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Half-life Measurements of 2_1^+ States in the Vicinity of ^{108}Zr and their Implications for Ground-state Deformations

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The A∼110 region of neutron-rich nuclei is one containing a rich variety of nuclear structure, with theory suggesting competition between several different shapes. To gain information about these shapes the half-lives of the 2_1^+ states have been measured for $^{102\text{-}108}$Zr and the surrounding region. The nuclei of interest were produced through the in-flight fission of a 345 MeV/nucleon ^{238}U beam by a ^{9}Be target and selected by the BigRIPS separator. At the final focal plane of the separator, the nuclei were implanted into 5 DSSDs (WAS3ABi). Gamma-rays emitted following β-decay, or decay of isomeric states, were detected in an array of 12 clusters of 7 HPGe detectors (EURICA) augmented with 18 $LaBr_3$(Ce) detectors. Beta-gamma timing, measured between fast scintillators around WAS3ABi and the $LaBr_3$(Ce) detectors, allowed the measurement of nuclear level half-lives in the nanosecond regime. The efficacy of the β-γ timing was tested by measuring the half-lives of the 2_1^+ level in ^{102,104}Zr and ^{106,108}Mo. The preliminary results are presented along with experimental details.

KEYWORDS: Ground-state deformation, lanthanum bromide, zirconium, molybdenum, EURICA

1. Introduction

Atomic nuclei with neutron- and proton-numbers midway between the classical magic numbers (2, 8, 20, 28, 50, 82...) can best be described by collective models. Deformed shapes are manifest in these *mid-shell* regions, with rigid quadrupole deformations giving rise to rotational states. The measurement of the excitation energies and half-lives of these states make it possible to quantify the quadrupole deformation.

Ground-state deformations of the A$\sim$110 region of neutron-rich nuclei demonstrate a strong dependence on neutron-number [1, 2]. Differing predictions [3, 4] of the magnitude of ground-state prolate deformation make this region an ideal testing ground of the nuclear models employed in the calculations. To experimentally deduce the deformations, a decay spectroscopy experiment was carried out at the RI Beam Factory (RIBF), RIKEN, to measure the half-lives of the 2^+_1 states of ^{102,104}Zr and ^{106,108}Mo. These proceedings will present the experimental details and some preliminary results.

2. Experimental set-up

Neutron-rich nuclei were produced through the in-flight fission of a 345 MeV/nucleon ^{238}U beam on a 555 mg/cm^2 ^{9}Be production target. The average primary beam intensity was $\sim$10 pnA throughout the experiment. Fission fragments were selected by the BigRIPS spectrometer according to their mass-to-charge ratio, and by their energy loss in an achromatic wedge degrader (proportional to their atomic number). Particle identification was carried out on an event-by-event basis using the $B\rho$-ΔE-TOF technique [5].

The fission fragments were implanted into the WAS3ABi active stopper, which comprises 5 DSSDs of 60$\times$ 40 strips each 1 mm^2 [6], which is situated between two plastic scintillators (β-plastics) of 2 mm thickness and 65$\times$ 45 mm^2 area.

An array of 18 $LaBr_3$(Ce) detectors [7–9], as well as the EURICA array [11], surrounded WAS3ABi for the purpose of measuring isomeric and β-delayed γ-rays. The excellent timing properties of the $LaBr_3$(Ce) detectors allow for the measurement of the half-lives of nuclear states in the sub-nanosecond range. Time difference, ΔT, measurements are taken between the average of the β-plastics and a signal in the $LaBr_3$(Ce) array.

3. Analysis & results

Two BigRIPS settings were used to select and identify the nuclei of interest, one of large transmittance containing ^{108}Nb, and one purified for ^{102,104}Y and ^{106}Nb. The particle identification plots of these settings are shown in the left and right panels of Fig. 1, respectively. Particle gates were applied to the β-decay parent of the nuclides of interest, as indicated in Fig. 1. To differentiate between a real β-decay event and a background event of the same character, a correlation condition was imposed that requires the β-like event to occur within the same pixel as the implanted ion and to occur within one half life of the parent nucleus being implanted.

Gamma-ray energy-ΔT matrices were constructed, where the energy is measured in the $LaBr_3$(Ce) array and ΔT is as described at the end of Sec. 2. Gamma-ray energy spectra gated on β-decays from ^{104}Y and ^{106}Nb are shown in the left panel of Fig. 2. Background-subtracted time-difference spectra are shown in the right panel of Fig. 2, for the $2^+_1 \rightarrow 0^+_{g.s}$ transitions in the daughter nuclei ^{104}Zr and ^{106}Mo. The half lives of higher-lying populated states are expected to be much shorter than that of

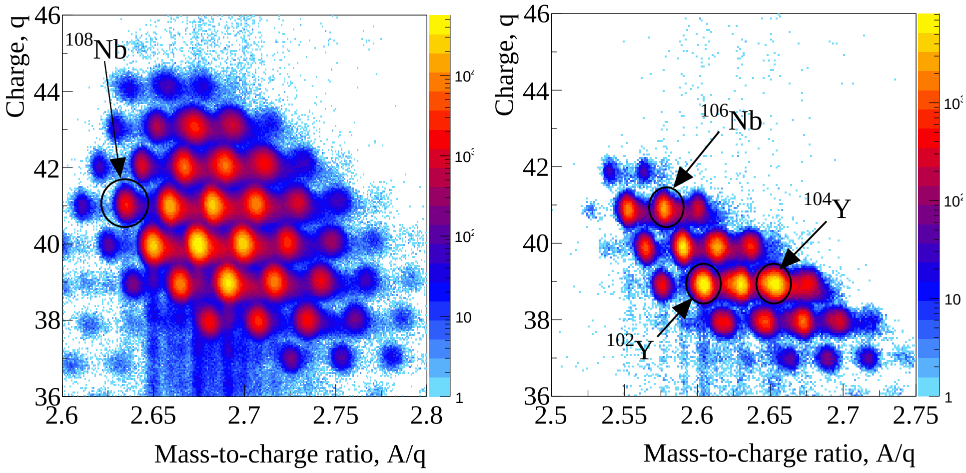

Fig. 1. Particle identification plots of two settings; Left: The wide, neutron-rich setting containing ^{108}Nb (labelled). Right: The purified beam setting focusing on $^{102,\,104}$Y and ^{106}Nb (labelled).

the $2_1^+ \rightarrow 0_{g.s}^+$ transitions [10] and within the experimental error. Table 1 lists the half-lives measured in this work and compares with literature values, indicating good agreement.

Table I. The measured half-lives compared with the literature values.

Nucleus	E(2_1^+) (keV)	$T_{1/2}^{\mathrm{exp}}$ (ns)	$T_{1/2}^{\mathrm{lit}}$ (ns)
^{106}Mo	171.5	1.26(33)	1.25(3) [12]
^{108}Mo	192.8	0.55(13)	0.5(3) [12]
^{102}Zr	151.8	1.80(30)	1.8(4) [12]
^{104}Zr	139.3	2.03(29)	2.0(3) [12]

4. Discussion

A low 2_1^+ energy and an increase in the reduced matrix element, $B(E2)$, of the $2_1^+ \rightarrow 0_{g.s}^+$ transition are key signatures of ground-state deformation. They also provide the information necessary to quantify the quadrupole deformation, β_2, assuming an axially symmetric rigid rotor.

The left panel of Fig. 3 shows the evolution of the 2_1^+ energy as a function of neutron-number for nuclei with $38 \leq Z \leq 44$ and reflects the β_2 values, shown in the right panel of Fig. 3, deduced from the measured 2_1^+ state half-life and excitation energy.

We have presented preliminary half-lives of some 2_1^+ states in neutron-rich nuclei in the A~110 mass region. The ability of the $LaBr_3$(Ce) array to measure half-lives in the nanosecond regime has been demonstrated, improving and adding to the previously reported results [12, 13].

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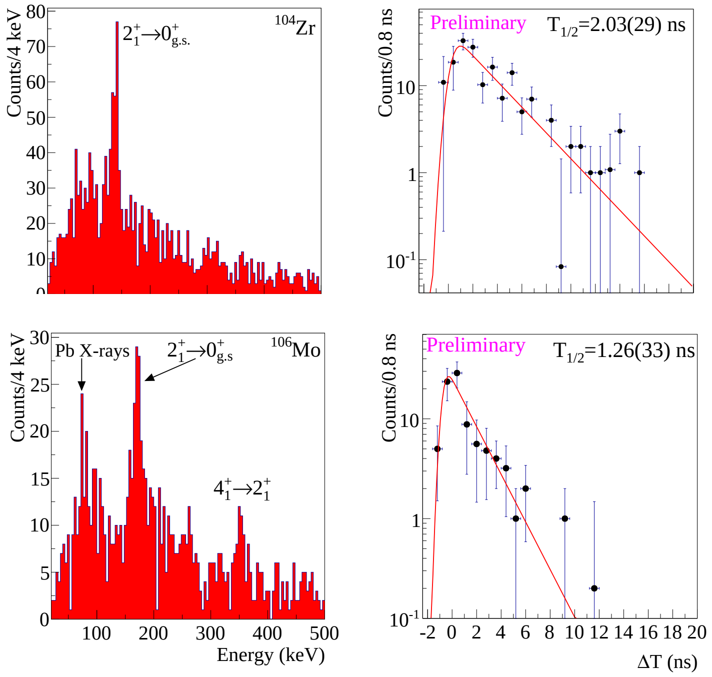

Fig. 2. Gamma-ray energy spectrum measured in the LaBr$_3$(Ce) array (left) and time difference spectrum for the $2_1^+ \rightarrow 0_{g.s}^+$ transition (right) in ^{104}Zr (top) and ^{106}Mo (bottom). The spectra are measured in coincidence with β-decays detected within 200 ms of a ^{104}Y implantation and 1 s of a ^{106}Nb implantation, respectively.

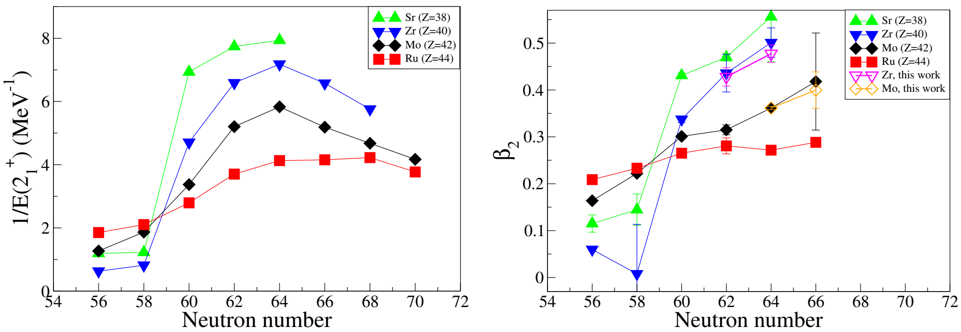

Fig. 3. Evolution of the energy of the 2_1^+ state as a function of neutron-number (left) and the quadrupole deformation parameter calculated from the measured half-lives, assuming axial symmetry (right) [12].

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