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NEW NOTATIONS IN THE PERIODIC TABLE

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New notations in the periodic table

Abstract - In 1985 the IUPAC Commission on the Nomenclature of Inorganic Chemistry circulated for public comment a proposed new notation for the groups of the periodic table. This gave rise to worldwide discussion in the chemical literature. This article reviews the historical process that led to the IUPAC proposals, and discusses them in relation to the response within the scientific community.

INTRODUCTION

Since Mendeleev first communicated his work, "Concerning the Relationship of the Properties of the Elements and their Atomic Weights", to the Russian Chemical Society in March 1869, which then subsequently appeared in synopsis form in the autumn of the same year in "Zeitschrift für Chemie" (ref. 1), numerous arrangements of the elements have been proposed and used (ref. 2). Only a few months after Mendeleev's publication, Lothar Meyer published an almost identical periodic table based upon the physical properties of the elements (ref. 3). Thomas Bayley (ref. 4) and Niels Bohr (ref. 5), whose work supplied the theoretical foundation for the periodic table, preferred a pyramidal arrangement of the elements. From this work, a long periodic table was developed and is shown in Fig. 1. At the same time, a short periodic table has been used, one which remained for some time more popular in Europe than in the USA even though the long periodic table has been published in increasing numbers in European textbooks.

CONFUSION IN THE PERIODIC TABLE OF THE ELEMENTS

H.G. Deming used the long periodic table (Fig. 1) (ref. 6) in his textbook "General Chemistry", which appeared in the USA for the first time in 1923, and designated the first two and the last five Main Groups with the notation "A", and the intervening Transition Groups with the notation "B". The numeration was chosen so that the characteristic oxides of the B groups would correspond to those of the A groups. The iron, cobalt, and nickel groups were designated neither A nor B. The Noble Gas Group was originally attached by Deming to the left side of the periodic table; the group was later switched to the right side and usually labeled as Group VIIIA (compare Fig. 1). This version of the periodic table was distributed for many years by the Sargent-Welch Scientific Company, Skokie, Illinois, USA.

In 1924, the W.M. Welch Manufacturing Company published a short periodic table, which can be traced back to a proposal made by Henry Hubbard, a former Secretary of the National Bureau of Standards. Hubbard designated elements of the Main and Transition Groups (III through VII) likewise with A and B; he applied these notations, however, in a reverse order compared to the notation of Deming.

In Europe the alkali metals and alkaline earth metals are usually designated as IA and IIA, respectively; the elements scandium to nickel as IIIA to VIIIA; copper and zinc groups as IB and IIB; and boron, carbon, nitrogen, oxygen, and halogens as IIIB to VIIB. The latter designations, using Arabic numerals, were also recommended by the "IUPAC Commission on the Nomenclature of Inorganic Chemistry" (CNIC) in the book "Nomenclature of Inorganic Chemistry" which appeared in 1970 (ref. 7), although the notation omits the elements of the first three periods.

The designations A and B have been extensively and rather arbitrarily used in the meantime in textbooks and in publications. An investigation of the application of the subgroup designations A and B in all articles, which appeared between 1972 and 1981 and covered by Chemical Abstracts, revealed a completely arbitrary use of the designations. Moreover, in more than 10 % of the articles it was nearly impossible, from the wording of the text, to recognize which elements were being discussed without further information (ref. 8).

PROPOSAL OF THE IUPAC CONCERNING GROUP DESIGNATIONS IN THE PERIODIC TABLE

Since the beginning of the 1980's, the CNIC has tried to find a solution to this problem before publication of the new edition of the "Nomenclature of Inorganic Chemistry (Part I)" which is to appear in 1988. After year-long discussion of the question, the committee formulated a proposal, which originally came from the Swedish National Committee for Chemistry. This proposal was in accord with a 1972 draft proposed by A. Ölander for which he had already obtained a copyright in 1956.

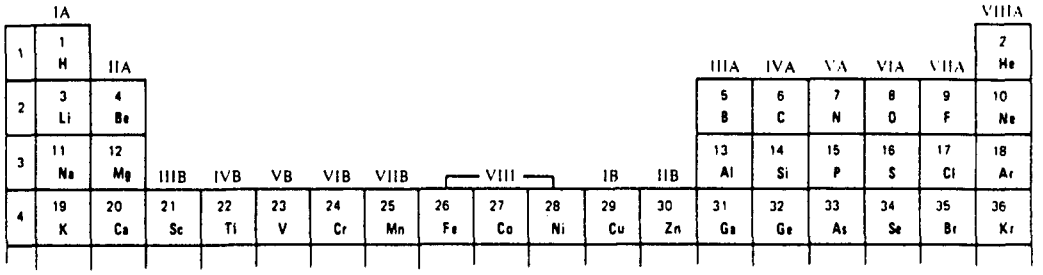

Fig. 1. Periodic table according to H.G. Deming

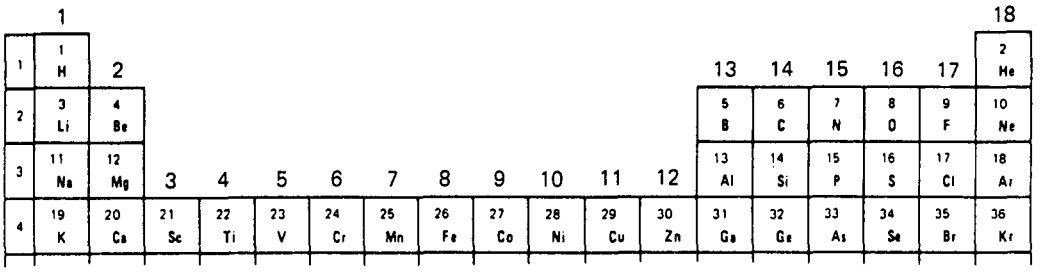

Fig. 2. Proposal of the IUPAC Commission for the Nomenclature of Inorganic Chemistry for Group Designations of the long periodic table of the elements

Ölander's periodic table was first published in 1964. The groups of the long periodic table, beginning with the Noble Gas Group, were designated with the numbers 0 to 17. The elements boron, carbon, nitrogen, oxygen, and fluorine, which are now the first elements of the Groups IIIA to VIIA or IIIB to VIIB, stand at the head of Groups 13 to 17. The new designations of these groups result from adding 10 to the presently used group numbers.

The CNIC proposal of designations of the groups, shown in Fig. 2, differs from that proposed by Ölander solely in that the noble gases appear as Group 18. A periodic table which simultaneously contains the designations of the IUPAC commission and designations from the "Chemical Abstracts Service", was offered by the VCH Publishers in Weinheim, Fed. Rep. of Germany, in 1985. The same group numbering was also approved by the Nomenclature Commission of the American Chemical Society (ACS), after the commission of the "Division of Inorganic Chemistry" of the ACS had introduced a much discussed proposal to the IUPAC Nomenclature Commission (ref. 9). The "New York State Education Department" adopted the new system in September 1986. Meanwhile, the Royal Dutch Chemical Society and the Dutch Organization of Science Teachers published the periodic table with the 1 to 18 numbering system.

The newly proposed numeration caused much resistance expressed in the form of letters to journals (ref. 10) and professional organizations.

All objections were previously known to the CNIC commission members based upon their own experiences. Important points of view for the change of notation were, as previously mentioned, considered so as to eliminate a completely arbitrary use of the A and B subgroup notation in the literature.

From many letters it became evident that the main concerns rest on the loss of correlation between column labels and such quantities as positive oxidation numbers and numbers of valence electrons for main group elements. Simple mnemonic aids, however, easily remove this drawback. An atom of either the main group or the transition elements has a number of valence electrons which corresponds to the last digit of its column label in the periodic system (only elements of group 10 have 10 valence electrons). The new group numbers are the sum of s + p + d electrons after the last noble gas. The new numbering also eliminates the lumping together of three families of elements under a single group number (old VIII, new 8, 9, 10).

Another objection concerns the common parlance of solid-state chemists and physicists, for example, III/V semiconductors. The properties of these materials, however, derive from their electronic and crystal structures and not from the labels of the columns of the periodic table. The notation III/V is still valid (ref. 11).

It is, however, noteworthy that the numeration of the groups from 1 to 18 was not rejected by all correspondents. In a series of letters to "Chemical and Engineering News", advantages of the 18-group notation were emphasized and mnemonic aids were offered to introduce the new system (ref. 12, 13).

During the August 16 - 21, 1986 meeting in Heidelberg and the August 17 - 22, 1987 meeting in Boston, MA, USA, CNIC dealt anew with the periodic system, since the revised, third edition of the "Nomenclature of Inorganic Chemistry (Part I)" will contain a periodic system for internal reference purposes. According to the resolution of the commission, the long periodic system with the group designations 1 to 18 will be used, as was repeatedly concluded in many previous sessions. Also at a meeting which took place during the CHEMRAWN VI Conference on May 19, 1987 in Tokyo and included Dr. W.G. Schneider, Canada (IUPAC president 1983 - 1985), Prof. C.N.R. Rao, India (president 1985 - 1987), Prof. V.A. Koptyug, USSR (president 1987 - 1989, Dr. M. Good (president of the ACS), Prof. K. Saito, Japan (president of the Division of Inorganic Chemistry of IUPAC 1985 - 1987), and the author of this article in his capacity as president-elect of the Division of Inorganic Chemistry, Prof. Rao favored after lengthy discussions the proposal to label the columns of the long periodic system with numbers 1 to 18.

On August 19, 1987 CNIC heard delegates from the Deutsche Zentralausschuß für Chemie, the German National Adhering Organization to IUPAC, and the American Chemical Society on this matter. Prof. Brodersen, University of Erlangen, Germany, recommended the use of the "code of chemical elements" (ref. 14) as the periodic system. CNIC rejected the proposal arguing that 1) the code of elements is rather an illustration of the Aufbau principle from which a periodic system is to be developed, 2) the noble gases are separated and members of two different columns, 3) group 2 contains elements which are chemically very different (He and the alkaline earth metals), and 4) for elements with higher group numbers, for example group 26, the relation to the number of valence electrons is not easy to recognize. The delegate of the ACS, Prof. H. Bent, North Carolina State University, Raleigh, N.C., who is chairman of an ad hoc-committee which was installed by the former ACS president, Prof. G. Pimentel, explained the requirements for a periodic system in his view. One of his proposals (Fig. 3, last line) is similar to a proposal made by Fluck (Fig. 3, first line) (ref. 1). It differs only by numbering the transition elements Sc to Cu and their homologues with 3d to 11d and Zn, Cd, and Hg with 2d in order to demonstrate, that the properties of

1	2	1d	2d	3d	4d	5d	6d	7d	8d	9d	10d	3	4	5	6	7	8	Fluck, 1983
1	2	3d	4d	5d	6d	7d	8d	9d	10d	11d	12d	13	14	15	16	17	18	ACS (ref. 9)
1L	2L	3L	4L	5L	6L	7L	⊢	8L	⊣	1R	2R	3R	4R	5R	6R	7R	0,8R	}
1M	2M	3T	4T	5T	6T	7T	⊢	8T	⊣	1T	2T	3M	4M	5M	6M	7M	0,8M	} Nelson (ref. 15)
M1	M2	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	M3	M4	M5	M6	M7	M8	}
1M	2M	3T	4T	5T	6T	7T	8T	9T	10T	11T	12T	3M	4M	5M	6M	7M	8M	}
1M	2M	3T	4T	5T	6T	7T	8T	9T	10T	1T	2T	3M	4M	5M	6M	7M	8M	} Gillespie (ref.17)
1	2	3d	4d	5d	6d	7d	8d	9d	10d	1d	2d	3	4	5	6	7	8	}
1	2	3d	4d	5d	6d	7d	8da	8db	8dc	1d	2d	3	4	5	6	7	8	} Kirschner(ref.18)
1	2	3*	4*	5*	6*	7*	8*	9*	10*	11*	2'	3	4	5	6	7	8	Sanderson(ref.19)
1	2	3d	4d	5d	6d	7d	8d	9d	10d	11d	2d	3	4	5	6	7	8	Bent, 1987

H																	He	
Li	Be											B	C	N	O	F	Ne	
Na	Mg											Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	

1f	2f	3f	4f	5f	6f	7f	8f	9f	10f	11f	12f	13f	14f	Fluck, 1983
3f	4f	5f	6f	7f	8f	9f	10f	11f	12f	13f	14f	15f	16f	ACS (ref. 9)
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	

Fig. 3. Proposals for Group designations in the long periodic table of the elements

the elements of the fourth period change markedly from Cu to Zn or that the signs of certain figures change from plus to minus (density of the solids; melting points; Paulings electronegativities; first ionization energy; oxidation potentials; acid strength of the bivalent ions; color of oxides, hydrated ions, cyano and cyclopentadienyl complexes versus colorlessness of the corresponding zinc compounds; etc.), and that the elements of the zinc group are not transition elements. Another of Prof. Bent's proposals, to designate various blocks (s, p, d) of the long periodic system with A, B, and C would, according to the opinion of CNIC, cause increasing confusion in the old and new literature.

CNIC did not deal with proposals based on the short form of the periodic table since the 18-column form has gained dominance throughout most of the world. CNIC realizes, however, that the short form will still be in use in some places.

In the appendix to the "Red Book" this and other forms of the periodic table in use will be shown with the comment: "The Commission has decided that over whatever length of time is required by appropriate and effective process, any ultimate recommendations on the format and family labeling of the Periodic Table must be responsive to the broadest possible constituency. Each group of this larger population is invited und urged to seek and present its local consensus to the IUPAC Commission on the Nomenclature of Inorganic Chemistry, Commission II.2."

SUBSEQUENT PROPOSALS FOR GROUP DESIGNATIONS IN THE PERIODIC TABLE

After the IUPAC proposals had become known, letters appeared in scientific journals presenting numerous other proposals for group designations; a few of these proposals are shown in Fig. 3, in order of their date of proposal. In part, they correspond to a proposal submitted by Fluck in a lecture on "International Aspects of the Periodic System in Chemical Education" at a symposium at the ACS National Meeting in Seattle, Washington, USA on March 24, 1983, and later during the August 11 - 16, 1983 meeting in Lyngby, Denmark. The proposed notation did not, however, reach a majority of approval within CNIC. From an educational point of view, this particular proposal attempted to distinguish the Main and Transition Groups from one another. The numbering of the Main Group remains unchanged compared to the usual formal notation. The group number specifies the sum of the s and p electrons in the valence shell with the exception of He. The numeration of the Transition Group elements agrees in most cases with the number of d electrons of the elements; this likewise applies to the f electrons for the elements La to Yb and Ac to No.

Similar proposals were later made by others, whereby the numbering of the Transition Group elements would mostly begin with 3, and the Group numbers 1 and 2 were chosen for the Cu and Zn groups. The highest usual oxidation number of the elements of every group would normally be indicated thereby, even though the number of exceptions to this rule is large. In comparison to Fluck's proposal, however, they have the disadvantage that the designations 3d, 4d, and so on, might give a false impression that these elements possess a corresponding number of d electrons. This disadvantage could eventually be dealt with by the use of Roman numerals for the notation.

P. Nelson (ref. 15) proposed three notation systems, which for application purposes, should be used simultaneously. His first proposal touches on the short periodic table whereby the subnotations A and B, according to the IUPAC recommendations for 1970 (ref. 7), are replaced by L and R (L = left and R = right). The second of Nelson's proposals for numeration likewise comes from the short periodic table, using however the subnotations which were chiefly used previously in the USA, whereby A would be replaced by M (M ≡ Main) and B by T (T = Transition). A third scheme is based upon the long periodic table. The division of the periodic table into M and T elements had first been used by R.T. Sanderson (ref. 16), who designated the zinc group as $M2^1$, since these elements with their complete d shells do not belong to the transition elements.

R.J. Gillespie's first proposal (ref. 17) reproduces the total number of s and d electrons for the Transition Group elements. For the elements Sc to Mn, the numbers correspond to the maximum oxidation number. At the same time, the relationship between the Main Group elements of the alkali metals to the halogens and the transition elements of scandium through manganese groups would be emphasized. Gillespie's second proposal emphasizes the relationship between the first two Main and Transition Groups, although the numeration of the latter no longer corresponds to the sum of the s and d electrons.

S. Kirschner's proposals (ref. 18) deviate at certain points from the previously specified notations. These proposals are, however, based upon similar points of view which are easily understood after reading the previous descussion. In order to bring the numbering of the iron, cobalt, and nickel groups into agreement with the maximum oxidation number, the subnotations 8da, 8db, and 8dc were chosen in his second proposal.

One of the latest proposals was made by R.T. Sanderson (see Fig. 3) (ref. 19). It is very similar to the proposal by H. Bent mentioned above.

THE ELEMENTS OF THE SCANDIUM GROUP

In the "Red Book" which will appear in 1988 the same arrangement was chosen for the elements of the scandium group as in the periodic table as originally proposed by CNIC and subsequently published by VCH Verlagsgesellschaft, Weinheim.

It is a compromise. According to the electron configurations of the elements, the scandium group consists of the elements

Sc, Y, Lu, Lr.

This was pointed out as early as 1959 by L.D. Landau (ref. 20) and later by other authors (ref. 13, 14, 20 to 25). Most periodic tables in textbooks and classrooms, however, list Sc, Y, La, and Ac as elements of the scandium group and designate the elements Ce to Lu and Th to Lr as lanthanides and actinides, respectively. The historical background for this arrangement is given in a paper by W.B. Jensen (ref. 21). Based upon their electronic configurations and their chemical and physical properties , the elements La to Yb and Ac to No should be inserted between barium and lutetium and between radium and lawrencium or for practical reasons be listed at the bottom of the table. The series La to Yb and Ac to No then, however, cannot be named correctly as lanthanides and actinides since they contain the elements lanthanum and actinium and not only elements similar to lanthanum and actinium as is purported by the ending -ide (or -oid according to an earlier IUPAC recommendation).

CONCLUSION

The various proposals discussed above all have merits. However, careful consideration of their advantages and disadvantages has nevertheless led CNIC to continue to prefer their original proposals, which have the advantage of providing a unique and unambiguous designation for each group. This form of the periodic table will therefore be set out in the Appendix to the new edition of the IUPAC Red Book (Nomenclature of Inorganic Chemistry), but will be related to those alternatives used most widely in the literature. However, IUPAC can only make recommendations, not laws, and the Commission encourages further discussion and comment on this subject, which is necessarily of concern to all members of the chemical community.

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