

*History and Philosophy of Science
История и философия на науката*

CHRONOLOGY OF CHEMICAL ELEMENTS DISCOVERIES

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Dedicated to Marie Skłodowska-Curie, 80th years of her death (4 July 1934)

Abstract. The discovery of chemical elements during the centuries from Antiquity up to now was observed in chemical and political point of view. A special attention was spared for the French chemists and the work of Marie Curie.

Keywords: chemical elements, history, discoveries

An element is matter, all of whose atoms are alike in having the same positive charge on the nucleus. Elements are divided into metals (approximately 80%) and no-metals. Currently there are 86 known metals. Before the 19th century only 24 of these metals had

been discovered and, of these 24 metals, 12 were discovered in the 18th century. Therefore, from the discovery of the first metals gold and copper until the end of the 17th century, some 7700 years, only 12 metals were known (Fig. 1). Four of them As, Sb, Zn and Bi were discovered in the 13th and 14th century, while Pt was discovered in the 16th century.

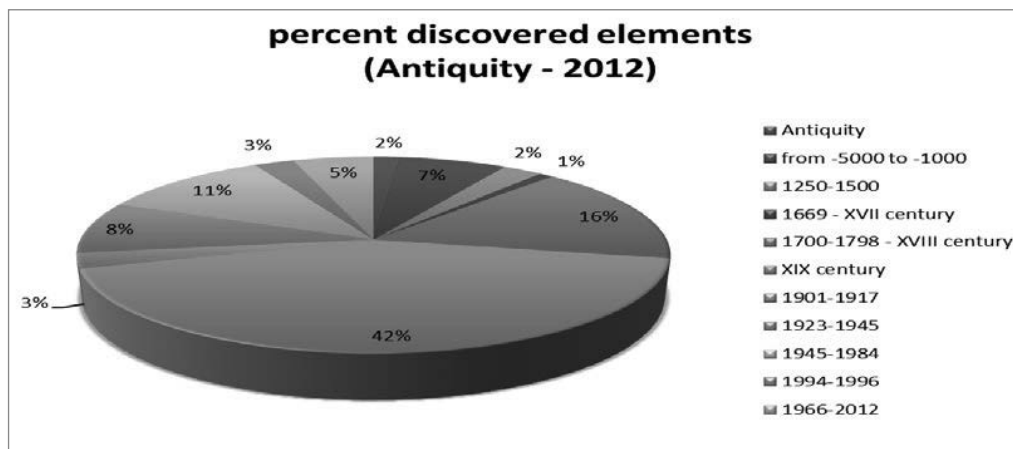


Fig. 1. Percent discovered elements over the years

The origin of the chemical elements show a wide diversity beginning with the use of some of primitive human societies that found native elements like gold and copper and extracted (smelted) iron and a few other metals from their ores. Modern historians categorize the Golden and Silver Age as mythical, but consider the Bronze and Iron Age historically valid. Stone age man learned to fashion gold into jewelry and ornaments, learning that it could be formed into sheets and wires easily. It may be the first metal used by humans. The Copper Age was a time period between the Neolithic and the Bronze Age. Edged weapons such as knives, swords, spearheads and axes were made of copper, as were brooches, pins and vessels for food and drink, in fact the tin was scarce. The seven metals, known as the metals of Antiquity, were the metals upon which civilization was based. These seven metals are presented in Table 1.

Their names are connected with the Sun, Moon and the five known planets at that time from the Solar system. Au like a Sun has everlasting brilliance. Ag like a Moon has rather cold luster. Cu was named after Venus, the goddess of beauty. The sparkling plated made from Cu or bronze were used as mirrors. Fe was used for weapons manufacture and Mars is the god of the war. Mercury is the god of the trade, in continuously movement, like Hg, that can not be detain in one place. The other two metals from the great group of seven are Sn and Pb.

Table 1. Metals in the Antiquity.

Element	Antiquity	Symbol	Planet
Au	6000 BC	☉	Sun
Cu	4200 BC	♀	Venus
Ag	4000 BC	☾	Moon
Pb	3500 BC	♄	Saturn
Sn	1750 BC	♃	Jupiter
Fe	1500 BC	♂	Mars
Hg	750 BC	☿	Mercury

The Bronze Age is a period characterized by the use of copper and its alloy with Sn bronze (3300-1200BC). The Iron Age is the period generally marked by the prevalent use of iron or steel as material for cutting tools and weapons. Around 3000BC, iron was a scarce and precious metal, between 1200BC and 1000BC, diffusion in the understanding of iron metallurgy and utilization of iron objects was fast and far-flung. The extraction of usable metal from oxidized iron ores is more difficult than tin and copper smelting. It is therefore not surprising that humans only mastered iron smelting after several millennia of bronze metallurgy. Before 1800 there were 12 metals in common use: Au, Cu, Ag, Pb, Sn, Fe, Hg, Bi, Zn, As, Sb and Pt (Table 2). The first element to be chemically discovered was phosphorus, prepared from urine by Brandt in 1669. Alchemists and chemists subsequently identified many more, with nearly all of the naturally occurring elements becoming known by 1900. In 1937, Tc became the first artificially synthesized element that does not occur naturally: ${}_{42}^{98}\text{Mo} + {}_1^2\text{H} \rightarrow {}_{43}^{99}\text{Tc} + \text{n}$. Its name came from the Greek word “τεχνηκός” meaning “artificial”. It was discovered by the Italian physicist Emilio Segre.

According to traditional accounts, the scientific revolution began in Europe towards the end of the Renaissance era and continued through the late 18th century. Although the displayed diagram (Fig. 1), we do not have to believe that chemical elements had been discovered only in 19th century. Gradually with increasing complexity of human life, exploring the world, the people’s need of new materials naturally augment. The more the time went on, the more the number of detected chemical elements growth. As a whole the humanity went through several major historical moments: Medieval, Renaissance, Absolutism, Enlightenment – rationalist age, 19th century, Modern Times – 19th–20th century, as a distinct historical period it is time of Cold War and the fall of Berlin Wall, 21st century – the time of new technologies and globalization.

Table 2. Discovered elements from Antiquity to 2000 year

Antiquity	Au, Ag, Cu, Fe, Sn, Pb, Sb, Hg, S, C, N	1840	Er, Tb
Middle Age	As, Bi, Zn, P	1850	
1700		1860	Cs, Rb, Tl, In, He
1710		1870	Ga, Ho, Yb, Sc, Tm
1720		1880	Gd, Pr, Nd, Ge, Dy, Sm
1730	Co, Pt	1890	Ar, Kr, Ne, Xe, Po, Ra, Ac
1740		1900	Rn, Eu, Lu
1750	Ni, Mg	1910	Pa, Re
1760	H	1920	Hf
1770	N, O, Cl, Mn, Ba	1930	Fr, Tc
1780	Mo, W, Te, Zr, U, Sr	1940	Np, At, Pu, Cm, Am, Pm, Bk
1790	Ti, Y, Be	1950	Cf, Es, Fm, Md, No
1800	V, Nb, Ta, Rh, Pa, Os, Ir, Ce	1960	Lr, Rf, Db
	K, Na, B, Ca, Ru, Ba	1970	Sg
1810	I, F, Li, Se, Cd	1980	Bh, Mt, Hs
1820	Si, Al, Br, Th	1990	Ds, Rg, Cn
1830	La	2000	Fl, Lv

Considering the historical periodization of the world, we understand why huge discovery of new elements started in the 19th century. By this time, Europe was under cultural economic and political influence of the Christian religion. Only accepting the ideas of the Renaissance, the people began to create the new worldview, understanding that it was not just the subject of what was happened. Man transcended its pragmatic nature and realized that they could change the world by studying the phenomena that occurred in the world. Gradually the society was being transformed into centralized world. The period – the end of the 17th century – beginning of 18th – was a time of new thinking, building the foundation of science. The final stage of the secularization completed. The knowledge, separated and arranged by experiential, was getting rid of dogma and prejudice. The new sciences such as chemistry, biology, mathematics, medicine started to separate. The basic of logos was put. Since this stage of human

development, the discovery of new chemical elements increased. The research on the nature and its structure were closely related to the chemical elements. The historical events occurring in the 18th century prepared the growth of the discovering of the chemical elements in 19th century. The states economical power divided the world into spheres of influence. In 18th century in Europe several important events happened. Firstly, it was the realization of the ideas of Baudelaire, Jean Jacques Rousseau, Charles Montesquieu and the subsequent French Revolution (1789–1799), which established a constitutional monarchy and republic. Change in state structure led to a change in the development of science and scientific discoveries. Along with the social revolution, in France came revolution in the chemical science. In France and Germany was discovered Uranium ${}_{92}\text{U}$, known with its powerful application in receiving of nuclear power and producing the atomic bomb.

The more interesting are the periods in which began the “boom” of discovery of chemical elements. On the chart (Fig. 2) that peak can be seen. The “boom” is followed by a period of decline (from 19th century to the end of the First World War 1914–1918). And again the period of growth is coming (the time between the First World War and 1985– the first beginning of the Soviet collapse). Another period of decline with its minimum is the years 1984–1996.

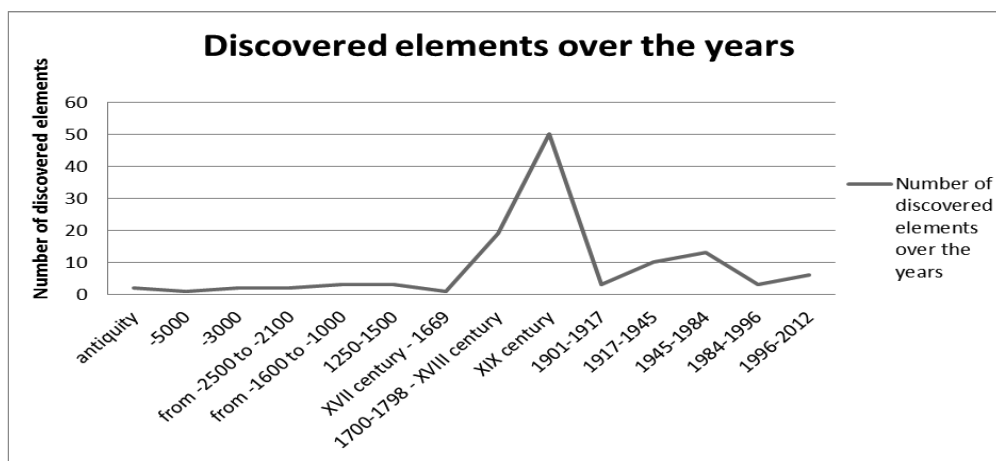


Fig. 2. Discovered elements over the years

Obviously the discovery of the chemical elements is associated with the historical events occurred in countries and depends on the financial and economical factors in these states (Figs. 3 and 4). In addition to this, the internal processes in a country weren't isolated from the international community. Apart of France, revolutions for democracy happened

in many others countries worldwide. Along with the civil revolutions, the 18th and of early 19th was characterized by a very big world revolution – industrial (1750–1850). This was a period of transition from a primary agrarian economy to industrial production. The increasing consumption in the industry required new discoveries in the science of chemistry that could lead to increasing production. That’s why 42 percent of known nowadays chemical elements were found out in the 19th century (the maximum in Fig. 2).

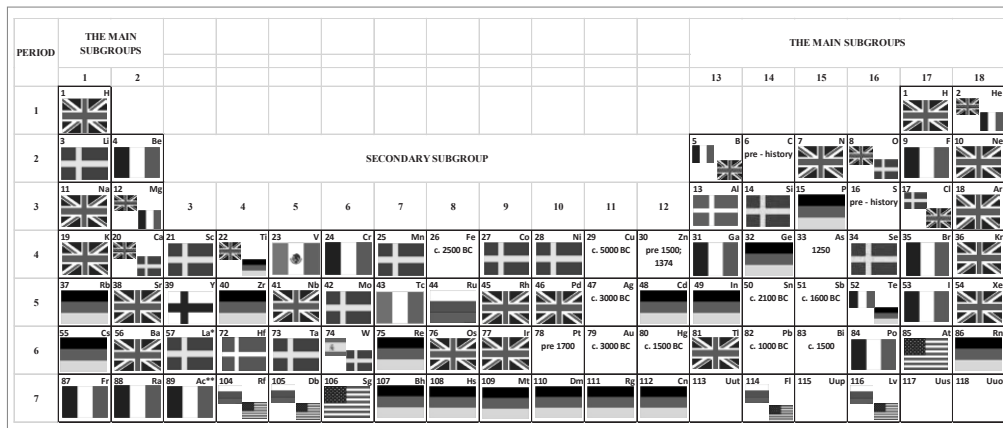


Fig. 3. Periodic table with nationality of the countries of the chemical elements discovered

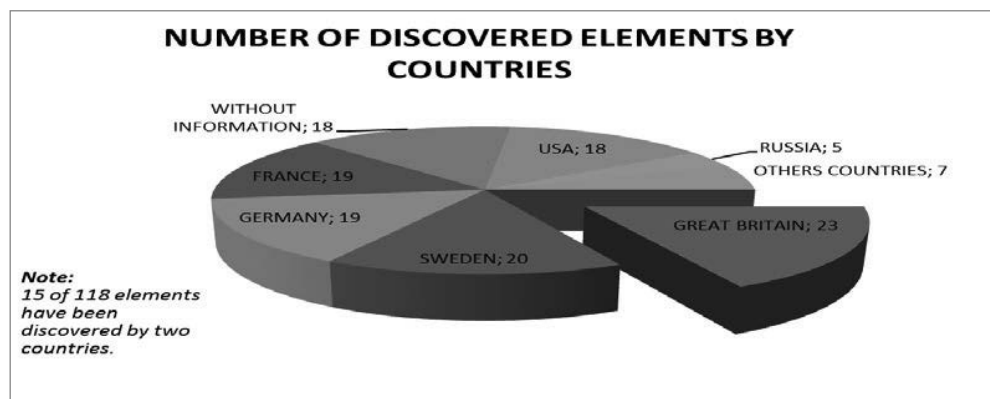


Fig. 4. Number of discovered elements by countries

The industrial revolution and Civil revolutions spread from Britain to Western Europe and North America, and gradually affected the whole world. In that period 1750–1850, England and Sweden had grown in the discovery of the chemical elements. England recorded in its history 17 new chemical elements such as Mg, O, Cl, Pd, Na, B, K, Ca, etc. (Fig. 5, Table 3) and Sweden – 17 chemical elements among which Ni, Mn, Mo, Li, Se, La, etc. (Fig. 6, Table 3).

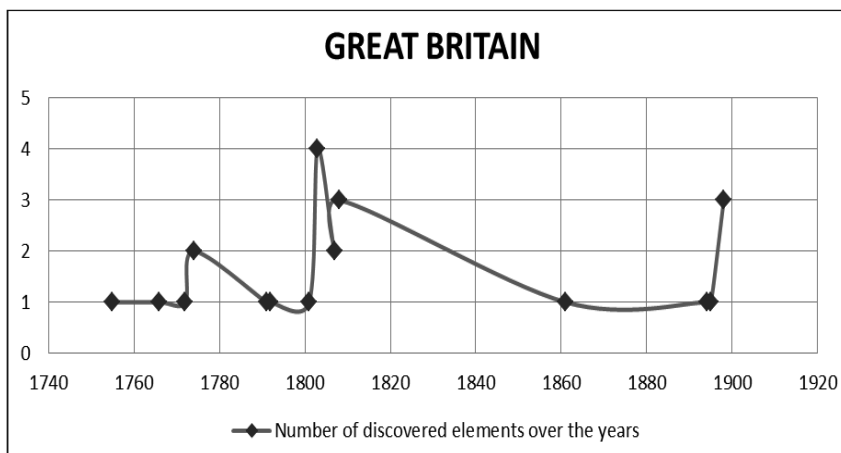


Fig. 5. Discovered elements by Great Britain over the years

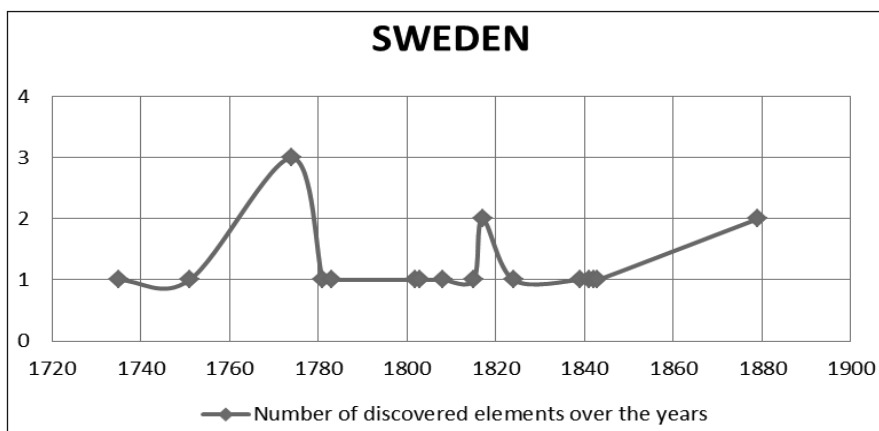


Fig. 6. Discovered elements by Sweden over the years

In comparison with them, France and Germany in the same period (1750–1850) found out much less elements (Figs. 7 and 8). Taking into account the political situation in these countries, it is a usual fact. During this time France changed several governments – Napoleon Bonaparte, Louis XVIII, Charles X, Louis Philippe and twice proclaimed French Republic with two constitutions. Weakened by the internal contradictions and the Napoleon’s wars, France and the French didn’t find time and energy to work for innovations in the periodic system.

Table 3. Chemists who discovered or were succeeded to isolate in pure state more than one element

Chemist	Nationality	Elements, discovered or isolate in pure state	Number	Year
Humphry Davy	English	K, Na, Mg, Ba, Ca, Sr, B	7	1807-1808
Jöns Jakob Berzelius	Swedish	Zr, Se, Ti, Si, Th, Ce	6	1818, 1823, 1829
William Ramsew	Scottish	He, Ar, Kr, Ne, Xe, Rn	6	1895, 1898
Carl Wilhelm Scheele	Swedish	O, Cl, Mn, Ba, Mo	5	1771, 1774
Carl Gustav Mosander	Swedish	Y, Ce, La, Er, Tb	5	1838, 1842
Martin-Henrich Klaproth	German	Te, Zr, U, Ce	4	1789
Paul-Émili Lecoq de Boisbaudran	French	Ga, Sm, Gd, Dy	4	1875, 1879, 1880, 1886
Smithson Tennant	English	Os, Ir	2	1803
Marie and Pierre Curie	French	Po, Ra	2	1898, 1902
Carl Auer von Welsbach	Austrian	Pr, Nd	2	1885
Louis-Nicolas Vauquelin	French	Be, Cr	2	1798
William Hyde Wollaston	English	Pd, Rh	2	1803, 1804

A history of modern chemistry can be taken to begin with the distinction of chemistry from alchemy by Robert Boyle in his work "The skeptical chemist" in 1661 and another important step was made by Antoine Lavoisier (Father of Modern Chemistry). Chemistry is considered to have become a full-fledged science with the work of Lavoisier, who developed a law of conservation of mass in 1789. Sulfur was first used at least 4000 years ago but it was recognized as an element by Antoine Lavoisier in 1777. Lavoisier also named hydrogen (1793), oxygen (1777) and nitrogen in 1776.

The French chemist and pharmacist Nicolas-Louis Vauquelin discovered Be in beryl and emerald, and Cr in 1797, but isolated chromium in 1798. Although H. Klaproth observed in 1789 uranium, E.-M. Péligot named it after the recently discovered planet Uranus.

Iodine was discovered in sea weed ash by the French Bernard Courtois in 1811 although it was proved to be an element in 1814 by Gay-Lussac.

The discovery of bromine was credited to the French Antoine-Jerome Balard. The French chemist Claude-Francois Geoffroy showed that bismuth was distinct from lead in 1753.

The metal Tl was first isolated by Claude-Auguste Lamy in 1862.

Although boron compounds were known for thousands of years, it was not isolated until 1808 when Louis Gay-Lussac and Louis-Jacques Thenand obtained boron in an impure state and the English chemist, Humphry Davy, prepared pure B by electrolyses.

The Mg in pure state was obtained in 1831 by the French pharmacist and chemist Antoine-Alexandre Brutus Bussy, but in 1808 H. Davy obtained the impure metal.

The element He was discovered by spectroscopy during a solar eclipse in the sun's chromosphere by the French astronomer Pierre-Jules-Cesar Janssen in 1868. Until 1895 it was thought to be only a solar constituent, when Scottish chemist William Ramsay found that it was identical to the He in the uranium ore cleveite (Table 3).

The name of gallium derives from the Latin Gallia for "France", since it was discovered in zinc blende by the French chemist Paul-Emile Lecoq de Boisbaudran in 1875 (Table 3).

The element with atomic number 89 and the chemical symbol Ac is a powerful source of alpha radiation and its discovery has been credited also to the French chemist Andre-Louis Debierne in 1899.

Marie Curie—the first woman to be awarded with Nobel Prize, the only woman to win in two fields (1903 in physics and 1911 in chemistry) and the only person to win in multiple sciences. As a scientist, she was a genius at measuring and working out methods for experiments. She discovered that the element thorium was also radioactive as U. In July 1898, Marie Curie and her husband published a paper announcing the existence of an element which they named "polonium", in honor of her native Poland. She never

succeeded in isolating Po, which has a half-life of only 138 days. On 26 December 1898, the Curies announced the existence of a second element, which they named “radium” (Table 3). Her research into radiation helped others discover the structure of the atom, one of the greatest puzzles of the universe. Radiation itself turned to be extremely dangerous, but it also proved to be very useful in areas such as treating cancer, generating electricity, and diagnostic medical problems. Marie Curie became one of the history’s best-known scientists. A century after Marie Skłodowska struggled to complete her education in a friendly but foreign country, the European Union demonstrated its belief that education is one of the best investments in society by enacting a system of financial support for young people. The most spectacular of such assistance programs are the EU Marie Curie Actions, started in 2002 and continued up to now.

During the ruling of Adolph Thiers 1871 as interim Head of State (1871–1875), France was stabilizing and the Paris Commune was quenched. Only in the management of Patrice de Mac Mahon, second president of the Third French Republic (1875–1879), France got its domestic stability and this affected in scientific discoveries. From 1871 to the beginning of World War I (1914–1918) the French discovered whole 9 chemical elements. This was the peak (Fig. 7). Among the detected elements except F, and trace elements are as Ra, Ac, Po, and lanthanides Sm, Dy, Eu, Lu. The discovery of the rare earth elements provided a long history of almost two hundred years of trial and error in the claims of element discovery. The fact that the similarity in the chemical properties of the rare earths(RE) make them especially difficult to chemically isolate led to a situation where many mixtures of elements were being mistaken for elemental species. Very pure RE samples did not become a reality until the middle twentieth century. Sm was discovered by the French chemist Lecoq de Boisbaudran in 1879. It was originally discovered in 1878 by the Swiss chemist Marc Delafontaine, who called it decipium but in 1881, he determined that his decipium could be resolved into two elements, one of which was identical to Boisbaudran’s samarium. In 1901, the French chemist Eugene-Anatole Demarcay showed that this samarium earth also contained europium. Lecoq de Boisbaudran was also discovered Dy (dysprosium) in a holmium sample in 1886 but the French George Urbain first isolated it in 1906. The chemist George Urbain in 1907 discovered lutetium, Lu (and independently by the Carl Auer von Welsback also (named cassiopeium)) and the name derives from “lutetia”, the ancient latin name for the city of Paris. In 1949 International Union of Pure and Applied Chemistry (IUPAC) adopted officially Urbain’s name based on consideration of prevailing usage, finally ending the controversy.

Although, in period of restoration after World War I, with discovery of Francium – Fr by Marguerite Perey, another French female scientist, France recorded in 1939 in its history last open chemical element and it was the last element discovered in nature,

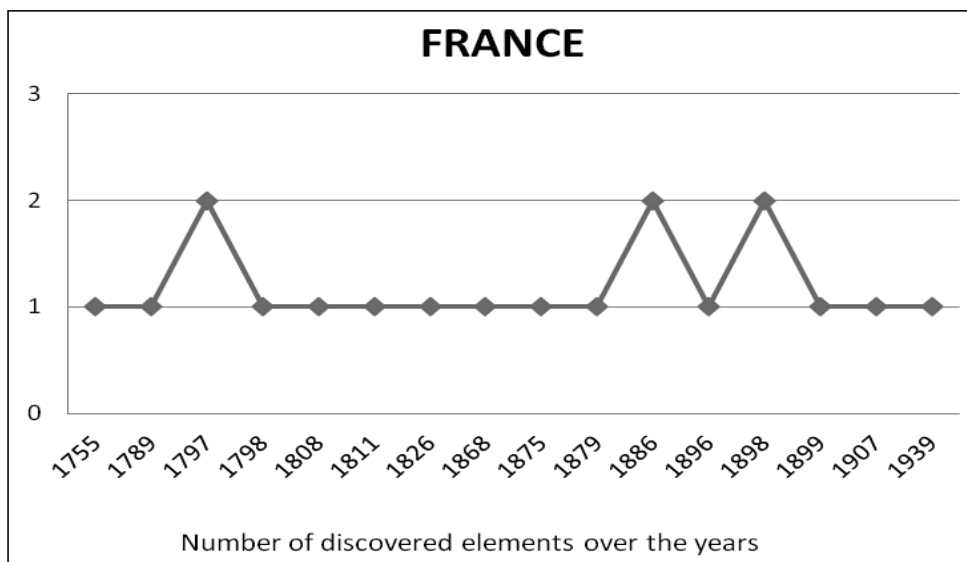


Fig. 7. Discovered elements by France over the years

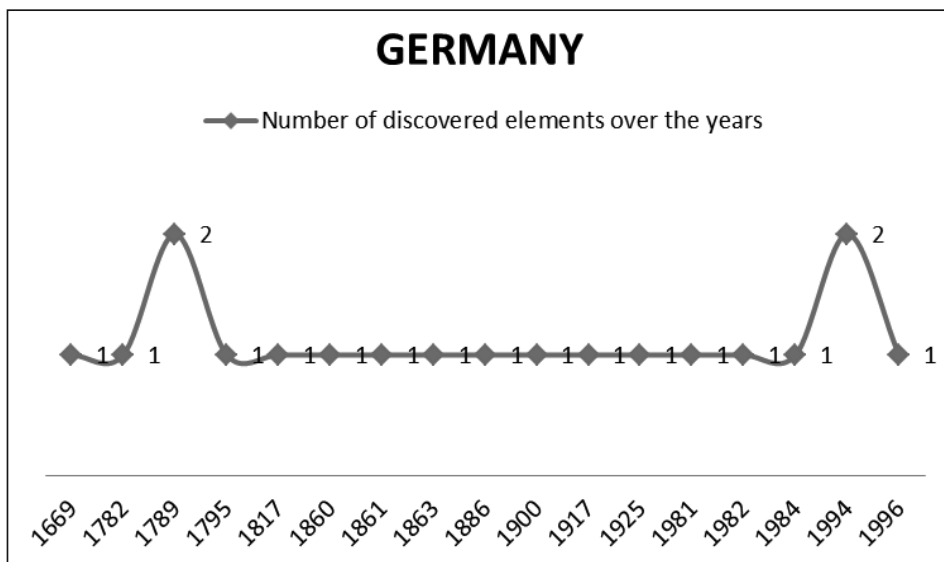


Fig. 8. Discovered elements by Germany over the years

rather than by synthesis. You will not find Francium in a list of chemical catalog for sale. Francium's most long-lived isotope, Fr-223, has a half-life of a mere 22 minutes. A quick calculation based upon the annual production of uranium (Fr is the fourth daughter in the U-235 decay series), yields an estimated 1.2×10^{-11} grams of this elusive element in the combine worldwide uranium production bins. Expected to be the most electropositive element with an estimated Pauling electronegativity of 0.7 and combining it with fluorine (isolated in 1886 by the French pharmacist and chemist Ferdinand-Frederic-Henri Moisson), the most electronegative element (4.0) we would obtain the most stable alkali halide FrF.

During the rule of Napoleon, France led incessant battles against Germany (Holy Roman Empire), which broke up in 1806. From that moment on the political map of Europe the Rhine Union began life. But this did not lead to stability in political terms. Between 1815–1871, Germany consisted of countless independent states, 39 of which formed the German Union. The lack of an authoritarian centralized state explained the few of discovered chemical elements in Germany over the period – only 5 chemical elements. After that period from 1871 until the end of World War I and the postwar years several important events in Germany happened. Firstly, it was the establishment, of the Second Reich, also known as the German Empire in 18.07.1871, by Otton von Bismarck. Secondly, Germany also failed in several military battles. It lost its provinces Alsace and Lorraine in 1871 battle with France. During World War I, Germany invaded France in 1914. The war ended in 1918, when the German emperor was forced to abdicate and the German Empire was inherited from the Weimar Republic. After war lost, according to the Treaty of Versailles, Germany was forced to pay excessive reparations. The political events and postwar crisis had a great impact on the chemical development and research. Logically, in comparison to 1814–1871 (57 years with 5 discovered elements), Germany discovered from 1871 to 1933, 4 chemical elements. No matter how contradictory the period was, new chemical elements were being discovered. However, the “more terrible” period in the field of the discovering chemical elements was forthcoming in Germany.

The Versailles Peace convention along with the global economics crisis led to a strengthening of the extreme left and strong political parties in Germany. This was precisely the moment when as a head of Germany in 1934 stood Adolf Hitler and The Third Reich was established. His politics in the field of science was evaluated as very contradictory. His regular army in the beginning of war achieved impressive results in the battlefield. This was due to the industry, which was developed in order to create a number of products, need for the population in the Third Reich. This all required good scientific basis and development. But one-party totalitarian state (Nazi Germany), with its repression apparatus pursued, killed prominent politicians, scientists and artists, and culminated in the massacre of millions of Jews (Holocaust). The period 1935–1945 was

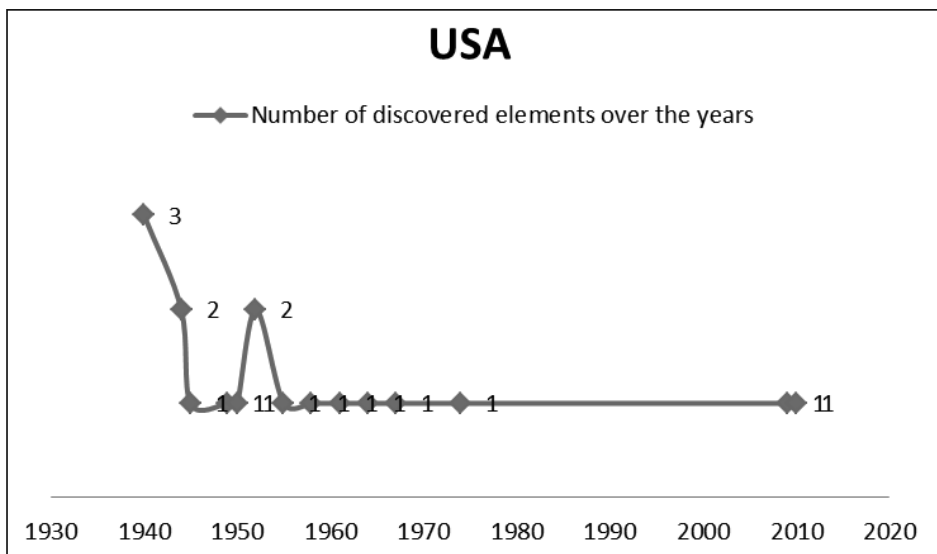


Fig. 9. Discovered elements by USA over the years

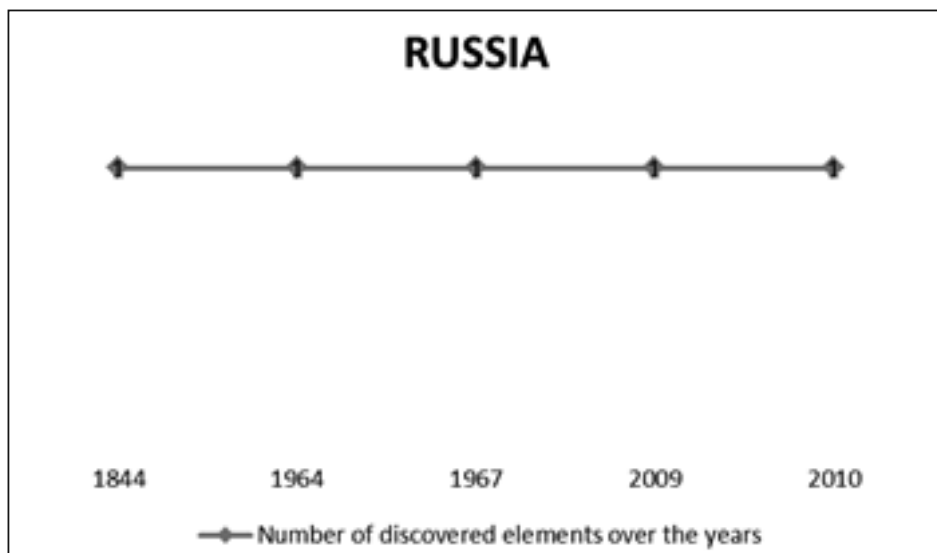


Fig. 10. Discovered elements by Russia over the years

characterized by no one chemical element had been discovered. This and the next period: 1945– 1981 (the period of Cold War between the East and the West) were “dead time for elements discovering”. Neither was found, nor synthesized (Fig. 8). Only at the end of Cold War, Germany revived its scientific research, in particular in chemistry, finding in 1981 – an element Bh. Followed series of breakthroughs in 1982, 1984, 1994, 1996 – with Mt, Hs, Ds, Rg, Cn, and their number reached 6 elements: from serial number 106 of Periodic table.

A very important point after the World War I was that new political forces have appeared at the international politics stage. The countries which left their traces in the history of the opening of chemical elements were the United States of America and the Union of Soviet Socialist Republics, which began to appear as major political forces. In geographical plan, USA has a large area, but only a single war was conducted in its territory – Civil War (1861–1865). Lack of military actions affected the normal course of business and research, the development of economy and society. Nevertheless, the USA was involved in two world wars, the military operations were conducted in Europe, Asia and Africa. This explained why the USA seemed to be at the top in 1940 by number of detected chemical elements – At, Np, Pu (Fig. 9). And more important, after this peak research, the successes of the research of the University of Berkeley continued. In the period 1945–1974 when the world was divided into two military – political blocks, the USA discovered 11 chemical elements for 29 years. This rate of discovery can be observed in the constant competition between the USA and USSR during this period in different areas. Interesting coincidence was that $_{104}\text{Rf}$ and $_{105}\text{Db}$ were detected at the same time by the USA and the USSR scientists. Until now, the story still couldn't say for sure what exactly had happened. We can not generally claim for sure whether the activities in the opening chemical elements by USSR and USA were the results of the actions of the various intelligence agencies. But surely chemical discoveries were clear result of scientific work with modern equipment.

At the same time the situation in the USSR was unlike the USA. Soviet Union fell behind with the discovering chemical elements. No doubt USSR had contribution in the systematization of elements in period and groups (activities Mendeleev master of piece), but this could not be asserted about elements. In its history, Russia had discovered only 5 chemical elements (Fig. 10). Ruthenium Ru was discovered in 1844, when Tsar Nikolai I ruled. During the Cold War, the Soviet Union in parallel with USA discovered $_{104}\text{Rf}$ and $_{105}\text{Db}$. Like Germany, the reason for the lack of the discovery and synthesis of new chemical elements should be search in deep communist ideology in science at that Totalitarian system, imposed by working class, with its centralized government also made an impact in the dissemination and promotion of freedom of speech

and science. These limitations in the freedom of science vanished with the Berlin Wall demolition. This was indicated by the common research activities between USA and Russia in supplementing the Periodic table with two new chemical elements. The both countries with complementary actions managed to find two extra elements in 2009 and 2010, respectively – $_{114}\text{Fl}$ and $_{116}\text{Lv}$.

All of all, the discovery of the chemical elements is a creative and profound work of the scientific thought during the centuries. This labour has been under strong influence of political changes, authoritatively ideologies as well as the conjectured circumstances in national and international aspect. This permit to conclude that the obstacles in political and economical point of view could slow up the development but not stopping the investigations and the need of research to study our surroundings and environment, based on the atoms of the chemical elements.

NOTES

1. Wikipedia.

BIBLIOGRAPHY

- Hofmann, S. & Münzenberg, G. (2000). The discovery of heaviest elements. *Rev. Mod. Phys.*, 72, 733-768.
- Holden, N.E. (2004). History of the origin of the chemical elements and their discoverers. *41st IUPAC General Assembly*, Brisbane, 29 June – 8 July.
- Krebs, R.E. (2006). *The history and use of our Earth's chemical elements: a reference guide*. Westport: Greenwood Press.
- Leigh, G.J. (1990). *Nomenclature of inorganic chemistry: recommendations*. New York: Blackwell.
- Orna, M.V. (2009). My favorite element: francium's daughter. *J. Chem. Educ.*, 86, 1364.
- Penczek, S. & Sobieszczak-Marciniak, M. (2009). From Poland to France, from France to Poland. *Chem. Intern.*, 31(4), 4-7.
- Scerri, E.R. (2007). *The periodic table: its story and its significance*. Oxford: Oxford University Press.
- Siegfried, R. (1963). The discovery of potassium and sodium, and the problem of the chemical elements. *Isis*, 54, 247-258.
- Steele, P. (2006). Marie Curie: the woman who changed the course of science. New York: National Geographic Children's Books.
- Wertime, T.A. (1954). The discovery of the element carbon. *Osiris*, 11, 211-220.
- Гольдманский, В.И. (1964). *Новые элементы в периодической системы Д.И. Менделеева*. Москва: Атомиздат.

- Гофман, К. (1984). *Можно ли делать золото: мошенники, обманщики и ученые в истории химических элементов*. Ленинград: Химия.
- Джуа, М. (1962). *История химии*. Москва: Мир.
- Нечаев, И. (1950). *Разкази за елементите*. София: Народна просвета.
- Петрянов-Соколов, И.В. (1983). *Популярная библиотека химических элементов. Книга первая: водород – палладий*. Москва: Наука.
- Петрянов-Соколов, И.В. (1983). *Популярная библиотека химических элементов. Книга вторая: серебро – нильсборий и далее*. Москва: Наука.
- Сиборг, Г. & Вэлленс, Э.Г. (1966). *Элементы Вселенной*. Москва: Наука.
- Таубе, П.Р. & Руденко, Е.И. (1961). *От водорода до ... нобелия?* Москва: Высшая школа.

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