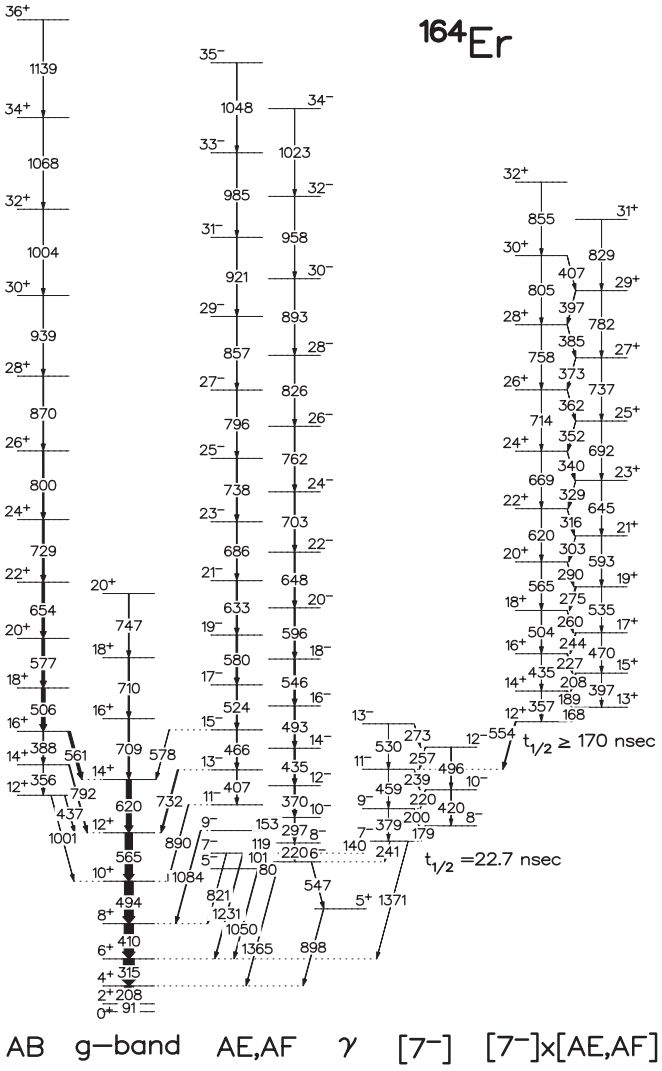

Fig. 1. Partial level scheme of ^{164}Er

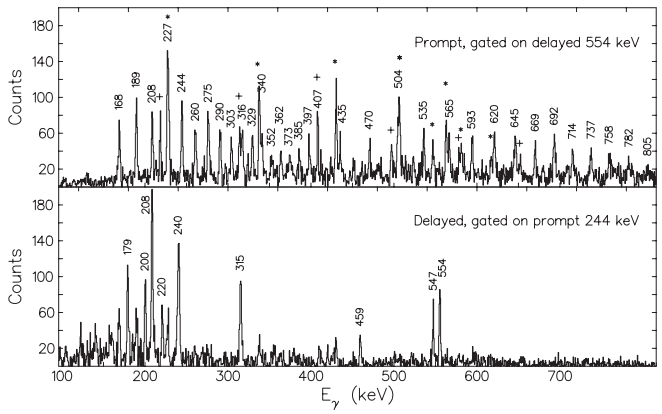

Fig. 2. (Upper part) Prompt (±13 ns) γ-rays in the new band, gated by the delayed (25–125 ns) 554 keV γ-ray. Randomly accepted γ-rays from the ground state rotational band in ^{162}Er are marked by asteriscs and γ-rays belonging to the ground state rotational band in ^{163}Er by crosses. (Lower part) Delayed γ-rays observed when gated on the prompt 244 keV in the new band

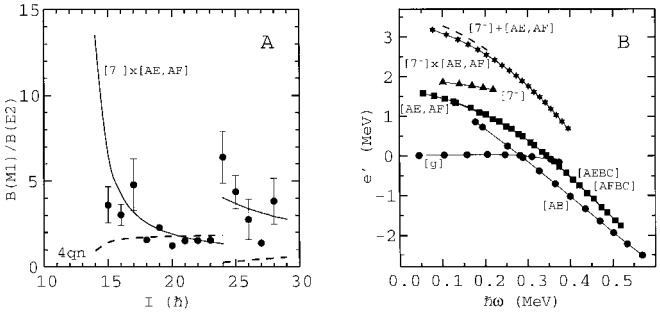

Fig. 3. A Experimental (*filled circles*) and calculated values of B(M1, I→I–1)/B(E2, I→I–2) ratios for the coupled band. **B** Routhian plot of selected bands in ^{164}Er, relative to a reference with $\Im_0 = 35\hbar^2 MeV^{-1}$ and $\Im_1 = 40\hbar^4 MeV^{-3}$

citations of protons and neutrons in an even-even system there is no expected pairing reduction in the 4-quasi-particle configuration. The gain in energy for [7$^-$]⊗[AE,AF] is 272 keV at the band head (ω = 0). A similar observation is found for a 14$^+$ 4-qp state in ^{174}Hf based on 2-qn 6$^-$ and 2-qp 8$^-$ states of similar intrinsic shell model structures [8]. The effect is most likely caused by residual neutron-proton interaction. In addition, there could be a change in geometry, i.e. the angle of rotation of the [7$^-$]⊗[AE,AF] configuration could be tilted further away from 90° than that of its constituents, cf [9]

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