First high-precision direct determination of the atomic mass of a superheavy nuclide

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We present the first direct measurement of the atomic mass of a superheavy nuclide. Atoms of ^{257}Db ($Z = 105$) were produced online at the RIKEN Nishina Center for Accelerator-Based Science using the fusion-evaporation reaction $^{208}\mathrm{Pb}(^{51}\mathrm{V}, 2n)^{257}\mathrm{Db}$. The gas-filled recoil ion separator GARIS-II was used to suppress both the unreacted primary beam and some transfer products, prior to delivering the energetic beam of ^{257}Db ions to a helium gas-filled ion stopping cell wherein they were thermalized. Thermalized $^{257}\mathrm{Db}^{3+}$ ions were then transferred to a multi-reflection time-of-flight mass spectrograph for mass analysis. An alpha particle detector embedded in the ion time-of-flight detector allowed disambiguation of the rare $^{257}\mathrm{Db}^{3+}$ time-of-flight detection events from background by means of correlation with characteristic α-decays (see also T. Niwase in this issue). The extreme sensitivity of this technique allowed a precision atomic mass determination from 11 events. The mass excess was determined to be $100\,063(231)_{\mathrm{stat}}(72)_{\mathrm{sys}}$ keV$/c^2$.

In recent experience, elements with a second ionization potential below 24 eV have been near uniformly extracted from the gas cell as doubly charged ions. Surprisingly, no counts were seen for $^{257}\mathrm{Db}^{2+}$, while $^{257}\mathrm{Db}^{3+}$ was observed with the rate which, based on cross-section, target thickness, and primary beam intensity, indicated it constituted the preponderance of ^{257}Db ions. The rate of $^{257}\mathrm{Db}^{3+}$ extracted from the gas cell was roughly 4 per day. These ions were analyzed by the MRTOF-MS with the α-TOF detector,[1] which allowed us to correlate ToF events with subsequent α-decays. Such correlations allowed removal of even low-intensity backgrounds and confirm that we were truly measuring $^{257}\mathrm{Db}^{3+}$.

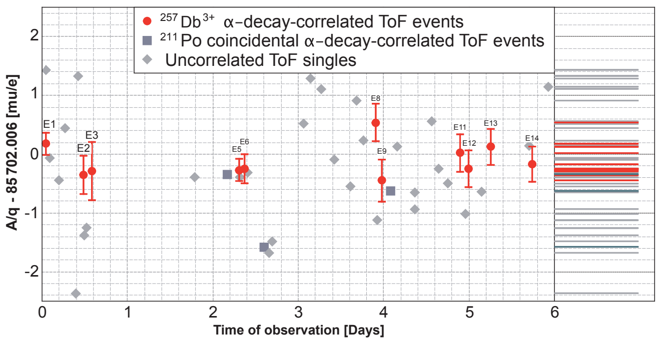

Fig. 1. Apparent A/q evaluated for each ToF single near the expected position of $^{257}\mathrm{Db}^{3+}$. The data are plotted in terms of deviation from the A/q for $^{257}\mathrm{Db}^{3+}$ as determined from AME16.[2] Statistical uncertainties are only evaluated for α-decay correlated ToF events.

Figure 1 shows the data measured over 105 hours of beam on target. As the MRTOF was operated with a resolving power of $R_{\mathrm{m}} \approx 300\,000$, the A/q range presented is about 10-FWHM. The red points represent events where the ToF signal was followed within 120 s by an α decay event with energy $E_\alpha \geq 7.0$ MeV to encompass all possible α-decays from ^{257}Db and its decay products; some α-decay-correlated ToF events within this gate were attributed to the α-decay of ^{211}Po.

Based on the 11 alpha decay correlated ToF events, the mass of ^{257}Db could be determined with a precision of 231 keV$/c^2$ (82 μu/e). The value is in agreement with indirect measurements.[2,3] Unfortunately, the mass resolution of the MRTOF and the energy resolution of the α-TOF were insufficient to resolve isomeric states. With recent improvements in the mass resolving power (See S. Yan in this issue) we should be able to resolve the isomer and ground state provided the isomer has excitation energy above 250 keV$/c^2$. A followup effort to determine the state order via MRTOF mass analysis is planned for FY2021.

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