DIRECT DETECTION OF THE ^{229}TH NUCLEAR CLOCK TRANSITION

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Today’s most precise time and frequency measurements are performed with optical atomic clocks. However, it has been proposed that they could potentially be outperformed by a nuclear clock, which employs a nuclear transition instead of an atomic shell transition. There is only one known nuclear state that could serve as a nuclear clock using currently available technology, namely, the isomeric first excited state of ^{229}Th. Since 40 years nuclear physicists have targeted the identification and characterization of the elusive isomeric ground state transition of ^{229m}Th. Evidence for its existence inferred only from indirect measurements suggests an excitation energy of 7.8(5) eV (corresponding to a VUV wavelength of 160(11) nm). Thus the first excited state in ^{229}Th represents the lowest nuclear excitation so far reported in the whole landscape of known isotopes.

Here we report the first direct detection of this nuclear state, which further confirms the iosomer's existence and lays the foundation for precise studies of its decay parameters [1]. Our experimental approach includes the separation of population of ^{229m}Th (via the 2% decay branch of ^{233}U α decay feeding ^{229m}Th) and its deexcitation. The $^{229(m)}$Th nuclei recoiling from a ^{233}U source are thermalized in the high-purity He atmosphere of a buffer-gas stopping cell and extracted (via RF+DC guiding fields) through a supersonic Laval nozzle into a radio frequency quadrupole (RFQ) ion guide and phase-space cooler, followed by a quadrupole mass separator to suppress α decay products along the ^{233}U chain. Dominant extraction could be achieved as $^{229(m)}$Th^{3+} [2]. Initial studies aiming at identifying a potential photonic deexcitation branch of the extracted ions failed in observing UV fluorescence. This motivated a search in the competing internal conversion (IC) decay channel. Consequently, the thorium ions were guided with the help of a triodic guidance structure towards a microchannel plate (MCP) detector, used for low-energy electron detection. The ions are collected in a soft landing at low kinetic energy directly on the MCP detector, which is placed in front of a phosphor screen. The latter is monitored by a charge-coupled device (CCD) camera, allowing for a spatially resolved signal detection.

Clear evidence of a strong IC signal could be achieved, which could be validated in a series of confirmation measurements as unambiguously originating from the isomeric ground state transition of ^{229m}Th. On the basis of this direct detection, the isomeric energy is constrained to between 6.3 and 18.3 electronvolts, and the half-life is found to be longer than 60 seconds for ^{229m}Th^{2+}. More precise determinations appear to be within reach, and would pave the way to the development of a nuclear frequency standard. Moreover, a nuclear clock promises intriguing applications in fundamental physics—for example, the investigation of possible time variations of fundamental constants.

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