Half-life determination of nuclear excited states of ^{229}Th by the coincidence measurement between α particles and γ rays from ^{233}U

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Studying the nuclear structure of ^{229}Th is important in that reflection-symmetric and reflection-asymmetric shapes are expected to coexist[1)] and the first nuclear excited isomeric state of ^{229}Th (^{229m}Th) has an extremely low energy of 8.3 eV,[2)] which would enable the development of nuclear laser spectroscopy and an ultraprecise nuclear clock. In this study, we measured the half-lives of nuclear excited states of ^{229}Th, populated through the alpha decay of ^{233}U, for further understanding of the nuclear properties of ^{229}Th. This work was also aimed at determining the half-life of the 29.2-keV state (Fig. 1). This half-life was one of the key parameters for exciting ^{229}Th from the ground state to the 29.2-keV state with synchrotron radiation to actively produce ^{229m}Th, which was recently realized by our group.[3)]

For the half-life determination, we performed a coincidence measurement between α particles and γ rays from a ^{233}U source prepared by electrodeposition. The ^{233}U source was placed inside a vacuum chamber enclosed by 5-cm Pb blocks for background γ-ray reduction. Emitted α particles from the source were measured with a passivated implanted planar silicon detector mounted inside the chamber, and γ rays that were emitted from the source and passed through a polyimide window out of the vacuum were measured with a $LaBr_3$(Ce) scintillator and photomultiplier. After amplification, α-particle and γ-ray signals were recorded with Computer-Aided Measurement And Control (CAMAC) modules to obtain time spectra of γ-ray signals following α-particle signals for each combination of α-particle and γ-ray energies.

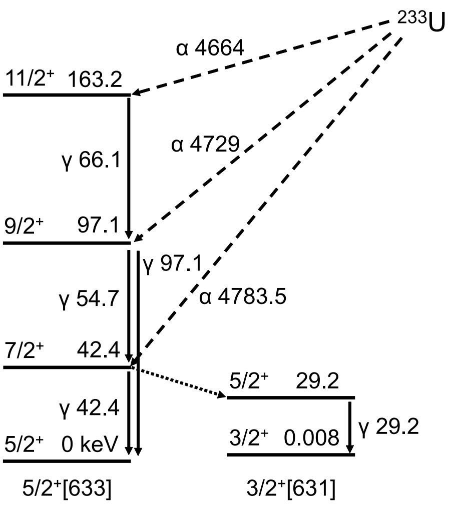

Fig. 1. Excited states of ^{229}Th the half-lives of which were determined, and α and γ transitions used for determining the half-lives (unit: keV).

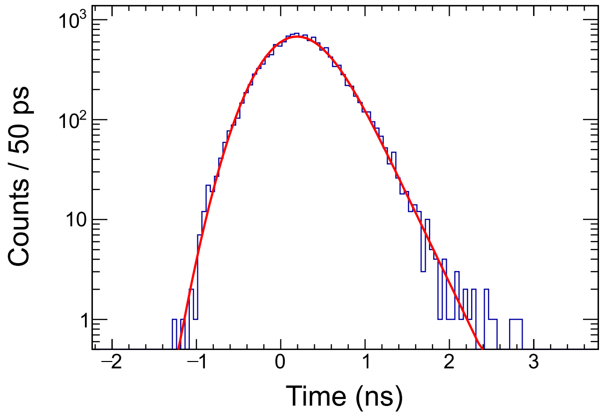

Fig. 2. Time spectrum of γ-ray signals following α-particle signals for 4783.5-keV α particles and 42.4-keV γ rays (histogram). A single exponential decay function convoluted with a Gaussian function is fitted to the data (curve).

Figure 2 shows a time spectrum for 4783.5-keV α particles and 42.4-keV γ rays. The half-life obtained from the fitting of a single exponential decay function convoluted with a Gaussian function was almost the same as the reference value (172(6) ps).[4)] From a time spectrum for 4783.5-keV α particles and 29.2-keV γ rays, we obtained the half-life of the 29.2-keV state, which is consistent with that obtained from our synchrotron excitation of ^{229}Th (82(4) ps).[3)] These coincidences with the previous results indicate that our experiments and data analysis were correctly performed. The half-life of the 97.1-keV state was obtained from γ rays of 54.7 and 97.1 keV detected in coincidence with 4729-keV alpha particles. The obtained half-life was seemingly shorter than the reference value (147(12) ps).[4)] This may be because our measurement has better and time resolutions than the previous measurement.[4)]

We could clearly observe the peak of 66.1-keV γ rays by gating the γ-ray spectrum with α particles of approximately 4664 keV, which allowed us to obtain the half-life of the 163.2-keV state for the first time. We will continue detailed analysis to precisely determine each half-life and discuss the nuclear properties of ^{229}Th based on the half-lives determined in this study.

References

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