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INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY
INORGANIC CHEMISTRY DIVISION*
NAMES AND SYMBOLS OF THE ELEMENTS WITH ATOMIC
NUMBERS 114 AND 116

IUPAC Provisional Recommendations

Prepared for publication by

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NAMES AND SYMBOLS OF THE ELEMENTS WITH ATOMIC NUMBERS 114 AND 116

Abstract: A joint IUPAC/IUPAP Working Party (JWP) has confirmed the discovery of the elements with atomic numbers 114 and 116. In accord with IUPAC procedures, the discoverers proposed names as follows: flerovium and symbol, Fl, for the element with $Z = 114$ and livermorium with the symbol Lv for the element with $Z = 116$. The Inorganic Chemistry Division recommended these proposals for acceptance and they were adopted by IUPAC by the Bureau on (date to be inserted) as delegated to act by the IUPAC Council meeting on 3–4 August 2011.

Keywords: Fl; flerovium; element 114; Lv; livermorium; element 116; element name; IUPAC Inorganic Chemistry Division; periodic table.

INTRODUCTION

In 2005 a joint Working Party (JWP) of independent experts drawn from IUPAC and IUPAP was appointed by the Presidents of the Unions to determine priority of claims to the discovery of elements with atomic numbers greater than 111. This JWP first considered literature and documentation submitted to it by June 30th 2007. All of its deliberations were carried out in accordance with the criteria for the discovery of elements previously established by the 1992 IUPAC/IUPAP Transfermium Working Group [1 – 3] and reinforced in subsequent IUPAC/IUPAP JWP discussions. The group first reported [4] on the discovery of element with atomic number 112 and this element was subsequently named copernicium with the symbol Cn [5]. The group then extended the deadline for the receipt of documentation to 31 July 2008 and issued a second report [6] in which the discovery of the elements with atomic numbers 114 and 116 were assigned to collaborative work between scientists from the Joint Institute for Nuclear Research in Dubna, Russia and from Lawrence Livermore National Laboratory, California, USA (the Dubna-Livermore collaborations). Prior to its publication, this report was sent to each of the claimant laboratories to be checked for technical accuracy. It was also reviewed by eight independent expert referees and its findings were accepted by the Executive Committees of the two Unions and by the Division Committee of the IUPAC Division of Inorganic Chemistry (Division II).

RECOMMENDATION

The 2011 JWP report [6] concluded that “the establishment of the identity of the isotope ^{283}Cn by a large number of decaying chains, originating from a variety of production pathways essentially triangulating its A, Z character enables that nuclide’s use in unequivocally recognizing higher- Z isotopes that are observed to decay through it.” From 2004 Dubna-Livermore collaborations the JWP noted: (i) the internal redundancy and extended decay chain sequence for identification of $Z = 114$ from $^{48}\text{Ca} + ^{242}\text{Pu}$ fusion [7,8]; and (ii) that the report of the production of $^{291}\text{116}$ from the fusion of ^{48}Ca with ^{245}Cm [9] is supported by extended decay chains that include, again, ^{283}Cn and descendants. It

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4 recommended that the Dubna-Livermore collaborations be credited with discovery of these
5 two new elements. A full synopsis of the relevant experiments and related efforts is presented
6 in the technical report [6] published online in *Pure and Applied Chemistry* on 1 June 2011.
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9 Following the assignment and in accordance with the procedures established by IUPAC for
10 the naming of elements [10] the discoverers at Dubna and Livermore were invited to propose
11 names and symbols for the elements with atomic numbers 114 and 116.
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13 For the element with atomic number 114 the discoverers proposed the name flerovium and
14 the symbol Fl. This proposal lies within tradition and will honour the Flerov Laboratory of
15 Nuclear Reactions where superheavy elements are synthesised. Georgiy N. Flerov (1913 –
16 1990) – was a renowned physicist, author of the discovery of the spontaneous fission of
17 uranium (1940, with Konstantin A. Petrzhak), pioneer in heavy-ion physics; and founder in
18 the Joint Institute for Nuclear Research the Laboratory of Nuclear Reactions (1957). It is an
19 especially appropriate choice because since 1991 this laboratory, in which the element was
20 synthesised, has borne his name. Professor G.N. Flerov is known also for his fundamental
21 work in various fields of physics that resulted in the discovery of new phenomena in
22 properties and interactions of the atomic nuclei; these have played a key role in the
23 establishment and development of many areas of further research.
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26 For the element with atomic number 116 the name proposed is livermorium with the symbol
27 Lv. This is again in line with tradition and honours the Lawrence Livermore National
28 Laboratory (1952). A group of researchers of this Laboratory with the heavy element
29 research group of the Flerov Laboratory of Nuclear Reactions took part in the work carried
30 out in Dubna on the synthesis of superheavy elements including element 116. Over the years
31 scientists at Livermore have been involved in many areas of nuclear science: the investigation
32 of fission properties of the heaviest elements, including the discovery of bimodal fission, and
33 the study of prompt gamma-rays emitted from fission fragments following fission, the
34 investigation of isomers and isomeric levels in many nuclei and the investigation of the
35 chemical properties of the heaviest elements.
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39 The Inorganic Chemistry Division Committee has considered the proposals of the discoverers
40 and recommends to the IUPAC Bureau and Council that the names flerovium with the
41 symbol Fl and the name livermorium with the symbol Lv for elements with atomic numbers
42 114 and 116, respectively, be accepted. Provisional recommendations of the name and
43 symbol were made available for review and comment in December 2011. The final
44 recommendation was approved by the IUPAC Bureau on (date to be inserted) as authorized
45 by Council at its meeting of 3-4 August 2011. This followed the statutory period during
46 which the recommendation was open for public comment.
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49 Finally, the reviews of the claims associated with elements 113, 115, and 118 are at this time
50 not conclusive and evidences were considered not to have met the criteria for discovery.
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REFERENCES

- [1] D. H. Wilkinson, A. H. Wapstra, I. Uhelea, R. C. Barber, N. N. Greenwood, A. Hryniewicz, Y. P. Jeannin, M. Lefort and M. Sakai. "Criteria that must be satisfied for the discovery of a new element to be recognized". *Pure Appl. Chem.* **63**, 879-886 (1991).
- [2] D. H. Wilkinson, A. H. Wapstra, I. Uhelea, R. C. Barber, N. N. Greenwood, A. Hryniewicz, Y.P. Jeannin, M. Lefort and M. Sakai. "Discovery of the transfermium elements. Part II: Introduction to the discovery profiles", *Pure Appl. Chem.* **65**, 1757-1763 (1993).
- [3] D. H. Wilkinson, A. H. Wapstra, I. Uhelea, R. C. Barber, N. N. Greenwood, A.

1st December 2011 - DRAFT not for circulation

- 1
2
3
4 Hrynkiewicz, Y.P. Jeannin, M. Lefort and M. Sakai, "Discovery of the transfermium
5 elements. Part III: Discovery Profiles of the transfermium elements", *Pure Appl. Chem.*
6 **65**, 1764-1814 (1993).
7
8
9
10
11 [4] P.J.Karol, R.C. Barber, H.Gäggeler, H.Nakahara, E.Vardaci and E. Vogt, "The discovery
12 of the element with atomic number 112", *Pure Appl. Chem.*, **81**, 1331-1343 (2009).
13
14
15 [5] Kazuyuki Tatsumi and John Corish, "Name and Symbol of the element with atomic
16 number 112 (IUPAC Recommendations 2010)", *Pure Appl. Chem.* **82**,753-755 (2010).
17
18
19 [6] Robert C Barber, Paul J. Karol, Horimici Nakhara, Emaluele Vardaci and Erich W Vogt,
20 "Discovery of the elements with atomic numbers greater than or equal to 113", *Pure Appl.*
21 *Chem.*, **83**, 1485-1498 (2011).
22
23 Errata to this article were published ibid p.1801
24
25
26
27 [7] Yu. Ts. Oganessian, A. V. Belozarov, A. V. Yeremin, A. G. Popeko, O. N. Malyshev, A.
28 V.Belozarov, G. V. Buklanov, L. Chelnokov, V. I. Chepigina, V. A. Gorshkov, S.
29 Hofmann, M. G. Itkis, A. P. Kabachenko, B. Kindler, G. Münzenberg, R. N. Sagaidak, S.
30 Saro, H.-J. Schött, B. Streicher, A. V. Shutov, A. I. Svirikhin, G. K. Vostokin. "Second
31 experiment at VASSILISSA separator on the synthesis of Element 112", *Eur. Phys. J. A*
32 **19**, 3 (2004).
33
34
35
36
37 [8] Yu. Ts. Oganessian, V. K. Utyonkov, Yu. V. Lobanov, F. Sh. Abdullin, A. N. Polyakov,
38 I. V. Shirokovsky, Yu. S. Tsyganov, G. G. Gulbekian, S. L. Bogomolov, B. N. Gikal,
39 A. N. Mezentsev, S. Iliev, V. G. Subbotin, A. M. Sukhov, A. A. Voinov, G. V.
40 Buklanov, K. Subotic, V. I. Zagrebaev, M. G. Itkis, J. B. Patin, K. J. Moody, J. F. Wild,
41 M. A. Stoyer, N. J. Stoyer, D. A. Shaughnessy, J. M. Kenneally, P. A. Wilk, R. W.
42 Lougheed, R. I. Il'kaev, S. P. Vesnovskii, "Measurements of cross sections and decay
43 properties of the isotopes of elements 112, 114, and 116 produced in the fusion reactions
44 $^{233,238}\text{U}$, ^{242}Pu , and $^{248}\text{Cm}+^{48}\text{Ca}$ " *Phys. Rev. C* **70**, 064609 (2004).
45
46
47
48 [9] Yu. Ts. Oganessian, V. K. Utyonkov, Yu. V. Lobanov, F. Sh. Abdullin, A. N. Polyakov, I.
49 V. Shirokovsky, Yu. S. Tsyganov, G. G. Gulbekian, S. L. Bogomolov, B. N. Gikal, A. N.
50 Mezentsev, S. Iliev, V. G. Subbotin, A. M. Sukhov, A. A. Voinov, G. V. Buklanov, K.
51 Subotic, V. I. Zagrebaev, M. G. Itkis, J. B. Patin, K. J. Moody, J. F. Wild, M. A. Stoyer,
52 N. J. Stoyer, D. A. Shaughnessy, J. M. Kenneally, R. W. Lougheed, "Measurements of
53 cross sections for the fusion-evaporation reactions $^{244}\text{Pu}(^{48}\text{Ca},\text{xn})^{292-x}114$ and
54 $^{245}\text{Cm}(^{48}\text{Ca},\text{xn})^{293-x}116$ " *Phys. Rev. C* **69**, 054607 (2004).
55
56
57
58
59 [10] W.H.Koppenol. "Naming of new elements" *Pure Appl.Chem.* **74**, 787-791 (2002).
60