Development of an Ion-mobility Spectrometer for Superheavy Element Research ◇

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Some of the most fascinating studies of the actinides and the transactinides concern the influence of increasingly strong relativistic effects on the valence-electron configuration of the atoms and its consequences on their chemical behavior. Relativistic effects are caused, roughly speaking, by a contraction of the wavefunctions of s- and $p_{1/2}$-electrons. Inner shell electrons influence indirectly via the shielding of the nuclear potential the valence electrons and, thus, the chemical properties as well. Relativistic quantum chemical atomic and molecular codes allow for predictions and descriptions of atomic and molecular properties.
However, direct comparison of the measured quantities with the quantum mechanical observables would represent a microscopic test of these Dirac-Fock calculations. The radial maximum of the wavefunction of the outermost orbital r_{max} and the expectation value $< r^2 >$, are both not only subjected to the above mentioned relativistic contraction but also reflect the electron configuration of the respective atoms and ions [1], see Fig. 1. Thus, systematic studies of r_{max} and $< r^2 >$ of actinides and transactinides will contribute to a better understanding of the electronic structure in strong (nuclear) fields. These observables can be determined by ion-mobility spectrometry, which is a well established technique for investigations of the ion-mobility of stable elements [2]. A drift-time spectrometer [3] is being developed for high-precision studies of the ion-mobility of actinides and transactinides. It consists of a drift cell and a detection system. For further details on the developed spectrometer see reference [4] and references therein.

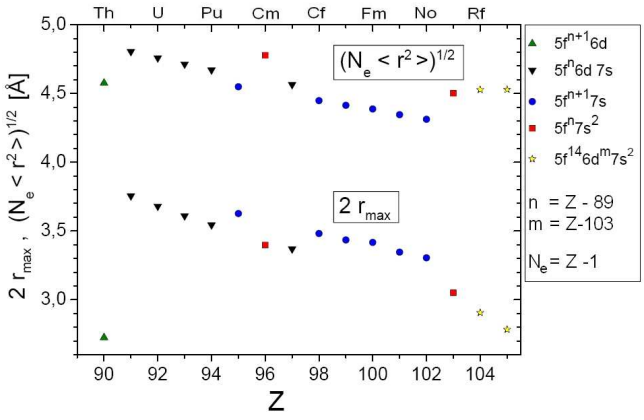

Fig. 1: Maximum of the outermost radial wave function r_{max} and $\sqrt{N_e < r^2 >}$ as function of the charge number Z. Number of electrons in the $5f$-shell $n = Z - 89$ and in the $6d$-shell $m = Z - 103$. Values taken from Ref. [1].

Test experiments, using a radioactive ^{223}Ra source of ⌀ 8 mm, were performed to determine the extraction efficiency and the extraction time of the drift cell. The ^{223}Ra source was mounted inside the buffer gas cell, so that radioactive daughter isotopes recoiling out of the source are stopped as singly charged ions in the argon buffer gas. The ions were guided by a moderate electric field of $E \approx 40$V/cm towards the extraction nozzle. After extraction the ions were deposited onto a PIN diode, which was placed 1 mm behind the nozzle. The number of deposited ions was detected via their subsequent α-decay. Due to its short half-life $t_{1/2} = 1.78$ ms, all measurements were performed at ^{215}Po, the second decay daughter of ^{223}Ra. The extraction time of the drift cell depends on the electric field and the buffer gas pressure inside the drift cell as well as on the starting position of the ions. At moderate electric fields and a fixed source nozzle distance of 79 mm, a linear dependence of the extraction time t_{ex} on the buffer gas pressure has been observed, see Fig. 2. Further, the mobility of $^{215}Po^+$ ions is found to be (1.9 ± 0.1) cm^2/Vs by assuming a homogenous electric field inside the cell. The extraction efficiency is a crucial parameter of buffer-gas cells for the production of low-energy radioactive beams produced by fusion-evaporation reactions. In the performed test experiments, the extraction efficiency ε_{ex} has been determined as function of the buffer gas pressure. It increases with the buffer gas pressure up to (57 ± 10) % at 80 mbar, which reflects the increasing friction force of the buffer gas jet needed for ion extraction.

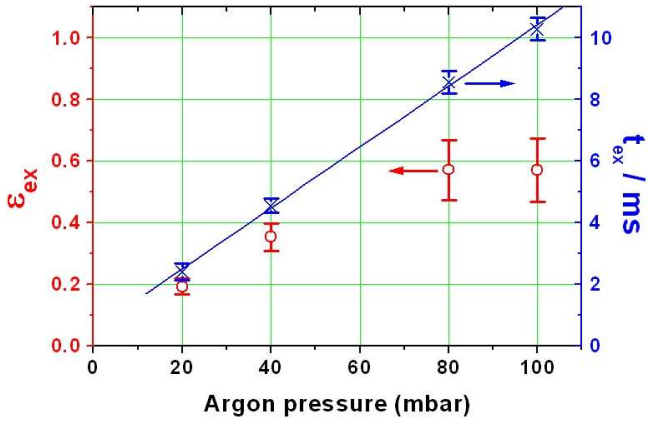

Fig. 2: Drift time and extraction efficiency of $^{215}Po^+$ ions at different buffer gas pressures and moderate electric fields. The source-nozzle distance was fixed at 79 mm. In the calculation of ε_{ex}, the escape and neutralization efficiencies of Po^+ into the buffer gas were assumed to be 14.5 % and 0 %, respectively.

The developed drift cell will be coupled to an existing mass selective detection system. For the first time, drift time measurements with a precision of $\frac{\Delta t}{t} < 0.01$ will be feasible at actinides and short-lived transactinides. At first, systematic studies will be carried out using filaments and laser resonance ionization. Two suitable laser systems consisting of excimer laser-pumped dye lasers have already been installed. First on-line test experiments will be performed at the MLL-tandem accelerator.

References

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