The Periodic Table: An Eight Period Table For The 21st Centrury

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Abstract: Throughout most of the 20th century, an eight-period periodic table (also known as an electron-configuration table) was offered as an improvement over the ubiquitous seven-period format of wall charts and textbooks. The eight-period version has never achieved wide acceptance although it has significant advantages. Many observers have questioned the way helium is displayed in this format. Now, a reinterpretation of the relationship of the first-period elements to successive elements may help make the eight-period table an attractive choice for the 21st century.

The Eight-Period Periodic Table: An Improved Display of the Elements

The periodic table of textbooks and wall charts is used in classrooms and laboratories around the world. This familiar format, which we designate the seven-period table, (Figure 1) has become the standard periodic table for the natural sciences despite the fact that it has serious shortcomings, both theoretical and pedagogical. By rearranging the table, (as shown in Figure 2) we can create a different format (Figure 3), which is both modular and algorithmic, that is, one which follows a mathematical plan of construction based on quantum principles and the electronic configuration system. We designate this version the "eight-period table".

The table in Figure 1 does not follow a regular plan; by logical extension one would assume that a table with an algorithmic base (Figure 3) is more desirable. While this viewpoint makes sense, it has also proved to be naive. Over the last seventy years, beginning perhaps with Deming's 1932 long table, a core band of loyal defenders has solidified around the seven-period version. As a result, students nowadays seem to be totally unaware that it is both logical and possible to present the periodic table in a form that is completely consistent with the system of electronic configuration, the eight-period system. Papers advocating the eight-period table have long since been buried in the literature; writers of today seem to be either unaware of them or unwilling to acknowledge them. For example, a recent review of periodic-table literature by Scerri [1] ignored all contributions by supporters of the eight-period plan, including the exhaustive study of Mazurs [2]. Scerri implies that there is no causal relationship between periodic structure and the well-known system of electronic configuration of atoms based on the work of Bohr. Other writers, like Emsley [3], have reinforced this viewpoint with statements like "it is not possible to place the elements in…tables based on electron shells;" likewise, Scerri [1] observes that "quantum mechanics cannot explain the periodic table."

In the quarter century since the appearance of Mazur's book, no new papers in support of an eight-period system have been published, yet the review of van Spronsen [4] is referred to often. van Spronsen, of course, supports the traditional system, while Mazurs favors an eight-period revision. Scientific journals have apparently been loath to accept any recent comment on the subject, despite the need for a fresh dialogue. This is partly due to the lack of new evidence to bolster the cause of the eight-period table and partly to the conviction of editors and reviewers that the discussion of the format of the table is over, as if the case were closed.

Structuring the Eight-Period Table

Upholders of the seven-period tradition object to the way helium is displayed at the top of group two. This has admittedly been a great stumbling block toward acceptance of the eight-period format, unless one is willing to ignore empirical chemistry altogether and resort to a purely quantum-chemical viewpoint. The relationship of hydrogen (Z = 1) and helium (Z = 2) to successive elements and to the structure of the table itself is worth analyzing. Traditionally, these elements are visualized in the context of terrestrial chemistry, as we normally encounter them on earth. If, however, the empirical basis of the periodic table is broadened to include cosmic helium and hydrogen, then a plausible case can be made in support of this move, thus weakening the main objection to an electron-configuration table of eight periods. We contend that rearranging the table in this way is advantageous to the understanding of periodicity. Justifying the transfer of helium is critical to the reorganization that follows.

The eight-period table is organized into the quantum orbitals, s, p, d, and f, displayed in the same order in which they appear in the natural build-up of the atom (Figure 4). Like the seven-period table, the eight-period version also reads from left to right; however, the separate orbital blocks, s, p, d, and f, are arranged in a right-to-left fashion, giving the impression of a staircase descending two steps at a time. In comparing the two versions, the composition of the orbital sections is exactly the same; the distinctive difference arises from the repositioning and realignment of the s section relative to the remaining body of the table. This realignment regularizes the number series that describes the element population of the successive periods.

Seven-period table: 2,8,8,16,16,32,32

Eight-period table: 2,2,8,8,16,16,32,32

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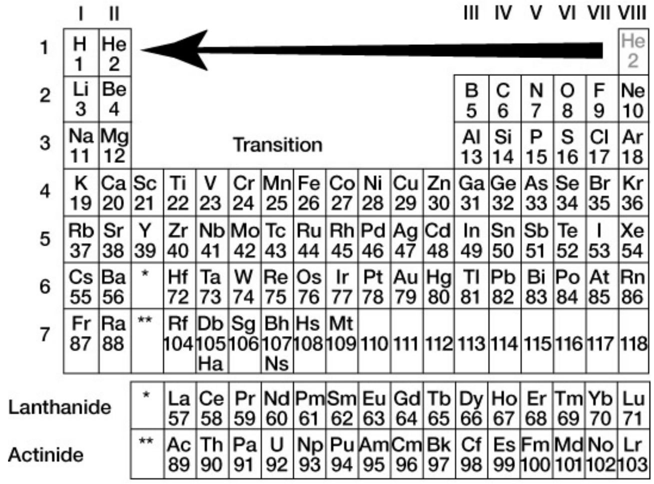

Figure 1. The version of the periodic table most commonly seen in textbooks, referred to herein as the seven-period table.

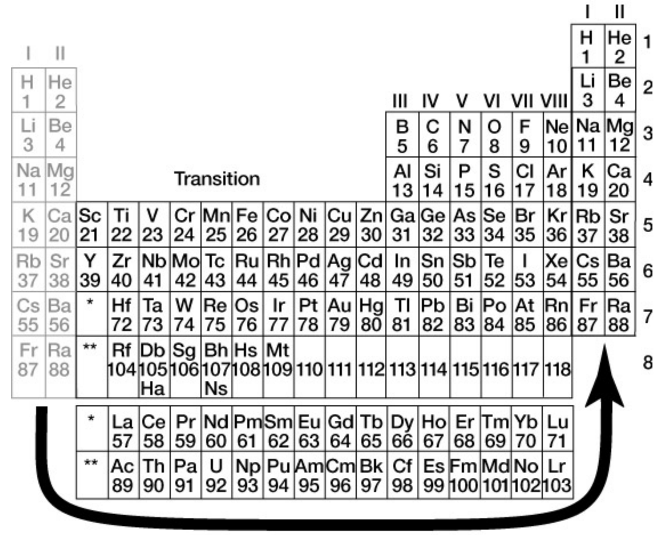

Figure 2. Generating the eight-period (or left-step) table by moving groups I and II from left to right and shifting up one period.

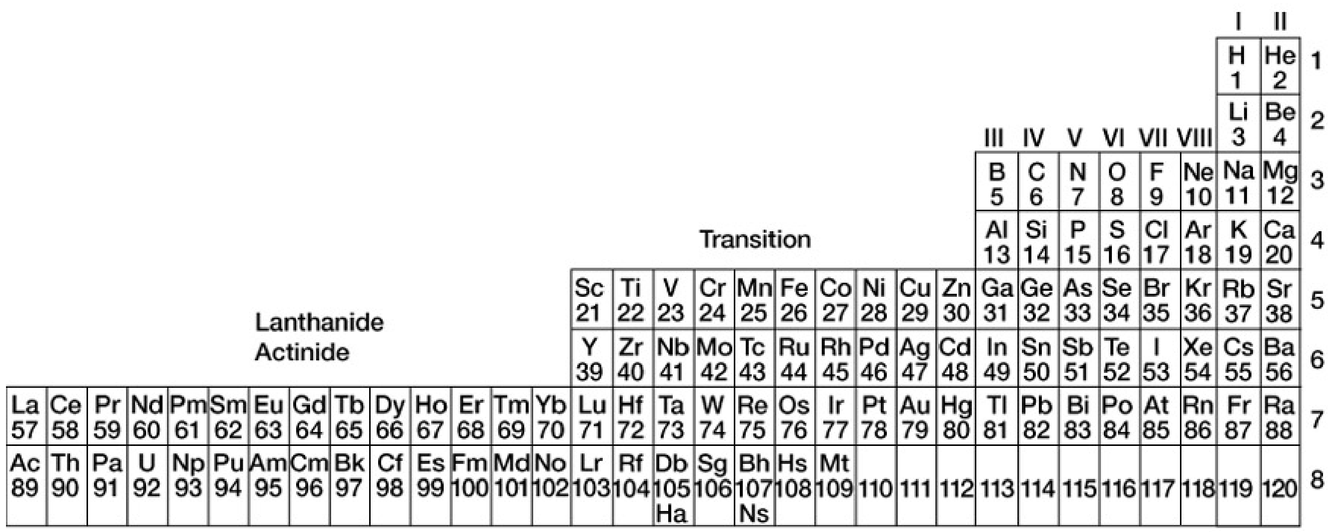

Figure 3. Eight-period table (left-step table) in full-width display, first published by Janet (1928).

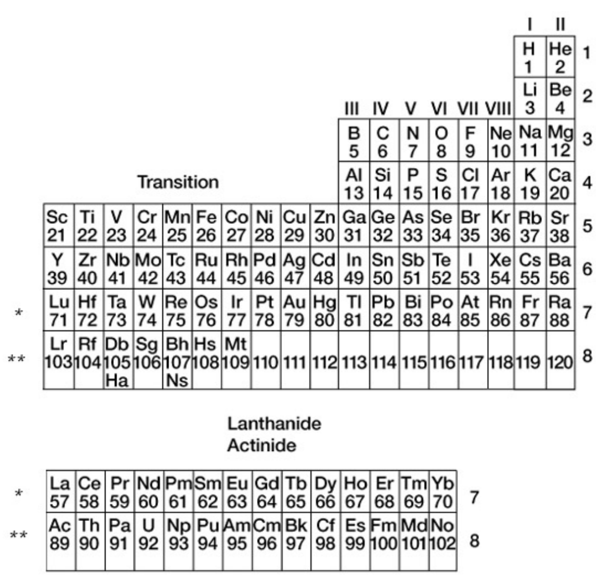

Figure 3a. Compacted form of Figure 3.

This operation expands the size of the table; the eighth period now ends at atomic number 120, rather than at 118 as before. The algorithm describing this series is $n = 2T^2$, where n is the population of elements in a given period and T is the tier or module in which that period occurs. The vertical division of the Table into s, p, d, and f orbitals follows the familiar relationship $n = 2(2l + 1)$ where n is the number of elements in a given orbital and l is an integer of the series 0,1,2,3…, which are the allowed integers for subshell quantum values. So, the structure of the eight-period table follows simple algorithms both vertically and horizontally; this cannot be said of the structure of the seven-period table. In addition, all periods are paired, giving the distinctive stepped profile of the eight-period table.

In essence, we have made the representation of the periodic table congruent to the system of electronic configuration by the simple relocation and realignment of the s column. The payoff for this reorganization is the creation of a powerful numerical relationship between the principal quantum numbers (n and l) of a given element and the period, P, in which that

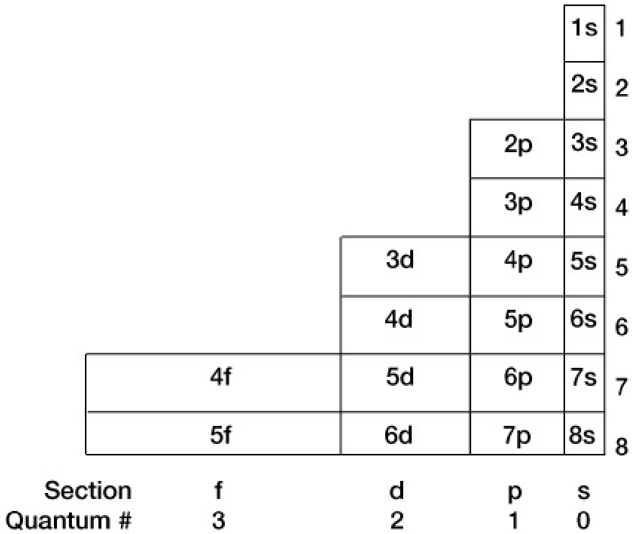

Figure 4. Quantum map of the eight-period table. The orbital designation in each block refers to the principal quantum number of the ideal terminal electrons of ground-state atoms of the respective elements in that block. Note the sum of the quantum numbers in each block equals the ordinal number of the period when expressed as n + l. For example, 3d = 3 + 2 = 5; 4f = 4 + 3 = 7; in general, n + l = *P*.

element occurs (here it is understood that "principal quantum number" refers to the first and second quantum numbers of the ideal terminal electron of the element in question or its real equivalent), that is

$$n + l = P$$

This expression provides a mathematical equivalence for the periodic law that is not obtainable from the seven-period table. Bent [5] notes that the n + *l* relationship explains the stepped appearance of the table mathematically, although the actual physical significance has yet to be understood. By directly linking the enumeration of the periods to the orbital numbers of quantum theory, we have tied the chart of Mendeleev to the atom of Bohr. The numerical form of the periodic law is absolutely dependent on the eight-period system for the enumeration of the elements. For this reason it has been totally unused for over fifty years and will continue to be unavailable as long as the seven-period table is in universal use.

Is Cosmic Evidence Admissible?

As we said before, the acceptance of the eight-period table revolves around the repositioning of helium to the top of group two. From a quantum mechanical point of view, Mazurs [6] suggests that helium and hydrogen should be regarded as a period disconnected groupwise from the elements below them when displayed in the eight-period format. The valence of hydrogen is equally well described as being either plus one or minus one; it can be classified either with group one or group seven. Indeed, the only variations encountered today among versions of the seven-period table are in the placement of hydrogen. Some formats put it in group one, some in group seven, and some in both groups. To propose that hydrogen should not be classified with either group then becomes logical because we are doing the same thing with helium. According to this logic, the first-period elements are drawn detached, above the main body of the table.

Mazurs and others have justified this placement by pointing out that 1s electrons are the only electrons in direct contact with the nucleus, which exaggerates the expected properties of these elements. Hydrogen is the most reactive element, while helium is by far the least reactive and has other unique physical properties, such as the superfluid condition, that cannot be classified.

The empiricists demand something beyond quantum-chemical reasons. After all, helium is always thought of first as a noble gas. Yet, unlike the other noble gases, it was not originally found as a fraction of liquid air, but as a line in the solar spectrum. Not until much later, even before the discovery of the other noble gases, was helium found on earth, as an alpha-decay product of uranium, present in natural gas. Terrestrial helium differs from the other inert gases both in its subterranean source and its origin as a nuclear particle. Helium, of course, has quite a different electronic configuration than the true noble gases, which all possess a p^6 terminal electron, compared to s^2 for helium. In addition, the electronegativity of the p^6 noble gases is much less than that of helium, allowing for the well-known ability of some of them to form chemical compounds. All of these differences, in sum, add up to a case for changing our present-day conceptions of helium as a noble gas and changing it to a different concept, one in which helium is unique, not associated groupwise with the elements below it.

The attractiveness of the eight-period table is perhaps a suggestion that an explanation of the helium problem will be found if we consider more recent developments in astrophysics and cosmology, where advances of the last thirty-to-forty years have by now built up a picture of the first-period elements that is considerably different than previous pictures. We now know hydrogen and helium are fundamental to the chemical evolution of the universe. The present day (detectable) mass of the universe consists of about 98% period-one elements, but only 2% heavier elements [7].

The big-bang cosmology implies that all higher matter descends from period-one elements. The observed cosmic abundances of hydrogen and helium are real facts, regardless of the validity of the big-bang theory. In the last thirty years, the case for this theory has matured and is now included in the curriculum of first-year courses. We therefore cite the cosmic-abundance results as evidence that the first two elements constitute a uniquely autonomous period, disjointed from the grouped elements below them. This might alter the conception chemists have of the first two elements, focusing attention not just on terrestrial chemistry but also on the roles helium and hydrogen play as the progenitors of all the higher elements. Thus, the first two elements in the table are above all the first elements in the cosmic synthesis of elements. It would be proper to display this information as part of the periodic table, and it would also resolve the placement of the first-period elements at the head of groups one and two.

If we accept this new way of looking at the period-one elements, then we have overcome a main obstacle to rationalizing the eight-period format. Each element is still in the same group as before, except for helium. The order of the orbital blocks from right to left is now s, p, d, f, rather than the confusing p, d, f*, s of before. This is the consequence of moving the column of s elements from the left side of the table to the right side. This gives the table a much different "feel", because the layout no longer ends with group eight, the p^6 elements. By moving groups one and two to the right and "up-shifting" one period, we have changed the composition and enumeration of all the periods. Except for groups one and two, all the elements are now in different periods. For example, oxygen previously in period two, is now in period three; iron was in period four and is now in period five; lanthanides, previously period six are now period seven, etc. This "shifting" means that our new eight-period table is in conflict with the nomenclature determined by IUPAC.

As a consequence of the shift, we have now allowed the f-orbital elements (f block) the full use of the space on the left of the chart, which is really their rightful space in the unfolding layout of the eight-period table. These elements, the lanthanide and actinide series, are depicted on the seven-period table as being crammed into the single spaces belonging to lutetium (atomic number 71) and lawrencium (atomic number 103). Almost every writer on the periodic table now agrees that this confusing placement arises from the historical difficulty of separating lutetium from ytterbium ($Z = 70$), its neighbor [8]. This separation resulted in the discovery of lutetium in 1907, the last of the naturally occurring lanthanides to be isolated. Because of the similarity of their chemistry, and the fact that a space at atomic number 71 seemed to be vacant, the rare earths have all been tucked together into this one empty slot.

Typically, chemistry texts explained this placement of the fourteen 4f elements by invoking their chemical similarity, because electrons were being added not to an outer orbital but to the nonbonding d orbital deeper in the electron cloud. Earlier texts referred to the lanthanides as an "inner transition" series, which implied that these elements were contained within the transition block. This conception of lanthanides then extended to the actinides, which at first were also thought to be transition elements. Uranium, for example, has a chemical similarity to tungsten, and comes below it in the table when mapped out as a transition element [9]. Because of this misconception, the products of neutron bombardment of uranium were initially expected to have the chemistry of the transition elements below tungsten: $Z = 75, 76, 77$, etc. Indeed, although such products were found by Meitner, Hahn and others [10], they were actually fission products of uranium like barium, strontium, etc. Not until 1940 and later were neptunium and the true transuranides identified and isolated from neutron-irradiated uranium [9]. Then, in 1945, Glenn Seaborg asserted the case for an actinide series (including new transuranium elements up to $Z = 95$), ending debate over where the actinide elements should be placed [11].

Yet, the footnote display of the f elements has continued up to the present, owing to a reluctance to take the next logical step (Figure 2) and move the s elements to the right side of the table, a move that cannot be effected without renumbering the periods.

On the practical side, many chemists and chemical educators have commented that a consequence of shifting the two s columns to the right is the loss of the well-known trend of the seven-period table, wherein metallic character is on the left and nonmetallic character on the right. Such diagrams can be found in most first-year texts and are a staple of the periodic-table curriculum. Several other trends that are usually presented in conjunction with the periodic table are also affected, namely gram-atomic volume, ionization potential, and electronegativity. We can mediate this problem in two ways.

The first is to retain the seven-period table to use in conjunction with the eight-period version for classroom purposes. Rather than abandoning the older format, it can be used side-by-side with the newer version, especially at the introductory level. The second approach is to identify new trends in the eight-period table. In his monograph, Bent [5], a physical chemist, identifies a number of new trends for the eight-period/left-step table, which supersede those similar trends of the traditional table. Nevertheless, if the picture of the elements that chemists keep in their minds is the sum total of these trends, then reforming their mental image will be a difficult process, because the character and variety of trends is obviously going to differ between the conflicting treatments of the table.

A Brief History of the Eight-Period Revision

The eight-period table is as old as the periodic-table concept itself. Mendeleev himself drew on the conviction that the periodic relationship was a mathematical one; he had concentrated in physics and mathematics in college and was inspired by the knowledge that the numbers three (the triad) and eight (the octet) were integral to the chemistry of elements. The even-tiered scheme was first suggested in Mendeleev's own original designs for the periodic table.

In 1913, Niels Bohr developed the quantum theory in order to explain the energy states of the hydrogen atom. At this time, almost all the naturally occurring elements had already been discovered; only hafnium and rhenium remained to be described. This filled most of the empty spaces in the table, but there was still a great deal of confusion and uncertainty about the exact arrangement of the elements. These questions, as it turned out, would be answered primarily by Bohr's new quantum theory. Bohr and his group fit the concept of energy levels to the existing spectral data in order to create the system of electronic configuration in use today. Bohr was the first to perceive that the discrete periods of the table were directly related to the energy levels of atoms. As this work neared completion in 1922, he designed a periodic table showing specifically the lanthanide and actinide relationship predicted by their homologous electronic configuration, an idea that was ahead of its time.

By 1928, Charles Janet, a retired French professor of biology and geology, had combined the periodic table with Bohr's novel system of electronic configuration to produce the table shown in Figure 3 [12]. Janet, who was also an engineer, published his new eight-period table, along with circular and helical versions, in a series of privately printed booklets. Janet incorporated Bohr's idea of an actinide series (four elements were known) homologous to the lanthanide series and located directly below it on the table. As we have previously mentioned, this conflicted with prevailing wisdom that actinides should be placed under transition elements. Janet's eight-period table remained little known, although his other circular and helical versions were often cited.

L. M. Simmons, a chemistry professor at Scots College, Sydney, Australia, referred to Janet's tables and added, for the first time, the new numbering of the periods [13]. During the postwar era, 1951–1971, V. I. Klechkovskii, a Soviet agricultural chemist, wrote many papers in Russian on the eight-period table. Mazurs' synopsis of the voluminous literature indicated that throughout the Soviet era, a parallel discussion on the same Periodic Table issues confronted scientists in the East. This was an area of active and imaginative interest in the Soviet state. Of great importance during this postwar period was the contribution of one Yeou Ta, writing in French in 1946, who first derived the numerical form of the periodic law from the Janet work. Of Yeou Ta's life or work, nothing is now known.

Much of the preceding work on developing the eight-period table was done not by well-known scientists, but by outsiders—men whose careers took place in areas other than chemical research. Janet, for example, was an engineer, biologist, and geologist,but not a chemist, who selfpublished his findings. Yeou Ta made one appearance on this stage and vanished.

Contributions of E.G. Mazurs

These and many other contributions were included by Edward G. Mazurs (1894–1983) in his exhaustive 1974 overview of the periodic yable. He emphasized the eight-period table and devised several good designs with three-dimensional character. The book itself owes its comprehensiveness to its author's fluency in languages; like many European emigrés, he spoke many, including Russian and German. The text of his book cites over eight hundred references in about twenty-four languages, the work of scientists and educators in some fifty countries. He classifies about 140 types of tables among these papers.

Mazur's book seems to have made little impact on the scientific public, but has gained a following among connoisseurs of the periodic table. He reasserted the idea of an eight-period table during a time when there was little interest. Because no biographical material exists for him, we will include some here [14].

Mazurs (pronounced mah-zhoors') was born in Latvia, when that Baltic Republic was under Czarist rule, so he received his education in Russian. After serving as a musician in the Russian Army during WWI, he returned to take a master's degree in chemistry from the University of Riga. He became a professor of chemistry at the university during the period of Latvian independence (1919-1940), which ended with the German occupation of 1940. As the Soviets reoccupied Lativia in 1944, Mazurs fled with his wife and nine-year-old son, ending up with many other Latvians at the large refugee camp in Regensberg, Germany, which eventually was liberated by American forces. He immigrated with his family to the Chicago area in 1949, where he learned English while working as a janitor at Argo Corn Products. He eventually stepped up to chemist at Argo, receiving American citizenship in 1955. Soon after, in 1957, he published the first edition of his periodic table book at his own expense. He retired from Argo in 1959 and moved to Santa Barbara, CA, where he became a chemistry professor at Westmont College, a small liberal arts school. There he resumed the teaching career that had been interrupted by the war and revised and expanded the second, "centenary" edition of his book. In this edition, he came to the conviction that the eight-period table best expressed the relationships of the periodic system [12]. Mazurs devised several electronic or eight-period tables for his book, using color to clarify the design. These were in fact blueprints for the periodic round table (PRT) [15], although at the time we patented the PRT, in 1977, we were unaware of Mazur's book. As is usually the case with periodic table innovations, the Mazurs' design of concentric circles [16] is an improvement of an earlier, almost identical version published by a German physicist, G. Haenzel, in National Socialist Germany.

Mazurs' centenary volume appeared several years after the anniversary and sold poorly compared to van Spronsen's. Although published by the University of Alabama Press, Mazurs again appears to have borne most of the cost of publication himself. The book is rich in graphics and source references, but the organizational scheme is puzzling and certain to discourage the casual reader. He has classified each distinctive type of periodic table through an exhaustive compilation of the world literature. He has then arranged the tables according to various historical, graphical and theoretical criteria. This multifaceted approach, though rich and comprehensive, is nevertheless confusing and hard to follow. Yet it is hard to imagine doing differently when dealing with such a wealth of material spread over the panoramic evolution of the periodic table. This subject is inherently complex and multidimensional, challenging any reviewer's organizational skills.

From our perspective, Mazur's work is important not just as an overview, but because he championed the eight-period table at a time when it was either ignored or forgotten by chemical educators. This was not always the case, as Mazur's bibliographies make clear. A number of papers [17-19] dated 1943-1964 argued for the adoption of the eight-period table, citing the need to unify the presentation of periodicity with the concept of electronic configuration. Yet, in the twenty-five years since publication of Mazur's book, this subject has literally disappeared from the literature. Why, we might ask, has such a promising development in the evolution of ideas come to naught?

There is no single answer to this question, just as there is no single way to visualize the table itself. The factors involved are historical, political, and scientific; in addition, there is the usual teleological struggle between ascending and descending paradigms for choosing a new way of visualizing the facts. What is clear now is that the interest is still alive, among chemical educators and others, in defining mechanisms to effectuate such a change and even in carrying such a process to its logical conclusion by actually changing the periodic table.

Politics and Mechanics of Changing the Periodic Table

The periodic table and related matters, including names and symbols of the elements, are considered part of chemical nomenclature and as such are under the aegis primarily of the International Union of Pure and Applied Chemistry (IUPAC) and secondarily, International Union of Pure and Applied Physics (IUPAP, the corresponding organization for physics). Founded in 1919, IUPAC consists of a membership selected from among its 45 constituent National Adhering Organizations. One must think of IUPAC and IUPAP as a kind of United Nations for chemistry and physics, respectively, agreeing on standards for the member nations (and the rest of the world). Until 2002, specific tasks involving the periodic table belong to the Committee on Nomenclature of Inorganic Compounds (CNIC). After that time, standing committees will be dissolved and matters such as periodic-table revision will be undertaken on an ad hoc basis.

Regarding the graphic layout of the periodic table, IUPAC has no recommendation; however, it does specify exactly the period and group numbers for each element. Those numbers are consistent only with a table of seven periods; the eight-period format is in conflict with IUPAC rules. So we might ask how to work within the auspices of the IUPAC system to change the numbering of the periods (of most elements). Is that a project that IUPAC would likely undertake?

Of course decisions made by IUPAC are actually made through a political process involving individuals from both the membership and hierarchy of the organization, as well as from interested parties in the adhering nations. In two problem areas IUPAC has recently made decisions that bear directly on the issue of the periodic table. These recent examples can tell us something about the nature of consensus and how difficult it can be to resolve problems democratically. The first of these situations concerned revising the numbering system for groups. The delegates agreed to replace the various designations in use that involve letters and Roman numerals with a uniform numbering system of Arabic numerals. These discussions took place in the 1970s and 1980s [20]; some two decades were spent in arriving at the solution.

The second problem was to name the new transfermium elements of atomic numbers 103-109, in which conflicts had arisen over claims of priority. These discussions started in the 1960s and were not resolved until 1997—more than three decades later. Clearly, the democratic process takes time, but it does provide the necessary forum for decision-making.

We have to point out that the above situations took place against a background of world discord extending back into the 1930s. True international discourse was virtually nonexistent for more than half of the century. As we begin the new millennium, the larger powers seem to have entered a period of cooperation and communication. If a constructive international spirit prevails for a while, then it is possible, through IUPAC, to resolve the periodic-table issue within a reasonable time frame, if the scientific community wishes to do so.

The Periodic Round Table: Three Dimensional Symmetry

Realizing that IUPAC (and IUPAP) approval of the eight-period system of numbering might take some time, we made the decision in 1995 to market the periodic round table directly to the public in 1995 through a Scientific American catalog of science-related products. The most attractive features of the three-dimensional space-filling model are its algorithmic regularity, the same as for the two-dimensional table of Janet (Figure 3), and its symmetry, a three-dimensional property. The transformation from two dimensions to three is achieved by unrolling the orbital blocks in order and rerolling them to give the structure in Figure 5, which is then transformed to the respective periods by cleaving it horizontally to create the eight discs (Figure 6). Each disc is further divided into subshells in the form of concentric circles, or rings, with radii in integral ratios of 1:2:3:4. An interesting consequence of this geometry is that every element occupies an identical area, equal to π divided by two—a consequence of the rules of electronic configuration. The periods are grouped in "tiers" or "modules" of two periods of equal radius, giving the structure a unique wedding cake appearance.

We gave this representation the name "periodic round table" for marketing purposes. Strictly speaking, there is no need to identify the three-dimensional periodic table by any other than a generic name, such as "3D", because we contend there is only one true representation of the periodic table in three dimensions and that is the one with eight periods. A very similar concept in space-filling tables has also recently been offered to the scientific public [21]. The "elementree" of Professor F. duFour of Canada looks, at first glance, identical to the periodic round table, except that the layers are polygonal rather than circular, and a separate piece for helium is carefully appended to the top layer. On closer inspection, however, du Four's creation is revealed to be a seven-period table, designed to take on the symmetrical property of the eight-period table without violating the IUPAC rules for numbering the periods. He has accomplished this by mounting the outer orbitals of each period-shape at a place in between the respective s elements on a central axis. In this way, one cannot tell to which period these s elements belong. There are two problems with this approach: (1) the user of the model is confused as to which elements belong to which period and (2) it is topologically impossible to transform the seven-period table into this three-dimensional form without breaking the line between the elements and shifting the 1s column to the right. While the "elementree" is a colorful display of the elements, it is not a periodic table, at least not by a set of rigorous criteria.

Is Beauty Truth and Truth Beauty?

The eight-period table is not in itself a physical reality but is a representation of a mathematical expression of reality. A question that has been posed by commentators on the periodic table is "to what extent is it desirable to simplify the empirical data on the elements in order to make everything fit so nicely that it comes out symmetrical and mathematical?" Do these algorithmic compressions of reality compromise the truth about the rough edges of uncooperative matter?

This is the kind of philosophical question that has been posed often in the last forty years by Thomas Kuhn [22] and others. In his excellent summary of the subject J. W. McAllister [23] hypothesizes that aesthetic factors are largely responsible for turning over old paradigms in order to get new theories and, usually, he observes, older scientists are reluctant to embrace a newer paradigm, instead favoring the more awkward aesthetic of an older model because it is familiar to them and treasured. To put it in another way, people, on whatever level, generally tend to resist change, even when change is beneficial from an aesthetic point of view.

Mendeleev (with help from his predecessors) performed such a paradigm shift by the creative act of taking the disparate elements and arranging them into a logical geometrical plan based on the similarity of chemical properties. This advance represented a quantum leap in the understanding of matter and was well received by scientists who rejoiced in the idea that the many kinds of matter were thus united in a systematic manner. On the other hand, the cold precision of the periodic system may have been intensely resented by alchemists and other mystical types who favored the retention of spiritual concepts like earth, air, fire, and water. When Bohr showed that the spectra of each element could be explained by a precise configuration of electronic energy states, and that these configurations could in turn be used to predict chemical

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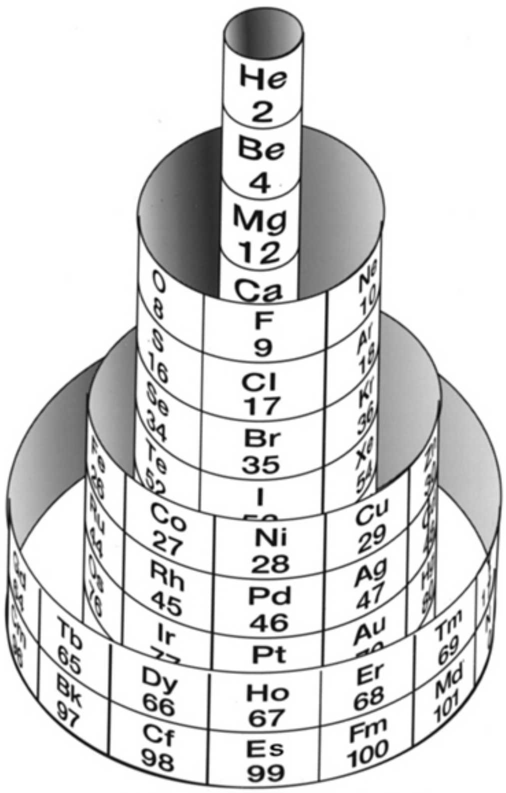

Figure 5. The Periodic RoundTable can be generated by identifying the right and left edges of the orbital blocks s, p, d, and f and rolling them up into concentric cylinders.

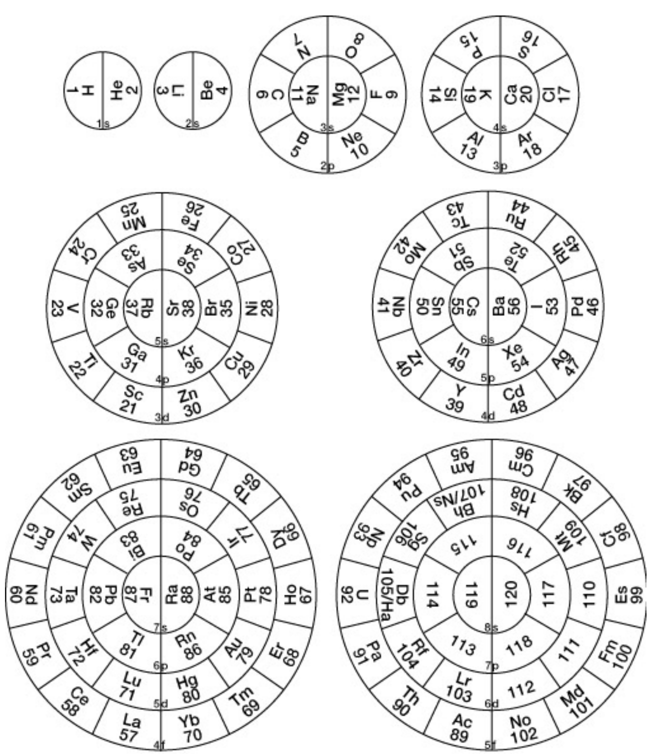

Figure 6. Disc display of the periods in the three-dimensional version. The orbital designation of each ring is shown at the origin for that ring. Reading is clockwise; however, there is no significance to this convention. The area occupied by each element is the same for all elements.

properties, perhaps many chemists no doubt saw their beloved world of tangible chemistry, which was above all a world of practice and experiment, start to crumble. The system of electronic configuration essentially transforms chemistry at this level into a branch of physics. The eight-period table expresses this transformation in a symmetrical and mathematical order that to some extent diminishes the individuality of each element and renders it simply a piece of the cosmic machinery.

For us, the periodic round table and the eight-period system are beautiful precisely because of their power to further unify all this information into one simple equation: $n + l = P$. Others might not see it that way. McAllister points out that the aesthetics of science are still subjective, that beauty is in the eye of the beholder. Chemists who learned from the seven-period table may not perceive an aesthetic improvement—although a physicist might. In our new millennium, such unified entities may be considered more valuable by younger chemists, whose methods include techniques borrowed from physics, biology, and computer science. The embrace of a new order may be jubilant, as it was with Mendeleev's table, or it may be reluctant. Theories, being composites of reality, rather than reality itself, are always somewhat subjective and open to interpretation and argument. Certainly few theoretical frameworks have led up to so much reinterpretation as the periodic table.

In the nineteenth century we added to our knowledge most of the elements in the periodic table. Although Mendeleev did not discover a single element, it was his description of the relationships among these disparate entities that created the real meaning in this process, ending some of the chaos that had prevailed. In the twentieth century, Mendeleev's insight was further refined by Bohr's system of electronic configuration, while the periodic table itself was filled out and extended by the creation of the synthetic elements. By the end of the twentieth century, interest in the elements had largely been sated. As we enter the twenty-first century, the periodic table has perhaps lost its novelty and excitement. Almost everyone assumes that the table is now in its final form, and complete, from the point of view of being able to inspire new work. The present seven-period table has certainly been "all right" in a purely functional sense and in the context of history, while development of the eight-period table will not lead to any miraculous insights in the sciences. That the eight-period table contains 120 elements as opposed to the 118 contained in the seven-period version does not lead to any revelations about the nature of these heavier elements, of which a few have already been synthesized.

In a larger sense, the periodic table and most of its elements have retreated into the background as we enter this new century. So why bother altering the table at this late date if its most important task has been realized—that of depicting the order of the elements? Three reasons come to mind: (1) to improve the teaching of science by implementing the numerical form of the periodic law, (2) to make the results of science more generally accessible to society through the aesthetic appeal of the three-dimensional form, and (3) simply to present the table in its anatomically correct format. It is never too late to rectify a mistake when one is modeling nature. Chemists have been reluctant to accept the validity of the minor modifications to Mendeleev's work entailed in generating the eight-period table. There is perhaps a feeling

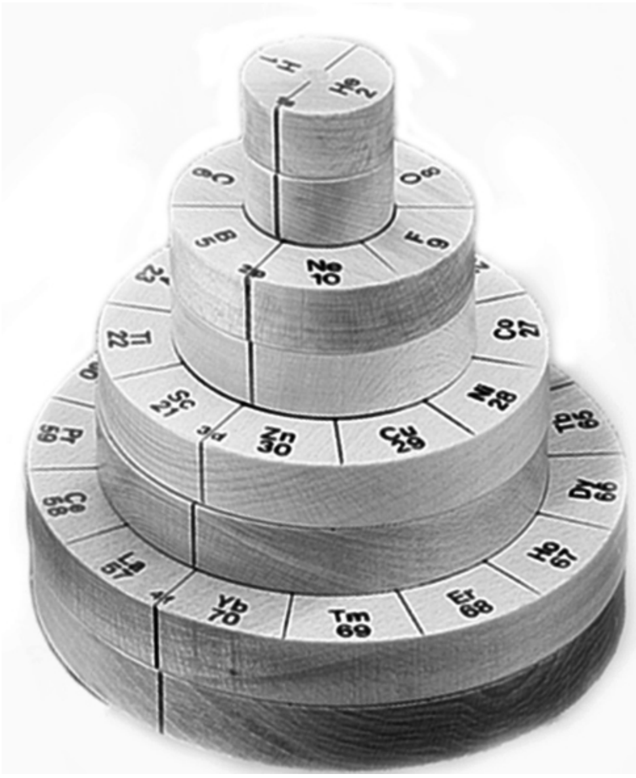

Figure 7. Periodic round table. Actual radii of the tiers = 1.5 in, 3 in, 4.5 in, 6 in. Height = 6 in. The nominal thickness of each disc (period) is 0.75 in and it is constructed of hardwood.

Figure 8. Edward G. Mazurs (a) Latvia, age 38; (b) California, age about 80; (c) with family, mid-1950s.

either that this is not terribly important or that it will somehow diminish Mendeleev's contribution. We prefer to see it in a different light, rather as the culmination of a long evolutionary process intertwined with developments in chemistry and the course of history itself. It is worth noting that most writers on the periodic table are dissatisfied with some aspect of it. Emsley proposes a sensible display of the f elements [24]; van Spronsen supports the placement of helium above the 2s elements [25]. Mazurs, of course, advocates both of the above, combined with a shift to eight periods. This would seem to indicate a general desire on the part of many chemical educators to do something with the table and get evolution back on track. Sometimes the periodic table has been ahead of its time and has predicted the future. At other times the table has been behind events, needing to be updated. Since the periodic table is itself an overview or theoretical doctrine, it must chronologically lag behind the data and information that shape it. Throughout its history, the periodic table has been revised, as chemists and physicists have groped their way further into unexplored regions and come out with new elements and ideas about the relationships among the elements. This statement flies in the face of the popular conception that the periodic table is a predictor of future facts, which is, of course, also true. For example, the predictive power of the periodic table was used famously to help characterize and identify numerous elements such as technetium (Z = 43) and hafnium (Z = 72); however, in some notable aspects the periodic table lagged behind the empirical results until the table itself could be modified to embrace these results. One such case is that of the lanthanide elements (atomic numbers 57–71). These elements were isolated one at a time or in groups over a period of years ending about a century ago. They were not properly displayed in the periodic table then and are not properly displayed there now. The periodic table had no predictive power in explaining how there could be so many rare-earth elements and why in fact there are just fourteen of them. (Factually speaking, lutetium (Z = 71) should not be called a lanthanide element). These questions were resolved by development of the theory of electronic configuration, not by the periodic table. Similarly, the actinide series of elements, like the lanthanides, were long thought to be somehow a subset of the transition series. As we have previously described in this paper, this misconception actually caused great problems in analyzing and explaining the results of early nucleus-building experiments by Meitner and Hahn. Not until Seaborg showed that the transuranium elements were in fact a series homologous to the lanthanides did the periodic table catch up to science. The results just cited have never yet been properly incorporated into a periodic-table model that could accommodate future g- orbital elements, which is why we are advocating the eight-period table.

Postscript

The author has recently received a monograph from Henry A. Bent presenting the case at length for the eight-period table. Bent essentially advocates the same eight-period version terming it the "left-step table" referring to its characteristic profile [3]. Bent, a retired professor of physical chemistry, chaired an ad hoc committee under the late ACS president, George Pimentel, in the 1980s, charged with the task of studying ACS acceptance of IUPAC's recently adopted 1–18 system for group numbering. Bent expanded that work into the analysis of revising the periodic table totally along the lines of electronic configuration as described in the work cited. Bent has suggested (personal communication) that use of the term "eight-period" may be short-sighted, as chemists will soon be into theoretical computations for g and h orbital elements, necessitating of course a ninth and tenth period!

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