A PROPOSAL OF A NEW VERSION FOR THE PERIODIC TABLE OF THE ELEMENTS

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SUMMARY: In spite of its usefulness, the present version of the Periodic Table of the elements shows serious defects from a didactic point of view. A through analysis of the periodicity of the physical properties of the elements - and especially recent data concerning electron affinity - shows cleanly that the best element for ending each period should be an alkaline earth metal. Thus a new chart is built. It consists of eight periods, separates the four blocks and provides a satisfactory picture of the electron configurations.

Key Word: Periodic table.

INTRODUCTION

Among the variety of the periodic table formats, the long or expanded form is now widely used. It displays clearly the seven periods and the sixteen groups/subgroups. Each period starts up with an alkaline element (with the exception of the first one which starts with hydrogen).

The first justification to this format was the periodical chemical behavior. The valence is I for the alkaline elements and then increases rightwards. Other justifications came further, especially the sharp variations observed at the beginning of each period for atomic sizes, ionization energies and electro negativities. These data, reported in many textbooks, are now so common that we adopt the periodic diagram without any controversy.

The periodic table still shows serious defects however from a didactic point of view.

- The numbering of groups is inconsistant with the positions of the columns.

- There is much confusion in the designations of subgroups (4).

- There are artificial empty spaces between consecutive elements in 5 periods (over 7). Due to the insertion of d-block and f-block elements, the main groups elements are displayed in two separate regions.

- It is difficult to explain the specifity of the first period. Whereas the other periods can be grouped by pairs containing $2p^2$ elements (where p is an integer), the first period remains single; yet its contents obey the relationship and p takes its first value: 1.

The last observation is, perhaps the most serious objection which arises, considering the regular periodicity of the quantum numbers and their interrelation with the electron configurations. It is striking that for instance, there is no straightforward relationship between the rank n of a period and its number of elements x. We proposed (12) two empirical relationships:

$x = 1/2\ (n+1)^2$ for n odd, and $x = 1/2\ (n+2)^2$ for n even.

It is possible, however, to demonstrate that the contents x of a peiod of rank n are given by a single relationship (11).

$x = 2\ (1\ (n/2) +1)^2$

where I is the integer part function (a rather unusual function in chemistry).

Let us correlate the arrangement of the elements in the table and the periodic building up order reproduced from the Aufbau principle (Figure 1). Along each dotted line the sum n+1 of the principal and the azimutal quantum numbers is a constant k (k being an integer varying

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from 1 to 8). We can observe that, since a period starts with a new main shell filling, the period change occurs within the same value of n+1.

When we describe a periodic phenomenon, the choice of periods' origins is arbitrary. It is carried out generally for a particular purpose. In the case of the periodic table of the elements, the justifications to the choice of the alkaline elements to begin the periods are not satisfactory for the following reasons:

- The correspondence between the valence (and/or the electrovalence) of an element and its group number is limited to few groups. Thus, the valence is not a convincing justification to the present format.

- As mentioned before, many textbooks give graphs comparing the sizes of atoms (or ions) with increasing atomic number. They stress upon the sharp changes

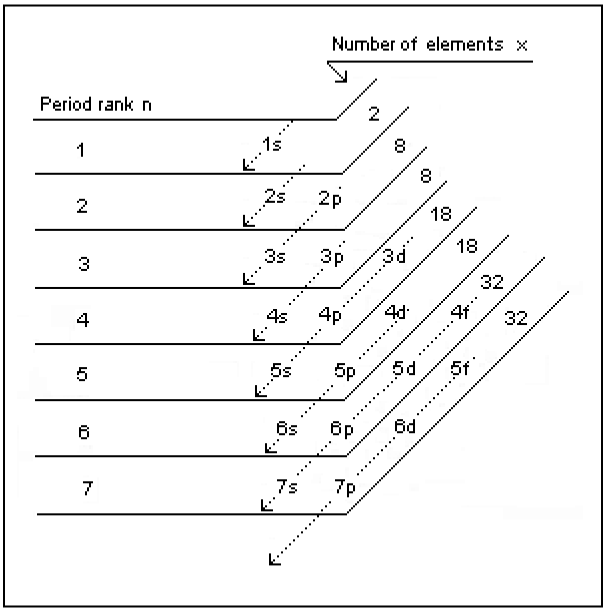

Figure 1: Correspondence between the periods and the Aufbau Principle.

observed just after the noble gases, hence justifying the occurrence of new periods. The same trend is reported for the first ionization energies. Actually, all these behaviors could have been predicted, considering the fact that, when we start filling a new shell, we involve a large increase of the atom's radius and energy level. Hence, the mentioned observations are the result of the way the table is built. They should not be used as a justification to the present display.

- In as far as the electronegativity is concerned, it is well known that is based upon either the average between the ionization energy and the electron affinity (Mullikan scale) or upon bonds strengths (Pauling scale). In both cases, we can find as before, via a similar analysis, the reason why the scales do fit the present format. We confine ourselves saying that, since the eletronegativity corresponds to the atoms ability to attract an electron in a band, its variation should parallel the trends in atomic sizes.

Let us consider, for a new approach for the periodic table, the other periodic properties of the elements.

The most significant is the variation of the electron affinity with the atomic number (Figure 2). Thanks to the

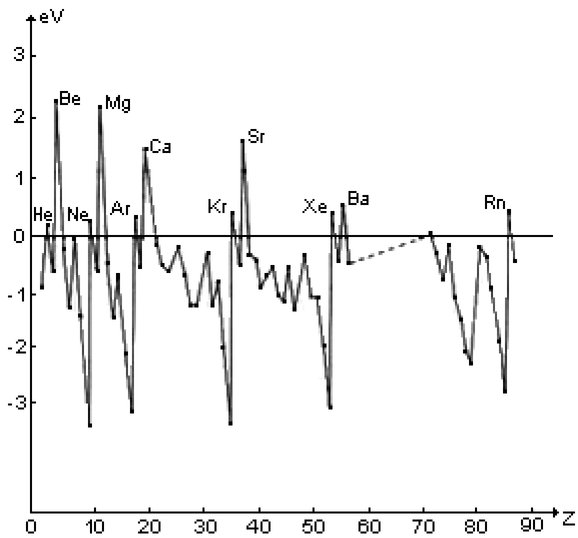

Figure 2: Electron affinities of the elements.

use of laser photodetachment experiments, we know, now, many electron affinities (6, 10). However, due to the ions' instability, some values need to be calculated. When an atom gains an electron, it achieves the configuration of its next right neighbor in a given period. The involved energy-measured through the electron affinity-is a straightforward indication of the variation of the arrangement stability with increasing atomic number.

We can see, in Figure 2, that the electron affinities of the alkaline earth elements are positive and very high. This means that these elements have the most stable configurations.

Taking into account all these data, it seemed to us that a rational choice of a period's origin could be at zero electron affinity when a sharp change occurs from a positive to a negative value. Thus, the period ends with the most stable arrangement.

Figure 3: The new periodic table version.

f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	P_1	P_2	P_3	P_4	P_5	P_6	S_1	S_2
																														H	He
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														Sc	Ti	V	→Cr	Mn	Fe	Co	Ni	→Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr
														Y	Zr	→Nb	→Mo	Tc	→Ru	→Rh	→→Pd	→Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba
←La	←Ce	Pr	Nd	Pm	Sm	Eu	←Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	→Pt	→Au	Hg	Tl	Pb	Bi	Po	At	Rn	Fr	Ra
←Ac	←←Th	←Pa	←U	←Np	Pu	Am	←Cm	Bk	Cf	Es	Fm	Md	No	Lr	Unq	Unp	Unh	Uns	Uno	Une											

The striking result of this approach is the fact that the alkaline earth metals (and helium) fit much better to end the periods than the noble gases (He excepted).

The new format that we may draw up, is given Figure 3. The last element of each period is an alkaline earth element (with the exception of the first period which ends with helium). There are two short periods containing two elements each. The number of periods becomes 8.

For further investigations to confirm the validity of this new model, we emphasized upon physical properties of the elements. In as far as these properties are concerned, the electronic configurations remain unchanged or slightly disturbed.

All the studied physical properties display periodic variations when plotted against atomic number Z. But we do not observe the very sharp changes noticed for atom's radii or ionization energies. The curves show trends roughly similar to those of sinusoidal functions. For the latter, the origin of the periods is usually chosen at the inversion center, when the second derivative changes its sign.

We drew the graphs (Figures 4 to 10) for seven properties of the elements which are: melting points (6), boiling points (6), heats of fusion (6, 13), heats of vaporization (6, 13) entropies of monoatomic gases (2, 6), specific gravities (6), and, finally, surface tensions for the liquids (6). For each property we fitted the best average straight line, using a linear regression analysis. We drew the straight line on the graph. Table 1 gives the constant a and the slope b for each straight line equation y = a+b Z.

We thought that the origin of each period should be near about the intersection point between the periodic curve and the average straight line. This way, when a period starts, we cross the average, a new trend in measured values do occur.

In each graph, we located explicitly the dots concerning the noble gases (when available) and those concern-

Table 1: Data of the average straight lines y = a+b Z.

y	a	b
Melting point	684.3	6.314
Boiling point	1291	18.85
Heat of fusion	1.987	.0244
Heat of vaporization	36.77	.5179
Entropy	36.56	.1067
Specific gravity	.3432	.1560
Surface tension	671.0	6.900

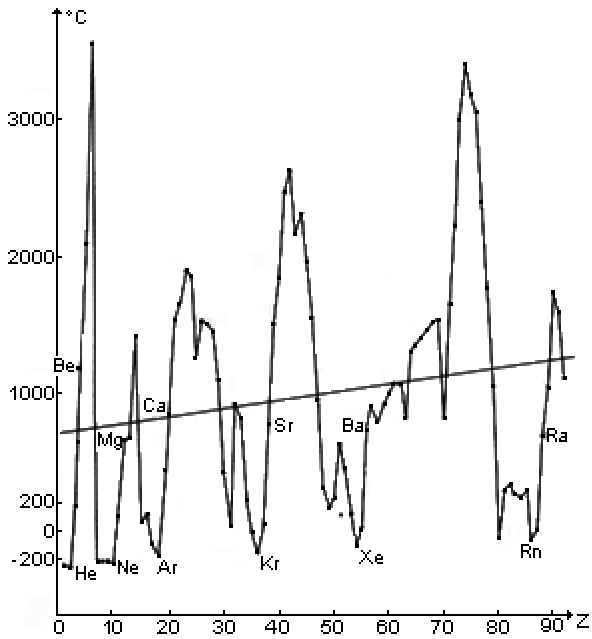

Figure 4: Melting points of the elements.

ing the alkaline earth metals. We can see clearly that the latter responds almost accurately to the new approach of the periodic table.

It is possible to compare readily in the graph, each element's data with the corresponding average. However, for quantitative purpose, we performed a residual analysis which confirms our conclusions.

As far as the first elements of the table are concerned, we cannot expect to observe a periodicity within very few data. It is also well known that the light elements behave somewhat differently from the elements of the same families. Therefore, the best way to justify the places of these first elements is to refer to their electronic configurations. Thus, and in accordance with the result drawn from the electron affinities, we put H above alkaline elements and He above alkaline earth elements.

Table 2 gives the characteristics of the eight periods of the new version. We can see that a period of rank k corresponds to the filling of shells and subshells, the quantum numbers of which follow the relationship

$$n + 1 = k$$

Going back to Figure 1, we observe that each period corresponds to each dotted line. This is a very simple interrelation between the periodic table and the Aufbau principle diagram.

The new periodic table version would be very easy to teach because of its rational build up. There is no empty space between consecutive elements within any period. It is not any more necessary to cut out the lanthanide and the actinide series. Main groups elements are near one-another. The blocks s, p, d, and f, are ordered rationally in the table, from right to left. Lanthanium and actinium are placed in f-block, whereas luthetium and lawrencium are placed in d-block. A compelling evidence for this reassignement has been reported (7).

Table 2: Characteristics of the eight new periods.

Period's rank (k)	Subshells filling	Number of element
1	1s	2
2	2s	2
3	2p 3s	8
4	3p 4s	8
5	3d 4p 5s	18
6	4d 5p 6s	18
7	4f 5d 6p 7s	32
8	5f 6d ...	32

Taking into account some recent comments about the groups designation (1,3,5,8), we suggest columns headings strictly related to the columns positions in each block, the first column being in the left and the last one being in the right of the block (Figure 3).

The periods can be grouped by pairs containing, respectively, 2, 8, 18, 32, …, $2p^2$ elements, the integer p being the rank of the pair. Then, the contents of a given period are readily determined.

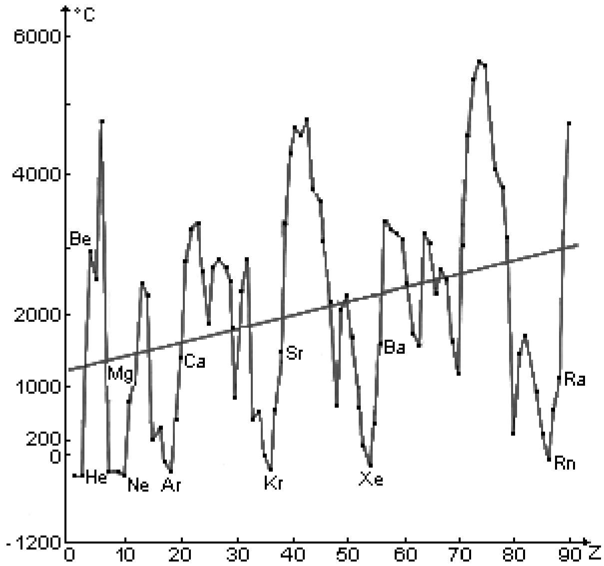

Figure 5: Boiling points of the elements.

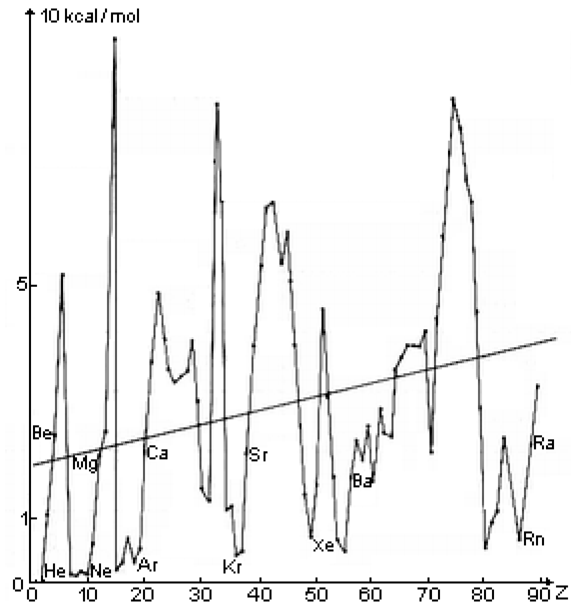

Figure 6: Heats of fusion of the elements.

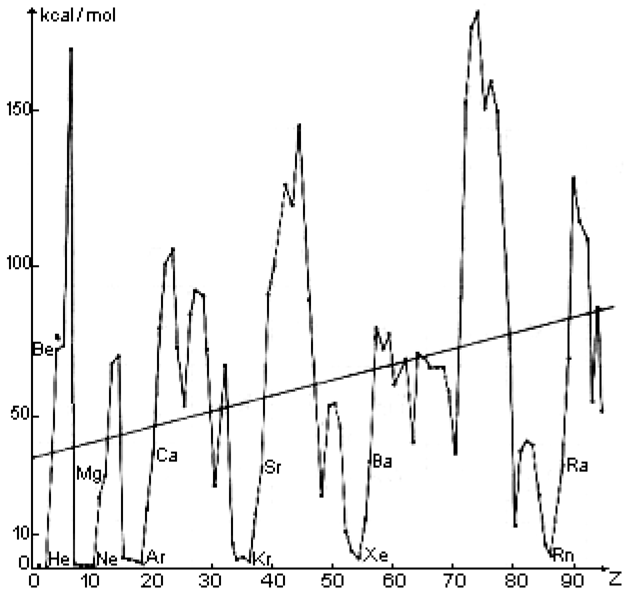

Figure 7: Heats of vaporization of the elements.

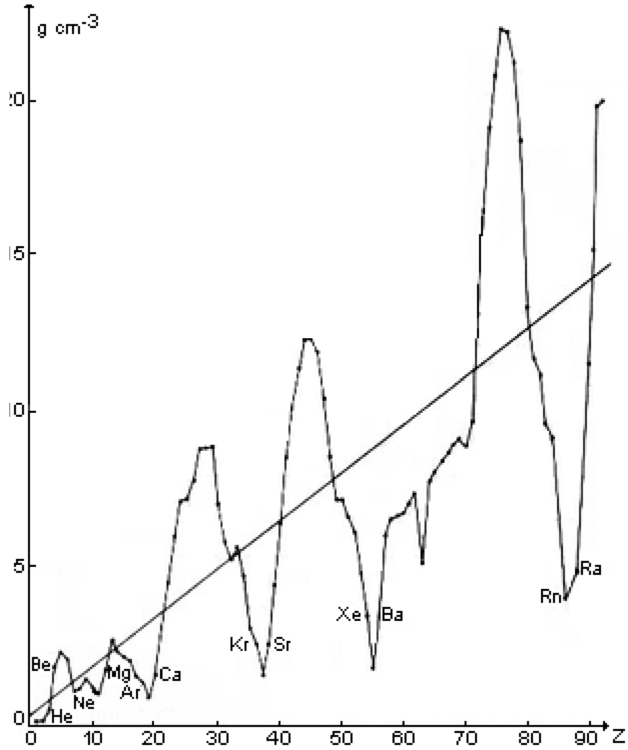

Figure 9: Specific gravities of the elements.

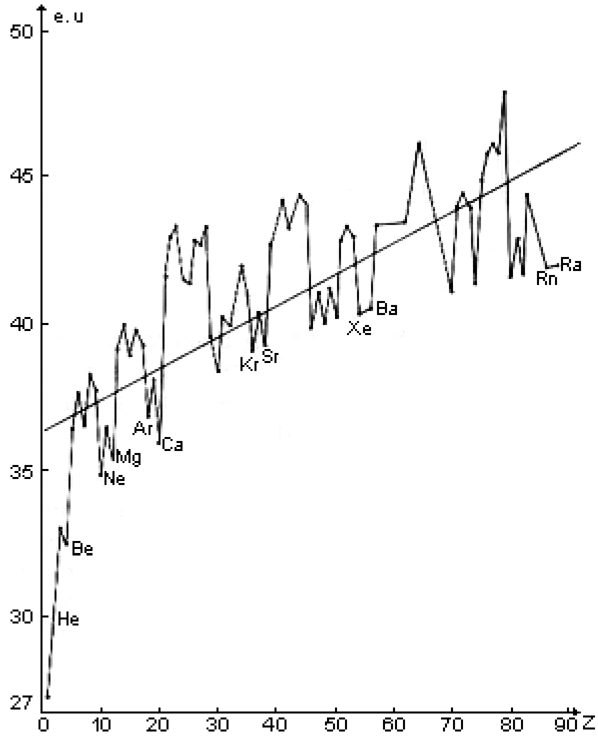

Figure 8: Entropies of monoatomic gases.

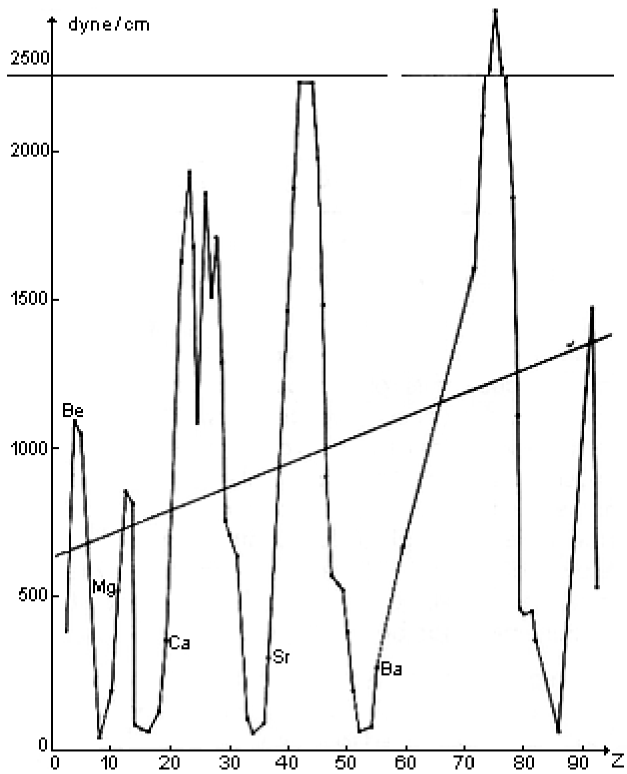

Figure 10: Surface tensions of the liquid elements.

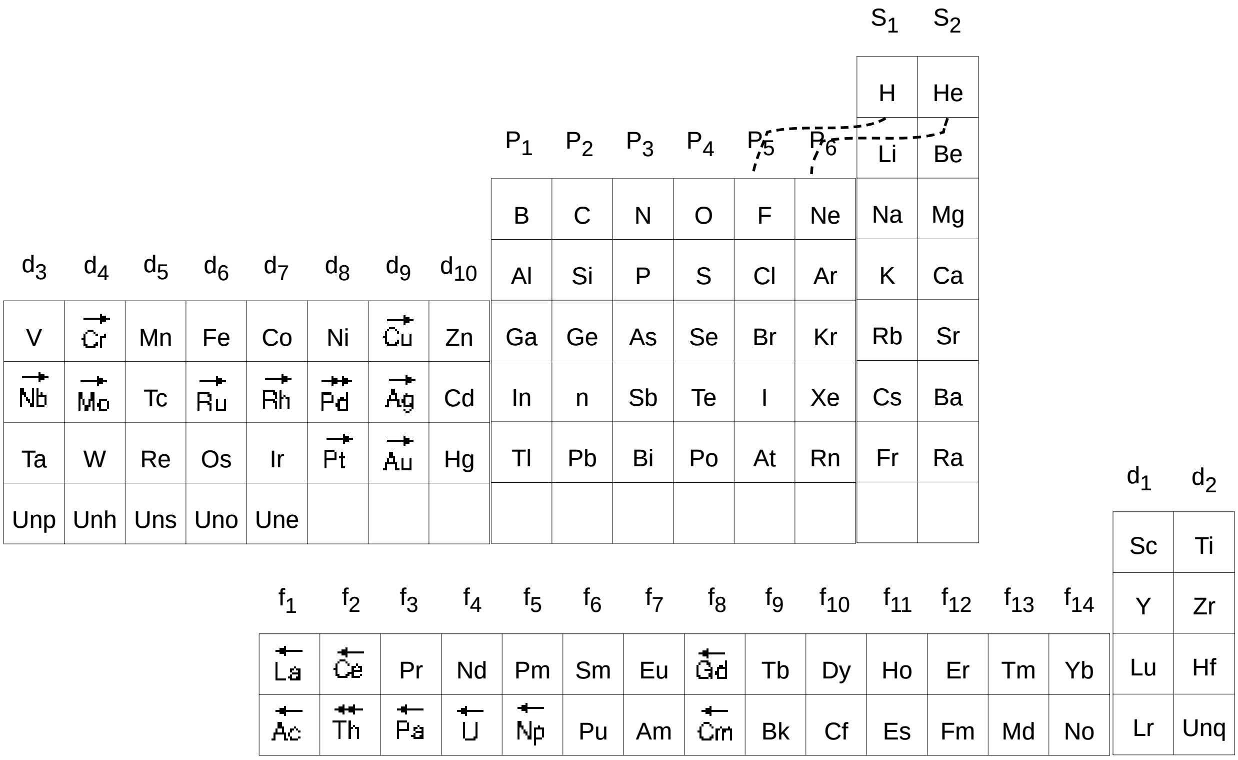

Figure 11: The two halves of the new periodic table.

It can be objected that the new version of the periodic table breaks the metals region. In fact, the transition metals show enough specificity to justify their separation from the alkaline and the alkaline earth metals, especially if we consider their chemical similarities across the row. This behavior is even more pronounced with the inner transition metals.

Actually, as stressed by several authors, we cannot expect from the periodic table, an indication of all the chemical properties. For instance, N.C. Fernelius (3) reported that "Jörgensen argues convincingly that there is no straightforward relation between the ground electron configuration of the neutral atom and the chemistry of a given element." We still notice that many chemical properties show a new behavior across the row, after the alkaline earth elements. For instance, Na_2O and MgO are basic, while Al_2O_3 is aphoteric; NaH, NaCl, MgH_2, $MgCl_2$ are ionic solids, but $(AlH_3)_n$, and $AlCl_3$ are covalent solids.

Similarly, concerning hydrogen and helium, it is true that some properties of these elements are in favor of putting H along with the halogens and He along with the noble gases. It is possible to move the two elements two steps leftwards, but it would be better to maintain the rational build up and as H and He are now close to the two p last families, it is easy to remind their respective links by using dotted lines (Figure 11).

In order to derive immediately every electron configuration, we suggest to add to the table rightward and leftward oriented arrows:

- in the d-block: one arrow for the nine nd^{x+1} configurations (instead of predicted nd^x), and two arrows for palladium which has $4d^{10}$ configuration (instead of $4d^8$ predicted by the table).

- in the f-block: one arrow for the eight nf^{x-1} configurations (instead of predicted nf^{x}), and two arrows for thorium which has $5f^0$ configuration (instead of predicted 51^2).

For didactic purpose, the best display consists of a unique chart with eight rows and thirty-two columns. However, when there is a lack of space-in small books-, the table can be folded in its middle after the group d_2 (Ti, Zr, Hf, Unq). It is also possible to divide the table into two parts of sixteen columns each, and put the left part under the right one (Figure 11). In this case, the width is shorter than the eighteen columns present format's. Having the columns correctly labeled, there will be no ambiguity and the student will understand easily this technical arrangement of the table.

Naturally, because of their immediate conception from the electronic configurations, the eight periods charts - like this or close to it - have been considered in the past by several authors including Mendeleiev himself (9). The n+1 rule was also reported (9). But, besides the electronic structures, there were no convincing data based on the properties of the elements to support the proposals.

Our study of the periodicity of the physical properties of the elements and especially typical of the physical properties of the elements and especially typical ones-like electron affinity (or "zeroth" ionization energy) and entropy of gaseous state - gives us enough confidence to propose the adoption of this chart which meets the didactic requirements for a better general chemistry teaching.

W.B. Guenther (5) reported recently that "it is safer to base periodic table on structure". He believes that it is time to drop out the old group designations, and suggests that table formats clearly separate the four blocks. Our proposal responds to this wish.

While further work is being done on the subject, we heartfully welcome all fruitfull comments from our colleagues.

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