# GAMMA-RAY SPECTROSCOPY IN THE VICINITY OF $^{108}$Zr*

F. Browne[a,b], A.M. Bruce[a], T. Sumikama[c], I. Nishizuka[c]
S. Nishimura[b], P. Doornenbal[b], G. Lorusso[b], Z. Patel[b,d]
S. Rice[b,d], L. Sinclair[b,e], P.-A. Söderström[b], H. Watanabe[b,f]
J. Wu[b,g], Z.Y. Xu[h], H. Baba[b], N. Chiga[c], R. Carroll[d], R. Daido[i]
F. Didierjean[m], Y. Fang[i], G. Gey[j,k,b], E. Ideguchi[i], N. Inabe[b]
T. Isobe[b], D. Kameda[b], I. Kojouharov[l], N. Kurz[l], T. Kubo[b]
S. Lalkovski[n], Z. Li[g], R. Lozeva[m], N. Naoki[b], H. Nishibata[i]
A. Odahara[i], Zs. Podolyák[d], P.H. Regan[d,o], O.J. Roberts[a]
H. Sakurai[b], H. Schaffner[l], G.S. Simpson[j], H. Suzuki[b]
H. Takeda[b], M. Tanaka[i], J. Taprogge[p,q,b], V. Werner[r,s]
O. Wieland[t], A. Yagi[i]

[a]School of Computing, Engineering and Mathematics, University of Brighton Brighton BN2 4GJ, UK; [b]RIKEN Nishina Center, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan; [c]Dept. of Physics, Tohoku University, Aoba, Sendai, Miyagi 980-8578, Japan; [d]Dept. of Physics, University of Surrey, Guildford GU2 7XH, UK; [e]Dept. of Physics, University of York, Heslington, York YO10 5DD, UK; [f]Dept. of Physics, Beihang University, Beijing 100191, China; [g]Dept. of Physics, Peking University, Beijing 100871, China; [h]Dept. of Physics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan; [i]Dept. of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan; [j]LPSC, UJF/INPG, CNRS/IN2P3, 38026 Grenoble Cedex, France; [k]ILL, 38042 Grenoble Cedex, France; [l]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany; [m]IPHC, CNRS/IN2P3 and University of Strasbourg, Strasbourg, France; [n]Dept. of Physics, University of Sofia, 1164 Sofia, Bulgaria; [o]National Physical Laboratory, Teddington, Middlesex, TW11 0LW, UK; [p]Departamento de Física Teórica, Universidad Autónoma de Madrid, 28049 Madrid, Spain; [q]Instituto de Estructura de la Materia, CSIC, 28006 Madrid, Spain; [r]A.W. Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06520, USA; [s]Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany; [t]INFN Sezione di Milano, 20133 Milano, Italy

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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

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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.

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## 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 $B(\mathrm{E2}; 2_1^+ \rightarrow 0_{\mathrm{g.s.}}^+)$ 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 $\beta$-delayed $\gamma$-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 $\beta$-decays by requiring that the $\beta$-decay had to occur in the same pixel as an implanted ion within approximately five times the $\beta$-decay half-life of the implanted nuclide. The $\beta$-electron was required to be detected in one of the $\beta$-plastics. As an example, the $\gamma$-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 $2_1^+ \to 0_{\rm g.s.}^+$ transition ($\Delta T$ is the time between a signal in the $\beta$-plastics and a $\gamma$-ray detection in the $LaBr_3$(Ce) array).

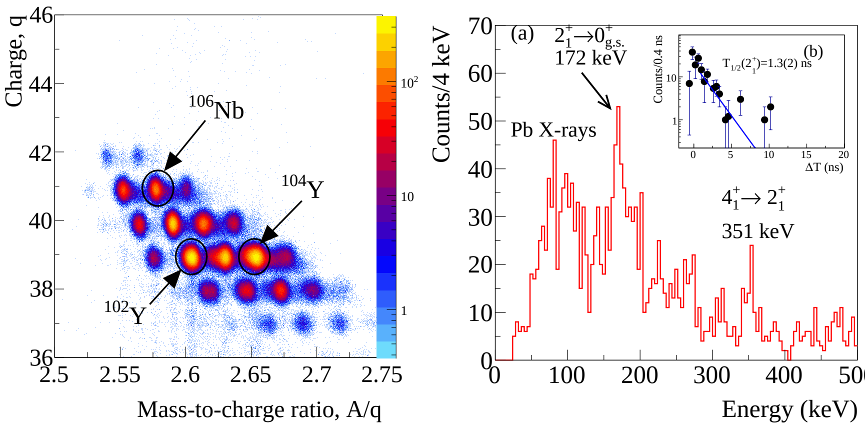


Fig. 1. Left: Particle identification plot with labels indicating the nuclides of interest. Right (a): Energy spectrum measured in the $LaBr_3$(Ce) array within 1 s of a $\beta$-decay correlated to an implantation of $^{106}$Nb. (b): Background-subtracted $\Delta T$ projection of the $2_1^+ \to 0_{\rm g.s.}^+$ transition, the curve (blue) is an exponential fit.

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 $4_1^+ \to 2_1^+$ transitions. The right panel of Fig. 2 shows the $B({\rm E2}; 2_1^+ \to 0_{\rm g.s.}^+)$ values obtained.

The presented method shall be extended to more neutron-rich isotopes in the region, to extend the knowledge of transition probabilities.

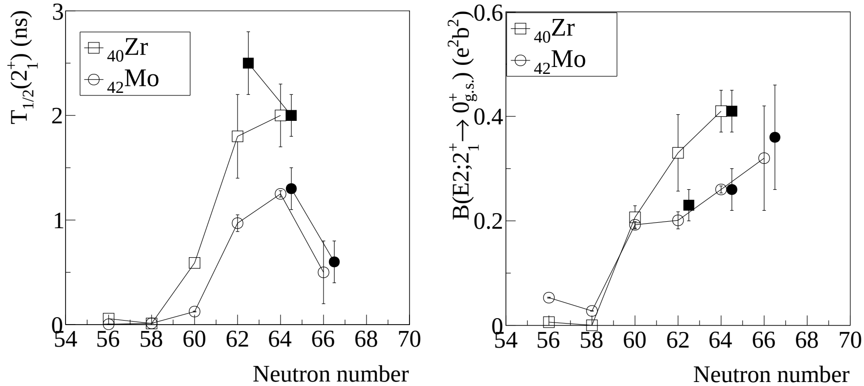


Fig. 2. Left: Half-lives of the $2_1^+$ states as a function of neutron-number for Mo and Zr. Right: The corresponding $B(\mathrm{E2}; 2_1^+ \rightarrow 0_{\mathrm{g.s.}}^+)$ transition probabilities. In both, the solid symbols are values determined in this work, open symbols from Ref. [10, 11, 13, 14].

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