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Alternative Periodic System of the Elements

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ABSTRACT

For more than 150 years since the discovery of the periodic table of elements, there has been a need for its constant supplementation and improvement. As a result, today there are over 700 different periodic systems that aim to present the position of the elements more simply, effectively in the periodic table, their interrelationships and the possibility of building different compounds. In addition to two-dimensional, both three- and four-dimensional systems of elements have appeared. All of them, in addition to their great didactic significance, also have great scientific significance and represent guidelines for scientists in various multidisciplinary research. The exploration of new elements of both a more perfect and a comprehensive periodic table continues.

Keywords: Periodic system, modern forms of the Periodic system, alternative forms of the Periodic systems

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Introduction

The periodic elements' table is a tabular arrangement of chemical elements, organized on the basis of their atomic numbers (number of protons in the nucleus), electronic configuration and repetitive chemical properties. The elements are arranged in ascending order of atomic numbers, which is usually indicated by a chemical symbol in each field. It ranges from element 1 (hydrogen H) in the upper left corner to the newly approved element 118 (oganesson Og) in the lower right corner. The standard form of the table consists of a network of elements arranged in 18 columns and 7 rows, with two rows of elements below that table - lanthanides and actinoids (Figure 1). The rows of the table are called periods, and the columns are called groups, and some of the columns have special names such as halogen elements or noble gases. The table can be divided into four rectangular blocks: *s*-block to the left, *p*-block to the right, *d*-block in the middle and *f*-block below it (Mazur, 1974).

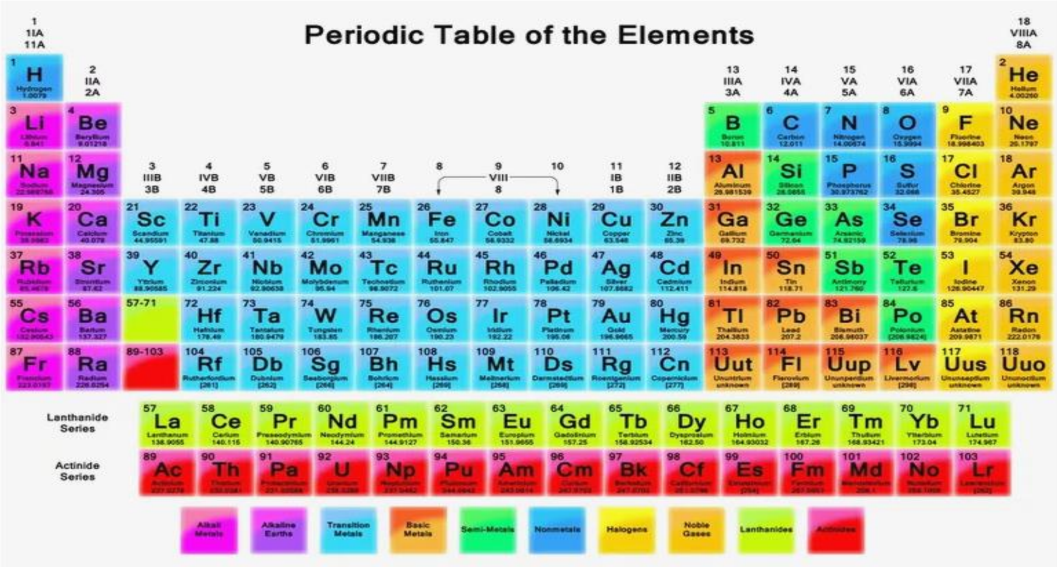


Figure 1. Periodic Table of the Elements

https://www.thoughtco.com/how-to-use-a-periodic-table-608807

Mendeleev's Periodic Table has historically expanded and improved with the discovery or synthesis of new elements and the development of new theoretical models.

When the four most recent additions to the table (synthetic elements nihonium, moscovium, tennessine and oganesson) were formally recognized in 2016, the remaining gaps were finally filled. All elements from atomic numbers 1 to 118 have been discovered or synthesized. On December 30, 2015, the International Union of Pure and Applied Chemistry (IUPAC, 2015) confirmed the completeness of the first seven rows of the Periodic Table (Figure 2).

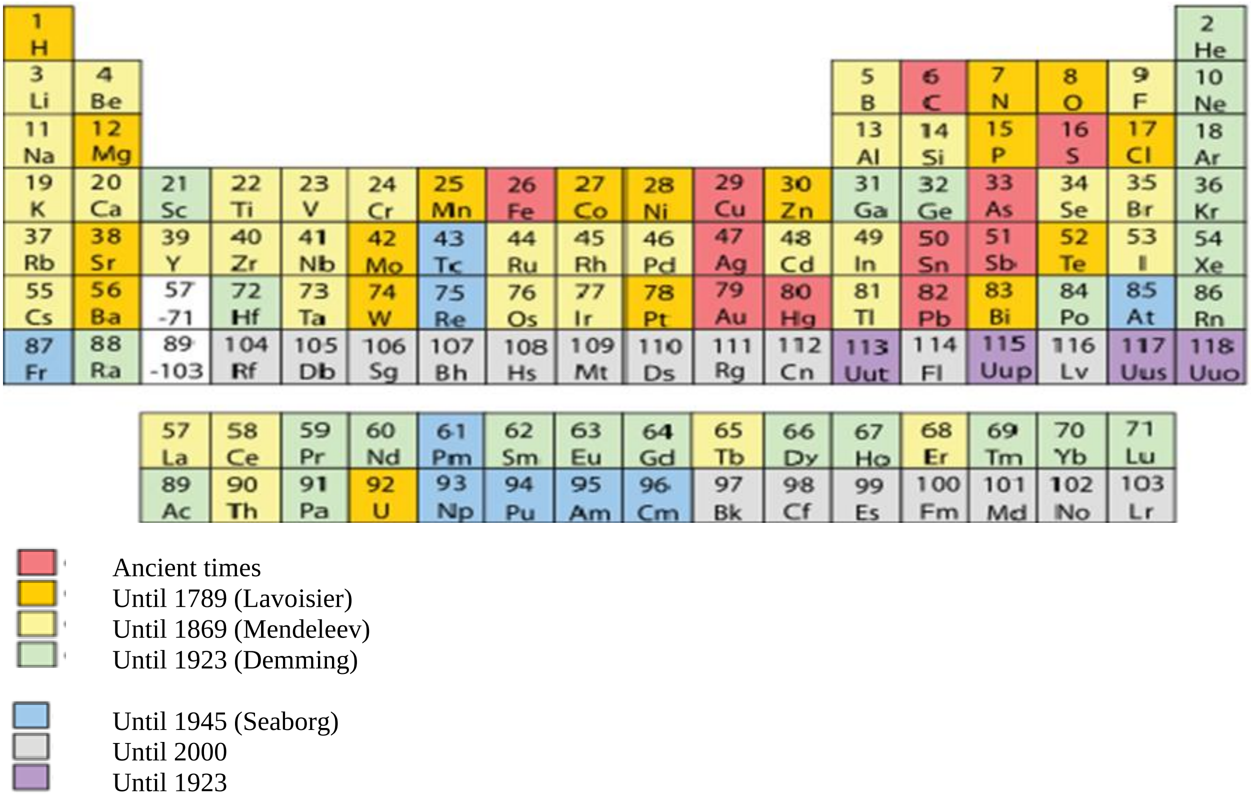


Figure 2. The discovery of chemical elements mapped to significant dates in the development of the periodic table

https://commons.wikimedia.org/wiki/File:Discovery_of_chemical_elements-en.svg

Elements with ordinal numbers up to 81 are stable elements found on Earth and they build most of the objects in the Universe. The next 13 elements are radioactive, but they are also on our planet. Although their half-life is very long, a million or even a billion years, they are rare on Earth, with the origin from meteorites and samples from the Moon. There are 24 more radioactive elements, which are created artificially, in special, laboratory conditions. Unlike naturally occurring radioactive elements, the half-life of this group of elements is much shorter.

The consequence of rapid decay is that these elements cannot be found in nature and are therefore synthesized in laboratories or nuclear reactors. Due to the rapid decay, detecting or determining their properties after production is a real challenge. The first element to be added as a synthetic was neptunium in 1940. (Siborg, 1946)

Alternative periodic systems

The periodic table remained essentially indisputable even after numerous discoveries in the world of science. Of course, there were some changes in the table, although they were relatively small and, in some cases, almost "cosmetic".

One might get the impression that Mendeleev's masterpiece has finally been completed, but the search for element 119 - which would be the first in a new order - is already underway in some laboratories in Japan.

The number of possible elements is not known. A somewhat recent estimate is that the Periodic Table could end shortly after crossing the ‘island of stability’, which is believed to occur around element 126, because the expansion of periodic and nuclide systems is limited by proton and neutron drop lines. Other significant proposals regarding the end of the Periodic Table include a break in element 128 proposed by John Emsley, a break in element 137 proposed by Richard Feynman, and a break in element 155 proposed by Albert Kazan.

It is not known whether the newly discovered elements will follow the trend of the current Periodic Table as the 8th period or whether additional adjustments and corrections will be necessary. There are currently several competing theoretical models for determining the position of elements with an atomic number less than or equal to 172 (Fricke et al., 1971)

It would be understandable to think that this would be the end of research. However, this is not the case. A simple internet search will reveal different variants of the periodic table.

Many researchers have created hundreds of variations in search of the perfect periodic table. There are short versions, long versions, circular versions, spiral versions, three and even four-dimensional versions. Many of them are certainly simply different ways of conveying the same information, but there are still disagreements about where some elements should be located. Alternative periodic systems are tabular representations of chemical elements that differ significantly from their organization or traditional layout in the Periodic Table. Many such systems have been invented so far, often for didactic reasons, because not all correlations between chemical elements can be effectively represented by a standard Periodic Table.

There are literally hundreds of variations (see Mark Leach's database), and spirals and 3D versions are particularly popular, such as "tongue behind cheek" (Figure 3) or the London Underground (Figure 4). Paul Giguere's 3-D periodic table consists of 4 billboards with the elements written on the front and the back (Giguère, 1965)

Figure 3. 3D 'Mendeleev flower' version of the table

https://theconversation.com/the-periodic-table-is-150-but-it-could-have-looked-very-different-106899

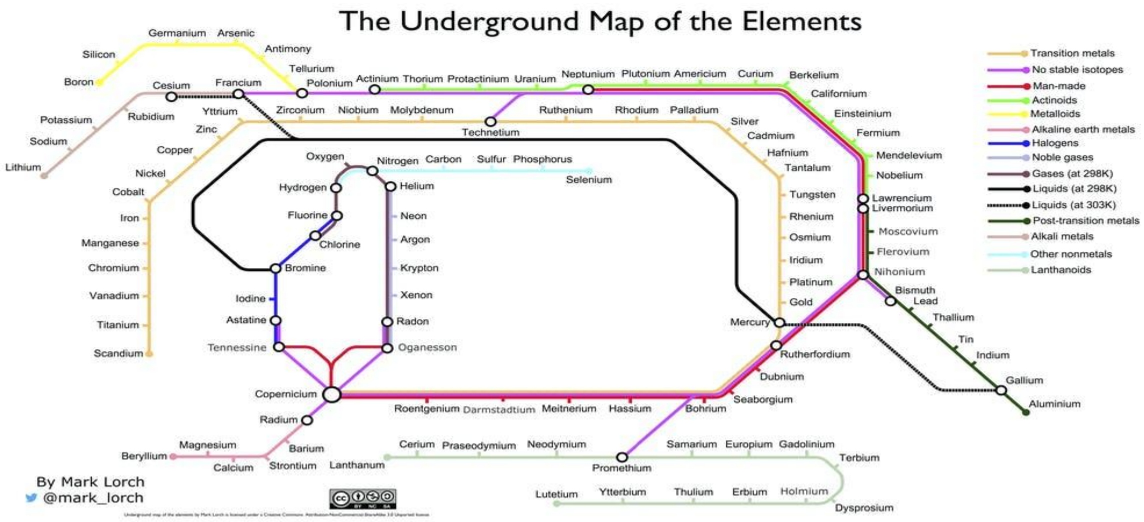
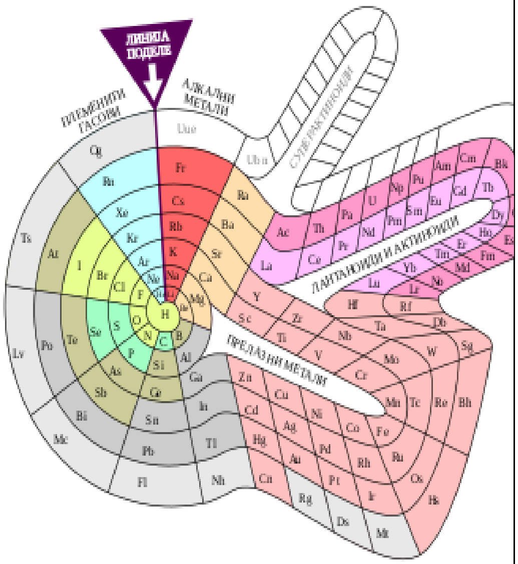


Figure 4. The Mark Lorch's underground map of the elements

https://theconversation.com/the-periodic-table-is-150-but-it-could-have-looked-very-different-106899

Alternative periodic systems are most often developed to emphasize the different chemical and physical properties of elements that are not so obvious in the traditional Periodic Table. Some systems aim to emphasize both the nucleon and electronic structure of atoms. This can be achieved by changing the spatial relationship or arrangement that each element has in relation to the other element in the system (Figure 5).



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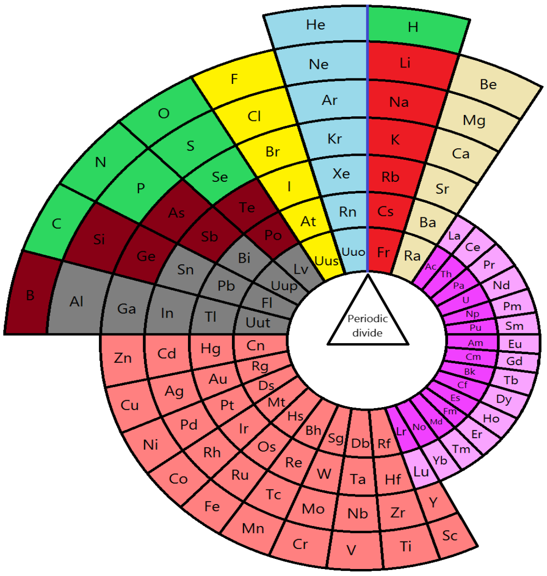

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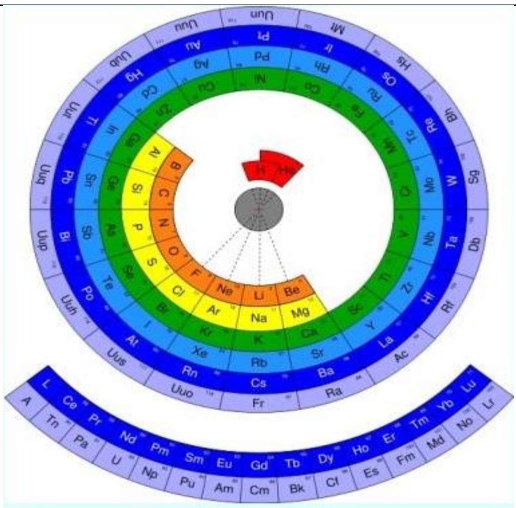

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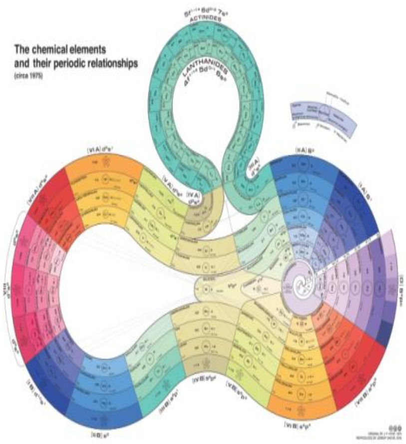

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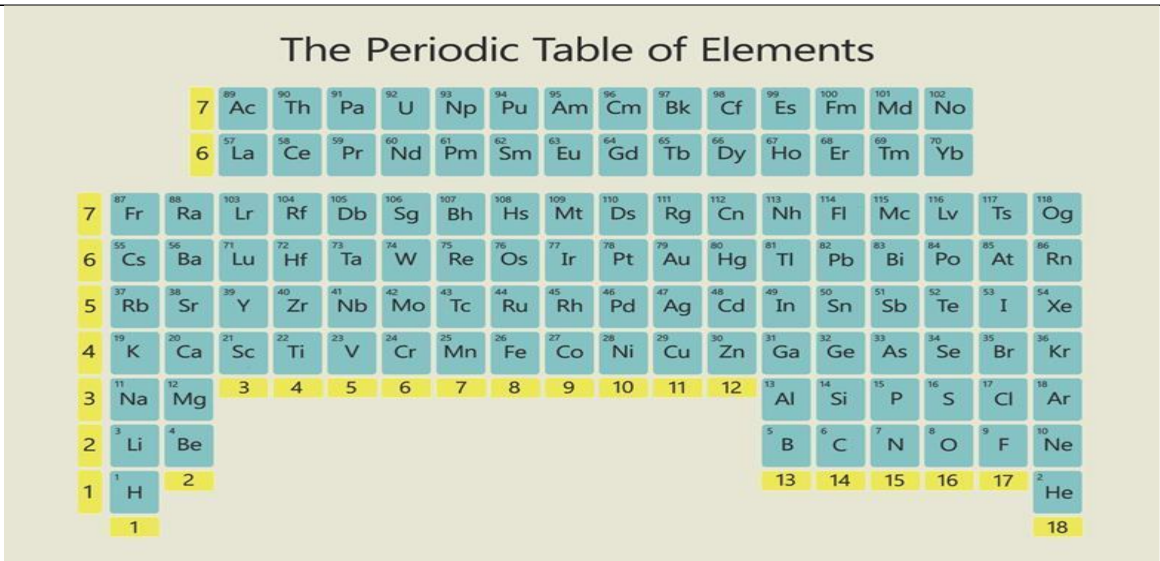

https://www.chemistryworld.com/news/does-the-periodic-table-make-ore-sense-upside-down/3010360.article

Figure 5. Alternative Periodic Table of the Elements

Other systems have emphasized the isolation of chemical elements throughout history.

Timmothy Stowe created the physicist's periodic table. This table is a three-dimensional and the three axes represent the principal quantum number, orbital quantum number, and orbital magnetic quantum number. Helium is again a group 2 element (Bradley, 2011).

In 1984 an idea of a "structure map" was explored by Pettifor, who suggested that a well-structured chemical space could be derived by changing the sequence of the elements in the periodic table. He proposed a chemical scale that determines the "distance" between the elements on an one-dimensional axis and a Mendeleev number (MN): an integer showing the position of an element in the sequence. Pettifor claimed that binary compounds with the same structure type occupy the same region in a two-dimensional map plotted using the MNs (the Pettifor's map). He evaluated the chemical scale by presenting a map clearly separating 34 different structure types of 574 binary AB compounds (Pettifor, 1984).

Later, Pettifor showed that the MN approach also works for other A_xB_y compounds. Although Pettifor derived the chemical scale and Mendeleev number empirically and based his assessment on only several hundred binary compounds, his study provided a phenomenally successful ordering of the elements confirmed in many later works. In this work, we denote Pettifor's MN as MNP. We expect that a nonempirical method of finding the MNs would perform even better (Pettifor, 1986).

Villars *et al.* proposed a different enumeration of the elements (called periodic number, PN), emphasizing the role of valence electrons. The atomic number (AN) of the elements together with their 'periodic number' (PN) were found to form an efficient pair for the discussion of metallurgical and structural problems. The periodic number PN represents a different enumeration of the elements, emphasizing the role of the valence electrons. In contrast to the atomic number, PN depends in detail on the underlying Periodic Table of the elements. As a first result we describe the elemental-property parameters 'atomic size SZ_a' and 'atomic reactivity RE_a', derived from fits to various experimental and theoretical data sets. We argue that all elemental-property parameter patterns are derived from AN and PN. AN and PN represent fundamental elemental-property parameters independent from each other. Any pattern, which shows well-defined functional behavior within each group number GN, as well as within each main quantum number QN, can be included. On the example of compound formers/non-formers in binary, ternary and quaternary chemical systems we demonstrate that a quantitative link exists between material properties and AN, PN (or simple functions of both) of the constituent element (Villars, 2008).

Glawe *et al.* proposed another sequence of elements (modified MN, in this work, we represent this as MNm) based on their similarity, defining elements A and B to be similar if they crystallize in the same structure type when combined with other elements of the periodic table. We believe that our proposed 'modified Pettifor scale' can be of use not only for the representation of structure maps, but also as a tool for both theorists and experimentalists to study possible chemical substitutions in the quest for new materials with tailored properties (Glawe, 2016).

In a correctly defined chemical space, closely located materials should have similar properties. The most promising materials will then be clustered in one or a few "islands" in this space. To predict new materials, it could be sufficient to explore these as lands instead of the entire chemical space. The fewer these islands are, the easier it would be to locate and explore them for promising materials. A chemical space containing many small islands is less amenable for the prediction of materials than the one with fewer big islands. Therefore, for evaluating each chemical space, it is useful to have these islands and calculate the number of (similar) materials they cover. For doing this, we used the idea of the clustering algorithm proposed by Rodriguez and Laio and applied it to clustering regions of the chemical space based on their similarity (Rodriguez and Laio, 2014).

The precise placement of certain elements depends on which features we want to emphasize. The last attempt to arrange the elements in this way was recently published in the journal Physical Chemistry by scientists *Zahed Allahyari* and *Artem R. Oganov*. Their approach, building on the earlier work of others, is to assign to each element what is called a Mendelian number (MN). There are several ways to derive such numbers, but the latest study uses a combination of two basic quantities that can be measured directly: the atomic radius of the element and electronegativity (Festschrift, 2020).

In a well-ordered sequence of elements, the atoms with similar properties are close to each other. Therefore, in the two-dimensional chemical space based on such a sequence, the properties of neighboring binary systems should exhibit a close relation. On this premise, we evaluate different MNs: atomic number (AN), Villars' periodic number (PN), Pettifor's Mendeleev number (MNP), modified Mendeleev number (MNm), and Mendeleev numbers obtained in this work-the universal sequence of elements (USE).

Only 1591 binary and 80 unary systems are studied in the database which is about half of the total binary and unary systems that can be created from the combination of 80 elements; in total, 3240 systems can be created.

The number of clusters (*i.e.*, islands) that cover all binary systems in the chemical spaces of the MNs is a good quantitative evaluation of these MNs. The lower the number of clusters is, the better-clustered the chemical space is.

Having a well-defined sequence of the elements (Mendeleev numbers, or MNs), where similar elements take neighboring places, one can produce an organized map of properties for binary or more complex systems that leads to the prediction of new materials by having information on their neighboring systems. A simple, physically meaningful, and universal way to order the elements was defined. MN (USE), in addition to a few previously known MNs such as atomic number (AN), Villars' periodic number (PN), Pettifor's Mendeleev number (MNP), and modified Mendeleev number (MNm), using provided data on binary systems from different databases, such as ICSD and COD, was examined. Two dimensional maps of the hardness, magnetization, enthalpy of formation, and atomization energy were plotted using the provided data in the space of MNs, and it turned out that most of these sequences (except for AN) indeed work well for clustering materials with similar properties. The evaluation of the MNs showed the overall best clustering rate of the chemical spaces produced by USE for target spaces, *i.e.*, hardness, magnetization, and enthalpy of formation. Also, unlike other MNs, USE can be defined at any arbitrary pressure, which is a step forward for the prediction of materials under pressure. Physical meaning of the Mendeleev number (previously defined empirically): it is a collapsed one-number representation of the important atomic properties (such as atomic radius, electronegativity, polarizability, and valence).

If we want to develop replacement materials that omit the use of certain elements, insights from the arrangement of elements according to their MN can prove useful in that search. The importance of the prevalence of elements used in the production of new materials is presented by the example of the periodic table in the figure below. This table not only illustrates the relative representation of the elements (the larger the framework for each element, the more it has), but also highlights the potential supply issue, relevant to technologies that have become ubiquitous and essential in our daily lives.

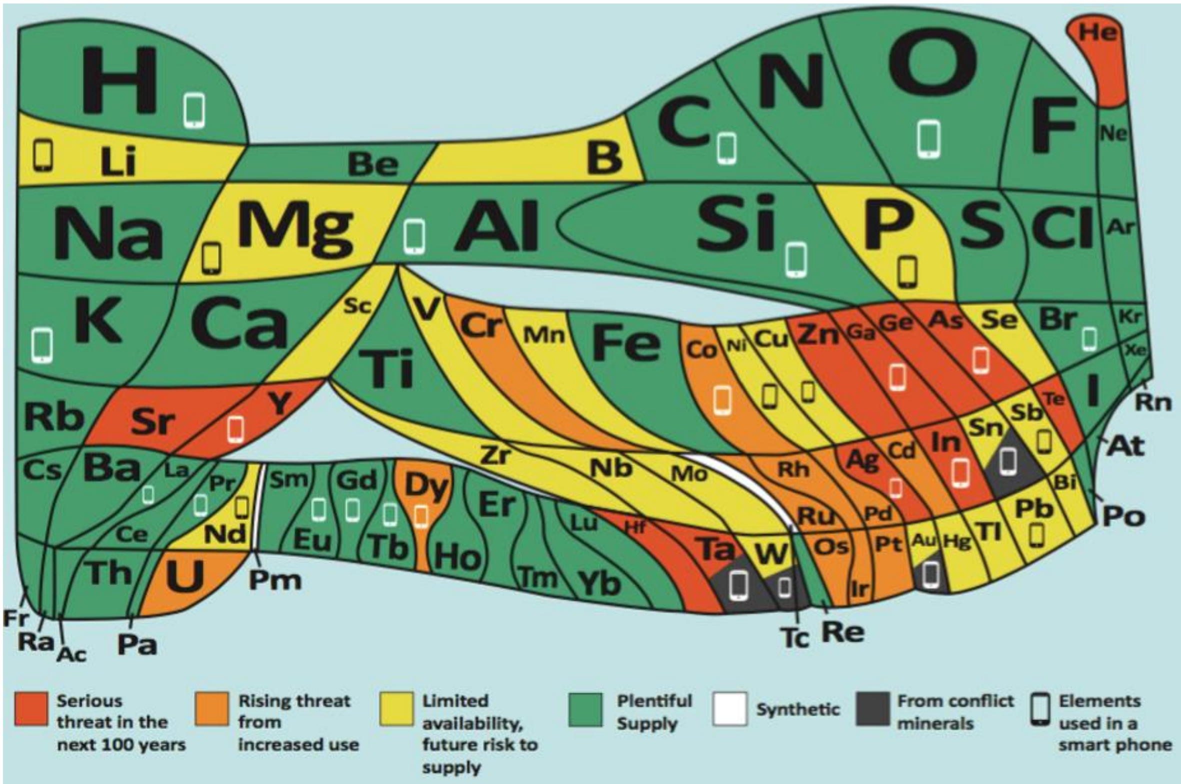

Figure 6. Periodic table showing the relative abundance of elements https://theconversation.com/periodic-table-new-version-warns-of-elements-that-are-endangered-110377

As part of the celebrations, the European Chemical Society published a completely new version of the periodic table (Figure 6).

Each area of the new system is marked with a color that indicates its distribution. In most cases, the elements are not lost, but as we use them, they fall apart and are much easier to recycle. Red indicates that the elements will be much less available in 100 years or less. The orange and yellow surfaces on the new periodic table predict problems caused by the increased use of these elements. Green means that a large amount is available. The four elements - tin (Sn), tantalum (Ta), tungsten (W) and gold (Au) - are colored black because they often originate from “conflicting” minerals; that is, from mines where wars are fought over their ownership. Their color can have a more ethical meaning because it is a reminder that producers must carefully monitor their origin to make sure that people are not harmed to provide the minerals in question.

The three main ways to preserve some elements that are already at a minimum are: replace them with others, recycle them, or simply reduce their use. Huge efforts are being made to find alternative materials. If we do not take these issues more seriously, many of the items and technologies we take for granted today may be relics of old age after a few generations - or only available to wealthier people. But as the new version of the periodic table underscores, we must do everything in our power to preserve and recycle the first 90 precious elements that make up our wonderfully diverse world (Norman, 2020).

Is the resistance of chemists to changes related to the line boundaries of the standard Periodic Table so great that they cannot accept other solutions, even when other tables offer a better representation of basic chemical principles? Maybe it is just pragmatism. One cynical critic suggested that the compressed version was favored because it fits well on a standard sheet of paper. Aesthetics are important, but they always take the last place in relation to clarity. Ideally, the data in the table should be visible and obvious.

One of the many virtues of the Periodic Table is that it brings simplification and coherence to the world of chemistry. Since the Periodic Table is by definition based on recurring trends, any such table can be used to obtain relationships between the properties of elements or to predict the properties of others. Instead of knowing the properties of all 118 currently known elements, it is enough to gain knowledge about the typical properties of about 10 of them. Therefore, the Periodic Table of the Elements, whether in standard form or in some other variant, provides a useful framework for the analysis of chemical behavior and is widely used in chemistry and other sciences.

Conclusion

Scientific theories are changing. The periodic table contains 118 elements and all rows and columns are filled in. Is it complete and perfect? Laboratories around the world are synthesizing new, even more difficult elements. Synthesis or the discovery of new weights raises the question of how much the 150-year-old Periodic Table of the Elements can be modified to meet any new extensions. After so many years since the creation of the Periodic Table, we can conclude that it is not only a basic educational tool but is useful for researchers looking for new materials. New Periodic Table models should not serve as replacements for previous views. Alternative periodic tables are developed often to highlight or emphasize different chemical or physical properties of the elements which are not so obvious in traditional periodic tables.

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Conflict-of-Interest Statement

None.

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