INSTITUT DE FRANCE
Académie des sciences

Comptes Rendus Chimie

Marco Fontani, Mary Virginia Orna and Mariagrazia Costa

Chemists and physicists behaving badly: The shadow side of two elemental discoveries

Volume 23, issue 3 (2020), p. 231-241

Published online: 24 September 2020
Issue date: 24 September 2020

https://doi.org/10.5802/crchim.1

Part of Special Issue: Variations around the Periodic Table
Guest editors: Pierre Braunstein (Université de Strasbourg, Académie des sciences) and Robert Guillaumont (Académie des sciences)

CENTRE MERSENNE

Les Comptes Rendus. Chimie *sont membres du Centre Mersenne pour l'édition scientifique ouverte*
www.centre-mersenne.org
e-ISSN : 1878-1543

Comptes Rendus
Chimie
2020, 23, nº 3, p. 231-241
https://doi.org/10.5802/crchim.1

Variations around the Periodic Table / *Variations autour du tableau périodique*

Chemists and physicists behaving badly: The shadow side of two elemental discoveries

Des chimistes, et leurs mauvaises habitudes

Marco Fontani[*, a], **Mary Virginia Orna**[b] **and Mariagrazia Costa**[a]

[a] Dipartimento di Chimica "Ugo Schiff", Università degli Studi di Firenze, Italy

[b] College of New Rochelle, New Rochelle, NY, USA

E-mails: marco.fontani@unifi.it (M. Fontani), maryvirginiaorna@gmail.com (M. V. Orna)

Abstract. It is appropriate to recall that 2019 was the year dedicated to the Periodic Table. But when we speak about false elements – in the aftermath of the celebrations marking this year, – we are greeted most warmly, but with some puzzlement, as to how it came to mind to celebrate "Mendeleev's creature" in such a peculiar way, that is, by commemorating elements that never existed. In the course of many years, we have discovered and collected a great number of discoveries of simple bodies that sooner or later turned out to be *detours* or false tracks.

Résumé. Il convient de rappeler que 2019 a été l'année consacrée au tableau périodique. Mais quand nous parlons de faux éléments – au lendemain des célébrations de cette année – nous sommes accueillis très chaleureusement, mais avec un peu de perplexité quant à l'idée de célébrer la "créature de Mendeleïev" d'une manière si particulière, c.-à-d., en commémorant des éléments qui n'ont jamais existé.

Keywords. Periodic table, Element 61, Transuranic elements, Missing elements, History of chemistry.

Note. D'après une conférence donnée le 19 novembre 2019 à l'Académie des sciences à Paris, à l'occasion d'une conférence-débat intitulée « Variations sur le Tableau Périodique » pour célébrer le 150ᵉ anniversaire de la publication de Mendeleïev.

Note. Based on a lecture given on Nov. 19, 2019, at the "Académie des sciences" in Paris, on the occasion of a "Conférence-débat" entitled "Variations around the Periodic Table" to celebrate the 150th anniversary of the Mendeleev's publication.

1.1. The twilight of naturally occurring elements: florentium, ausonium and hesperium

Both of the stories we are going to tell have a common denominator: geographic and chronological. The location is Italy; the relevant time period for these stories is the twenty years of Fascism that left indelible marks on Italian history. The little known case of element 61, the so called, ill-fated *florentium*, was completely forgotten soon after it was expelled from the Periodic Table. The second case, a bit more famous, regards the first attempt to synthesize transuranic elements (*ausonium* and *hesperium*) by

* Corresponding author.

the Nobel laureate Enrico Fermi and his co-workers in 1934–1938. This double story does not aim to fill out only those particular gaps in the Periodic table. It is mainly written to underline the fact that the experimental sciences are, by their very nature, susceptible to many errors.

It is an ego-ridden tale, a story of extreme nationalism, of pride and prevarication, to make a case for elements that never were. Nevertheless, it is necessary to remember that speaking of the periodic table does not mean to speak exclusively of chemistry or physics. The periodic table is an extremely versatile object, both for its multiple applications in science and for its sociological ramifications up to its representations in pop art and sci-fiction.

"... its (the Periodic Table's) capacity to unify apparently disconnected phenomena under a simple framework facilitates our understanding of periodicity, making the table an icon of aesthetic value, and an object of philosophical inquiry" [1].

2.1. The ill-fated rare earth

The history of the element with atomic number 61 is so unusual that it deserves an extended discussion. The study of the rare earths reached its apogee during the years when chemists tried to order the chemical elements according to a rule. In 1862, the French scientist Alexandre-Émile Béguyer de Chancourtois (1820–1886) arranged the elements in order of their atomic weights, drawing a diagram on a cylindrical graph; similar elements tended to be arranged in vertical columns. Unfortunately, only the report (not the chart) was published, and consequently this unique idea went unnoticed. Two years later, the English chemist John Alexander Reina Newlands (1837–1898) made his famous attempt; he arranged all the known elements on the basis of their increasing atomic weight. He observed that this arrangement allowed for the attribution of an order, at least partial, to the properties of the elements. In 1869, the Russian chemist Dmitrij Ivanovich Mendeleev (1834–1907) presented a paper to the Russian Chemical Society – "On the relationship between properties and atomic weight of the elements" – and considered his discovery a "direct consequence of the set of deductions drawn from the experimental facts accumulated towards the end of decade 1860–1870." In the same year, Julius Lothar Meyer (1830–1895) had arrived at the same conclusions, but his publication appeared later.

The Periodic Table allowed one to predict the existence of elements not yet known and to estimate their chemical properties. In 1879, didymium ceased to be mentioned as a single element: the French chemist Paul-E. Lecoq de Boisbaudran (1838–1912) separated samarium from it.

Six years later, Carl Auer von Welsbach (1858–1829) extracted two other elements from didymium: *neo-didymium* (neodymium) and *praseo-didymium* (praseodymium). In 1886, William Crookes (1832–1919) [2] stated that Nd and Pr were a mixture of several elements including element 61; Eugène-Anatole Demarçay (1852–1903), Henri Becquerel (1852–1908), M. G. Tomson, and Ksewetter came to similar conclusions [3–8].

Gerhard Krüss (1859–1895) and Lars Fredrik Nilson (1840–1899) firmly supported the idea that the "old" didymium should be considered a mixture of nine elements [9]. At the beginning of the 20th century, Bohuslav Brauner (1855–1935) announced that he had discovered a fraction containing element 61 [10] among the products of many fractional crystallizations.[1]

In 1913, after H. G. J. Moseley's discovery of the true ordering principle of the elements, the atomic number, scientists could say that there was only one missing element between Nd and the Sm. This realization should have facilitated its discovery, but things went wrong really quickly: a series of alleged discoveries of element 61 appeared in the scientific literature almost like clockwork. In 1917, Joseph Maria Eder (1855–1944), photographing the arc spectrum of samarium salts, observed some unknown lines that he attributed to a new element, presumably element 61 [11]. In 1921, Charles James (1880–1928), studying the solubility of the rare earth carbonates, tried to isolate element 61 with the help of James M. Cork (1894–1957) and Heman C. Fogg (1895–1952) [12,13].

The following year, the Swedish geochemist Assar Hadding (1886–1962) observed some unknown spectral-lines in fluocerite samples [14]. In 1922, Carl Clarence Kiess (1887–1967), with the aid of a

[1] Fractional crystallization was the method of choice for separating out the rare earth elements from one another.

large concave grating spectrograph, observed 125 lines which he attributed to element 61 [15]. On the contrary, in 1924, Wilhelm Prandtl (1878–1956) and Grimm came to the conclusion that element 61 was not present in rare earth minerals [16]. Gerald J. Druce (1894–1950) and Frederik H. Loring in 1925 sought it out, but without success, in manganese minerals [17].

Although in the 1920s, X-ray spectroscopy was a highly developed science, the path of chemists was rather bumpy and full of obstacles, especially since it was impossible to discover the presence of a substance that was not there.

2.2. A new metal from the City of Florence

Element 61 was also the subject of intense research in Italy. The historical context, in which these studies took place, was as follows. 1919 was the year of the Versailles peace conference, and the birth of the League of Nations. Italy was torn by deep social tensions. In that year, the Superintendent of the "Istituto di Studi Superiori Pratici e di Perfezionamento" (later University of Florence), Marquis Filippo Torrigiani (1851–1924), named Luigi Rolla to occupy the chair of general chemistry. Rolla, born in Genoa on 21st May 1882, studied under Jacobus Henricus Van't Hoff (1852–1911) and Walter Nernst (1864–1941), at the Prussian Academy of Sciences in Berlin. He was also one of the first chemists with an intimate knowledge of quantum physics. After WWI, Luigi Rolla resumed contact with his German colleagues; he was the first in Italy to conceive a link between the ionization energies of elements belonging to the same group. With his assistant, Giorgio Piccardi (1895–1972), he carried on experiments to measure the first ionization potentials of the various rare earth elements. At that time, six boxes in the periodic table remained vacant: atomic numbers 43, 61, 72, 75, 85 and 87.

The chemical separation and purification of the elements and the roentgenographic control of the purity of the rare earths took a long time and involved a considerable workforce: Professor Rolla enlisted four new graduates in his research: Giorgio Piccardi, Giovanni Canneri (1897–1964), Luigi Mazza (1898–1978), and Lorenzo Fernandes (1902–1977). When the purification work was well under way, Fernandes observed some unknown spectral-lines. Rolla, still trying to finish his studies on the ionization potential of the elements, allowed the temptation to discover element 61 to creep into his mind. Almost immediately after completing his ionization potential studies [18], Rolla undertook the hunt for the element 61. From the beginning, the researchers assumed that this element might be contained in Brazilian monazite sands [19] in such small quantities that it could hardly be extracted. For two years, Rolla and his group worked hard and, in the spring of 1924, they were able to announce that they had photographed the "characteristic X-ray spectrum" of the element 61. The hunt could be said to be complete yet, instead of rejoicing, Rolla was assailed with a doubt. He was aware that many scientists had stumbled upon the fatal error of announcing a discovery that later was revealed to be false. This was Rolla's dilemma: either make a premature announcement or postpone the discovery and risk being scooped by someone else. Eventually, the prospect of success and prestige made him to throw caution to the winds.

Rolla was cautious by nature and even in announcing his results to the scientific community, he opted for the least compromising way. In June 1924, he delivered a sealed envelope to the *Accademia dei Lincei* containing a sample of the new (alleged) element and the results of the analyses [20]. The package was to remain secret until he, or other chemists, brought forth other evidence of the existence of the element 61. In this way, he could defend the priority of his discovery without exposing himself too much. It was a compromise solution that turned out to be counter-productive. In those years, it was thought that the problem of the isolation of element 61 consisted only in finding a large enough quantity of raw material and in conducting a sufficiently large number of fractional crystallizations. Senator Felice Bensa (1878–1963) was fascinated by the story of the element sought by Rolla, and he donated one million liras to the University of Florence for the purpose of obtaining the monazite. In autumn, 1925, Rolla began to isolate the missing element. The first floor of the Chemistry laboratory took the appearance of an industrial laboratory [21]. By successive fractional crystallizations, many rare earth elements were obtained in a state of purity never reached before; the spectroscopic and photometric check was carried out after each separation personally by Giorgio Piccardi [22], both to verify the purity of the fraction, and to see in which fractions the metal 61 would concentrate.

In 1907, when the chemist, Georges Urbain (1872–1938), reported, to the Academy of Sciences of Paris, to have completed about 15,000 fractional crystallizations to isolate the element 71, the assembly was very impressed; we know that, in Florence, Rolla and his colleagues carried out a total of 56,142 fractional crystallizations [23]. Since Professor Rolla and his assistants failed to isolate the element 61, Rolla decided to send the material to the Physical Institute directed by Professor Rita Brunetti. Rita Brunetti was born in Ferrara on June 23rd, 1890; she moved to Florence as assistant to Professor Antonio Garbasso (1871–1933). When the latter was enlisted in the Italian Army, Brunetti assumed the direction of the Physical Institute. Luigi Rolla hoped that Professor Brunetti would be able to solve this chemical puzzle and confirm the existence of the unknown element [24]. As possible proof of the existence of the new element, Brunetti studied the intensity of some absorption spectral lines [25].

2.3. Illinium upsets Rolla's plan

The years passed as the Italian group continued to carry out long and exhausting fractional crystallizations, when, like a bolt from the blue sky, a group of American chemists at the University of Illinois, B. Smith Hopkins (1873–1952), J. Allen Harris (1900–1972) and Leonard Yntema (1892–1976) announced the discovery of element 61 [26–29]. The University of Illinois team had worked on the same material as Luigi Rolla had and they came to the same results. B. Smith Hopkins christened the new element *illinium*.

While the scientific community congratulated the American scientists for their discovery, the existence of *illinium* was confirmed by various groups of Anglo-Saxon and German researchers [30,31]. The dismay in Florence was great. Rolla went to Rome and asked the *Accademia dei Lincei* to break the seals of the envelope he had deposited in 1924. During the formal sitting of the Accademia, Rolla, before addressing the topic of his priority, warmed the audience by making the sensational announcement of his discovery: element 61, was named florentium (symbol Fr). In Italy, the news was bedecked in the raiment of a dizzying nationalism.

A fierce controversy arose between the United States and Italy to determine which team had actually discovered element 61. Rolla did not lose heart; in a letter to "Nature" [32] he claimed priority for his discovery, pointing out that his work had started 18 months previous to that of his American colleagues. A long and painful diatribe followed. It was not so easy to attribute recognition to both parties, considering that the prestige at stake was not only for individual scientist or his respective university. Before that time, no one in either country, Italy or the USA, had discovered a chemical element. In addition, in 1926, diplomatic relations between Italy and the United States were particularly tense. In the USA, two Italian anarchists, Nicola Sacco (1891–1927) and Bartolomeo Vanzetti (1888–1927), were waiting to be executed.

Luigi Rolla remained in contact for a long time with Hopkins. The relations between the two teams, apparently cordial, concealed a mutual distrust. Rolla went much further: alarmed by the astonishing news of his colleague, who claimed to have isolated *illinium* in a weighable amount, in 1927, he sailed to the USA to see for himself. Later, on the way back to Italy, he stopped at the Institute of Physics directed by Niels Bohr (1885–1962) in Copenhagen. There he subjected his own "enriched" sample to a scrupulous spectroscopic examination. Bohr's response left no room for doubt. In a firey letter addressed to his Florentine colleague, Rita Brunetti, Rolla wrote: "Dear Miss Professor [...] in the samples you analyzed, and that you affirmed the existence of element 61, there is nothing" [33]. Why Rolla pushed ahead is not clear. His results were disheartening, but the belief that his American colleagues would reach the goal first made him proceed without caution [34].

In 1926, Walter Noddack (1893–1960) and his wife Ida Tacke (1896–1978), who had recently announced the discovery of the *masurium* ($Z = 43$) and rhenium ($Z = 75$), suggested that *illinium* could be related to samarium as radium is to radon, that is to say, *illinium* could be a sort of samarium-radioactive-product still unknown [35]. Their speculation turned out to be fanciful and unfounded, even though Ida Tacke-Noddack had looked in the right direction: element 61 is radioactive. From the 1930s, the fate of element 61 was inextricably linked to that of element 43. In agreement with the empirical law of Josef Mattauch (1895–1976), both elements cannot exist because they do not have stable isotopes: *illinium* and *florentium* died before being born, but element 61 survived. As time went by, physicists came up with the idea that nuclear synthesis was the only plausible path to obtain it.

2.4. A third name for the element 61

In 1938, a team of nuclear chemists at the University of Ohio conducted the first experimental synthesis of element 61. A neodymium target was bombarded with beams of fast deuterons, D^+. The reaction should have generated an *illinium* isotope [36–38]:

$$\mathrm{Nd} + \mathrm{D}^+ \rightarrow \mathrm{Il} + \mathrm{n}$$

Their results were inconclusive. The X-ray spectra showed the same lines observed by Hopkins in 1926; however, the very nature of this mysterious radioactive element was never clarified. From that date, reports of Il isotopes began to appear in several scientific journals. *Illinium* returned to being a reality, albeit as an artificial element. Rightly, Laurence Larkin Quill (1901-1989) took the credit for this discovery. Quill himself studied chemistry under the guidance of B. Smith Hopkins, and – as student – had worked on the concentration of element 61.

The team led by Quill renamed element 61 *cyclonium* (symbol Cy) due to the fact it was synthesized using a cyclotron; however, the symbol Cy did not remain long in box 61. The researchers had measured *cyclonium*'s radioactive signal, but no one succeeded in extracting this new element, nor they had managed to record its spectrum.

2.5. The gloomy end of florentium

Despite the heavy financial support from the University and industry, the Florentine chemists were not able to extract even a speck of florentium. It seemed, on the contrary, that the more the means grew, the more elusive this metal became. After the alternating initial events, Rolla decided to send Fernandes to Freiburg to get acquainted with the most recent X-ray spectroscopic techniques. On his return, the young man set up the equipment and after about a month the first frames were recorded. They were all sharp and full of spectral lines, but none of them was identifiable with that of element 61 [39].

In the summer of 1928, Fernandes tried to convince his mentor to publish a retraction of *florentium*. In response, Rolla forbade the young man to mention his negative results to anyone. The disagreements between disciple and Rolla grew over time until they culminated with the dismissal of Fernandes on 5th March 1930. Rolla had accused his former student of a series of nasty manipulative activities: negligence, working for third parties, exploiting University resources, damaging the X-ray instrument, and even committing acts of sabotage [40].

Facing this problem, Fernandes went directly to the Rector of the University, Enrico Burci (1862–1933), for support. His choice could not have been less prudent. In fact, Burci was an iron-fisted Fascist who despised this type of action. Burci determined that Fernandes' tenure in the laboratory was over. Fernandes sought new employment in Milan but, in his own words he says: "I had already been hired by Montecatini [Company] ... when on the eve of my transfer ..., Professor Rolla blew up my accommodation; he continues to defame me everywhere and with anyone" [41].

Fernandes decided to sue his professor and *florentium* became the object, no longer of the chemical bench, but that of a tribunal. Rolla was depicted as a traitor who tried to hide from the scientific world the failure of his alleged discovery. Rivers of ink flowed but, in the end, the verdict favored (no surprise!) the elderly professor, well ensconced both in the academic, and in the Fascist hierarchy.

In accordance with isotopic statistics [42], Rolla and Piccardi never detected the presence of element 61 in their enriched samples of neodymium and samarium. If the moment of pomp and triumph had been linked to the publication of the discovery in the most widespread German, English and even French journals [43], the retraction note appeared in a minor journal of the Vatican State, partially written in Latin. In 1941, Rolla and Piccardi presented to the "*Pontificia Academia Scientiarum*" a long document concerning the identification of rare earth elements and in particular the search for element 61 [44]. Spectroscopic investigation by Fathers Josef Junkes (1900–1984) and Alois Gatterer (1886–1953) negated the presence of this element. Part of the retraction states:

"... Ne vestigium quidem alterius elementi detegitur neque cogniti neque incogniti et in specie nullibi signum vel levissimum elementi 61”.[2]

So, as it were on tiptoe, Luigi Rolla abandoned every priority claim to the discovery of element 61. He did everything he could, if not to hide his failure, at least to reduce his role. Taking advantage of the humiliating fact that his discovery was always considered secondary, he hinted that the credit for the element 61 fiasco should go to Smith Hopkins.

In the meantime, Professor Rita Brunetti, consumed by a malignant tumor, closed her eyes forever on June 28th, 1942 [45].

Rolla lived just long enough to learn about the fission synthesis of the element that would be called promethium. He missed the satisfaction of being aware of the existence of natural promethium; that discovery occurred in 1968 by the chemist Paul K. Kuroda (1917–2001) [46], although the levels of natural element 61 were so small that they could never be detected by the instrumentation available to either Rolla or Smith Hopkins. Luigi Rolla died on 8th November 1960, in his hometown of Genoa where he had returned in 1935, embittered by the failed discovery of *florentium*.

2.6. Conclusion

One of the greatest discoveries of the 20th century was uranium fission. Thirty isotopes of different elements were produced by uranium-235 fission and about 3% of these elements consists of a mixture of isotopes of element 61. In the 1930s, it was impossible to extract element 61 from the mix. During WWII, a group of American chemists, Jacob Akiba Marinsky (1918–2005), Lawrence Elgin Glendenin (1918–2008), and Charles DuBois Coryell (1912–1971) developed a new ion-exchange chromatography technique, which they used to separate “uranium fragments.” At the bottom of this “molecular sieve” they found two real treasures: two isotopes of element 61 with atomic masses of 147 and 149.

Eventually, element 61, after having its name changed from *illinium* to *florentium* and to *cyclonium*, was christened with a permanent name [47] in the following manner.

During a working-dinner, Mrs Coryell proposed the name *prometheum* for this element. In the ancient Greek myth, Prometheus stole fire from heaven and gave it to men and for this reason he was tortured by Zeus. The name was accepted although later, it was slightly changed to promethium to conform to the element ending of most of the metals in the periodic system. The discovery was kept secret for wartime reasons. In 1947, the first publication on this discovery finally appeared [48].

In June, 1948, the participants at the National Meeting of the American Chemical Society (ACS), held in Syracuse, New York, could see the very first promethium samples on display: $PmCl_3$, yellow, and $Pm(NO_3)_3$, pink. Each sample weighed only 3 mg [49].

In 1956, a group of American scientists led by Paul K. Kuroda organized a titanic task-force to extract natural promethium present in pitchblende uraniferous deposits in Oklo, Gabon [50].

Unlike Rolla, B. Smith Hopkins remained faithful to his discovery until the end of his days. Having been widowed in 1938, four years later, he remarried one of his former students, Dr. May Lee Whitsitt. Together with his second wife, he traveled the United States far and wide and spent a considerable fortune in the attempt to save his *illinium* from oblivion. In 1948, he went to the Syracuse ACS meeting and observed the first samples of promethium; Jacob A. Marinsky, to whom most of the credit for the discovery of element 61 goes, told of a professor, “old and bilious,” who did not want to admit to having under his eyes that very element for which he had hunted in vain for over twenty years.

After this sad interlude, Hopkins moved to Urbana Champaign, Illinois and there he died on August 27th, 1952, aged 79. Dr. May Whitsitt continued the defense of *illinium* tenaciously even after her husband’s passing, and in some way “[she] took up the battle . . . hoping the discovery of her husband would be vindicated. She had many of Hopkins’ samples and she wanted to know if more modern techniques would help clear the matter up” [51].

The last survivor of the events of 1926 was Lorenzo Fernandes. In 1938, after the facts described so far, following the promulgation of the racial laws, he was forced to emigrate to France. After the liberation of Florence, in August 1944, he returned to his hometown and was among the founders of the first Ital-

[2] There are no traces of any other element, neither known, nor unknown, and above all, there is no trace, or very small indication, of the element 61.

ian company to build radar units. This success in industry provided the unfortunate chemist with a considerable source of livelihood; he was a reserved person no longer interested in chemistry, nor did he ever want to return to those sad days of the *florentium* fiasco, even in memory. On saturday, June 25, 1977, around noon, while he was chatting amiably with guests in the living room of his villa, he collapsed on the floor, struck by a mortal heart attack. He had just turned seventy-five. The disciple of Rolla, then his successor in Florence, Giorgio Piccardi, had spent many years working on the fractional crystallization of the rare earths in search of the elusive *florentium*; he was a man of exceptional intellectual honesty and, when his students asked him what he thought of all the work done for the search for element 61, he politely replied: "Dear boys, the great Poincaré defined science as the cemetery of hypotheses; if our hypothesis will be buried in it, I will be honored." Then, with elegance, he resumed his lecture where he had left off.

3.1. Into the unknown: the regrettable case of ausonium and hesperium, or littorium and mussolinium

The initial attempt to create the first synthetic transuranic elements arose from investigations completely different from those one could imagine. In Rome, the famous team of young physicists, the so called "Panisperna boys," directed by Enrico Fermi (1901–1954), made the first attempt to violate the secrets of the nucleus.

On March 25th, 1934, Enrico Fermi announced he had observed neutron-induced radioactivity in samples of aluminum and fluorine. This brilliant result constituted the synthesis of previous discoveries: two months earlier the Joliot-Curies had discovered artificial radioactivity (produced by alpha particles, deuterons and protons). In October 1934 a second and crucial discovery followed: the braking effect of hydrogenated substances on neutrons; this discovery would lead eventually to the practical use of nuclear energy. 1934 marked the year of a revival of "Italian Physics," which for centuries had lain dormant. Thanks to Fermi's successes, Rome became worldwide focal point for atomic physics. This had been the dream of the Director of the Institute of Physics, Senator Orso Mario Corbino (1876–1937), and it was, at long last, come to fulfilment. He had invested all of his resources in the young, 25-year old, untried, but promising Enrico Fermi; whom he asked to occupy the first Chair of Theoretical Physics in Italy, created especially for him. Enrico Fermi was born in Rome on September 29, 1901 and from a very young age, he exhibited an extraordinary talent for science and mathematics. Soon after his nomination as full professor, on March 18th, 1929, Fermi was inducted into the Royal Academy of Italy, with all the privileges pertaining thereto. Only a few weeks later, on April 27th, he enrolled in the National Fascist Party.

In 1933, the Fermi team was not numerous, but relied on the fact of being homogeneous with respect to both age and talent. In addition to Fermi, nicknamed "the Pope" for obvious reasons, the group included Franco Rasetti (1901–2001), aka the "Cardinal Vicar" because he was Fermi's spokesman, Emilio Segrè (1905–1989), called the Basilisk because he could wither you with a single glance, Edoardo Amaldi (1908–1989), and Bruno Pontecorvo (1913–1993) called "the puppy" as the youngest member of the group. On the recommendation of Giulio Cesare Trabacchi (1884–1959), from the Radium Office and Director of Oncology, Fermi enlisted one chemist, Oscar D'Agostino (1901–1975).

Fermi believed that the "time" of nuclear physics had come: knowledge of the atom had been roughly completed, but its inner cogs remained to be investigated. The year in which the Joliot-Curies announced the discovery of artificial radioactivity, Fermi decided to radically change his research interests, moving abruptly from theoretical to experimental physics. The discovery of Frédéric Joliot (1900–1958) and Irène Curie (1897–1956) resonated with Fermi in an extraordinary way: he was among the first men of science to appreciate the enormous importance of their discovery. He decided to attack the atom with neutrons instead of alpha particles (a decision born of need: he did not have enough alpha projectiles). In January 1934, D'Agostino, the chemist, was sent to Marie Curie's (1867–1934) laboratory in Paris to learn the necessary radiochemical techniques that would be useful for Fermi's research. At first, D'Agostino, a Neapolitan, was looked upon with a certain suspicion; artificial radioactivity had only been discovered a few weeks before and it looked like Fermi had sent his colleague to spy. So D'Agostino was assigned to a secondary task under the supervision of the Ukrainian physicist Moïse N. Haïssinsky (1898–1976).

Meanwhile, in Rome, Fermi asked Professor Trabacchi to give him part of his precious treasure: 1.6 g of radium chloride. Fermi's ingenious idea was to utilize neutrons to bombard atomic nuclei. Lacking an electric charge, these neutral particles would not be repelled by the electric charge of the nucleus. However, these "bullets," unlike the alpha particles (helium nuclei) used by the Joliot-Curies, are not spontaneously emitted by radioactive substances. To obtain these neutral projectiles it was necessary to bombard light elements (such as beryllium) with alpha particles emitted by radium. Fermi thus obtained a neutron for hundred thousand alpha particles emitted. The very low yield in neutron production made him doubtful about the feasibility of this method, but he decided to try anyway. Fermi was a genius with flair. He, himself, designed and built, with the aid of Amaldi's significant manual talents, the detectors to count atomic disintegrations. Shortly afterwards, they started their experiments: first hydrogen, then lithium, then boron, carbon, nitrogen and oxygen. These targets showed no induced radioactivity at all. The whole idea seemed useless.

But persistence paid off: when Fermi started irradiating fluorine, the Geiger-Mueller counter placed near the irradiated sample began to emit the characteristic rattle signaling that the fluoride had become radioactive. The number of chemical elements that became radioactive by neutron bombardment grew rapidly. Fermi needed a chemist for the characterization of the new radioelements. In March 1934, Madame Curie, mortally ill, had closed her "Institut" for the Easter holidays and D'Agostino went back home. On Easter Monday, D'Agostino paid a visit to his former colleagues at the Institute of Physics. The scene he faced was astonishing: all the physicists except Rasetti, who was collecting butterflies in Morocco, were in feverish activity. Oscar D'Agostino was immediately co-opted to share in the work and never returned to Mme Curie in Paris. In April of the same year, the first works on neutron-induced radioactivity on fluorine and aluminum appeared in the scientific literature [52–55].

This was only the beginning; very soon many other radioactive isotopes were discovered. The following June 3rd, during a formal session of the Academy of Italy, Senator Corbino, in his role as Director of the Institute of Physics, read to His Majesty the King, Vittorio Emanuele III (1869–1947), the inaugural address. Corbino was Sicilian and with a deep southern accent talked about his "boys" with unusual warmth. The public did not grasp the strictly scientific meaning of what he was talking about. What struck them was the fact that Fermi and his team had managed to discover at least one new element: the first transuranic with atomic number 93. The national press spoke immediately of a "Fascist victory" [56], but outside Italy, many scientists expressed their deep-seated doubts.

It was even reported that Queen Elena of Montenegro (1873–1952), intrigued by the news, asked Fermi to show her samples of the newly formed element. Despite the fact that Fermi talked about "prudence" and "new and delicate tests", he nevertheless went ahead and published the results. It really seemed that the group was really able to synthesize two new elementary substances [57,58] with atomic numbers (Z) 93 and 94.

How did all this come about? In their 1934 experiments, Enrico Fermi and his collaborators supposed that they had discovered a new property of uranium when bombarded with neutrons. The irradiated isotope of Uranium-238 absorbs a single neutron, thus becoming a new isotope of atomic mass 239. Since U-239 now has an excess of neutrons, it seemed that it would show the tendency to emit β particles (electrons), behaving very much like some of the other, lighter, elements they had worked with before. When an atomic nucleus emits a negative β particle, it leaves behind a recoil nucleus with an additional positive charge; the total nuclear charge (atomic number) is now $Z+1$. But when we change the atomic number, we change the identity, and therefore the chemistry, of that element. Element 92 would be transformed into the very first transuranic element with atomic number 93. To confirm their hypothesis, Fermi and D'Agostino reported that the radioactivity induced by neutrons in uranium, apparently, did not resemble any of the elements that preceded it in the periodic system. Element 93 appeared to have the properties of manganese.

Fermi extracted two β-emitting substances: element 93, which spontaneously changed into the next element with atomic number 94. Initially, Fermi, and the German chemists Otto Hahn (1879–1968) and Fritz Strassmann (1902–1980), believed that the transuranic elements were the homologues of rhenium and iridium and, consequently, they should be placed in the seventh period of the Periodic Table.

A little later some journalists reported a fanciful story: Fermi had cherished the idea of naming element 93 *mussolinium* in honor of the Duce, although no one of the group had ever thought of it [59]. Benito Mussolini (1883–1945) kept an eye on the work of the young physicist, above all for the prestige that accrued to Italy. If not the dictator himself, but at least some Fascist party leaders hoped that the new element could be called *littorium*, after the symbol of the Dictatorship. The dean of Roman physicists, Corbino, demonstrated strong sense of humor: he pointed out that these new elements had very short half-lives and to be associated with the Dictatorship might imply a similar lifetime for the regime: a very bad omen indeed. In reality, the results of the experiments were not conclusive at all.

3.2. The underrated "kemikerin" and her ignored hypothesis

The scientific community seemed to accept Fermi's discoveries except for a chemist from the University of Freiburg. Ida Tacke Noddack (1896–1978). Hers was the only voice that dared to speak out [60], denying the existence of Fermi's artificial elements. Fermi and Fermi's colleagues painted Ida Tacke-Noddack as a charlatan; and with ill-concealed superiority, her article was labeled "ridiculous."

In fact, Rasetti, as soon as he read the article, burst out laughing and Segrè fumed. Fermi only shook his head. He had placed too much trust in the incomplete theories of his time; he thought of the atomic nucleus as a "tank" and a slow neutron like a "billiard ball." However, if Segrè was angry and Rasetti dismissive, Fermi was worried about Ida Noddack's criticism. If true, it could compromise his reputation. Fermi decided to ask for the opinion of the Nobel laureate Niels Bohr (1885–1962). The answer that came from Copenhagen was a masterpiece of diplomacy: theoretically everything could be possible as, perhaps, it could be also impossible.

Things remained unresolved. Eventually, Otto Hahn (1879–1968) and Lise Meitner (1878–1968), working in Berlin, repeated Fermi's experiments and confirmed his data. In addition, they were also able to observe traces of the elements 95, 96 and 97 which they tentatively called *eka-iridium*, *eka-platinum* and *eka-aurum* [61]. This was the international confirmation that Fermi was waiting for. Following Rasetti's erudite suggestion that the two new elements 93 and 94 should be called *ausonium* and *hesperium*, Fermi accepted and transmitted this unusual proposal to Corbino. The press release by the latter came on December 16, 1935 [62] with the following words: "[Until now,] Italian science did not have the good fortune to contribute to the discovery of new chemical elements as has already happened in other parts of the world. Today it is now taking part with the creation of two new elements which have never existed before and greets this event in the year of the Empire by christening them with the ancient names that symbolize the sacred name of Italy".

These words, charged with nationalism and rhetoric, betrayed the fact that the truth was far from being revealed. In those turbulent years, Irène Joliot-Curie, Hans von Halban (1908–1964) and Pierre Preiswerk (1907–1972) published some concluding remarks on the artificial radioactivity of thorium [63]. They were not in agreement with the possibility of a nuclear reaction which led to elements with an atomic number higher than that of thorium. They came to similar conclusions also in the case of uranium. Otto Hahn and Lise Meitner, unlike Fermi, wanted to check Joliot-Curie's claims and resumed their experiments with uranium. This time, they did it right: uranium, instead of the nuclear reaction described by Fermi, seemed to split into two fragments [64–66]. Fermi's myopia and Rasetti's arrogance assured them of losing the chance of discovering nuclear fission. A new scenario opened up for the world: Fermi unintentionally lit the fuse that would eventually detonate a new weapon; the atomic bomb.

The relationship between Fermi and Mussolini were and remained cordial until the latter, in 1938, promulgated the infamous racial laws. In fact, in 1927, Fermi had married a woman of Jewish heritage, Laura Capon (1907–1977), and ten years later he looked at the future with a certain degree of fear, although on the eve of the Second World War he had reached the pinnacle of social status among academic and Fascist elites: university professor, member of the new born Accademia d'Italia, member of the Board of Directors of EIAR (Ente Italiano per le Audizioni Radiofoniche, present day RAI), consultant of many firms including Magneti Marelli. Thus, in September 1938, Fermi applied for a permanent position at four American universities. All responded positively. Fermi opted for Columbia University in New York City. He concealed his plans from the Fascist authorities, declaring that he would remain in the United States for only six months. His "transition" was providentially facilitated by the announcement that he was awarded the Nobel Prize for physics and the prize money was a windfall that allowed him to carry out all his objectives. In fact, before he knew he had won the Prize, Fermi made some very unusual purchases, buying up jewels and gold. He left Rome for Stockholm to collect his prize, and then "escaped" directly to New York, with his wife, two sons and their nanny. In Sweden, where he delivered the *lectio magistralis*, he spoke about his twin transuranic elements. In fact, on that occasion, Professor Henning Pleijel (1873–1962), President of the Nobel Committee for Physics of the Swedish Royal Academy of Sciences, in explaining Fermi's scientific acumen to the King used these words:

– "*Fermi's researches on Uranium made it most probable that a series of new elements could be found, which exist beyond the element up to now held to be the heaviest, namely Uranium with rank number 92. Fermi even succeeded in producing two new elements, 93 and 94 in rank number. These new elements he called Ausonium and Hesperium*" –

On that occasion and for the first time, *ausonium (Ao)* and *hesperium (Hs)*, were mentioned; Fermi described the series of nuclear reactions as follows:

$$^{238}\mathrm{U} + \mathrm{n} \rightarrow {}^{239}\mathrm{U} \rightarrow {}^{239}\mathrm{Ao} + \mathrm{n} \rightarrow {}^{239}\mathrm{Hs} + \beta$$

Pleijel could not have chosen a worse moment to make this statement; a few days later Otto Hahn and Fritz Strassmann (1902–1980) discovered uranium fission [67]. Thus, they realized that the products obtained from uranium bombardment were not the elements Ao and Hs, but fragments of uranium nuclei. *Ausonium* and *hesperium* had lasted the duration of a single morning.

3.3. Conclusion

Fermi had probably created some atoms of element 93, but they were actually hidden among the uranium fragments. In 1934, it was impossible to discern their presence. Elements 93 and 94 were prepared through nuclear reactions only in 1940. The first one was created by E. M. McMillan (1907–1991) and P. H. Abelson (1913–2004) [68]. Later they called it neptunium after the planet Neptune. The second one, plutonium, was discovered by Glenn T. Seaborg (1912–1999), Arthur G. Wahl (1917–2006) and John W. Kennedy (1916–1957). It was christened plutonium after the planet Pluto, following the tradition in naming uranium and neptunium [69,70].

With Fermi's departure and Corbino's death in 1937, the "Panispera boys"' scientific team broke up like the uranium nucleus under neutron bombardment. Franco Rasetti and Emilio Segrè emigrated to Canada and the United States, respectively. Bruno Pontecorvo moved to France where he came into contact with Communist circles and soon after the conclusion of the war, he fled to the Soviet Union. In the late 1940s, Fermi was involved in the development of the first atomic bomb; his collaboration with the army alienated Rasetti. He went back to Italy a couple of times between 1949 and 1954 to hold seminars or conferences. During his last visit, in the summer of 1954, he was diagnosed with a metastatic malignant stomach tumor. He died soon afterwards on November 29th of that same year.

References

[1] J. H. Maar, A. Maar, "The Periodic Table and its Iconicity: an Essay", *Substantia*, 2019, **3**, 29-48, Suppl. 5.

[2] W. Crookes, *Proc. R. Soc.*, 1886, **40**, 502.

[3] E. A. Demarçay, *Compt. Rend.*, 1886, **102**, 1551.

[4] E. A. Demarçay, *Compt. Rend.*, 1887, **105**, 276.

[5] H. Becquerel, *Compt. Rend.*, 1887, **104**, 777.

[6] H. Becquerel, *Compt. Rend.*, 1887, **104**, 1691.

[7] G. M. Tomson, *Chem. News*, 1887, **55**, 227.

[8] Ksewetter, *Ber. Chem. Ges.*, 1888, **21**, 2310.

[9] G. Krüss, L. F. Nilson, *Ber. Chem. Ges.*, 1887, **20**, 2134.

[10] B. Brauner, *Z. Anorg. Chem.*, 1902, **32**, 1-30.

[11] J. Eder, *Sitzber. Akad. Wiss. Wien, Math. Natur.*, 1917, **Klasse IIa**, 125.

[12] J. Brinton, *J. Am. Chem. Soc.*, 1921, **43**, 1446.

[13] J. M. Cork, C. James, H. C. Fogg, *Proc. Natl Acad. Sci. USA*, 1926, **12**, 696-699.

[14] A. Hadding, *Z. Anorg. Allg. Chem.*, 1922, **122**, 195.

[15] C. C. Kiess, *Bur. Stand. Sci. Pap.*, 1922, **18**, 201-219.

[16] W. Prandtl, A. Grimm, *Z. Anorg. Allg. Chem.*, 1924, **136**, 283.

[17] G. Druce, F. Loring, *Chem. News*, 1925, **131**, 273.

[18] L. Rolla, *Atti Soc. Ital. Progresso Sci.*, 1926, **15**, 58.

[19] L. Rolla, L. Fernandes, *Le Terre Rare*, Ed. Zanichelli, Bologna, 1929.

[20] L. Rolla, L. Fernandes, *Gazz. Chim. It.*, 1926, **LVI**, 535.

[21] L. Rolla, L. Fernandes, *Gazz. Chim. It.*, 1927, **LVII**, 704.

[22] P. Manzelli, G. Masini, M. G. Costa, *I segreti dell'acqua - l'opera scientifica di Giorgio Piccardi*, di Renzo Ed., Roma, 1994.
[23] L. Rolla, *La Ric. Sci.*, 1933, **II**, 3, anno IV.
[24] R. Brunetti, *Gazz. Chim. It.*, 1927, **LVII**, 335.
[25] L. Rolla, L. Fernandes, *Gazz. Chim. It.*, 1927, **LVI**, 688.
[26] B. S. Hopkins, J. A. Harris, L. Yntema, *Nature*, 1926, **117**, 792.
[27] B. S. Hopkins, J. A. Harris, L. Yntema, *Science*, 1926, **63**, 575.
[28] B. S. Hopkins, J. A. Harris, L. Yntema, *J. Am. Chem. Soc.*, 1926, **48**, 1585.
[29] B. S. Hopkins, J. A. Harris, L. Yntema, *J. Am. Chem. Soc.*, 1926, **48**, 1594.
[30] C. James, J. M. Cork, H. C. Fogg, *Proc. Natl Acad. Sci. USA*, 1926, **12**, 696.
[31] R. J. Meyer, G. Schumacher, A. Kotowski, "Über das Element 61 (Illinium)", *Naturwissenschaften*, 1926, **14**, 771-772.
[32] L. Rolla, *Nature*, 1927, **CXIX**, 637.
[33] Letter from Luigi Rolla to Rita Brunetti, (1927); professor Michele Della Corte Found, Università di Firenze.
[34] L. Rolla, L. Fernandes, *Gazz. Chim. It.*, 1927, **LVII**, 290.
[35] W. Noddack, I. Tacke, *Metallborse*, 1920, **16**, 985.
[36] H. B. Law, M. L. Pool, J. D. Kurbatov, L. L. Quill, *Phys. Rev.*, 1941, **59**, 936.
[37] J. D. Kurbatov, M. L. Pool, *Phys. Rev.*, 1943, **63**, 463.
[38] M. L. Pool, J. D. Kurbatov, L. L. Quill, D. C. MacDonald, *Phys. Rev.*, 1942, **61**, 106.
[39] Archivio Storico dell'Università di Firenze; anno 1930, 10d./2908.
[40] Archivio Storico dell'Università di Firenze; anno 1930, 10d./1930.
[41] Archivio Storico dell'Università di Firenze; anno 1930, 10d./3389.
[42] J. Mattauch, *Naturwissenschaften*, 1940, **19**, 206.
[43] L. Rolla, L. Fernanses, *Chim. Ind.*, 1927, 394.
[44] A. Gatterer, J. Junkes, L. Rolla, G. Piccardi, *Pontificia Acad. Sci. Comment.*, 1942, **VI**, 385.
[45] Z. Ollano, *Nuovo cimento*, 1942, **XIX**, 225.
[46] M. Attrep Jr., P. K. Kuroda, *J. Inorg. Nucl. Chem.*, 1968, **30**, 699.
[47] J. A. Marinsky, L. E. Glendenin, *Chem. Eng. News*, 1948, **26**, 2346.
[48] J. A. Marinsky, L. E. Glendenin, C. D. Coryell, *J. Am. Chem. Soc.*, 1947, **69**, 2781.
[49] J. A. Marinsky, L. E. Glendenin, *Chem. Eng. News*, 1948, **26**, 2346.
[50] J. A. Marinsky, in *Episodes from the History of the Rare Hearth Elements* (C. H. Evans, ed.), 1996, Ch. 6, 91-107.
[51] P. Wood, *The Sun*, March 16, 1986, C-1.
[52] E. Fermi, E. Amaldi, E. Segrè, O. D'Agostino, *Ric. Sci.*, 1934, **5**, 330.
[53] E. Amaldi, O. D'Agostino, E. Fermi, F. Rasetti, E. Segrè, *Ric. Sci.*, 1934, **5**, 452.
[54] E. Amaldi, O. D'Agostino, E. Fermi, F. Rasetti, E. Segrè, *Ric. Sci.*, 1934, **5**, 467.
[55] E. Amaldi, O. D'Agostino, E. Fermi, F. Rasetti, E. Segrè, *Ric. Sci.*, 1934, **5**, 21.
[56] Il Giornale d'Italia, 5 giugno 1934, anno XII.
[57] E. Fermi, F. Rasetti, O. D'Agostino, *Ric. Sci.*, 1934, **6**, 9.
[58] E. Amaldi, O. D'Agostino, E. Fermi, B. Pontecorvo, F. Rasetti, *Ric. Sci.*, 1934, **6**, 435.
[59] O. D'Agostino, in *Il chimico dei fantasmi*, a cura di Giovanni Acocella, Mephite, 2002.
[60] N. I. Tacke, *Angew. Chem.*, 1934, **47**, 653.
[61] O. Hahn, L. Meitner, F. Strassmann, *Nature*, 1938, **23**, 37.
[62] O. M. Corbino, La Nuova Antologia, (1935), 16 Dicembre.
[63] I. Joliot-Curie, H. von Halban, P. Preiswerk, *Compt. Rend.*, 1935, **200**, 2079.
[64] O. Hahn, F. Strassmann, *Naturwissenschaften*, 1939, **27**, 11.
[65] L. Meitner, O. R. Frisch, *Nature*, 1939, **143**, 239.
[66] O. R. Frisch, *Nature*, 1939, **143**, 276.
[67] T. Powers, *La storia dell'Atomica tedesca – Heisenberg's war*, Ed. Arnoldo Mondadori, Milano, 1994.
[68] E. McMillan, P. H. Abelson, *Phys. Rev.*, 1940, **57**, 1185.
[69] G. T. Seaborg, A. G. Wahl, *J. Am. Chem. Soc.*, 1948, **70**, 1128.
[70] G. T. Seaborg, A. G. Wahl, J. W. Kennedy, *Phys. Rev.*, 1946, **69**, 367.