S. Afr. J. Chem., 2024, 78, 108–112
https://journals.co.za/content/journal/chem/

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

Isatai Nurlybayev, Bazarkhan Imangaliyeva*, Gulnara Beketova, Gulsim Zhaumitova, Shynar Karassayeva

Department of Chemistry and Chemical Technology, K. Zhubanov Aktobe Regional University, Aktobe, Republic of Kazakhstan

ABSTRACT

The article considers the periodic table of chemical elements, and that it is a graphic representation of the periodic law, although more than 150 years have passed since the opening of the periodic law, there is no precise formulation of the mathematical formula of this law. The formulas presented in the article are difficult to summarize the periodic law, they are difficult to understand, so the goal of the 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. The object of study is the 32-cell version of the periodic table, which does not break the table into parts with the introduction of lanthanides and actinoids into the lower part of the table. It best shows how periods are similar and the main physical and chemical properties of elements in groups, as well as how often they happen, when subscripts (lanthanides and actinides) are put together in a single table that matches the natural ordinal number of where these elements are in periods. The definitions of periodic law are compared, and the work of research scientists is analyzed. This article provides suggestions on how to fill such inconsistencies. Nowadays, there are more than 700 variants of the graphic construction of Periodic Table; the most recognized is IUPAC.

KEYWORDS

periodic table, chemical elements, ladder table, similar periods, convenient formulation

Received 11 August 2023, revised 4 March 2024, accepted 8 March 2024

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 the discovery of the so-called Periodic Law, by D. I. Mendeleev (1869), but there is still no precise formulation of it with a mathematical expression. The author's formulation of the PL is as follows: "The properties of simple bodies, as well 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, observing anomalies (Ar-K, Co-Ni, Te-I) was dictated by the need to preserve the most important manifestation of PT and the similarity properties of chemical elements within the group. The final explanation the placement of all the elements in the PT is in 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 the development of the theory of atom structure, exploring the X-ray spectra of various elements in 1913, G. Moseley established that the ordinal numbers of chemical elements in PT were reflected the values of the nuclear charges of their atoms. Therefore, the formulation of PL has 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.[2-5]

The first and second formulations of PL do not correspond to reality.

First, we do not observe any periodic dependence on 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 or 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 law variants is useless without a simultaneous demonstration of PL.

MATERIALS AND METHODS

Currently, there are more than 700 options for the graphical construction of PT. The most recognized International Union of Pure and Applied Chemistry (IUPAC) are 18- and 32-cell tables. The focal point of our investigation centers on the 32-cell configuration of the periodic table. This version is selected based on its comprehensive representation of the periodic table's continuity, integrating lanthanides and actinides within the main body of the table rather than relegating them to a separate section. This approach ensures a unified view of the elemental sequence, reflecting a natural progression in the atomic numbers of elements across the 6th and 7th periods. The decision to study this version is grounded in the principle that maintaining the integrity of the periodic sequence facilitates a clearer understanding of element periodicity and group similarities. This configuration preserves the coherence of periodic trends and physicochemical properties across all elements, thereby offering a more holistic perspective on the periodic law's application. This rationale aligns with the scientific objective to depict the periodic table in a manner that most accurately reflects the intrinsic relationships and properties of the elements, supporting a seamless interpretation of their periodic behavior. 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 (ns^1) (or hydrogen is the first period) and ends with an inert gas (ns^2 np^6). One of the first variants of a 32-cell long table is the ladder (pyramidal) table proposed by

*To whom correspondence should be addressed
Email: imangaliyevabazarkhan6@gmail.com

ISSN 1996-840X Online / South African Chemical Institute / https://saci.co.za/journal

https://doi.org/10.17159/0379-4350/2024/v78a15

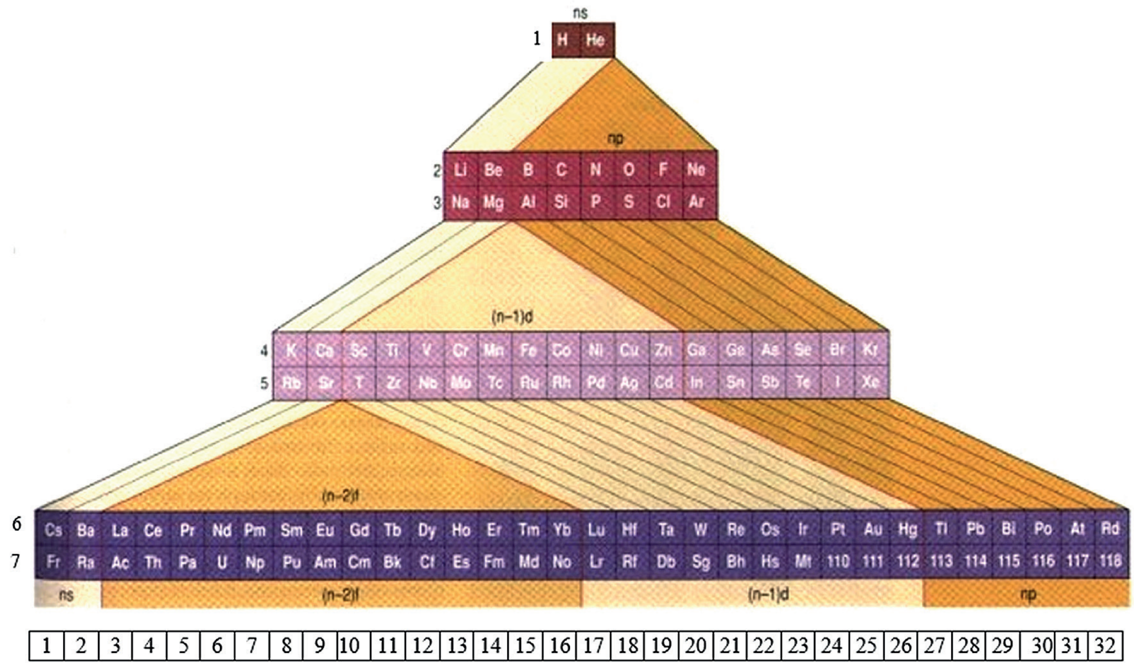

Figure 1: The ladder (pyramidal) form of the Periodic Table of chemical elements of N. Bora.
Note: A modern version with the cells of elements of the 6th and 7th periods numbered by authors.

Periods		Group of elements (Group)																																L_n
Similar	Traditional IUPAC	1	2	3															4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	1	1 (H)																														1 H $1s^1$ 1.0079	2 He $1s^2$ 4.0026	2
2	2	3 Li $2s^1$ 6.941	4 Be $2s^2$ 9.0218																									5 B $2s^2 2p^1$ 10.81	6 C $2s^2 2p^2$ 12.011	7 N $2s^2 2p^3$ 14.0067	8 O $2s^2 2p^4$ 15.9994	9 F $2s^2 2p^5$ 18.9984	10 Ne $2s^2 2p^6$ 20.179	8
	3	11 Na $3s^1$ 22.9898	12 Mg $3s^2$ 24.305																									13 Al $3s^2 3p^1$ 26.98154	14 Si $3s^2 3p^2$ 28.086	15 P $3s^2 3p^3$ 30.9737	16 S $3s^2 3p^4$ 32.06	17 Cl $3s^2 3p^5$ 35.453	18 Ar $3s^2 3p^6$ 39.948	
3	4	19 K $4s^1$ 39.09	20 Ca $4s^2$ 40.08	21 Sc $3d^1 4s^2$ 44.956															22 Ti $3d^2 4s^2$ 47.90	23 V $3d^3 4s^2$ 50.941	24 Cr $3d^5 4s^1$ 51.996	25 Mn $3d^5 4s^2$ 54.9380	26 Fe $3d^6 4s^2$ 55.847	27 Co $3d^7 4s^2$ 58.9332	28 Ni $3d^8 4s^2$ 58.70	29 Cu $3d^{10} 4s^1$ 63.54	30 Zn $3d^{10} 4s^2$ 65.38	31 Ga $4s^2 4p^1$ 69.72	32 Ge $4s^2 4p^2$ 72.59	33 As $4s^2 4p^3$ 74.9216	34 Se $4s^2 4p^4$ 78.96	35 Br $4s^2 4p^5$ 79.904	36 Kr $4s^2 4p^6$ 83.80	18
	5	37 Rb $5s^1$ 85.467	38 Sr $5s^2$ 87.62	39 Y $4d^1 5s^2$ 88.905															40 Zr $4d^2 5s^2$ 91.22	41 Nb $4d^4 5s^1$ 92.906	42 Mo $4d^5 5s^1$ 95.94	43 Tc $4d^6 5s$ [97]	44 Ru $4d^7 5s^1$ 101.07	45 Rh $4d^8 5s^1$ 102.905	46 Pd $4d^{10}$ 106.4	47 Ag $4d^{10} 5s^1$ 107.868	48 Cd $4d^{10} 5s^2$ 112.40	49 In $5s^2 5p^1$ 114.82	50 Sn $5s^2 5p^2$ 118.69	51 Sb $5s^2 5p^3$ 121.75	52 Te $5s^2 5p^4$ 127.50	53 I $5s^2 5p^5$ 126.9045	54 Xe $5s^2 5p^6$ 131.30	
4	6	55 Cs $6s^1$ 132.905	56 Ba $6s^2$ 137.34	57 La $5d^1 6s^2$ 138.905	58 Ce $4f^2 6s^2$ 140.12	59 Pr $4f^3 6s^2$ 140.907	60 Nd $4f^4 6s^2$ 144.24	61 Pm $4f^5 6s^2$ [145]	62 Sm $4f^6 6s^2$ 150.4	63 Eu $4f^7 6s^2$ 151.96	64 Gd $4f^7 5d^1 6s^2$ 157.25	65 Tb $4f^9 6s^2$ 158.925	66 Dy $4f^{10} 6s^2$ 162.50	67 Ho $4f^{11} 6s^2$ 164.930	68 Er $4f^{12} 6s^2$ 167.26	69 Tm $4f^{13} 6s^2$ 168.934	70 Yb $4f^{14} 6s^2$ 173.04	71 Lu $4f^{14} 5d^1 6s^2$ 174.97	72 Hf $5d^2 6s^2$ 178.49	73 Ta $5d^3 6s^2$ 180.948	74 W $5d^4 6s^2$ 183.85	75 Re $5d^5 6s^2$ 186.207	76 Os $5d^6 6s^2$ 190.2	77 Ir $5d^7 6s^2$ 192.22	78 Pt $5d^9 6s^1$ 195.09	79 Au $5d^{10} 6s^1$ 196.966	80 Hg $5d^{10} 6s^2$ 200.59	81 Tl $6s^2 6p^1$ 204.37	82 Pb $6s^2 6p^2$ 207.2	83 Bi $6s^2 6p^3$ 208.9804	84 Po $6s^2 6p^4$ [209]	85 At $6s^2 6p^5$ [210]	86 Rn $6s^2 6p^6$ [222]	32
	7	87 Fr $7s^1$ [223]	88 Ra $7s^2$ [226]	89 Ac $6d^1 7s^2$ [227]	90 Th $6d^2 7s^2$	91 Pa $5f^2 6d^1 7s^2$ [231]	92 U $5f^3 6d^1 7s^2$ 238.029	93 Np $5f^4 7s^2$ [237]	94 Pu $5f^6 7s^2$ [244]	95 Am $5f^7 7s^2$ [243]	96 Cm $5f^7 6d^1 7s^2$ [247]	97 Bk $5f^9 7s^2$ [247]	98 Cf $5f^{10} 7s^2$ [251]	99 Es $5f^{11} 7s^2$ [254]	100 Fm $5f^{12} 7s^2$ [257]	101 Md	102 (No) $5f^{14} 7s^2$ [259]	103 (Lr) $5f^{14} 6d^1 7s^2$ [260]	104 Rf $6d^2 7s^2$ [261]	105 Db $6d^3 7s^2$ [262]	106 Sg $6d^4 7s^2$ [266]	107 Bh $6d^5 7s^2$ [264]	108 Hs $6d^6 7s^2$ [269]	109 Mt $6d^7 7s^2$ [278]	110 Ds $6d^8 7s^2$ [281]	111 Rg $6d^9 7s^2$ [280]	112 Cn $6d^{10} 7s^2$ [285]	113 Nh $7s^2 7p^1$ [286]	114 Fl $7s^2 7p^2$ [289]	115 Mc $7s^2 7p^3$ [286]	116 Lv $7s^2 7p^4$ [293]	117 Ts $7s^2 7p^5$ [294]	118 Og $7s^2 7p^6$ [294]	
		ns		d^1	f														(n-1) d									np						
cell numbers		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	

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

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 two 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. The traditional (IUPAC) periods are also represented by Arabic numerals but underlined below for the 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]

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):

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

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

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

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

The 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 per the energy of the system's state. 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 – $2s^2 2p^6$ at the external energy level, which can accommodate 8$\bar{e}$-and in the period, there are already eight 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, eight elements in the period on the outer electronic layer.[10] In the 4th period, a 4f-orbital is added to the outermost 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, electrons. 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.[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 (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 and 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 PT 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]

RESULTS AND DISCUSSION

Groups have a more significant role than periods in 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 fundamental 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.
2. The periodicity of the change in another property – in the shift 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. 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 exact 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.

STRUCTURAL COHERENCE AND PERIODICITY IN THE UNIFIED PERIODIC TABLE

The quest for a simplified mathematical expression of the periodic law has driven the analysis of the periodic table's structure, specifically within the 32-cell version that integrates lanthanides and actinides into the main body of the table.[16] This structure represents a departure from traditional depictions that relegate these elements to separate sections and instead opts for a seamless progression that respects the natural order of atomic numbers. Such a representation is instrumental in demonstrating the periodicity and similarities in the physicochemical properties of elements within their respective groups.[17]

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	$L_n = 2{\cdot}1^2 = 2$

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, A⁰				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-

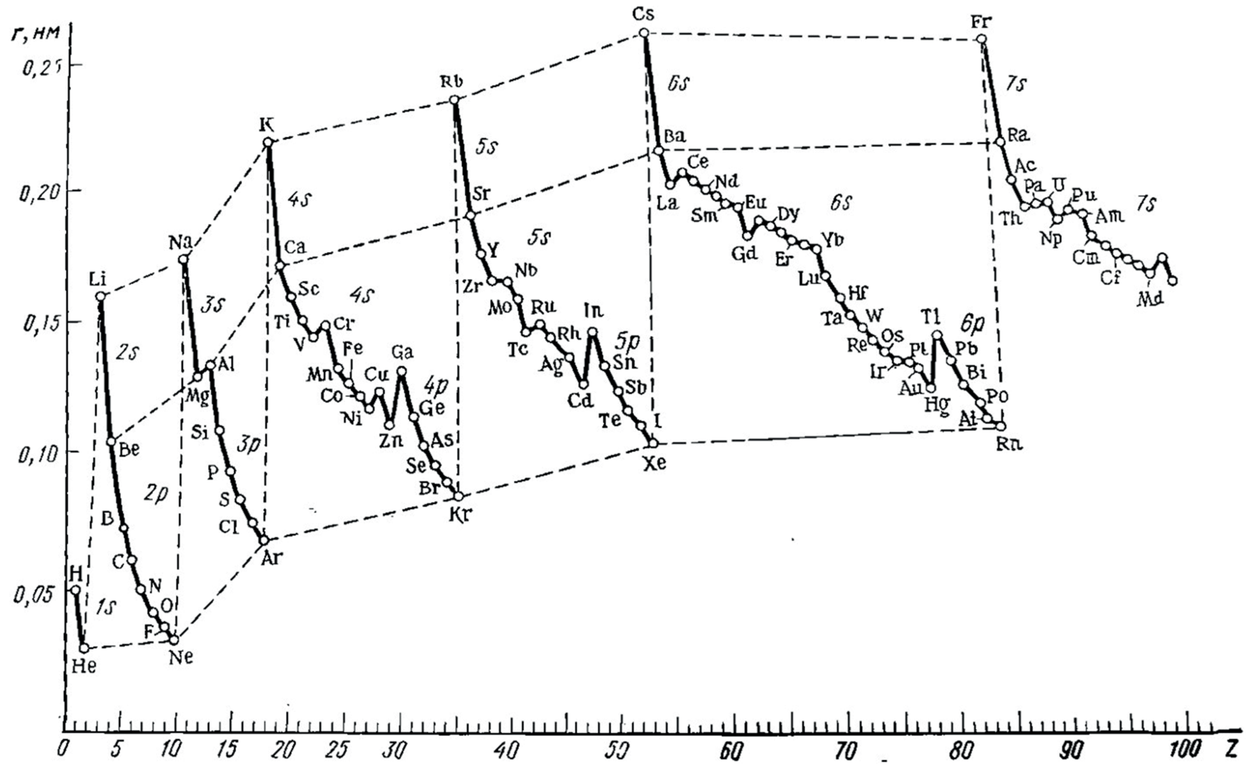

Figure 3: The dependence of orbital atom radius on the order number of the element.

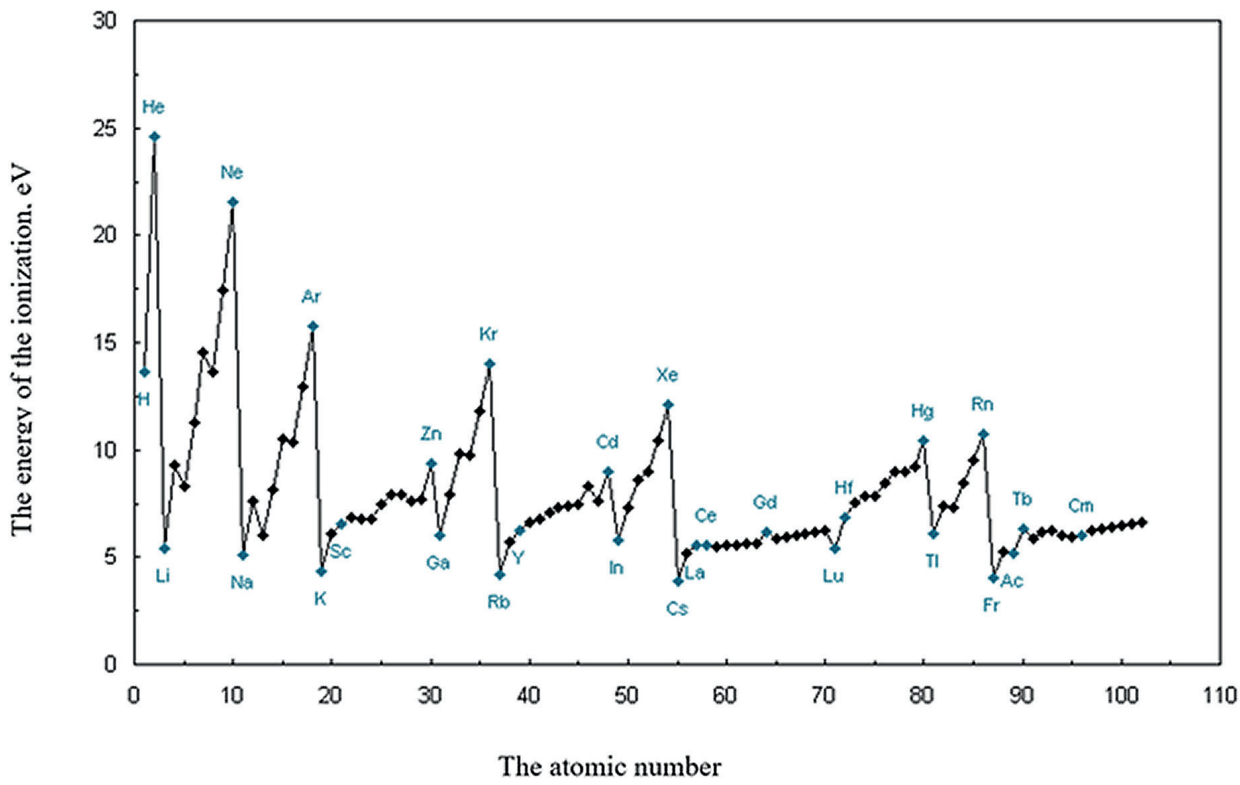

Figure 4: The energy of the ionization of atoms depends on the atomic number of the element.

The integrity of the periodic sequence is maintained in this configuration, ensuring that the element's periodic behavior and group similarities are coherent and evident. The number of elements in the periods is derived from the general formula $Ln = 2n^2$, which reflects twice the square of the number of similar periods, thereby simplifying the traditional complex equations.

A visual representation of this can be seen in the attached entity-relationship diagram, which serves as a foundational structure for the proposed periodic table (Figure 5). This table presents a unified view, where the similarity of periods and the main physicochemical properties of elements are clearly identified, fulfilling the aim of portraying a more holistic understanding of the periodic law.

The revised approach and the resultant formula offer a fresh perspective on the periodic table's design, one that is both scientifically robust and mathematically elegant. This method aligns with the primary goal of rendering the periodic table in a manner that most accurately mirrors the intrinsic relationships and properties of the elements, thereby validating the applicability of the new law across the full spectrum of periods and groups.

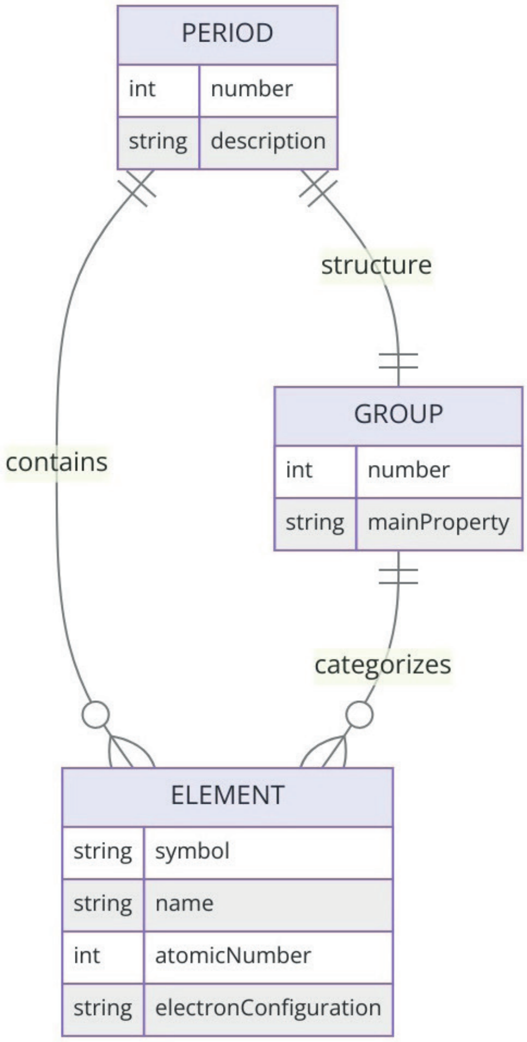

Figure 5: Entity-relationship diagram illustrating the structural coherence and periodicity in the unified periodic table

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 electrons 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 author's 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.

ACKNOWLEDGMENTS

None.

FUNDING

None.

DECLARATION OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

ORCID ID

Bazarkhan Imangaliyeva: https://orcid.org/0009-0001-5108-8159

REFERENCES

1. Druzhinin PA. The mystery of Mendeleev's table: a history of the publication of Dmitri Mendeleev's discovery of the periodic law. Novoe literaturnoe obozrenie; 2019.
2. Glinka NL. General chemistry: Manual for graduate students. TechSmith; 2018.
3. Pauling L. General chemistry. Mir, 1974.
4. Tretyakov YuD, Tamm ME (Ed.). Inorganic chemistry (Vol. 1-3). Vol. 1: Physical and chemical foundations of inorganic chemistry. Akademia; 2004.
5. Gorbunov AI, Gurov AA, Filippov GG, Shapoval VN. Theoretical foundations of general chemistry: A textbook for students of technical universities. N.E. Bauman Publishing House of MSTU; 2001.
6. Nurlybaev IN, Kogisov SM, Duzelbaeva SD. Clarification of the formulation of Mendeleev's periodic law. Proceedings of the International Conference. 2012;12(1):107–109.
7. Nurlybaev IN, Semkina KYu. On the formulation of the periodic law and the similarity of the periods of the periodic system of D.I. Mendeleev. XIX Mendeleev Congress on General and Applied Chemistry. 2011;8:561.
8. Agisheva AA, Imangalieva BS, Duzelbaeva SD. Improving the structure of the periodic table of chemical elements. Pedagogical Review, 2014;2:2–5.
9. Akhmetov NS. General and inorganic chemistry. Lan; 2018.
10. Goncharov EG, Kondrashin VYu, Khoviv AM, Afinogenov YuP. A short course in theoretical inorganic chemistry. Lan; 2017.
11. Egorov VV. General chemistry. Lan; 2021.
12. Contreras RR. Periodic table of chemical elements: One hundred and fifty years of history. Avances en Quimica. 2019;14(1):41–60.
13. Bramstedt K. Partnering ethics and chemistry in secondary and university stem education via an innovatively designed periodic table of chemical elements. Acta Bioeth. 2020;26(1):101–106. https://doi.org/10.4067/S1726-569X2020000100101.
14. Noval VE, Carriazo JG. The periodicity of chemical elements and the performance of materials: A complement for the comprehending of the periodic table. Quim Nova. 2019;42(2):232–236.
15. Matlin SA, Mehta G, Hopf H, Krief A. The periodic table of the chemical elements and sustainable development. Eur J Inorg Chem. 2019;2019(39-40):4170–4173. https://doi.org/10.1002/ejic.201801409.
16. Doroshkevich AS, Lyubchyk AI, Shilo AV, Zelenyak TYu, Glazunova VA, Burhovetskiy VV, Saprykina AV, Holmurodov KhT, Nosolev IK, Doroshkevich VS, et al. Chemical-electric energy conversion effect in zirconia nanopowder systems. J of Surf Investig. 2017;11(3):523–529. https://doi.org/10.1134/S1027451017030053.
17. Grigore E, Pantea O, Bombos D, Calin C, Bondarev A, Gheorghe C. Effect of inhibitors based amine derivates on some carbon steel corrosion. Revista de Chimie. 2015;66(5):685–690.