

## Initial effort to resolve isomers in MRTOF-MS via in-trap decay

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The SHE-mass project is a joint effort between KEK and RIKEN with a long-term goal of identifying new superheavy element (SHE) isotopes produced via hot fusion. It makes use of cryogenic-capable, high-purity helium gas cell to convert the energetic (5~50 MeV) evaporation products of fusion reactions into thermal ions. The evaporation products are separated from projectile-like fragments by use of the gas-filled recoil ion separator GARIS-II<sup>1)</sup>. The thermalized ions are transferred to a multi-reflection time-of-flight mass spectrograph<sup>2)</sup> (MRTOF-MS) which can analyze the ions with a mass resolving power of  $R_m > 100\,000$ . The SHE-mass system is described in some detail in<sup>3)</sup>.

In addition to SHE studies, it has been foreseen to use the system to study neutron-deficient isotopes from Po through Pa, where the  $N=126$  shell-closure approaches the proton drip-line. Investigations of these nuclei have mostly been limited to  $\alpha$ -decay studies up to now. However, the vast amount of *known* isomeric states among nuclei in this region casts some doubt on the veracity of  $\alpha$ -decay studies and indicates a need for direct mass measurements.

Most isomeric states in this region have half-lives shorter than 1 ms, significantly shorter than the measurement cycle for MRTOF-MS. Unfortunately, many known isomers in this region have sufficiently long half-lives as to impact MRTOF-MS. Additionally, distinguishing most of these isomers from their ground states requires higher mass resolving power than is currently available from MRTOF-MS.

In the majority of cases, however, the ground state and/or the isomeric state(s) exhibit  $T_{1/2} \ll 10$  s. Thus, by storing the ions in the preparation trap for an extended period before analysis in the MRTOF-MS, the isomer can decay away. We have developed a mathematical framework to use mass measurements at multiple storage times to determine the isomeric ratio and allow for precise determination of ground state masses.

As a first test of this, we used the  $^{165}\text{Ho}(^{48}\text{Ca}, 7n)$  to produce  $^{206}\text{Fr}^{2+}$  ions<sup>4)</sup>. The duration of accumulation in the preparation trap was then varied up to 2.64 s prior to mass analysis. Unfortunately, the charge-exchange lifetime of the  $\text{Fr}^{2+}$  was short compared to the ground state decay lifetime (see Fig. 1), resulting

in a complicated and ongoing analysis to determine the isomeric ratio.

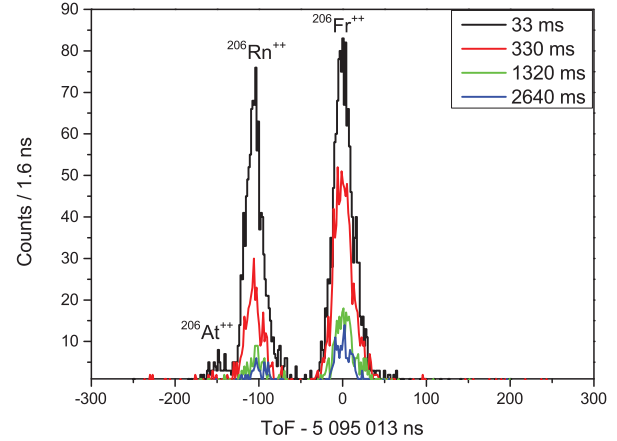


Fig. 1. ToF spectra observed for  $A/q=103$  ions for various accumulation durations. Reductions are presumed to be caused by charge-exchange in the preparation trap.

We can use the relative intensities of observed ions as a function of accumulation time to estimate the charge exchange lifetimes in the preparation trap for doubly-charged ions of a variety of elements, listed in Table 1. The short lifetimes can be expected, as the trap is not UHV clean and operates at room temperature. In the future, we will try to repeat such studies with the traps being cryogenically cooled.

Table 1. Loss half-lives in the preparation trap. IP1 and IP2 are the first and second ionization potentials.

Ion	IP1 [eV]	IP2 [eV]	$T_{1/2}^{decay}$	$T_{1/2}^{loss}$
$^{211}\text{Ra}^{2+}$	5.3	10.14	13.2 s	>2 s
$^{206}\text{Fr}^{2+}$	4.1	22.4	16 s	422(16) ms
$^{207}\text{Fr}^{2+}$	4.1	22.4	14.8 s	414(58) ms
$^{206}\text{Rn}^{2+}$	10.7	21.4	5.67 m	183(14) ms
$^{207}\text{Rn}^{2+}$	10.7	21.4	9.25 m	216(16) ms
$^{206}\text{At}^{2+}$	9.3	17.9	30.6 m	134(32) ms
$^{207}\text{At}^{2+}$	9.3	17.9	1.81 h	157(16) ms

### References

- 1) D. Kaji et al., Nucl. Instrum. and Methods Phys. Res. B, 317 (2013) 311-314.
- 2) P. Schury et al., Nuclear Inst. and Methods in Physics Research B 335 (2014) 39-53.
- 3) P. Schury et al., Phys. Rev. C 95 (2017) 011305(R).
- 4) "Observation of the extraction of  $\text{Fr}^{2+}$  from a cryogenic gas cell", this volume.

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