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Mixed-symmetry octupole and hexadecapole excitations in *N=52* isotones

Andreas Hennig[1,a], Mark Spieker[1], Volker Werner[2,3], Tan Ahn[2,4], Vassia Anagnostatou[2,5], Nathan Cooper[2], Vera Derya[1], Michael Elvers[1,2], Janis Endres[1], Phil Goddard[2,5], Andreas Heinz[2,6], Richard O. Hughes[2,7], Gabriela Ilie[2,8], Milena N. Mineva[9], Simon G. Pickstone[1], Pavel Petkov[1,9], Norbert Pietralla[3], Desirée Radeck[1,2], Tim J. Ross[5,7], Deniz Savran[10,11], and Andreas Zilges[1]

[1] *Institut für Kernphysik, Universität zu Köln, D-50937 Köln, Germany*
[2] *Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520, USA*
[3] *Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany*
[4] *National Superconducting Cyclotron Laboratory NSCL, Michigan State University, East Lansing, Michigan 48824, USA*
[5] *Department of Physics, University of Surrey, Guildford, GU2 7XH, UK*
[6] *Fundamental Fysik, Chalmers Tekniska Högskola, SE-41296 Göteborg, Sweden*
[7] *University of Richmond, Richmond, Virginia 23173, USA*
[8] *National Institute for Physics and Nuclear Engineering, Bucharest-Magurele, RO-77125, Romania*
[9] *Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, BG-1784 Sofia, Bulgaria*
[10] *ExtreMe Matter Institute EMMI and Research Division, GSI, D-64291 Darmstadt, Germany*
[11] *Frankfurt Institute for Advanced Studies FIAS, D-60438 Frankfurt a.M., Germany*

Abstract. In addition to the well-established quadrupole mixed-symmetry states, octupole and hexadecapole excitations with mixed-symmetry character have been recently proposed for the $N = 52$ isotones ^{92}Zr and ^{94}Mo. We performed two inelastic proton-scattering experiments to study this kind of excitations in the heaviest stable $N = 52$ isotone ^{96}Ru. From the combined experimental data of both experiments absolute transition strengths were extracted.

1 Introduction

Isovector excitations of valence-shell nucleons are usually denoted as mixed-symmetry states (MSS) [1]. They are predicted in the proton-neutron version of the Interacting Boson Model (IBM-2) [2–4] and can be distinguished from fully-symmetric states (FSS) by their F-spin quantum number [5]. As an experimental signature for MSS, the IBM-2 predicts strong $M1$ transitions to their symmetric counterparts with transition matrix elements in the order of 1 μ_N. The collective structure of low-lying states in near-spherical, vibrational nuclei is dominated by the quadrupole degree of freedom. By now, mixed-symmetry quadrupole excitations in vibrational nuclei are well established as collective features near closed shells [6]. In addition to the quadrupole degree of freedom, mixed-symmetry excitations of octupole and hexadecapole character have been proposed in the $N = 52$ isotones ^{92}Zr and ^{94}Mo [7–9]. The identification is based on remarkably strong $M1$ transitions between the lowest-lying 3^- and 4^+ states. Recently, the strong $M1$ transition between the lowest-lying 4^+ states in ^{94}Mo was successfully described by including g-boson excitations in IBM-2 calculations [9], suggesting FS and MS one-phonon hexadecapole admixtures in the 4^+_1 and 4^+_2 states, respectively. It is the purpose of the present work to study possible mixed-symmetry octupole and hexadecapole states in the heaviest stable $N = 52$ isotone ^{96}Ru.

2 Experiments

The determination of absolute transition strengths requires the measurement of spins and parities of excited states, γ-decay branching ratios, multipole mixing ratios, and nuclear level lifetimes. For this purpose, two inelastic proton-scattering experiments were performed. In a first experiment, performed at the Wright Nuclear Structure Laboratory (WNSL) at Yale University, USA, a proton beam with an energy of $E_p = 8.4$ MeV impinged on a 106 μg/cm^2 enriched ^{96}Ru target, supported by a ^{12}C backing with a thickness of 14 μg/cm^2. The scattered protons were detected in coincidence with de-exciting γ-rays using five silicon particle detectors and eight BGO-shielded Clover-type HPGe detectors, respectively. From the acquired $p\gamma$ coincidence data γ-decay branching ratios were extracted, while the additionally acquired $\gamma\gamma$ coincidence data were used to determine spins and multipole mixing ratios by means of a $\gamma\gamma$ angular correlation analysis.

In order to extract nuclear level lifetimes in the fs range, we performed a second proton scattering experiment at the Institute for Nuclear Physics at the Univer-

[a] e-mail: hennig@ikp.uni-koeln.de

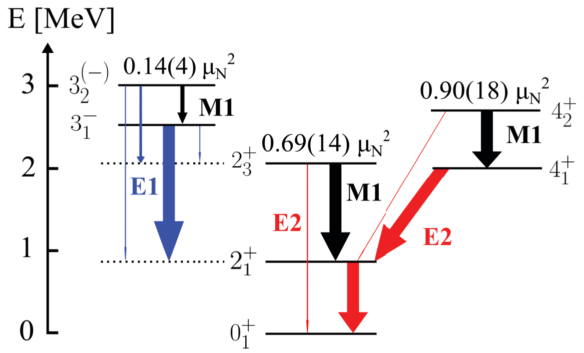

Figure 1. (Color online) Excerpt of the experimental level scheme of ^{96}Ru. $M1$, $E1$, and $E2$ transitions are indicated with black, blue, and red arrows, respectively. The width of the arrows is proportional to the γ-decay branching ratios. Along with the $2^+_{ms}(\equiv 2^+_3) \rightarrow 2^+_1$ transition [13], $M1$ transitions with sizeable strengths were observed between the lowest-lying 3^- and 4^+ states.

sity of Cologne, Germany. The same target as used for the experiment at WNSL was bombarded with a beam of 7.0 MeV protons. The scattered protons were detected with the new particle detector array SONIC embedded within the γ-spectrometer HORUS to allow for a coincident detection of scattered protons and de-exciting γ-rays. Nuclear level lifetimes were extracted by means of the Doppler-shift attenuation method (DSAM) [10] from the $p\gamma$ coincidence data. Since the initial direction and velocity of the recoil nucleus, as well as its excitation energy can be extracted from the energy of the scattered proton, the $p\gamma$ coincidence yields several advantages for the DSAM measurement [11]:

- The angle θ_γ between the direction of the γ-ray emission and the direction of motion of the recoil nucleus can be extracted on an event-by-event basis.
- Feeding from higher-lying states is eliminated by gating on the excitation energy.
- Peak centroids can be extracted from proton-gated γ-ray spectra, yielding an increased peak-to-background ratio.

The slowing-down process of the ^{96}Ru recoil nuclei in the target and stopper materials was modeled by means of the Monte-Carlo simulation program DSTOP96 [12]. A comparison of the calculated Doppler-shift attenuation factor with the experimentally determined value finally yields the nuclear level lifetime.

3 Experimental results

From the combined experimental data of both experiments absolute transition strengths were calculated. The results concerning one-phonon mixed-symmetry states in ^{96}Ru are shown in Figure 1, pointing out $M1$ transitions with sizeable strengths of 0.14(4) μ_N^2 and 0.90(18) μ_N^2 between the low-lying 3^- and 4^+ states, respectively. Based on their absolute $M1$ transition strengths, the $3_2^{(-)}$ state at E_x = 3077 keV and the 4_2^+ state at E_x = 2462 keV are likely candidates to show mixed-symmetry one-phonon octupole and hexadecapole contributions, respectively.

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