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Lifetime measurements in N=Z ^{72}Kr

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Abstract
High-spin states in the $N = Z$ nucleus ^{72}Kr have been populated in the ^{40}Ca(^{40}Ca, 2α) ^{72}Kr fusion–evaporation reaction at a beam energy of 165 MeV and using a thin isotopically enriched ^{40}Ca target. The experiment, performed at Argonne National Laboratory close to Chicago, USA, employed the Gammasphere array for γ-ray detection coupled to the Microball array for charged particle detection. The previously observed bands in ^{72}Kr were extended to a higher excitation energy of ∼24 MeV and higher angular momentum of 30$\hbar$. Using the Doppler-shift attenuation method, the lifetimes of high-spin states were measured for the first time in order to investigate deformation changes associated with the $g_{9/2}$ proton and neutron alignments in this $N = Z$ nucleus. An excellent agreement with theoretical calculations including only standard $t = 1$ np pairing was observed.

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1. Introduction

High-spin states in the $N = Z$ nucleus ^{72}Kr have been reported in several publications [1–4]. The 'delayed' crossing between the ground state band and one of the bands observed to high spin (band 2 in figure 1) was considered as a possible signature of $t = 0$ np pairing. However, the observation of a second high-spin band (band 4 in figure 1), which is interpreted as the double S-band, showed that the alignment observed at $\hbar\omega = 0.69$ MeV is very close to the crossing frequencies in ^{74}Kr and ^{76}Kr at 0.68 and 0.65 MeV, respectively. New experiments to measure state lifetimes over the spin range in which the $g_{9/2}$ proton and neutron alignments occur in ^{72}Kr were essential to investigate deformation changes during these alignments and to test our understanding of residual isoscalar and isovector interactions in $N = Z$ nuclei.

2. Experimental set-up

The experiment, performed at Argonne National Laboratory, employed the ^{40}Ca(^{40}Ca, 2α) ^{72}Kr fusion–evaporation reaction at a beam energy of 165 MeV. The 0.350 mg cm^{-2} thin isotopically enriched ^{40}Ca target was sandwiched between

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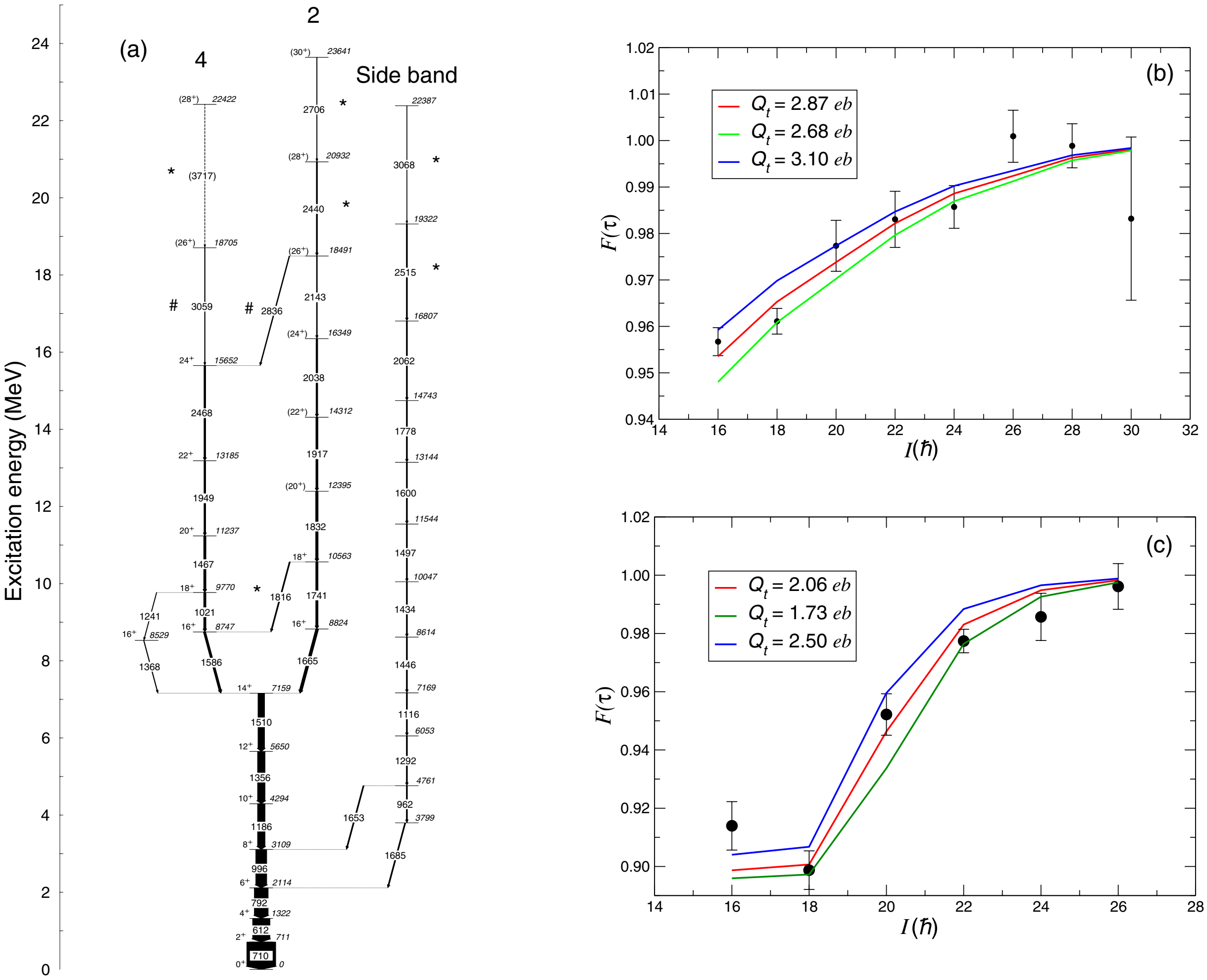

Figure 1. (a) Proposed high-spin level scheme of ^{72}Kr from the present experiment. Experimental $F(\tau)$ values and transition quadrupole moments, Q_t, for bands 2 and 4 as a function of angular momentum are shown in (b) and (c), respectively.

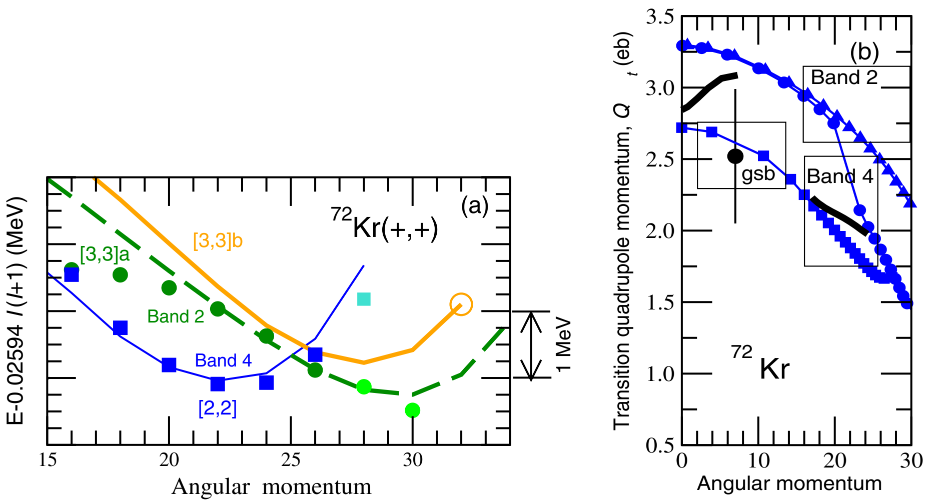

Figure 2. (a) Lowest configurations calculated within the CNS model (lines) and experimental values (symbols), given relative to a rigid rotor. (b) Transition quadrupole moments as a function of angular momentum. The data point at $I = 8\hbar$ is from [1], while boxes represent the measured transition quadrupole moments and their uncertainties within the measured spin range from the present work. The CRMF calculations are shown by filled symbols connected by lines and the CRHB calculations using the Lipkin–Nogami (LN) method for particle number projection are shown by thick lines. See [13] and text for details.

two thin layers of Au to prevent oxidation. The experimental set-up consisted of the Gammasphere array [5] in combination with the 4π charged-particle detector array Microball [6]. To provide γ-ray multiplicity and sum-energy measurements [7], and additional selectivity by total energy conservation requirements [8], the Heavimet collimators were removed from the

Gammasphere detectors. Based on the charged-particle energies and directions detected in Microball, the momenta of the recoiling residual nuclei were determined for each event, allowing for a more accurate Doppler-shift correction of the γ-ray energies, leading to a significantly improved energy resolution. Additional experimental details can be found in [9, 10].

3. Results

Figure 1 shows the level scheme of ^{72}Kr obtained from the present experiment. In addition to the previous level scheme published in [3], the transitions marked with a pound sign (#) are firmly established, and the transitions marked with an asterisk (*) are newly observed.

The main focus of this work were the lifetimes of high-spin states determined using the centroid-shift Doppler-shift attenuation method [11]. The experimental $F(\tau)$ values of bands 2 and 4, as a function of angular momentum, are shown in figures 2(b) and (c), respectively. In order to extract a quadrupole moment from these measurements, the decay of the band was modelled assuming a constant in-band Q_t and the feeding of the band and the slowing down of the recoils in the target were treated as in [12]. The best fit to the data is obtained with $Q_t = 2.87(^{23}_{19})$ eb for band 2 and $Q_t = 2.06(^{44}_{33})$ eb for band 4. The uncertainties in the quadrupole moments do not include the systematic uncertainties due to the stopping power, which are typically of 10%. Further analysis in which the Q_t values are allowed to change smoothly with spin is ongoing, although it is clear from the results that band 2 has a higher Q_t than band 4.

4. Theoretical calculations

Theoretical calculations for ^{72}Kr have been performed with Cranked Nilsson–Strutinsky (CNS) calculations without pairing, the cranked relativistic mean field (CRMF) and the cranked relativistic Hartree–Bogoliubov (CRHB) [13]. In the CNS calculations, the bands are labelled by the number of $g_{9/2}$ protons and neutrons, as [p,n]. In [13], band 2 was assigned to the [3, 3] configuration, while band 4 was assigned to the [2, 2] configuration (i.e. the double S-band). Figure 2(a) shows the experimental excitation energies relative to a rigid rotor versus angular momentum for bands 2 and 4 (filled symbols) and the CNS calculations (lines). The CRMF calculations are very similar and for this reason are not shown here. There is excellent agreement between the experimental data and the theoretical calculations, especially in the unpaired regime for $I > 20\hbar$. Figure 2(b) shows the experimental and calculated transition quadrupole moments as a function of angular moment. The data point at $I = 8\hbar$ is obtained from a previous experiment using conventional Doppler-shift attenuation techniques [1]. The boxes show the measured transition quadrupole moments and their uncertainties within the measured spin range obtained from the present experiment. They are in good agreement with both the CRMF (filled symbols connected by lines) and CRHB calculations using the LN method for particle number projection (thick lines). It should be noted that the agreement between experiment and theory requires only the standard $t = 1$ pair field.

5. Conclusions

An experiment to populate high-spin states in the $N = Z$ nucleus ^{72}Kr was performed with Gammasphere. The level scheme was extended up to an excitation energy of ∼24 MeV and an angular momentum of $30\hbar$ and lifetimes of high-spin states were measured for the first time using the Doppler-shift attenuation method. The experiment is in good agreement with theoretical calculations (CRHB + LN) involving standard $t = 1$ pairing [13].

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References

[1] de Angelis G *et al* 1997 *Phys. Rev. Lett.* B **415** 217
[2] Fischer S M *et al* 2001 *Phys. Rev. Lett.* **87** 132501
[3] Fischer S M *et al* 2003 *Phys. Rev.* C **67** 064318
[4] Kelsall N *et al* 2001 *Phys. Rev.* C **64** 024309
[5] Lee I-Y 1990 *Nucl. Phys.* A **520** 641c
[6] Sarantites D G *et al* 1996 *Nucl. Instrum. Methods* A **381** 418
[7] Devlin M *et al* 1996 *Nucl. Instrum. Methods* A **383** 506
[8] Svensson C E *et al* 1997 *Nucl. Instrum. Methods* A **396** 288
[9] Valiente-Dobón J J *et al* 2005 *Phys. Rev.* C **71** 034311
[10] Andreoiu C *et al* 2006 *Phys. Rev.* C in press
[11] Cederwall B *et al* 1995 *Nucl. Instrum. Methods* A **354** 591
[12] Svensson C E *et al* 1997 *Phys. Rev. Lett.* **79** 1233
[13] Afanasjev A V and Frauendorf S 2005 *Phys. Rev.* C **71** 064318