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Superheavy elements with $Z = 114$ and 116 have been named flerovium and livermorium

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International Union of Pure and Applied Chemistry (IUPAC), which was established in 1919 by chemists from industry and academia, for more than 90 years has succeeded in fostering worldwide communications in chemical sciences and in uniting the academic, industrial and public sectors of chemistry in a common language. IUPAC is recognized as the world authority in chemistry and related areas. One of the crucial problems coming within the jurisdiction of IUPAC is the recognition of the discovery of new elements and their designation. In particular, this was on the agenda of an international festive colloquium held in Moscow on October 24, 2012.

Criteria to be satisfied for the discovery of a new chemical element to be recognized were delineated by the IUPAP/IUPAC Transfermium Working Group. Superheavy elements with $Z = 113–118$ have been synthesized experimentally at the G. N. Flerov Laboratory of Nuclear Reactions (FLNR) of the Joint Institute for Nuclear Research (JINR, Dubna, Russia) in the framework of a large collaboration between the Flerov Laboratory, the Institute of Atomic Reactors (IAR, Dimitrovgrad, Russia), the Lawrence Livermore National Laboratory (LLNL, Livermore, California, USA) and the Oak Ridge National Laboratory (ORNL, Oak-Ridge, USA). Factors which have been regarded positively included low background events, cross-bombardments, excitation functions, reproducibility in productions and in decays, physicochemical behavior, and spatial correlations between evaporations and subsequent decays. After considering the presented data in June 2011, IUPAC credited the Dubna–Livermore collaboration with the discovery of new elements with $Z = 114$ and 116.

On May 23, 2012, IUPAC has officially approved the names flerovium (atomic symbol Fl) and livermorium (atomic symbol Lv) for elements of atomic numbers 114 and 116, respectively. Priority for the discovery of these elements was assigned, in accordance with the agreed criteria, to the collaboration between the JINR and LLNL.

At the international festive colloquium dedicated to the discovery and naming of the superheavy elements with atomic numbers 114 and 116, Vice-Director of the Joint Institute for Nuclear Research Professor Mikhail G. Itkis introduced its participants, the authors of the discovery of the new chemical elements, leading scientists and engineers from the JINR, plenipotentiaries and ambassadors of the JINR member- and associate-member- states, official establishment of the governing bodies of Russia, members of the Russian Academy of Sciences (RAS), including members of the Presidium of RAS, members of the IUPAC Executive Committee, mayors of Livermore and Dubna and other honored guests.

The international festive colloquium has been opened by a lecture of the scientific leader of the Flerov Laboratory, Academician Yury Ts. Oganessian on the history of the discovery of superheavy elements.

Transactinides that exist due to a stabilizing effect of nucleon shells are referred to as superheavy elements. Following the well-known ^{208}Pb, which has closed proton ($Z = 82$) and neutron ($N = 126$) shells, in the mid-1960s, the next shell closure has been predicted for ^{298}114 ($N = 184$). This effect in neighboring nuclei is expected to be responsible for the formation of an island of increased stability superheavy elements.

The promise of discovering superheavy elements was very attractive, and their synthesis seemed reachable using available heavy ion accelerators without serious problems in the early 1970s. Both on- and off-line chemical methods have been used for the separation of eka-Hg, eka-Pb and eka-Rn from reaction products. No evidence for the formation of superheavy nuclei has been obtained during 30 years.

Progress in the development of accelerator technics, especially, ion sources and new data on reaction mechanisms and the properties of transactinide nuclei obtained in the past 30 years allowed one to use ^{48}Ca double magic nuclei as a projectile for the synthesis of superheavy elements in the late 1990s. This rare and expensive isotope has been produced at the Electrokhimpribor industrial complex (Lesnoy, Russia).

The targets consisted of the enriched isotopes of ^{233,238}U, ^{237}Np, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, ^{249}Bk and ^{249}Cf as oxides deposited on titanium foils. Unique highly enriched isotopes have been delivered by the Institute of Atomic Reactors, Russian Federal Nuclear Center (Sarov), Lawrence Livermore National Laboratory and Oak Ridge National Laboratory.

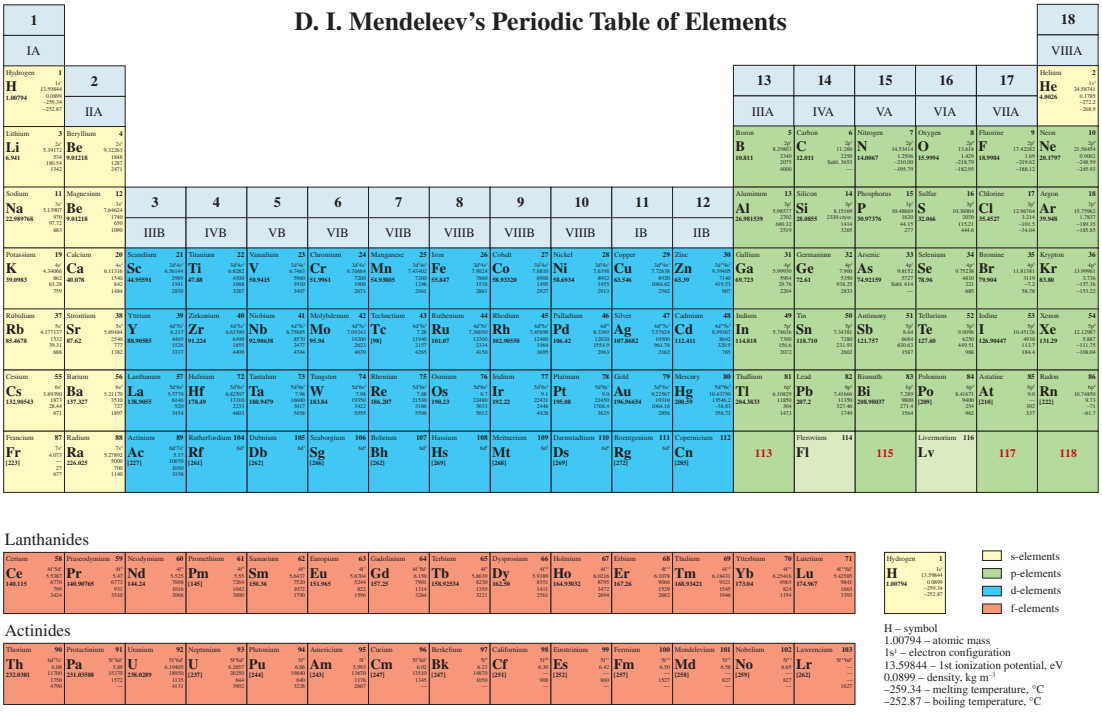
Heavy reaction products were separated in-flight from beam particles by the Dubna Gas-Filled Recoil Separator. This technique makes it possible to measure decay properties at an extremely low background. The analysis of events collected in experiments has been performed to find generic links mother–daughter–grand-daughter–… in decay chains.

In reactions studied in 2000–2012, the decay of the heaviest isotopes of Rf, Db, Bh, Hs, Mt, Ds, Rg, Cn and 20 isotopes of new elements with $Z = 113–118$ was observed among the products of complete fusion reactions.

Later, data on the decay properties of isotopes of the elements with $Z = 114$ and 116 have been reproduced by scientists in Germany and the United States.

The characterization of the chemical properties of the latest discovered elements is of special interest in the context of the chemical behavior of heavy and superheavy elements. Some of them have half-life periods from several seconds to about a day, times reachable by radiochemical methods.

Radiochemical experiments are in progress, but even the first experimental data suggest a Hg-like behavior of Cn ($Z = 112$) and a noble gas-like behavior of flerovium ($Z = 114$). This observation is the first indication of the influence of relativistic effects on the properties of superheavy atoms. This problem is



fundamental for modern chemistry. Radiochemical studies also served for the identification of new elements.

At the Flerov Laboratory, considerable progress in the synthesis and characterization of odd superheavy elements 113, 115 and 117 has been achieved, and an official claim to discovery of these elements has been submitted to the IUPAC. Additional support for this claim has been provided by German colleagues, who have reproduced the FLNR data last year.

Now, the development of a 'superheavy element factory' based on the new high-current cyclotron at the Flerov Laboratory is in progress. It is expected that the overall increase of the luminosity of experiments and the use of high-efficiency next generation on-line separators will increase the yield of superheavy nuclei by almost two orders of magnitude. This will allow us to start detailed studies of the spectroscopic and physicochemical properties of new elements.

The experiments that led to the discovery of superheavy elements have been performed with the support of the Nuclear Energy State Corporation (Rosatom, former Ministry of Atomic Energy of Russia) and numerous grants from the Russian Foundation for Basic Research and the Swiss National Scientific Foundation; the United States Department of Energy supported the studies performed in the Lawrence Livermore National Laboratory.

The format of the international festive colloquium did not provide a discussion of the reports. After historical reminiscences, there has come the solemn minute – the President of the IUPAC, Professor Kazuyuki Tatsumi officially announced the names of the new chemical elements with Z = 114 and 116. From that moment on, the new elements flerovium and livermorium are included into the D. I. Mendeleev's Periodic Table of the Elements.

The name flerovium honors the G. N. Flerov Laboratory of Nuclear Reactions where superheavy elements are synthesized. Georgiy N. Flerov (1913–1990) was a renowned physicist, who discovered the spontaneous fission of uranium, a pioneer in heavy-ion physics and the founder of the Laboratory of Nuclear Reactions at the Joint Institute for Nuclear Research (1957).

The name livermorium honors the Lawrence Livermore National Laboratory. A group of researchers from this laboratory with the heavy element research group of the FLNR took part in the work carried out in Dubna on the synthesis of superheavy elements including livermorium.

Vice-President of RAS, Academician Sergei M. Aldoshin stressed in his honoring speech that the existence of superheavy elements belongs to the most fundamental problems in natural sciences because it affects nuclear and atomic physics, quantum chemistry, the electrodynamics of strong fields, astrophysics and cosmology. Aldoshin also extended congratulations to all scientists at the Joint Institute for Nuclear Research on behalf of the President of RAS, Academician Yuri S. Osipov on the brilliant scientific successes and wished them to continue outstanding research in nuclear chemistry.

Vice-Chair of the National Committee of Russian Chemists, Chair of the Interdepartmental RAS–RosAtom Scientific Council, Academician Boris F. Myasoedov noted that the discovery of flerovium and livermorium enriched Mendeleev's periodic table and opened up a new area of chemistry – the relativistic chemistry of superheavy elements. The study of the physicochemical behavior of newly synthesized elements represents an outstanding example of single-atom chemistry.

Honoring speeches were also given by Vice-Directror of the Lawrence Livermore National Laboratory, Professor William H. Goldstein, the mayor of Livermore John Marchand, former director of the National Institute of Nuclear and Particle Physics and French National Centre for Scientific Research (CNRS), Professor Michel Spiro (France), Vice-Director of Facility for Antiproton and Ion Research (FAIR), Professor Hartmut Eickhoff (Germany), Vice-Director of the Oak Ridge National Laboratory, Professor James B. Roberto (USA), Chair of the Division of Nuclear Chemistry and Technology of the American Chemical Society, Professor Heino Nitsche (USA) and Chair of the Committee of Plenipotentiaries of the Joint Institute for Nuclear Research, Professor Micael Valigurski (Poland).

Giving credit for the discovery of the two new superheavy elements, it is necessary to emphasize the decisive importance of international scientific cooperation in these complicated branches of science.

December 10, 2012