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# Julius Lothar (von) Meyer (1830-1895) and the Periodic System

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**Abstract.** The logo of the "International Year of the Periodic Table of Chemical Elements" (IYPT) shows only Dmitri I. Mendeleev (1834-1907) and none of the other scholars who were closely related with the discovery of the classification of elements. As early as 1864 the German physical chemist Lothar Meyer used a table to explain the "peculiar regularities" that were found among the atomic weights; by the end of that decade he had considered more elements and improved the system. Among other discoverers of the periodicity, Meyer and his colleague Karl Seubert (1851-1942) determined and recalculated atomic weights. This essay depicts the biography of Lothar Meyer and evaluates his contributions to the development of a classification system for chemical elements in several steps, to the periodic arrangement of elements. Finally, Meyer's opinion of the use of the periodic tables in teaching and organizing the material in courses on inorganic chemistry is presented.

**Keywords.** Julius Lothar (von) Meyer, systems of elements, periodic table, use in teaching process

## INTRODUCTION

It was 150 years ago – on 17 February 1869 (Julian calendar) or 1 March 1869 (Gregorian calendar) – that Dmitri Ivanovič Mendeleev (1834-1907) arranged a two-dimensional grid of the elements. For this reason, the United Nations General Assembly and UNESCO proclaimed 2019 as the "International Year of the Periodic Table of Chemical Elements" (IYPT). The IYPT logo shows Mendeleev's portrait. But in the 1860s there were also other scholars who were thinking about a classification of elements. Among these Meyer stands out as the most known contender to Mendeleev. His endeavor was actually also in connection with writing a textbook like Mendeleev. This paper is dedicated to the contributions of Meyer to the periodic system. It presents his biography as well as his work in connection with the classification of elements, before providing a brief analysis of Meyer's train of thought on periodicity and the role the periodic system can play in chemistry teaching. Through this example, we aim to illustrate that while it does not diminish Mendeleev's accomplishments, it does frame these accomplishments in a wider historical context where many similar pursuits were undertaken by the fellow chemists of his time.[1]

## LOTHAR MEYER – HIS BIOGRAPHY

Julius Lothar Meyer (Fig. 1) was born in Varel, Germany on 19 August 1830, in the current district of Friesland in Lower Saxony.[2] The *gymnasium* in Varel bears his name today. Lothar's father, Heinrich Friedrich August Jacob Meyer (1783-1850), was a physician. He and his wife, Anna Sophie Wilhelmine Biermann (1800-1853), had at least eight children, most of whom died young. Only three of Lothar's siblings reached adulthood, Oskar August Emil Meyer (1834-1909), who became a professor of physics in Breslau and was well-known for his work on viscosity, Eugen Theodor Meyer (1836-1890), who became a farmer, and Selma Corinna Helmine Meyer (1839-1928).

Initially, Lothar was tutored at home. From 1841 until his confirmation he attended a citizens school (*Höhere Bürgerschule*), but his school education was interrupted due to poor health, particularly strong headaches. Lothar Meyer worked in a gardening nursery, regained his health, and from 1847 he was able to continue his education at the *Old Gymnasium* in Oldenburg. In 1851 he passed his school leaving examination, the *Abitur*. He decided to study medicine and to become a physician like his father, who had died in the meantime.

On 8 May 1851, Lothar Meyer enrolled at the University of Zurich, where he attended lectures in medical subjects, but also in chemistry, physics, mineralogy, geology, botany and zoology, until the end of the winter term 1852/53. He was especially interested in Carl Ludwig's (1816-1895) instruction in physiology – perhaps this led to his interest in gas exchange of the blood?

Around Easter 1853 Meyer traveled to Würzburg, and in February 1854 he completed his Doctor of Medicine with a thesis paper on the pigment cells of frogs. A year later he moved to Heidelberg to work with the famous Robert Bunsen (1811-1899). Although he was enrolled for medicine, he was more interested in chemistry. He investigated the behavior of gases in the blood, trying to determine how much oxygen, nitrogen, and carbon dioxide are in arterial blood and to establish regularities for the gas exchange. These results were summarized in the paper *The gases of the blood* in 1857, which he submitted to the faculty of medicine as a second doctoral thesis.[3] It is unclear as to why he felt the need to complete a second dissertation, following his medical degree. Even though his first paper on the frog offered poor results, there is no evidence that the faculty granted his degree coupled with an obligation for a second paper. It is also not possible to examine the archived documents in Würzburg, as most were destroyed during World War II.[4] It is possible that Meyer felt obliged to do this because he was aware of the poor reception of his first paper.

**Figure 1.** Lothar Meyer. Scan from K. Seubert, *Ber. Dtsch. Chem. Ges.* **1896**, *28*, 1109–1146, here p. 1110.

Later, in Heidelberg, Lothar Meyer met other scientists, including Friedrich Beilstein (1838-1906), Henry Roscoe (1833-1915), Hans Landolt (1831-1910) and August Kekulé (1829-1896). Meyer remembered that Kekulé presented the type-theory of Charles Gerhardt (1816-1856) and Alexander Williamson (1824-1904) to the other young chemists, even though Bunsen was not interested in these new ideas.[5]

Lothar Meyer went to Königsberg (today Kaliningrad in Russia) with his brother, Oskar August Emil, and Landolt in the winter term 1856/57 to expand his knowledge of physics. This exposed him to the lectures of Franz Ernst Neumann (1798-1895) about electromagnetism and the wave theory of light. He also continued his physiological research in the laboratory of Gustav Werther (1815-1869), he was interested in the effect of carbon monoxide on blood. These results were published in a paper which was submitted to the Faculty of Philosophy in Breslau to earn the degree Dr. phil. Meyer showed that carbon monoxide is attracted to blood by chemical forces. This means that the blood cannot transport oxygen. He was not able to discover which substance attracts the carbon monoxide. This phase of his education exposed Meyer to analytical and physiological problems; he was educated in mathematical physics and learned about new theories in chemistry. The time in Königsberg was critical for Meyer's turn to physical approaches to chemistry. Franz Ernst Neumann is regarded as the founder of theoretical physics as a university discipline in Germany. He connected the use of precise measuring devices with mathematical approaches and the use of error calculation.[6] These principles were adopted by Meyer.

For his habilitation degree, the qualification as *Privatdozent,* Meyer worked on the development of chemical theories ranging from Claude-Louis Berthollet (1748-1822) to Jöns Jacob Berzelius (1779-1848).

From Easter 1859 onwards, Lothar Meyer supervised the chemical laboratory of the Institute of Physiology at the University of Breslau (today Wrocław in Poland). He gave lectures about plant and animal chemistry, photo chemistry, gas and volumetric analysis, and he offered refresher courses on organic and inorganic chemistry.[7]

In September 1860 the first International conference of Chemistry took place in Karlsruhe. It was organized by Kekulé together with Karl Weltzien (1813-1870) and Charles Adolphe Wurtz (1817-1884). The goal was the clarification of the atomistic system: what is an atom, what is a molecule, but also to decide the basis for determining atomic weights. In a sparkling speech Stanislao Cannizzaro (1826-1910) demanded recognition and a consequent application of the theory of Amadeo Avogadro (1776-1856). Cannizzaro also distributed prints of his *Sunto di un corso di filosofia chimica* (Short course of theoretical chemistry).[8]

Meyer and Mendeleev, who also attended the conference, were struck by this proposal that opened new perspectives. And Meyer – trained both in organic and physical chemistry – started to work on molecular theory. He wrote a paper on chemical statics which he first wanted to publish in *Poggendorff´s Annalen der Physik*.[9] He mentioned his intention to publish it in letters to Kekulé und Hermann Kolbe (1818-1884),[10] but it seems that he later used this material for his textbook, *Die modernen Theorien der Chemie und ihre Bedeutung für die chemische Statik* (Modern theories of chemistry and its importance for the chemical statics). In the foreword to the second edition, written in August 1872, Lothar Meyer says that he had started with the manuscript ten years earlier.[11] A letter addressed to his brother corroborates this timing.[12] The book was finally published in July 1864; the second edition was issued in 1872, the following editions in 1876, 1883, and 1884. The book became more and more comprehensive, the fifth edition reaching 626 pages.

There was no chance for Meyer to pursue an academic career in Breslau, so he took a position at the forest academy in Neustadt-Eberswalde, where he had many teaching tasks in the fields of mineralogy, chemistry, physics, and sometimes even botany. This left him little time for scientific work. At first he had to establish a "considerably cute laboratory from miserable cottage".[13] And he complained that he could not find research students, the students of the forest academy were only interested in finishing the chemistry classes.[14] So this position posed not only issues of time – he did not have his own students to work with. In 1867 he was appointed to be professor of inorganic science at the forest academy, but in 1868 he left the academy and became a professor of chemistry and the director of the chemical laboratory at the Polytechnikum in Karlsruhe. There he found better working conditions, teaching only chemistry, and he had his own students for scientific work.

From 1868 to 1875 Meyer worked in Karlsruhe; he turned a professorship in Königsberg down. But his health problems had surfaced again. During the winter term 1874/75 he was released from his teaching duties, which were then assigned to August Michaelis (1847-1916).

1876, Lothar Meyer received a full professorship in Tübingen as the successor of Rudolph Fittig (1835-1910). His financial situation improved, but the most important benefit was that he had finally become a full university professor, as the polytechnic institutions had no rights to award doctorates. Meyer was offered a considerably well-equipped laboratory in Tübingen's Wilhelmstraße 9 (part of which is still there). Meyer and his family lived on the upper floor and he refurbished some of the laboratory rooms for his research interests, improving the technical equipment.[15] In Tübingen Meyer worked together with his colleague Karl Seubert on the redetermination of atomic weights. The results were published in a book in 1883. Later Seubert was the first biographer to write about Meyer and was responsible for publishing or republishing his most important papers.[16]

Meyer's good working and research conditions in Tübingen, his integration in the social life of this town and his state of health were reasons for turning down professorships in Leipzig (1887) and Breslau (1889). He received several awards, including the Davy medal given to him and Mendeleev on 2 November 1882, recognizing their research on the classification of elements. In

1883 Lothar Meyer became an honorary member of the Chemical Society London; in 1887 he joined the Physikalischer Verein (Physical society) in Frankfurt/Main; in 1889 the Manchester Literary and Philosophical Society. A year prior to this, in 1888, Meyer had been appointed corresponding member of the Mathematics and Physics section of the Prussian Academy of Science and in 1891 of the Academy of Science St. Petersburg. In 1892 Lothar Meyer was knighted with the decoration of the Honorable Cross of the Royal House of Württemberg.

At the start of the 1894/95 academic year, Lothar von Meyer was elected rector of the University Tübingen: shortly after the term, on 11 April 1895, he died. His grave is in the *Stadtfriedhof* cemetery in Tübingen.

## LOTHAR MEYER AND THE CLASSIFICATION OF ELEMENTS

Lothar Meyer left his mark on multiple fields of chemistry, but this paper discusses only his activities in connection with the classification of chemical elements.

The question of classification systems in chemistry came about as a consequence of the large amount of new knowledge about chemical compounds and elements at the turn from the 18$^{th}$ to the 19$^{th}$ century – especially in connection with the revival of atomic theory and the possibility to determine relative atomic weights, but also with the discovery of many new elements. The atomic weights opened the path to a classification based not only on qualitative properties but also on quantitative data.[17] This was connected with attempts for a deeper understanding of the nature of elements and atoms and it was one of the scientific interests of Meyer after his turn from physiological to problems of theoretical chemistry. Meyer also wanted to show the interrelation between hypothesis and theories based on them.[18]

Lothar Meyer's considerations about the nature of the elements were connected inter alia with ideas of William Prout (1785-1850) and Johann Wolfgang Döbereiner (1780-1849).

Early in the century, the physician Prout had observed that atomic weights are whole multiples of the atomic weight of hydrogen, and later proposed that hydrogen should be the primeval matter (greek: prote hyle). The experimental possibilities for determining atomic weights had since then been improved, in consequence, it could be demonstrated already before 1850 that most atomic weights are not integers. But despite the issues with Prout's hypothesis, many scholars continued to debate these ideas throughout the 19$^{th}$ century and beyond. For instance, it has been suggested that Ernest Rutherford (1871-1937) introduced the term proton in 1920 not only for etymological reasons (greek *proton* = the first), but also in commemoration of William Prout.[19] As Meyer mentions in the first paragraph of *Moderne Theorien*[20], he thought that matter consists of discrete particles, the atoms. He posited that it is unclear if these are really indivisible. Later Meyer followed the idea that atoms consist of smaller aggregates.

Meyer was also influenced by the theory of *triads*, as first described in 1816[21] by Johann Wolfgang Döbereiner, professor of chemistry in Jena and well-known for his pneumatic gas lighter, the *Döbereiner Feuerzeug*. He also tried to classify around 30 elements based on their chemical analogy, such as Ca, Ba, Sr, or Cl, Br, I, or Li, Na, K in the alkali group. He compared their atomic weights and found that the atomic weights of the middle elements of each of the series of three elements were roughly the mean value of the other two. These groups of three elements were later called *triads*.[22] In his 4$^{th}$ edition of 1883, Meyer established that Döbereiner's work was propagated by Leopold Gmelin in his *Handbuch der Chemie*.[23] Meyer was curious about these numerical relations and in his book *Moderne Theorien* he discusses "the peculiar regularities"[24] that were found between atomic weights by Döbereiner and later by many other scholars. Meyer used the notion of there being an arithmetic relationship between atomic weights. He suspected that these relationships were responsible for the idea that atoms are an aggregate of smaller units. This explanation was adopted from the homologous series in organic chemistry, which are characterized by the repeated addition of constant fragments.

In the first edition of *Moderne Theorien* Meyer arranged fifty elements into three tables with the aim to underline the mathematical relations between the atomic weights. The first included twenty-eight elements, which were grouped consequently with respect to their increasing atomic weights and valency. He described the relations as "six well-characterized groups of elements"[25] (Fig. 2).

Meyer combined elements with the same valency and similar chemical properties. The atomic weight of the elements increases in each row from left to the right. A regular change of valency can be established – but Meyer did not use the word periodicity in his text. The table also includes the differences of atomic weights of elements which were paired in the column. Meyer underlined the regularity for the differences in the atomic weights. In the first rows one finds as difference nearly 16, later nearly 46 and then 87-90 which is more or less the double value of 46.[26] The integration of these numerical values demonstrates again Meyer's interest in finding a similarity to the homologous series. And it is

| | Valency 4 | | Valency 3 | | Valency 2 | | Valency 1 | | Valency 1 | | Valency 2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | - | | - | | - | | - | Li | = 7,03 | (Be | = 9,3?) |
| difference = | | - | | - | | - | | - | | 16,02 | | (14,7) |
| | C | = 12,0 | N | = 14,04 | O | = 16,00 | Fl | = 19,0 | Na | = 23,05 | Mg | = 24,0 |
| difference = | | 16,5 | | 16,96 | | 16,07 | | 16,46 | | 16,08 | | 16,0 |
| | Si | = 28,5 | P | = 31,0 | S | = 32,07 | Cl | = 35,46 | K | = 39,13 | Ca | = 40,0 |
| difference = | 89,1/2 | = 44,55 | | 44,0 | | 46,7 | | 44,51 | | 46,3 | | 47,6 |
| | - | | As | = 75,0 | Se | = 78,8 | Br | = 79,97 | Rb | = 85,4 | Sr | = 87,6 |
| difference = | 89,1/2 | = 44,55 | | 45,6 | | 49,5 | | 46,8 | | 47,6 | | 49,5 |
| | Sn | = 117,6 | Sb | = 120,6 | Te | = 128,3 | J | = 126,8 | Cs | = 133,0 | Ba | = 137,1 |
| difference = | 89,4 | = 2 · 44,7 | 87,4 | = 2 · 43,7 | | - | | - | (71 | = 2 · 35,5) | | - |
| | Pb | = 207,0 | Bi | = 208,0 | | - | | - | (Tl | = 204 ?) | | - |

**Figure 2.** Meyer's table of "well-characterized groups of elements". Adapted from L. Meyer, *Die modernen Theorien der Chemie und ihre Bedeutung für die chemische Statik,* Maruschke & Berendt, Breslau, **1864**, p. 137.

noteworthy that Meyer uses values with one or two decimal points.

It should be mentioned that the increase of atomic weight from row to row has two exceptions. Although one can clearly see that tellurium has a higher atomic weight than iodine, Meyer arranged Te prior to I, which corresponds with the valency. The second exception in the order of increasing atomic weights is thallium which Meyer placed after Bi in the group of the alkaline metals with valency one. He mentioned that the difference of the atomic weights between Ca and Tl differs extremely from 2x46 and assumed a wrong determination in the case of Tl. Question marks in the table indicate Meyer's doubts concerning the correctness of some of these atomic weights.

This table also contains gaps, marked with dashes. One example of such a gap concerns the precautionary prediction of the atomic weight. The element following silicon in the group of elements with valency four should have an atomic weight 44.55 higher than silicon (28.5), namely 73,05. But Meyer did not discuss this prediction like later Mendeleev.

The difference 46 of atomic weights and the valency were also the basis for the two other tables of elements published by Meyer in 1864 (Fig. 3 and 4). Meyer did not give an explanation why he did not place the following 22 elements in one table. We can only see that the first (Fig. 3) belongs to elements with valency four and six, the second (Fig. 4) to valency two, four and mixed. Later Meyer explained that he contemplated combining all tables in one but he was concerned with the uncertainties and potential mistakes in atomic weights.[27]

In Fig. 4 Meyer placed Mn and Fe on the same spot because of the similarity of the atomic weights. In the consequence he formulated two differences – the difference in the atomic weights Ru-Mn, and Ru-Fe.

| | Valency 4 | | Valency 6 | |
|---|---|---|---|---|
| | Ti | = 48 | Mo | = 92 |
| difference = | | 42 | | 45 |
| | Zr | = 90 | Vd | = 137 |
| difference = | | 47,6 | | 47 |
| | Ta | = 137,6 | W | = 184 |

**Figure 3.** Groups of six elements with the difference of nearly 46 of atomic weights and the valency four and six. Adapted from L. Meyer, *Die modernen Theorien der Chemie und ihre Bedeutung für die chemische Statik,* Maruschke & Berendt, Breslau, **1864**, p. 138.

Today, the elements of the table in Fig. 2 are known as the main group of elements, those of the tables in Fig. 3 and 4 are the transition elements. Meyer finished his explanations by asserting that there is no doubt about a certain law (*bestimmte Gesetzmäßigkeit*) in the numerical values of the atomic weights. He reasoned that discrepancies are linked with incorrectness of atomic weights. He wrote:

> *We can assume that some of the discrepancies result to some extent from the incorrect determination of atomic weights. But this is not valid for all. It is not fair – as is done often – to correct or to change the empirically estimated atomic weights until the experiment has delivered more exactly determined values.*[28]

By 1866 at the latest, Meyer had started to examine the atomic weights with the claim of more correctness. When he arrived in Karlsruhe to take his teaching duties, he had no time for this task; it was only in Tübingen where he could continue this research program, together with Seubert.

During his time in Eberswalde, Meyer was already working on the second edition of *Moderne Theorien*. It

| | Valency 4 | | Valency 4 | | Valency 4 | | Valency 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mn | = 55,1 | Ni | = 58,7 | Co | = 58,7 | Zn | = 65,0 | Cu | = 63,5 |
| | Fe | = 56,0 | | | | | | | | |
| difference = | | 49,2<br>48,3 | | 45,6 | | 47,3 | | 46,9 | | 44,4 |
| | Ru | = 104,3 | Rh | = 104,3 | Pd | = 106,0 | Cd | = 111,9 | Ag | = 107,94 |
| difference = | 92,8 | = 2·46,4 | 92,8 | = 2·46,4 | 93,0 | = 2·46,5 | 88,3 | = 2·44,2 | 88,8 | = 2·44,4 |
| | Pt | = 197,1 | I (Ir) | = 197,1 | Os | = 199,0 | Hg | = 200,2 | Au | = 196,7 |

**Figure 4.** Groups of six elements with the difference of nearly 46 of atomic weights and the valency two, four and mixed. Adapted from L. Meyer, *Die modernen Theorien der Chemie und ihre Bedeutung für die chemische Statik,* Maruschke & Berendt, Breslau, **1864**, p. 138.

may be assumed that it is to this aim that he drafted a new, more extensive table with 52 elements in 1868. But this system was not published in a timely manner. It was not until 1895 that Seubert published it on two pages along with several important papers about the historical development of the periodic system.[29]

We assume it was Seubert who used not one, but two pages to print the table in a better, readable format (see Fig. 5). He explained that it is necessary to combine the two pages in such a manner that C and N, P and Si, Sb and Sn, Bi and Pb became neighbors.[30] Only under this condition Meyer‘s table would be faithfully reproduced. Otherwise the table was just too long to be printed in a book page.

In this version Meyer also included aluminum and chromium, which had not been presented in 1864. He allotted chromium its own column, but aluminum presented him with problems. Seubert noted that Meyer first placed Al in the fourth column, then moved it to the third column, and finally decided to go with his first decision.[31] It is more astonishing that aluminum does not fit in the order of increasing atomic weights. It would fit better in the third row, prior to Si. But most elements are placed in rows with regularly increasing atomic weight – from left to right and top down. However, if one checks the table carefully one can find some more irregularities concerning the increasing atomic weight. If molybdenum were placed next to zirconium and vanadium next to tantalum there would be less irregularity. It is unclear whether Seubert transferred the data correctly. The original version of the table could not be found. But if one assumes that the new table is a combination of the first three (Fig. 2, 3 and 4), one can see table 2 (Fig. 3) has been moved to columns 14 and 15.[32] In this table Mo followed Ti, Vd followed Zr, and W followed Ta. Thus it is unlikely that Seubert made a mistake.

The new table has 16 columns, the last of which is empty. Hydrogen is not considered. The reason was Meyer‘s belief in a special role of hydrogen comparable to Prout‘s theory. The already accepted elements of boron, indium, niobium, thorium, uranium, and some rare earths metals are also excluded. If we compare these multiple columns with modern representations of the periodic system, we can find some matches concerning the main group of elements (columns 8 to 13 or the first table from 1864). The table in Fig. 5 also displays an empty space for the element following silicon (see in column 8), as it was the case in the first 1864 table (Fig. 2). These constant differences were viewed by Meyer as proof of the complexity of the atoms, as being constituted as aggregates of smaller units, and he used this constancy in the difference to suggest an element after silicon. While Mendeleev went further boldly, also successfully predicting chemical properties for what he called "eka-silicon" (germanium), Meyer stopped short and did not elaborate on his prediction.

Meyer didn't keep that draft as he gave the original document to his successor in Eberswalde. This was the mineralogist and geologist Adolf Remelé (1839-1915), who reported indeed that Meyer had left the hand-written draft to him:

> *When I came in July 1868 as his successor for chemistry, physics and mineralogy I got the inventory which belonged to the teaching post. But he also gave me the self-written arrangement of elements by increasing atomic weights which was a more comprehensive and completed scheme of that from 1864 and established that he will publish it soon.*[33]

It is unclear why Remelé did not return this draft to Meyer in the years of the priority dispute, or why Meyer did not ask for it. Remelé showed it to Meyer only in 1893; a copy was most likely sent to Seubert in 1895.[34]

Long before Seubert's publication of Meyer's draft in 1895, Meyer finished a paper about the nature of chemical elements as a function of their atomic weights in 1869 and published it in March 1870.[35] It contains a table with 55 elements (Fig. 6). Hydrogen is again not considered with respect to its "exceptional position"[36]. Other elements with uncertainties of their atomic weights were excluded by Meyer. It seems that for Meyer it was very important to use reliable data. In Mendeleev's 1869 paper 63 elements were regarded, uncertainties in the atomic weight were simply marked. In contrast to Mendeleev who published atomic weights as integers or one decimal point at most, Meyer systematically used weights with one or two decimals in his publications.

The table in Fig. 6 portrays how Meyer ordered the elements strictly according to increasing atomic weights, following the first column top down, then repeating this in the second column, etc. He highlighted some uncertainties such as Te and Os with question marks. What is new is that the column does not combine elements with similar properties – these are found in one row. In total there are nine columns and 16 rows (the second row has three dashes). Perhaps Meyer was influenced by Mendeleev's first table and changed the rows and columns? Meyer also mentioned the constant differences of the atomic weights: From column I to column II, and from II to III, etc. Later Meyer changed rows and columns again.

Anhang. 6

**Entwurf eines Systems der Elemente von Lothar Meyer. 1868.**

§ 91

Nicht gedruckt. Wiedergabe nach dem Manuscript.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| | | Al — 27,3*) | Al = 27,3 *) | | | | C = 12,00 |
| | | $\frac{28,7}{2}$ = 14,3 | | | | | 16,5 |
| | | | | | | | Si = 28,5 |
| | | | | | | | $\frac{89,1}{2}$ = 44,55 |
| Cr = 52,6 | Mn = 55,1 | Fe = 56,0 | Co = 58,7 | Ni = 58,7 | Cu = 63,5 | Zn = 65,0 | — |
| | 49,2 | 48,3 | 47,3 | | 44,4 | 46,9 | $\frac{89,1}{2}$ = 44,55 |
| | Ru = 104,3 | Rh = 104,3 | Pd = 106,0 | | Ag = 107,94 | Cd = 111,9 | Sn = 117,6 |
| | 92,8 = 2·46,4 | 92,8 = 2·46,4 | 93 = 2·46,5 | | 88,8 = 2·44,4 | 88,3 = 2·44,15 | 89,4 = 2·44,7 |
| | Pt = 197,1 | Ir = 197,1 | Os = 199,0 | | Au = 196,7 | Hg = 200,2 | Pb = 207,0 |

*) Im Original durchstrichen und durch daruntergesetzte Punkte wieder gültig gemacht. K. S.

Lothar Meyer

| 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|
| | | | Li = 7,03 | Be = 9,3 | | | |
| | | | 16,02 | 14,7 | | | |
| N = 14,04 | O = 16,00 | Fl = 19,0 | Na = 23,05 | Mg = 24,0 | | | |
| 16,96 | 16,07 | 16,46 | 16,08 | 16,0 | | | |
| P = 31,0 | S = 32,07 | Cl = 35,46 | K = 39,13 | Ca = 40,0 | Ti = 48 | Mo = 92 | |
| 44,0 | 46,7 | 44,51 | 46,3 | 47,6 | 42 | 45 | |
| As = 75,0 | Se = 78,8 | Br = 79,97 | Rb = 85,4 | Sr = 87,6 | Zr = 90 | Vd = 137 | |
| 45,6 | 49,5 | 46,8 | 47,6 | 49,5 | 47,6 | 47 | |
| Sb = 120,6 | Te = 128,3 | J = 126,8 | Cs = 133,0 | Ba = 137,1 | Ta = 137,6 | W = 181 | |
| 87,4 = 2·43,7 | | | 71 = 2·35,5 | | | | |
| Bi = 208,0 | | | ? Tl = 204 ? | | | | |

S. *L. Gmelin*, Hdb. 5. Aufl. I, 47 ff.; Münch. gel. Anz. 1850 Bd. **30**, S. 261, 272, abgedr. Ann. Chem. Pharm. 1858. **105**, 187; *J. Dumas*, C. r. 1857, t. **45**, p. 709; auch Ann. Chem. Pharm. **105**, S. 74 u. a.

**Seite 7 hat man sich in der Weise seitlich an Seite 6 angereiht zu denken, dass N = 14,04 in Spalte 9 neben C = 12,00 in Spalte 8 zu stehen kommt, P neben Si, Sb neben Sn, Bi neben Pb.**
**K. S.**

Natur der Atome: Gründe gegen ihre Einfachheit. 7

**Figure 5.** Meyer's unpublished draft of an elements' system. Scan from K. Seubert, *Das natürliche System der chemischen Elemente,* 2nd edition, Engelmann, Leipzig, **1913**, pp. 6-7.

| I | II | III | IV | V | VI | VII | VIII | IX |
|---|---|---|---|---|---|---|---|---|
| | B = 11,0 | Al = 27,3 | | — | | ? In = 113,4 | | Tl = 202,7 |
| | | | — | | — | | — | |
| | C = 11,97 | Si = 28 | | — | | Sn = 117,8 | | Pb = 206,4 |
| | | | Ti = 48 | | Zr = 89,7 | | — | |
| | N = 14,01 | P = 30,9 | | As = 74,9 | | Sb = 122,1 | | Bi = 207,5 |
| | | | V = 51,2 | | Nb = 93,7 | | Ta = 182,2 | |
| | O = 15,96 | S = 31,98 | | Se = 78 | | Te = 128 ? | | — |
| | | | Cr = 52,4 | | Mo = 95,6 | | W = 183,5 | |
| — | F = 19,1 | Cl = 35,38 | | Br = 79,75 | | J = 126,5 | | — |
| | | | Mn = 54,8 | | Ru = 103,5 | | Os = 198,6? | |
| | | | Fe = 55,9 | | Rh = 104,1 | | Ir = 196,7 | |
| | | Co = | Ni = 58,6 | | Pd = 106,2 | | Pt = 196,7 | |
| Li = 7,01 | Na = 22,99 | K = 39,04 | | Rb = 85,2 | | Cs = 132,7 | | — |
| | | | Cu = 63,3 | | Ag = 107,66 | | Au = 196,2 | |
| ? Be = 9,3 | Mg = 23,9 | Ca = 39,9 | | Sr = 87,0 | | Ba = 136,8 | | — |
| | | | Zn = 64,9 | | Cd = 111,6 | | Hg = 199,8 | |

**Differenz von I zu II und von II zu III ungefähr = 16.**
**Differenz von III zu V, IV zu VI, V zu VII schwankend um 46.**
**Differenz von VI zu VIII, von VII zu IX = 88 bis 92.**

**Figure 6.** Meyer's classification of elements from 1870. Scan from K. Seubert, *Das natürliche System der chemischen Elemente.* 2nd edition, Engelmann, Leipzig, **1913**, p.11.

As noted above, this table contains dashes. It seems that these are place holders for those elements with uncertain atomic weights or for elements yet unknown. He wrote:

*These elements [with uncertain atomic weights G.B.] will later at least partly occupy these gaps which are still in the table. Other gaps will be filled by elements which will be discovered in future; prospective discoveries will possibly move one or the other element from its place and substitute it by another one, which fits better.*[37]

In this 1870 publication, Meyer also used the newly determined atomic weights and for the first time mentioned a periodic function of the atomic weight:

*The same or similar properties recur when the atomic weight increased for a certain size, at first 16, later 46 and finally 88 to 92 units.*[38]

From 1864 on, Meyer had arranged the elements with respect to chemical properties, such as valency, and thus expressed periodicity but this was implicit. To explain the concept of periodicity more clearly, he used the relation between the atomic volume and the atomic weight. Meyer calculated the atomic volume as the quotient of the atomic weight and the density of the elements in the solid state, except for chlorine for which he used the liquid state. The graphic presentation shows the periodicity clearly – it is actually more striking than the tables (Fig. 7).

Like Mendeleev, Meyer predicted the discovery of new elements but he did not describe any properties. Meyer was impressed by periodicity but explicitly mentioned that it was still not clear what the reasons for the periodic change might be:

*These and similar regularities cannot be a simple coincidence but we must recognize that the empiric way to the establishment is not the key to the recognition of its internal primary link. But it seems that a starting point is found for the study of the constitution of the hitherto undecomposable atoms, it is a guideline for future examinations of elements.*[39]

In the meantime Mendeleev had published his natural system of elements, copies of which were sent to other chemists in Russia and several other countries. By the end of 1869 the correspondent of the *Berichte der Deutschen Chemischen Gesellschaft* (Reports from the German Chemical Society) Viktor von Richter (1841-1891) had reported on the interesting relationship in the system of elements that Mendeleev had developed.[40] A short review of Mendeleev's system was also published in the *Zeitschrift für Chemie* (Journal of Chemistry) in Germany.[41]

Meyer was acquainted with Mendeleev's paper and wrote in his own 1870 paper that "the hereinafter published table is in the main identical with that of Mendelejeff".[42] Subsequently many readers and also Mendeleev understood this phrase as an admission that Meyer did

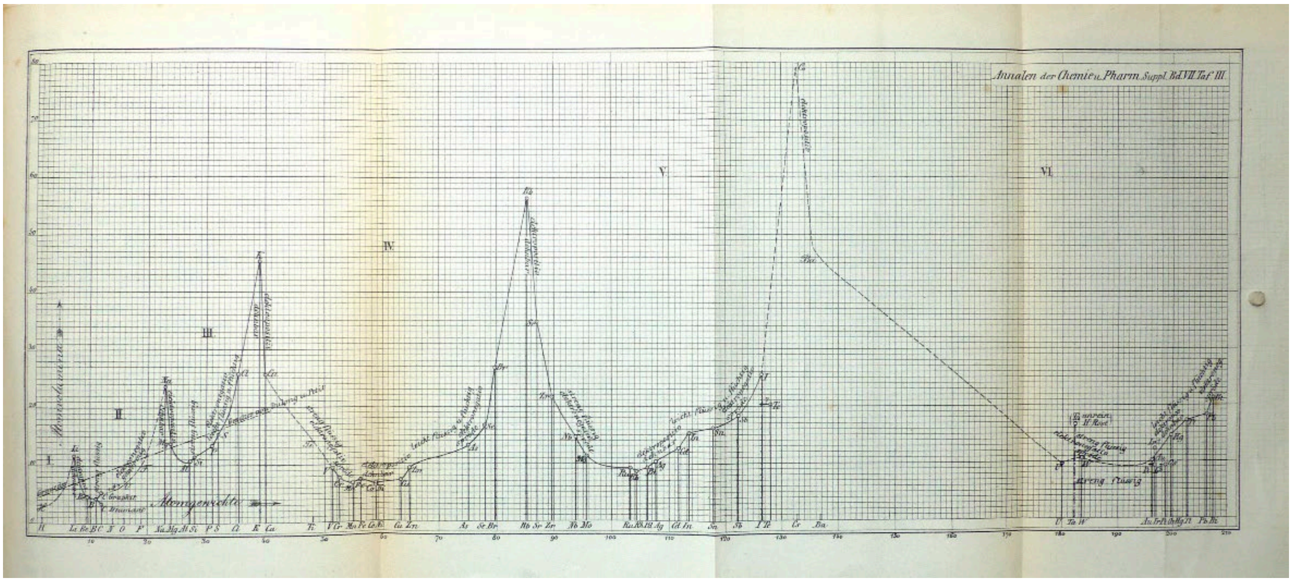



**Figure 7.** Presentation of the graph which shows the periodic relation between atomic volume and atom weight. Scan from L. Meyer, *Annalen der Chemie und Pharmacie*. VII. Supplementband **1871**, 354-364.

not publish his own ideas, but elaborated on Mendeleev's. Mendeleev answered with two publications in 1871.[43] But subsequently both Meyer and Mendeleev focused mainly on other scientific problems. Meyer did however publish several papers after 1878 on the determination of atomic weights. The priority dispute began again in 1879, but we shall not discuss it further here.[44]

## THE PERIODIC SYSTEM AND THE COURSE OF INORGANIC CHEMISTRY

We will now turn to the question of how Lothar Meyer valued the periodic system as a didactic tool. He was interested in questions like the organization of school and university instruction[45], but also in the issue of how to integrate the periodic system into the study of inorganic chemistry. Meyer reported on this topic in Berlin two years before his death; this lecture was published later.[46]

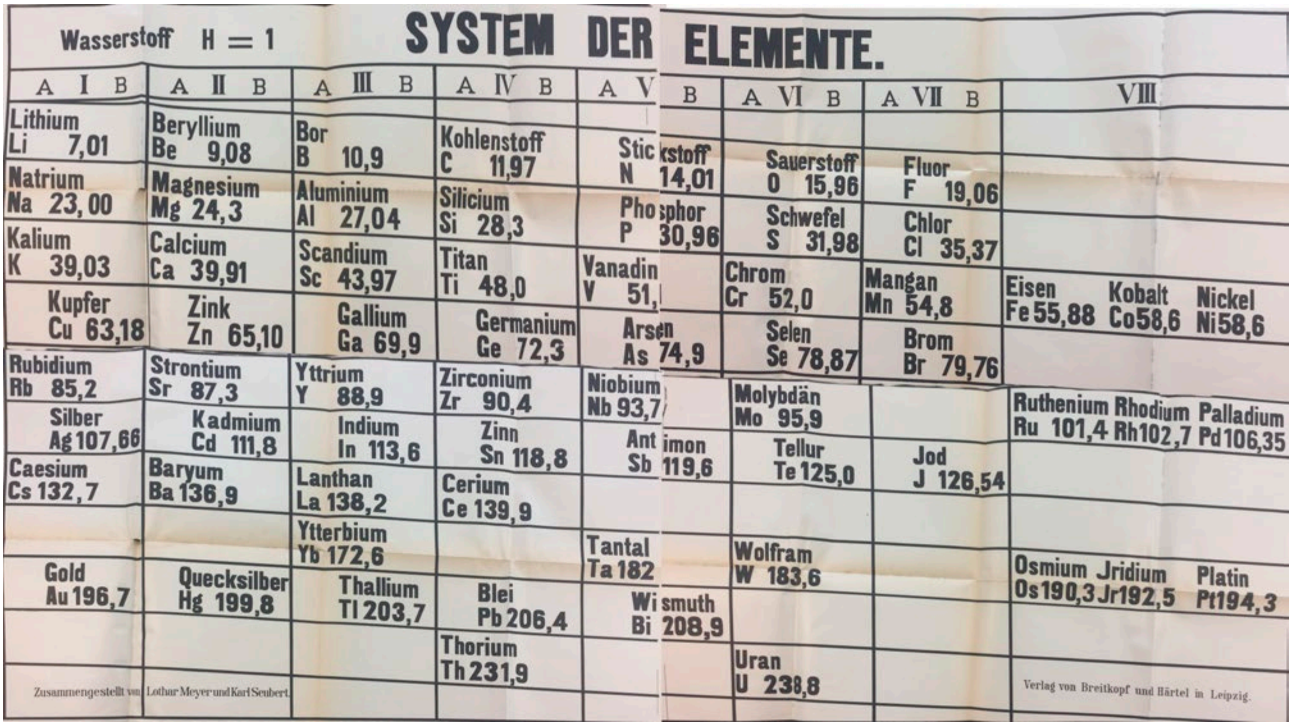
In this paper he used the table type presented in Fig. 8. It shows that Meyer returned to his first ordering: he combined elements with similar chemical properties in one column and not in one row. One can also establish that he separated most of the transition elements from the rest. Meyer introduced this distinction already in the second edition of the *Moderne Theorien*.[47] In that edition one finds also for the first time tables starting with the alkali metals. Meyer explained the reason: those elements display the maximum atomic volume for each row.[48]

Sometimes Meyer used in his papers presentations of the system which reminds of the spiraled form used by Alexandre-Emile Béguyer de Chancourtois (1819-1886).[49] Such a representation type was also used for a printed chart (Fig. 9).[50]

It can be assumed that this format is similar to the one he used in the lecture hall in Tübingen. Meyer noted that he understood his contribution to the periodic system as a modification of the Döbereiner system and not as a new qualitative step. He called his system neither a new theory nor a new law. He emphasized that the system would be well-suited to giving students an overview. Meyer also pointed out that during the last twenty years this system had only received minimal attention in textbooks, where it received a brief mention or cursory explanation. Only a small number of textbooks used it as a fundamental part of the arrangement for the teach-

| I | II | III | IV | V | VI | VII | VIII | | |
|---|---|---|---|---|---|---|---|---|---|
| Li | Be | B | C | N | O | F | | | |
| Na | Mg | Al | Si | P | S | Cl | | | |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni |
| Cu | Zn | Ga | Ge | As | Se | Br | | | |
| Rb | Sr | Y | Zr | Nb | Mo | — | Ru | Rh | Pd |
| Ag | Cd | Jn | Sn | Sb | Te | J | | | |
| Cs | Ba | La | Ce | — | — | — | | | |
| — | — | Yb | — | Ta | W | — | | | |
| Au | Hg | Tl | Pb | Bi | — | — | Os | Jr | Pt |
| — | — | — | Th | — | U | — | | | |

**Figure 8.** One of the last presentations of Meyer's arrangement of elements in 1893. Scan from L. Meyer, *Ber. Dtsch. Chem. Ges.* **1893**, *26***,** 1230–1250, here 1232.


Wasserstoff H = 1 SYSTEM DER ELEMENTE.

| A I B | A II B | A III B | A IV B | A V B | A VI B | A VII B | VIII |
|---|---|---|---|---|---|---|---|
| Lithium Li 7,01 | Beryllium Be 9,08 | Bor B 10,9 | Kohlenstoff C 11,97 | Stickstoff N 14,01 | Sauerstoff O 15,96 | Fluor F 19,06 | |
| Natrium Na 23,00 | Magnesium Mg 24,3 | Aluminium Al 27,04 | Silicium Si 28,3 | Phosphor P 30,96 | Schwefel S 31,98 | Chlor Cl 35,37 | |
| Kalium K 39,03 | Calcium Ca 39,91 | Scandium Sc 43,97 | Titan Ti 48,0 | Vanadin V 51, | Chrom Cr 52,0 | Mangan Mn 54,8 | Eisen Fe 55,88 Kobalt Co 58,6 Nickel Ni 58,6 |
| Kupfer Cu 63,18 | Zink Zn 65,10 | Gallium Ga 69,9 | Germanium Ge 72,3 | Arsen As 74,9 | Selen Se 78,87 | Brom Br 79,76 | |
| Rubidium Rb 85,2 | Strontium Sr 87,3 | Yttrium Y 88,9 | Zirconium Zr 90,4 | Niobium Nb 93,7 | Molybdän Mo 95,9 | | Ruthenium Ru 101,4 Rhodium Rh 102,7 Palladium Pd 106,35 |
| Silber Ag 107,66 | Kadmium Cd 111,8 | Indium In 113,6 | Zinn Sn 118,8 | Antimon Sb 119,6 | Tellur Te 125,0 | Jod J 126,54 | |
| Caesium Cs 132,7 | Baryum Ba 136,9 | Lanthan La 138,2 | Cerium Ce 139,9 | | | | |
| | | Ytterbium Yb 172,6 | | Tantal Ta 182 | Wolfram W 183,6 | | Osmium Os 190,3 Jridium Jr 192,5 Platin Pt 194,3 |
| Gold Au 196,7 | Quecksilber Hg 199,8 | Thallium Tl 203,7 | Blei Pb 206,4 | Wismuth Bi 208,9 | | | |
| | | | Thorium Th 231,9 | | Uran U 238,8 | | |

Zusammengestellt von Lothar Meyer und Karl Seubert. Verlag von Breitkopf und Härtel in Leipzig.

**Figure 9.** Meyer's system of elements as chart. Combination of four individually printed unbounded parts. Scan from L. Meyer, K. Seubert, *Das natürliche System der Elemente. Nach den zuverlässigsten Atomgewichtswerthen zusammengestellt.* 2nd edition, Breitkopf&Härtel, Leipzig, **1896**.

ing content.[51] He established that the course of organic chemistry, with its type-theory and the homologous series, is better systematized than inorganic chemistry. For example, several ways can be used for an overview of the metals. The use of the periodic system must be prepared. If someone is unacquainted with the system he will need explicit instruction, as the system was not self-explanatory. Meyer noted that he had modified his own course several times and emphasized that in any case it is necessary to start with simple substances.

In teaching, Meyer started with a short introduction about the relation between chemistry and physics He regretted that the type theory in organic chemistry had not found yet an equivalent in inorganic chemistry. Then he turned to some aspects of history of chemistry like alchemy or the phlogiston theory. He mentioned Johan Baptista van Helmont (1580-1640), Antoine Laurent de Lavoisier (1743-1794) and Bunsen and combined his historical approach with the introduction of elements and compounds which are connected with those savants. Later he introduced the atomic weights and discussed the compounds. Then he was able to explain the periodic system. Meyer mentions using a large chart to illustrate the system in the lecture hall, as well as a model using a rotating cylinder.

He started with hydrogen as the foundation for the atomic weights, then he dealt with group VII (compare figure 8). He delayed working with group I, as it seemed too complicated for the students. Meyer finished his paper by expressing his wish that readers would try this course and perhaps find a better way of arranging the material on the basis of the periodic system.

## CONCLUSION

Today the periodic system has its atom-theoretical explanation. Its representation as a table can be found in nearly every chemical cabinet. The subject matter in courses of inorganic chemistry is organized on the basis of the groups of the periodic system. However, Lothar Meyer's contribution to this system is often forgotten and mainly Mendeleev's is appreciated. After Meyer's death Mendeleev often emphasized the importance of his predictions and their confirmation. For most people this was easy to understand. Meyer's accurateness in determining atomic weights and his reflections on the nature of atoms were not so easily understandable.

This paper presented Lothar Meyer's biography and key achievements in the field of classification of the elements. It demonstrates that Meyer tried to find an explanation to Döbereiner´s triads and that he started to determine and to recalculate the atomic weights of elements as a result of irregularities in his classifications. Meyer was very cautious concerning predictions of new elements, as his main interest was the understanding the nature of atoms. He also was interested in using the periodic table for instruction in inorganic chemistry.

By analyzing the successive reworkings of his classification, and the discovery of periodicity as much as the absence of archives allows, it is possible to follow the train of Meyer's thoughts in this endeavor. This demonstrates that the Karlsruhe conference was key, as was the case for Mendeleev, but also underlines differences between the two pursuits. A convinced atomist, Meyer also paid much attention to valency and other atomic properties such as the atomic radii. In his recollections, it is also clear that Meyer saw his work as a continuation of prior developments such as Döbereiner. He did not predicted new elements explicitly, but he was more successful in placing most elements in the right order. Mendeleev ordered all known elements, but with more mistakes than Meyer. On the other side he predicted not only the elements but described their properties. Mendeleev always insisted on his proposal as being a breakthrough. As this paper illustrates, the finding and development of the periodic system was more than one man's feat.

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25. Ibid, p.136.
26. Ibid, p. 138.
27. L. Meyer, *Ber. Dtsch. Chem. Ges.* **1896**, *13*, 259-265, here p. 259.
28. Zum Theil allerdings können diese Abweichungen mit Fug und Recht angesehen werden als hervorgebracht durch unrichtig bestimmte Werthe der Atomgewichte. Bei allen dürfte indess dies kaum der Fall sein; und ganz sicherlich ist man nicht berechtigt, wie das nur zu oft geschehen ist, um eine vermeintlichen Gesetzmäßigkeit willen die empirisch gefundenen Atomgewichte willkürlich zu corrigieren und zu verändern, ehe das Experiment genauer bestimmte Werthe an ihre Stelle gesetzt hat. Source 24, p. 139 (all translations by the author).
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33. Als ich im Juli 1868 als sein Nachfolger im Lehramt der Chemie, Physik und Mineralogie die ihm unterstellten Inventarien übernahm, übergab er mir mit dem Bemerken, er denke die Sache doch bald zu veröffentlichen, eine eigenhändig geschriebene Anordnung der Elemente nach den Atomgrößen, welche eine wesentliche Ergänzung und Vervollkommnung seines vorerwähnten Schemas von 1864 darstellt. A. Remelé, *Zeitschrift für Forst- und Jagdwesen* **1895**, *27*, 721-724.
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36. Source 29, p. 12.
37. Diese Elemente werden voraussichtlich später, z. Th. wenigstens, die Lücken ausfüllen, welche sich in der Tabelle jetzt noch finden. Andere Lücken werden möglicherweise durch später zu entdeckende Elemente ausgefüllt werden; vielleicht auch wird durch künftige Entdeckungen das eine oder andere Element aus seiner Stelle verdrängt und durch ein besser hinein passendes ersetzt werden. Ibid, p. 12.
38. Dieselben oder ähnliche Eigenschaften kehren wieder, wenn das Atomgewicht um eine gewisse Grösse, die zunächst 16, dann etwa 46 und schließlich 88 bis 92 Einheiten beträgt, gewachsen ist. Ibid, p. 13.
39. Wenn diese und ähnliche Regelmässigkeiten unmöglich reines Spiel des Zufalls sein können, so müssen wir uns andererseits gestehen, dass wir mit der empirischen Ermittlung derselben noch keineswegs den Schlüssel zur Erkenntnis ihres inneren ursächlichen Zusammenhangs gefunden haben. Aber es scheint wenigstens ein Ausgangspunkt gewonnen zu sein für die Erforschung der Constitution der bis jetzt unzerlegten Atome, eine Richtschnur für fernere vergleichende Untersuchung der Elemente. Ibid, p.16.
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