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Measurement of 2_1^+ level lifetimes in ^{162}Yb and ^{162}Er by fast electronic scintillation timing

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Abstract. Lifetime measurements for the 2_1^+ levels of ^{162}Er and ^{162}Yb were obtained in β^+/ε decay at the Yale Moving Tape Collector by fast electronic scintillation timing of $\beta^+\gamma$ coincidences.

PACS. 21.10.Re Collective levels – 21.10.Tg Lifetimes – 27.70.+q $150 \le A \le 189$

Advanced fast electronic scintillation timing (FEST) techniques developed by Mach, Moszyński, Gill, and collaborators [1–4] in the late 1980s constitute a valuable complement to other lifetime measurement techniques, making possible measurements for levels populated in β-decay with lifetimes as short as several ps. These techniques are based upon electronic timing of the interval between β-particle emission and subsequent γ-ray decay, making use of the ΔE signal from a thin slice of fast plastic scintillation material for β detection and the fast ultraviolet component of scintillation light from BaF_2 [5] for γ detection. A coincidence with an additional γ-ray detected in a Ge detector can be used for cascade selection, either when the energy resolution of the BaF_2 detector is insufficient to isolate the γ-ray of interest in singles or when it is necessary to choose specific γ-ray feeding paths for the lifetime measurement.

The FEST method was originally designed for use with neutron-rich nuclei provided by reactors or ISOL-type sources, but it has also been successfully applied to the study of proton-rich nuclei [6–8], as in the present measurements. Challenges associated with measurements on proton-rich nuclei include the presence of delayed coincident background radiation from β^+ annihilation, with a time profile which extends into the ns range and is strongly dependent upon detector geometry and absorber materials [9], and competition from electron capture, in which no emitted β^+-particle is available for timing [10].

Nuclei in the transitional rare-earth region ($N \approx 90$) exhibit a wealth of interesting collective phenomena. Over the course of the transition from spherical to axially symmetric deformed shape, the nature of the low-lying excitations changes from vibrational to rotational, with accompanying changes in the 2^+ level energy and $B(E2)$ observables. A full suite of information on such transitional nuclei must include lifetime information on excited states. The purpose of this paper is to report lifetime measurements for the 2_1^+ levels in ^{162}Yb and ^{162}Er obtained by the FEST method.

Measurement of the 2_1^+ level lifetime of ^{162}Yb was carried out in β^+/ε decay at the Yale Moving Tape Collector [11,12]. Parent ^{162}Lu nuclei were produced through the reaction ^{147}Sm(^{19}F$, 4n$)^{162}Lu at a beam energy of 95 MeV,

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using an ~ 7 pnA beam provided by the Yale ESTU tandem accelerator incident upon a 1.8 mg/cm^2 98% isotopically enriched target. The unreacted primary beam nuclei were stopped by a 3 mm diameter gold plug 7 cm downstream of the target. In contrast, the fusion-evaporation product nuclei, which were emitted from the target with a much wider angular distribution [11], largely bypassed the plug and were embedded into a 16 mm Kapton tape 1.5 cm further downstream, which carried the collected activity to a shielded detector area. The ^{162}Lu parent nucleus decays to ^{162}Yb with a half-life of ~ 1.4 min [13]. The tape was advanced at 125 s intervals.

The measurement was performed using an integrated multidetector array for $\gamma\gamma$ coincidence spectroscopy and fast $\beta\gamma$ scintillation timing measurements. Three Compton-suppressed segmented YRAST Ball Clover HPGe detectors [14] and one LEPS detector were positioned about the source in close geometry, with an array photopeak efficiency of 1.1% at 1.3 MeV. This array provides $\gamma\gamma$ angular correlation and Compton polarimetry capability [15]. Fast timing β-particle detection was accomplished with a disk of NE111A plastic scintillation material (1.3 cm diameter and 3 mm thick) coupled to a Photonis XP2020 photomultiplier tube and covered only by a thin (20 μm) aluminum foil to minimize the energy loss of β-particles entering the detector. Fast timing γ-ray detection was carried out with a BaF_2 crystal in the shape of a conical fustrum (1.91 cm forward diameter, 2.54 cm length, and 2.54 cm rear diameter) [16] coupled using Viscasil silicone fluid [17,18] for transmission of the fast ultraviolet scintillation light to a quartz-windowed Photonis XP2020Q photomultiplier tube. The voltage divider chains for both photomultiplier tubes were modified to provide timing signals from the ninth dynode [19]. The tape carrying the activity passed through the detector area under vacuum inside a flat aluminum transport duct (1.3 cm $\times$ 3.8 cm rectangular cross-section), allowing the scintillation detectors to be placed facing each other across the tape with minimal separation, with β-particles exiting through a 51 μm polypropylene vacuum window [20].

Data were acquired in event mode with a Ge singles (or higher fold) or plastic scintillation detector trigger, using a VME-based acquisition system with readout by an Intel/Linux front end computer. In 79 h, the experiment yielded 1.2×10^6 plastic-BaF_2 coincidence events, including 1.5×10^5 Ge-plastic-BaF_2 triple coincidence events.

The fast timing electronics followed the principles of refs. [1,2]. Timing discrimination was carried out using Tennelec TC454 constant fraction discriminators with minimal (3 cm) external wire delays. The plastic-BaF_2 relative timing was measured using an Ortec 567 TAC, calibrated using known delays. Only signals in the ΔE peak for β^+-particles traversing the plastic scintillator (with a threshold energy of ~ 500 keV) were used in the analysis [2].

The 167 keV $2_1^+ \to 0_1^+$ γ-ray transition in ^{162}Yb is by far the most intense observed transition in the β^+-decay of ^{162}Lu (fig. 1(a)). Consequently, a high-statistics measurement of its decay time can be carried out from the full

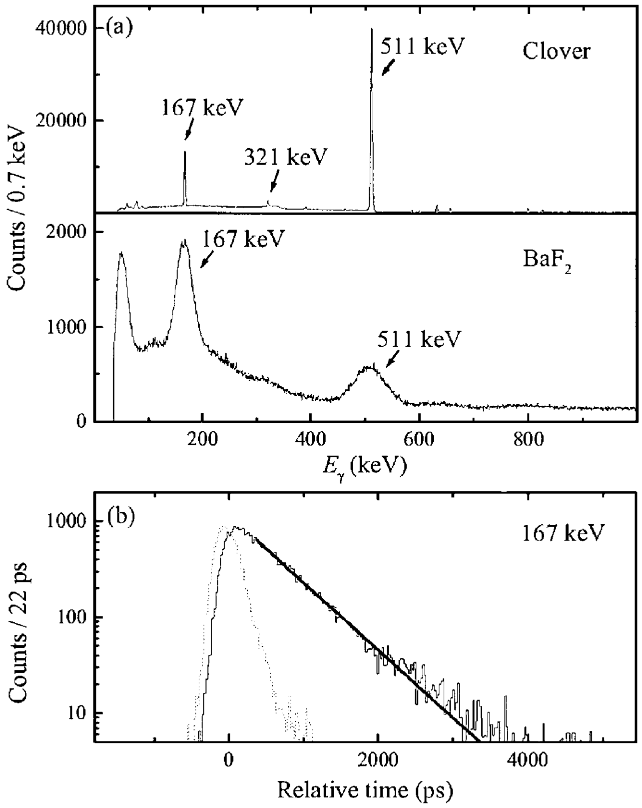

Fig. 1. Spectra from the ^{162}Yb measurement. (a) Clover and BaF_2 detector energy spectra coincident with β^+ ΔE signals, showing the 167 keV $2_1^+ \to 0_1^+$ and 321 keV $4_1^+ \to 2_1^+$ γ-ray transitions as well as 511 keV annihilation radiation. (b) Measured time distribution for the 167 keV BaF_2 detector γ-ray time signal relative to the β^+ time signal, together with the fitted $\tau = 618$ ps decay curve (heavy line). The prompt response curve (dotted) is shown for comparison (see text).

plastic-BaF_2 coincidence data (fig. 1(a)), without it being necessary to require triple coincidences with a feeding γ-ray transition detected in the Ge detector. The plastic-BaF_2 time spectrum obtained for ~ 167 keV energy deposition in the BaF_2 detector contains both a prompt background from partial-energy deposition by higher-energy γ-rays from ^{162}Yb and a small delayed background from partial-energy deposition by 511 keV annihilation γ-rays. The time distribution obtained for a 10%-width energy gate on the 167 keV transition in the BaF_2 detector with a local background subtraction is shown in fig. 1(b). The prompt timing response at this energy (obtained using $\gamma\gamma$ coincidences from ^{60}Co decay, with Compton energy deposition in both timing detectors, shifted [2] so that the time response centroids at higher energies coincide with those for prompt Compton events in the ^{162}Yb data) is shown for comparison in fig. 1(b). The decay time of the transition deduced using the slope method is 618(19) ps, where the uncertainty accounts for both statistical and systematic (including background subtraction walk [3]) contributions. Corroborating results were obtained, but with larger statistical uncertainties, using time spectra gated on specific feeding γ-ray transitions detected in the Ge array as

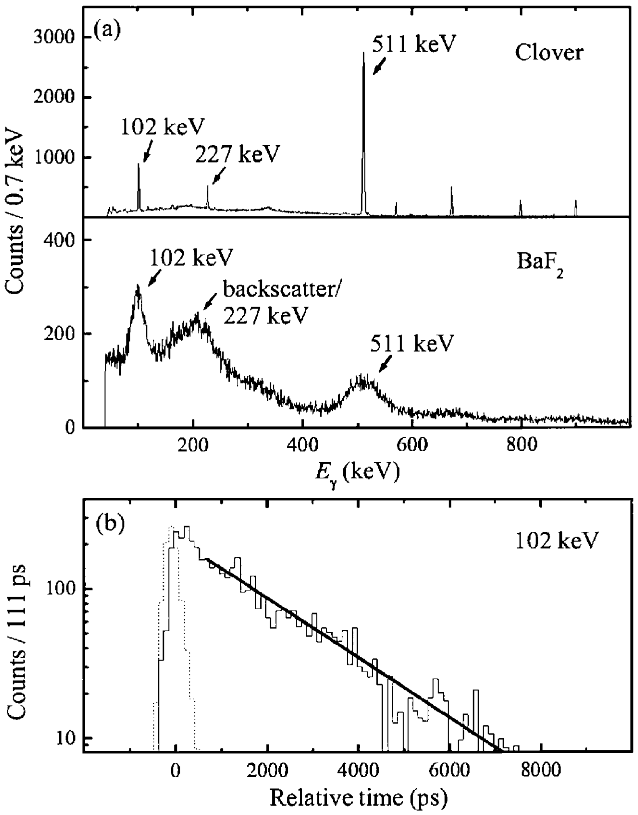

Fig. 2. Spectra from the ^{162}Er measurement. (a) Clover and BaF_2 detector energy spectra from Clover-plastic-BaF_2 triples events, 102 keV $2_1^+ \to 0_1^+$ and 227 keV $4_1^+ \to 2_1^+$ γ-ray transitions as well as 511 keV annihilation radiation and backscatter (see text). (b) Measured time distribution for 102 keV γ-ray detection in the BaF_2 detector relative to the β^+ time signal, shown with the fitted $\tau = 2.2$ ns decay curve (heavy line). The prompt response curve (dotted) is shown for comparison (see text).

well as on 511 keV annihilation radiation detected in the Ge array (which selects events in which the partner annihilation γ-ray does *not* enter the BaF_2 detector, providing a reduced background for the 167 keV γ-ray). For all analyses, the slope was obtained by a Gaussian-error-weighted least-squares fit of the time spectrum, sufficiently compressed [1] to provide a deduced lifetime stable against counting fluctuations, over a range of time channels excluding the prompt region and extreme tail region.

The decay time of the 167 keV transition can be interpreted directly as the lifetime of the 2_1^+ level it depopulates, due to comparatively short decay times of the higher-lying feeding transitions. Approximately 10% of the β^+-coincident feeding of the 2_1^+ level comes through the 321 keV $4_1^+ \to 2_1^+$ transition (fig. 1(a)), and so the 15.3(14) ps lifetime of the 4_1^+ level [13] introduces a small feeding delay to the population of the 2_1^+ level; however, the contribution of this delay to the effective lifetime (reciprocal of the logarithmic slope of the decay curve) for the 167 keV transition is much less than 1 ps in the time region used for the analysis.

Table 1. Values for the lifetimes of the first-excited 2^+ states in ^{162}Yb and ^{162}Er as determined by various methods in prior experiments and in the present work.

Nuclide	τ (ps)	Ref.	Method
^{162}Yb	633(53)	[21]	Recoil conversion electron shadow
	577(19)	[22]	Recoil Doppler
	618(19)	Present	
^{162}Er	$1.69(14)\times10^3$	[23]	Electronic timing
	$1.96(6)\times10^3$ (a)	[24]	Coulomb excitation
	$2.2(4)\times10^3$	Present	

(a) Deduced from the reported $B(E2; 0_1^+ \to 2_1^+)$ value using a total electron conversion coefficient of 2.76(8) [13].

Measurement of the 2_1^+ level lifetime of ^{162}Er was carried out in a similar configuration of the Yale Moving Tape Collector. Parent ^{162}Yb nuclei were produced through the reaction ^{155}Gd(^{12}C$, 5n)^{162}$Yb at a beam energy of 86 MeV, with an $\sim$ 20 pnA beam incident upon a 5 mg/cm^2 99.8% isotopically enriched target. The ^{162}Yb parent nucleus decays with an 18.9 min half-life through β^+/ε decay to $^{162\mathrm{g}}$Tm, which in turn decays with a 21.7 min half-life to ^{162}Er [13], and so the tape was advanced at $\sim$ 1 h intervals. Data were acquired in event mode with a Ge singles (or higher fold) trigger using the YRAST Ball FERA/VME data acquisition system [14], yielding 5.3×10^5 Ge-plastic-BaF_2 triple coincidence events in 100 h.

The lifetime of the 2_1^+ level in ^{162}Er is deduced, by a similar analysis, from $\beta\gamma$ coincidences involving the 102 keV $2_1^+ \to 0_1^+$ transition. The decay of $^{162\mathrm{g}}$Tm to ^{162}Er proceeds predominantly by electron capture, with a β^+-decay fraction of only $\sim$ 6% [25]. Since in the vast majority of decays only γ-rays are present, the detection of true β^+ ΔE signals in the plastic scintillation detector competes with a substantial background of γ-ray Compton scattering interactions in the plastic scintillator depositing energies in the same energy range. Detection of the corresponding Compton-scattered γ-rays in the BaF_2 detector gives rise to a strong coincident backscatter peak in the BaF_2 energy spectrum (fig. 2(a)). However, the 102 keV $2_1^+ \to 0_1^+$ transition is largely resolved from the backscatter peak in the BaF_2 spectrum (fig. 2(a)), and the time spectrum from the backscatter events is essentially prompt (with an excess flight time of only $\sim$ 100 ps relative to prompt γ-rays), so this background has little influence on the lifetime measurement. The time distribution obtained for a 30%-width energy gate on the 102 keV transition in the BaF_2 detector with a local background subtraction is shown in fig. 2(b). The lifetime deduced using the slope method is 2.2(4) ns. The larger relative uncertainty obtained for this lifetime compared to the lifetime in ^{162}Yb is a result both of lower statistics and uncertainties in the local background subtraction in the BaF_2 detector due to the adjacent backscatter peak.

The values for the lifetimes of the 2_1^+ levels in ^{162}Yb and ^{162}Er obtained in the present work are summarized in table 1. These are similar to values determined by various methods in prior experiments, also shown in table 1. The $B(E2)$ values deduced from the data indicate moderate deformation of these nuclei, as expected from the nuclear-structure evolution in this region [26]. The fast electronic scintillation timing method in an accelerator environment is suitable for the study of low-lying states in transitional and deformed nuclei populated in β^+-decay and constitutes part of the Yale Moving Tape Collector program investigating the evolution of nuclear structure in the $A \approx 100$ and $A \approx 160$ regions.

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