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ORIGINAL PAPER

Name game: the naming history of the chemical elements: part 2—turbulent nineteenth century

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Abstract
The second article of the "Naming game…" series provides detailed information on the discovery and naming of elements in the nineteenth century. Outlines of discoveries of 46 elements were presented, with particular emphasis on publications in which the name appeared for the first time. In the article the short historical information about every element naming is presented. The process of naming each chemical element was analyzed, with particular emphasis on the first publication with a given name.

Keywords Chemical elements · Naming history · History of chemistry

Introduction

By the end of the eighteenth century 37 chemical elements had been described and named. In the nineteenth century, discoveries accelerated, mainly due to the intensive development of analytical and physical chemistry. A kind of race began in which the framework of the rules was established only by Dmitri Mendeleev in 1869 with the formulation of the law of periodicity of chemical elements. It was a turning point in the development of chemistry, making it possible to predict the existence and properties of yet undiscovered elements. This fact allowed the scientists to search more systematically. Another milestone in the discovery of elements was the application of a spectrometer that allowed the discovery of new elements only on the basis of their electromagnetic spectrum. The article also highlights some of the more spectacular and important "blind alleys" in the history of science, as well as prosaic mishaps and coincidences during the discoveries that happened to nineteenth-century researchers in the race for the laurel of the first discoverer.

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From tantalum to actinium—nomenclature history of nineteenth century

The following paragraphs discuss 46 chemical elements discovered and named in the nineteenth century. The discussed elements are distinguished in the periodic table of elements in Fig. 1.

Tantalum

Tantalum was first extracted from mineral samples and described by Anders Ekeberg in his work presented in the journal *Kungliga Svenska Vetenskapsakademiens Handlingar* in 1802, in the article entitled *Uplysning om ytter jordens egenskaper, i synnerhet i jämförelse med berylljorden: om de fossilier, hvari förstnämnde jord innehålles, samt om en ny uptäckt kropp af metallisk natur* (Ekeberg 1802). For over forty years tantalum and niobium were thought to be one and the same as they share very similar chemical and physical properties and are always found together in nature (Baccolo 2015).

Niobium

Naming of niobium had a complex and somewhat unusual history. In short: a new element was discovered in 1801 by Charles Hatchet in the mineral found in the British Museum (Hatchet 1802). Both the new element and the mineral were named in the same manner "columbium" and "columbite" respectively, reflecting that the specimen of the ore came from America (Columbia) (Wisniak 2015). In 1809 William Hyde Wollaston questioned the existence of columbium as a different element from tantalum (Wollaston 1809). In a way this critical paper nullified the studies of the composition of columbite. Therefore, when the German chemist Heinrich Rose in 1844 published his studies on the tantalum ores, he did not receive any major objections to propose names "niobium" and "pelopium"

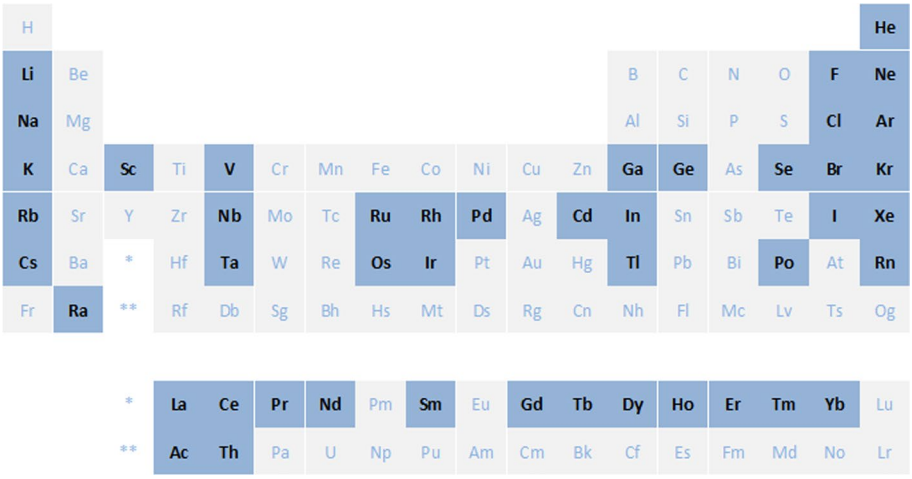

Fig. 1 Elements discovered and named in nineteenth century

for the suggested new elements in the ore without looking back at previous research (Rose 1844). Thus, the name niobium appeared for the first time in 1844 in the Rose's work entitled *Ueber die Zusammensetzung der Tantalite und ein im Tantalite von Baiern enthaltenes neues Metall,* published in *Annalen der Physik*. As it shortly occured, "pelopium" was a mixture of niobium and tantalum. During the next two decades the series of studies clarified that niobium and columbium were one and the same element. However, instead of replacing one name with the other, the scientific world of that time adopted both names which were used interchangeably. The name columbium (symbol Cb) remained in use predominantly in American journals. Double nomenclature caused more and more confusion over time. Finally the name niobium was chosen for the element #41 at the 15th Conference of the Union of Chemistry in Amsterdam in 1949, and a year later it was officially adopted by the International Union of Pure and Applied Chemistry (Rayner-Canham and Zheng 2008). An interesting fact is that the term "columbium", used for the description of the element #41 in American scientific articles specialized mainly in the field of metallurgy and social sciences (concerning e.g. metal ore conflicts), has remained in a rudimentary form to this day.

Cerium

Cerium was the second discovered rare earth metal after yttrium. The works on isolation of this element were conducted in Sweden by Jöns Jakob Berzelius and Wilhelm Hisinger, and independently in Germany, by Martin Heinrich Klaproth—both in 1803. Originally, the element was isolated in the form of its oxide, which was named "ceria" by Berzelius and "ochroit" by Klaproth. The Swedish report was sent to Germany to be published in the 2nd tome of the *Neues Allgemeines Journal der Chemie* with the year inscription 1803. The title of the paper was *Cerium, ein neues Metall aus einer schwedischen Steinart, Bastnäs Tungsten genannt* (Hisinger and Berzelius 1803). The results of Klaproth's experiment were printed simultaneously in the same issue of this journal (Klaproth 1803). In order to somehow establish the priority, the results of the Swedes were also printed in Swedish as a kind of low-circulation report entitled *Cerium en ny metall funnen a Bastnas Tungsten fran Riddarhyttan i Westmanland* (Hisinger and Berzelius 1804). After several letter exchanges between Europe's foremost analysts, Klaproth eventually recognized the Swedish results of the analyses and the right to name the new element (Trofast 1996). Finally, it was Carl Gustaf Mosander who in 1826 isolated the metal in elemental state (Mosander 1826). After a few years, both "yttria" and "ceria" became rich material for the search for various other elements that make up the group of the so-called "rare earth elements"(Evans 1996).

Osmium and iridium

Osmium and iridium were discovered by Smithson Tennant as a result of scientific studies of the dark, insoluble residue left after dissolving of platinum in *aqua regia*. This English chemist described his discovery in the *Philosophical Transactions of the Royal Society of London* in 1804, in the article entitled *On two metals, found in the black powder remaining after the solution of platina* (Tennant 1804). The interesting history (differing in details from generally accepted version) of naming of the hypothetical metal in the platinum residue as "ptene" by Antoine Foucroy and Louis Vaquelin is thoroughly described

by Haubrichs and Zaffalon (Haubrichs and Zaffalon 2017). However, both French chemists finally recognized the priority of the discovery of new elements by Smithson Tennant (Griffith 2004).

Rhodium

Platinum studies focused not only on the *aqua regia* insoluble black residue, but also on the solution. It turned out that, in addition to platinum, it hides two other, previously unknown, chemical elements (rhodium and palladium). Both were discovered by William Wollastone (Griffith 2003). The first one—rhodium was presented in the paper entitled: *On a new metal, found in crude platina* published in 1804 in *Philosophical Transactions of the Royal Society of London,* i.e. in the same issue as previously described paper of Smithson Tennant discussing osmium and iridium (Wollaston 1804).

Palladium

The science historians mostly agree that the way to present palladium and the history of its discovery, full of twists and emotions, was the most extraordinary and bizarre event in all of the discovering-element history (Griffith 2003; Usselman 1978).The world learned about palladium from an advertising leaflet, sent anonymously by William Wollaston to the scientists in London in April 1803. The leaflet listed some properties of a theoretically new noble metal called "*palladium or new silver"* and even advertised palladium for sale. The text of the leaflet, together with the critical opinion about new metal of Richard Chenevix, was reprinted in the Nicholson's *Journal of Natural Philosophy, Chemistry and the Arts* in August 1803. Thus, not counting the leaflet, the first information on palladium was included in the above mentioned note entitled *Some Account of a Pretended New Metal Offered for Sale, and Examined by Richard Chenevix* (Nicholson 1803). Without going into details, at this point it should be clarified that this unusual manner of publishing of a new element discovery was dictated by the desire of Wollaston to keep the process of malleable platinum production in secret. Palladium was in fact a by-product of the above mentioned process. Wollaston, together with Tennant, invested a lot in this business and did not want to disclose the details of the purification process to the competition (especially to Vauquelin and Fourcroy). On the other hand Wollaston wanted to be considered as the palladium discoverer(Cottington 1991; Wisniak 2006). The critical opinion of Chenevix about the discovery, which was read to the Royal Academy in London at 12th of May 1803 (Chenevix 1803), forced Wollaston to admit the palladium discovery in 1805 in the paper, which he read to the Royal Society on 4th July 1805(Wollaston 1805).

Sodium and potassium—an inseparable pair

Similar to the elements described first in their "earths", both the terms *potasse* and *soude* functioned in the literature for description of alkali since medieval and even ancient times, sometimes interchangeably. Again, it is extremely difficult to state who was the first to recognize their individuality. Moreover, those two elements' names exist in two popular versions depending on the language group, so they need to be included in this study.

Potassium/kalium

The word potassium is derived from the word "potash" which refers to potassium compounds having been originally obtained by leaching wood-ashes and evaporating the solution gathered in a large iron pot or pan since no later than fifteenth century (Harper 2000). The composition of potash had not been known until the beginning of nineteenth century. In 1789, in his *Traité élémentaire de chimie,* Lavoiser stated that potash (La potasse) is complex but he did not manage to decompose it yet (Lavoisier 1789). It was also Martin Heinrich Klaproth who worked on the so called alkali—residues which arise after roasting, and proposed the name "kali" for vegetable alkali and "natron" for mineral alkali (Klaproth 1797). Finally Humpry Davy managed to separate new element and made his discovery public in the Bakerian lecture at the Royal Society of London on 19 November 1807, among others proposing the name potassium. The lecture was published in 1808 in *Philosophical Transactionsof the Royal Society London* under the title: *On some new phenomena of chemical changes produced by electricity, particularly the decomposition of the fixed Alkalies, and the exhibition of the new substances which constitute their bases; and on the general nature of alkaline bodies* (Davy 1808a).The results of Davy's research were made public in German in the 28th and 31st volume of the *Annalen der Physik* (Davy 1809; Davy 1808b). The Editor Ludwig Wilhelm Gilbert, however, wrote in the footnote of the second paper: "In our German nomenclature, I would suggest the names kalium and natronium…[for potassium and sodium]" (Davy 1809). Consequently, Gilbert started to use the name "kalium" in subsequent German articles. He probably followed the proposal of Klaproth from 1797.

Sodium/natrium

The word sodium is derived from Arabic صُداع (ṣudāʿ) meaning splitting pain in the head, as the medieval "sodanum" (sodium carbonate) was used to combat this pain. This terminology inspired Humphrey Davy to name the element sodium when he first isolated it by passing an electric current through sodium hydroxide. He read his discovery in his Bakerian lecture in 1808 (presented in the previous paragraph regarding potassium) (Davy 1808a). The term sodium was presented together with potassium.

The history of the word "natrium" is similar to "kalium". Both names were upheld by Klaproth and Gilbert. The word "natron" derives from the Ancient Egyptian word nṯrj describing deposits of sodium carbonate and bicarbonate mined in Wadi El Natrun. Klaproth proposed the name "natron" for so-called mineral alkali in contrast to wood alkali (Klaproth 1797). Consequently, Gilbert, while translating the work of Davy, insisted on using "natronium" instead of sodium (Davy 1809). The name natronium was shortened later by Berzelius to "natrium"(Berzelius 1814).

To sum up, the English and French speaking countries followed Davy´s proposals potassium and sodium and the German countries adopted Gilbert/Klaproth's names kalium and natrium.

Chlorine and the other halogens

Chlorine was discovered in 1774 by Carl Wilhelm Scheele. He produced chlorine gas by heating pyrolusite (MnO_2) with hydrogen chloride (Scheele 1774), but did not recognize it as an element. It was Humpry Davy who, in his lecture from 15th of November 1810, proved that the Scheele's gas was actually a distinct element. The Davy's lecture, entitled *On some of the Combinations of Oxymuriatic Gas and Oxygene, and on the chemical Relations of these Principles, to inflammable Bodies* with name proposal was printed in *Philosophical Transactions of the Royal Society*, dated already to 1811 (Davy 1811).

Iodine

Iodine was accidently discovered by Bernard Courtois in 1811. However, the name "iode" was proposed by Joseph Gay-Lussac and published under Courtois's name in the paper *Découverte d'une substance nouvelle dans le Vareck* in *Annales de Chemie* in 1813 (Courtois 1813). It must be added that in the same volume of the journal there are three other articles about iodine—two by Joseph Gay-Lussac and one by Humpry Davy (Davy 1813a; Gay-Lussac 1813a, 1813b). Rather awkward history of publishing of the new discovery and the competition between scientists from two countries in conflict with each other is pictured in the publications of Kelly and Wisniak (Kelly 1961; Wisniak 2002). The English name iodine was proposed by Humpry Davy in 1814 (Davy 1814).

Fluorine

It was already Georgius Agricola who described in his treaties "fluores" as stones/gems that become liquid in fire and in this manner they lower the melting point of metals during smelting. The earliest treatise is entitled *Medici Bermannvs, Sive De Re Metallica* from 1530, where the explanation of "fluores" can be found at pages 125–127 (Agricola 1530). One of these "stones"—fluxes was certainly fluorspar (CaF_2). The first scientific article on the "Flußspat" was published by Andreas Marggraf in 1770 (Marggraf 1770). Later Carl Wilhelm Scheele did a lot of work concerning fluorspar (Flußspat) and the acid, which he named Flußspatsäure (hydrofluoric acid). At the beginning of 19th century it became more and more evident that the "fluoric acid" is a complex compound of a new element, similarly like muriatic acid (HCl) turned out to be a compound of newly discovered chlorine. From 1809 till 1812 Humpry Davy and André Marie Ampère exchanged several letters discussing this problem (Tressaud 2019). In 1813 Humpry Davy finally published the paper *Some experiments and observations on the substances produced in different chemical processes on fluor spar (*in the *Philosophical Transactions of the Royal Society of London,* which was typical for him) in which he proposed (inspired by Ampère) the name *fluorine,* assigned for the still putative element—a compound of "fluoric acid" (Davy 1813b). Ampere, however, soon changed his mind and renamed the new element "phtore", which is still in use in some languages (Ampère 1816). Finally, fluorine was only isolated in 1886 by Henri Moissan (Moissan 1886).

Bromine

Bromine was discovered independently by two chemists, Carl Jacob Löwig, from a mineral water spring, and Antoine Balard, from seaweed. Löwig made his discovery in 1825, but he simply not completed his studies of the element until 1827 (Löwig 1827). Balard made his announcement in 1826 and therefore he was credited to propose the name. At first he wanted to name the new element "muride". However, in his article *Mémoire sur une substance particulière contenue dans l'eau de la mer,* published in *Annales de Chimie et de Physique,* he states that prof. Joseph Anglada persuaded him to name this new element "brome"(Balard 1826). On the other hand, in the same issue of the journal, Vauquelin, Gay-Lussac and Thénard, who were members of the French Academy, claimed in the *Rapport sur la Mémoire de M. Balard relatif à une nouvelle Substance*" that they had renamed the new element "brome"(Vacqelin et al. 1826; Wisniak 2004). The suffix -ine in the English name was added as such a suffix was used for other, previously discovered halogens.

Selenium

Selenium was first identified by Jöns Jacob Berzelius and Johann Gottlieb Gahn in 1817. Berzelius announced the new element discovery with the name proposal in a series of letters sent to various scientists and journal editors all over Europe, which resulted in a number of "selenic" publications. The first two articles appeared in the *Journal für Chemie und Physik*, issued still with the year indication 1817 (although the letters were sent already in 1818):

- *Ein neues mineralisches Alkali und ein neues Metall*, in which, apart from the "lithion" (lithium) element, the name selenium was announced (Berzelius 1817a),
- *Ueber das Selenium*, dedicated particularly to the new element (Berzelius 1817b).

The other papers, based on Berzelius' letters from the same time, but dated already to 1818:
In *Annales de Chimie et de Physique*:

- *Recherches sur un nouveau corps minéral trouvé dans le soufre fabriqué à Fahlun* (Berzelius 1818a).

In *Annals of Philosophy*:

- *On the Discovery of a new Alkali and a new Metal (letter)* (Berzelius 1818b),
- *On Selenium and Lithion* (Berzelius 1818c).

In *Afhandlingar i Fysik, Kemi och Mineralogi:*

- *Undersökning af en ny Mineral-kropp, funnen i de orenare sorterna af det vid Fahlun tillverkade svaflet* (Berzelius 1818d)—the 102 pages long article.

In *Kongliga Svenska vetenskapsakademiens handlingar:*

- *Undersökning af an ny Mineral-kropp, som innehalles i det vid Fahlun tillverkade svafvel* (Berzelius 1818e).

In *Annalen der Physik:*

- *Chemische Entdeckungen im Mineralreiche, gemacht zu Fahlun in Schweden: Selenium ein neuer metallartiger Körper, Lithon ein neues Alkali, Thorina eine neue Erde* (Berzelius 1818f).

The whole history of selenium discovery, among others, is described in detail by Jan Trofast (Trofast 2011).

Lithium

Lithium was discovered in the mineral petalite by Johan August Arfwedson, a student of Jakob Berzelius, in 1817. The discovery was described in 1817 in the same article as selenium, entitled *Ein neues mineralisches Alkali und ein neues Metal* in *Journal für Chemie und Physik*. In the article Berzelius proposed the name "lithion" for the newly discovered alkali (Berzelius 1817a). The element name lithium appears in one of Berzelius' papers in *Annalen der Physik,* as added in the footnote probably by the editor Ludwig Wilhelm Gilbert (Berzelius 1818f). Lithium was not isolated until 1821, when William Thomas Brande described its retrieval by electrolysis of lithium oxide. He confirmed and established the name lithium for the obtained metal in pure form (Brande 1821).

Cadmium

The history of cadmium identification is complex, as more than a few scholars and pharmacists made claim to the discovery. Finally it was Friedrich Stromeyer, who isolated new metal in 1817, who gave the name "Kadmium" to the new element, and whose proposal was honored. His discovery was described in *Journal für Chemie und Physik*, in the article *Ein neu entdecktes Metall und Analyse eines neuen Minerals* (Stromeyer 1817). The intricate history of the discovery of cadmium between 1817 and 1818 and of the alternative names proposals is described, among others, in the book by Fontani (Fontani et al. 2015a). Regardless of assigning the palm to the discovery of cadmium, it is undisputed and worth emphasizing that this element was historically the first metal isolated from an ore by-component of another element (zinc). It became possible thanks to the relatively advanced development of analytical chemistry already at that time.

Vanadium

Vanadium was discovered by Spanish chemist Andrés Manuel del Río in 1801, however, the evidence he provided did not convince scientists from the rest of the Europe. That is why he withdrew his claim of the discovery of a new element (Caswell 2003). The element

was rediscovered by Nils Gabriel Sefström in 1830. He proposed the name vanadium for the new metal in the paper *Om Vanadium, en ny metall, funnen uti stångjern, som är tillverkadt af malm ifrån Taberget i Småland* published in *Kungliga Svenska Vetenskapsacademiens Handlingar* (Sefström 1830). However, he isolated only vanadium compounds. The metal was isolated by Henry Roscoe in 1867 (Roscoe 1869).

Thorium

In 1818 Jöns Jacob Berzelius announced that three years earlier he had found "new earth", which he named "Thorina" or "Thorjord", depending on language (Berzelius et al. 1818; Berzelius 1818f). However, it turned out to be a compound of yttrium, that is why he retracted his findings in 1824 (Berzelius 1824). He, however, later reintroduced the name of the previously putated "earth". He named the new earth, which he was given for studies from Jens Esmark. The new element was given the name thorium and the mineral it was obtained from was named "thorit". The discovery was announced by Berzelius in 1829 in the publication *Undersökning af ett nytt mineral, som innehåller en förut obekant jord*, published in *Kungliga Svenska Vetenskapsakademiens Handlingar* (Berzelius 1829; Waggoner 1975).

Lanthanum

Lanthanum, as an oxide of the new element, was isolated from cerium compounds by Carl Gustaf Mosander. His discovery of the element became quickly known from Berzelius's letters to the colleagues abroad in 1839. Such information appears in a few papers in the form of a letter. The first one, in which the name suggestion "Lantane" can be found, was probably the excerpt from the letter to Jules Pelouze, dated February 22, 1839, entitled *Nouveau metal* and published in *Comptes rendus hebdomadaires des seances de l'Academie des sciences de Paris* (Berzelius 1839). To get acquainted with full article the scientific world had to wait till the meeting of the Scandinavian Naturalists Society (*Skandinaviska Naturforskare Sällskapet*) in July 1842, at which the paper was read and published in the same year in *Forhandlinger ved de Skandinaviske Naturforskeres Möde* under the title *Något om cer och lanthan* (Mosander 1842).

Erbium and terbium

The story of naming elements 65 and 68 is inversely proportional in its complexity to the innovativeness (fantasy) of the proposed names (which originated from the village name—Ytterby, much like yttrium and ytterbium). Carl Gustaf Mosander managed to split yttria ("earth" of yttrium) into three new oxides: colourless yttrium oxide, yellow "erbium" oxide and reddish "terbium" oxide. His achievements were presented at the *13th Meeting of the British Association for the Advancement of Science*, and printed in the report from this meeting, as well as in *Philosophical Magazine* (Mosander 1844, 1843). However, in 1860 Nils Johan Berlin, in his article *Om de i den blandade ytterjorden befintliga oxider* published in *Forhandlinger ved de Skandinaviske Naturforskeres Möde,* described the analysis of *yttria,* in which he found only the rose (orange) colored salt apart from the yttrium.

Berlin gave the name (a little confusingly, as inversely to Mosander) "erbia" (erbinjorden) for this compound. In the same article he also questioned the existence of terbium (Berlin 1860). Later Marc Delafontaine followed him in naming the rose-colored oxide the "erbine"(Delafontaine 1864). However, contrary to Nils Berlin, Delafontaine continued to support the point of view that terbium existed. In 1866 he wrote: "the matter of existence of the third "earth"(except yttria and erbia) will therefore remain pending until further information is provided"(Delafontaine 1866). Moreover, he proposed the name "mosandrium" for this element, which did not pan out. Finally, the French scientist proved that the yellow-oxide earth existed, but, at the prompting of Marignac, he decided to name it "terbine" (1877) for the "earth" and eventually terbium (1878) for the element. He depicted his propositions, and systematized the nomenclature in two papers published in *Archives des sciences physiques et naturelles*: *Recherches sur quelques minéraux niobifères et tantalifères* and *Sur le terbium et ses composés et sur l'existence probable d'un nouveau mêtal dans la samarskite de la Caroline du Nord* (Delafontaine 1878, 1877). As the name erbium had been already assigned to the orange oxide by Nils Berlin, the reused name terbium was assigned by Delafontaine to the yellow oxide. Thus, the original Mosander's names were switched.

Ruthenium

Rhutenium was discovered at least three times. Once by Jędrzej Śniadecki, around 1808, and it was named *Vestium* (Śniadecki 1808). However, his work was never confirmed. The second time the element was found in platinum by Gottfried Osann. Although he already signaled the discovery in papers in 1826 and 1827, the name ruthenium did not appear until 1828, in the article *Fortsetzung der Untersuchung des Platins vom Ural* published in *Annalen der Physik und Chemie* (Osann 1828). However, the Osann's results were questioned and finally he withdrew his discovery in 1829 (Osann 1829). In 1844 Karl Ernest Claus showed that the compounds prepared by Gottfried Osann contained small amounts of a new element. Claus remained with the name ruthenium for his discovery. This (re)discovery was first reported in Russian in 1844 in paper *Химические исследования остатков уральской платиновой руды и металла рутения (Chemical studies of the remains of the Ural platinum ore and ruthenium metal)* in the journal *Учёныезаписки Казанского университета (Scientific notes of the Kazan University)* (Klaus 1844). In the abbreviated form the article was presented in the same year in the *Bulletin de la classe physico-mathématique de l'Académie impériale des Sciences de St. Pétersbourg* in the article *Découverte d'un nouveau metal* (Claus 1844).

Caesium, rubidium and the beginnings of spectroscopic discoveries

Caesium/cesium and rubidium were discovered simultaneously by Gustav Kirchhoff and Robert Bunsen in 1860. These were the first elements discovered spectroscopically. The names of both metals appeared in the work from 1861, dealing with the analysis of the spectra of elements, entitled *Chemische Analyse durch Spectralbeobachtungen. Zweite Abhandlung*, published in *Annalen der Physik und Chemie* (Kirchhoff and Bunsen 1861). Rubidium was probably isolated for the first time by Bunsen around 1863, and caesium in 1882 by Carl Setterberg (Bunsen 1863; Setterberg 1882).

Thallium

Thallium was discovered by William Crookes and almost simultaneously by Claude-Auguste Lamy. Both scientist conducted their discoveries with use of the spectroscope. However, it was Crookes, who first announced the new discovery in *Chemical News* in 1861 (Crookes 1861a), later reprinted in other scientific journals. The name thallium appeared already in the second article of the cited journal discussing this element and entitled *Further remarks on the supposed new metalloid* (Crookes 1861b). Both scientists were able to isolate small quantities of the metal by 1862 (Crookes 1863; Lamy 1862).

Indium

Indium was discovered spectroscopically by Ferdinand Reich and Theodor Richter in 1863. The new indigo-colored line was observed in the ores from the mines around Freiberg. They announced their discovery and proposed the name in the same year in the paper *Vorläufige Notiz über ein neues Metall*, in the *Journal für praktische Chemie* (Reich and Richter 1863). A year later Richter isolated the metal for the first time (Reich and Richter 1864).

Gallium

Gallium was the first element discovered after Dimitri Mendelev's proposal of his periodic table (Akeroyd 2010). He predicted the existence of this metal and named it "eka-aluminium" (Mendeleev 1869). The metal was discovered by Paul Émile Lecoq de Boisbaudran in the sphalerite mineral in 1875. He described his discovery with the name proposal in *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences* in the note entitled *Caractères chimiques et spectroscopiques d'un nouveau métal, le gallium, découvert dans une blende de la mine de Pierrefitte, vallée d'Argelès (Pyrénées)* (Lecoq de Boisbaudran 1875). The isolation of metallic gallium was described three years later by Lecoque and Jungfleisch (Lecoq de Boisbaudran and Jungfleisch 1878).

Germanium

Germanium was discovered by Clemens Alexander Winkler in the argyrodite mineral. He described and named the new element in 1886 in the paper entitled: *Germanium, Ge, ein neues, nicht metallisches Element,* published in *Berichte der Deutschen Chemischen Gesellschaft* (Winkler 1886). The first name choice of Winkler for the new element was in fact "neptunium" after the planet discovered in 1846. However, he shortly realized that this name had already been assigned to another "element" that later turned out to be false (an alloy of niobium and tantalum) (Fontani et al. 2015b).

The rare earth elements discovered in nineteenth century—ytterbium to gadolinium

Ytterbium

Jean Charles Galissard de Marignac is credited with the discovery of another rare earth element—ytterbium, in 1878. However, in the first paper about the isolation of the "new earth" from the gadolinite mineral, recognized as a pioneer article dealing with this topic, there is no name suggestion (Marignac 1878a). The name "ytterbine" for the "earth" of the new element appeared in the following note published in *Comptes rendus hebdomadaires des séances de l'Académie des sciencest,* entitled *Sur l'ytterbine, nouvelle terre contenue dans la gadolinite* (Marignac 1878b). After the lutetium separation from ytterbia in 1907, the element #70 was renamed "neoytterbium" by Georges Urbain (Urbain 1907). However, from the beginning of the 1920s the name ytterbium gradually began to replace Urbain's proposal in the scientific publications (headed by the Journal of the American Chemical Society) and became established in the nomenclature.

Holmium, thulium

Holmium was discovered in the "earth erbia", simultaneously by Jacques-Louis Soret, Marc Delafontaine and Per Teodor Cleve. However, it was Cleve who proposed its name. Cleve also found another element in the same sample, which he named thulium, Both discoveries were described and the names appeared in 1879, in the paper *Sur deux nouveaux éléments dans l'erbine,* published in *Comptes rendus de l'Académie des sciences* (Cleve 1879).

Scandium

Scandium was found in the sample of "ytterbia" by Lars Frederick Nilson, who prepared scandium oxide and described the new element in the note from 1879: *Sur le scandium, élément nouveau* published in *Comptes rendus hebdomadaires des séances de l'Académie des sciences* (Nilson 1879).

Samarium

Paul Émile Lecoq de Boisbaudran isolated samarium oxide from the samarskite mineral in 1879. Lecoq called the new earth "samaria" and new element samarium, after the mineral source. His discovery was described in *Comptes rendus hebdomadaires des séances de l'Académie des sciences,* in the note *Recherches sur le samarium, radical d'une terre nouvelle extraite de la samarskite* (Lecoq de Boisbaudran 1879). As the name of the mineral originated from the name of Vasili Yevgrafovich Samarsky-Bykhovets—a Russian mining engineer, thus, samarium became the first chemical element to be named after a person.

Praseodymium, neodymium

In 1885 Carl Auer von Welsbach proofed that the element "didymium" was in fact a compound of two elements, which he named "praseodym" and "neodym". He published his

discovery in the German periodical *Monatshefte für Chemie und verwandte Teile anderer Wissenschaften* in the article *Die Zerlegung des Didyms in seine Elemente* (von Welsbach 1885).

Dysprosium

Paul Émile Lecoq de Boisbaudran also separated and named dysprosium, while working with holmium oxide in 1886. He described his discovery in two short notes *L'holmine (ou terre X de M Soret) contient au moins deux radicaux métalliques* and *Sur le dysprosium,* published separately in *Comptes rendus hebdomadaires des séances de l'Académie des sciences* (Lecoq de Boisbaudran 1886a, 1886b).

Gadolinium

The element gadolinium was isolated from "terbia" by Jean Charles Galissard de Marignac in 1880. However, the French scientist temporarily named it Yα (Marignac 1880). In 1886 Paul Émile Lecoq de Boisbaudran produced a more pure form of the "earth Yα" from the "earth didymia". In a short communication published in *Comptes rendus hebdomadaires des séances de l'Académie des sciences* he announced that Marignac had chosen to give the name gadolinium to the metal from the previously discovered "earth" Yα. The title of the note was *Le Yα de M. de Marignac est définitivement nomme gadolinium* (Lecoq de Boisbaudran 1886c).

Noble gases discoveries and nomenclature

Argon

Argon was the first isolated noble gas. The first official paper about this element, with the name proposal, was published by its discoverers William Ramsay and John William Strutt (Lord Rayleigh) in the *Philosophical Transactions of the Royal Society of London* in 1895. The title of the paper was *Argon, a new constituent of the atmosphere* (Strutt and Ramsay 1895).

Helium

Helium was discovered in the spectrum of the Sun by Norman Lockyer while he was studying a total solar eclipse in 1868. However, Lockyer never seemed to have formally proposed the name "helium" in a published paper. That is why, surprisingly, the first time the word "helium" officially appeared was at page XCIX of the *Address of William Thomson* (Lord Kelvin), printed in the *Report of the 41st Annual meeting of the British Association for the Advancement of Science* in 1872 (held in 1871). The remarkable fact is that both the information about the discoverer and the name of the element were inserted in the footprint of the speech (Thomson 1872). However, the Report wasn't printed in its full version until 1872, and there were at least two earlier reprints of the *"Inaugural Address of Sir William Thomson"* published just after the Meeting in August 1871. The first one in the relatively new periodical *Nature*, and the second one in the *Chemical News and Journal of Physical*

Science (Thomson 1871a, 1871b). The first portions of terrestrial helium were obtained by William Ramsay by boiling mineral cleveite with dilute sulfuric acid in 1895—27 years after discovery of He in the Sun (Ramsay 1895a; Ramsay 1895b).

Krypton

It was the name "krypton" that was used by William Ramsey to describe above mentioned gas found in mineral cleveite in 1895 (Jensen 2004). Nevertheless, when it turned out that the gas had already been identified by Lockyer as helium, Ramsay withdrew from the proposal. However, in 1898 he re-used the name krypton for the gas found in the residue left from evaporating nearly all components of liquid air. The new element was described by him and his assistant Morris Travers in the *Proceedings of the Royal Society of London* in the note: *On a New Constituent of Atmospheric Air* (Ramsay and Travers 1898a).

Neon

The same experiment as in case of krypton was repeated a few weeks later. As a result the duet Ramsay—Travers discovered a new spectral green line originated from unknown element, which they named neon. The discovery was described in the same issue of *Proceedings of the Royal Society of London* as krypton, in the article *On the Companions of Argon* (Ramsay and Travers 1898b).

Xenon

Xenon was discovered in September 1898 by Ramsay and Travers as well. They obtained the new gas after multiple fractionation of krypton (Davies 2012). The first official announcement of the xenon discovery and name was published in October 1898 in the *Report of the Meeting of the British Association for the Advancement of Science.* The speech was called *On the extraction from air of the companions of argon and neon* (Ramsay and Travers 1899).

Polonium and the beginning of the era of radioactive elements

Polonium was the first element discovered while studying the phenomenon of radioactivity, described by Henri Becquerel in 1896 (Becquerel 1896). The discovery and the name proposal of the first radioactive element was announced by Pierre Curie and Marie Skłodowska-Curie in 1898 in *Comptes rendus hebdomadaires des séances de l'Académie des sciences* in the note *Sur une substance nouvelle radio-active, contenue dans la pechblende* (Curie and Skłodowska-Curie 1898).

Radium

Radium was discovered in the same laboratory as polonium, but a few months later. Both the description and name proposal were presented by the Curies and their colleague Gustave Bémont in the same issue of *Comptes rendus hebdomadaires de l'Académie des*

sciences as polonium, but in the second article entitled *Sur une nouvelle substance fortement radioactive, contenue dans la pechblende* (Curie et al. 1898).

Radon

In 1899 Ernest Rutherford and Robert Owens discovered another radioactive element, which turned out to be a gas emitted by thorium oxide (Owens and Rutherford 1899). In the same year the Curies observed the radioactive gas emitted by radium (Curie and Curie 1899). For several years the name "radium emanation" was in use for this gas. In 1910 Ramsay and Whytlaw-Gray proposed the name "niton", which was not widely accepted though (Ramsay and Whytlaw-Gray 1911). It was Curt Schmidt in 1918, whose name proposal—radon, for the gaseous element was finally accepted. He presented his suggestion in the article *Periodisches System und Genesis der Elemente* printed in *Zeitschrift für anorganische und allgemeine Chemie* (Schmidt 1918). In 1923, the International Committee for Chemical Elements and International Union of Pure and Applied Chemistry (IUPAC) finally accepted the name proposed by Schmidt (the other Schmidt's proposals for the isotopes of this element, "thoron" and "akton", were changed later, when isotopes were decided to be numbered instead of having a name).

Actinium

André Louis Debierne was the discoverer of the element #89. In 1899 he received several hundred kilograms of the pitch blend from the Curies. After separating uranium, radium and polonium, he found a radioactive material in the remains, which was almost 100,000 times more active than uranium. He described his discovery in a few articles in 1899 and 1900 in *Comptes rendus hebdomadaires.* The name proposal appeared in the note from 1900, entitled *Sur un nouvelle matière radio-actif—l'actinium.* Thus, actinium was the last element discovered and named in nineteenth century (Debierne 1900).

Summary

In the nineteenth century, the notion of a chemical element as an indivisible entity was established. It was a period of intensive development of analytical and physical chemistry, which resulted in the discovery of 46 new chemical elements. However, the discovery and official publication of the name of the element did not always go hand in hand. The best examples of this are the discovery stories of palladium, helium or radon. The period in question was extremely turbulent in terms of the discoveries of the elements. Researchers have been arguing for many years about the palm of priority for discoveries, as in the case of the discovery of cadmium or iodine. In the background of the nineteenth century research there was also the so-called Great History of rivalry and wars between France, Prussia (and then the Second German Reich) and Great Britain, which influenced the mutual recognition of research as well as giving and unifying the names of elements (e.g. iodine, sodium or potassium). On the other hand, the desire to write down on the pages of history as a discoverer of a new element, with still imperfect analytics, caused a number of false discoveries or duplication of earlier discoveries. The so-called "non-existent elements" and the stories of their "discoveries" are only partially described in this paper in some subsections, when a given history is strongly connected with an existing element (e.g.

didymium, columbium, phtore, vestium, etc.). However, these facts are described in more detail in an excellent book of M. Fontani et al. *The Lost Elements: The Periodic Table's Shadow Side* (Fontani et al. 2015b). The nineteenth century in the history of chemistry ended with the discovery of elements with unstable isotopes. Thus, it is the discoveries of radioactive elements that will dominate the following decades.

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