Moscovium and Nihonium: FIONA measures the mass number of two superheavy elements

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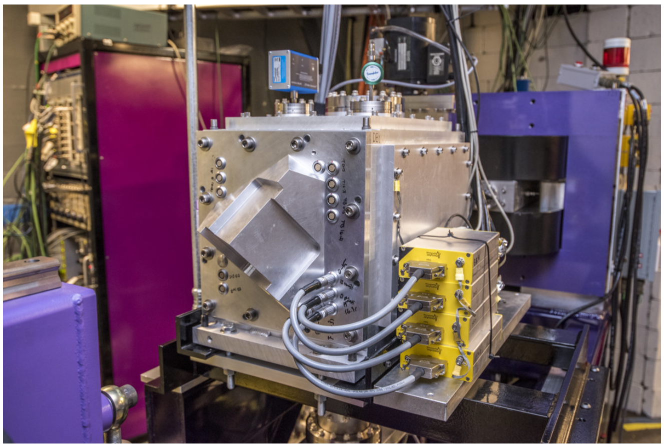


A view of FIONA's instrumentation. Credit: Marilyn Chung/Berkeley Lab

A team led by nuclear physicists at the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) has reported the first direct measurements of the mass numbers for the nuclei of two superheavy elements: moscovium, which is element 115, and nihonium, element 113.

They obtained the results using FIONA, a new tool at Berkeley Lab that is designed to resolve the nuclear and atomic properties of the heaviest elements. The results are detailed in the Nov. 28 edition of the *Physical Review Letters* journal.

FIONA is an acronym that means: "For the Identification Of Nuclide A," with "A" representing the scientific symbol for an element's mass number—the total number of protons and neutrons in an atom's nucleus. Protons are positively charged and the proton count is also known as the atomic number; neutrons have a neutral charge. Superheavy elements are human-made and have a higher atomic number than those found in naturally occurring elements.

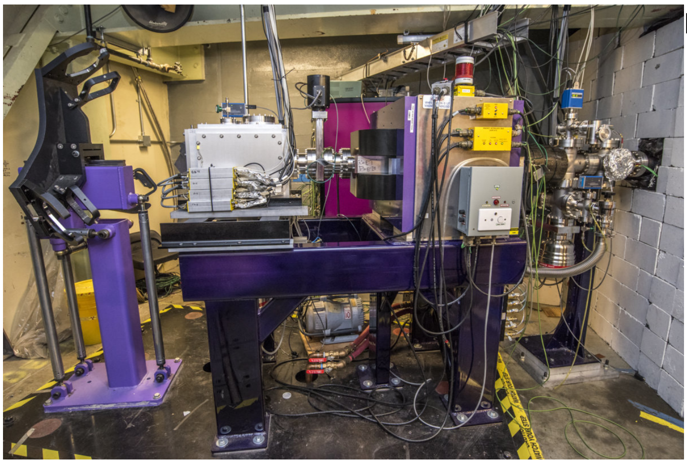
The global rush for mass numbers

Gathering and validating this first data from FIONA had been a top priority for the Lab's 88-Inch Cyclotron and Nuclear Science Division since FIONA's commissioning wrapped up in early 2018. Cyclotron staff worked with visiting and in-house scientists to conduct FIONA's first experimental run, which spanned five weeks.

"It is very exciting to see FIONA come online, as it is extremely important to pin down the masses of superheavy elements," said Barbara Jacak, Nuclear Science Division director. "Until now the mass assignments have been made with circumstantial evidence rather than by direct measurement."

Jackie Gates, a staff scientist in Berkeley Lab's Nuclear Science Division who played a leading role in the conception, construction, and testing of FIONA, and who leads FIONA's mass-number-determination efforts, said, "There has been a lot of interest in making an experimental measurement of superheavy mass numbers."

Gates added that this effort to measure superheavy elements' mass numbers is of global interest, with teams from Argonne National Laboratory and Japan's nuclear research program among those also making mass measurements of superheavy elements using slightly different approaches or tools.



FIONA is a new system at Berkeley Lab's 88-Inch-Cyclotron that enables direct mass number measurements of superheavy elements. Credit: Marilyn Chung/Berkeley Lab

Guy Savard, a senior scientist at Argonne National Laboratory, designed, built, and contributed several components for FIONA. He also aided in the commissioning of FIONA and in its first scientific campaign.

Roderick Clark, a senior scientist in Berkeley Lab's Nuclear Science Division, said, "Everyone is coming together in this grand race. This can open up a whole range of physics of these heavy and superheavy samples," as well as new studies of the structure and chemistry of these exotic elements, and a deeper understanding of how they bond with other elements.

"If we can measure the mass of one of these superheavy elements, you can nail down the entire region," Clark said.

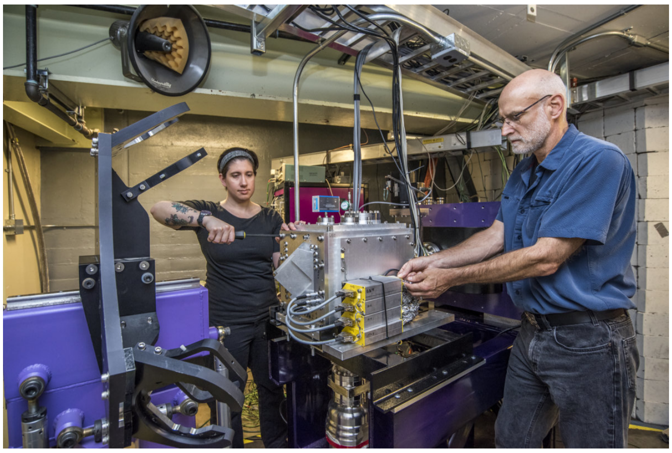
A new chapter in heavy element research

The mass number and atomic number (or "Z") - a measure of the total number of protons in an atom's nucleus—of superheavy elements have relied on the accuracy of nuclear mass models. So it's important to have a reliable way to measure these numbers with experiments in case there is a problem with models, noted Ken Gregorich, a recently retired senior scientist in Berkeley Lab's Nuclear Science Division who worked closely with Gates to build and commission FIONA.

For example, superheavy elements could possibly exhibit unexpected nuclear shapes or densities of protons and neutrons that aren't accounted for in the models, he said.

Berkeley Lab has made enormous contributions to the field of heavy-element research: Lab scientists have played a role in the discovery of 16 elements on the periodic table, dating back to the synthesis of neptunium in 1940, and have also supplied hundreds of isotope identifications. Isotopes are different forms of elements that share the same number of protons but have a different number of neutrons in their nuclei.

FIONA (see related article) is an add-on to the Berkeley Gas-filled Separator (BGS). For decades, the BGS has separated heavy elements from other types of charged particles that can act as unwanted "noise" in experiments. FIONA is designed to trap and cool individual atoms, separate them based on their mass and charge properties, and deliver them to a low-noise detector station on a timescale of 20 milliseconds, or 20 thousandths of a second.



Jackie Gates, left, and Ken Gregorich, work on FIONA during its early commissioning in 2017. Credit: Marilyn Chung/Berkeley Lab

'One atom a day'

"We can make one atom a day, give or take," of a desired superheavy element, Gregorich noted. In its early operation, FIONA was specifically tasked with trapping individual moscovium atoms. "We have about a 14 percent chance of trapping each atom," he added. So researchers had hoped to capture a single measurement of moscovium's mass number per week.

Moscovium was discovered in 2015 in Russia by a joint U.S.-Russian team that included scientists from Lawrence Livermore National Laboratory, and the discovery of nihonium is credited to a team in Japan in 2004. The element names were formally approved in 2016.

To produce moscovium, scientists at the 88-Inch Cyclotron bombarded a target composed of americium, an isotope of an element discovered by Berkeley Lab's Glenn T. Seaborg and others in 1944, with a particle beam produced from the rare isotope calcium-48. The needed half-gram of calcium-48 was provided by the DOE Isotope Program.

There is a distinct looping signature for each atom trapped and measured by FIONA—a bit like watching a fixed point on a bicycle tire as the bicycle rolls forward. The trajectory of this looping behavior is related to the atomic "mass-to-charge ratio—the timing and position of the energy signal measured in the detector tells scientists the mass number.

Ideally, the measurement includes several steps in the particle's decay chain: Moscovium has a half-life of about 160 milliseconds, meaning an atom has a 50 percent chance to decay to another element known as a "daughter" element in the decay chain every 160 milliseconds. Capturing its energy signature at several steps in this decay chain can confirm which parent atom began this cascade.

"We have been trying to establish the mass number and the proton number here for many years now," said Paul Fallon, a senior scientist in Berkeley Lab's Nuclear Science Division who leads the division's low-energy program. Detector sensitivity has steadily improved, as has the ability to isolate individual atoms from other noise, he noted. "Now, we have our first definitive measurements."

Confirming the mass numbers of element 113 and element 115

In FIONA's first scientific run, researchers identified one moscovium atom and its related decay daughters, and one nihonium atom and its decay daughters. The measurements of the atoms and the decay chains confirm the predicted mass numbers for both elements.

While researchers had been seeking only to create and measure the properties of a moscovium atom, they were also able to confirm a measurement for nihonium after a moscovium atom decayed into nihonium before reaching FIONA.

"The success of this first measurement is incredibly exciting," said Jennifer Pore, a postdoctoral fellow who was involved in FIONA's commissioning experiments. "The unique capabilities of FIONA have sparked a new renaissance of superheavy element research at the 88-Inch Cyclotron."

Gregorich credited the efforts of staff at the 88-Inch Cyclotron—including mechanical, electrical, operations, and control systems experts—for maximizing FIONA experimental time during its initial five-week scientific run.

He noted particular contributions from other BGS and FIONA group members, including Greg Pang, a former project scientist who was involved in FIONA's construction and testing; Jeff Kwarsick, a graduate student whose Ph.D. thesis is focused on FIONA results; and Nick Esker, a former graduate student whose Ph.D. work focused on the mass separator technique incorporated by FIONA.

Plans for new measurements and the addition of 'SHEDevil'

Fallon said that another scientific run is planned for FIONA within the next six months, during which nuclear physics researchers may pursue a new round of measurements for moscovium and nihonium, or for other superheavy elements.

There are also plans to install and test a new tool, dubbed "SHEDevil" (for Super Heavy Element Detector for Extreme Ventures In Low statistics) that will help scientists learn the shape of superheavy atoms' nuclei by detecting gamma rays produced in their decay. These gamma rays will provide clues to the arrangement of neutrons and protons in the nuclei.

Provided by Lawrence Berkeley National Laboratory

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