TRIGA-TRAP: A new facility for high-precision mass measurements on neutron-rich fission products and actinoids

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Introduction: The nuclear mass is one of the most fundamental properties in nature since it reflects all interactions in the nucleus. Therefore, high-precision mass data has its application in many fields of physics, but especially in nuclear astrophysics and nuclear structure studies [1]. The natural abundances of the elements as we observe today can be explained by different nucleosynthesis processes. One of them is the rapid neutron capture process (r-process), which proceeds far away from the stable nuclides in the region of nuclei with neutron excess. Most of them are presently not accessible in experiments, which has triggered the planning of new radioactive beam facilities. The research reactor TRIGA Mainz with the recently installed Penning trap mass spectrometer TRIGA-TRAP [2] already now provides the possibility to extend the limit for high-precision mass measurements towards the r-process nuclides. In off-line experiments samples of actinoids from uranium to californium will be investigated as well. Recently, the masses of the three nobelium isotopes $^{252\text{-}254}$No have been measured at SHIPTRAP (GSI, Darmstadt). Masses of other nuclides above uranium are determined via alpha-decay chains but have not been measured directly. TRIGA-TRAP is besides SHIPTRAP (GSI, Darmstadt) the only facility world-wide, where direct mass measurements of transuranium elements are performed.

Status of the experiment: After initial development at the physics institute, the TRIGA-TRAP mass spectrometer has been relocated and commissioned at beam port B of the TRIGA Mainz. The cryogenic double-Penning trap system has been very precisely positioned in a 7 T superconducting magnet. Two off-line ion sources were brought into operation, which provide stable reference ions like alkalines or carbon clusters [3]. Certain actinoids can be ionized as well by one of these sources. The carbon cluster ions are used for absolute mass calibration, and to perform systematic tests of the Penning trap setup. First measurements have been carried out in the second half of 2008, where cyclotron resonances have been recorded for different cluster sizes up to C_{24}^+ (see Fig 1). Due to comparably high residual gas pressure in the measurement trap, the excitation time, and thus, the line width of the resonance presently limit the achievable relative mass uncertainty to about 10^{-7} using a conventional non-interrupted excitation scheme. By the implementation of time-separated oscillatory fields, which is known as the Ramsey technique [4], the uncertainty could be improved to about 5×10^{-8} for a single measurement sufficient for first mass measurements on actinoid elements. The feasibility of this approach has been demonstrated by performing measurements on several gadolinium isotopes and first data on $^{241}Am^{16}O^+$ ions have been recorded.

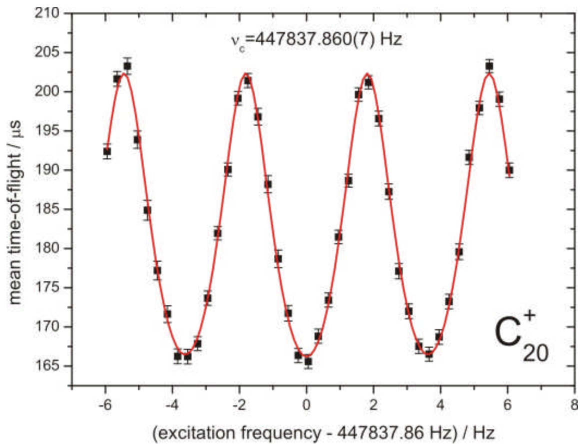

Figure 1. Excitation of C_{20}^+ carbon cluster ions with time-separated oscillatory fields including a fit of the theoretical line shape. The mass value is extracted from the centroid frequency.

Outlook: A new differential pumping-barrier assembly will be implemented in order to suppress the helium buffer gas flow between the preparation trap and measurement trap further. In addition, an ion getter pump will be installed. These improvements will enable extended observation times, thus line widths below 1 Hz could be achieved. Extensive work is undertaken to set-up an ECR source on a high-voltage platform in combination with a carbon aerosol gas jet arrangement in order to have access to fission products from the reactor [5].

We will focus on finalizing and commissioning the non-destructive ion detection system. Having two independent ion detection techniques implemented within the same Penning trap mass spectrometer, TRIGA-TRAP will be unique among the on-line Penning trap mass spectrometers for short-lived nuclides. Ultimately single-ion sensitivity will enable measurements on nuclides with extremely low production rate [6].

References

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