

Research Group for Superheavy Elements

Group Leader : Matthias Schädel

Members : Kazuaki Tsukada, Masato Asai, Atsushi Toyoshima, Tetsuya Sato
Yusuke Kaneya, Sunao Miyashita, Yuichiro Nagame

The research objectives of this group are to understand chemical and nuclear properties of superheavy elements (SHEs) placed at the uppermost end of the Periodic Table and on the heaviest frontier of the nuclear chart. To clarify the chemical properties of SHEs, we investigate valence electronic structures of SHEs through experimental determinations of ionization potentials, redox potentials, and compound formations of SHEs. To elucidate the limits of stability of the heaviest nuclei, we investigate the shell structure of superheavy nuclei through experimental assignments of proton and neutron single-particle orbitals and through the evolution of nuclear deformation at the highest proton and neutron numbers. Examples for the progress in FY2013 are reported in the following.

Measurement of the $\text{Md}^{3+}/\text{Md}^{2+}$ reduction potential studied with the flow electrolytic chromatography

Relativistic effects are strongly affecting ground-state electron configurations of the heaviest elements. For the actinides, theoretical calculations predict that the relativistic expansion of the inner 5f orbital contributes to the actinide contraction. These changes of relativistic origin influence binding energies of valence orbitals and the stabilities of electron configurations. It is, however, difficult to directly measure energetic levels of the heaviest actinides with atomic number > 100 by any spectroscopic method as these elements are not available in macro amount. Redox reactions between the divalent and trivalent oxidation states on the actinides are related to the energies of the electron transitions between the $5f^{n-1}6d7s^2$ and $5f^n$ states. This indicates that redox potentials of actinides help providing information on the relative stabilities of the 5f orbital and other electron configurations.

Recently, we have developed a novel method of electrolytic column chromatography available for single ions. Carbon fibers modified with Nafion perfluorinated ion-exchange resin were employed as a working electrode as well as a cation-exchanger. This technique was successfully applied to the oxidation of nobelium (No) [1]. In this present report, the reduction potential of Md was determined with similar electrolytic column chromatography [2].

The isotope ^{255}Md (half-life, $t_{1/2} = 27$ min) was produced in the irradiation of a ^{248}Cm target with ^{11}B beams at the JAEA tandem accelerator. Attached to tiny KCl particles in a He gas stream, nuclear reaction products, recoiling out of the target, were transported to a chemistry laboratory. After collection, trivalent actinide ions including Md were chemically separated from KCl with a chromatographic HDEHP column in 0.1 M HCl. Subsequently, a dried sample was dissolved with 0.10 M HCl. This solution was then fed with 0.10 M HCl into a Nafion electrode column. Potentials between -0.3 and -0.9 V vs. a Ag/AgCl reference electrode (SSE) in 1.0 M LiCl were applied. To determine the elution position of Md, the effluent from the Nafion electrode was collected on eight Ta discs and evaporated to dryness. Remaining products were then stripped with 3.0 M HCl and were also collected and dried. Alpha particle

measurements started ~ 12 min with passivated implanted planar silicon detectors.

In Figure 1, reduction probabilities of Md and Eu are shown as a function of the applied potential. From the applied potential at 50% reduction probability, formal reduction potentials of the $\text{Md}^{3+} + e^- \rightarrow \text{Md}^{2+}$ and $\text{Eu}^{3+} + e^- \rightarrow \text{Eu}^{2+}$ couples were evaluated to be -0.40 ± 0.03 V and -0.70 V vs. a SSE, respectively. Applying the SSE versus a normal hydrogen electrode (NHE) relationship as well as the correction with a linear relationship between our measured formal potentials with standard potentials, we obtain -0.16 ± 0.05 V vs. a NHE for the reduction potential of Md. The present result helps to validate and improve empirical models and it provides an opportunity to test model calculations based on modern relativistic quantum-chemical treatments.

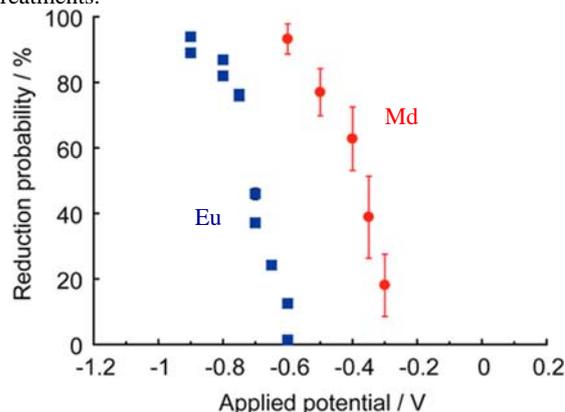


Fig.1 The reduction probabilities of Md(III-II) and Eu(III-II) studied with a flow electrolytic chromatography apparatus.

Spectroscopy of element 115 decay chains

An international team created a few short-lived atoms of element 115 at the GSI Helmholtz Center for Heavy Ion Research in Germany by bombarding a ^{243}Am target with ^{48}Ca beams [3]. Thirty correlated α -decay chains were detected and a high-resolution α , x-ray, and γ -ray coincidence spectroscopy experiment was conducted. The events are consistent with previous assignments of similar decay chains to originate from element $Z=115$ [4]. This includes first candidates for Z fingerprinting the decay of Mt by means of characteristic K-x ray detection along α -decay chains anticipated to start from element $Z=115$. There is potential for direct determination of the atomic number of the decay products of superheavy elements. This paper was selected among “the Top Ten Physics Newsmakers of 2013” by APS News.

References

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