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Discoveries and names of heavy chemical elements: from curium to copernicium and beyond

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ABSTRACT

The present state of the synthesis and studies of the properties of heavy nuclei is shortly presented. Main attention is given to superheavy nuclei, in particular to isotopes of copernicium, the heaviest element the discovery and name of which have been approved by IUPAC, and to isotopes of the recently observed element 117. The rules used in naming newly discovered elements and recent changes in these names or these elements are discussed.

1. INTRODUCTION

The synthesis of heavy nuclei and heavy elements, which does not occur in the natural state in the Earth, has a long history. This is already over 70 years since 1940, when the first transuranium element (neptunium with the atomic number Z=93) was synthesized at Berkeley. Up to the present day, 26 elements heavier than uranium (Z=92) with Z from 93 to 118 have been produced in nuclear reactions performed in the laboratory (see e.g. [1–7]). The lightest of them, up to Z=101 (mendelevium), were obtained with light projectiles (neutrons, deuterons and α particles). To produce heavier ones, one needed to use heavy ions.

A specific class of heaviest nuclei and of respective elements are superheavy nuclei (SHN) and superheavy elements (SHE). These are the transactinide (translawrencium) nuclei and respective elements. Detailed calculations, based on various nuclear models, indicate that these nuclei exist only due to their shell structure. Without this structure one could not observe them.

The objective of this paper is to give a short review of the present state of the synthesis and studies of the properties of heavy nuclei. (Similar consideration has been performed in Ref. [8]). In the description of these studies, we will mainly concentrate on the nuclei of three elements. One of them is the element 96 named curium to honor Maria and Pierre Curie. The present year (2011) is announced to be The International Year of Chemistry, celebrated in reference to the centenary of the Nobel Prize (in chemistry) awarded to Maria Skłodowska-Curie. The second one is the element 112 (copernicium), the heaviest one, the discovery and the name of which have been approved by IUPAC. The third one is the element 117 synthesized recently in Dubna [6].

Synthesis of a new element involves its direct naming. We will describe the rules used in this process. Finally, we will shortly summarize the results obtained up to the present day in the study of superheavy nuclei.

2. CURIUM

The element 96 (curium, Cm) was discovered in 1944 (see e.g. [1]). It was synthesized at Berkeley with the use of one of its cyclotrons and identified chemically at the Metallurgical Laboratory in Chicago. Such procedure was possible because the discovered isotope, ^{242}Cm, has sufficiently long half-life (163 days). The name curium was proposed for it by G.T. Seaborg, the main coauthor of the discovery.

Presently, already 17 isotopes of Cm are known. The element is produced and cumulated in a macroscopic scale. The most stable isotope is ^{247}Cm with the half-life of $1.6 \cdot 10^7$ y. Some isotopes of curium are used as targets in the synthesis of superheavy nuclei. For example, 4 isotopes of the element 116 (^{290,291,292,293}116) were produced in the reactions of ^{48}Ca (projectiles) with ^{245}Cm and ^{248}Cm as targets.

3. COPERNICIUM

The superheavy element 112 (copernicium, Cn) was synthesized [9] in 1996 at the GSI-Darmstadt institute (Germany). It was produced in the nuclear reaction

$$^{70}_{30}\mathrm{Zn} + ^{208}_{82}\mathrm{Pb} \rightarrow ^{278}_{112}\mathrm{Cn}^{*} \rightarrow ^{277}_{112}\mathrm{Cn} + 1\mathrm{n}. \quad (1)$$

Here, the compound nucleus ^{278}Cn* was formed by the fusion of the projectile ^{70}Zn and the target ^{208}Pb nuclei. Due to the strong binding (i.e. relatively small mass) of the nucleus ^{208}Pb, the excitation (denoted by the asterisk) of the compound nucleus $^{278}_{112}$Cn* is relatively small (around 15 MeV) and is sufficient for the emission of only one neutron to produce the final nucleus ^{277}Cn. The raction (1) represents the class of the cold-fusion reactions. All the superheavy elements with Z up to 112 were discovered with the use of this kind of reactions.

The time of the irradiation of ^{208}Pb was around three weeks. The intensity of the ^{70}Zn beam was $3 \cdot 10^{12}$ ions/s, so the total dose of the ions was about $5 \cdot 10^{18}$. Only one superheavy nucleus ^{277}Cn was observed. The measured cross section was about 0.5 pb. This illustrates how small is the probability of such synthesis. The measured half-life of ^{277}Cn was about 0.2 ms. The small cross section together with the small half-life show that such nuclei (atoms) cannot be collected. They are available only at the scale: one nucleus (one atom) at a time. Thus, physics of superheavy nuclei is a physics of single nuclei and chemistry of superheavy elements is a chemistry of single atoms. Figure 1 shows the decay chains of all four nuclei ^{277}Cn observed up to now, with some details of the observation.

Although the discovery took place in 1996, it had been approved by IUPAC until 2009. Important for this approval was the confirmation of the discovery in another experiment at GSI [10] and, first of all, by the Japanese group of Kosuke Morita at RIKEN (the accelerator center near Tokyo) [7]. The name copernicium, proposed by the authors, was approved by IUPAC in 2010 and announced on February 19, 2010, on the birthday of the great astronomer.

4. THE ELEMENT 117

The element 117 was synthesized most recently (in 2010) at JINR-Dubna [6]. The heaviest element (118) of all produced up to now was observed earlier (in 2006) [4] at the same laboratory. Two isotopes of 117 were obtained in the following hot-fusion reactions

$$^{48}_{20}\mathrm{Ca} + {}^{249}\mathrm{Bk} \rightarrow {}^{297}117^{*} \rightarrow {}^{294}117 + 3\mathrm{n}, \quad (2)$$

$$^{48}_{20}\mathrm{Ca} + {}^{249}\mathrm{Bk} \rightarrow {}^{297}117^{*} \rightarrow {}^{293}117 + 4\mathrm{n}. \quad (3)$$

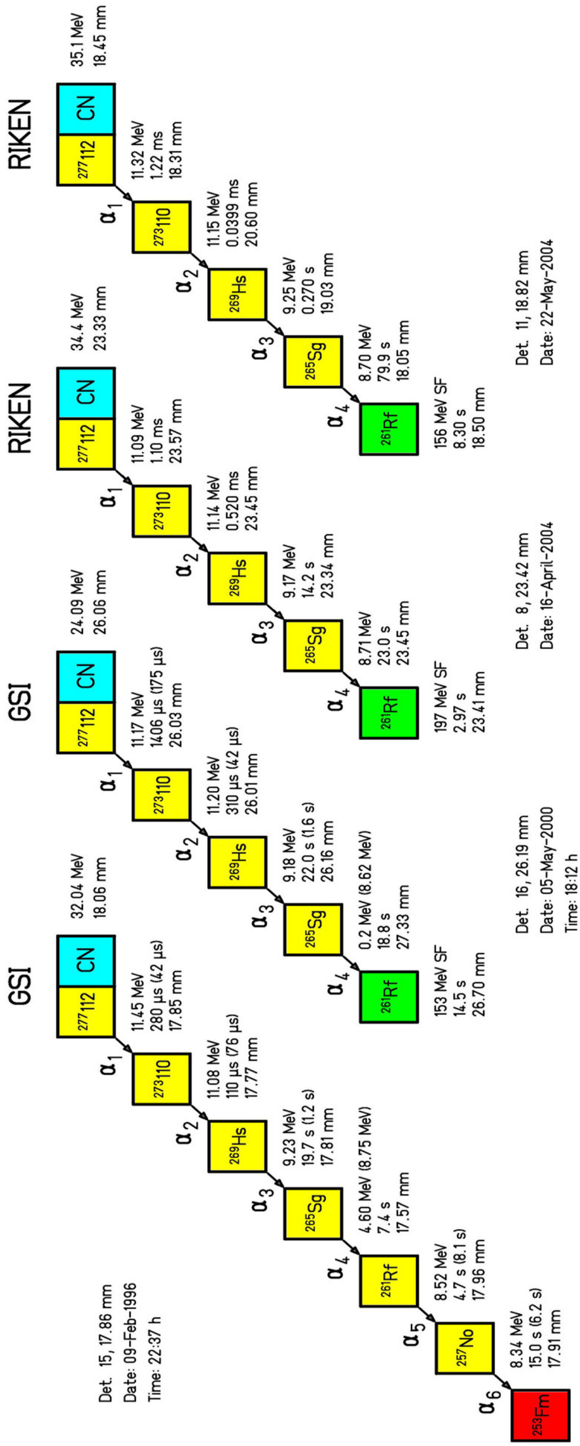


Fig. 1. Four α-decay chains of the nucleus $^{277}112$ (see text).

One atom of the isotope $^{294}117$ was produced with the cross-section of about 0.5 pb and five atoms of the isotope $^{293}117$ were obtained with the cross section of about 1.3 pb. The observed half-life of the former nucleus was 78 ms and that of the latter one was 15 ms. The decay energies and half-lives of all the nuclei in both decay chains were predicted, with a reasonable accuracy,

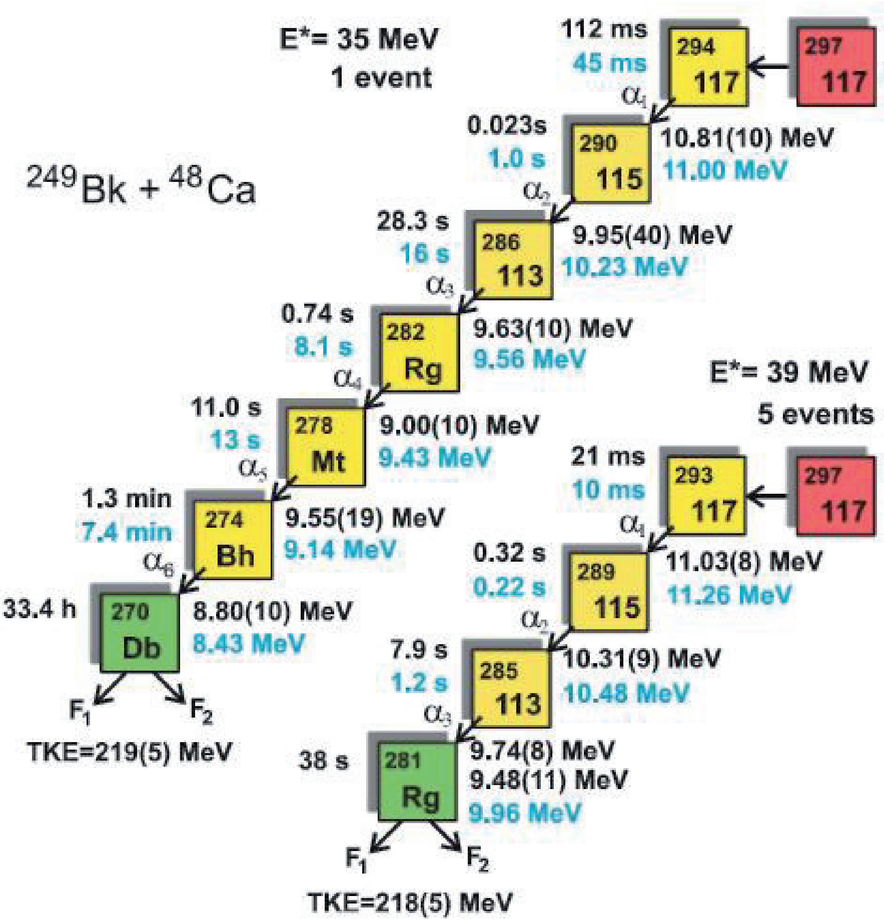


Fig. 2. The α-decay chains of two isotopes of the new element 117 (see text).

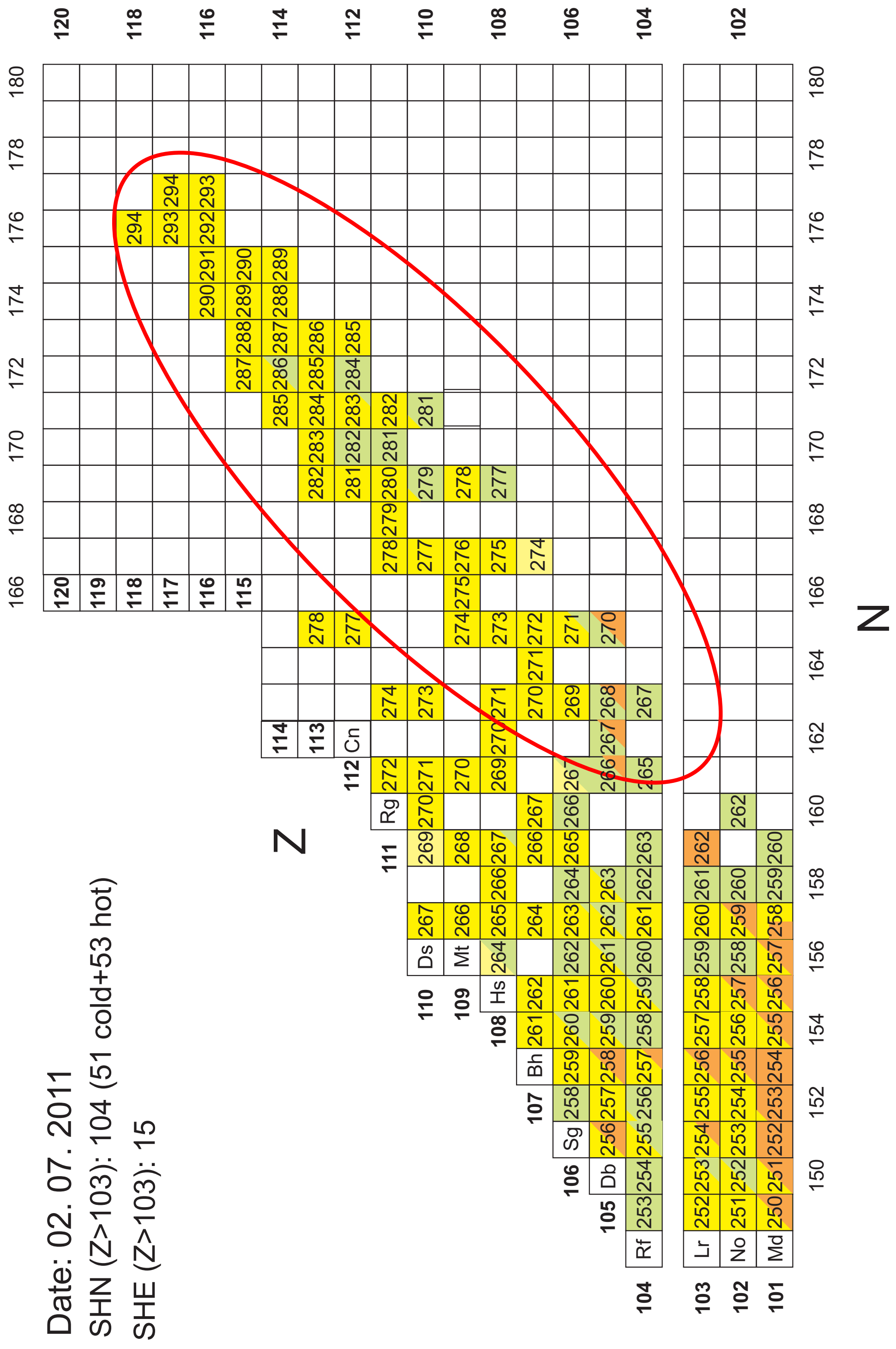
by theoretical calculations [19]. The experimental as well as theoretical results are shown in Fig. 2, taken from Ref. [6]. The half-lives are given on the left side of the box representing a nucleus and the decay energies are shown under the box. The predicted values (in the original figure shown in blue) are given below the experimental ones (in the original figure shown in black). All of the eleven nuclei appearing in the two decay chains of Fig. 2 were observed for the first time.

5. NAMING OF HEAVY ELEMENTS

Names of new elements may be proposed by the discoverers. The first two transuranium elements were named by the astronomical analogy: after uranium come neptunium and plutonium. Then, there appeared two ideas. One was geographical, names of the country (americium, Z=95), regions of the country (californium, Z=98, hassium, Z=108) or cities (berkelium, Z=97, dubnium, Z=105, darmstadtium, Z=110) important for the discoverers. The second idea were names of great physicists and chemists (curium, Z=96, einsteinium, Z=99, fermium, Z=100, bohrium, Z=107, roentgenium, Z=111,...). The chosen great physicists and chemists were rather contemporary scientists, but at the same time those who have already passed away. For example, the names einsteinium and fermium were given quite soon after the death of Einstein and Fermi. Naming elements according to these two ideas created a rather long tradition. The first break of this tradition occurred when the name seaborgium taken from the name of still alive physicist and chemist G.T. Seaborg was given to the element 106. The second break came in the recent year (2010), when the name of an astronomer, living a few centuries ago, was given to the element 112.

6. GENERAL RESULTS OF THE STUDIES OF SUPERHEAVY NUCLEI

Studies of superheavy nuclei and of superheavy elements constitute a present fast developing parts of nuclear physics and nuclear chemistry. Up to this day, 104 superheavy nuclei with Z=104-118 have been observed. These are isotopes of 15 superheavy chemical elements. Of these nuclei, 51 nuclides (50 ones with Z=104-112 and one, $^{278}113$, with Z=113) were obtained in cold-fusion reactions and 53 (with Z=113-118, except $^{278}113$) were produced in the hot-fusion ones (i.e. in the reactions in which the actinide targets are used). This is illustrated in the present-day chart of heaviest nuclei shown in Fig. 3. For each nucleus in the chart, characterized by the proton number Z, the neutron number N, and the mass number A, the decay modes of it are shown. In the original form of the figure, the α decay is denoted by yellow, fission by green, and electron capture by orange coloures.


Date: 02. 07. 2011
SHN (Z>103): 104 (51 cold+53 hot)
SHE (Z>103): 15
Z
N

The detailed description of experiments, in which the nuclei shown in Fig. 3 and discussed in this paper have been produced, may be found e.g. in Refs. [1−3,5,11] and references given there. One should say that a significant contribution to these results has been made by chemists (e.g. [12−16]). This is because in order to study chemical properties of superheavy elements (SHE), one needs first to synthesize them and the latter is done by physical methods, which brings knowledge of physical properties of nuclei of these elements. One cannot separate the efforts of these two groups of scientists, closely cooperating with each other in the studies of superheavy nuclei and elements.

The experimental research has been accompanied by the theoretical one, done by both, more traditional, macroscopic-microscopic methods (e.g. [17−19]) and, more recent, purely microscopic ones (e.g. [20−24]). The latter represent self-consistent calculations of the Hatree-Fock type with the use of effective density-dependent interactions of both zero (Skyrme) and finite (Gogny) ranges, and also of the relativistic mean field approach.

Concluding our considerations, one can say that the described synthesis and studies of heaviest nuclei and heaviest elements are a continuation of the research of Maria Skłodowska-Curie and Pierre Curie on the radioactivity and in particular of the Maria studies honoured by the Nobel Prize delivered to her a hundred years ago. This is because the same radioactivity is used as a method in the present-day identification and studies of the heaviest nuclei.

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