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New Approaches
Нови подходи

ON THE PLACEMENT OF HYDROGEN AND HELIUM IN THE PERIODIC SYSTEM: A NEW APPROACH

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Abstract. In this paper the epistemological problem of the rightful position of hydrogen and helium in the periodic system is addressed. We argue for the need of introducing a new approach in order to face this traditional and complex problem. In this sense, we identify the main secondary criteria of classification involved in the discussion and analyze them in conceptual terms. On the basis of this approach, we argue that none of them has explanatory priority over the others when it comes to deciding about the inclusion of hydrogen and helium in a particular family of elements. This implies that the different criteria have the same epistemological status, until we get new arguments or new evidence. As a result, a new table which shows a "democratic" relationship among the three main secondary criteria of classification proposed is put forth.

Keywords: hydrogen, helium, quantum mechanics, electronegativity, triads of atomic number

Introduction

The placement of hydrogen and helium in the periodic system[1)] is probably the most discussed topic in the foundations of the periodic table and the source of much debate among theoretical chemists, chemical educators, philosophers of chemistry, physicists, and amateur scientists. Since a long time ago there exist disagreements as to exactly which family of elements should hydrogen and helium is included in.

The standard periodic table is a representation of the elements in two directions: the first direction, called 'the Mendeleev line', is defined in terms of a numerical sequence given unambiguously by the atomic number (primary criterion). Although not as categorically as this criterion, the second direction is nowadays given by the number of electrons in the outer-shell of the atom (secondary criterion), and leads to the grouping of the elements in columns based on chemical similarities. The epistemological problem of the position of hydrogen and helium in the periodic system concerns to the controversy about the best secondary criterion to classify elements into groups.

The aim of this paper is to address this issue by putting forward new arguments. We begin by reviewing the history of the problem, in particular by showing those proposals that have been relevant to solve this conundrum over the years. Later, the three main secondary criteria –quantum mechanics, electronegativity, and triads of elements– are identified and critically analyzed in conceptual terms. On the basis of this approach, we argue that none of them has explanatory priority when it comes to deciding about the inclusion of hydrogen and helium in a particular family of elements, until we get new arguments or new evidence. A suggested solution might be then a "pluralist" criterion, that is, a new criterion made up as a "balance" of all of them. As a result, a new chart is presented along with some virtues and features. Finally, we raise some brief considerations about the role of argumentation in classroom and the link with the philosophy of chemistry.

A brief history of the problem

The question about the proper place for hydrogen is present since Dmitri Mendeleev's first periodic table published in 1869, in which this element is disconnected from the other ones (Fig. 1). The table of 1871 shows hydrogen at the head of the alkali metals in Group I (Fig. 2), a place that remains very popular till now.

In 1906 Mendeleev drew up his last periodic system, where hydrogen retains the place as in his previous table, but now helium appears over the noble gases family (Group 0), as usually does. Some years before, Thomas Bayley in 1882 and lately Julius Thomsen in 1895 designed periodic tables in the form of inverted pyramids (Van Spronsen, 1969). These authors depicted hydrogen in a central position and linked it to seven elements, from lithium to fluorine, by means of lines. In 1922 Niels Bohr presented a left-inverted pyramid similar to Bayley's and Thomsen's tables, where the noble gases family was added (Fig. 3). Hydrogen and helium are close together and placed centrally in this design. By means of lines, the author connected hydrogen with both alkali metals and halogens, and considered helium as a member of noble gases.

			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=106,6	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?		

Fig. 1. The first periodic table published by Mendeleev in 1869. Hydrogen is separated from the rest of the elements (Mendeleev, 1869); table on page 70

		Группа I.	Группа II.	Группа III.	Группа IV.	Группа V.	Группа VI.	Группа VII.	Группа VIII. Переходъ къ групп. I.
Типическіе элементы.		H=1 Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
Первый періодъ	Рядъ 1-й	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
	— 2-й	K=39	Ca=40	—=44	Ti=50?	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63
Второй періодъ	— 3-й	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
	— 4-й	Rb=85	Sr=87	(?Yt=88?)	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=104, Ag=108
Третій періодъ	— 5-й	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=128?	J=127	
	— 6-й	Cs=133	Ba=137	—=137	Ce=138?	—	—	—	— —
Четвер. періодъ	— 7-й	—	—	—	—	—	—	—	
	— 8-й	—	—	—	—	Ta=182	W=184	—	Os=199?, Ir=198?, Pt=197, Au=197
Пятый періодъ	— 9-й	(Au=197)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
	— 10-й	—	—	—	Th=232	—	Ur=240	—	
Высшая соляная окись.		R^2O	R^2O^2 или RO	R^2O^3	R^2O^4 или RO^2	R^2O^5	R^2O^6 или RO^3	R^2O^7	R^2O^8 или RO^4
Высшее водородное соединеніе.				(RH^5?)	RH^4	RH^3	RH^2	RH	—

Fig. 2. Mendeleev's short-form periodic table of 1871. Hydrogen is now over the Group I but in a separated row (Mendeleev, 1871); table on page 31

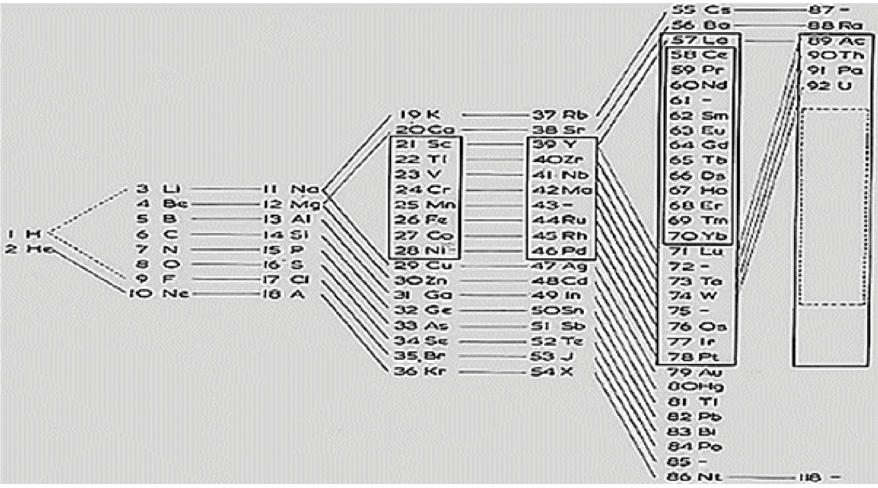


Fig. 3. The left-inverted pyramid drew up by Bohr in 1922. Hydrogen is related to both lithium and fluorine, and helium heads the noble gases. Reprinted with permission from Bohr, N. (1922). The theory of spectra and atomic constitution. Cambridge: Cambridge University Press.

TABLE I.
Classification of the Elements According to the Arrangement of Their Electrons.

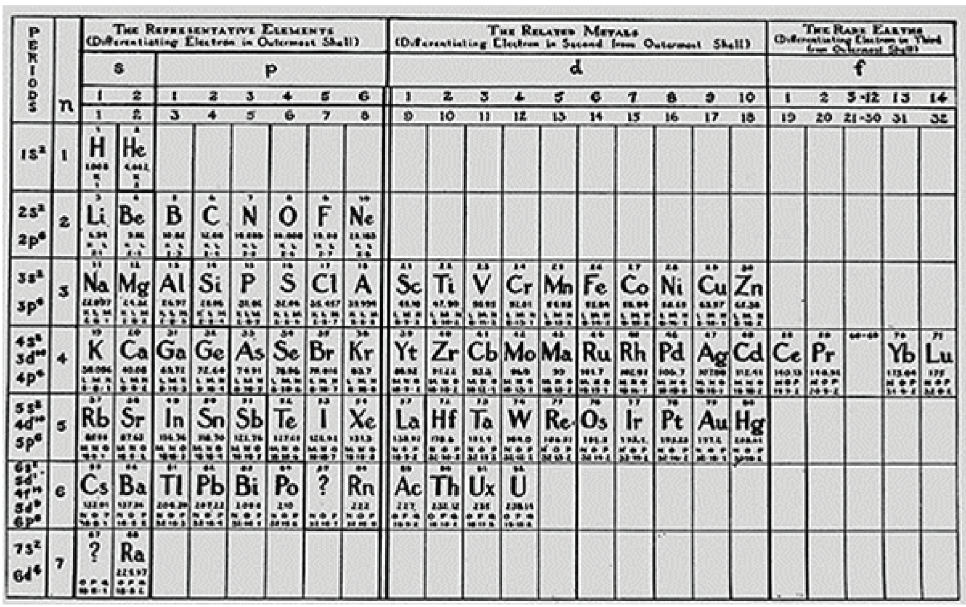
Layer.	N	E = 0	1	2	3	4	5	6	7	8	9	10
I			H	He								
IIa	2	He	Li	Be	B	C	N	O	F	Ne		
IIb	10	Ne	Na	Mg	Al	Si	P	S	Cl	A		
IIIa	18	A	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni
			11	12	13	14	15	16	17	18		
IIIa	28	Niβ	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
IIIb	36	Kr	Rb	Sr	Y	Zr	Cb	Mo	43	Ru	Rh	Pd
			11	12	13	14	15	16	17	18		
IIIb	46	Pdβ	Ag	Cd	In	Sn	Sb	Te	I	Xe		
IVa	54	Xe	Cs	Ba	La	Ce	Pr	Nd	61	Sa	Eu	Gd
			11	12	13	14	15	16	17	18		
IVa			Tb	Ho	Dy	Er	Tm	Tm_2	Yb	Lu		
		14	15	16	17	18	19	20	21	22	23	24
IVa	68	Erβ	Tmβ	$Tm_2β$	Ybβ	Luβ	Ta	W	75	Os	Ir	Pt
			25	26	27	28	29	30	31	32		
IVa	78	Ptβ	Au	Hg	Tl	Pb	Bi	RaF	85	Nt		
IVb	86	Nt	87	Ra	Ac	Th	Ux_2	U				

Fig. 4. Langmuir's periodic table of 1919. Helium is at the top both of noble gases and of alkaline earth metals. Note also that hydrogen is next to helium. Reprinted with permission from Langmuir, I. The arrangements of electrons in atoms and molecules. J. Am. Chem. Soc., 1919, 41, 868–934. Copyright 1919 American Chemical Society.

In 1895, J. W. Retgers published a table in which hydrogen is just placed not among the alkali metals, but at the top of the halogens family (Mazurs, 1974). In Irving Langmuir's periodic system of 1919, hydrogen is still heading the alkali group, but helium is now duplicated under both the noble gases and the alkaline earth metals groups. A positive feature of this arrangement is that hydrogen and helium are kept together (Fig. 4).

In the periodic system designed by the German chemist Andreas von Antropoff (1926), hydrogen is placed centrally and related to lithium and fluorine. In the case of helium, it is put at the first row along hydrogen and also heads the Group 0, the noble gases; this means that it is duplicated on the left and on the right of the table.

As in Langmuir's table, helium was grouped as a member of the alkaline earth metals in a chart designed by the French engineer Charles Janet in 1928. This is known as the left-step periodic table. According to Eric Scerri (2007), the elegant shape of this periodic system was based on aesthetic criterion. In turn, in 1943 W. F. Luder, based on Robert Ebel's suggestion (Ebel, 1938), used the electronic configuration as a criterion to put helium also as a member of that family of elements (Fig. 5).



Periods	n	The Representative Elements (Differentiating Electron in Outermost Shell)								The Related Metals (Differentiating Electron in Second from Outermost Shell)										The Rare Earths (Differentiating Electron in Third from Outermost Shell)				
		s		p						d										f				
		1	2	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	1	2	3-12	13	14
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21-30	31	32
$1s^2$	1	H	He																					
$2s^2$ $2p^6$	2	Li	Be	B	C	N	O	F	Ne															
$3s^2$ $3p^6$	3	Na	Mg	Al	Si	P	S	Cl	A	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn					
$4s^2$ $3d^{10}$ $4p^6$	4	K	Ca	Ga	Ge	As	Se	Br	Kr	Yt	Zr	Cb	Mo	Ma	Ru	Rh	Pd	Ag	Cd	Ce	Pr		Yb	Lu
$5s^2$ $4d^{10}$ $5p^6$	5	Rb	Sr	In	Sn	Sb	Te	I	Xe	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg					
$6s^2$ $5d^1$ $4f^{14}$ $5d^9$ $6p^6$	6	Cs	Ba	Tl	Pb	Bi	Po	?	Rn	Ac	Th	Ux	U											
$7s^2$ $6d^4$	7	?	Ra																					

Fig. 5. The periodic system of Luder. The elements are arranged by their electronic configurations. Thus, hydrogen, 1s 1 , is placed above lithium and helium, 1s 2 , on top of beryllium. Reprinted with permission from Luder, W. F. Electron configuration as the basis of the periodic table. J. Chem. Educ., 1943, 20, 21–26. Copyright 1943 American Chemical Society.

Two decades later, Robert Sanderson proposed electronegativity as a categorical criterion to place hydrogen between boron (Group 13) and carbon (Group 14) (Fig. 6).

A few years ago, a new categorical criterion was put forward to settle this issue: this criterion is based on the atomic number triads. The notion of triad of elements was proposed by the German chemist Johannes Döbereiner in 1817 on the grounds of the atomic weight. When this concept was replaced by that of the atomic number as a better criterion for ordering the elements, the notion of triad became exact. Thus, according to this new perspective, hydrogen should be relocated into the halogens given that this element forms the perfect triad of atomic number H (1), F (9), Cl (17). In the case of helium, it preserves its place at the above of noble gases because it forms the triad He (2), Ne (10), Ar (18) (Fig. 7).

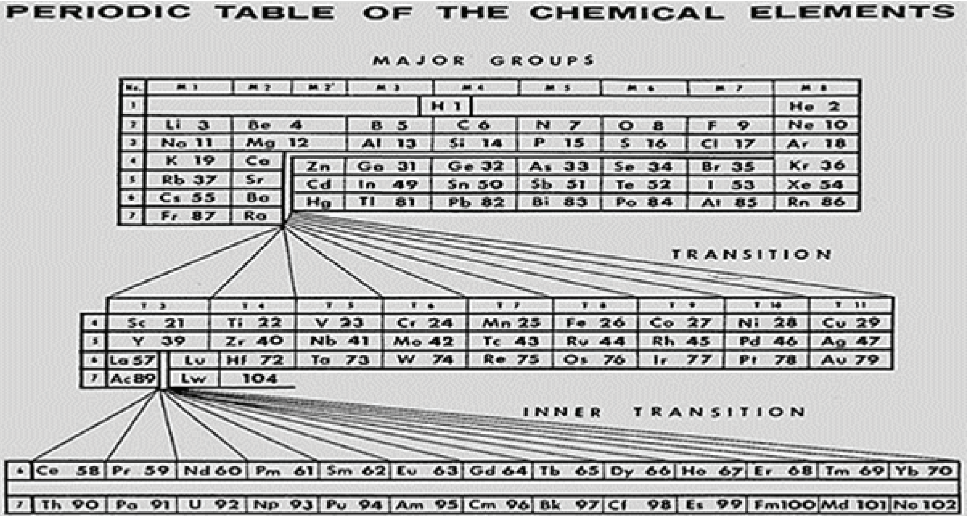


Fig. 6. The periodic table drawn by Sanderson in 1964. Helium is placed heading the noble gases and hydrogen is placed in an intermediate position between the boron and the carbon groups on the basis of its electronegativity. Reprinted with permission from Sanderson, R. T. A rational periodic table. J. Chem. Educ., 1964, 41, 187–189. Copyright 1964 American Chemical Society.

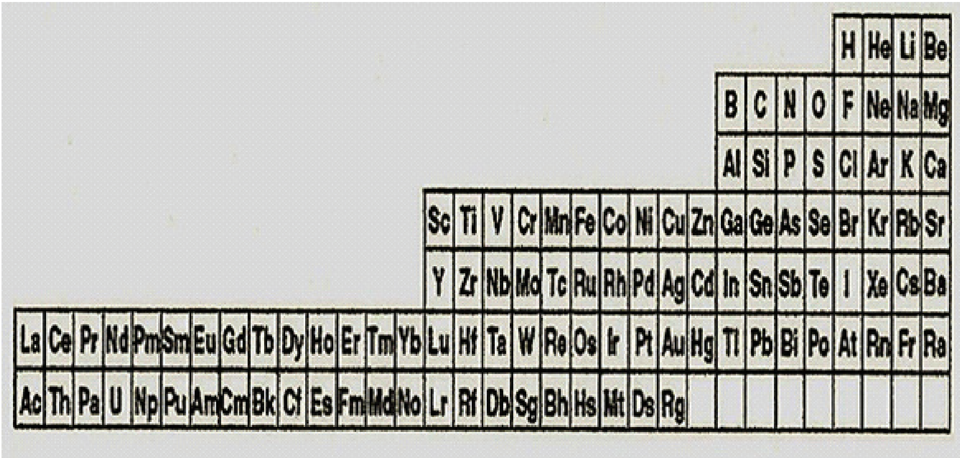


Fig. 7. Eric Scerri's periodic table. Hydrogen heads the halogens (Group 1) and helium the noble gases (Group 2). Reprinted with permission from Scerri, E. R. The role of triads in the evolution of the periodic table: past and present. J. Chem. Educ., 2008, 85, 585–589. Copyright 2008 American Chemical Society. The author has published another chart that differs only in shape from the one shown here but the position of both elements is the same (Scerri 2008b).

The current state of the debate: proposals and problems

The goal of the periodic table is to arrange the elements according to some patterns, in order to those elements similar in their chemical and physical properties are grouped together. At present, it is generally accepted that, in the standard periodic table, hydrogen falls into alkali metals because of its *outer-shell configuration* ($1s^1$) or *valence*, whereas helium belongs to noble gases according to *the number of electrons to fill the outer-shell*. This means that hydrogen and helium are placed in the conventional periodic table according to two different criteria, as Eric Scerri (2010) usually claims. Nonetheless, this inconsistency is not generally pointed out in the chemistry textbooks.

As it is well-known, the first historical criterion to classify elements into groups was based on their chemical and physical properties. That was the way followed by Dmitri Mendeleev and others pioneers of the periodic system in the decade of 1860. From this view, hydrogen is the most difficult element to place due to its unusual chemical behavior. Although it is a light gas at room pressure,[2)] hydrogen usually heads the alkali metals –sometimes carrying a slightly different color– according to its one valence electron and because it is an electropositive element that loses its electron readily. But hydrogen is also a good candidate to be grouped with the halogens. Some researchers support its inclusion therein by pointing out the similarities between their chemical and physical properties, and by stressing that hydrogen can form hydride anions (Dash, 1963; 1964; Sacks, 2006). In contrast, Ronald Rich (2005) considers the resemblance to halogens real but weak, because the halide ions are stable in water but the hydride ion is not. In turn, J. W. van Spronsen (1969) claimed that the alkali group seems a proper place for hydrogen because it forms a unipositive ion and halides, but there is a disparity between alkali hydrides and halides. As we see, the question about the similarity of hydrogen both to halogens and to alkali metals is a long-standing matter of debate.[3)]

The unique behavior of hydrogen also makes it resemble to the carbon family. Marshall Cronyn (2003) has defended this perspective on the grounds of the correlation among relevant physical properties such as ionization potential, electron affinity and electronegativity, as well as the comparison of the chemistry of H–H, C–H, and Si–H bonds. Others authors have also supported the possible inclusion of hydrogen in the carbon group (Stewart, 2004; Rich & Laing, 2011). However, as it is well-known carbon is tetravalent but hydrogen is monovalent, and the boiling and melting points of hydrogen are very lower than those of the elements of Group 14.

In conclusion, although there is no controversy concerning the position of helium as a member of noble gases family according to its chemical behavior,[4)] it is easy to appreciate that the placement of hydrogen, on the contrary, is underdetermined: although this element can either loses or gains an electron it is not a typical alkali metal, nor is it a typical halogen, nor a typical member of the carbon group.

Let us then examine the secondary classifications involved in this discussion: electronic configurations, electronegativity, and triads of elements. The quantum mechanical criterion –that is, the use of orbitals and electronic configurations popularized in the representations of the periodic systems by L. M. Simmons and V. M. Klechkovskii (Mazurs, 1974)– appears to be the modern approach to explain chemical periodicity. According to this standpoint, the number of valence electrons seems to govern the chemical behavior of the elements. This reductionist statement is usually taken for granted and pervades the education in chemistry. However, Scerri (2010) has stressed that although quantum mechanics provides an excellent way of calculating the properties of individual elements, it is not the case when it comes to determining "global properties", that is, the membership of elements into particular groups. The idea that elements in the same group of the periodic table share the same outer-shell configuration shows several exceptions, among them the transition metal series like nickel, palladium, and platinum.[5)] In this sense, quantum mechanics has not satisfactorily solved the position of these elements because "The periodicity in the chemical properties of the elements is a complicated matter and is only approximately reflected in the electronic configurations of atoms" (Scerri, 1991), p.122. On this basis, we agree with Scerri (2007), p.242 when he claims that "[...] the possession of a particular number of outer-shell electrons is neither a necessary nor a sufficient condition for an element's being in any particular group".

The number of outer electrons as a secondary criterion of classification implies that hydrogen is a member of alkali metals while helium should be a member of the alkaline earth family. But, according to its electronic structure, hydrogen might be placed at the top of carbon group since its valence-shell is half-filled like the elements of that group, or also among the halogens since one electron to complete their valence-shell is required.

As already mentioned, the now popular Janet's table (Katz, 2001) shows in its regular design that helium is placed heading the earth alkaline metals, which determines that the *s* block is together on the right side of the chart. This approach has an increasing number of supporters nowadays (Bent, 2006; Bent & Weinhold, 2007; Tsimmerman, 2013), but at the same time it has been criticized. For example, Rich (2005) has pointed out that the electronic similarity of helium is different from chemical similarity. Meanwhile, Scerri (2012a) claimed that, from a chemical viewpoint, the membership of helium among alkaline earth metals turns out to be a complete heresy to chemists. Even more, it has been claimed that its adoption would amount "to putting the cart of quantum mechanics before the horse of chemistry" (Labarca, 2013), p.8.

The corollary is that the widespread standpoint according to which quantum mechanics supposedly explains fully the membership of elements into groups, finds a clear obstacle when it comes to placing both elements by applying a unique criterion. This fact should make us remember that any scientific theory has an application domain, and quantum mechanics cannot elude this point, which is acknowledged by the present-day philosophy of science.

Although not as usual as a classificatory criterion, electronegativity has had a revival in the last years. One of the main defenders is Mark Leach (2013), who strongly advocates for electronegativity with respect to the explanation of chemical periodicity. Following the way opened up by Sanderson who used electronegativity as a criterion and placed hydrogen between boron and carbon, Cronyn (2003) analyses the similarity of hydrogen to the carbon family and proposes in fact that it should head that group.[6)] In turn, Geoff Rayner-Canham & Tina Overton (2010) emphasize that, although hydrogen has not a definitive place in the periodic system, on the basis of its intermediate value of electronegativity between alkali metals and halogens it makes sense to place it midway between those families. Leland Allen (1989) proposed a periodic system in three dimensions in which electronegativity was in fact the third dimension. Although electronegativity is a very useful concept in modern chemistry, the different scales of electronegativity that coexist at present, show that there is no a clear consensus in relation to the meaning of the concept. A recent article analyses the electronegativity in purely conceptual terms, in particular its epistemological status.[7)] The authors conclude that albeit electronegativity is a concept widely used, there is not a unified characterization on its status: is it a classificatory concept, a property, or a disposition?"

As mentioned above, the last criterion identified in the problem under discussion was proposed by Eric Scerri a few years ago and concerns with the retrieved Döbereiner's rule, but now in terms of the atomic number. Some authors have questioned this idea by claiming that hydrogen and helium do not belong to any triad in principle (Bent, 2006). The epistemological status of triads has also been put in doubt (Schwarz, 2010), though Scerri (2010) has lately given new arguments to defend this criterion on the basis of Bonchev's information theoretical approach. Other authors have also reassessed the power of the triads, not only as one of the pillars in the evolution of the periodic system, but also in the prediction of chemical properties (Laing, 2009).

It has been also argued that the anomalous behavior of the first two elements of the periodic system would be part of the well-known *first-element rule*, according to which, in its simple version, the first element in any group of the table shows anomalies when compared with the rest of the elements of its group. Hydrogen is a gas unlike the other members of the alkali family. However, in the case of noble gases William Jensen and Henry Bent arrive to different conclusions when it comes to deciding the position of helium. For the former author, helium remains as a noble gas, whereas Bent relocates it to the alkaline earth metals in agreeing with the left-step periodic table (Scerri, 2007).

The difficulty to place mainly hydrogen but also helium in appropriate groups has led to some researchers to appeal to other kinds of solutions. For example, it has been suggested that hydrogen and helium should be put out of the periodic table in an isolated group unrelated to alkali metals, halogens, or to the noble gases family (Ramírez-Torres, 1955; Guenther, 1970; Greemwood & Earmshaw, 1984). Herb Kaesz & Peter Atkins (2003) proposed a modification of the periodic table by removing hydrogen from the main body of the table due to its anomalies or particularities and making it to float above the chart. In their proposal, hydrogen is linked to helium, which heads the noble gases, through a horizontal line.[8)]At the same time, the idea of duplicating the positions of both elements (Laing, 2007; Rich & Laing, 2011) or even triplicate the placement of hydrogen above alkali, halogens, and carbon columns (Rich, 2005) have also been suggested. Two kinds of criticism might be posed to this last solution. The first one was suggested by Scerri (2012b), who claims that this goes against the basic principle of the modern periodic table: '*one element, one place'*. The second criticism is that duplicating or even triplicating the elements under discussion does not dissolve the problem: while the criterion for placing helium is the number of electrons to complete the outer-shell, in the case of hydrogen it is possible to see that two or three criteria are present, respectively.

The case for helium also poses troubles. The criteria usually proposed put this element into two possible groups. It is at the top of noble gases in most current periodic tables. But taking into consideration its atomic ground-state electronic configuration ($1s^2$), the earth alkaline metals should be the proper group for this element. This approach is favored in general by physicists and is displayed in some designs (Mazurs, 1974), as well as in the reappeared left-step periodic table, as already mentioned. Nevertheless, despite similar spectroscopic ground states between helium and beryllium, new arguments tend to reject the placement of the former in the earth alkaline column (Ramírez-Solís & Novaro, 2014).

A new approach to the problem

As we have seen, both elements seem to resist any attempt of assigning a specific position in some particular family of elements. Even though there are several criteria proposed to decide their positions in the periodic system, it seems that no single place appears to be satisfactory. This is explicitly expressed by Richard Treptow (1994), p.1011, who said: "The properties of hydrogen, for example, are so unique that this element cannot be properly assigned to any family".

In this complex scenario, it seems then reasonable to pose the question: what categorical criterion should be favored -electronic configurations, electronegativity, or triads of atomic number? The situation looks as a trilemma. However, if it is conceded that none of the three candidates has *explanatory priority*, that is, if they do not provide an unambiguous means of classifying elements into groups, it is then reasonable to ask why a single criterion should be privileged. This leads us to the following question: why not a new arrangement where the main secondary criteria are considered simultaneously? In other words, is it possible a new and positive secondary criterion for deciding on the placement for hydrogen and helium in the periodic system?

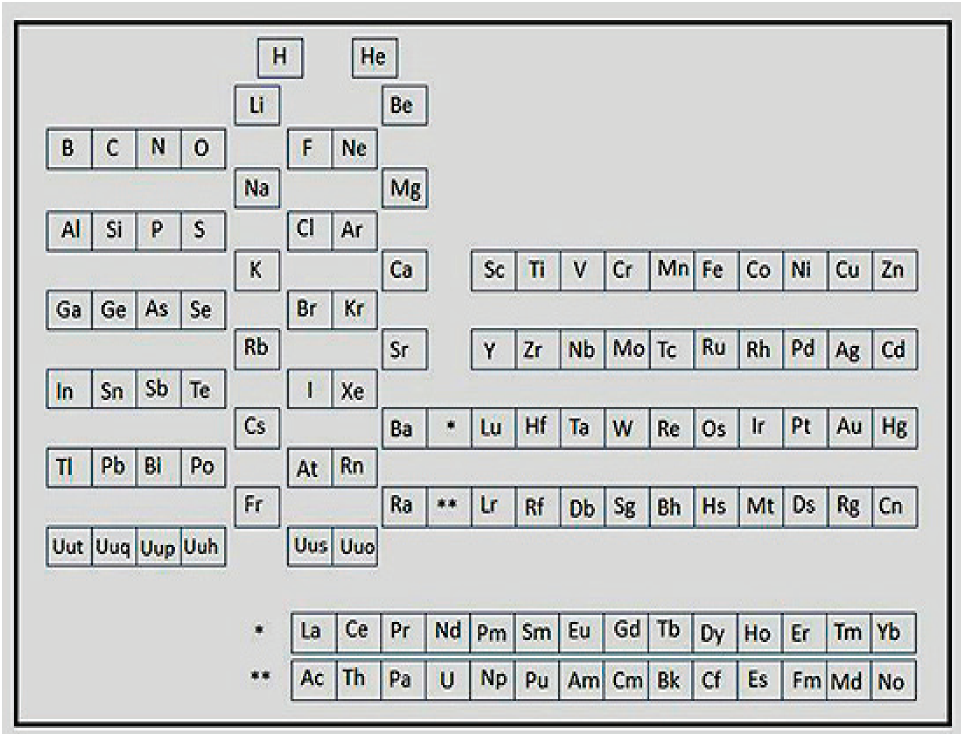


Fig. 8. Srivaths–Labarca Periodic Table

In this new arrangement the three main criteria proposed for the position of hydrogen and helium are simultaneously taken into account. Consequently, hydrogen is in-between alkali metals and halogens, whereas helium is midway between the noble gases family and the alkaline earth elements.

In the light of these arguments, as possible solution to this conundrum we propose a sort of "balance" among the main perspectives identified in the debate. This means to resist the compromise of both hydrogen and helium with any particular criteria. But, at the same time, this implies neither hydrogen float *à la* Atkins (Kaesz & Atkins, 2003) nor that both elements are disconnected from the rest of the elements (Guenther, 1970; Greemwood & Earmshaw 1984). On the contrary, in the new arrangement proposed both elements "have a foot in each of the criteria", paraphrasing and extending Michael Laing's statement (2007), p.132.

Therefore, the new table takes into consideration the three main criteria proposed to solve the position of the first two elements: quantum mechanics, electronegativity, and triads of atomic number. This implies that all of them have *the same epistemological* *status*, until we get new arguments or new evidence. Thus, in the new chart hydrogen is in-between alkali metals and halogens, whereas helium is in-between noble gases and alkaline earth elements (Fig. 8).

Virtues and features of the new periodic table

The main virtues and features of the new periodic system proposed are summarized as follows: (1) The secondary criteria proposed to settle this epistemological problem (electronic configurations, electronegativity, and triads of elements) are simultaneously taken into account in this format; (2) A "democratic" relationship among them avoids the modern reductionist approach, which tries to understand the periodic system only on the basis of electronic configurations. This implies, in turn, to recover the traditional idea of the periodic table as a genuine icon of the chemistry world not reduced to quantum mechanics; (3) The predominant role of electronic configurations in the representation of the periodic system is downplayed; (4) Hydrogen and helium are kept together; (5) Easy visualization of the patterns of both elements with the secondary criteria proposed in the assignment of the positions of hydrogen and helium; (6) The new design avoids drawing lines, not only for hydrogen but also for helium;[9)] (7) Even though the chart is not symmetric, it is centered. It can be naturally read from left to right and from top to down without gaps as in the conventional table; (8) In relation to the periodic patterns, by means of an "axis of periodicity" vertically drawn in-between hydrogen and helium, the periodic properties vary as one moves from the centre to the left and to the right continuously; (9) The design shows respect for 18 columns according to the IUPAC recommendation (Leigh, 2009).[10)]

Conclusions

The proper placement of hydrogen and helium is an ongoing question at the core of the periodic system. In this paper we have argued that this epistemological problem needs new arguments based on the difficulties and inconsistencies that the main secondary criteria reveal. In this sense, we have presented a new periodic system where the first two elements are not just confined to specific groups but are placed in an intermediate position between families of elements. Finally, independently of the acceptation of the arguments raised here, we do believe that this topic gives an excellent opportunity to chemistry teachers for developing arguments, a major theme in the field of science education since mid-90's (Erduran & Jiménez-Aleixandre, 2007). In this respect, philosophy of chemistry becomes an excellent pedagogical tool (Lombardi & Labarca, 2007) to foster argumentation processes in the classroom.

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NOTES

1. There exists a conceptual difference between the terms 'periodic table' and 'periodic system' in strict sense. However, in this work we will use these terms as synonyms.
2. A recently research has announced the first evidence for metallic hydrogen (Eremets & Troyan, 2011) but this claim has been disputed (Amato, 2012).
3. Cf. Van Spronsen (1969), p. 302.
4. Grandinetti (2013) has recently proposed to shift helium to the top of Group 2, based on the lower stability of neon compounds with respect to the helium ones.
5. The electronic configurations for nickel, palladium, and platinum are [Ar] $4s^1\ 3d^9$, [Kr] $5s^0\ 4d^{10}$, and [Xe] $6s^1\ 4f^{14}\ 5d^9$, respectively.
6. For a critique to this standpoint, see Sacks (2006).
7. Ruthenberg, K. & Martínez González, J. C. (2015). What is electronegativity?. Preprint.
8. This idea has been convincingly criticized by Scerri (2004).
9. See, for instance, the tables depicted by Pauling (1957) and Jensen (1986).
10. This implies a value judgment neither about the others shapes of the periodic table (helical, circular, pyramidal, etc.) nor about the long-form or 32 columns.

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