Alpha-decay correlated mass measurement of $^{206,207}$Ra using an MRTOF-MS system equipped with an $\alpha$-TOF detector

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Toward the precise mass measurement of heavy and superheavy nuclides, the SHE-Mass-II facility1) was constructed with a multi-reflection time-of-flight mass spectrometer (MRTOF-MS)2) coupled with the gas-filled recoil ion separator GARIS-II.3) We installed an $\alpha$-TOF4) detector, which simultaneously records the time-of-flight (TOF) signal and subsequent $\alpha$-decay. In order to demonstrate the $\alpha$-TOF detector, an experiment was performed using the $^{51}$V + $^{153}$Tb reaction. A $^{51}$V beam was accelerated to 6.0 MeV/nucleon by the RIKEN Ring Cyclotron (RRC). The beam energy on the target was reduced by an aluminum degrader to 4.8 MeV/nucleon. The beam impinged upon 460 $\mu$g/cm$^2$-thick $^{153}$Tb targets with a 3 $\mu$m Ti backing, mounted in a rotating target wheel.

The fusion evaporation residues (ERs) were separated from the primary beam and transported using GARIS-II. After decelerating ERs using a Mylar foil, the ERs were stopped in a cryogenic helium gas catcher, and the thermalized ions were extracted by a radio frequency (RF) carpet and transported to the MRTOF-MS via multiple RF ion traps.

We observed ERs, $^{206,207}$Fr, and $^{206,207}$Ra as doubly charged ions. The subsequent $\alpha$-decays were additionally detected by the $\alpha$-TOF detector. Using $^{206,207}$Fr as the isobaric references, the masses of $^{206,207}$Ra were directly determined. The mass excess of $^{206}$Ra was 3540(54) keV, which agrees with the values reported in AME2016.5)

The TOF spectrum for the $A/q = 103.5$ region is shown in Fig. 1. The singles events and $^{207}$Ra decay-correlated events are plotted. In the case of the ground state of $^{207}$Ra, the correlated events of the TOF and the $\alpha$-decay could not be observed, because the incoming rate was higher than the decay rate, while the decay-correlated events were observed in the isomeric state $^{207g}$Ra owing to its short half-life. The energies of the $\alpha$-decay were selected as higher than 7.32 MeV, 2$\sigma$ apart from the centroid of $^{207g}$Ra, to avoid contamination from $^{207a}$Ra.

The peaks of singles $^{207s/m}$Ra$^{2+}$ and decay-correlated $^{207g}$Ra$^{2+}$ were fitted. The shape of the peak was determined by $^{207}$Fr$^{2+}$. The mass excess of $^{207g}$Ra was determined to be 3538(15) keV, and the excitation energy of $^{207m}$Ra was $E_{\text{ex}} = 552(42)$ keV from the $\alpha$-decay correlated TOF spectrum. These values are consistent with those evaluated by $\alpha$-decay spectroscopy.5)

The alpha branching ratio of $^{207m}$Ra was determined from the counting of TOF and $\alpha$-decay events. The spin parity was expected to be 13/2$^+$ based on its single-particle level energy and the analogous reduced alpha width to the neighboring nuclei.

References
5) M. Wang et al., Chin. Phys. C 41, 030003 (2017).