Half-lives of isomeric states in ^{57}Fe and ^{83}Kr

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The half-lives of the 14.4 keV isomeric state in ^{57}Fe and the 9.4 keV isomeric state in ^{83}Kr have been accurately measured using electronic timing. The two isomers were populated in the electron capture decays of ^{57}Co and ^{83}Rb, and the time distributions between γ-γ cascades proceeding via the isomers were determined. Results are 99.2(4) and 155.1(12) ns for the ^{57}Fe and ^{83}Kr states respectively.

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Precise lifetimes of isomeric states are required to refine nuclear model calculations. They can also provide valuable information relevant to related scientific fields. Isomers often have large internal conversion coefficients (ICC) and have been used in experiments to measure changes of those coefficients with ionic charge state q. Examples are given by the 14.4 keV level in ^{57}Fe and the 9.4 keV state in ^{83}Kr. Charge-changing events in beams containing the ^{57}Fe isomer [1] and the ^{83}Kr isomer [2] have been observed as the beams pass through magnetic spectrometers. These experiments have determined the IC decay probabilities per unit time, $\lambda_{IC}(q)$, where $\lambda_{IC}(q)=\alpha_{IC}(q)\lambda_\gamma$, with λ_γ the γ-decay probability per unit time and $\alpha_{IC}(q)$ the total ICC for charge state q. In order to effect comparisons between the $\alpha_{IC}(q)$ determined experimentally in this way and values calculated using the best available electron wave functions, the parameter λ_γ must be known. Any inconsistencies between the experimental and calculated $\alpha_{IC}(q)$ values may be due either to lack of understanding of the physical processes that occur in highly ionized atoms or to incorrect values of the isomeric half-lives used to determine λ_γ. This Brief Report describes experiments performed to measure accurately the half-life of the 14.4 keV state in ^{57}Fe and that of the 9.4 keV level in ^{83}Kr.

Previous measurements on the 14.4 keV level in ^{57}Fe have been evaluated [3] to yield a half-life of 98.1(3) ns. This value is an unweighted average of several results, and the experiments [4,5] with the smallest quoted errors give barely consistent half-lives of 99.3(5) and 97.7(2) ns. The only result available [6] for the 9.4 keV level in ^{83}Kr is a half-life of 147(4) ns. Lifetimes near these values can conveniently be measured using electronic timing techniques, and we have remeasured them using a modified fast-slow coincidence technique with an accurately calibrated time-to-amplitude converter (TAC).

The experiment on ^{57}Fe used a planar Ge detector (LEPS; low-energy photon spectrometer) to observe the 14.4 keV γ ray deexciting the isomer, which was populated following the electron capture decay of ^{57}Co. This proceeds 99.7% of the time to the 136.5 keV level in ^{57}Fe, which in turn decays predominantly to the 14.4 keV isomeric level with emission of a γ ray of energy 122.1 keV, observed in these experiments with a coaxial Ge detector. The time distribution of coincident events in the two detectors was measured using conventional fast circuitry to feed pulses into the TAC. Information on the TAC output and the energies deposited in the two detectors was recorded on magnetic tape for each event. Off-line analysis enabled a decay curve to be obtained for events for which the signal in the LEPS detector fell under the total-energy peak of the 14.4 keV γ ray, and the signal in the Ge detector fell under the total-energy peak of the 122.1 keV γ ray. Figure 1 shows the decay curve and also the time distribution of coincidences between Fe K-X rays of energy $\sim$ 6.5 keV and events in the Ge detector under the total-energy peak of the 136.5 keV γ ray. The latter time distribution is that for coincidences between x rays that accompany the electron capture process and γ rays deexciting the 136.5 keV level, which has a half-life of 8.7 ns.

A similar experimental procedure was followed for the determination of the lifetime of the 9.4 keV state in ^{83}Kr. The LEPS detector was used to observe the 9.4 keV γ ray deexciting the isomer, which was populated following the electron capture decay of ^{83}Rb. The decay proceeds $\sim$ 60%

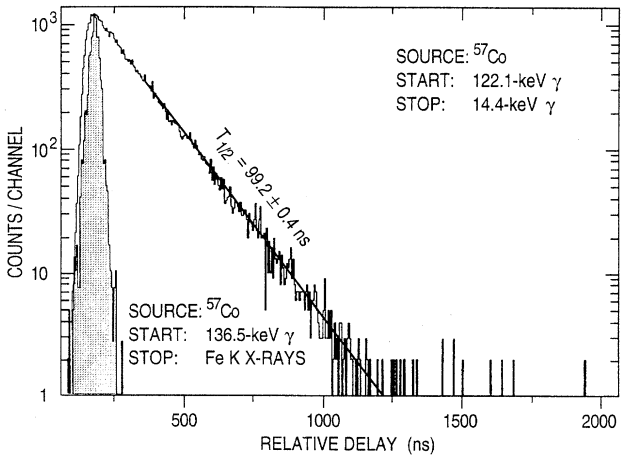

FIG. 1. The decay curve for coincident γ rays proceeding through the 14.4 keV level in ^{57}Fe. The "prompt" curve for coincidences between ^{57}Fe K-X rays and 136.5 keV γ rays is also shown.

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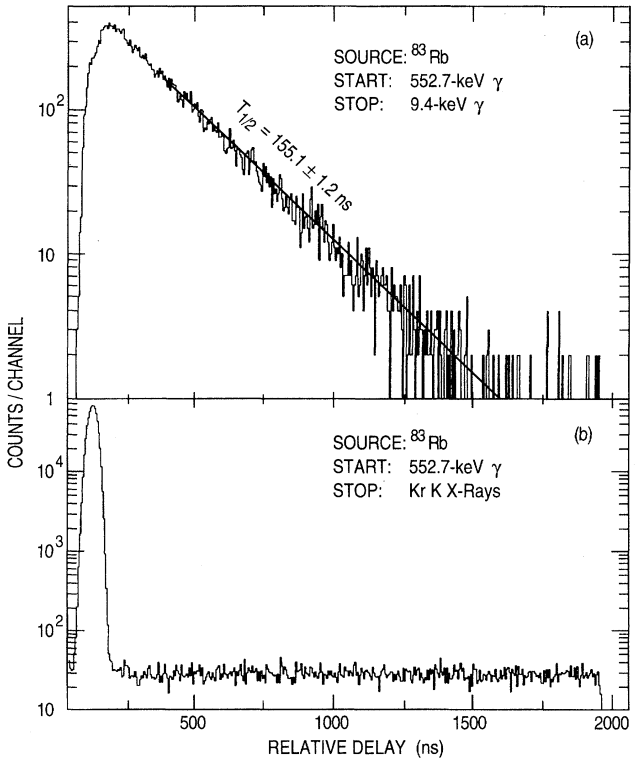

FIG. 2. The decay curve for coincident γ rays proceeding through the 9.4 keV level in ^{83}Kr. The prompt curve for coincidences between Kr K_α-X rays and 552.6 keV γ rays from the short-lived 562.0 keV level is also shown.

of the time [7] to the 562.0 keV state in ^{83}Kr, which partially decays to the 9.4 keV level with emission of a γ ray of energy 552.6 keV. This γ ray was observed in the Ge detector. Figure 2 shows the decay curve obtained for events under the total energy peaks of the 9.4 keV and 552.6 keV γ rays. Figure 2 also shows the prompt curve obtained from coincidences between Kr K_α-X rays of energy 12.6 keV and 552.6 keV γ rays from the short-lived 562.0 keV level.

The time calibration of the TAC was determined using two separate calibrated crystal oscillators with results in agreement to better than 0.1%. Decay curves were fitted in terms of a single exponential decay plus a constant background, and different experimental runs for the same isomer gave consistent results and values of the normalized statistic χ^2 close to unity. Combining the ^{57}Fe data gave a half-life of 99.2(3) ns, and the ^{83}Kr data gave a half-life of 155.1(11) ns.

The errors quoted above are statistical only, and possible sources of systematic errors must be considered. The decay curves may be distorted due to instrument response, i.e., because of the form of the time distribution for prompt coincidences. Although the prompt curves shown on Figs. 1 and 2 do not correspond to the precise energy intervals used for the decay curves, the ^{83}Kr prompt distribution is expected to approximate very closely the shape that should be used in analysis. Deconvolution from the decay data of the instrumental response given by the prompt curve results in insignificant changes to the ^{83}Kr half-life as long as fits are taken over times that begin sufficiently later than time zero. The "prompt" curve on Fig. 1 is a convolution of the real prompt curve with a half-life of 8.7 ns, that of the 136.5 keV state in ^{57}Fe, and so has a width greater than that of the real prompt distribution. The latter would be similar to the prompt curve on Fig. 2, and, again, as long as fits to the decay curve are made over portions that begin $\sim$ 20 ns later than time zero, there is insignificant influence on the results. A second source of systematic error can arise if the energy windows used for the decay curves contain a small fraction of events that are correlated in time with a decay constant within two or three orders of magnitude of the one being measured. The decay schemes of ^{57}Co and ^{84}Rb suggest no such possibilities. In addition, when the data were fitted in terms of two decaying components plus a constant background, there were no significant changes to the extracted half-lives, nor were any significant second components revealed. Estimated systematic errors are ± 0.2 ns, primarily reflecting a lack of certainty of contaminant components. Combined errors are quoted in the abstract.

In summary, we have measured the half-life of the 14.4 keV level in ^{57}Fe to be 99.2 $\pm$ 0.3 $\pm$ 0.2 ns and that of the 9.4 keV level in ^{83}Kr to be 155.1 $\pm$ 1.1 $\pm$ 0.2 ns. These results can reliably be used as standards or for the interpretation of calculations or experiments that require their accurate values.

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