FIRST REPORT OF A DOUBLET 2209-keV STATE IN ^{100}Zr*

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A β-decay experiment aiming at investigation of the low-spin structure of ^{100}Zr was performed using the GRIFFIN spectrometer at TRIUMF-ISAC. Based on the obtained data, a new 2^+ state is postulated which is degenerate in energy with the established (5^+) level at 2209 keV.

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1. Introduction

The ground-state structures of nuclei with proton numbers $Z \approx 40$ undergo dramatic changes between neutron numbers $N = 58$ and 60, including the sudden departures at $N = 60$ of the mean-square charge radii from smooth trends observed for the lighter isotopes (see, *e.g.*, Refs. [1, 2]). This effect is accompanied by equally dramatic changes observed in the energy spectra. These observations are consistent with the suggestion of shape coexistence occurring in the region, which has been put on a firm footing through Coulomb-excitation measurements [3–5]. The prevailing current understanding, reinforced by the data available for ^{96,98}Sr [3], is that the deformed 0_2^+ configuration in ^{98}Zr becomes the ground-state configuration in ^{100}Zr, while the spherical ground-state configuration of ^{98}Zr becomes an excited state in ^{100}Zr [2, 6]. There are, however, conflicting interpretations for the structure of ^{98}Zr [7, 8], and the natures of the low-lying excited 0^+ states in ^{100}Zr are not well established, although the similarity of the decay of the 0_2^+ state to that of its counterpart in ^{98}Sr is strongly suggestive of a spherical, or very weakly deformed shape [2, 6]. With the goal of obtaining more detailed spectroscopic data for ^{100}Zr, we undertook an experiment at the TRIUMF-ISAC facility [9] to study the β decay of ^{100}Y.

2. Experimental details

Radioactive species were produced at the TRIUMF-ISAC facility by bombarding a UC$_x$ primary target with 480-MeV protons. Products of the reaction diffused to the surface of the target where they were ionized and mass separated selecting the singly-charged $A = 100$ ions, resulting in a beam that was a mixture of ^{100}Rb and ^{100}Sr. In a repeating cycle, the beam was deposited onto a mylar tape at the center of the GRIFFIN spectrometer [10] for 3.5 seconds, *i.e.* approximately five half-lives of the ^{100}Y (1^-) ground state (the daughter of ^{100}Sr and grand-daughter of ^{100}Rb), and then deflected for one second to observe the decay. The GRIFFIN spectrometer consisted of 15 HPGe clover detectors equipped with BGO anti-Compton shields, as well as ancillary detectors used for conversion electrons (PACES), β particles (Zero-Degree Scintillator), and for fast timing (seven LaBr$_3$ detectors) [10]. The data were collected in a triggerless mode.

The present work focuses on the γ-ray singles and coincidence data from the HPGe detectors. Their energy and efficiency calibrations were performed using the standard ^{152}Eu, ^{56,60}Co, ^{133}Ba, and ^{207}Bi sources. Additionally, add-back and cross-talk corrections were implemented that improved the peak-to-total ratio and energy resolution. During the sorting of the data, a prompt γ–γ coincidence matrix was created using a timing condition of $\Delta t \leq 300$ ns between events, and a time-random background matrix was subtracted.

3. First observation of a doublet 2209-keV state

The (5^+) state at 2209 keV in ^{100}Zr was first reported by the study of Ref. [11] that used fission to populate high-spin states, and it was postulated to be a member of a "proto-γ" band together with the known levels at 1398 keV (presumed (3^+)) and 1856 keV (a 4^+ state) [12], as well as proposed (6^+) and (7^+) states at 2472 and 2776 keV, respectively. According to Ref. [11], the (5^+) level is mainly depopulated by the 810-keV and 1644-keV transitions, both of which were observed in our data, however, the intensity of the 1644-keV γ ray in the spectrum obtained by gating on the $4^+_1 \to 2^+_1$ transition (Fig. 1 (a)) cannot be attributed solely to the $(5^+) \to 4^+_1$ decay. Moreover, it is not expected that a state with $J^\pi = 5^+$ will be strongly populated via β decay of the $(1)^-$ ground state of ^{100}Y. This led us to conclude that another state, with a different spin, exists at 2209 keV.

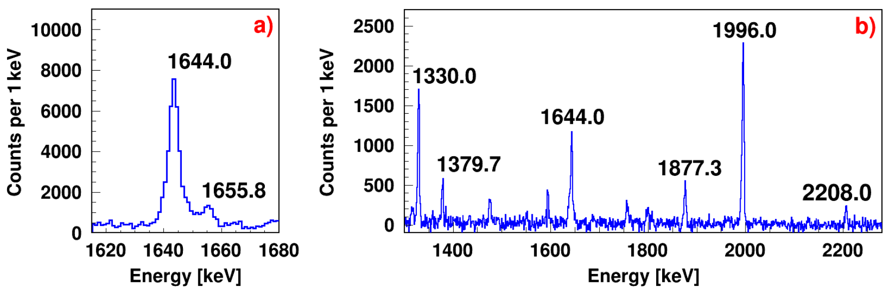

Fig. 1. (a) Portion of the γ-ray spectrum observed in coincidence with the $4^+_1 \to 2^+_1$ transition. The 1656-keV peak corresponds to the $(2^+, 3, 4^+) \to 4^+_1$ transition, depopulating the state at 2220 keV [12]. (b) Portion of the γ-ray spectrum observed in coincidence with the 637-keV γ ray. The transitions depopulating the proposed 2^+ state at 2209 keV are labelled with their energies.

Table 1. Relative γ-ray intensities of the transitions depopulating the new state at 2208.6(1) keV, normalized to that of the 2208.6-keV $\to 2^+_1$ transition. Summing corrections have not been applied.

I^π_f	E_f [keV]	E_γ [keV]	I_γ	I^π_f	E_f [keV]	E_γ [keV]	I_γ
2^+_1	212.6	1995.97(8)	100(5)	0^+_3	829.3	1379.69(8)	19(1)
2^+_2	878.7	1329.99(5)	58(3)	0^+_1	0	2208.04(11)	9(1)
4^+_1	564.6	1644.01(12)	50(4)	(2^+)	1294.9	913.78(7)	9(1)
0^+_2	331.2	1877.34(10)	23(1)	$(1, 2^+)$	1441.5	767.30(5)	7(1)

A newly observed γ ray at 637 keV was placed as a feeding transition to the 2209-keV level. A coincidence with this γ ray revealed a number of new transitions, shown in Fig. 1 (b), assigned as depopulating the 2209-keV state as shown in Fig. 2; their relative intensities are given in Table 1. Since the decaying transitions feed levels with spins ranging from 0^+ to 4^+, we assign the spin-parity of the new 2209-keV level as 2^+. Thus far, there is insufficient information to suggest the nature of this new level. Future work will focus on γ–γ angular correlations to determine the E2/M1 mixing ratios of the transitions that may provide clues for it.

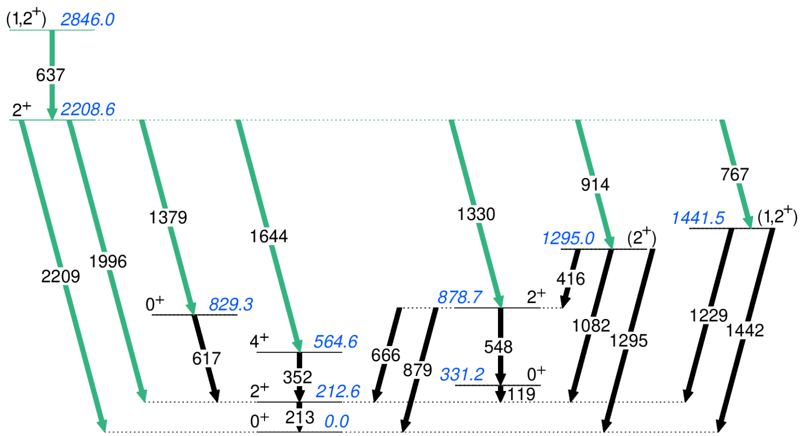

Fig. 2. (Color online) Partial level scheme of ^{100}Zr, deduced from the present experiment, presenting the feeding and depopulating transitions (in green/gray) of the new state at 2208.6 keV.

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