Lawrencium's place at the table

Yuichiro Nagame ponders on the steps it took to make lawrencium, and its location in the periodic table.

The discovery — or, rather, the synthesis — of lawrencium spanned several years and several experiments from two research teams, in Berkeley, USA, and in Dubna, Russia¹. In 1961, the US-based team first reported the synthesis of an isotope of element 103. Mixed californium isotope targets $^{249,250,251,252}\text{Cf}$ were bombarded with boron beams; the reaction products were caught by a metalized Mylar tape and moved past a series of α -particle detectors. A new α -emitting nuclide with an energy of 8.6 MeV and a half-life of approximately 8 s was assigned to the isotope ^{257}Lr .

Subsequent identification of element 103 — though one that conflicted with the mass assignment of the Berkeley team — came from Dubna in 1965, from bombarding a ^{243}Am target with a beam of ^{18}O ions. After sustained efforts on both sides, conclusive identification of isotopes with mass numbers 255 through 260 finally came from Berkeley in 1971, from bombardments of ^{248}Cm with ^{14}N and ^{15}N ions, and ^{249}Cf with ^{10}B and ^{11}B ions. These results also confirmed most of the previous reports, apart from the identification of the first isotope created, which was in fact ^{258}Lr .

The recognition of the new element also occurred in several steps. It was the Berkeley team who suggested the name lawrencium, with the symbol *Lw*, in honour of Ernest O. Lawrence, inventor of the cyclotron particle accelerator (pictured). The International Union of Pure and Applied Chemistry (IUPAC) approved the name in 1971, though changed the symbol to *Lr*. In 1992, however, a Transfermium Working Group set up by IUPAC and IUPAP (International Union of Pure and Applied Physics) re-evaluated all the reported data and recommended that both the Berkeley and the Dubna teams should share credit for the discovery of element 103 (ref. 2), leading to their official recognition as co-discoverers in 1997. The name, by then commonly accepted, remained unchanged.

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At present, twelve isotopes are known with mass numbers 252–262 and 266 — the longest-lived one with a half-life of 11 h — as well as two metastable nuclear isomers with mass numbers 253 and 255.

Chemical studies of heavy elements with atomic numbers $Z \geq 100$ are extremely difficult because the atoms exhibit short half-lives and must be produced at accelerators, in quantities of a few atoms, or often even one atom, at a time. Thus experimental procedures must be repeated hundreds or thousands of times to give statistically significant results. The first chemical characterization came with ^{256}Lr as early as 1970, through a fast solvent extraction technique¹. Over 200 individual experiments, overall involving approximately 1,500 lawrencium atoms, showed that it exhibits a stable +3 oxidation state in solution, as expected for an actinide. The ionic radius of Lr^{3+} was first evaluated in 1988 through cation-exchange chromatography with the longer-lived isotope ^{260}Lr , and its accuracy was later improved to 0.0881 ± 0.0001 nm.

According to the actinide concept formulated by Seaborg, which placed the 5f elements ($Z = 89$ –103) in the periodic

table as a new transition series directly below the lanthanides, lawrencium is the last of the actinides and sits directly under lutetium. Yet despite — or owing to — recent advances in understanding lawrencium and lutetium, a debate³ has emerged over their place in the table: is it in the *f*-block, *d*-block or *p*-block?

By analogy with lutetium, which has an electronic structure of $[\text{Xe}]4f^{14}6s^25d^1$, the electronic configuration of lawrencium would be expected to be $[\text{Rn}]5f^{14}7s^26d^1$. These configurations may place both elements below scandium and yttrium in the *d*-block — a move supported by some chemical similarities between the four elements. Because of relativistic effects, however, the $7p_{1/2}$ orbital of lawrencium is expected to be stabilized below the $6d$ orbital, giving instead a revised configuration of $[\text{Rn}]5f^{14}7s^27p_{1/2}^1$, which suggests it would also not be out of place in the *p*-block.

Recently, in our group, the first ionization energy of lawrencium was measured using an efficient surface ion-source and a single-atom detection system coupled to a mass separator⁴. A surprisingly low energy of 4.96 eV — lower than that of sodium — was found to be required to remove one electron from a neutral atom. This makes element 103 the easiest actinide to ionize, and is in excellent agreement with the predicted $[\text{Rn}]5f^{14}7s^27p_{1/2}^1$ configuration.

Nevertheless, these measurements can be taken to support lawrencium's place as an *f*-block actinide, a *d*-block transition metal or a *p* element, such that they have not allowed the question of its location to be unambiguously settled, and lawrencium continues to create controversies. □

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