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A High-Resolution Study of the ${}^{110}\text{Tc} \rightarrow {}^{110}\text{Ru} \rightarrow$ 110 Rh \rightarrow 110 Pd Decay Chain with the GRETINA Array

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Abstract. Spectroscopic data, such as precise γ -ray branching and E2/M1 multipolemixing ratios, provide vital constraints when performing multi-dimensional Coulomb-excitation analyses. Consequently, as part of our new Coulomb-excitation campaign aimed at investigating the role of exotic non-axial (triaxial) deformations in the unstable refractory Ru-Mo isotopes, additional beta-decay data was obtained. These measurements make use of ANL's CARIBU facility, which provides intense beams of radioactive refractory isotopes along with the excellent efficiency and angular resolution of the GRETINA γ -ray tracking array. In this article, we report on the analysis of the A = 110 decay chain, focussing on the identification of previously unreported states in ¹¹⁰Ru following the decay of ¹¹⁰Tc.



1. Introduction

As most nuclei are expected to show some degree of axial symmetry, the observation of triaxial deformation, where all three deformation axes have different lengths, has become a key topic of nuclear structure physics in recent years. In particular, it is not known whether such deformations are restricted to only a few nuclei or if it is spread over a larger area. Additionally, it is unclear whether triaxial deformation can represent both rigid and soft nuclear shapes. To this end, recent Coulomb-excitation results for the ⁷⁶Ge nucleus are particularly interesting [1] as, in this work, it is demonstrated in a model-independent way, that ⁷⁶Ge has a relatively rigid triaxial ground-state shape, albeit for a case where rich spectroscopic data is available.

A simple, but not definitive, signature of triaxial deformation, according to the Rigid Triaxial Rotor Model of Davydov et al. [2, 3], is the presence of low-lying 2_2^+ states. The Os-Pt nuclei are one such region where low-lying 2_2^+ states are observed, and evidence for low-lying triaxial deformation has been observed [4]. The other region where this key signature is observed is the neutron-rich Ru-Mo nuclei. However, despite longstanding interest, Coulomb-excitation measurements of these nuclei have not been possible, until recent years, due to the refractory nature of these nuclei whereby their physical properties prevent their release from traditional Isotope Separation Online (ISOL) targets.

Building upon our previous work, e.g. [5], and in order to take advantage of the improved experimental setup at ANL's ATLAS facility, we performed in 2018 a further series of Coulombexcitation and decay experiments, focussed on the neutron-rich Ru-Mo region. A crucial improvement, which resulted in significantly cleaner beams, was the successful use of Electron Beam Ion Source (EBIS) charge breeder [6] instead of the Electron Cyclotron Resonance (ECR) source employed in previous studies. The results from the Coulomb-excitation studies are in the final stages of analysis and will be reported shortly. This article, therefore, focusses on the decay measurements which constituted the other half of the experimental campaign. The primary goal of performing decay measurements, in addition to Coulomb excitation, was to obtain precise γ branching and E2/M1 multipole-mixing ratios by taking advantage of the angular sensitivity of the GRETINA array. Both quantities serve as valuable additional constraints in the multidimensional Coulomb-excitation analysis. In particular, knowledge of multipole-mixing ratios allow for M1 matrix elements to be determined in addition to E2 ones. However, as we can report, the available beam intensity and the excellent efficiency of the GRETINA detection setup have also enabled the ¹¹⁰Ru level scheme to be extended.

2. Experimental Details

The experimental campaign took place at Argonne National Laboratory's ATLAS (Argonne Tandem Linac Accelerator System) facility. Beams of neutron-rich refractory isotopes were provided by the CARIBU facility [7], which consists of a ~ 1.7 Ci 252 Cf source placed within a gas catcher which acts to efficiently thermalize the fission fragments in order to produce a beam of 1^+ ions. The ions of interest were selected with an isobar separator and then directed to the new EBIS [6] for charge breeding before being sent to the ATLAS linac for post acceleration. For the ¹¹⁰Ru studies the beam consisted of ¹¹⁰Tc, ¹¹⁰Ru and ¹¹⁰Rh ($t_{1/2}=0.900(13)$ s, 12.04(17) s and 28.0(13) s, respectively) [8] with negligible stable contamination. For the Coulomb-excitation measurements the beam impinged on a 1.5 mg/cm^2 -thick ²⁰⁸Pb target at the centre of the GRETINA + CHICO2 experimental apparatus while for the decay measurement the ²⁰⁸Pb target was replaced with a thick ¹⁹⁷Au foil. The GRETINA array [9] is composed of 11 modules with 4 segmented HPGe detectors per module, the CHICO2 heavy-ion counter [10] is not required for the beta-decay measurements and consequently, will not be discussed further here. Energy and efficiency calibrations of the GRETINA array were performed with standard ⁶⁰Co, ¹³⁷Cs, ¹⁵²Eu and ¹⁸²Ta sources with particular care taken to verify the γ -ray tracking and add-back algorithms used in the data analysis with the source data.

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3. Preliminary Results

The data were sorted offline into $E_{\gamma,1} - E_{\gamma,2}$ coincidence matrices, from which level schemes could be constructed, and into $E_{\gamma,1} - E_{\gamma,2} - \theta_{1,2}$ cubes, which are used to determine the angular correlations of the emitted γ rays. An example coincidence spectrum, gated on the 241-keV $2_1^+ \rightarrow 0_1^+$ transition in ¹¹⁰Ru is shown in Figure 1 below, while Figure 2 provides the spectrum obtained with a coincidence gate set on the newly observed 3188-keV transition. It is clear that the spectra are of excellent quality and, furthermore, that the obtained statistics are greater than that of other previously reported ¹¹⁰Tc \rightarrow ¹¹⁰Ru beta-decay studies, [11, 12, 13].



Figure 1. A γ -ray energy spectrum showing transitions in coincidence with the 241-keV $2_1^+ \rightarrow 0_1^+$ transition in ¹¹⁰Ru following the beta decay of ¹¹⁰Tc. The energies in red indicate previously unreported transitions with the inset showing a zoomed in portion of the high-energy region of the spectrum, where a number of new transitions were identified.



Figure 2. A background subtracted spectrum showing γ rays detected in coincidence with the new 3188-keV transition in ¹¹⁰Ru, a partial decay scheme is shown in the inset.

The updated ¹¹⁰Ru level scheme is displayed in Figure 3, where the new states are indicated

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Figure 3. A preliminary level scheme with all the observed transitions in ¹¹⁰Ru following the beta decay of ¹¹⁰Tc. Previously unreported transitions are drawn as dashed lines.

4. Outlook

The ¹¹⁰Ru level scheme has been extended by performing a high-resolution study of the ¹¹⁰Tc \rightarrow ¹¹⁰Ru \rightarrow ¹¹⁰Rh \rightarrow ¹¹⁰Pd decay chain with beams of radioactive, refractory isotopes provided by ANL's CARIBU facility [7]. In addition, the high-statistics data allow for precise γ -ray branching ratios to be determined as well as for an angular-correlation analysis, aimed at extracting E2/M1 multipole-mixing ratios. Both the improved γ -ray branching ratios and the new multipole-mixing ratios serve as key additional constraints for the ongoing Coulomb-excitation analysis. In addition, the complementary nature of Coulomb-excitation and beta-decay measurements has been demonstrated; this will be particularly important as we move towards the next-generation of radioactive beam facilities, where Coulomb-excitation studies will be performed on nuclei where vital spectroscopic data is scarce.

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