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Measurement of the First Ionization Potentials of Short-lived Lanthanides Using a Surface Ionization Method

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The first ionization potential (IP) directly reflects a valence electronic configuration influenced by relativistic effects which are significantly noticeable for heavy elements. Information on IP of heavy elements, therefore, gives us a better understanding of relativistic effects. IPs of heavy actinides with atomic number Z > 100, however, have not been measured by conventional techniques, such as resonance ionization mass spectrometry (RIMS), because these elements are only available in non-weighable quantities down to the one-atom-at-a-time scale. This condition forces us to call for a different experimental approach.
Here, we have focused on a surface ionization process. Since the surface ionization process takes place between an atom and a metal surface, this method is applicable to one-atom-at-a-time scale experiments. In fact, we ionized and mass-separated short-lived isotopes using the surface ionization method installed in the JAEA-ISOL system [1]. Further improvement of the surface ionization type ion-source has been recently applied to measure the IP of lawrencium (Lr, Z = 103). 27-s 256Lr produced in the 249Cf + 11B reaction was successfully ionized [2]. The IP measurement of Lr is now under way.
In this work, we measured ionization efficiencies of various short-lived lanthanides and evaluated their IPs, as a test experiment for measurement of IPs of heavy actinides.
Short-lived lanthanides, 143mSm, 143Eu, 148mTb, 154Ho, 157Er, and 165Yb, were produced by the irradiation of a 67.9- MeV 11B4+ beam delivered from the JAEA tandem accelerator on 136Ce / 141Pr / 159Tb and 142Nd / 147Sm / natEu targets. Short-lived 168Lu was also produced in the reaction of 162Dy with a 11B4+ beam. Nuclear reaction products recoiling from the targets were transported to the ion-source of the JAEA-ISOL set up by a He/CdI2 gas-jet transport system. The products were ionized in the ion-source, accelerated with 30 kV, mass-separated, and collected on an aluminized Mylar tape. The amounts of the collected ions were determined by gamma-ray measurement with a HP-Ge detector. To calculate ionization efficiencies, the amounts of the transported products were also determined by direct collection using a separate catcher system.
IPs of various short-lived lanthanides are evaluated based on the following Saha-Langmuir equation:
α= n_i/n_0 =exp((φ-IP)/kT) ,
where n_i and n_0 indicate the number of ions and that of atoms on a metal surface, respectively. T, k, and φ are the absolute temperature of the metal surface, the Boltzmann constant, and the work function of the specific metal surface, respectively. The experimental ionization efficiency β is expressed by using the α as follows:
β= n_i/(n_0+n_i)= α/(α+1) .
Obtained IP values of short-lived lanthanides with tracer scale atoms were compared with literature values measured with macro-scale amounts of these elements.

[1] S. Ichikawa, et al., Nucl. Instr. and Meth. A 374, 330 (1996).
[2] T. K. Sato, et al., Rev. Sci. Instrum. 84, 023304 (2013).

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