Unravelling Relativistic Effects in the Heaviest Actinide Element

The first-time measurement of the first ionization potential of lawrencium (element 103)

An international collaboration led by the research group of superheavy elements at Japan Atomic Energy Agency (JAEA), Tokai, Japan has achieved the ionization potential measurement of lawrencium (element 103) with a novel-type technique at the JAEA tandem accelerator. The international team consists of research groups from JAEA, the Institute for Nuclear Chemistry at the Johannes Gutenberg University (JGU) Mainz, Germany, the Helmholtz Institute Mainz (HIM), Germany, the GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany, the European Organization for Nuclear Research (CERN), Geneva, Switzerland, Ibaraki University, Japan, Niigata University, Japan, Hiroshima University, Japan, Massey University, Auckland, New Zealand, and Tel Aviv University, Israel.

Based on the empirically developed "actinide concept", and in agreement with theoretical calculations, in today's Periodic Table the series of actinide elements terminates with element 103, lawrencium (Lr). We have measured the first ionization potential of Lr which reflects the binding energy of the most weakly-bound valence electron in lawrencium's atomic shell. Effects of relativity strongly affect this energy, and our experimental result is in excellent agreement with a new theoretical calculation, which includes these effects. We show that removing the outermost electron requires least energy in Lr among all actinides, as was expected. This validates the position of Lr as the last actinide element and confirms the architecture of the Periodic Table.

Since the introduction of the "actinide concept" as the most dramatic modern revision of the Periodic Table of the Elements by Glenn T. Seaborg in the 1940s, the element with atomic number 103, lawrencium (Lr), played a crucial role as the last element in the actinide series. This special position turned out to set this element into the focus of questions on the influence of relativistic effects and the determination of properties confirming its position as the last actinide element. Consequently, the quest for data on chemical and physical properties of Lr was driving experimental and theoretical studies. Two aspects most frequently addressed concerned its ground state electronic configuration and the value of its first ionization potential. As the last element in the actinide series, and similar to Lu as the last element in the lanthanide series, it was expected that Lr has a very low first ionization potential that is strongly influenced by relativistic effects.

However, Lr is only accessible atom-at-a-time in syntheses at heavy-ion accelerators, and only short-lived isotopes are known. Therefore, experimental investigations on Lr are very rare and, so far, were limited to a few studies of some basic chemical properties. In our work, for which we exploited our novel combination and advancement of methods and techniques, we report on the first and accurate measurement of the first ionization potential of Lr. This is complemented by a state-of-the-art theoretical work devoted to this property as well as to the ground state electronic configuration. The very good agreement between calculated and experimental result validates our quantum chemical calculations. Our experimental technique opens up new perspectives for similar studies of yet more exotic, superheavy elements.

The new findings have been presented in the Nature magazine (Tetsuya K. Sato et al., Nature XX (2015) YYYYYY).

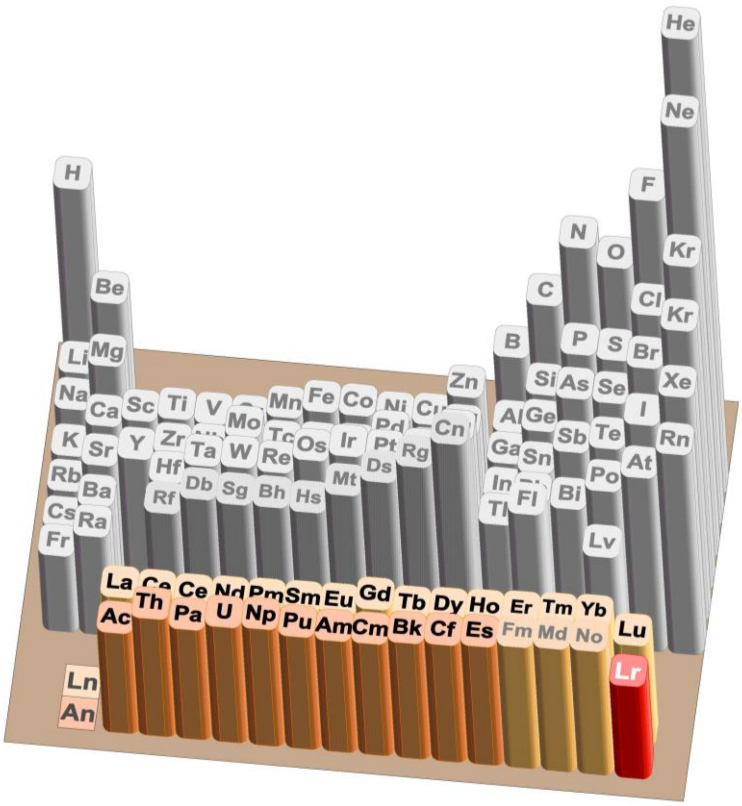

Fig. 1 Periodic Table of the Elements (Ln: Lanthanides, An: Actinides). Bar sizes reflect the energies of the first ionization potentials. The result for Lr in our first time measurement is shown in red. The binding energy of the least bound valence electron of Lr, measured through its ionization potential, is weaker than in its homolog Lu and weaker than any other chemical element except group-1 elements heavier than Na.

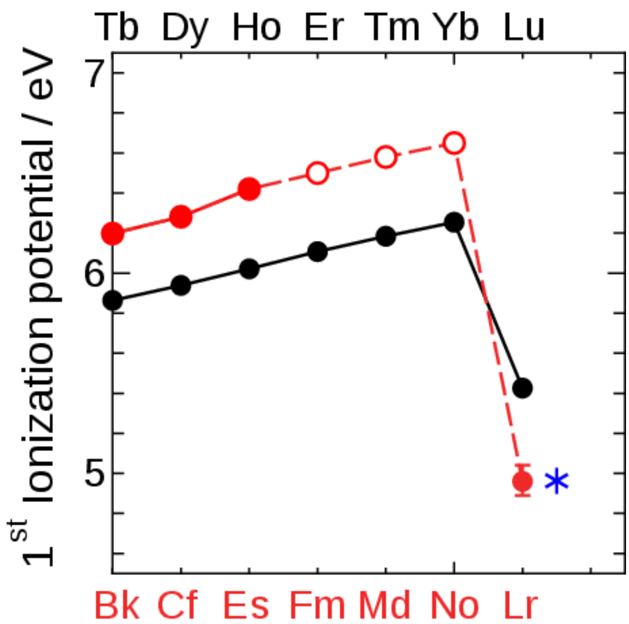

Fig. 2 Ionization potential of heavy lanthanides (black symbol) and actinides (red symbol) including our present results for Lr. A closed and open symbol indicates an experimental and estimated value, respectively. The blue star * depicts the present theoretical value for Lr demonstrating the excellent agreement between theory and experiment.

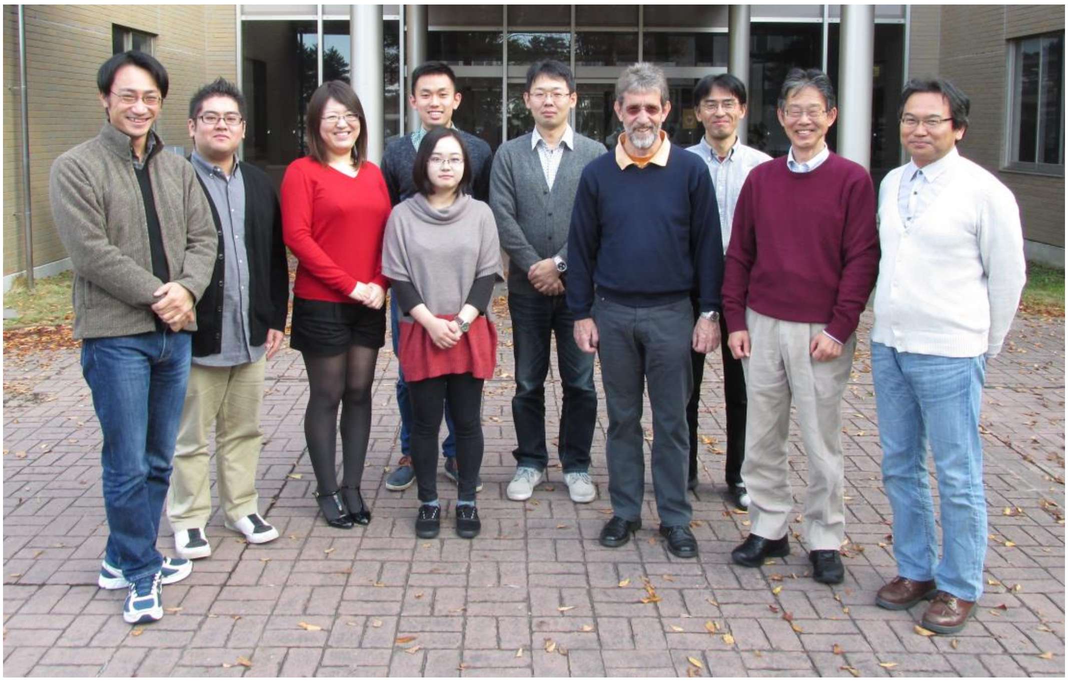

Fig. 3 Research group for superheavy elements at the Advance Science Research Center (ASRC) of the Japan Atomic Energy Agency (JAEA), Tokai.

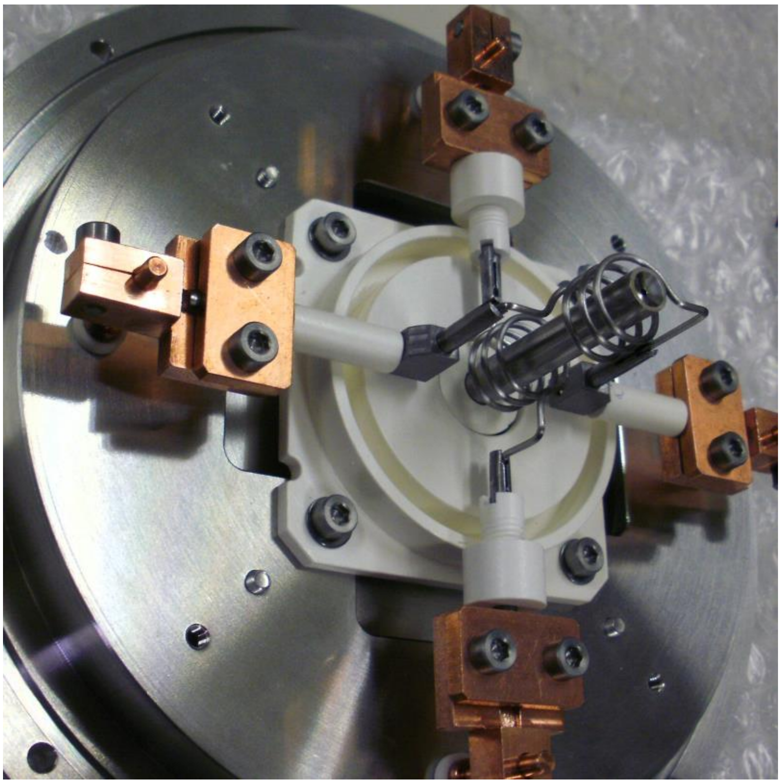

Fig. 4 Ionizer cavity (the grey Tantalum crucible in the centre of the photo surrounded by two heating filaments) of the newly developed surface ion-source installed in the JAEA-ISOL system at the JAEA Tandem in Tokai, Japan.