# CLASSICS OF SCIENCE: Periodic Law of the Elements

*Chemistry*

The elements known to Mendeleeff are shown in his original table reproduced on this page. **Wt. 45, 68, and 70 are his eka-boron, eka-aluminum and eka-silicon.** He predicted the properties of these elements, and elements with the properties he predicted were discovered within 15 years. They are gallium, scandium and germanium. The other gap in his list, Wt. 180, is Hafnium, discovered in 1922.

*THE PERIODIC LAW OF THE CHEMICAL ELEMENTS. By Professor Mendeleeff. (Faraday Lecture delivered before the Fellows of the Chemical Society in the Theatre of the Royal Institution, on Tuesday, June 4th, 1889.)*

The high honour bestowed by the Chemical Society in inviting me to pay a tribute to the world-famed name of Faraday by delivering this lecture has induced me to take for its subject the Periodic Law of the Elements—this being a generalisation in chemistry which has of late attracted much attention. . . .

It was in March, 1869, that I ventured to lay before the then youthful Russian Chemical Society the ideas upon the same subject, which I had expressed in my just written "Principles of Chemistry."

Without entering into details, I will give the conclusions I then arrived at, in the very words I used:

"1. The elements, if arranged according to their atomic weights, exhibit an evident *periodicity* of properties.

"2. Elements which are similar as regards their chemical properties have atomic weights which are either of nearly the same value (*e. g.*, platinum, iridium, osmium) or which increase regularly (*e. g.*, potassium, rubidium, cæsium).

"3. The arrangement of the elements, or of groups of elements in the order of their atomic weights corresponds to their so-called *valencies* as well as, to some extent, to their distinctive chemical properties—as is apparent among other series in that of lithium, beryllium, barium, carbon, nitrogen, oxygen and iron.

"4. The elements which are the most widely diffused have *small* atomic weights.

"5. The *magnitude* of the atomic weight determines the character of the element just as the magnitude of the molecule determines the character of a compound body.

"6. We must expect the discovery of many yet *unknown* elements, for example, elements analogous to aluminum and silicon, whose atomic weight would be between 65 and 75.

## **Соотношеніе свойствъ съ атомнымъ вѣсомъ элементовъ.**

Д. Менделѣева.

но въ ней, мнѣ кажется, уже ясно выражается примѣнимость выставляемаго мною начала ко всей совокупности элементовъ, пай которыхъ извѣстенъ съ достовѣрностію. На этотъ разъ я и желалъ преимущественно найдти общую систему элементовъ. Вотъ этотъ опытъ.

| | | | | | |
|---|---|---|---|---|---|
| | | | Ti=50 | Zr=90 | ?=180. |
| | | | V=51 | Nb=94 | Ta=182. |
| | | | Cr=52 | Mo=96 | W=186. |
| | | | Mn=55 | Rh=104,4 | Pt=197,4 |
| | | | Fe=56 | Ru=104,4 | Ir=198. |
| | | | Ni=Co=59 | Pl=1066, | Os=199. |
| H=1 | | | Cu=63,4 | Ag=108 | Hg=200. |
| | Be=9,4 | Mg=24 | Zn=65,2 | Cd=112 | |
| | B=11 | Al=27,4 | ?=68 | Ur=116 | Au=197? |
| | C=12 | Si=28 | ?=70 | Sn=118 | |
| | N=14 | P=31 | As=75 | Sb=122 | Bi=210 |
| | O=16 | S=32 | Se=79,4 | Te=128? | |
| | F=19 | Cl=35,5 | Br=80 | I=127 | |
| Li=7 | Na=23 | K=39 | Rb=85,4 | Cs=133 | Tl=204 |
| | | Ca=40 | Sr=87,6 | Ba=137 | Pb=207 |
| | | ?=45 | Ce=92 | | |
| | | ?Er=56 | La=94 | | |
| | | ?Yt=60 | Di=95 | | |
| | | ?In=75,6 | Th=118? | | |

*FACSIMILE OF MENDELEEFF'S ORIGINAL TABLE. In the text above it, he explains that this is only one of many possible arrangements to show the periodic function. The arrangement more familiar to us is the work of Lothar Meyer.*

"7. The atomic weight of an element may sometimes be amended by a knowledge of those of the contiguous elements. Thus, the atomic weight of tellurium must lie between 123 and 126, and cannot be 128.

"8. Certain characteristic properties of the elements can be foretold from their atomic weights.

"The aim of this communication will be fully attained if I succeed in drawing the attention of investigators to those relations which exist between the atomic weights of dissimilar elements, which, as far as I know, have hitherto been almost completely neglected. I believe that the solution of some of the most important problems of our science lies in researches of this kind."

Today, 20 years after the above conclusions were formulated, they may still be considered as expressing the essence of the now well-known periodic law. . . .

### *The Periodicity of the Elements*

The periodic law, by insisting on the necessity for a revision of supposed facts, exposed itself at once to destruction in its very origin. Its first requirements, however, have been almost entirely satisfied during the last 20 years; the supposed facts have yielded to the law, thus proving that the law itself was a legitimate induction from the verified facts. But our inductions from data have often to do with such details of a science so rich in facts that only generalisations which cover a wide range of important phenomena can attract general attention. What were the regions touched on by the periodic law? This is what we shall now consider.

The most important point to notice is, that periodic functions, used for the purpose of expressing changes which are dependent on variations of time and space, *(Turn to next page)*

## Periodic Law of the Elements—*Continued*

have been long known. They are familiar to the mind when we have to deal with motion in closed cycles, or with any kind of deviation from a stable position, such as occurs in pendulum-oscillations. A like periodic function became evident in the case of the elements, depending on the mass of the atom. The primary conception of the masses of bodies or of the masses of atoms belongs to a category which the present state of science forbids us to discuss, because as yet we have no means of dissecting or analysing the conception. All that was known of functions dependent on masses derived its origin from Galileo and Newton, and indicated that such functions either decrease or increase with the increase of mass, like the attraction of celestial bodies. The numerical expression of the phenomena was always found to be proportional to the mass, and in no case was an increase of mass followed by a recurrence of properties such as is disclosed by the periodic law of the elements. This constituted such a novelty in the study of the phenomena of nature that, although it did not lift the veil which conceals the true conception of mass, it nevertheless indicated that the explanation of that conception must be searched for in the masses of the atoms; the more so, as all masses are nothing but aggregations, or additions, of chemical atoms which would be best described as chemical individuals. . . . The periodic law has shown that our chemical individuals display a harmonic periodicity of properties, dependent on their masses. Now, natural science has long been accustomed to deal with periodicities observed in nature, to seize them with the vice of mathematical analysis, to submit them to the rasp of experiment. And these instruments of scientific thought would surely, long since, have mastered the problem connected with the chemical elements, were it not for a new feature which was brought to light by the periodic law and which gave a peculiar and original character to the periodic function.

If we mark on an axis of abscissæ a series of lengths proportional to angles, and trace ordinates which are proportional to sines or other trigonometrical functions, we get periodic curves of a harmonic character. So it might seem, at first sight, that with the increase of atomic weights the function of the properties of the elements should also vary in the same harmonious way. But in this case there is no such continuous change as in the curves just referred to, because the periods do not contain the infinite number of points constituting a curve, but a *finite* number only of such points. An example will better illustrate this view. The atomic weights—

Ag=108 Cd=112 In=113 Sn=118
Sb=120 Te=125 I=127

steadily increase, and their increase is accompanied by a modification of many properties which constitutes the essence of the periodic law. Thus, for example, the densities of the above elements decrease steadily, being respectively—

10·5 8·6 7·4 7·2 6·7 6·4 4·9

while their oxides contain an increasing quantity of oxygen:—

$Ag_2O$ $Cd_2O_2$ $In_2O_3$ $Sn_2O_4$
$Sb_2O_5$ $Te_2O_6$ $I_2O_7$

But to connect by a curve the summits of the ordinates expressing any of these properties would involve the rejection of Dalton's law of multiple proportions. Not only are there no intermediate elements between silver, which gives AgCl, and cadmium, which gives $CdCl_2$, but, according to the very essence of the periodic law there can be none; in fact a uniform curve would be inapplicable in such a case, as it would lead us to expect elements possessed of special properties at any point of the curve. The periods of the elements have thus a character very different from those which are so simply represented by geometers. They correspond to points, to numbers, to sudden changes of the masses, and not to a continuous evolution . . . .

### *Law Enlarges Our Vision*

In the remaining part of my communication I shall endeavour to show, and as briefly as possible, in how far the periodic law contributes to enlarge our range of vision. Before the promulgation of this law the chemical elements were mere fragmentary, incidental facts in Nature; there was no special reason to expect the discovery of new elements, and the new ones which were discovered from time to time appeared to be possessed of quite novel properties. The law of periodicity first enabled us to perceive undiscovered elements at a distance which formerly was inaccessible to chemical vision; and long ere they were discovered new elements appeared before our eyes possessed of a number of well-defined properties. We now know three cases of elements whose existence and properties were foreseen by the instrumentality of the periodic law. I need but mention the brilliant discovery of gallium, which proved to correspond to eka- aluminium of the periodic law, by Lecoq de Boisbaudran; of *scandium*, corresponding to eka-boron. by Nilson; and of *germanium*, which proved to correspond in all respects to eka-silicium, by Winckler. When, in 1871, I described to the Russian Chemical Society the properties, clearly defined by the periodic law, which such elements ought to possess, I never hoped that I should live to mention their discovery to the Chemical Society of Great Britain as a confirmation of the exactitude and the generality of the periodic law. Now, that I have had the happiness of doing so, I unhesitatingly say that although greatly enlarging our vision, even now the periodic law needs further improvements in order that it may become a trustworthy instrument in further discoveries.* . . .

*I foresee some more new elements, but not with the same certitude as before. I shall give one example, and yet I do not see it quite distinctly. In the series which contains Hg = 204, Pb = 206, and Bi = 208, we can guess the existence (at the place VI—11) of an element analogous to tellurium, which we can describe as dvi-tellurium. Dt having an atomic weight of 212, and the property of forming the oxide $DtO_3$. If this element really exists, it ought in the free state to be an easily fusible, crystalline, non-volatile metal of a grey colour, having a density of about 9.3, capable of giving a dioxide, $DtO_2$, equally endowed with feeble acid and basic properties. This dioxide must give on active oxidation an unstable higher oxide, $OtO_3$, which should resemble in its properties $PbO_2$ and $Bi_2O_5$. Dvi-tellurium hydride, if it be found to exist, will be a less stable compound than even $H_2Te$. The compounds of dvi-tellurium will be easily reduced, and it will form characteristic definite alloys with other metals .[Dvi-tellurium is now known as Polonium, a radio-active element discovered by Mme. Curie but never isolated.—Ed.]

**Dmitri Ivanovich Mendeleeff** was born February 7, (new style) 1834 in Tobolsk, Siberia, and died in St. Petersburg, Russia, February 2, 1907. He graduated in chemistry from the University at St. Petersburg at the age of 22. Five years later he began to teach, following that profession for 29 years. For the last 14 years of his life he was director of the Russian Bureau of Weights and Measures. Mendeleef's famous book, "The Principles of Chemistry," in which his idea of the periodic law of the chemical elements was set forth, was written in 1868, and the following year the account of the law was read before the Russian Chemical Society and published in their Journal.

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