Eur. Phys. J. A **20**, 131–132 (2004)
DOI 10.1140/epja/i2002-10338-7

THE EUROPEAN
PHYSICAL JOURNAL A

High-spin structure of N $\simeq$ Z nuclei around the A = 72 region

N.S. Kelsall[1], C.E. Svensson[2], S. Fischer[3], D.E. Appelbe[4], R.A.E. Austin[5], D.P. Balamuth[6], G.C. Ball[7], J.A. Cameron[5], M.P. Carpenter[8], R.M Clark[9], M. Cromaz[9], M.A. Deleplanque[9], R.M. Diamond[9], P. Fallon[9], D.F. Hodgson[7], R.V.F. Janssens[8], D.G. Jenkins[8], G.J. Lane[9], C.J. Lister[8], A.O. Macchiavelli[9], C.D. O'Leary[1], D.G. Sarantities[10], F.S. Stephens[9], D.C. Schmidt[3], D. Seweryniak[8], K. Vetter[9], J.C. Waddington[5], R. Wadsworth[1,a], D. Ward[9], A.N. Wilson[1], A.V. Afanasjev[8,11,12], S. Frauendorf[11], and I. Ragnarsson[13]

[1] Department of Physics, University of York, York, YO10 5DD, UK
[2] Department of Physics, University of Guelph, Guelph, Ontario, Canada
[3] Department of Physics, DePaul University, Chicago, IL 60614, USA
[4] CLRC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, UK
[5] Department of Physics, McMaster University, Hamilton, Ontario, Canada
[6] Department of Physics and Astronomy, University of Pennsylvania, PA 19104, USA
[7] TRIUMF Laboratory, 4004 Westbrook Mall, Vancouver, BC, VT 2AS, Canada
[8] Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA
[9] Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720 USA
[10] Department of Chemistry, Washington University, St. Louis, MO 68130, USA
[11] Department of Physics, University of Notre Dame, IN 465566, USA
[12] Laboratory of Radiation Physics, Institute of Solid State Physics, University of Latvia, LV2169 Salaspils, Miera Str. 31, Latvia
[13] Department of Mathematical Physics, Lund Institute of Technology, 22100 Lund, Sweden

Received: 31 October 2002 /
Published online: 24 February 2004 –

Abstract. High-spin states have been studied in ^{72}Kr and ^{72}Br using the ^{40}Ca + ^{40}Ca and ^{36}Ar + ^{40}Ca reactions at 164 and 145 MeV, respectively. The properties and configurations of the high-spin bands observed have been interpreted using unpaired cranked Nilsson-Strutinsky (CNS), and for ^{72}Kr, paired cranked relativistic Hartree-Bogoliubov (CRHB) calculations. In ^{72}Kr a new band has been identified that has the properties expected for the doubly aligned S-band configuration. In ^{72}Br the previously known bands have been extended to higher spin. This has lead to a re-interpretation of the configurations.

PACS. 21.10.Re Collective levels – 23.20.Lv γ transitions and level energies – 27.50.+e $59 \leq A \leq 89$

1 Introduction and experimental details

The structure of ^{72}Kr has received much attention in recent years (see [1–4]). A major puzzle has been the fact that experimentally the crossing of the ground-state vacuum configuration with the $\pi(g_{\frac{9}{2}})^2 \otimes \nu(g_{\frac{9}{2}})^2$ configuration appeared to be delayed much more than expected by various theoretical models. Moreover, the properties of the recently observed [2] high-spin band did not conform to the expectations of the models. In the present work a new band has been identified which has the expected properties for the missing doubly aligned S-band configuration.

The high-spin spectroscopy of ^{72}Br has been investigated previously [5] and configuration assignments made to the positive- and negative-parity structures observed. In the present work all the structures have been extended to higher spin. The new results suggest that there is a need to re-evaluate the previously assigned configurations.

The data discussed in this paper were obtained from two experiments performed with the GAMMASPHERE array. The ^{36}Ar + ^{40}Ca reaction at 145 MeV was performed at the ATLAS facility at the Argonne National Laboratory. This experiment used the MICROBALL array and the Washington University neutron shell. The second experiment, using the ^{40}Ca + ^{40}Ca reaction at a beam energy of 164 MeV, was performed at the Lawrence Berkeley National Laboratory. In the latter case only the MICROBALL ancillary detector was used. Thin ^{40}Ca targets ($\sim$ 400–500 μg/cm^2) were used in all the experiments. These had $\sim$ 100–500 μg/cm^2 flashes of Au on the front and back to prevent oxidation. For the data analysis of ^{72}Kr an E_γ-E_γ-E_γ cube was sorted by demanding 2α particles in coincidence with the γ-rays, whilst for ^{72}Br the coincidence requirement was 1 to 3 protons and a neutron.

[a] e-mail: rw10@york.ac.uk

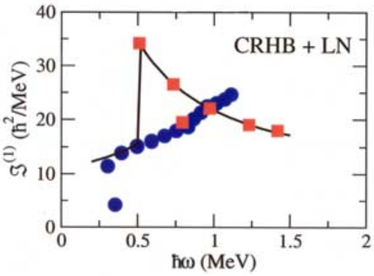

Fig. 1. $J^{(1)}$ moment of inertia *versus* rotational frequency for bands in ^{72}Kr. Data for the new band are represented by the squares. The solid line represents the CRHB calculations.

2 Results and discussion

A new band with γ-ray energies of 1588, 1023, 1469, 1947, 2464, (2837) keV has been found in ^{72}Kr. This structure feeds in to the known 14^+ state and appears to be lower in energy than, and in parallel with, the previously reported high-spin structure [2,3]. Assuming the above transitions are $E2$ in nature then the properties of the band are consistent with those expected from unpaired CNS [6] and paired CRHB [7] calculations for the $\pi(g_{\frac{9}{2}})^2 \otimes \nu(g_{\frac{9}{2}})^2$ configuration. Figure 1 compares data for ^{72}Kr with the results of CRHB calculations using an NL3 force and the Lipkin-Nogami method for particle number projection. The solid line in the figure shows the evolution of the ground-state configuration with rotational frequency. Clearly, the agreement between the new band and the calculations is very good. The jump in $J^{(1)}$ values at $\hbar\omega \sim 0.5$ MeV results from the simultaneous alignment of pairs of $g_{\frac{9}{2}}$ protons and neutrons.

Previous work in ^{72}Br [5] identified two positive- and two negative-parity signature partner bands. The positive-parity bands were tentatively identified with the [1,3] configuration, (where [p,n] is the number of $g_{\frac{9}{2}}$ protons, neutrons in the configuration) whilst the negative-parity bands were associated with the [2,3] configuration. In the present work the $(\pi, \alpha) = (-,0), (-,1)$ bands have been extended by 3 transitions of 2083, 2520, 3065 keV and 1965, 2443, 2999 keV, respectively. The positive-parity $\alpha = 1$ band has been extended by 6 transitions with energies of 1945, 2031, 2093, 2297, 2576 and 2985 keV and the $\alpha = 0$ band by two transitions of 1838 and 1979 keV.

The positive- and negative-parity bands are compared with unpaired CNS calculations in fig. 2. From this comparison we believe that the previous assignment of a [1,3] configuration to the positive-parity bands is incorrect. The calculations suggest that it has a [3,3] configuration. The change in slope in the calculations at spin $\sim 21\hbar$ in the $\alpha = 1$ band corresponds to a change in γ deformation from $\sim -15°$ to $\sim 15°$. The data also appear to show similar behaviour, suggesting that the predicted shape change is observed experimentally.

For the negative-parity bands in the medium-spin range the [2,3] configuration was found to nicely reproduce the experimentally observed signature inversion [5]. However, beyond spin $18\hbar$ the calculations do not agree with the data (see fig. 2). We have performed additional

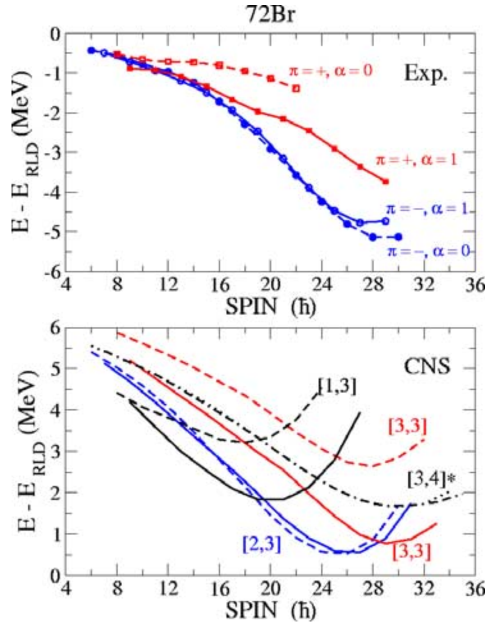

Fig. 2. Experimental (upper) and theoretical (lower) level energies for bands in ^{72}Br relative to a rotational liquid-drop reference energy.

CNS calculations to try to understand the experimentally observed signature splitting for these bands. A possible structure is the [3,4]* configuration, see fig. 2. The additional $g_{\frac{9}{2}}$ particles drive the nucleus to a large deformation, thus making it favourable to have holes in the upsloping $f_{\frac{7}{2}}$ orbitals. The resulting [3,4]* configuration at $\epsilon_2 \sim 0.4$ has a broken ^{56}Ni core with two-proton and one-neutron hole in the $f_{\frac{7}{2}}$ orbital. It is this latter feature that is responsible for the zero-signature splitting.

In the current calculations the [3,4]* configuration resides well above the [2,3] configuration and one would not expect any mixing between the two. However, if the position of the $g_{\frac{9}{2}}$ orbital in the CNS calculations were too high (there is evidence from other nuclei in this mass region that this is the case, [6,8]), then the energy of the [3,4]* configuration will be lowered relative to the [2,3] configuration. This could allow the two configurations to mix, with the higher-spin region being dominated by the [3,4]* configuration. An interesting consequence of this is that one would expect the negative-parity bands to become more deformed at high spin. Note, however, that none of the configurations discussed so far can explain the magnitude and sign of the splitting above $25\hbar$. The nature of this remains to be investigated.

References

1. G. de Angelis *et al.*, Phys. Lett. B **415**, 217 (1997).
2. S.M. Fischer *et al.*, Phys. Rev. Lett. **87**, 132501 (2001).
3. N.S. Kelsall *et al.*, Phys. Rev. C **64**, 024309 (2001).
4. Y. Sun, J.A. Sheihk, Phys. Rev. C **65**, 031302 (2001).
5. C. Plettner *et al.*, Phys. Rev. Lett. **85**, 2454 (2000).
6. A.V. Afanasjev *et al.*, Phys. Rep. **322**, 1 (1999).
7. A.V. Afanasjev *et al.*, Nucl. Phys. A **676**, 196 (2000).
8. C.E. Svensson *et al.*, to be published in Phys. Rev. C.