Complete-ium!

Race to the end of period 7

BY **DAVE SAMMUT**

Four more superheavy elements have made it to the periodic table, but what evidence did their creators need to get them there?

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Science is celebrating the creation of four new elements. On the cusp of New Year's Eve 2015, IUPAC's Joint Working Party announced its decision on the discovery and priority of elements 113, 115, 117 and 118, and global joy erupted in fireworks the very next day.

Chemists are, of course, delighted to hear that period 7 of the periodic table is now complete – a delight somewhat tempered by the knowledge that we're going to have to buy a new edition of *SI chemical data* now, and again when the elements are actually named.

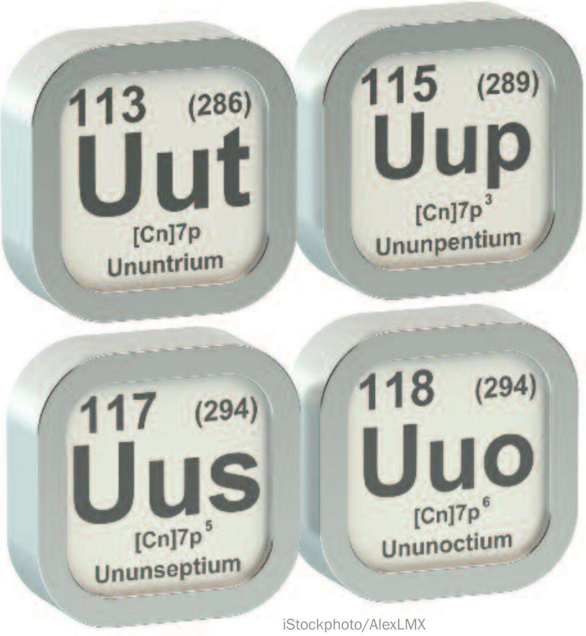
My first response was, of course, 'how?' How were these new elements created? How can we even tell? How do these new elements behave?

Creation and competition

My high school chemistry teacher once likened subatomic particle physics to 'crashing two cars into each other at really high speed, then trying to work out what they're made of by looking at what falls off'. In simple terms, the science of creating these synthetic new superheavy elements is pretty similar. We crash two atomic cars into each other at some fraction of the speed of light, and hope that if they stick together for just long enough they'll fuse into a new atomic truck … *then* we look at the bits that start falling off.

The creation of ununtrium (Uut, atomic number 113) is a perfect case in point. It was claimed in 2003 from the Joint Institute for Nuclear Research (JINR) in Dubna, Russia (via a collaborative project with the Lawrence Livermore National

Laboratory (LLNL) in California USA), based on the production of element 115 by bombarding an americium target with high-energy calcium particles, where the new atoms then quickly decayed to element 113.



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The problem was that this element 113 atom then fissioned directly (rather than decaying to already known isotopes), and therefore did not meet the criteria set down by IUPAC that the new atom must demonstrate 'firm connections to known nuclides'. Falling back on the analogy, the truck fell apart again into a couple of wrecked cars before someone could read the license plate.

The JINR/LLNL team then claims that over the subsequent years, it has produced element 113 'about 100' times across five different isotopes, and that this is sufficient evidence for their joint discovery with the Americans. IUPAC disagreed.

A group at the RIKEN facility in Japan claimed the discovery of element 113 in 2004 via the bombardment of a bismuth target with zinc. Their atom had the advantage of decaying via a series of alpha emissions to an 'anchor' element (a known isotope), which comes closer to satisfying IUPAC's criteria for the 'discovery' of a new element. However, the RIKEN facility produced only two atoms, then spent another seven years trying fruitlessly to repeat their results. They only succeeded in 2012; hence the fact that the element has only now been ratified, 13 years since it was first claimed by either side.

Press comments from the groups in response to the IUPAC announcement pretty strongly indicate competitive feelings. The RIKEN team expressed pride in discovering element 113; so too the Livermore group, in being credited with the collaborative discovery of 115, 117 and 118 (oh, and also finding 113 first). The JINR team was more blunt – what I read between the lines was 'not only did we find 113 first, but we produced much more of it, ours lasted longer and we taught the Japanese team leader everything he knows. So there [tongue poke].'

Detecting the new elements

The next obvious question is how they even detect just one atom of a new element. The high-energy particles are bombarded onto static metal targets. These targets are extremely thin, so the new particles are basically 'knocked free' following the collision. Remember, those particles are coming at a decent fraction of the speed of light. Coming off as charged particles, the target atoms are separated in gas-filled separators based on the average charge state and momentum via dipole/quadropole controls and magnetic fields – the same principles as mass spectroscopy.

Two main types of silicon radiation detectors are used in superheavy element research: those working on the principle of charge separation (resistive strip passivated implanted planar silicon (PIPS) detectors) and positional detectors termed double-side silicon strip detectors (DSSD).

Advanced calculations are used to separate/suppress the decay of background products from the rare decays of the anticipated elements.

If that sounds vague, that's because it is. As Arthur C. Clarke noted in his third law, 'any sufficiently advanced technology is indistinguishable from magic'. Even having read a couple of JINR papers on the topic, as far as this author is concerned that's how the new atoms are detected – magic.

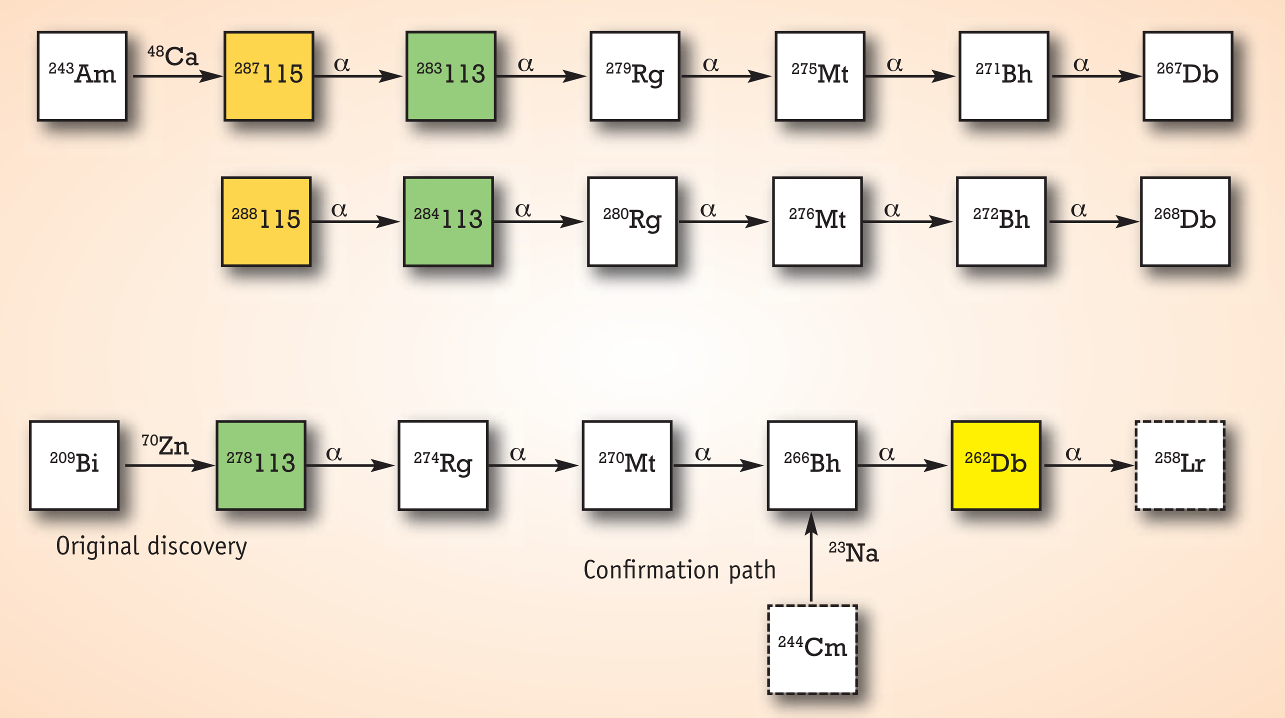
Superheavy elements and the 'island of stability'

Elements with more than 82 protons are unstable. Up to this point in the periodic table, theoretical physical chemists have pretty accurate models to predict the behaviour of the elements, balancing the strong nuclear force (holding nuclei together) against the repulsive force of the protons (seeking to tear the nuclei apart). Even neutrons are slightly repulsive towards each other.

These theories predict 'magic numbers' of protons and neutrons to fill 'shells' of quantum energy levels within the nuclei and confer stability, in much the same way that electron shell theories work. One 'magic number' combination is 82 protons and 126 neutrons, and ^{207}Pb is the heaviest naturally occurring stable element.

According to these theories, an 'island of stability' is suggested to exist somewhere up in the region of about 114, 120 or 126 protons, and (across multiple models) 184 neutrons. At this combination, the atoms should be resistant to alpha decay, and half-lives have been predicted anywhere from minutes to millions of years.

The problem is that the models don't work well for superheavy elements because of relativistic effects, so the estimates are still rubbery. Relativistic effects can be used to explain anomalous properties of the known elements, such as why mercury is a liquid to –39°C. The $6s^2$ orbital is contracted and the bonding of the Hg–Hg pair is dominated by van der Waals



The JINR/LLNL collaboration bombarded an americium target with calcium, producing multiple isotopes of element 115 depending on the energy of the collision. It was claimed that these isotopes showed an alpha decay to element 113, then via four alpha decays to dubnium, which then fissioned. (Main data source: bit.ly/1THCANj)

The RIKEN team bombarded a bismuth target with zinc to directly produce element 113 as an extremely rare event. The element 113 atoms underwent four alpha decays to dubnium-262. In a subsequent experiment, RIKEN confirmed this path by bombarding a curium target with sodium to produce bohrium, which showed an alpha decay to the same dubnium-262 isotope, then to lawrencium-258, which was a known isotope. (Main data source: bit.ly/1THCANj)

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forces; hence, the weak bonding and low melting point.

The exact nature of the strong force is still subject to extensive research, and the global study of SHEs contributes to this developing understanding.

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> *One fact should be emphasized from the outset: while the various theoretical predictions about the superheavy nuclei differ as to the expected half-lives and regions of stability, all theoretical predictions are in agreement: superheavy nuclei can exist. Thus, the search for superheavy nuclei remains as a unique, rigorous test of the predictive power of modern theories of the structure of nuclei.*
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> Seaborg G.T., Loveland W. *Contemporary Physics*, 1987, vol. 28, p. 33

Properties of the new elements

Given their extremely short half-lives (just milliseconds for some isotopes), the new elements have been subject to relatively little physical experimentation.

Element 113 sits in group 13, under gallium, indium and thallium. It is predicted to have a much higher density than thallium (potentially 16–18 g/cm^3, as compared to 11.9 g/cm^3), with a counter-trend atomic radius smaller than thallium. However, the few experiments conducted on Uut isotopes conducted by JINR have been inconclusive, given the tiny number of elements produced.

A more thoroughly studied element is flerovium-289 (element 114). It has a 'magic number' of protons, but too few neutrons for stability, giving it a half-life of 2.6 seconds. This slightly longer half-life has allowed some limited experimental chemistry, but this is

What's in a name?

IUPAC's decision on priority is not without controversy and deep division, just as it was during the 30 years of discovery and naming of elements 104–109, which were only resolved in 1997.

The Transfermium Wars, as they came to be known, were a period of acrimonious debate, where both the priority of discovery and the naming of those synthetic elements were hotly contested between laboratories in the US, Russia and Germany. The debate only ended when IUPAC awarded elements 104 (rutherfordium) and 106 (seaborgium) to the US, 105 (dubnium) and 107 (bohrium) to Russia, and 108 (hassium) and 109 (meitnerium) to Germany.

Since 1992, IUPAC's rules have stated that new elements can be named after a mythological concept, a mineral, a place or country, or a property or scientist. The name should sound similar across multiple languages, and it should have an ending that reflects and maintains historical and chemical consistency. This would be in general '-ium' for elements belonging to groups 1–16, '-ine' for elements of group 17 and '-on' for elements of group 18 (noting that this aspect is under review).

The successful laboratories now have the right to propose names. However, fans of author Terry Pratchett (who died in 2015) are actively campaigning for element 117 to be named octarine after the magical element in Pratchett's novels (chn.ge/1paf92G).

again limited by the rarity of the synthesis reactions – generally only one or two atoms at a time.

A 2008 report from JINR initially suggested that flerovium has chemical properties closer to noble gases than to lead (its nearest group 14 element) (bit.ly/1LgULqx). This was an unexpected result, and differed from the models, but experiments suffered from the decay of the flerovium to dubnium during transport through the gas separator (1–2 seconds). Follow-up tests by the same collaborative teams in 2010 cast further doubt on the initial interpretation.

The GSI Helmholtzzentrum für Schwerionenforschung weighed in with a 2012 paper stating 'Relativistically stabilized sub-shell closures give rise to a new category of elements in the Periodic Table: volatile metals (bit.ly/1oLgwF1). The prototype for this property is element 114 which, due to the relativistic stabilization of its electron configuration, is volatile in its elementary state …'. In simple terms, just as relativistic effects are cited as the reason that mercury is unexpectedly a liquid at room temperature (a break from the expected metallic bond trend), the GSI paper predicts that the enhanced relativistic effects for the heavier flerovium might actually make it a gas at the same temperature.

GSI's paper is one of the more accessible works found by the author on the predicted theoretical physical and chemical properties of the superheavy elements. Even so, it was still heavy going.

Forging ahead

Every scientist working on this endeavour is to be congratulated for further extending the limits of human knowledge, and for the way that their work has captured the public's imagination. Like a modern-day Haphaestus, science is forging fantastical new materials for the world, the ultimate act of creation. Who knows what more might lie just beyond the edge of our current capabilities?

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