LIFETIMES OF HIGH-SPIN STATES IN ^{76}Kr *

J.J. Valiente-Dobón[a], C.E. Svensson[a], C.D. O'Leary[b]
I. Ragnarsson[c], C. Andreoiu[a,d], R.A.E. Austin[e]
M.P. Carpenter[f], D. Dashdorj[g], P. Finlay[a], S.J. Freeman[f]
P.E. Garrett[h], A. Görgen[i], J. Greene[f], G.F. Grinyer[a]
B. Hyland[a], D. Jenkins[b], F. Johnston-Theasby[b], P. Joshi[b]
N.S. Kelsall[b], A.O. Macchiavelli[j], F. Moore[f], G. Mukherjee[f]
A.A. Phillips[a], W. Reviol[k], D. Sarantites[k], M.A. Schumaker[a]
D. Seweryniak[f], M.B. Smith[l], R. Wadsworth[b], and D. Ward[j]

[a]Department of Physics, University of Guelph
Guelph, Ontario N1G 2W1, Canada
[b]Department of Physics, University of York, Heslington, York YO10 5DD, UK
[c]Department of Physics, Lund Institute of Technology
P.O. Box 118 S-221 00 Lund, Sweden
[d]Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 3BX, UK
[e]McMaster University, Hamilton, Ontario L8S 4K1, Canada
[f]Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA
[g]North Carolina State University, Raleigh, North Carolina 27695, USA
[h]Lawrence Livermore National Laboratory, Livermore, California 94551, USA
[i]CEA Saclay, DAPNIA/SPhN, 91191 Gif-sur-Yvette Cedex, France
[j]Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
[k]Department of Chemistry, Washington University, St. Louis MO 63130, USA
[l]TRIUMF, Vancouver, British Columbia, V6T 2A3, Canada

(Received December 12, 2004)

High-spin states in $^{76}_{36}\mathrm{Kr}_{40}$ have been populated in the ^{40}Ca(^{40}Ca,4p)^{76}Kr fusion–evaporation reaction at a beam energy of 165 MeV, and studied using the Gammasphere and Microball multi-detector arrays. The ground-state band and two signature-split negative-parity bands of ^{76}Kr have been extended to $\sim 30\hbar$. Lifetime measurements using the Doppler-shift attenuation method indicate that the transition quadrupole moment of these three bands decrease as they approach their maximum-spin states.

PACS numbers: 23.20.Lv, 27.50.+e, 21.10.Re, 21.60.Ev

* Presented at the XXXIX Zakopane School of Physics — International Symposium "Atomic Nuclei at Extreme Values of Temperature, Spin and Isospin", Zakopane, Poland, August 31–September 5, 2004.

1. Introduction

The proton-rich nucleus ${}^{76}_{36}\mathrm{Kr}_{40}$ is known to have a large deformation near its ground state [1]. Theoretical calculations have predicted a highly-deformed near-prolate shape for the ground state of this nucleus [2, 3]. The highly-deformed ground state was confirmed by lifetime measurements, yielding a quadrupole deformation of $|\beta_2|\approx 0.33$ [3] (considering an axial symmetric shape). The yrast negative-parity excited band observed in ^{76}Kr has been previously assigned the two-quasiproton configuration based on the $\pi[431]\frac{3}{2}^{+} \otimes \pi[312]\frac{3}{2}^{-}$ Nilsson orbitals [3]. Lifetimes of the low-spin states in the ground-state band for ^{76}Kr have been previously studied up to spin $I^{\pi}=10^{+}$ [3, 4]. This paper reports on the high-spin states of ^{76}Kr and their lifetimes.

2. Experiment

High-spin states in ^{76}Kr were populated via the ^{40}Ca(^{40}Ca,4p)^{76}Kr reaction. A 165-MeV ^{40}Ca beam provided by the Atlas accelerator at Argonne National Laboratory was incident upon a 350 μg/cm^2 ^{40}Ca target, which was sandwiched between two 150 μg/cm^2 Au layers to prevent oxidation. Gamma rays were detected with 99 Compton-suppressed HPGe detectors of the Gammasphere array [5], in coincidence with charged particles detected and identified with the 95-element CsI(Tl) Microball detector [6]. More details about the experimental setup and analysis can be found in Ref. [7].

3. Results and discussion

Figure 1 (left) shows the decay scheme for the ground-state and the favoured negative-parity bands for ^{76}Kr. In this work we focus on the lifetimes, or equivalently on the transitional quadrupole moments Q_{t}, of the high-spin states of these bands. These lifetimes are of the order of tens of femtoseconds. The centroid-shift Doppler attenuation method [8] was used to measure the lifetimes of these very fast transitions. These states decay while the recoil ions are slowing down inside the thin ^{40}Ca target. The stopping powers were obtained using the SRIM-2003 code [9]. Lifetimes are sensitive to the initial recoil velocity, which is determined from the momenta of the emitted particles. The lifetime measurement could therefore be biased if the particle detection efficiency of Microball presented any angular dependence. The detection efficiency of Microball for the 4-proton channel is nearly isotropic as can be seen in Fig. 1 (top inset) and no bias is expected in the lifetime measurement. The Doppler shifts were measured from the sum of single gates on the last three transitions at the top of each band. Side feeding was only considered into the top three

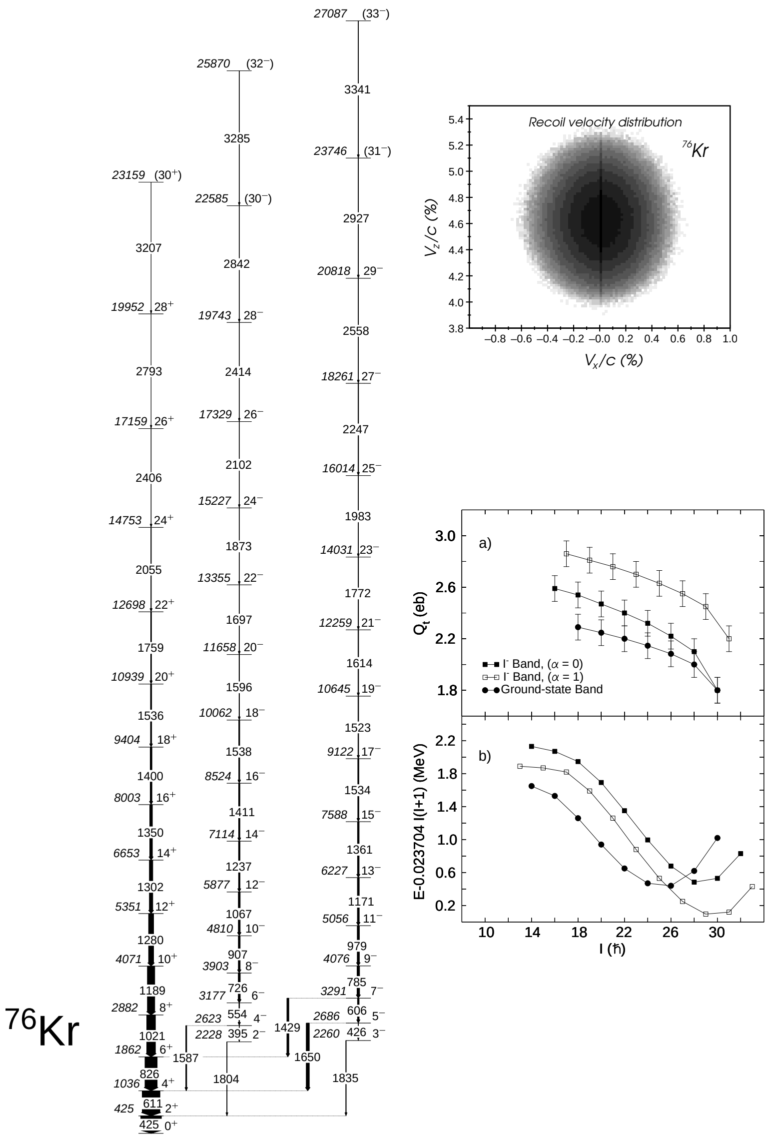

Fig. 1. Decay scheme for the ground-state and the favoured negative-parity bands for ^{76}Kr (left). The top inset shows the initial ^{76}Kr velocity distribution in the v_x–v_z plane. The lower inset (a) shows the measured transitional quadrupole moments $Q_{\rm t}$ for the ground-state and the favoured negative-parity bands. The lower inset (b) shows the energies of the high-spin states relative to a standard rigid rotor [12], with a moment of inertia of $\mathrm{Im} = 21\hbar^2\mathrm{MeV}^{-1}$, *versus* spin.

states. A rotational band sequence, with four transitions, was considered. The quadrupole moment of the side feeding bands was chosen to be the same as in the band under consideration. The $Q_{\rm t}$ values of the ground-state and the favoured negative-parity bands were found to decrease with spin and were approximately modelled as $Q_{\rm t}(I) = Q_{\rm t}^{\rm top} + \delta Q_{\rm t}\sqrt{I^{\rm top} - I}$, where the "top" superscript indicates the highest experimental spin state for which a centroid shift could be measured in a band and $\delta Q_{\rm t}$ is the variation of the $Q_{\rm t}$ within the band, see Fig. 1 (lower inset (a)). This decrease of the $Q_{\rm t}$ as a function of spin is well known in terminating bands and has been previously observed in other mass regions, $A \sim 110$ [10], $A \sim 60$ [11]. Figure 1 (lower inset (b)) shows the energies of the states for the three bands relative to a rigid rotor and it can be observed, in all the cases, a smooth increase in the energies of the highest spin states. This behaviour in the state energies is also a signature of band termination [12]. The differences in the $Q_{\rm t}$ values for each band, see Fig. 1 (lower inset (a)), are related to the different single-particle configurations of the bands. To understand this further, configuration-dependent cranked Nilsson–Strutinsky (CNS) calculation without pairing [13,14] have been performed. The theoretical bands are labelled by $[p, n]$, where p (n) represents the number of $g_{9/2}$ proton (neutron) orbitals occupied. It was found that the ground-state band has a [2,4] configuration, while the favoured negative-parity band has a [3,4] configuration, see Ref. [7] for details.

REFERENCES

[1] R.B. Piercey *et al.*, *Phys. Rev. Lett.* **47**, 1514 (1981).

[2] R. Bengtsson *et al.*, *Phys. Scr.* **29**, 402 (1984).

[3] C.J. Gross *et al.*, *Nucl. Phys.* **A501**, 367 (1989).

[4] R.B. Piercey *et al.*, *Phys. Rev. C* **25**, 1941 (1982).

[5] I.-Y. Lee, *Nucl. Phys.* **A520**, 641c (1990).

[6] D.G. Sarantites *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **381**, 418 (1996).

[7] J.J. Valiente-Dobón *et al.*, *Phys. Rev.* , **C**, in press.

[8] B. Cederwall *et al.*, *Nucl. Instrum. Meth. Phys. Res. A* **354**, 591 (1995).

[9] J.F. Ziegler, `http://www.srim.org`.

[10] R. Wadsworth *et al.*, *Phys. Rev. Lett.* **80**, 1174 (1998).

[11] C.E. Svensson *et al.*, *Phys. Rev. Lett.* **80**, 2558 (1998).

[12] A.V. Afanasjev *et al.*, *Phys. Rep.* **322**, 1 (1999).

[13] T. Bengtsson, I. Ragnarsson, *Nucl. Phys.* **A436**, 14 (1985).

[14] A.V. Afanasjev, I. Ragnarsson, *Nucl. Phys.* **A591**, 387 (1995).