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Similarity of periods and periodicity in groups of periodic tables of chemical elements: Periodic law

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Abstract: The article considers the periodic table of chemical elements, and that it is a graphic representation of the periodic law (PL), although more than 150 years have passed since the opening of the periodic law, there is no clear formulation of the mathematical formula of this law. The definitions of PL are compared and the work of research scientists is analyzed. Currently, throughout the world, the law is not mentioned in courses in general chemistry and physics, only the table of D.I. Mendeleev is used. This article provides suggestions on how to fill such inconsistencies. Nowadays, there are more than 700 variants of the graphic construction of P.T., the most recognized is IUPAC. The object of our study is the 32-cell version of the periodic table, which, in our opinion, does not break the table into parts with the introduction of lanthanides and actinoids into the lower part of the table. It most fully reflects the similarity of periods and the main physicochemical properties of elements in groups, as well as their periodicity, when joining subscripts (lanthanides and actinides) into a single table corresponding to the natural ordinal number of the location of these elements in periods. The formulas presented in the article are difficult to summarize the P.L., they are difficult to understand, so the goal of our study is to derive a simplified mathematical equation and formulate a periodic law based on an analysis of the literature and its data on periodic changes in the properties of chemical elements and their compounds.

Keywords: the periodic law, the periodic table, chemical elements, ladder table, similar periods, convenient formulation.

1. Introduction

The Periodic Table (PT) of chemical elements is an ordered number of elements, which is a graphical expression of the periodic law (PL). More than 150 years have passed since its discovery so – called Periodic Law by D. I. Mendeleev (1869), but there is still no clear formulation of it with a mathematical expression (as the author himself emphasized – D. I. Mendeleev). The author's formulation of the PL is as follows: "The properties of simple bodies, as the shape and properties of compound elements are periodically dependent on the atomic weight of elements" [1].

Although like his predecessors and contemporaries D.I. Mendeleev linked the periodicity in changing the properties of chemical elements with the value of their atomic weight; he violates this sequence in several places. So, the observance of anomalies (Ar-K, Co-Ni, Te-I) was dictated by the need to preserve the most important manifestation of PT and similarity properties of chemical elements within the group. The final explanation the placement of all the elements in the PT is full and strict accordance with their physicochemical properties and not in accordance with the atomic mass, was found only after clarifying the meaning of the ordinal (atomic) number of elements.

After the discovery of electrons and development of the theory of atom structure, exploring the X-ray spectra of various elements in 1913 G. Moseley

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established that the ordinal numbers of chemical elements in PT were really reflected the values of the nuclear charges of their atoms. Therefore, the formulation of PL has undergone changes: "the properties of simple substances, as forms and properties of compound elements are periodically dependent on the charges of nucleus atom elements" this formulation is still repeated in many textbooks for schools and universities in some countries of the post-Soviet space [2-4].

In our opinion, both the first and second formulations of PL do not correspond to reality.

First, we do not observe any periodic dependence in the change in atomic weight or nuclear charge. The atomic weights of the elements are random, and the charges of the atomic nucleus increase monotonically with an increase in the ordinal number of the element. Secondly, there is no mathematical equation and corresponding formulation. In given formulations of PL, neither the properties of elements nor the specific type of periodic dependence is defined, so none of these variants of law is useless without a simultaneous demonstration of PL. In this regard, the law is often not mentioned at all in the courses of general chemistry and physics currently around the world, but only a table is considered, since the establishment of a law primarily means the creation or use of an adequate mathematical expression necessary for the quantitative formulation of the law. Only such a formulation will make it possible to break the "vicious circle" in the definitions of the law through the table and tables through the law [5]. In this article, we have tried to fill (eliminate) this discrepancy.

2. Computational Method

Currently, there are more than 700 options for graphical construction of PT. The most recognized International Union of Pure and Applied Chemistry (IUPAC) are 18- and 32-cell tables. The object of our research is the 32-cell version of the periodic table, which in our opinion does not break the table into parts with the removal of lanthanides and actinides in the lower part of the table. It mostly fully reflects the similarity of periods and the main physicochemical properties of elements in groups, as their periodicity, when descenders (lanthanides and actinides) are added to a single table corresponding to the natural ordinal number of the arrangement of these elements in the 6th and 7th periods.

The main principle of building tables is to select periods (horizontal rows) and groups (vertical columns) in them. A period is a set of elements that begins with an alkali metal (ns1) (or hydrogen is the first period) and ends with an inert gas (ns2 np6). One of the first variants of a 32-cell long table is the ladder (pyramidal) table proposed by N. Bohr in 1921, where such periods are clearly distinguished (Figure 1). Currently, IUPAC has approved the following 32-cell table (Figure 2), which also seems to represent a staircase divided into 2 parts (if you connect the upper left and right parts of 1-3 similar periods (Figure 2) or 1-5 typical ones, we get a table similar to N. Bohr).

Similarities are called periods that have the same number of elements or electrons in the outer and pre- outer levels filled with electrons with similar physicochemical properties and are designated by Arabic numerals, and the traditional (IUPAC) periods are also designated by Arabic numerals, but underlined below for convenience of mathematical expression of the periodic law, offered by us. The similarity of the periods of PT and the possibility of its application in the formulation of the PL was considered by us in the works [6-8].

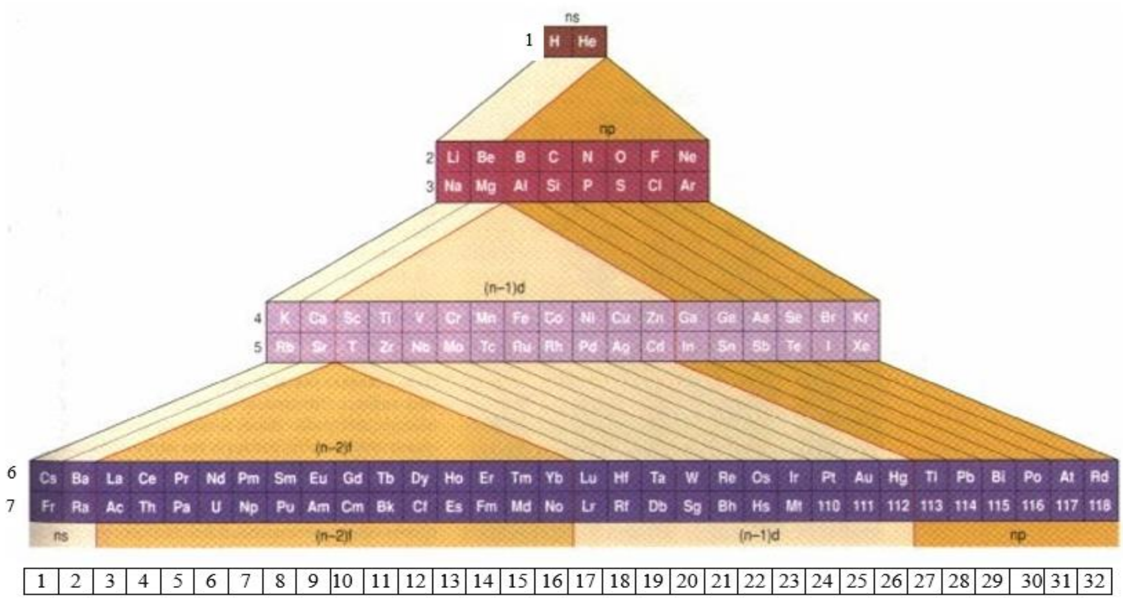

Figure 1. The ladder (pyramidal) form of the Periodic Table of chemical elements of N. Bora.

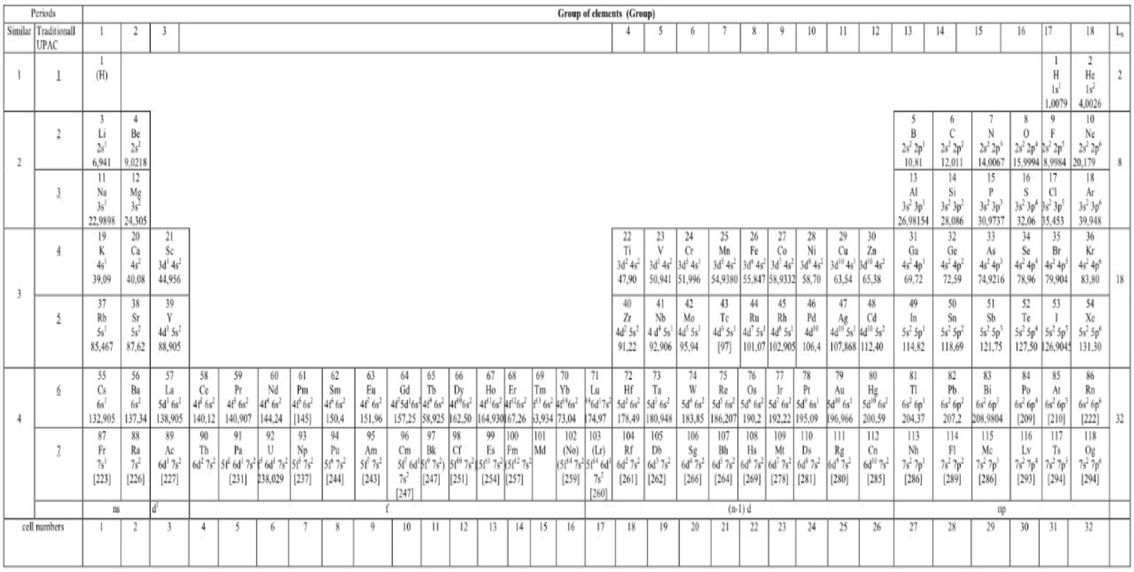

Figure 2. Long 32-cellular form of periodic table of chemical element

Table 1. The order of filling the outer electron layers in periods with electrons and the number of elements in them

	Fillable AO	Periods		$L_n = 2Pn^2$
		IUPAC	similar	
Energy	$7p^6, 7s^2, 6d^{10}$,5f14	7	4	$L_n = 2 \cdot 4^2 = 32$
	$6p^6, 6s^2, 5d^{10}, 4f^{14}$	6		
	$5p^6, 5s^2, 4d^{10}$	5	3	$L_n = 2 \cdot 3^2 = 18$
	$4p^6, 4s^2, 3d^{10}$	4		
	$3p^6, 3s^2$	3	2	$L_n = 2 \cdot 2^2 = 8$
	$2p^6, 2s^2$	2		
	$1s^2$	1	1	$L_n = 2 \cdot 1^2 = 2$

To determine the number of elements in the periods, the following formulas are proposed [4]. For odd periods (1) and even periods (2), and the general [5] formula (3):

$$L_n = \frac{(n+1)^2}{2} \quad (1)$$

$$L_n = \frac{(n+2)^2}{2} \quad (2)$$

$$\mathrm{Ln} = \frac{[2n+3+(-1)^n]^2}{8} \quad (3)$$

where: L_n – is the number of elements in the period, n – is the number of the period.

Above formulas are cumbersome and difficult to summarize the PL, are difficult to perceive and do not correspond to the purpose of our study–of a simplified conclusion of a mathematical equation and the formulation of periodic law [9].

Let us consider the order of filling the atoms of elements with external electrons in periods occurring in accordance with the energy of the state of the system. In the 1st period there is one atomic orbital (AO) on which only two electrons ($\bar{e}$) can fit, so there are only two elements in it (H and He). In the 2nd period, there are already four AO–$2s^22p^6$ at the external energy level, which can accommodate 8$\bar{e}$-and in the period there are already 8 elements. In the 3rd period, the 3d AO is added to the $3s^2p^6$ AO at the external level, and 18$\bar{e}$ or 18 elements can fit in this layer. However, the d-AO is not filled in and there are only 8$\bar{e}$ and, accordingly, 8 elements in the period on the outer electronic layer [10]. In the 4th period, a 4f-orbital is added to the outer electron layer, and 32$\bar{e}$ or 32 elements can already fit in the outer electron layers. However, the 4f-orbitals are not filled, but the free 3d-orbital is filled, the number of $\bar{e}$ in the outer layers reaches 18$\bar{e}$ and, accordingly, there are 18 elements in the period.

The filling of external AOs with electrons in the 5th period is the same as in the fourth period and they contain 18 electrons and, accordingly, elements. A similar filling of the outer electron layers is observed in the 6th and 7th periods of the PS: $6s^2$, $4f^{14}$, $5d^{10}$, $6p^6$; $7s^2$, $5f^{14}$, $6d^{10}$, $7p^6$ which can hold 32 electrons or 32 elements [11]. Thus, if we compare the order of filling the outer electron layers in the atoms of elements with electrons, which mainly affect the physicochemical properties of elements and their compounds, we will get the following Table 1:

Similar periods are Arabic numbers without a dash, IUPAC-with a dash (1-7). As can be seen from the table, similar periods (in terms of the number of elements in them and electrons in the external electronic configurations) are combined and designated as follows: 1-7 IUPAC periods, 1-4 similar periods (4). The first has no such thing and remains the same: I -(1).

The scheme of the mutual arrangement of the external and pre-external electronic energy sublevels in the atom and their filling with electrons (the arrow indicates the increase in energy). n is the number of a similar period [12]. From Table 1, it can be seen that a numerical series of elements in the periods is obtained 2; 8, 8; 18, 18; 32, 32: to which you can apply the formula for calculating the number of elements in the periods [6].

$$L_n=2n^2 \quad (4)$$

From the above data, it follows that the number of chemical elements in similar periods of the periodic table is equal to twice the square of the number of similar periods. Application of the method of synergetic information theory (STI) for the analysis of the electronic system of atoms of chemical elements P.T. confirmed the periodic nature of the dependence of the properties of elements on the ordinal number of periods [13]. In STI, such periods are called orbital-wave periods of the structural organization of electronic systems of atoms of chemical elements, and half-periods (typical (IUPAC) periods) are denoted by the symbol tn. Then the number of elements in chemical periods is,

$$tn = 2N2 \quad (5)$$

The application of this formula to the seven known chemical periods of PT gave a number series: 2; 8, 8; 18, 18; 32, 32 corresponding to the number of elements introduced by us for similar periods [14].

3. Results and discussion

Groups have a more significant role than periods for explaining the structure and structure of atoms from the standpoint of quantum mechanical theory, since elements of the same group have the same configurations of external electronic layers that affect the basic physicochemical properties of elements [15].

Let us consider the periodic change of some properties of atoms in groups:

1. The periodicity changes in the properties of the elements are clear and visible changes in the radius of the atoms (Figure 3, Table 2). From top to bottom

in the group, the radii of the atom of the elements increase, since the outer and pre-outer electron layers are further away from the nucleus and at a higher energy level [11]. This change occurs in 8-8, 18-18, and 32-32 elements.

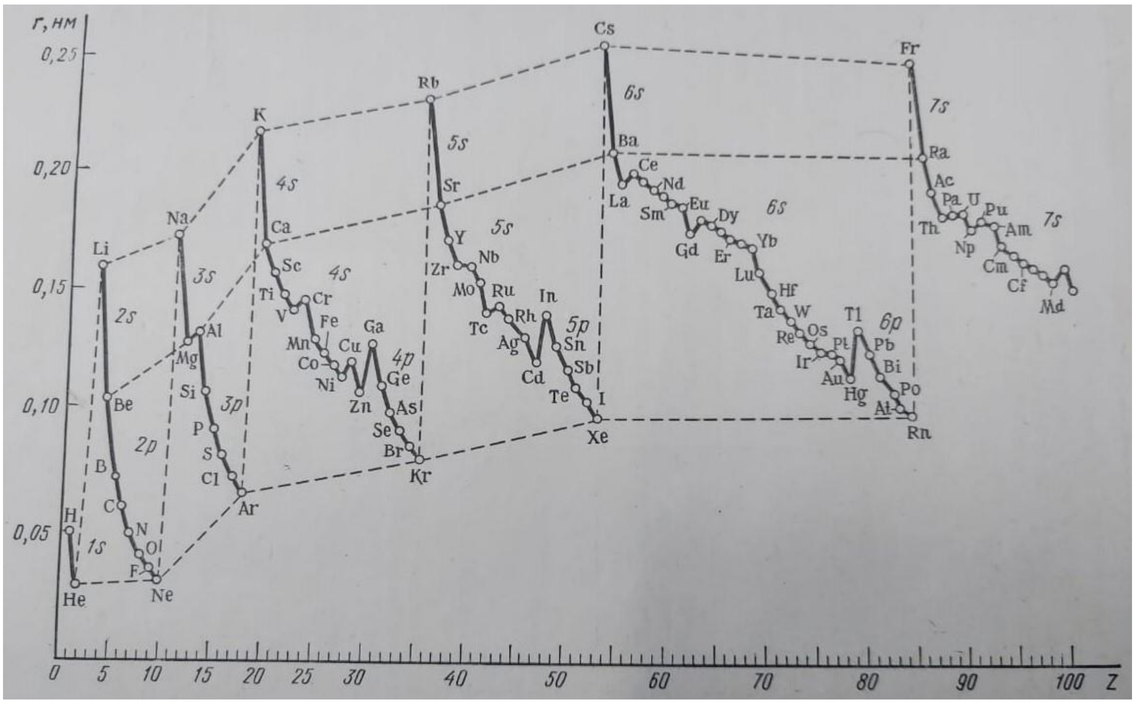

Figure 3. The dependence of orbital atom radius on the order number of the element

Table 2. Group of elements in the 18-and 32-cell and IUPAC tables

Periods		**Group of elements in the 18-and 32-cell and IUPAC tables**							
similar	traditional	1	2	15	17	1	2	15	17
		Radius of atoms, A^0				Ionization energies, эВ			
2	2	^{3}Li 1.3	^{4}Be 1.0	^{7}N 0.8	^{9}F 0.7	Li 5.4	Be 9.3	N 14.5	F 17.4
	3	^{11}Na 1.5	^{12}Mg 1.3	^{15}P 1.1	^{17}Cl 1.0	Na 5.1	Mg 7.6	P 10.6	Cl 13.0
3	4	^{19}K 2.0	^{20}Ca 1.7	^{33}As 1.2	^{35}Br 1.1	K 4.3	Ca 6.1	As 9.8	Br 11.8
	5	^{37}Rb 2.1	^{38}Sr 1.9	^{51}Sb 1.4	^{53}I 1.3	Rb 4.2	Sr 5.7	Sb 8.6	I 10.5
4	6	^{55}Cs 2.3	^{56}Ba 2.0	^{83}Bi 1.5	^{85}At -	Cs 3.9	Ba 5.2	Bi 7.3	At 9.2
	7	^{87}Fr -	^{88}Ra -	^{115}Mc -	^{117}Ts -	Fr 3.8	Ra -	Mc -	Ts-

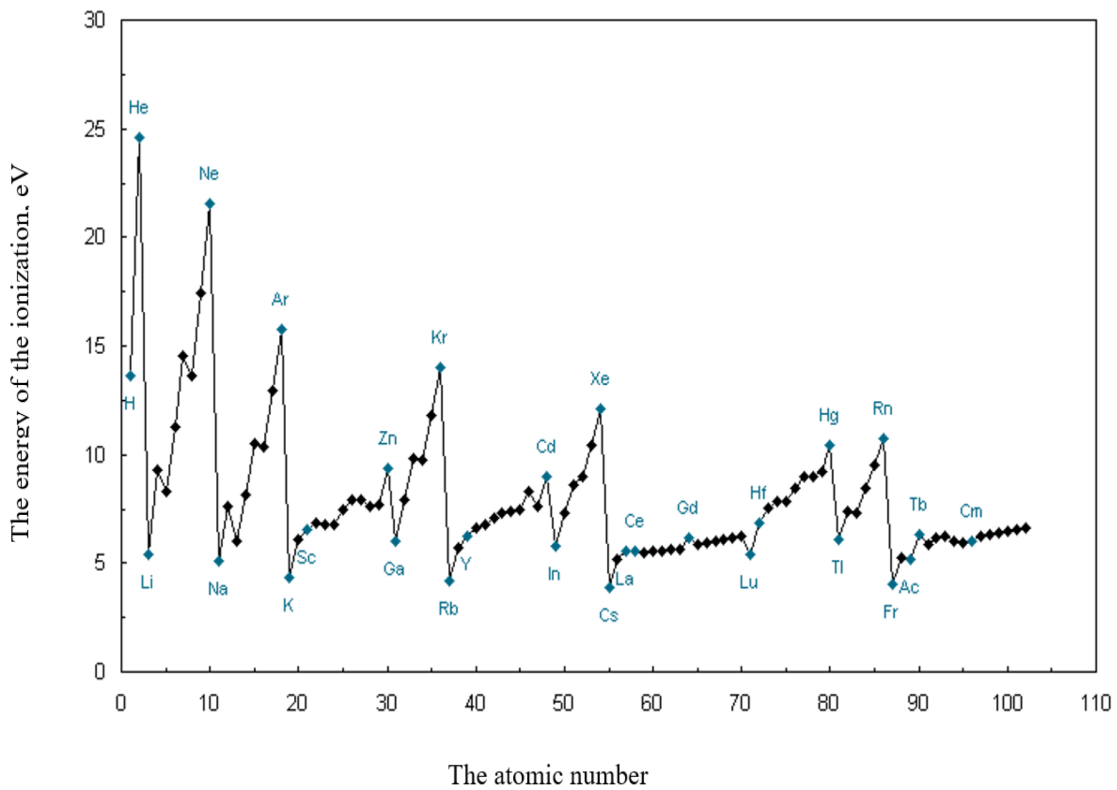

Figure 4. The energy of the ionization of atoms depends on the atomic number of the element.

2. The periodicity of the change in another property – in the change of the first ionization energy is shown in Figure 4, Table 2. Each element of the top row has a lower ionization energy, because it is easier to remove an electron less bound to the nucleus. The figure clearly shows how the value of the ionization energy gradually increases with increasing atomic number Z until Z reaches the value characteristic of the noble gas, and then, when moving to the next element, it drops to the value characteristic of the elements of the first group (alkali metals). Changes occur in the same order as above: 8-8; 18-18 and 32-32.

The same periodic change in physical and chemical properties can be seen in the change in the affinity of the atom to the electron and the electron.

4. Conclusions

From the given data, it can be seen that the change in the properties of chemical elements in the groups occurs with the same frequency as in the periods. Therefore, we can formulate a periodic law for them: the number of elements in periods, and the properties of chemical elements and compounds in groups with an increase in the charge of the nucleus of atoms change with a periodicity equal to twice the square of the number of similarity periods Ln = 〖2n〗 ^2. The scientific novelty of the work lies in the fact that, based on the analysis of the literature and its own data on the periodic change in the properties of chemical elements and their compounds, the concept of a periodic law is revived with a simplified and convenient formulation.

In this regard, an expanded Periodic Table is proposed with a column on the left – the numbers of similar periods and on the right-the quantity of elements in these periods.

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