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

Andreas Hennig$^{1,8}$, 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$^{1,7}$, 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

e-mail: hennig@ikp.uni-koeln.de

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 $N = 52$ isotope $^{96}$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 $M_1$ transitions to their symmetric counterparts with transition matrix elements in the order of $\mu_N$. 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 $M_1$ transitions between the lowest-lying $3^-$ and $4^+$ states. Recently, the strong $M_1$ 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 $N = 52$ isotope $^{96}$Ru.

2 Experiments

The determination of absolute transition strengths requires the measurement of spins and parities of excited states, $\gamma$-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 $106$ $\mu$m$^2$ enriched $^{96}$Ru target, supported by a $^{12}$C backing with a thickness of $14$ $\mu$m$^2$. The scattered protons were detected in coincidence with de-exciting $\gamma$-rays using five silicon particle detectors and eight BGO-shielded Clover-type HPGe detectors, respectively. From the acquired $p\gamma$ coincidence data $\gamma$-decay branching ratios were extracted, while the additionally acquired $g\gamma$ coincidence data were used to determine spins and multipole mixing ratios by means of a $g\gamma$ 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-
The low-lying sizeable strengths of $M_1$ nuclear level lifetime. With the experimentally determined value finally yields the comparison of the calculated Doppler-shift attenuation factor.

Target and stopper materials was modeled by means of the concerning one-phonon mixed-symmetry states in $^{96}$Ru absolute transition strengths were calculated. The results from the combined experimental data of both experiments 3 Experimental results

The slowing-down process of the $^{96}$Ru recoil nuclei in the measurement \[11\]: Doppler-shift attenuation method (DSAM) \[10\] from the energy of the scattered proton, the identity of the recoil nucleus, as well as its excitation energy can be extracted from the energy of the scattered proton, the $\gamma$ coincidence yields several advantages for the DSAM measurement \[11\]:

- The angle $\theta$, between the direction of the $\gamma$-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 $\gamma$-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 $M_1$ transitions with sizeable strengths of $0.14(4) \mu_N^2$ and $0.90(18) \mu_N^2$ between the low-lying $3^-$ and $4^+$ states, respectively. Based on their absolute $M_1$ transition strengths, the $3_{1}^{(-)}$ 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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