The half-lives of $2_{1}^{+}$ states were measured for $^{102,104}$Zr and $^{106,108}$Mo to test a new implementation of a LaBr$_3$(Ce) array at the RIBF, RIKEN, Japan. The nuclei of interest were produced through the fission of a
345 MeV/nucleon $^{238}$U beam and selected by the BigRIPS separator. Fission fragments were implanted into the WAS3ABi active stopper, surrounding which, 18 LaBr$_3$(Ce) detectors provided fast $\gamma$-ray detection. Timing between the LaBr$_3$(Ce) array and plastic scintillators allowed for the measurement of half-lives of low-lying states. The preliminary results, which agree with literature values, are presented along with experimental details.

DOI:10.5506/APhysPolB.46.721
PACS numbers: 21.10.Re, 21.10.Tg, 23.20.Js, 27.60.+j

1. Introduction

The $A \sim 100$, $Z \sim 40$ region of the nuclear chart has long been known for its sudden onset of static quadrupole deformation at $N \sim 60$ [1]. This was first ascribed to the neutron–proton interactions of the spatially-overlapping spin–orbit partner orbits, $\pi g_{7/2}$ and $\nu g_{9/2}$ [2]. However, more recent calculations [3] and $g$-factor [4] measurements have underlined the importance of core polarisation and the influence of the low-$\Omega$ $\nu h_{11/2}$ orbitals.

The complexity of the factors which drive deformation in the neutron-rich zirconium region require stringent testing. The reproduction of energy levels can provide some evidence that the wave-function employed in calculations is correct, however, observables, such as the reduced transition probabilities serve as a more robust test.

In these proceedings, we present the measurement of the known half-lives of the $2^+_1$ states in $^{102,104}$Zr and $^{106,108}$Mo through $\beta-\gamma$ spectroscopy. From these, the $B$(E2; $2^+_1 \rightarrow 0^+_{g.s.}$) values are computed.

2. Experimental set-up

A decay spectroscopy experiment was carried out at the RI Beam Factory (RIBF). The in-flight fission of a $^{238}$U$^{86+}$ primary beam of average intensity $6.24 \times 10^{10}$ particles/s accelerated to an energy of 345 MeV/nucleon produced a secondary beam of neutron-rich nuclides. Fission fragments were selected by the BigRIPS spectrometer using the $B\rho-\Delta E-B\rho$ method [5] and identified using TOF–$B\rho-\Delta E$ measurements [6].

The secondary beam was implanted into the WAS3ABi silicon array [7], which detected ion implantations and their subsequent $\beta$-decays. Precise timing of $\beta$-electron emission was achieved using plastic scintillators of 2 mm thickness and area $65 \times 45$ mm$^2$ installed upstream and downstream of WAS3ABi. An array of 18 LaBr$_3$(Ce) [8] detectors, as well as the EURICA [9]
array, surrounded WAS3ABi for the purpose of measuring isomeric and β-delayed γ-rays. The photopeak efficiency of the LaBr$_3$(Ce) array at $\sim 150$ keV was measured to be 4%.

3. Experimental results

Implanted fission fragments were correlated with their β-decays by requiring that the β-decay had to occur in the same pixel as an implanted ion within approximately five times the β-decay half-life of the implanted nuclide. The β-electron was required to be detected in one of the β-plastics. As an example, the γ-ray energy spectrum of $^{106}$Mo is shown in the right panel of Fig. 1, the inset shows the background-subtracted time-difference, $\Delta T$, spectrum of the $2^+ \rightarrow 0^+_{g.s.}$ transition ($\Delta T$ is the time between a signal in the β-plastics and a γ-ray detection in the LaBr$_3$(Ce) array).

To extract the half-life of the $2^+_1$ states for $^{104,106}$Zr and $^{106,108}$Mo, an exponential fit was carried out on the delayed shoulder of the $\Delta T$ spectrum between 2 and 15 ns. The results, presented in the left of Fig. 2 agree with adopted values [10, 11, 13, 14], with the exception of $^{102}$Zr. This deviation is tentatively attributed to the influence of the half-life of a $K^\pi = 4^-$ state [12]. For the four nuclei under discussion, no delayed component was observed for the feeding $4^+_1 \rightarrow 2^+_1$ transitions. The right panel of Fig. 2 shows the $B(E2; 2^+_1 \rightarrow 0^+_{g.s.})$ values obtained.

The presented method shall be extended to more neutron-rich isotopes in the region, to extend the knowledge of transition probabilities.
Fig. 2. Left: Half-lives of the $2^+_1$ states as a function of neutron-number for Mo and Zr. Right: The corresponding $B(E2; 2^+_1 \rightarrow 0^+_{g.s.})$ transition probabilities. In both, the solid symbols are values determined in this work, open symbols from Ref. [10, 11, 13, 14].

We acknowledge the accelerator team for delivering the $^{238}$U beam. This work was supported in part by the UK STFC, the UK NMO and D.O.E. grant No. DE-FG02-91ER-40609.

REFERENCES