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Level Lifetimes in ^{94}Zr from DSAM Measurements following Inelastic Neutron Scattering

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Inelastic neutron scattering (INS) with the detection of emitted γ rays, *i.e.*, the (n,n′γ) reaction, has been utilized at the University of Kentucky Accelerator Laboratory for many years to study the detailed structure of stable nuclei [1]. Through γ-ray excitation function, γ-ray angular distribution, and γ-γ coincidence measurements, level schemes of the low-spin states of stable nuclei can be established, and the Doppler-shift attenuation method (DSAM) can be utilized to determine the lifetimes of excited nuclear states [2]. Moreover, DSAM-INS measurements frequently yield lifetimes for states that are not populated with other reactions. For example, without the lifetimes of non-yrast 2^+ and 4^+ states in ^{94}Zr, novel collective structure, which provided new insights into shape coexistence and the role of subshells in nuclear collectivity, would have otherwise gone unnoticed [3]. This work also exposed that the chemical properties of the scattering samples used in DSAM-INS lifetime measurements must be understood and led to the resolution of a nuclear structure anomaly [4].

Several years ago, our group performed ^{94}Zr(n,n′γ) measurements with an enriched $^{94}ZrO_2$ scattering sample. Based on the observation that the 752.5-keV transition from the second 2^+ state at 1671.4 keV to the first excited state at 918.8 keV exhibits a large $B(M1;2_2^+\rightarrow 2_1^+)$, we identified the second 2^+ state as the lowest mixed-symmetry state [4]. In addition, these measurements of ^{94}Zr revealed anomalous behavior unobserved in other nuclei; the B(E2) value for the transition from the second excited 2^+ state to the ground state was found to be larger than that from the first 2^+ state to the ground state. This nucleus thus emerged as the lone example of an inversion of the B(E2) strengths for the lowest-lying 2^+ excitations.

As questions have been raised about this anomaly, we carried out additional (n,n′γ) measurements using metallic Zr, ZrO_2, and $Zr(OH)_4$ samples of natural isotopic composition [5]. The lifetime of the second 2^+ state was redetermined by DSAM, and a new value for $B(E2;2_2^+\rightarrow 0_1^+)$ was obtained. The results differ significantly from the previously published values [4], with the new B(E2) found to be roughly half of the previous value and slightly less than $B(E2;2_1^+\rightarrow 0_1^+)$. A reanalysis of the original γ-ray data from the enriched $^{94}ZrO_2$ sample failed to expose the source of this discrepancy; however, powder x-ray diffraction and scanning electron microscopy performed on each scattering sample, including the enriched scattering sample used previously, provide clues to an explanation and reveal the role of the chemical properties of the sample material in DSAM lifetime determinations.

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