PERIODIC MEANINGFUL SYMBOLS FOR THE CHEMICAL ELEMENTS

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SUMMARY: The present symbols of the elements are main abbreviations of names in accordance with a very old tradition. Considering the recent attempts to rationalize the symbols of the elements beyond Z=103, we propose to proceed much further and conceive for every element a meaningful symbol able to predict its properties. For this purpose we refer to the electron structures and feel logical to link the symbol to the valence shell population. The symbol is built with one or two letters whose frame determines the involved valence shells and with right superscript numbers indicating the valence - electron population. Thus, using seven letters only and limited small numbers we could conceive a set of periodic rational symbols. We do not need any more to refer to Latin-Greek roots and even to the periodic table of the elements.

Key Words: Symbols of the elements, periodic table.

INTRODUCTION

An important challenge facing chemists is to provide a quick understanding of the chemical properties of a given substance. In other words, an ambitious objective should be to put in a formula enough data to precisely define a compound. This needs significant improvements of the present chemical symbolism. Could this be achieved in spite of the weight of scholarly traditions?

Naturally, the basic substances to consider, as a first step, are the elements themselves.

The elements are represented by symbols and characterized by their atomic numbers. Unfortunately neither the symbol nor the atomic number Z do provide a ready information about the behavior of a given element.

The symbol is only a main abbreviation of the name. And there is such a variety of origins of the names that very few ones only can make mnemonic devices predicting limited properties of the elements (3).

Similarly the atomic number being the entire electronic population in the neutral atom, determines the identity of an element. While the properties are governed by the valence electrons which in general do not appear readily through the value of Z, we need to refer to the building-up principle. The information then is not promptly available.

In connection with this it is clear that neither the symbol nor the atomic number show the periodicity of the properties and the similarities between the families of elements.

These facts explain why the periodic table of the elements is considered as the most useful reference for chemists. By locating the symbol in the chart we could deduce properties and predict similarities. For example, considering separately the three individual elements $_{29}Cu$, $_{47}Ag$, and $_{79}Au$, we do not find out any sign showing properties and similarities whereas these three elements belong to the same group IB and to consecutive periods of the table.

The symbols as well as the atomic numbers which are displayed in the periodic chart are obviously a periodic. Noticing this fact, J. Arthur Campbell (1) suggested the use of visible periodic symbols such as atomic and ionic sizes, valence electrons and ionic charges. It is a stimulating challenge to try to respond to this wish although it is difficult to attempt to change the long historical traditions.

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Chemistry is becoming a key science needed by most areas of research and development and to day's students rightfully seek a better understanding of the chemist's lexicon by doing less memorizing. This shows the worth of trying to conceive a rational system to represent the elements.

HISTORICAL BACKGROUND

Considering the long discovery history of the elements (11) it can easily be understood why the present symbols of the elements lack the useful information.

The theory of four 'elements', earth, water, air and fire appeared a long time ago with Empedocle (495-435 BC). The first 'chemical' symbols are then introduced by Plato (427-347 BC) who used geometrical forms to represent these 'elements' with the objective to relate the form to the property. The triangles adopted during the Middle Ages show the main differences between the four 'elements' especially through the apex orientation.

Then came alchemy era and the handling of plenty of substances designated by a lot of symbols originating from cosmology, astronomy, astrology, metallurgy, etc...

During the period of the phlogistic theory (introduced by G.E. Stahl at the end of the seventeenth century) there was a serious attempt to give meaningful symbolism to the chemical substances. At the same time R. Boyle defined the element as a substance which can not be decomposed into other substances. After Lavoisier's quantitative experiments, Hassenfratz and Adet proposed instructive symbols such as triangles for alkaline and alkaline-earth substances, circles for metals, squares for acids. The substances are then distinguished by putting initials of their names in the geometrical figures.

This attempt to rationalize symbolism partly disappeared with Dalton's atomic theory (1810). Putting emphasis on the spherical shape of the atom rather than on its properties, Dalton generalized the use of circles. Ten years later, Berzelius cancelled even the circles; the symbols consisted in the initials of the Greek or Latin names. This is confirmed by Liebig a few decades later for the 61 elements known at that time.

Thus, step by step, the symbol lost its deductive message. It became a main abbreviation of a name, just a short way to designate an element.

It is clear that using letters makes the handling of formulas much easier, but normally it is expected from a symbol to bring a message which, as far as the elements are concerned, could inform about the chemical behavior. There exists no general link between the name (and/or the symbol) and the properties since naming customs varied with every period of the elements' discovery. Though first related to property and mineral ores, the names became more and more geographical and person oriented (8,9).

In 1968 Rothery (10) proposed the use of the atomic number itself as the symbol of an element. This numerical system of nomenclature was the first interesting step towards a rational symbolism.

In 1976, another attempt is made to systemize the symbolism by the IUPAC Commission on Nomenclature of Inorganic Chemistry (4, 6). The proposal deals with the new discovered elements beyond Z=103. The name derives from the atomic number using Latin or Greek roots indicating what the three digits of Z are. The symbol is then built from the three first letters of the roots. For example, the element 104 is the Unnilquadium, symbol Unq. 'Un' is used for 1, 'nil' for O and 'quad' for 4. Such symbols let us promptly deduce the atomic number Z.

This proposal has been adopted by several recent textbooks.

PROPOSAL OF NEW SYMBOLS

The positive response to the IUPAC Commission proposal highlights the need of instructive symbolism in chemistry. Therefore, the next improvement could be the generalization of the Commission proposal to every element thus leading to systematic names and symbols. For example, neon (Z=10) could be the unnilium, symbol Un, and niobium (Z=41) be the quadunium, symbol Qu, etc...

But, as already stressed, the atomic number Z does not bring any straightforward data about the properties of the elements and their remarkable periodicity. Our goal is to bring the symbolism much closer to the modern systematic approach of chemistry based on repetitive behavior. Therefore, we focus our attention on the information provided by the periodic table. Obviously the symbols should be linked to the valence-electron populations and to the outermost levels which accommodate them. In other words, we seek to know the two 'coordinates' of the element's location in the periodic table. However, rather than using group and period we put emphasis on outer configurations, i.e. valence electrons and related shells.

The valence electrons being responsible for chemical changes, they account for the properties hence for the striking vertical similarities shown by the groups. They occupy the energy levels beyond each noble gas core as follows:

- Sub-shells ns and np for the main group elements,
- Sub-shells ns and (n-1)d for the transition elements,
- Sub-shells ns and (n-2)f for the inner transition elements (in some cases however (n-1)d is partly involved).

The electrons filling the f-orbitals of the inner transition elements are not playing the same role as the other type of valence electrons, due to the specific horizontal similarity within lanthanides and actinides. But we need to know their number to precisely identify the element. Then the maximum number of valence electrons will be following:

- 8 for the main group elements
- 12 for the transition elements
- 16 for the inner transition elements

These numbers should appear in the symbol as well as in the involved outer energy levels. In this way we could readily picture the outer electron configuration. A priory the symbol should be a combination between a shell, a sub-shell and a valence electron population. In fact, as shown later, the sub-shell is easily deduced from the valence electron population and the corresponding shell.

We first precise the involved shell (from shell 1 to shell 7). For that purpose we propose to use letters instead of numbers. Then the valence-electron population will be attached to the letter as a right superscript. Therefore the full symbol will be mainly a capital letter. In this way we maintain the long tradition of letter symbols and we avoid ambiguities occurring by using numbers only (10). As an example, a formula built with numbers only such as

$1^{1}{}_{3}\ 2^{5}$ read 1,1, 3, 2, 5

can be wrongly understood

$1^{1}3^{2}{}_{5}$.

Which letters are best suited to represent the seven outer shells?

The first approach consisted in referring to the roots given by the IUPAC Commission on Nomenclature of Inorganic Chemistry. For shells

1, 2, 3, 4, 5, 6, 7,

we respectively obtain

U, B, T, Q, P, H, S

deduced from the roots

Un, Bi, Tri, Quad, Pent, Hex, Sept.

Although rational this approach is not fully satisfactory. We still need to know Latin or Greek roots to deduce the meaning of the symbol, and nowadays most scientists ignore Latin and Greek languages. Because we aimed at proposing symbols involving logical deductions we tried to find letters whose shapes could clearly indicate which outer shells they might represent. Then we looked for a link between the geometric frame of the letter and the rank of the shell. For that purpose we first selected letters made up of straight lines only, and we found it very easy to connect the number of lines to the rank of the shell.

Thus we propose the use of the following letters:

- I (one line) for shell 1,
- L (two lines) for shell 2,
- N (three lines) for shell 3,
- M (four lines) for shell 4.

So far it can be seen that the correlation is straightforward. But how can we go further? Obviously, we have to use the closed curves which characterize many letters' frames. Therefore, if we retain a loop to represent the number 5, using the letter O, then we can efficiently go ahead. For by adding one line to the loop we may obtain the letter P, and by adding a second line we may obtain R.

Thus,

- O is used for shell 5,
- P is used for shell 6,
- R is used for shell 7.

We only need to remember that a loop means 5. Then, we clearly deduce what the letters P and R do represent.

Fortunately, this proposal comes across the original naming of the shells: K, L, M, N, O, P, Q with only three slight differences: I instead of K, M and N inverted, R instead of Q. This coincidence is very useful especially to remind that O means shell 5 as it has been previously chosen.

It is also interesting to realize that the letters we propose show, sometimes after rotation, a striking resemblance to the Indian digits used in the Middle-East and in

Table 1:Main-group elements, examples.

Present symbol	H	C	O	Cl	Cr	In	Pb
Outer shell structure	$1s^1$	$2s^2 2p^2$	$2s^2 2p^4$	$3s^2 3p^5$	$4s^2 4p^6$	$5s^2 5p^1$	$6s^2 6p^2$
Valence electrons	1	4	6	7	8	3	4
New symbol	I^1	L^4	L^6	N^7	M^8	O^3	P^4

some Asian countries. In particular the number 5 is represented by a loop.

The symbol will then consist in combining the meaningful letters and the valence electron populations as right superscripts. For the main group elements these electrons belong to the same shell. They first occupy the s-sub-shell then the p sub-shell when their number is greater than 2.

Table 2: Symbols for main-group elements.

Alkaline elements	Present symbols	Li	Na	K	Rb	Cs	Fr
	New symbols	L^1	N^1	M^1	O^1	P^1	R^1
Alkaline earth elements	Present symbols	Be	Mg	Ca	Sr	Ba	Ra
	New symbols	L^2	N^2	M^2	O^2	P^2	R^2
Halogens	Present symbols	F	Cl	Br	I	At	
	New symbols	L^7	N^7	M^7	O^7	p^7	
Noble gases	Present symbols	He	Ne	Ar	Cr	Xe	Rn
	New symbols	I^2	L^8	N^8	M^8	O^8	P^8

Table 1 shows how easy it is to deduce the outer shell configuration (row 2) from the new symbol (row4) and vice-versa. If needed we can write the complete electron structure using the building -up principle and determine the atomic number Z. One important fact is the symbol's periodicity as it can be observed in Table 2.

Table 3: Symbols for transition elements.

Group III B	Present symbols New symbols	Sc M_N^3	Y O_M^3	Lu Po^3	Lr R_p^3
Group VII B	Present symbols New symbols	Mn M_N^7	Tc O_M^7	Re Po^7	Und R_p^7
Group I B	Present symbols New symbols	Cu M_N^{11}	Ag O_M^{11}	Au Po^{11}	
Group II B	Present symbols New symbols	Zn M_N^{12}	Cd O_M^{12}	Hg Po^{12}	

It can be seen that the new symbol although explicit are very simple as far as the main group elements are concerned. What about the other elements?

The symbols for transition and inner transition elements need a further precision since the valence electrons generally belong to two different shells as already mentioned. Then we propose to use two letter symbols, the big letter corresponding to the highest shell. Therefore the big letter refers to the ns sub-shell while the small letter deals with the (n-1)d sub-shell for the transition elements and with the (n-2)f sub-shell for the inner transition series.

For example, scandium has 3 valence electrons accommodated in the following order: $4s^2$ $3d^1$. Hence, the symbol will precise the shell number 4 by M, the shell number 3 by N and then the three valence electrons. Therefore, the symbol is $\mathrm{M}{\scriptstyle\mathrm{N}}^3$. Although small the second letter should be a capital letter in order to maintain the explicit shape.

The next element belonging to the same group III B is yttrium. Y, with the outer configuration $5s^2$ $4d^1$. Hence, its symbol will be O_M^3.

Table 3 gives some examples. The symbols are very easily deduced from each other.

Here we do not innovate very much by using a two-letter symbol. The right subscript ranges from 3 to 12 reminding the groups numbering (8, 9, 10 deal with the trials, while 11 and 12 correspond to groups IB and IIB).

The determination of the outer electron configuration is immediately deduced from the symbol. As an example, rhenium, Re, new symbol P_O^7, has the outer structure: $6s^2$ $5d^5$. 6 and 5 correspond to P and o respectively. The seven electrons are shared between the s and d sub-shells and it is known that normally the sub-shell s is filled first to capacity.

It can be noticed that the symbol applies to the exceptions where one or two s-electrons enter the d-sub-shell, since the total number given by the symbol remains unchanged. However, just like the present periodic table, the symbol did not show which these exceptions were. For this precise detail an additional sign is needed as we have already proposed for the periodic table (7).

Table 5: The new symbols in the periodic table.

I^1 L^1 N^1 M^1 O^1 P^1 R^1	L^2 N^2 M^2 O^2 P^2 R^2	M_N^3 O_M^3 Po^3 R_p^3	M_N^4 O_M^4 Po^4 R_p^4	M_N^5 O_M^5 Po^5 R_p^5	M_N^6 O_M^6 Po^6 R_p^6	M_N^7 O_M^7 Po^7 R_p^7	M_N^8 O_M^8 Po^8 R_p^8	M_N^9 O_M^9 Po^9 R_p^9	M_N^{10} O_M^{10} Po^{10}	M_N^{11} O_M^{11} Po^{11}	M_N^{12} O_M^{12} Po^{12}	L^3 N^3 M^3 O^3 P^3	L^4 N^4 M^4 O^4 P^4	L^5 N^5 M^5 O^5 P^5	L^6 N^6 M^6 O^6 P^6	L^7 N^7 M^7 O^7 P^7	I^2 L^8 N^8 M^8 O^8 P^8
		P_M^3 Ro^3	P_M^4 Ro^4	P_M^5 Ro^5	P_M^6 Ro^6	P_M^7 Ro^7	P_M^8 Ro^8	P_M^9 Ro^9	P_M^{10} Ro^{10}	P_M^{11} Ro^{11}	P_M^{12} Ro^{12}	P_M^{13} Ro^{13}	P_M^{14} Ro^{14}	P_M^{15} Ro^{15}	P_M^{16} Ro^{16}		

The same approach is used for the inner-transition series. The symbol will combine the ns level and the (n-2)f level which are concerned by the valence electrons. For the lanthanides n=6, then the symbol will be P_M^X P and $_M$ representing the shells 6 and 4 respectively, x being the number of valence electrons. Similarly n=7 for the actinides then the symbol will be R_O^X, R and $_O$ corresponding to shells 7 and 5.

Table 4.

Lanthanides	Present symbols New symbols	La P_M^3	Ce P_M^4	Pr P_M^5	Nd P_M^6	Pm P_M^7
Actinides	Present symbols New symbols	Ac Ro^3	Th Ro^4	Po Ro^5	U Ro^6	Np Ro^7

Table 4 gives some examples of the new symbols.

The complete set of the new symbols of the elements can be shown using the periodic chart (Table 5).

DISCUSSION

We focus the discussion on some objections that could arise about this proposal.

i. Are these new symbols easier to remember? The answer is obviously yes. Only seven letters, instead of the present 25 ones, are used. Furthermore, they are meaningful in the sense that they involve logical deductions. Each big letter characterizes at once a shell and a period. As for the attached numbers they are valence electrons usually well-known by chemists.

Table 6: Examples of formulas.

Compound	water	ammonia	carbon dioxide	sulfate ion	cyanide ion	sodium chloride	calcium fluoride
Formula	$I^1_2L^6$	$L^5I^1_3$	$L^4L^6_2$	$N^6L^6_4$--	L^4L^5-	N^1N^7	$M^2L^7_2$
Displayed formula	I^1-L^6-I^1	I^1-L^5-I^1 I^1	L^6=L^4=L^6	L^6 L^6-N^6-L^6 L^6	L^4=L^5-	$N^{1+}N^{7-}$	$I^{7-}M^{2++}I^{7-}$

Naturally there is no more a link between the name and the symbol, but the present supposed link itself varies with the language. Furthermore there is no general rule predicting the symbols from the names. For instance, how can we logically rely Fe, Cu and Y to iron, copper and yttrium? Many arbitrary choices have to be accepted by students learning symbols for the first time, even in the Greek-Latin cultural area.

Interestingly, modern symbolism aims at providing straight forward information. For example the adopted Hermann-Maugin symbols for space groups consist of several letters and/ or figures, while Schoenflies notation, being shorter and less explicit, becomes outmoded.

ii. Is it arbitrary to connect numbers to letters? No, because this is a long tradition. It has been done by Hebrews, Greeks, Romans and Arabs. We still use Roman figures consisting of letters I, V, X....., even in inorganic chemistry for representing oxidation numbers or groups of elements.

Similarly, we do not innovate by suggesting a link between lines and numbers. This exists clearly in Japanese as well as in Chinese traditional digits. As already mentioned this link appears also in Indian digits. Even zero is significant; it is represented by a dot which might mean no line at all.

iii. Usually the right superscript of a symbol is used for the oxidation number and for the charge number of the ion (5). It is now used for the symbol itself.

This is true, but no ambiguity would occur for the oxidation number which is given in Roman figures. It can be added as a second right superscript and this is not cumbersome since we are used to several right subscripts especially in chemical thermodynamics.

For example manganese (II) will be written $\mathrm{M_N}^{7\mathrm{II}}$, rhodium (I) will be $\mathrm{O_M}^{91}$.

As for the charge number of the ion we recommend either to use brackets to distinguish the charge number (and this is usually done for polyatomic ions) or to give as many signs as needed to express the charge.

Examples:

Cl^{--} is written either		$(\mathrm{N}^{7})^{--}$	or	N^{7-}
O^{2-}	"	$(\mathrm{L}^{6})^{2-}$	or	L^{6----}
Na^{+}	"	$(\mathrm{N}^{1})^{+}$	or	N^{1+}
Ca^{2+}	"	$(\mathrm{M}^{2})^{2+}$	or	M^{2++}
Fe^{3+}	"	$(\mathrm{M_N}^{8})^{3+}$	or	$\mathrm{M_N}^{8+++}$

The second way is much quicker. Since it has been already currently used, it could be adopted with the new symbols when the charge number is small.

iv. What are the advantages of using the new symbols? The most obvious one is that it is no more necessary to work through the periodic table. The symbol contains the full information needed to predict chemical facts and show the similarities. The first step when we study an element is to seek for its outer electronic configuration. This is now readily given by the symbol itself and that facilitates the presentations in inorganic chemistry. Through the meaningful letter and/or the right superscript number it is possible to compare for neighboring elements the periodic properties such as atomic radii, ionization energies, electro negativities, etc. It is also noticeable that whenever needed the atomic number can be deduced from the symbol. In fact Z will now become useless in most cases.

The formulas are much easier to interpret since the composition of the most important compounds depends on the valence-electron populations. From the symbol the octet rule is readily applied, and the bonds formation is easy to interpret. For example, with nitrogen L^5 we normally expect 3 covalent bonds, which occur in ammonia $\mathrm{L}^5\mathrm{I}_3{}^1$. If one electron is removed, then we obtain the four bonds observed in ammonium ion $\mathrm{L}^5\mathrm{I}_4{}^{1+}$. In both examples the eight electrons appear in the formula through the superscripts and the subscripts.

Table 6 shows the tendency of the atoms to be surrounded by 8 electrons (or 2 electrons in the case of hydrogen). The dative bond is clearly understood, for example in the case of the sulfate ion: the four oxygen atoms (L^6) need two electrons each, three are provided by sulfur (N^6) and one by the ionic charge.

For ionic substances the noble-gas core of the ions can be observed straight in the formulas.

In fact, this is a consequence of another advantage of the new symbols: the Lewis electron-dot formulas are readily deduced for any element. Thus predictions can be made about the number and the type of bonds able to occur.

Some previously hidden informations may now appear from these explicit symbols. As an illustration, let us consider the well-known zigzag line which separates metals from nonmetals in the periodic table. This line is drawn just behind the elements L^2, N^3, M^4, O^5 and P^6. Therefore, we can notice that nonmetals are main-group elements (the noble gases excepted) whose number of valence electrons is greater than the rank of the corresponding outer shell. The higher the difference the more pronounced the nonmetallic character.

CONCLUSION

As science of matter chemistry has a specific jargon requiring a great deal of memorization (2). Any serious attempt to improve this important side of chemical education should first investigate the symbols of the elements which are the basis of the chemist's language. If we only consider that the present symbolism has been adopted during the first half of the nineteenth century, even before the discovery of the periodic table by Mendeleev, we can imagine how out of date the present symbols of the elements might be. As a matter of fact it is common knowledge that these symbols are main abbreviations of names generally unable to remind any data related to the properties and their periodicity.

Being convinced that it is time to question the use of an old symbolism ignoring the huge advancement of chemistry during the twentieth century, we tried in this paper to propose symbols that could be pedagogically effective and account for the elements' behaviors. For this purpose we referred to the electron structures as an important achievement of modern physical chemistry. Feeling logical to link the symbol to the valence shell and its electron population we built up rational and meaningful symbols for the elements. Thus, for any given element, we could readily make reliable predictions of properties and similarities.

We used seven letters only and limited small numbers as right superscripts. The new symbols show the periodicity as well as the outer electron configuration. Those are the basic data used in chemistry.

The new symbolism, though rationally built, is not a complete innovation since several meaningful selected letters keep the significance they already have as shell denominations.

This proposal is put forward with the expectation that it will make learning chemistry more attractive not only to chemists themselves but also to biologists, geologists, engineers, etc. Aware of the need to improve chemical education we do not yet minimize the difficulty to get rid of very old scholarly traditions. We do hope that the chemical societies and especially the Committee on Teaching of Chemistry of IUPAC will be receptive to the new way of writing symbols and formulas and help its diffusion among chemists. The proposed new 'ALPHABET' of chemistry has the advantage to be language-independent. It could be a universal tool for a better learning all over the world.

We would be grateful to our colleagues to test the effectiveness of the proposal and assess the students' reactions, putting emphasis on the fact that using the new symbols we do not any more need to refer to the periodic table of the elements. We welcome any thoughts, suggestions and comments which could make this proposal a successful reality.

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