

Research Group for Superheavy Elements

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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.

The highlight of our program in 2014 was the first-time measurement of the first ionization potential of lawrencium (Lr, $Z = 103$) [1]. Lr is the heaviest actinide element and is located at the transition into the SHEs. The result clearly reveals, in agreement with theoretical expectations, that the valence electrons of Lr are most weakly bound. The new findings have been presented in the Nature magazine and are also presented as a highlight at this annual report. This signature confirms the end of the actinide series at element 103 and validates the architecture of the periodic table in this region, where relativistic effects play a crucial role. In addition, the extraction and reduction behavior of Mo and W, lighter homologs of seaborgium (Sg, $Z = 106$), was studied in continuous on-line experiments at the JAEA tandem accelerator to develop a new chemistry assembly consisting of a membrane degasser (MDG), a flow electrolytic column (FEC), and the continuous liquid-liquid extraction apparatus (SISAK). Extraction yields of Mo and W from 0.1 M HCl/0.9 M LiCl into 4-isopropyltropolone (hinokitiol, HT) in toluene were investigated. In reduction experiment, Mo(VI) was successfully reduced to a lower oxidation state while W(VI) showed no reduction under the given conditions [2].

In the extremely demanding field of SHE chemistry and physics, worldwide unique and high-risk forefront experiments can only be performed in international collaborations. We actively initiated and participated in experiments to contribute the unique and sometimes crucial experience. In return, such collaborations extended the range of our own experimental possibilities and gave us a world-wide perspective. Our role in international collaborations revealed new perspectives which will be of importance in the future. In the context of pushing and probing the limits of existence and production of SHEs, a collaborative experiment was performed which successfully confirmed earlier reports on the synthesis of element 117 produced in the reaction of ^{48}Ca on ^{249}Bk [3]. Two decay chains consisting of seven α decays and a spontaneous fission were identified and assigned to the isotope $^{294}117$ and its decay products. In addition, the hitherto unknown α -decay of ^{270}Db ($Z = 105$) was observed. The identification of the long-lived ($T_{1/2} \approx 1.0$ h) α -emitter ^{270}Db was an important step towards the observation of even long-lived nuclei of superheavy

elements. This paper was selected among “the Top Ten Physics News Stories in 2014” by APS News.

Synthesis and detection of a Seaborgium carbonyl complex

Essential for one of the most recent highlight in SHE chemistry [4] was the joint effort of an international collaboration. Based on preparatory studies [5], the international team achieved the synthesis of a new class of chemical compounds for SHEs. For the first time, a chemical bond was established between a superheavy element – Sg in the present study – and a carbon atom. One atom-at-a-time, a total of 18 atoms of Sg formed seaborgium hexacarbonyl complexes; each one having six carbon monoxide molecules bound to a neutral seaborgium atom. Its volatility and its adsorption on a silicon dioxide surface were studied (Fig. 1), and were compared with properties of similar compounds of the lighter homologs of seaborgium in the same group of the Periodic Table. This study opened up the path towards the completely new field of metal-organic compounds of SHE. The first synthesis and investigation of $\text{Sg}(\text{CO})_6$ establishes perspectives for much more detailed investigations of the chemical behavior of elements at the end of the Periodic Table, where the effects of relativity on chemical properties is most pronounced.

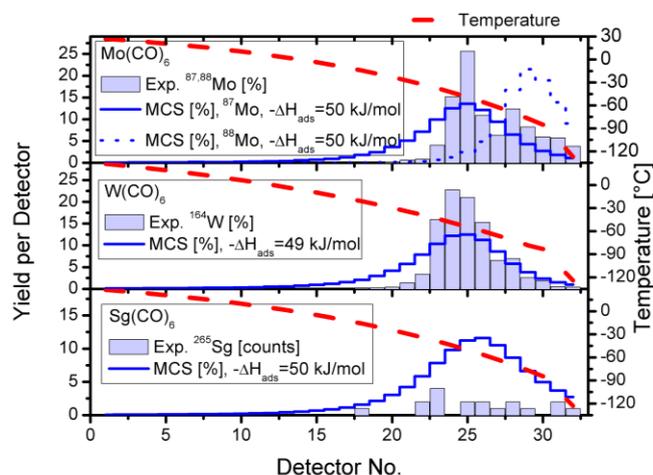


Fig.1 Deposition patterns of volatile hexacarbonyl complexes of Mo, W, and Sg along the negative temperature gradient of the thermochromatography detector COMPACT; Courtesy J. Even, see [4] for more details.

Reference.

- [1] T. K. Sato *et al.*, Nature **520**, 209 (2015).
- [2] A. Toyoshima *et al.*, J. Radioanal. Nucl. Chem, **303**, 1169 (2015).
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- [5] J. Even *et al.*, Inorg. Chem. **51**, 6431 (2012).