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Order From Confusion: International Chemical Standardization and the Elements, 1947-1990

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Abstract. The International Union of Pure and Applied Chemistry (IUPAC) is the international standards making body for chemistry whose goal is to create a common language for the global chemistry community. The IUPAC governs the use and creation of names, symbols, and terminology. It also establishes criteria for the discovery of new elements and assesses discovery claims, develops rules for naming new elements, and defines group numbering and collective names. This paper examines a series of episodes in which the Commission on Nomenclature of Inorganic Chemistry (CNIC) made changes in the nomenclature of the elements and to the periodic table. They faced protests in their attempts to harmonize the names of elements, create a systematic nomenclature for elements with an atomic number greater than 100, and changed the group numbering on the periodic table, dropping the use of A and B sub-group labels in favor of Arabic numbers 1 through 18. By allowing for difference while advocating for uniformity, CNIC persevered in creating order out of confusion through standardized nomenclature.

Keywords. Chemical elements, periodic table, IUPAC, nomenclature.

1. INTRODUCTION

The need for standardization in chemical terminology, symbols, and nomenclature was well-recognized in the nineteenth century. The first international chemical conference held at Karlsruhe in 1860 made some attempt at this.[1] A congress was held at Geneva in 1892 to create a standardized nomenclature for organic chemistry. This nomenclature did not cover the entirety of organic chemistry and it failed to be adopted, although it did later form the basis for today's standardized nomenclature.[2] International chemical conferences in the first decades of the twentieth century made gestures towards standardization but little was accomplished. A notable exception was the International Committee on Atomic Weights (IACW), formed in 1900 after a mail ballot found overwhelming acceptance of O=16 as the basis for the determination of atomic weights, rather than H=1.[3] Although it took several years for the O=16 standard to be fully accepted, the IACW continues to carry out its mandate regarding atomic weights.

The International Association of Chemical Societies (IACS) was formed in 1911 with the intention of developing international chemical standards in the areas of nomenclature and notation, classification, atomic weights, and information related activities such as the indexing of chemical literature. Commissions were created to study the nomenclature of organic and inorganic chemistry and the standardization of symbols for physical constants.[4] The proposed work of the IACS was "Promethean" and questions were raised regarding its funding and membership.[5] Before these could be resolved, World War I intervened and the IACS was dissolved in its wake.

The International Union of Pure and Applied Chemistry (IUPAC) was formed in 1919 to replace the IACS. Its purpose is to organize cooperation between scientific societies around the world, to coordinate their activities, and to contribute to the advancement of chemistry as a whole.[6] The IUPAC is the international standards making body for chemistry whose goal is to "create a common language for the global chemistry community."[7] The common language for chemistry is largely a standardized one. The IUPAC publishes several books of nomenclature rules, known as the color books, that cover the many subdisciplines of chemistry. These rules govern the use and creation of names, symbols, and terminology.

Many of the IUPAC's standardization activities are related to the elements and thus to the periodic table. The IUPAC reviews atomic weights, establishes criteria for the discovery of new elements and assesses discovery claims, develops rules for naming new elements and coordinates their naming, and defines group numbering and collective names. However, the IUPAC does not recommend the use of a specific form of the periodic table.[8]

Much of the standardization work regarding the elements and the periodic table fell to two commissions within the IUPAC's Inorganic Division.[9] The Commission on Atomic Weights, the continuation of the IACW, was responsible for the regular evaluation and dissemination of the atomic weights of the elements. It was also responsible for officially naming new elements until after World War II when that duty was shifted to the Commission on Nomenclature of Inorganic Chemistry (CNIC). The CNIC was responsible for the development, maintenance, and publication of rules relating to the names of inorganic substances, including the elements. The CNIC, in particular, was responsible for several major changes in the nomenclature of the elements and to the periodic table during the second half of the twentieth century.

This paper examines several episodes associated with these changes. The first set of changes regarded the elimination of alternate names for the elements, in which the CNIC opted for the adoption of "good names" over the wishes of chemists in France, the United States, and elsewhere (sections 2 and 3). The second set of changes occurred in the wake of new elements being synthesized in accelerators rather than being isolated from materials found in the earth. In their attempt to name these elements, the CNIC came up against the belief in the traditional right of discoverers to name that which they discovered (sections 4 and 5). The final set of changes examined in this paper are associated with the group numbering found on the periodic table. Although the use of A and B sub-group labels with the traditional Roman numeral group numbering was pedagogically useful, the CNIC insisted on changing the group numbers to resolve confusion that was perceived to be important for the chemical literature (sections 6 and 7). As I will show, these episodes reveal that the CNIC walked a line between uniformity and the allowance of difference as they persisted in making changes they believed were necessary to achieve order from confusion through standardized nomenclature.

2. THE NEED FOR INTERNATIONALIZED ELEMENT NAMES

The elements are the foundation of the periodic table. Their names are the cornerstone of inorganic chemical nomenclature, the basis on which the names of compounds, minerals, and other substances are derived. Standardized element names are the cornerstone of a common language for chemistry. Atherton Seidell (1878-1961),[10] a chemist with the U.S. Public Health Service, argued in 1929 that "one of the most urgently needed improvements is probably the unification of the names of the earliest recognized elements."[11] At that time, there were 80 known elements. Thirty-eight of those elements had the same names in English, French, and German, and all but five ended with the suffix *-ium*. Another 24 elements had names that differed only in spelling in the three languages. A further four elements were generally comparable and would be easy to modify for the sake of uniformity. The remaining 14 elements, however, had a great variety of names (Fig. 1). Chemists were required to learn all of these names in order to read the literature, particularly with regard to compounds.

Seidell surveyed 150 chemists who had attended meetings of the IUPAC and who were otherwise known to be interested in nomenclature matters.[12] He sent a letter outlining the advantages of having uniformity in chemical terminology, as well as a list of five questions regarding the unification of nomenclature in general and the unification of the names of the elements in particu-

Symbol	French name	German name	English name	Early name
Ag	Argent	Silber	Silver	Argentum
Au	Or	Gold	Gold	Aurum
C	Carbone	Kohlenstoff	Carbon	Carbon
Cu	Cuivre	Kupfer	Copper	Cuprum
Fe	Fer	Eisen	Iron	Ferrum
H	Hydrogene	Wasserstoff	Hydrogen	Hydrogen
Hg	Mercure	Quecksilber	Mercury	Hydrargyrum
K	Potassium	Kalium	Potassium	Kalium
N	Azote	Stickstoff	Nitrogen	Nitrogen
Na	Sodium	Natrium	Sodium	Natrium
O	Oxygene	Sauerstoff	Oxygen	Oxygen
Pb	Plomb	Blei	Lead	Plumbum
Sa	Etain	Zinn	Tim	Stannum
S	Soufre	Schwefel	Sulfur	Sulfur

Figure 1. The 14 elements with the greatest variety of names according to Seidell (1929).

lar. Among the questions Seidell asked was, "Will the advantages resulting from a unification of the names of the more common elements repay the effort to accomplish this end?"[13] More than half of the responses were opposed to the unification of the names of the elements. Among the reasons given were the belief that atomic numbers and internationalized symbols should be used rather than internationalized names, the belief that universal approval of new names would not be possible, as well as concern that confusion would result if the names of the most commonly known elements were to be changed and that relations between chemists and the public would be strained. The survey, Seidell concluded, showed "that efforts to improve the nomenclature of chemistry must be confined to new names and to the harmonizing of variations in usage which do not conflict with fundamental language differences."[14]

Seidell had also asked if a permanent international committee should be responsible for the formulation and promulgation of rules for chemical nomenclature. About two-thirds responded favorably to this idea and half of the survey respondents thought any standardization attempts should be handled by the IUPAC. In fact, the IUPAC Committee for the Reform of Inorganic Chemical Nomenclature was already at work. Their 1926 report noted that all of the "very diverse propositions" that had been submitted to date could be divided into roughly ten categories, none of which included the names of elements.[15] Draft rules were issued in 1940, although this draft was only published in Germany, Britain, and the United States. The aim of these rules was "the unification of Inorganic Chemical Nomenclature and the removal of names which are out of date or incorrect."[16] However, the names of the elements were not considered. This was because the IUPAC Committee on Atomic Weights was in charge of naming new elements. It was not until after World War II that the responsibility for element names was shifted to the Commission on Nomenclature of Inorganic Chemistry (CNIC).[17]

A more comprehensive set of nomenclature rules for inorganic chemistry was developed in the early 1950s. Before the 1951 IUPAC meeting in New York City, a chemical nomenclature symposium was held at which several members of the CNIC presented papers. These papers reflected many of the same views that Seidell's survey brought to the fore. Henry Bassett (1881-1965) noted that it was desirable for nomenclature to differ as little as possible as chemistry was an international pursuit. But he also allowed that some differences were inevitable, particularly in areas "where chemistry touches the lives of people," as in the case of commonly used elements such as silver or lead.[18] Kai A. Jensen (1908-1992), on the other hand, saw "no fundamental reason for not introducing a much more radical unification of chemical terms."[19] Reaching a middle ground between these two perspectives would be the task of the CNIC when it came to the naming of the elements, both old and new.

3. ELEMENTS WITH MORE THAN ONE NAME

The CNIC held their first post-war meeting in London in 1947 where they returned to the draft rules that had been drawn up in the late 1930s. They recognized that "a prerequisite of any international system of nomenclature was the acceptance, in all countries adhering to the Union, of the same list of names and (particularly) symbols for the elements themselves."[20] Towards this end, they resolved to obtain a set of symbols for the elements that was internationally acceptable. They also asked that the responsibility of naming new elements should be shared by the Commission on Atomic Weights and by the CNIC.[21] This was an important step in the process of harmonizing the names of all of the elements.

Much of the discussion at the CNIC's 1949 meeting in Amsterdam revolved around the names of elements. The CNIC recommended names for eight recently discovered or synthesized elements (Fig. 2). They also recommended names for six elements that were known by more than one name (Fig. 3).[22] Little controversy was expected at the recommendation for three of the elements. Element 91 was known as both protoactinium

Atomic Number	Name & Symbol
41	Technetium, Tc
61	Promethium, Pm
85	Astatine, At
87	Francium, Fr
93	Neptunium, Np
94	Plutonium, Pu
95	Americium, Am
96	Curium, Cm

Figure 2. Newly synthesized elements named by the CNIC in 1949.

Atomic Number	Official Name (1949)	Alternate Name
4	Beryllium	Glucinum
41	Niobium	Columbium
71	Lutetium	Cassiopium
72	Hafnium	Celtium
74	Wolfram	Tungsten
91	Protactinium	Prototactinium

Figure 3. Elements whose names were changed by the CNIC in 1949.

and protactinium, and it was decided that protactinium was more convenient. Element 72 had been known as both hafnium and celtium. Although the differing names were the result of a now settled priority dispute,[23] hafnium was the more generally accepted name. Element 71 also had two names stemming from a resolved priority controversy,[24] lutecium and cassiopium, but lutecium was more widely used. The CNIC changed the spelling from lutecium to lutetium.

The CNIC anticipated that the remaining three elements would be more controversial. The first of these three elements was element 4, which had been known as glucinium, glucinum, and beryllium. The conflicting names were the product of a tangled history, as well as a question of priority and a conflict in language.[25] Glucinium fairly quickly fell out of use in favor of glucinum, which was used in both English and French. Germanic languages tended to use beryllium. The two names coexisted fairly peaceably although the question of which should be used was regularly raised at the turn of the twentieth century. The American Association on the Spelling and Pronunciation of Chemical Terms approved the use of glucinum, largely on the basis of priority, but despite the decision it was still a matter of debate in the United States and elsewhere.[26] In 1949, the CNIC recommended the use of beryllium. By this time the name was widely accepted although glucinum continued to be used in French-language journals into the 1980s.

Element 41 was the second element with multiple names that the CNIC felt could be controversial. It was known as both columbium and niobium. This element also had a somewhat complicated history and both names co-existed for many years.[27] In 1913, the IASC, the IUPAC's precursor, endorsed the name niobium.[28] This decision did not go over well in the United States as the mineral in which the element had been discovered, columbite, was found in America. The English chemist who isolated the element named it columbium, after Columbia, a historic as well as poetic name for America (Fig. 4). The CNIC likewise recommended the use of niobium in 1949 with a similar outcry from American chemists. Evan J. Crane (1889-1966), an American member of the CNIC, argued that cooperation was more important than selfishness and noted, "Our French colleagues made a similar concession in giving up 'glucinum' in favor of 'beryllium.'"[29] Much like their French colleagues, American chemists were reluctant to give up the name columbium and it continued to be used for many years after the 1949 recommendation.

The last of the three elements that was thought to be controversial was element 74. It had been known from the late eighteenth century as both wolfram and tungsten. Wolfram was generally preferred in Germanic and Scandinavian countries while other countries preferred to use tungsten, although here, too, there were priority issues.[30] The first attempt to harmonize these names was undertaken by the CNIC in 1949. They recommended the use of wolfram, although they allowed that tungsten could be used for commercial purposes. There were

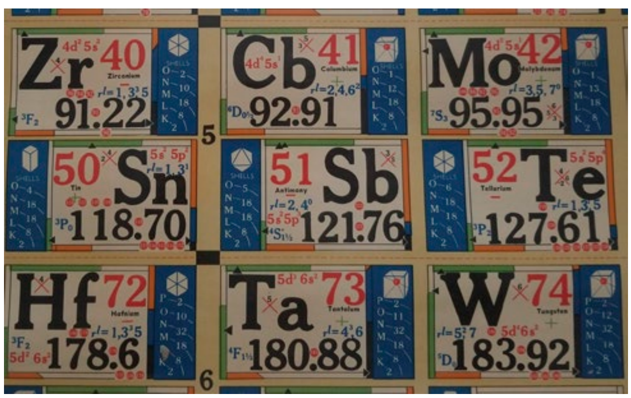

Figure 4. Detail from the 1947 edition of the Periodic Chart of the Atoms (Welch Scientific Company) showing element 41 with the name columbium, as well element 74 with the symbol W and the name tungsten (Photo taken by the author; table in author's personal collection).

objections to this recommendation and the matter was taken up again at the 1951 meeting. An erroneous report appeared in the press that the CNIC was abolishing the use of tungsten which "provoked a storm of protest from all over the world."[31] Although no other recommendation was made, future editions of the rules for inorganic chemical nomenclature almost exclusively used the name tungsten, albeit with the symbol W which required a note explaining its origin.[32] Protests, however quiet, continued to be made. It was not until 2009 that the IUPAC's Division on Chemical Nomenclature and Structure Representation[33] declared that "the case was now closed" – tungsten was the only recommended name for element 74.[34]

There was a traditional belief that the person who discovered an element was the person to name it, therefore the name chosen by the person with priority should be the one used. However, the names chosen by the CNIC did not always follow this tradition, one reason why the alternate names for elements 4, 41, and 74 continued to linger after the 1949 recommendation. One of the important – and controversial – stances taken by the CNIC in 1949 was antithetical to this tradition. No importance was placed on priority, rather, as Bassett, the CNIC chair, stated at the time, "a good name was always preferable to a bad one."[35] (What constituted a "good" name was not explained.) This decision was enshrined as a part of Rule 1.12 in the official *Nomenclature of Inorganic Chemistry*: "It should be emphasized that their selection carries no implication regarding priority of discovery."[36] The CNIC would fall back on this rule frequently in the following decades as they struggled to prevent confusion in element names while confronted with discoverers demanding their traditional right to name their discovery.

4. THE CHALLENGES OF SYNTHETIC ELEMENTS

The first official inorganic nomenclature rules, known as the Red Book, were published in 1957. At the same time, the CNIC was faced with new challenges as a result of the discovery of new synthetic elements. These elements were different in several ways. In regard to nomenclature, a new trend arose in naming elements after people rather than after characteristics, places, or mythological figures, which created new difficulties in standardizing names across languages. Scientifically, these elements were different as they were created in accelerators. As the elements get heavier, it becomes possible to create only one or a handful of atoms at a time. They had very short half-lives. They were generally detected through physical rather than chemical methods. Although there were only a handful of laboratories in the world that synthesized new elements, they frequently criticized each other's discoveries, leading to priority disputes. The CNIC's stance that element names had no implication regarding priority of discovery was put to the test.

With the increasing importance of physics in the detection of new elements, the IUPAC would need to cooperate with the International Union of Pure and Applied Physics (IUPAP). Similar to the IUPAC, the IUPAP was founded in 1922 to promote international cooperation in physics; create standards in the areas of symbols, units, and nomenclature; and prepare and publish tables of physical constants and abstracts of papers.[37] The IUPAP has a Commission on Symbols, Units, Nomenclature, Atomic Masses, and Fundamental Constants (SUN-AMCO), founded in 1931, who also publishes a so-called Red Book that provides authoritative guidance on the matters in its name.[38] Despite its interest in nomenclature, the responsibility for the naming of new elements resides with the IUPAC, not the IUPAP. However, due to the IUPAC's lack of expertise in physics, a series of joint working groups was instituted to deal with the priority issues arising from the discovery of new synthetic elements.

The first synthetic element that would highlight the IUPAC's lack of expertise was element 102. At their 1957 meeting in Paris, the CNIC received word from the Nobel Institute in Stockholm that a new element had been synthesized. Element 102 was the result of a collaboration between Argonne National Laboratory in the United States, the Harwell Atomic Energy Research Establishment in England, and the Nobel Institute. The meeting minutes reflect a sense of excitement at the news, as well as a sense of urgency.[39] If the report could be confirmed while the CNIC was meeting, the proposed name could be considered immediately rather than waiting until their next meeting two years hence. The Nobel Institute was contacted and news reports of the discovery were confirmed. The name, nobelium, was approved for element 102.

The hasty naming of element 102 was unfortunate. When the Commission on Atomic Weights had been in charge of naming new elements, they had waited to accept an element until a measurable amount had been separated and its atomic weight determined, a process that could take years.[40] The CNIC, however, did not wait for another lab to reproduce and confirm the Nobel Institute's results. In 1963, they were informed by Glenn T. Seaborg (1912-1999) that his group at the Lawrence Berkeley Laboratory (LBL) in the United States had been unable to reproduce the Stockholm results. However, they had been able to synthesize a different isotope of element 102 and therefore objected to the use of the name nobelium. The CNIC reiterated Rule 1.12 and suggested that as the name nobelium was already in use, it would remain.[41] They were in part concerned that a change in element names could cause confusion, particularly for indexing services as *Chemical Abstracts*, but they also did not want to set a precedent that element names could be changed upon request.

In 1968, the CNIC learned that Georgi N. Flerov (1913-1990) and his group at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, had obtained different isotopes of element 102 and called into question the results of both the original experiment in Stockholm and the LBL experiments. At their meeting in Copenhagen that year, the CNIC "unanimously decided that it could not re-open discussion concerning the name of an element on which a definitive decision had already been taken." They again reiterated Rule 1.12, that an element's name had little to do with priority of discovery. The CNIC also noted that priority could be difficult to determine and, as a nomenclature committee, they "had no special competence to judge" in matters of priority. [42] In short, determination of priority was not a matter of nomenclature.

Element 102 was not the only element whose discovery was under dispute. In 1961, LBL announced the discovery of element 103. The CNIC confirmed the suggested name, lawrencium, at their meeting in Brighton in 1963. But again in 1968, JINR announced that the results obtained at LBL were incorrect and that they had discovered element 103, for which they suggested a different name. The CNIC received this notification during their meeting in Copenhagen and their stance on the name of element 102 was also applied to the situation with element 103. The name lawrencium was reconfirmed.[43]

Another issue arose when the name for element 103 was proposed by LBL in 1963. The name lawrencium was derived from Ernest O. Lawrence (1901-1958), the founder of LBL and the inventor of the cyclotron. The proposed symbol for lawrencium was Lw. Heinrich Remy (1890-1974), a member of the CNIC, observed that the letter w was "an uncommon letter in many languages and difficult to pronounce." He suggested that the spelling of the lawrencium be changed to laurentium. After discussion, Jensen, the chair, remarked that they had "no right to modify the spelling" of a proper name but in order "to make the name more acceptable," the symbol was changed from Lw to Lr.[44]

This was not the first element for which the symbol was modified. In 1955, the CNIC approved the name mendelevium for element 101 with the symbol Mv, after Dmitrii Mendeleev (1834-1907). At the 1957 meeting in Paris, however, the CNIC voted to change the symbol to Md. No reason was given in the minutes, but as later explained this was done because "it is not customary to choose one of the last letters of the name as the second letter of a two-letter symbol" and because not all transliterations of Mendeleev's name use the letter v.[45] Another element whose proposed symbol was changed was element 99. The name einsteinium was proposed, with symbol E, after Albert Einstein (1879-1955). At their meeting in Reading in 1956, the CNIC approved the name but expressed concern at having an element with a single letter symbol. Two letter symbols were preferred so as to avoid any confusion with the symbols of physical quantities.[46] They suggested the symbol Es and it was officially recommended at the 1957 meeting.

The challenges faced by the CNIC in regards to the names and symbols of new synthetic elements were the result of several factors. One was the desire for a truly global chemical nomenclature. Although standardization was the goal, the realities of language could put the achievement of that goal into question. The increasing use of personal names as the basis for element names, such as those of Lawrence and Mendeleev, prevented the ability of the CNIC to attain true standardization for both element names and symbols. Another factor was the insistence of discoverers exercising what they perceived to be their traditional right to name the element they discovered. Competing names offered by competing laboratories was a step back from the harmonization in element names the CNIC began to achieve in 1949. Although the CNIC reiterated Rule 1.12, their insistence that names had little to do with discovery was a roadblock on the path to a standardized nomenclature.

5. THE TENSION BETWEEN CHEMISTRY AND PHYSICS

Elements on the periodic table have only one name and symbol. Even those elements that have lingering alternate names, such as wolfram and tungsten, are shown with only one name and symbol. The CNIC had refrained from renaming elements 102 and 103 when new claims about their discovery were reported, citing the confusion that could be caused by changing their names. In reiterating Rule 1.12, they reinforced their position that element names had little to do with priority of discovery. However, elements 104 and 105 presented a new test of their resolve as the discoverers frequently

– and increasingly publicly and vitriolically – presented their claims while denigrating the claims of others.[47]

The first claim for the discovery of element 104 came in 1964. Flerov's group at JINR announced they had identified an isotope of element 104 but found it "quite desirable to conduct chemical experiments for additional identification."[48] This announcement was followed in 1966 by publication of chemical studies of element 104. Flerov then sent a letter to the IUPAC claiming the discovery of element 104 and suggesting a name, kurchatovium. This name was in honor of Igor V. Kurchatov (1903-1960), who was widely regarded as the founder of the Soviet atomic bomb program and had recently passed away.

The group at LBL was also attempting to synthesize element 104. They had not been able to confirm the results of JINR's experiments but, after running a different experiment, announced in 1969 they had synthesized two isotopes of element 104.[49] A name was not proposed in the initial announcement, however in a paper given at the Welch Foundation Conference later that year, Albert Ghiorso (1915-2010) proposed the name rutherfordium in honor of Ernest Rutherford (1871-1937), "the great pioneer of nuclear science."[50] Ghiorso and the LBL group then notified the CNIC of this suggestion. Ghiorso's letter also included the news that LBL had discovered element 105. They proposed the name hahnium, in honor of German chemist Otto Hahn (1879-1968).[51] In much the same manner, Flerov's group wrote to the CNIC in the summer of 1969 announcing they had discovered element 105. They proposed to name the element after Niels Bohr (1885-1962).[52] Though they left the name and symbol unspecified at the time, they later suggested nielsbohrium (Fig. 5).

This situation was not tolerable to the CNIC. An element having two unofficial names in use ran contrary to the goal of a standardized international chemical nomenclature. The use of multiple names for these new elements was a potential source of confusion, not only in publications but also in indexing. At their 1969 meeting in Cortina d'Ampezzo, they had discussed the matter with the Commission on Atomic Weights. The CNIC ultimately recommended that elements should not be named for a period of five years after the initial announcement of their discovery. This would allow for confirmation of the discovery to occur, preferably at another laboratory and in another country.[53] The CNIC also once again reiterated their position on element names having little to do with priority of discovery.

At the 1968 meeting in Copenhagen, the CNIC had raised the possibility of a systematic nomenclature for the elements. This would, they believed, end the "needless controversy" that had arisen.[58] The idea was again raised in 1969. At the 1971 meeting in Washington, D.C., it was unanimously recommended that a systematic nomenclature be devised for elements beyond 105. (They still hoped that LBL and JINR would solve the problems regarding elements 104 and 105 themselves.) This systematic nomenclature was to be a numerically derived system based on atomic number.[55] With this nomenclature in place, all elements claimed to have been discovered would have a name ready to be used until priority could be determined and a new name proposed by the discoverer (Fig. 6).

In 1971, the CNIC chair W. Conard Fernelius (1905-1986) wrote a position paper on the naming of the elements. It began, "Communication among chemists and between chemists and other professionals has been greatly aided through the years by the existence of a logical, systematic, and generally agreed-upon nomenclature practice." However, there were still "real problems that require the vigilance, vision, and persuasion of nomenclature committees and commissions to establish order in their use, to secure agreement among users and to avoid duplicate names and patterns."[56] It was by these means that a common language for chemistry would be achieved, a part of which was the recognition of a single name for each element.

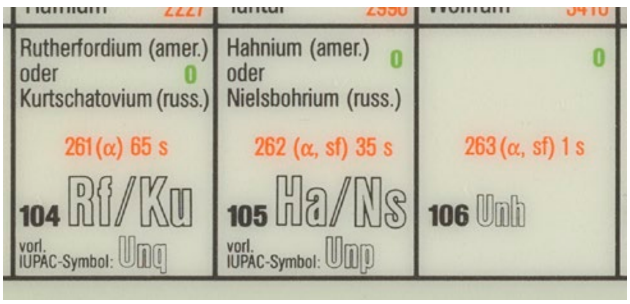

Figure 5. Detail from a 1985 German periodic table (VCH Verlagsgesellschaft) showing multiple names for elements 104 and 105 (Original courtesy of the Science History Institute, Philadelphia, PA, https://digital.sciencehistory.org/works/k3569525k).

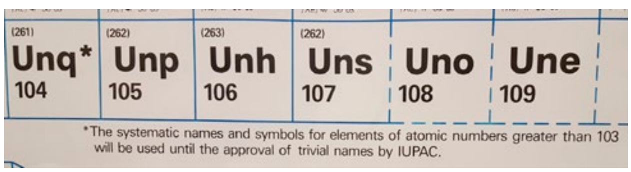

Figure 6. Detail from a 1988 periodic table wallchart (Central Scientific Company) showing the IUPAC systematic nomenclature for elements with an atomic number greater than 100 (Photo taken by the author at Wellesley College, September 2016).

A systematic nomenclature ensured that names be ready for use upon discovery, preventing the use of multiple, unofficial, names in publications as well as in indexing services such as *Chemical Abstracts*. It had long been acknowledged that these services were vital to chemists. The development of a standard international nomenclature was meant, in part, to facilitate their creation and use. Among the responses Seidell had received to his survey in 1929 were recommendations for the use of symbols and Latin names for the elements, amid other suggestions, in indexes and compendia if names could not be harmonized (see Section 2).

The systematic nomenclature was a major topic of discussion at the CNIC's meeting in Munich in 1973. They agreed that the names used should be short, related to atomic number, and end in the suffix *-ium*, while the symbols should be three letters rather than the usual two. The names would be derived from a standard set of numerical roots, based on a mixture of Latin and Greek on the grounds that they were easily recognizable by chemists.[57] Thus, for example, the name of element 106 would be Unnilhexium (un + nil + hex) with the symbol Unh, and 116 would be Ununhexium (un + un + hex) with symbol Uuh. The system was able to accommodate elements up to number 999. Although this system would be in place, the CNIC did not want to deny the right of discoverers to name new elements.[58]

Although there was no expectation that the systematic names for elements 101 through 103 would be used, the CNIC's system was expanded to begin with element 101 after a "virtually unanimous" vote by the Bureau, one of the IUPAC's executive bodies.[59] The systematic nomenclature was eventually published as an official IUPAC Recommendation in 1979.[60] Even then the system was not welcomed. The IUPAP's SUN-AMCO commission expressed dismay that its proposal, as well as that of the IUPAP's Commission on Nuclear Physics, were seemingly not taken into consideration by the CNIC. Both preferred a system in which the atomic number took the place of a lettered symbol.[61]

In a letter regarding another controversy (see sections 6 and 7), one chemical educator wrote, "I don't really care if all the new elements are named after Soviets, Germans, or Martians, so long as they are named after someone, someplace, or something."[62] Chemical and physical researchers described the systematic nomenclature as "artificial and ugly" and "utterly ridiculous," and one physicist commented that he doubted anyone would use it.[63] This may not have been the reaction the CNIC was hoping for when they developed the systematic nomenclature. However, it served its intended purpose. Elements that were claimed to have been newly discovered had placeholder names that allowed them to be discussed in the literature and located in indexing services and reference works without the confusion of multiple names.

The systematic names avoided the appearance of official acceptance of one discovery claim over another. In order to solve the priority disputes over the synthetic elements, a joint IUPAP-IUPAC group, the Transfermium Working Group (TWG), was formed in 1986 at the behest of the IUPAP. The TWG formulated a set of criteria that needed to be satisfied in order to determine if an element had been developed and then applied those criteria to the claims for elements 101 through 109.[64] Once discovery had been assigned by the TWG, discoverers were asked to suggest names and symbols to the CNIC for official approval. By way of the systematic nomenclature and the creation of the TWG, the CNIC adroitly escaped from adjudicating discovery claims and instituted a standardized chemical nomenclature that furthered their goal of a common language for chemistry.

6. CONFUSION IN GROUP NUMBERING

The names and symbols of the elements are one of the important aspects of the periodic table. Another is the group numbers which run across the top of the table, one number for each column. Group numbers are used to refer to a set of elements which have similar characteristics and propertiers. These group numbers have been the subject of confusion for many years. Until the 1980s, most group numbers on periodic tables consisted of eight Roman numerals, with some of these having sub-group labels of A and B, such IIIA or IVB. These labels were considered an important pedagogical device as they made a clear distinction between main group elements and the transition elements. The main, or major, group elements comprise the s-block and p-block, referring to their electron configuration. The transition elements, often called the transition metals, comprise the d-block. Without A and B sub-group labels on a periodic table, the distinction would need to be made through the use of mnemonics or a visual cue, such as different colors as seen in Fig. 7.

The periodic table developed by Horace G. Deming (1885-1970), first published in 1923 and widely adopted in the following decades, gave the main group elements the sub-group label A and the transition elements the sub-group label B. Another popular table in the United States, the Periodic Chart of the Atoms, created by

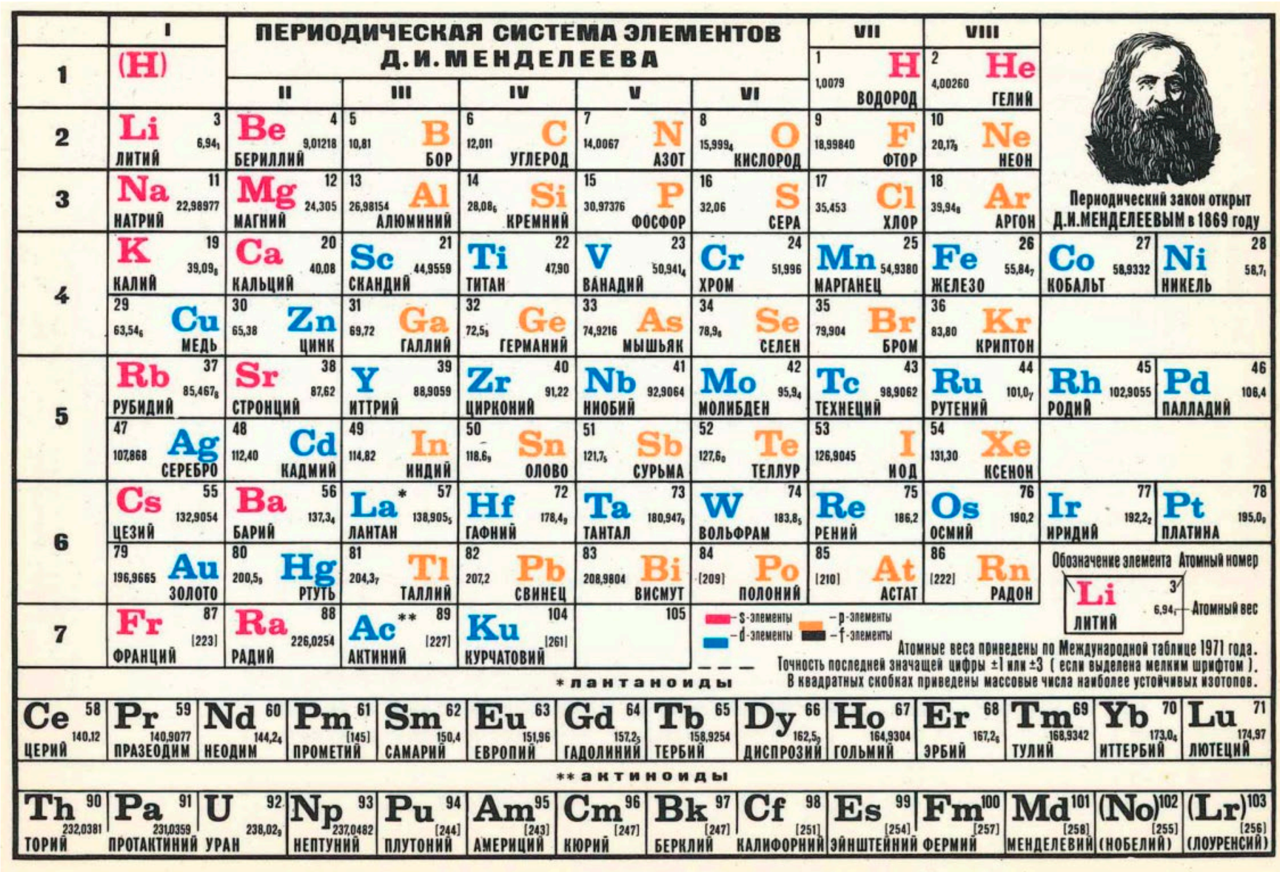

Figure 7. A Russian short-form periodic table that uses colors to denote the elements belonging to different blocks (Khimia, Moscow, 1987) (Photo taken by the author; table in author's personal collection).

Henry D. Hubbard (1870-1943), gave the sub-group labels in the opposite manner of Deming.[65] Unlike Hubbard's table, many short-form tables popular in the Soviet Bloc as well as in Europe well into the 1960s, did not use the A and B labels. When the long form table began to become popular in Europe, the A and B subgroup labels were applied somewhat arbitrarily. A survey of publications found that "in more than 10% of the articles it was nearly impossible, from the wording of the text, to recognize which elements were being discussed."[66] Confusion could also be caused in the classroom. British chemist Joseph Chatt (1914-1994) noted of wall charts purchased from American companies, "In England students are usually told that the chart is wrong and in some Universities I have seen sticky labels with the correct sub-group numbering stuck over the [other] numbers."[67]

Early on, in 1958, the question of group names was first raised by Lamberto Malatesta (1912-2007), a member of the CNIC. The first edition of the Red Book had been sent to the publisher and it was too late to make any changes. It was decided to consider the question for the second edition, work on which was just beginning.[68] At their next meeting in Munich in 1959, the CNIC discussed the topics of the form of the periodic table, the confusion in group numbering, the need for a definition of transition elements, and the group names used for the rare earth elements. It was decided that "no firm rules should be laid down" but nonetheless the CNIC should issue a statement. A small sub-committee was appointed to examine these matters and make a recommendation regarding the use of A/B sub-group labels and group names for the elements.[69]

K. A. Jensen, a member of the sub-committee, prepared a report on these issues. The majority of this report – six of the eight pages – concerned solely the form of the periodic table. He stated: "There are so many types that a standardization seems highly desirable. Even if the commission can not *[sic]* agree on one standard table we could perhaps agree on a small number of different tables which could be recommended for different purposes."[70] The report then examined three main

The Periodic System of the Elements.

		I Group.	II Group.	III Group.	IV Group.	V Group.	VI Group.	VII Group.	VIII Group.		
H-Compounds. Highest salt-forming oxides.		— M_2O	— MO	— M_2O_3	MH_4 MO_2	MH_3 M_2O_5	MH_2 MO_3	MH M_2O_7	MO_3	MO_2	(M_2H) MO
Periods.	Series.										
1st	1st	H 1 Li 7	Be 9	B 11	C 12	N 14	O 16	Fl 19			
2d	2d	Na 23	Mg 24	Al 27	Si 28	P 31	S 32	Cl 35.4			
3d	3d	K 39	Ca 40	Sc 44	Ti 48	V 51	Cr 52	Mn 55	Fe 56	Co 58	Ni 58
	4th	Cu 63	Zn 65	Ga 70	— 73	As 75	Se 79	Br 79.7			
4th	5th	Rb 85	Sr 87	Y 89	Zr 90	Nb 94	Mo 96	— 100	Ru 104	Rh 104	Pd 106
	6th	Ag 108	Cd 112	In 113	Sn 117	Sb 120	Te 126	I 126.5			
5th	7th	Cs 133	Ba 137	La 139	(Ce 140	Di 142)	—	—	—	—	—
	8th	—	—	—	—	—	—	—			
	9th	—	—	Yb 173	—	Ta 182	W 184	—	Os(195)	Ir 193	Pt 195
	10th	Au 197	Hg 200	Tl 204	Pb 206	Bi 210	—	—			
		—	—	—	Th 232	—	Ur 240	—			

Figure 8. Von Richter's Periodic Table (1885) which used no A/B sub-group labels.

types of tables: short tables with eight groups and no sub-groups, short tables with sub-groups, and medium and long tables. Jensen concluded that "the most satisfactory – I should even say the only satisfactory – periodic system is a slightly modified form of the old von Richter table."[71] The table used in Victor von Richter's (1841-1891) popular nineteenth century textbook was a short-form table with no sub-groups (Fig. 8).[72]

The sub-committee discussed this report at a meeting in Elsinore in 1962. It was agreed to begin with "the least controversial matters" and move towards the most controversial. Given that the majority of the report was about the form of the periodic table, the minutes do not reflect any discussion of which, if any, forms should be recommended as a standard. There was a decision that the inert gases should be on the left-hand side of the table as Group 0, although placing them on both sides would be permissible. The committee also agreed to accept the neutron as the first element, with atomic number 0, and placed in Group 0 with the inert gases. A definition of transition elements was agreed upon, as well as names for the rare earths series.[73]

It was decided to use sub-group labels A/B. These sub-groups would apply only to periods 4 through 7. In order to prevent confusion, the first of the sub-groups in each group was to be given the label A while the second would be B. Sub-groups labeled A were those headed by the elements K, Ca, Sc, Ti, V, Cr, and Mn. Sub-groups labeled B were those headed by the elements Cu, Zn, Ga, Ge, As, Se, and Br.[74] These A and B groups would become the ones officially recommended in the IUPAC Red Book.[75]

A sample table was drawn and the sub-committee chair asked the members to privately inquire if the table would be acceptable. This was a standard practice for the IUPAC nomenclature commissions who preferred to "test the water" before issuing official recommendations.[76] In this case, it was a particularly prudent precaution. Some reactions to the proposals were moderate. Marguerite Perey (1909-1975) agreed with the placement of the inert gases on the left-hand side but questioned the inclusion of the neutron in the periodic table.[77] Kazuo Yamazaki (1911-2010) presented the thoughts of Japanese chemists who likewise were against the inclusion of the neutron but were divided over the location of the inert gases, they also believed that the placement of the A and B sub-group labels within the sample table needed further consideration.[78]

The Chemical Society relayed the comments of British chemists to the CNIC. Their comments focused more on the form of the sample periodic table that was enclosed with the sub-committee's recommendations. Their reactions ranged from astonishment to dread. The Chemical Society argued that all chemical education was based on the long-form table, not the short-form which was considered to be obsolete.[79] As one British chemist put it, "if we must have a party line about the Periodic Table, let us at least base it on the ideas of 1963, and not those of 1863."[80] Another was less sanguine, stating he had read the proposals "with a feeling little short of complete horror" and was distressed to find the IUPAC recommending a return to the short-form table.[81]

There was nothing in the nomenclature sub-com-

Recommended Format for the Periodic Table of the Elements

1	2	3d	4d	5d	6d	7d	8d	9d	10d	11d	12d	13	14	15	16	17	18
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
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac**															
3f		*Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
		**Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		

Figure 9. Periodic Table recommended by the ACS in 1984 (Courtesy of the American Chemical Society).

mittee's proposals about the form of the periodic table. However, they sent only one sample table and it was a short-form. Many asked to comment on the proposals justifiably assumed the committee was recommending that specific form of the periodic table. Chatt, member of the sub-committee, stated that he strongly recommended a long-form table be used to illustrate their proposals as it was "so much more useful in teaching chemistry that we should take care that we do not create the impression that the short form has I.U.P.A.C. preference."[82] Despite this warning, he was voted down.[83]

At their 1963 meeting in Brighton, the CNIC discussed the sub-committee's proposals as well as the responses that had been received. After deliberations, they decided that whether or not the neutron was an element was a matter of definition rather than nomenclature, so it was dropped. It does not seem they discussed the position of the inert gases in the periodic table. Following some discussion, they recommended that if subgroup labels A/B were used, they should be capitalized. Otherwise, the CNIC decided they did "not wish to encourage the use of these letters or of any particular form of the Periodic Table."[84]

The second edition of the Red Book was issued in 1970. It included a recommendation for sub-groups for those who wished to use them, but no recommendation that they must be used. There is no mention of the form of periodic table nor is there a periodic table printed anywhere in the text.[85] The reactions of chemists, particularly those who were educators, were likely a shocking and unwelcome surprise to the CNIC. In response, the minutes of their 1975 meeting in Santiago de Compostella contain a statement that it is "desirable" that a periodic table "portray groups, periods of differing lengths, A and B subgroups, transition elements, and the accepted chemical families." A "policy decision" reflected their new belief that, "Approval of an[y] particular form of the periodic table is not a problem of nomenclature."[86]

7. RENUMBERING THE GROUPS

The CNIC's recommendation for the use of A/B sub-group labeling had consequences they likely did not expect. Scientific supply companies in the United States took note of their recommendations and began selling periodic tables with the new recommended labeling. However, they placed these labels in a different place than usual, sparking even more confusion.[87] The Committee on Nomenclature of the American Chemical Society (ACS) attempted to solve the confusion and in 1984 approved a recommended format for the periodic table (Fig. 9). It was a long-form table with group numbers 1-18, groups 3-12 had a sub-label of *d* to denote the d-block elements, and the lanthanides and actinides below the table were given the label 3f.

This new table was published in the *Journal of Chemical Education* and in *Chemistry in Britain*,[88] where it sparked a series of letters about the use (or lack thereof) of A/B labels and the advisability of moving to the 1-18 group numbering. The chair of the Royal Society of Chemistry's Educational Publications Committee, wrote that they had "recommended that the RSC should not adopt the 18-group formulation."[89] Another letter writer expressed the hope that "all enlightened non-teaching members of the RSC will add their weight of protest along with the teachers."[90] A different writer had at first wondered whether "this was one of the more elegant spoofs perpetrated by the quality press on All Fools' Day," but he was disabused of that notion by checking the date and concluded, "There is no valid reason for falling into line with the ACS model and the IUPAC recommendation unless it really does aid learning and understanding and avoid confusion."[91]

A year later, a member of the CNIC, G. Jeffery Leigh (1934-), published a short article in *Chemistry International* that proposed the use of the long-form table with the group numbers 1-18.[92] Meanwhile, *Chemical & Engineering News* published a brief story titled, "Group notation revised in periodic table," that erroneously stated an IUPAC recommendation for the use of group numbers 1-18 was "working its way through IUPAC approval procedures."[93] This article also sparked a storm of letters.[94] One chemistry professor wrote, "Unfortunately, the recommended numbering system … represents a giant step backward from a pedagogical standpoint" as it destroyed the relationship between group number and atomic structure.[95] Another argued that, "This revision 'to remove ambiguities' between the U.S. and European practices seems to be one of those compromises in which chemical education in the U.S. loses – again."[96]

Reactions in other countries varied. The Portuguese Chemical Society requested more information "on the appropriateness of enforcing the new numbering scheme for the periodic table … in secondary school education," particularly "given the strong controversy that this IUPAC ruling has provoked."[97] In response, the chair of the CNIC, Daryle H. Busch (1928-), stated that the Ducth Ministry for Education "has advised the use of numbering scheme and has accepted it for state examinations" and the State of New York had done similarly. "The system appears to be well used in France … and in Sweden." Busch also noted that "special versions" of the periodic table using the 1-18 numbering had been published for display in Germany, the Netherlands, and the United States.[98]

One of the "special versions" was published in a German chemistry magazine which sparked astonishment in Klaus Brodersen (1926-1997), chair of the ADUC, a society of German chemistry professors. In a letter to *Nachrichten aus Chemie, Technik und Laboratorium* titled "Save the 8-Group Periodic Table," he stated, "The 18-group periodic table will certainly do a disservice to chemistry." He noted that "many rules of the behavior of the elements, which are easy to learn for every student, are now made more difficult or dull." This included the loss of relationships between valence and group numbers as well a variety of mnemonics.[99] Ekkehard Fluck (1931-), a member of the CNIC, and Karl Rumpf (1908-1997) laid out the case for the 18-group table and stated that it would be easy enough to create new mnemonics.[100]

The West German Deutscher Zentralausschuß für Chemie raised "a formal objection" to the 1-18 recommendation. The proposal, they wrote, "does not make sense and should be rejected since it will create great confusion in chemistry lessons."[101] This confusion would in part be due to a unique situation in West Germany. "While universities are usually free to use whatever nomenclature they want, schools in the Federal Republic are bound to follow IUPAC recommendations." This could potentially cause great confusion as students moved from elementary and secondary schools into universities where they would be confronted with an unfa-

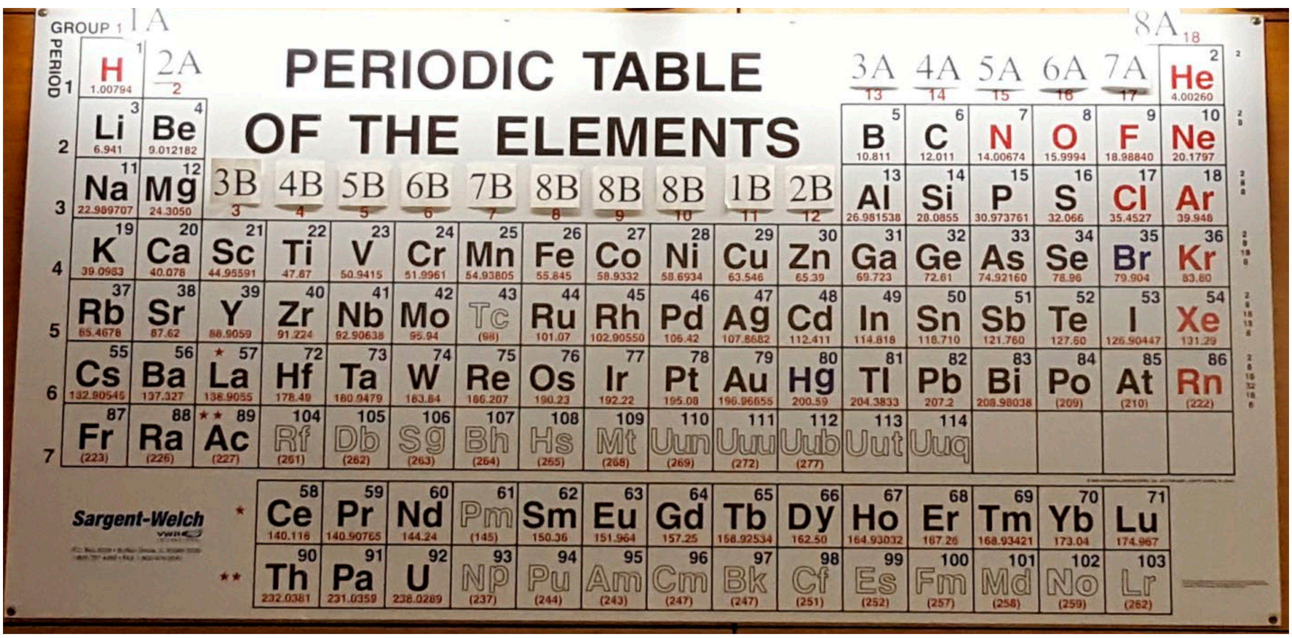

Figure 10. A periodic table wallchart (Sargent-Welch) on which the A/B group numbers have been taped above the 1-18 group numbers (Photo taken by the author at the University of Massachusetts Amherst, June 2016).

miliar group number system. Most textbooks would also need to be revised "because much information about chemical behaviour is usually inferred from the site an element occupies in an 8 group periodic system." Ursula A. Hofacker (? -) concluded that, "a recommendation of the Inorganic Nomenclature Committee to use both forms of the periodic system would be most desirable."[102]

The National Committee of Soviet Chemists strongly objected to the recommendation to drop the A and B sub-group labels and use group numbers 1-18 instead. Unlike the majority of countries, Russia and many members of the Soviet Bloc continued to use the short-form table. The table was considered to be an important part of Russian history, given the role played by Dmitrii Mendeleev in the discovery of the periodic law. The chairman of the National Committee wrote to the IUPAC president noting, "we feel it particularly important to keep table's traditional form … and to reject all groundless attempts to renounce the generally accepted … 8-groups form of periodic table." They also objected to the change on pedagogical grounds.[103]

As these letters were flooding into the chemical news magazines and the IUPAC, the CNIC was well underway with work on a new version of the Red Book. At their 1982 meeting in Paris, they unanimously agreed to the provisional dropping of the A/B sub-group labels. There was also an agreement for a system based on the long-form periodic table.[104] After the publication of the ACS recommended periodic table and the articles in both *Chemical & Engineering News* and *Chemistry International*, the IUPAC became alarmed by "the storm of concern" that ranged "from severe criticism, to tacit approval." The IUPAC president, Chintamani N. R. Rao (1934-), rather unusually wrote to the CNIC expressing his concern and wondering "how the problem will be settled." Further, Kazuo Saito (1923-1998), the president of the Inorganic Division, attended the CNIC meeting in Heidelberg in 1986 – also an unusual event – to impress upon them the importance of the issue.[105]

As most of the objections related to pedagogy, one way to "settle" the problem might have been for the CNIC to consult the IUPAC Committee on Teaching of Chemistry (CTC).[106] However, they apparently did not do so. In a letter to the IUPAC's Executive Secretary, David J. Waddington (1932-), the chair of the CTC, remarked on the "considerable disquiet" regarding the proposed 18-group periodic table. He had "received several unfavourable comments" at the most recent CTC meeting. Members, he said, "were concerned on two counts. One was on the elementary point about consultation within the IUPAC family. The second was on the difficulties foreseen in teaching the new form."[107] If the CTC's objections were made known to the CNIC, they were not enough to change their intentions to move ahead.

After extensive debate, the CNIC acknowledged "the reluctance of some users of the periodic table, mainly teachers" to drop the use of A/B labelling. However, they wished to bring an end to the confusion that was to be found in the literature and in indexing services. While they did not wish to "legislate," they noted that in many countries there was already a tendency to use the long-form table, thereby making the use of group numbers 1-18 easier.[108] As a result of this meeting, Busch, the chair of the CNIC, published an article in *Chemistry International* which laid out their reasons for the recommendation to use the 18-group periodic table. He noted that "it is neither the purpose nor the intent of CNIC arbitrarily to set the format of the Periodic Table to be used in all parts of the world," however, "it is a reasonable mission for CNIC to offer broadly useful solutions when direct conflicts in usage occur."[109]

In response to the many protests, the CNIC continued to state that they were not legislating the adoption of a particular form of the periodic table. Indeed, the new edition of the Red Book contained four periodic tables. The table on the frontispiece was a long-form table using the 1-18 group numbering. An appendix contained a short-form table that used the recommended A/B subgroup numbers, a long-form table that used both systems, and a 32-column table that also used both systems of numbering. The CNIC stated that "common worldwide practice in teaching and research overwhelmingly supports the eighteen-column format," however they "did not wish to deprecate any specific Periodic Table format."[110] Regarding A/B sub-groups, the text stated "this usage is to be avoided."[111] However, three of the four tables included in the appendix used this system.

The new edition of the Red Book was published in 1990 with little fanfare. An article was published in *Chemical & Engineering News* announcing its release[112] but unlike the article in 1985 about the periodic table, it was not followed by months of letters to the editor. That did not mean there was whole-hearted acceptance of the new numbering system. Scientific supply companies began printing periodic tables with group numbers 1-18 but a long tradition of educators modifying commercial products to suit their purposes continued. Much as English chemists had once placed sticky labels over the "wrong" group labels, some have stuck the old group labels orver or above the new 1-18 labels as in Fig. 10. Once again, the CNIC recommended uniformity to end perceived confusion while also leaving the door open for the continuation of difference.

8. CONCLUSION

One of the many letters published in the midst of the controversy over the use of A and B sub-group letters noted, "The progression of scientific thought toward worldwide unification of terms, as evidenced by the acceptance of SI units and IUPAC naming conventions, meets an obdurate foe when faced with the periodic table of the elements."[113] The IUPAC Commission on Nomenclature of Inorganic Chemistry (CNIC) ran into this obdurate foe in their attempts to further develop a common language for chemistry. As Fernelius had written in his position paper on the naming of elements, "vigilance, vision, and persuasion" was necessary for establishing order out of confusion. The episodes examined in this paper illustrate the persistence of the CNIC in walking the line between a radical unification of chemical terms and the inevitability of differences, a persistence that caused even the obdurate foe to give way.

This line was a difficult one when it came to the names of the elements. As the CNIC discovered when harmonizing the names of the elements after World War II, their perception of what constituted "a good name" was not necessarily welcomed. The lingering use of alternate names for elements 4 and 41 was a case of the inevitability of differences that eventually turned into the acceptance of standardization. The "storm of protest" over the name of element 74 – tungsten or wolfram? – on the other hand was an example of the inevitability of difference not gracefully giving in to the goal of unification.

The CNIC's insistence on divorcing priority of discovery from the naming of an element, Rule 1.12, engendered more than a storm of protest. In the face of decades of continual protest from Berkeley and Dubna demanding that the traditional right of discoverers be upheld, the CNIC persisted in putting off making decisions they argued were not matters of nomenclature. In response, they developed a systematic nomenclature for elements with an atomic weight greater than 100. Although this system was met with scorn by chemists and physicists alike, the recommendation was welcomed by indexing services such as *Chemical Abstracts* and found its way onto periodic tables worldwide.

The protests that arose of the change of group numbering were perhaps more contentious than those over the naming of synthetic elements. The non-standard use of the A and B sub-group labels were perceived by the CNIC to be a source of confusion, one that could be readily solved by the use of standardized nomenclature. They did not seem to realize the pedagogical importance of the labels, even if they were not standard across the world, and when faced with protest, they did not consult within the IUPAC family. The Committee on Teaching of Chemistry could have been a source of information, if not a partner in how best to approach a change, but even their objections went unheeded. And again, despite the protests that arose, the CNIC was successful in walking the line between radical unification and allowing difference.

On the whole, as these episodes illustrate, the periodic table and the elements were an "obdurate foe" but one that gave way to persistence. Their belief in the power of standardized nomenclature to resolve perceived confusion allowed the CNIC to persevere in the face of protests from multiple directions. In the end, they were responsible for changes to the periodic table and the nomenclature of the elements that advanced the goal of developing a common language for chemistry based on "the existence of a logical, systematic, and generally agreed-upon nomenclature practice."

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