A periodic table based on triads

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1.- Introduction

In the last decades, the notion of triad has been recovered by Eric Scerri (2008a, 2010, 2011), who suggested it as a possible categorical criterion to represent chemical periodicity. In particular, he reformulates the notion of triad in terms of atomic number instead of atomic weights and, in this way, the value of the intermediate term of the triad is the exact average of the values of the two extremes. The author notes that the attempt of finding new triads is very important since this relation is based exclusively on the atomic number, that is, the only feature of the elements considered as basic substances. In this work, I will follow Scerri's general proposal.

The main purpose of my work is to obtain a representation where all the relations among the chemical elements that form the groups of the periodic system can be reconstructed on the basis of triads, without using electronic configurations.

2.- The general structure of the table

Following Scerri's program, for the construction of the table I use the increasing atomic number as a primary criterion, and the formation of triads of atomic number as a secondary criterion. However, in this proposal the notion of triad will be redefined in a way slightly different than the original notion (this point will be considered in detail in Section 4).

The table is structured in the following way (see Figure 1). The periods of this table are obtained by organizing the elements according increasing atomic number, beginning by 1. The ten periods contain 1, 1, 8, 8, 18, 18, 32, 32, 18, 18, 8, 8, 1 and 1 elements, respectively, and are organized in 5 blocks of two periods of the same length: blocks A, B, C, D, E, and G. In this way, the table exhibits a double symmetry: a right-left symmetry and an up-down symmetry.

- The zero period, consisting of element 0.
- The first period, consisting of element 1.

- The second period begins with element 2 and continues until element 9. At this point we obtain the triad of the zero generation (0-1-2).
- The third period begins with element 10 and continues until element 17. At this point we obtain the triad of the first generation (1-9-17).
- The fourth period begins with element 18 and continues until element 35. At this point we obtain the triads of the second generation, represented by the lines down to the left between blocks B y C (from 2-10-18 to 9-17-25).
- The fifth period begins with element 36 and continues until element 53. Here we obtain the triads of the third generation, represented by the lines down to the right between blocks B y C (from 10-28-46 to 17-35-53).
- The sixth period begins with element 54 and continues until element 85. Here we obtain the triads of the fourth generation, represented by the lines down to the left between blocks C and D (from 18-36-54 to 35-53-71).
- The seventh period begins with element 86 and continues until element 117. Here we obtain the triads of the fifth generation, represented by the lines down to the right between blocks C and D (from 36-68-100 to 53-85-117).
- The eighth period begins with element 118, includes the hypothetical, not yet discovered elements 119 to 135. Here we obtain the triads of the sixth generation, represented by the lines down to the right between blocks D and E (from 54-86-118 to 71-103-135).
- The ninth period begins with element 136 and continues until element 153, all of them hypothetical, not yet discovered elements. Here we obtain the triads of the eighth generation, represented by the lines down to the left between blocks D and E (from 100-118-136 to 117-135-153).
- The tenth period begins with element 154 and continues until element 161, all of them hypothetical, not yet discovered elements. Here we obtain the triads of the ninth generation, represented by the lines down to the right between blocks E and F (from 118-136-154 to 125-143-161).
- The eleventh period begins with element 162 and continues until element 169, all of them hypothetical, not yet discovered elements. Here we obtain the triads of the ninth generation, represented by the lines down to the left between blocks E and F (from 146-154-168 to 153-161-169).

- The twelfth period contains only the element 170. Here we obtain the triad of the tenth generation, represented by the line down to the right between the F and G blocks (only 154-162-170).
- Finally, the thirteenth period contains only the element 171 (final). Here we obtain the triad of the eleventh generation, represented by the line down to the left between blocks F and G (only 169-170-171).

The table begins with element 0 and finishes with element 171. They belong to the triads 0-1-2 and 169-170-171, respectively; the first “opens” and the second “closes” the series of triads (the meaning of these elements will be discussed in the next sections).

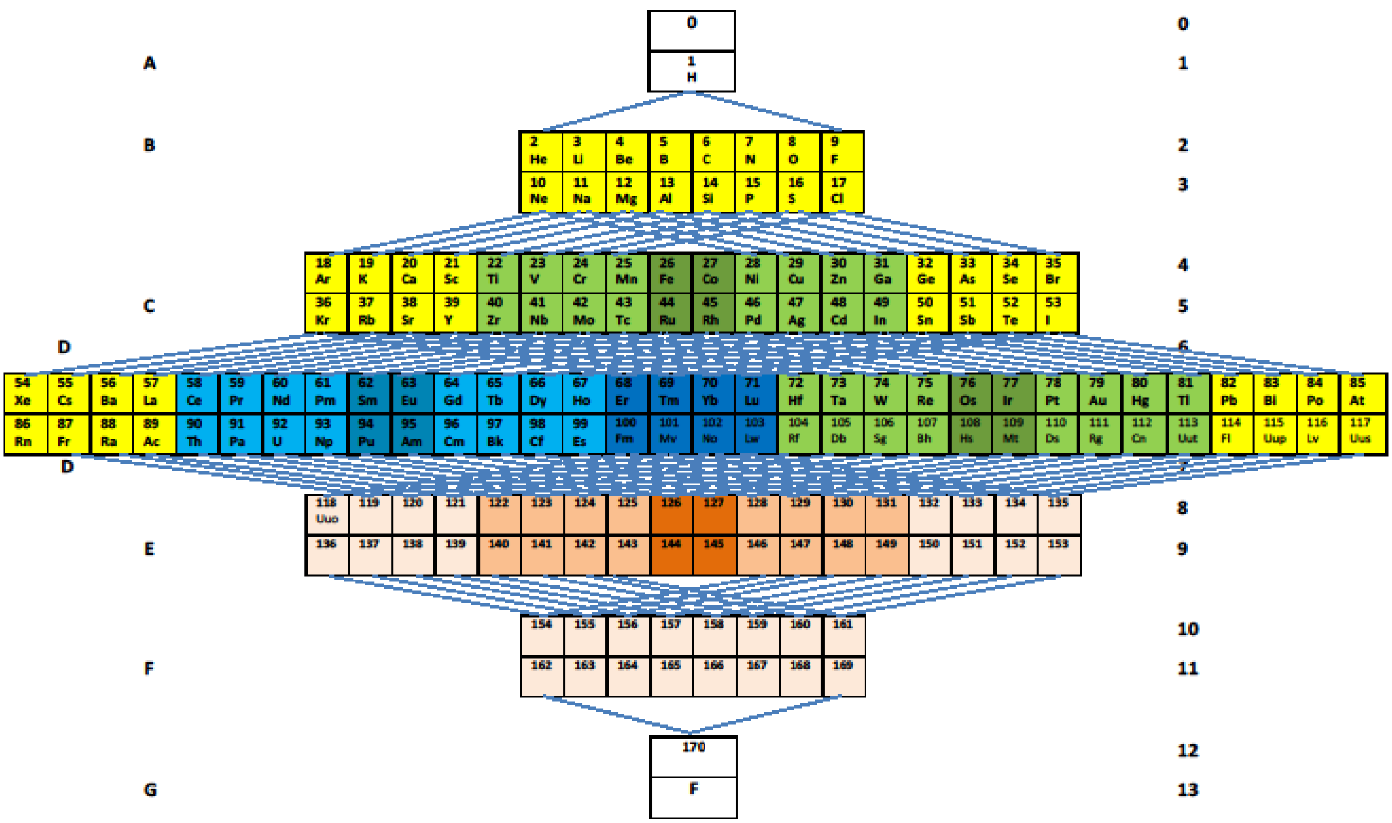

Figure 1: The periodic table

On this basis, the triads are organized in the following way, where the generation is the number of the period where the triad begins (see Figure 2):

- Zero generation: 1 triad, 0-H-He.
- First generation: 1 triad, H-F-Cl.
- Second generation: 8 triads, from H-F-Cl to O-S-Cr.
- Third generation: 8 triads, from Fe-Co-Rh to S-Se-Te.
- Fourth generation: 18 triads, from Cl-Br-I to Se-Te-Yb.
- Fifth generation: 18 triads, from Br-Ho-Es to Te-Po-Lv.
- Sixth generation: 18 triads, from I-At-Uus to Yb-No-134
- Seventh generation: 18 triads, from Es-Uus-135 to Lv-134-152
- Eight generation: 8 triads, from Uus-135-153 to 124-142-160.
- Ninth generation: 8 triads, from 145-153-151 to 152-160-168.
- Tenth generation: 1 triad, 154-162-170.
- Eleventh generation: 1 triad, 169-170-171.

In this way the table includes all the triads proposed by Scerri (2008a), and new triads whose meaning will be discussed in the next sections. See the table of the complete list of triads below, in Figure 2.

Triad 0G	**Triad 1G**	**Triads 6 G**	**Triads 7G**
0-H-He	H-F-Cl	Xe-Rd-Uuo	Fm-Uuo-135
		Cs-Fr-119	Md-119-137
Triads 2G	**Triads 3G**	Ba-Ra-120	No-120-138
He-Ne-Ar	Ne-Ni-Pd	La-Ac-121	Lw-121-139
Li-Na-K	Na-Cu-Ag	Ce-Th-122	Rf-122-140
Be-Mg-Ca	Mg-Zn-Cd	Pr-Pa-123	Db-123-141
B-Al-Sc	Al-Ga-In	Nd-U-124	Sg-124-142
C-Si-Ti	Si-Ge-Sn	Pm-Np-125	Bh-125-143
N-P-V	P-As-Sb	Sm-Pu-126	Hs-126-144
O-S-Cr	S-Se-Te	Eu-Am-127	Mt-127-145
F-Cl-Mn	Cl-Br-I	Gb-Cm-128	Ds-128-146
		Tb-Bk-129	Rg-129-147
Triads 4G	**Triads 5G**	Dy-Cf-130	Cn-130-148
Ar-Kr-Xe	Kr-Er-Fm	Ho-Es-131	Uut-131-149
K-Rb-Cs	Rb-Tm-Mv	Er-Fm-132	Fl-132-150
Ca-Sr-Ba	Sr-Yb-No	Tm-Md-133	Uup-133-151
Sc-Y-La	Y-Lu-Lw	Yb-No-134	Lv-134-152
Ti-Zr-Ce	Zr-Hf-Rf	Lu-Lw-135	Uus-135-153
V-Nb-Pr	Nb-Ta-Db		
Cr-Mo-Nd	Mo-W-Sg	**Triads 8G**	**Triads 9G**
Mn-Tc-Pm	Tc-Re-Bh	Uuo-136-154	146-154-162
Fe-Ru-Sm	Ru-Os-Hs	119-136-155	147-155-163
Co-Rh-Eu	Rh-Ir-Mt	120-138-156	148-156-164
Ni-Pd-Gd	Pd-Pt-Ds	121-139-157	149-157-165
Cu-Ag-Tb	Ag-Au-Rg	122-140-158	150-158-166
Zn-Cd-Dy	Cd-Hg-Cn	123-141-159	151-159-167
Ga-In-Ho	In-Tl-Uut	124-142-160	152-160-168
Ge-Sn-Er	Sn-Pb-Fl	161-143-161	153-161-169
As-Sb-Tm	Sb-Bi-Uup		
Se-Te-Yb	Te-Po-Lv	**Triad 10G**	**Triad 11G**
Br-I-Lu	I-At-Uus	154-162-170	169-170-171

Figure 2: The complete list of triads. In black similar elements, in red connecting elements (see Section 4).

3.- Periodicity trees

Although the table is based on triads of atomic numbers, the fundamental relationship in the architecture of the table is what we will call “periodicity trees”: symmetric systems of elements interrelated by means of triads belonging to different generations. There are two kinds of periodicity trees:

- 1 tree of 44 elements: 44 elements organized in 24 triads.
- 8 trees of 20 elements: the 20 elements are organized in 12 triads.
- 2 trees of 8 elements: the 8 elements are organized in 4 triads.

Figure 3 shows the periodicity tree 0, which connects 44 elements through triads: the first element (0) and the last element (171) belong to this tree. Moreover, this tree includes all the elements that begin and end periods; so, it provides a sort of “skeleton” to the table introduced here, and contains the elements belonging to the groups of noble gases and of halogens of the standard Periodic Table (SPT).

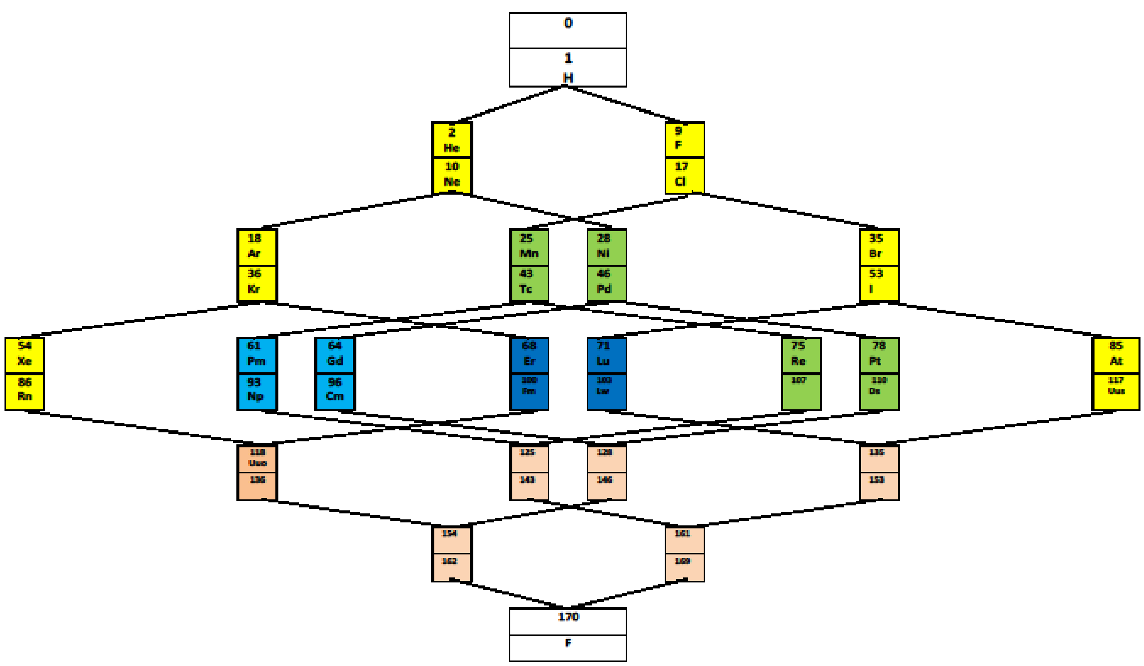

Figure 3: Periodicity tree 0

The six trees of 20 elements have the structure shown in Figure 4.

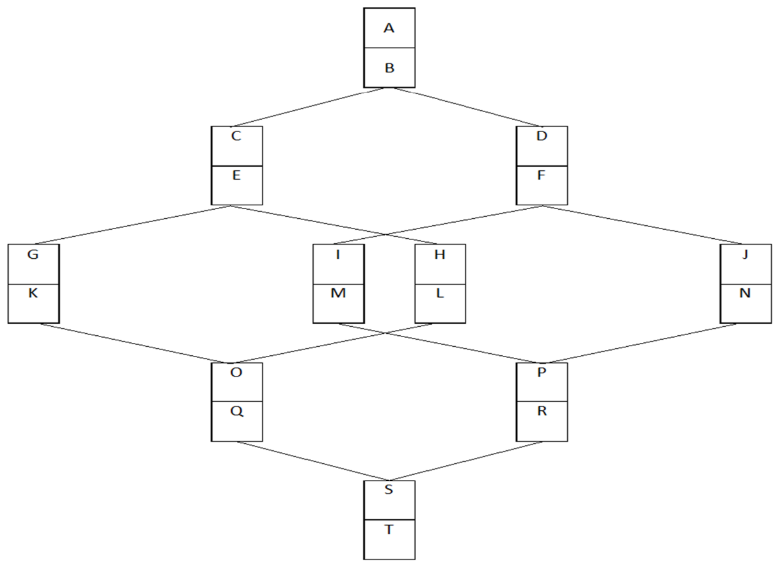

Figure 4: Generic periodicity tree of 20 elements

These trees are composed by the following abstract triads: A-B-C, B-D-F, C-E-G, D-F-I, E-H-L, F-JN,G-K-O, I-M-P, L-O-Q, N-P-R, O-Q-S and R-S-T. As can be seen, en each one of these triads, two elements belong to the same block and the third connects that block with another. For instance, in AB-C, the elements A and B belong to the first block and C connects this block with the second. In BD-F, D and F belong to the second block and B connects this block with the first. Let us see that, in these structures, it is possible to relate the groups A and B of the SPT by means of the connecting elements. For example, the groups I-A (Li, Na, K, Rb, Cs and Fr) and I-B (Cu, Ag, Au and Rg), which are disconnected in the SPT, here belong to the same periodicity tree (see Figure 5,: Periodicity tree 1). The same happens with the remaining seven groups. In particular, groups II, III, IV, V and VI of the SPT can be found in the periodicity trees 2, 3, 4, 5 and 6, respectively; this recovers the chemical similarities considered by Mendeleev in his last table, where the groups were not placed in different positions in the table.

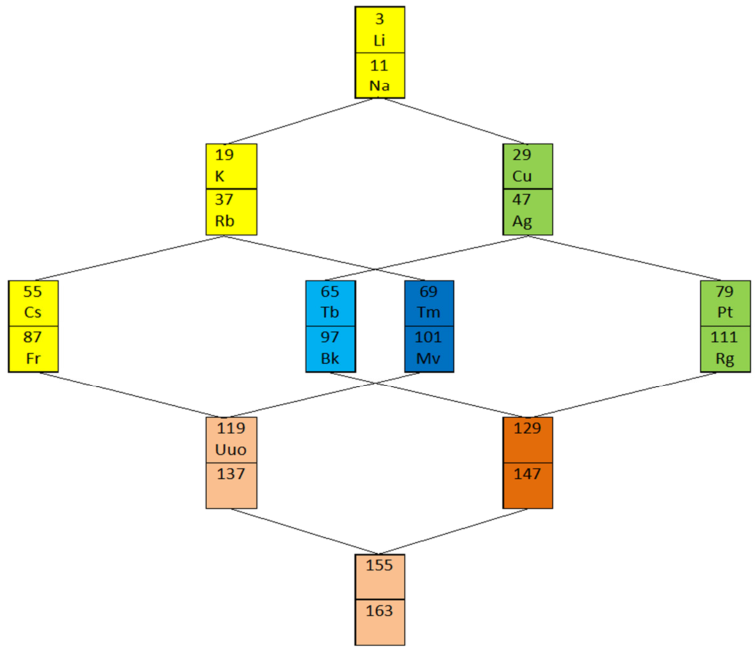

Figure 5: Periodicity tree 1

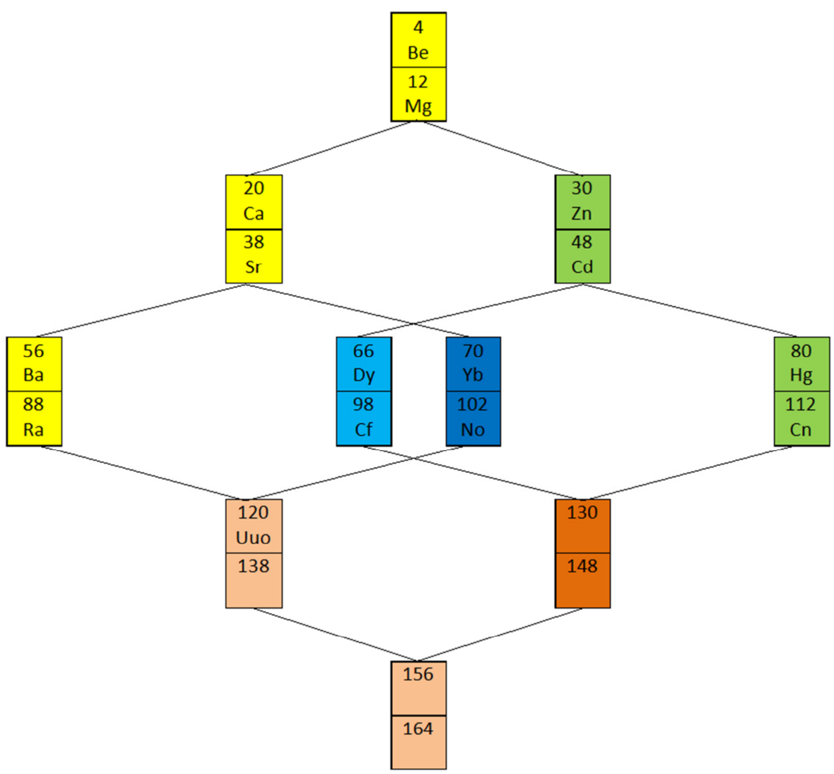

Figure 6: Periodicity tree 2

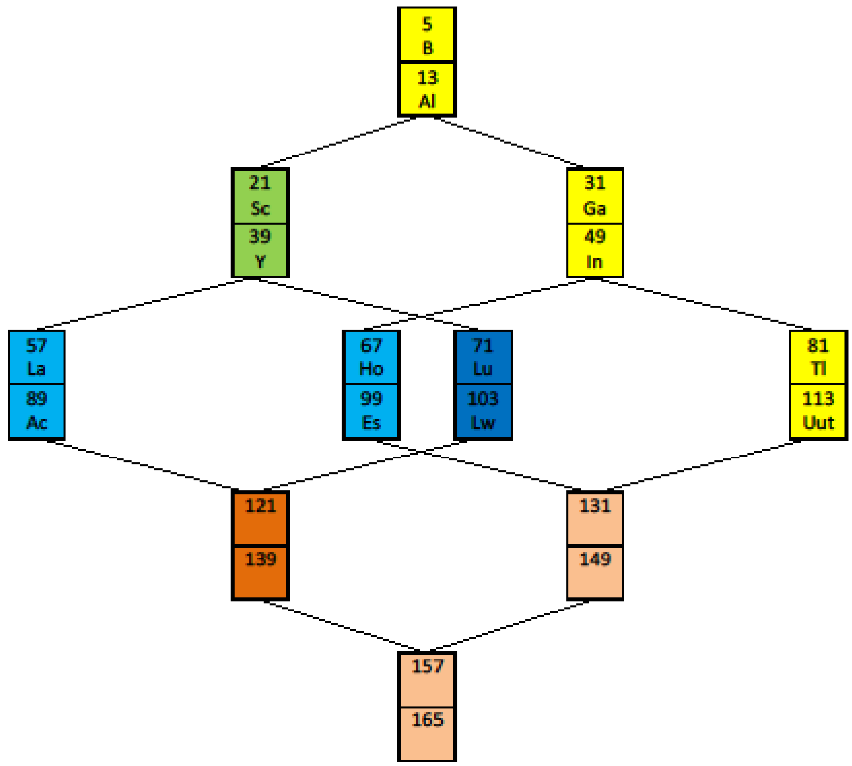

Figure 7: Periodicity tree 3

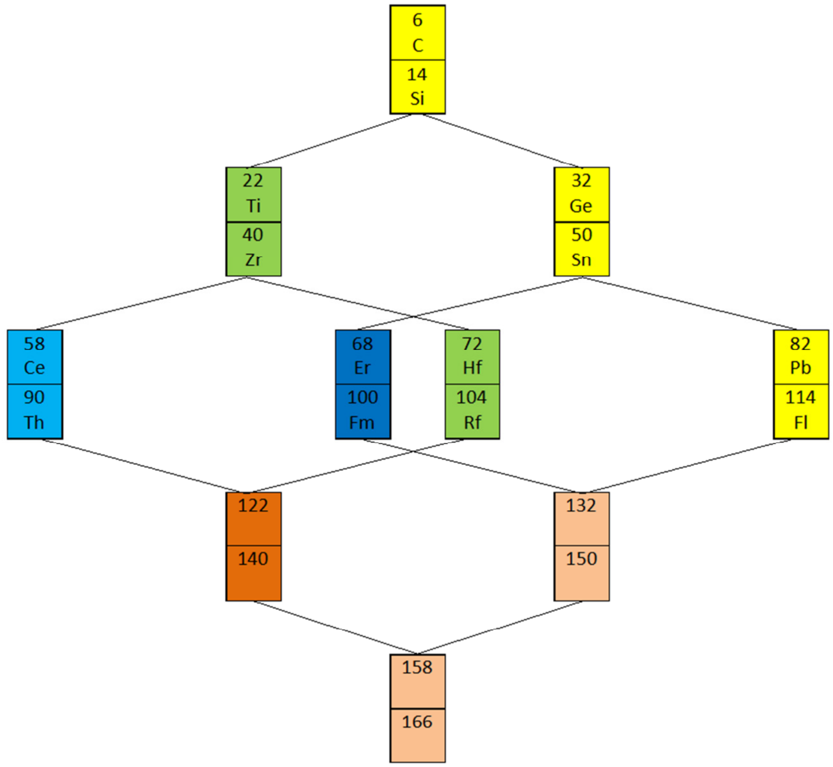

Figure 8: Periodicity tree 4

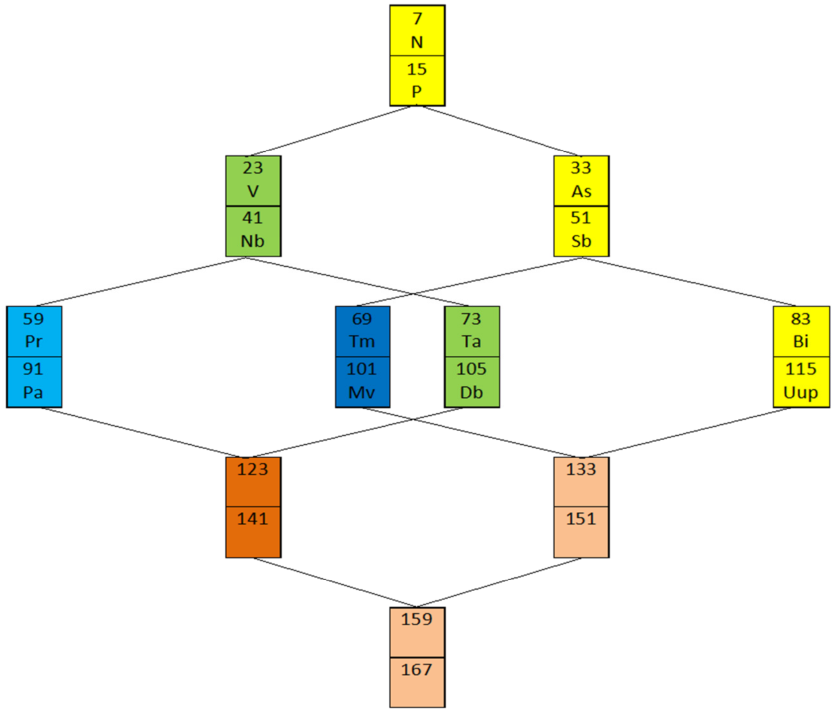

Figure 9: Periodicity tree 5

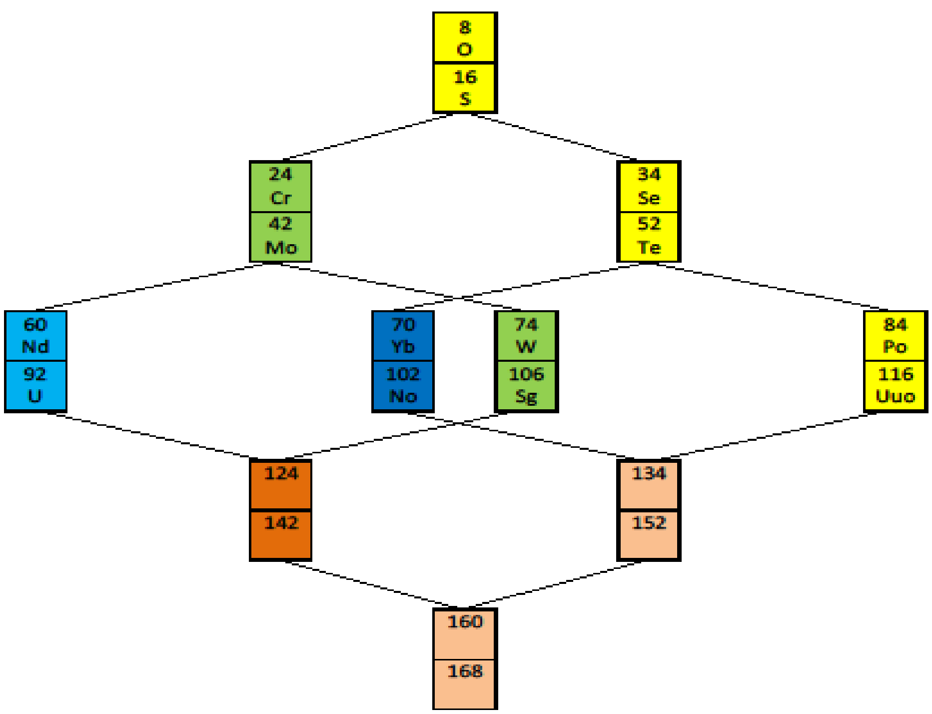

Figure 10: Periodicity tree 6

The two trees of 8 elements can be viewed as a substructure of the previous one, as shown in Figure 11. In this case the four triads are C-E-G, E-H-L, G-K-O, L-O-Q.

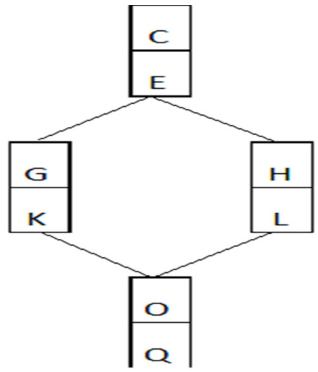

Figure 11: Generic periodicity tree of 8 elements

The:

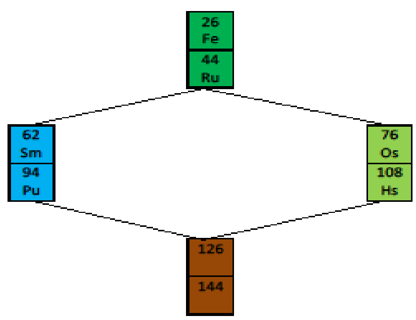

Figure 12: Periodicity tree 7

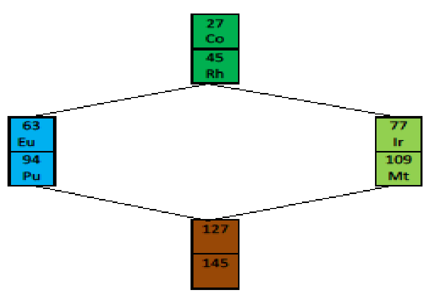

Figure 13: Periodicity tree 8

In this way, the nine trees reconstruct the whole table. In a certain sense, the requirements of period doubling and that all the elements belong to at least one triad led to a structure where the periodicity trees arise, with their symmetry peculiarities. And, in turn, this leads to a redefinition of the concept of triad.

4.- Redefinition of the concept of triad

The table proposed fulfills the requirement that all the elements belong to at least one triad. But there are some triads whose three elements do not manifest phenomenological similarities. Nevertheless, the concept of triad can be retained if it is slightly modified according to the new structure.

From the new viewpoint, a triad is still a collection of three elements, where the atomic number of the middle one is the average of the other two. But now two of the elements of the triad belong to consecutive periods of the same length, that is, to the same block, and the third belongs to a different block, that is, to a period of different length. Therefore, the elements belonging to the same block exhibit chemical similarity; and the third, 'connecting' element plays the role of linking consecutive blocks (see again Figure 2).

5.- The length of the periods

Once the new definition of triads is accepted, the periodicity trees become a natural consequence of that definition. The tree 0 contains all the elements that begin or end periods. The 6 trees of 20 elements begin in the six elements of the first period that do not belong to previous tree (tree 0). The 2 trees of 8 elements begin in the two elements of the fourth period that do not belong to the previous trees (trees 0 to 6). Therefore, the length of the first eight periods results from the architecture of the trees: 1-1-8-8-18-18-32-32.

If we followed this progression, the eighth period should have 50 elements. However, the anomalous chemical properties of some of the elements of the seventh period with respect to those of the sixth (in particular from the element 104 and mainly the element 117) suggest the possibility of a reversion of the progression in the length of the periods. On this basis, in the proposed table we have introduced that reversion from period eight, in such a way that the lengths of the 14 periods are 1-1-8-8-18-18-32-32-18-18-8-8-1-1.

This means that chemical information plays a relevant role in the development of the proposal of this new table, for deciding the length of the periods and for articulating the periodicity trees. As a consequence, the chemical information can also be read from the table.

Finally, it is interesting to notice that, besides its symmetry left-right, the table shows a suggestive up-down symmetry that have interesting consequences to be considered in the next section.

6.- The relation with the standard periodic table

Although the proposed table is completely different than the SPT, the new positions of the elements manifest in a certain sense the relations of the SPT:

- In block B we find the first elements, corresponding to the 8 groups of the series A of the SPT. Those groups can be reconstructed with the elements belonging to the 4 first columns and the 4 last columns of the blocks C and D (except group 3).
- In the central part of block C we find the elements with strong metallic character, placed in successive order as in the SPT.
- Block D contains the lanthanides and actinides, placed in successive order. But, here, unlike the SPT, they are not separated form the other elements, but they preserve the increasing order of atomic number (as in long-form tables).

Finally, it is interesting to notice that, given its up-down symmetry, the new table also predicts a final element. This means that, due to the formal structure of the table, there must exist an element of maximum atomic number, whose value is in agreement with quantum-mechanical calculations (*cfr*. Scerri 2013). This means that, according to this periodic system and independently of any quantum-mechanical consideration, there is a limit in the variety of the elements that may exist in nature; and this is an intrinsic limit, independent of any technical possibility,

7.- The answer to traditional problems

The proposed table also allows us to take a position about the traditional open problems regarding the ordering of the elements.

7.1.- The position of H and He

This table offers a solution for the problem of the position of H and He.

Hydrogen participates in the triads 0-1-2 and 1-9-17, which are meaningful from an empirical viewpoint. In the case of 0-1-2, the three elements have atomic manifestations as macroscopic without neutrons:

- The element 0 has no neutrons by definition.
- Hydrogen has the isotope of mass one as the most frequent isotope.
- Helium can form the so-called 'diproton', with mass 2.

These three elements have also the common characteristic of forming atomic species with no electronic configuration:

- The element 0 by definition.
- Hydrogen forms the specie H^+.
- Helium can form alfa particles.

On the other hand, the triad 1-9-17 makes manifest the fact that H has chemical properties analogous to the group of halogens (*cfr*. Scerri 2008a).

In the case of He, it belongs to the triad He-Ne-Ar, in agreement with the SPT. In turn, the group of noble gases is recovered by the left branch in the proposed table.

It is interesting to notice that the relative positions of H and He (H with the halogens and He with the noble gases) are similar to those offered by by Scerri (2008a, 2008b); this is not surprising because his decision about H and He is also based on triads, and the new table includes all the triads proposed by Scerri.

7.2.- The problems of group 3 of the standard periodic table

Another controversy is that related with the position of the elements in group 3 of the SPT. In particular, the disagreement is what elements have to be placed below Sc and Y: some tables place the pair La and Ac, and others the pair Lu and Lw.

The new table shows that in a certain sense, both pairs are "below" Sc and Y (see Figure 1).This is particularly evident in the periodicity tree 3 (see Figure 7): Sc and Y form a triad with La, but Y forms a triad with Lu and Lw. So, the structure of triads interconnected with each other allows us to acknowledge that there are good reasons for the two solutions, but that those solutions, taken independently of the whole architecture of the table, prove to be both partial.

7.3.- The problems of group 2 of the standard periodic table

In the SPT, the position of Be and Mg is also an issue under discussion. They can be placed with the Alkaline earth metals, but also “above” the elements of group II-B (Zn, Cd and Hg). There are good reasons for the two solutions, and both preserve the increasing number in the SPT. This problem is related with the debate about which elements should be part of the class of the “transition metals” (*cfr*. Jensen 2003).

In the table proposed here, Be and Mg are connected through triadic relations and form the tree 2 (see Fig. 6). In this way, elements of similar chemical properties are related in a natural way by means of the periodicity trees of the present table.

8.- The element 0

The new table permits to accommodate an element 0, which forms a triad with H and He. This initial element is conceived as an undifferentiated substance, which in a certain sense persists in all the elements. The neutron in an empirical manifestation of the element 0. This agrees with some recent proposals, as that of Philip Stewart (2004), who presented a representation of the periodic table in spiral form, known as “chemical galaxy”. This “galaxy” contains in its center the chemical element 0, whose “atoms” are the neutrons.

The possibility of an element 0 can be traced back to the works of Mendeleev, who believed in the existence of an element of “group zero” en the “period zero”; he expected that this element were the ether (Stewart 2007). Andreas von Antropoff (1926) coined the word ‘neutronio’ six years before the discovering of the neutron, for naming a hypothetical element 0. This author proposed a representation of the periodic system with the element 0 places at the left of hydrogen in his helicoidal periodic table. There are also antecedents of the element 0 in Janet (1929), Emerson (1944) and Clark (1950).

The idea of an element 0 might sound strange when the chemical elements are characterized by their phenomenological properties. If, on the contrary, chemical elements are conceived from an abstract viewpoint, the existence of an element defined in a theoretical manner by following the same progression that organizes all the elements can be accepted with no perplexity: it would be an element that possesses zero electrons and zero protons, without losing for this reason its real character. So characterized from this abstract perspective[1], it is clear that the zero element is the neutron, which corresponds to the element with atomic number 0, mass number 1, and null electronic configuration. This element forms the first triad with hydrogen (1) and helium (2).

Not only the neutron is an entity that can be theoretically defined, but its effective presence is empirically manifested in the so-called "nuclear reactions".

9.- Concluding remarks

The proposed table adopts the atomic number as the primary criterion and the formation of triads as the secondary criterion:

- The elements are ordered according to their increasing atomic number.
- All the elements belong to at least one triad of atomic number.
- Triads are redefined in such a way that the two elements belonging to the same block (two successive periods of the same length) have similar macroscopic properties, and the third element inter-connects blocks.
- Triads are organized in periodicity trees that inter-relate different blocks

This table has the following advantages:

- Since all the elements belong at least to a triad, the formation of triads can become the secondary criterion for the construction of the table.
- Among its 108 triads (including those with the hypothetical non-discovered yet elements), this table includes all the triads of the standard periodic table.
- The well-defined concept of periodicity tree replaces the too narrow concept of group of the SPT. Moreover, the trees meaningfully relate elements of the groups A and B of the SPT.

[1] In this work, the distinction between simple substance and basic substance is relevant (Scerri 2007), but we will not focus on this point here.

- The table manifests a suggestive double symmetry, left-right and up-down, which is not deliberately looked for, but is the result of the requirements of the construction of the table.
- The table permits to accommodate a first element 0, and a final, not yet discovered element 171, whose atomic number approximately agrees with quantum-mechanical calculations.
- Since the table includes all the not yet discovered elements in clearly definite positions, it has a relevant predictive power that will be able to be tested in the future.

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