

## Review

# Row 7 of the periodic table complete: Can we expect more new elements; and if so, when?



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## ABSTRACT

In this perspective the impact of the completion of the 7th row up to  $Z = 118$ , by the addition of four new elements in the periodic table – nihonium, moscovium, tennesine and oganesson – is described. Also the methods of how to “synthesize” new chemical elements, and the methods and difficulties of verifying such new elements are briefly discussed. Some speculations are presented about possible new element discoveries in the coming years.

Finally, the pathway of how the IUPAC names of the new elements are determined, are presented and illustrated by the most recent 4 additions of new elements.

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## 1. Introduction and history

At the end of 2015, IUPAC (International Union of Pure and Applied Chemistry) and IUPAP (International Union of Pure and Applied Physics) have officially recognized the discovery of 4 new elements [1,2] and by the end of 2016 IUPAC has published their names and symbols [3]; this decision was ratified at the July 13 World Council meeting of all IUPAC country members, while meeting in Sao Paulo. The first reports of the synthesis of these elements go back 10–15 years as detailed in the validation papers [1,2]. This implies that the process of verification is time consuming and – as illustrated below – requires a very careful, even painstaking process.

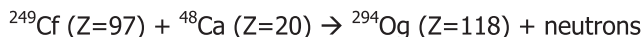
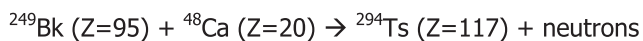
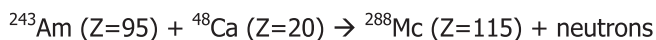
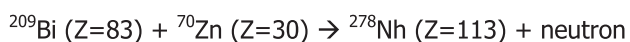
Ever since the introduction of the first periodic tables by Meyer and Mendeleev just before and in 1867 [4,5] with some 50–60 elements known, and who both received the Royal Society Davy Medal for this discovery in 1882 [6], new elements have been added continuously (see below).

The Periodic Table (System) was discovered in an era when atomic structures and electrons were not known and equipment to purify and separate elements was still primitive. The discoveries of Mendeleev, Meyer and others are therefore to be seen as immense. After the first International Conference of Chemists in 1860 (Karlsruhe) which both Mendeleev and Meyer attended, it became clear that a number of scientists had noted some regularities between chemical elements. The discoveries published in 1869 by Mendeleev, first in a vertical order, later that year in a horizontal arrangement, were preceded by discoveries of similar “regularities”

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from Béguyer de Chancourtois, Newlands, Odling, Hinrichs and Lothar Meyer [4,5]. Only Meyer produced a quite similar tabular arrangement, in fact just after Mendeleev. There is general acceptance that Mendeleev published his system noting that there was a periodic classification, i.e., the periodic law and the systematic arrangements of the elements, including some of the not yet discovered elements for which he even predicted chemical properties. That some of these predictions were incorrect and that in his system there was no place for the Noble Gases, still make him the generally accepted chief architect, since he discovered the “system”; only later it was changed to “Table” as we now use in the Periodic Table of Elements. Remarkably, the word “System” is still used as in “Periodic System” in a number of languages, e.g., Danish (“Periodiske system”), Dutch (“Periodiek systeem”) and German (“Periodensystem”), just as Mendeleev and Meyer did in their papers.

Even before the latest four additions to the Periodic Table [3], speculations had been published about the possible end of the Periodic Table [7], most recently followed by a detailed web-based discussion, at the Smithsonian Magazine [8]. The most significant increase in the previous century no doubt has been the extension of the actinide series by Seaborg in 1940s [9–12], which has resulted into a Noble Prize award in 1951.



**Scheme 1.** Examples of reaction equations for the synthesis of the 4 new elements.

Given the very difficult process of proving newly discovered elements, a very careful protocol has been in use by IUPAC and IUPAP for a number of decades now. This process describes recognition of the assignments of the new elements, after detailed verification, and how to arrive at names and symbols for these new heavy chemical elements [13]. This whole process has been summarized in an overview by John Corish [14]. With the upcoming recognition and name giving of elements 117 and 118, which would belong to group 17 and 18 of the Periodic Table, also the rules for name giving had been updated in 2016 [15], so that names from these groups will all end in “-ine” (group 17), or “-on” (group 18). It should perhaps be noted here that the classification of a newly discovered element in a group is determined by the Z number and column structure of the Periodic Table. This would not imply chemical properties resembling the elements higher in the column. Relativistic effects do play a role and the heavier the involved elements the more pronounced such relativistic effects will be.

## 2. New element generation and discussion

After the gradual filling of the Periodic Table up till uranium (element 92), synthetic elements were gradually added and they were usually made from bombardment of the heaviest elements with neutrons, or with helium nuclei. In this way, more heavy nuclei were added in the so-called cold fusion process [9–12].

In a long special-issue article of Chemistry World, Yuri Oganessian and others have been interviewed by Kit Chapman, and in that article a full description of all aspects of new-element synthesis is presented, including the so-called island of stability and the sea of instability [16].

In theory, any collision of two nuclei may generate a new element. This was known already for decades by experiments of



**Fig. 1.** Picture of the wall of the chemistry building in Murcia Spain.



Fig. 2. Stamp describing the discovery of nihonium and its subsequent decomposition scheme.

physicists looking at the X-ray radiation produced by atom–atom collisions with ion beams; this radiation cannot be attributed to either of the original nuclei and is described as originating from transients forming a “quasi-molecule” or “quasi-atoms” during the heavy-ion collision. The collision time is  $10^{-15}$  s, which is long enough to observe the characteristic X-ray radiation of the “quasi-species” [17,18].

However, in reality the “new elements” may not be seen at all, as they do not live long enough. For the most recent additions quite rigorous methods have been used and fusions of nuclei have been tried for several decades in specialized laboratories [19]. The process may appear relatively simple as recently described in Chemistry World [20] and starts with bombardments of light nuclei on heavy-atom targets. In this way elements up to fermium ( $Z = 100$ ) were made [19,21]. One can imagine that this process is not very efficient, as repulsive forces between the protons in the nuclei will win from the attractive forces that keep the nuclei together. Separation of the new atoms from the unreacted material to a special detector will – by studying the decay chain in detail – detect the new element.

To make even heavier nuclei, it was realized by Oganessian [16] that heavier bombarding atoms were required, and especially

those nuclei with large numbers of neutrons, such as an isotope of calcium having 28 neutrons instead of the usual 20, i.e.  $^{48}\text{Ca}$  with a natural abundance of only 1%. Since, the target material also needs to be very heavy and stable to prevent it from burning or falling apart, accurate chemical handling and high-level purifications are required. It is here where collaboration of physicists and chemists comes in, as is shown below by the example of the synthesis of element 117 (tennessine). Examples of reaction equations for the synthesis of the four newest elements by bombardment, are given in Scheme 1 below, after [1,2].

It is evident that the nuclear physicists are responsible for the final discoveries. However, the importance of the mutual dependence of chemistry and physics is clearly visible by the discovery story of tennessine. For its synthesis, berkelium is required, and this is produced and purified by chemists in the Oak Ridge National Lab (Tennessee, USA). So, beautiful and painstaking physics is preceded by equally beautiful and painstaking chemistry to synthesize and separate the unique target materials and deliver them to the high-energy physicists, all within a half-life time (310 days). The whole process of element synthesis is nicely presented in an instructive video [22].

As the discovery and claiming of the new elements are done in laboratories of physicists but with collaborations with chemists being needed to prepare and purify target materials, it is understandable that the recognition of new elements needs authorization jointly by both IUPAP and IUPAC, a process briefly summarized below.

### 3. Claiming, validation and naming

After claims for new elements have been made and published, and after the published claims have been discussed worldwide, a committee jointly appointed by IUPAC and IUPAP is in charge of and has the authority of the validation. After one or more elements have been validated by this committee, using long-standing and established criteria [13], one or more papers describing the recognition are published in Pure and Applied Chemistry.

At this stage, the inventors are invited by IUPAC to propose names and symbols for the newly discovered element(s), using the most recent criteria for the naming of new elements [15]. The proposed names and symbols are checked by IUPAC (i.e., its Inorganic Chemistry Division) for suitability and whether they meet the criteria [15]. These criteria are that only discoverers can propose names, and such names and their symbols have not been in use before within IUPAC. The proposed names can be after a scientist, a mythological concept or character, a mineral, a chemical property, a place e.g., a region, city or country [15].

A provisional paper with the names and symbols is made available for public review during 5 months, and only after these 5 months the names and symbols can be finally accepted by IUPAC and published in Pure and Applied Chemistry. The most recently added 4 names have been published in 2016 [3], and publicity around these discoveries and naming was significant.

Celebrations were held in Moscow and Tokyo, in March 2017, and in Sao Paolo at the General Assembly of IUPAC, where the 4 names and symbols were ratified by the Council in July 2017. In Murcia (Spain) a new Science building was decorated on the outside by a meters high and meters wide Periodic Table, while in Japan a special stamp was introduced for nihonium (see Figs. 1 and 2).

### 4. Final remarks

#### 4.1. Can we soon expect claims for more heavy elements?

Of course, the question now arises whether we can expect more heavy elements to be discovered in the near future. This topic is

under speculation in many places, see e.g., a web page of the Smithsonian Magazine [23]. Yuri Oganessian and his colleagues have commented on this topic when they were interviewed in Chemistry World [16]. First of all they need heavier projectiles than  $^{48}\text{Ca}$  in beams, perhaps  $^{50}\text{Ti}$  or heavier, for example V or Cr. Also they need heavier targets, like curium. It needs no discussion to realize that any new element with atomic number  $Z$ , can only be made if the sum of projectile  $Z$  and the target  $Z$  match the new element  $Z$ . But most importantly, the researchers in this field do need more intense accelerator beams, like the one under construction in Dubna, as well as a more efficient separator of the fragments.

This would make it unlikely that we will have new elements in the next 3–5 years. In a recent statement of the Japanese/American collaboration teams described in Chemistry World [24], they speak of bombarding curium by vanadium (to start in December 2017) to hunt for 119 and 120; the Russian/American collaboration plans to start the search for these elements in 2019, by using berkelium and titanium.

#### 4.2. Are there superheavy elements in outer space?

It has been speculated that if superheavy elements have ever been in space, they would have gone, even if their half lives would be a billion years. However, their decomposition traces could still be visible in meteorites, like olivine ( $\text{MgSiO}_3$ ), where such elements would have left a trace of damaged material, and since such a trace ages over time it could be detectable e.g., under a microscope. A team is already looking at this possibility [16].

#### 4.3. The collapse of the periodic table?

It is possible to study the chemistry for some of the heavy elements that can be produced in large enough amounts and with long enough half-lives. Thus, it may be possible to study the periodicity for instance, and cases are under study to elucidate whether the chemistry of copernicium (112) and flerovium (114)

resembles that of mercury and lead. Relativistic effects come into play, and the heavier the elements the more pronounced these effects are. So it is likely that oganesson (118) is more reactive than the other noble gases, which would mark the end of the periodicity as we currently understand and teach it.

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